HOMESTAKE MINING COMPANY OF CALIFORNIA

Grants Reclamation Project

ENVIRONMENTAL REPORT For the Groundwater Corrective Action Program

Radioactive Materials License #SUA-1471

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Submitted By:
Homestake Mining Company of California

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LIST OF ACRONYMS

ACL	Alternate Concentration Limit
ADAMS	Agencywide Documents Access and Management System
AEC	Atomic Energy Commission
ac-ft	Acre feet
ALARA	As Low as Reasonably Achievable
amsl	Above Mean Sea Level
ARAR	Applicable or Relevant and Appropriate Requirements
bgs	Below Ground Surface
ºC	Degree Celsius
CAP	Corrective Action Program
CASA	Complete Archaeological Service Associates
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
cmol$^+$/kg	centimoles of positive charge per kilogram
DCGLs	Derived concentration guideline levels
DO	Dissolved Oxygen
DOE	U.S. Department of Energy
DOM	Domestic
DP	Discharge Permit
EC	Electrical Conductivity
ECP	East Collection Pond
EP	Evaporation Pond
EPA	U.S. Environmental Protection Agency
ERG	Environmental Restoration Group, Inc.
°F	Degrees Fahrenheit
ft	Feet or foot
ft/ft	Foot per Foot
gpd	Gallons per Day
gpd/ft	Gallons per day per foot
gpm	Gallons per Minute
GRP	Grants Reclamation Project
HDPE	High Density Polyethylene
HMC	Homestake Mining Company of California
HPRO	High Pressure Reverse Osmosis Unit
HSE	Health, Safety, and Environmental Compliance
IND	Industrial

LIST OF ACRONYMS (Continued)

IRR	Irrigation
ITRC	Interstate Technology & Regulatory Council
km^2	Square kilometers
kPa	kiloPascal
License	NRC Source Materials License SUA-1471
LLC	Limited Liability Company
LM	Office of Legacy Management
LPRO	Low Pressure Reverse Osmosis Unit
m/sec	Meters per second
meq/L	Milliequivalent per Liter
mg/L	Milligrams per Liter
MCL	Maximum Contaminant Level
MUL	Multiple use domestic
-N	As Nitrogen
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NMAC	New Mexico Administrative Codes
NMED	New Mexico Environment Department
NMEID	New Mexico Environmental Improvement Division
NMONRT	New Mexico Office of Natural Resources Trustee
NMOSE	New Mexico Office of the State Engineer
NMSA	New Mexico Statutes and Authorities
NMSU	New Mexico State University
NPL	National Priorities List
NPV	Net Present Value
NRC	U.S. Nuclear Regulatory Commission
NRCS	Natural Resource Conservation Service
mg/L	Milligrams per Liter
ORP	Oxidation reduction potential
pCi/g	Picocurie per gram
pCi/L	Picocurie per Liter
pCi/m-s	Picocurie per meter second
POC	Point of Compliance
POE	Point of Exposure
PPE	Personal protection equipment
PRB	Permeable reactive barrier
PTT	Post-treatment tank
QA	Quality Assurance

LIST OF ACRONYMS (Concluded)

RO	Reverse Osmosis
RSO	Radiation Safety Officer
RST	Radiation Safety Technician
SAC	Southwest Archaeological Consultants, Inc.
SAG	San Andres-Glorieta Aquifer
SAN	sanitary water for commercial
SCADA	Supervisory control and data acquisition
SCCM	Surface complexation mixing model
SERP	Safety and Environmental Review Panel
STK	Stock
TEC	Taschek Environmental Consulting
TDS	Total dissolved solids
tpd	Tons per day
USACE	United States Army Corps of Engineers
WCP	West Collection Pond
WME	Worthington Miller Environmental
WRCC	Western Regional Climate Center
XRD	X-ray diffraction

1 INTRODUCTION

1.1 INTRODUCTION

Homestake Mining Company of California (HMC) is requesting an amendment to United States Nuclear Regulatory Commission (NRC) Radioactive Materials License SUA-1471 (License) for the Grants Reclamation Project (GRP) to modify License Conditions 15, 28, 35, and 36 which address groundwater compliance, groundwater corrective action, financial surety, and reporting. The GRP is a former uranium mill that is owned and operated by HMC and is located 5.5 miles north of Milan, New Mexico, in Cibola County (Figure 1-1). Specifically, the Alternate Concentration Limit (ACL) Application requests approval of ACLs for the specific constituents identified in License Condition 35B, specific constituents not listed in License Condition 35B, removal of License Conditions 35C and 35E for implementation of groundwater corrective action, as well as modification of the groundwater monitoring program currently identified in License Condition 35A, and the associated reporting timeframes identified in Condition 15. This Environmental Report accompanies the ACL Application and assesses the environmental impacts associated with these requested licensing actions.

The GRP was initially regulated by the NRC and the New Mexico Environmental Improvement Division (NMEID). Portions of the GRP were added to the National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) at the request of the State of New Mexico in 1983. The GRP is currently regulated by the NRC, the U.S. Environmental Protection Agency (EPA), and the New Mexico Environment Department (NMED).

The former Homestake uranium mill processed ore from local mines in the Ambrosia Lake and Mt. Taylor districts from 1958 to 1990 and deposited the mill tailings in licensed unlined impoundments from which constituents have subsequently migrated into the underlying groundwater. 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.

A groundwater corrective action program is ongoing at the GRP in accordance with License Condition 35 in an effort to remediate groundwater constituents to the License groundwater protection standards identified in License Condition 35B for the alluvial aquifer and the Upper, Middle, and Lower Chinle groundwater beneath the GRP (Table 1-1). The Groundwater Corrective Action Program (CAP), approved by NRC in 1989, is implemented using an adaptive, ongoing strategy that includes source control, groundwater plume control, evaporation, and water treatment. Three 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, 2017), as identified in License Condition 44. 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, 2020b) 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 9 hazardous 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 include metals, molybdenum, selenium, vanadium, as well as radionuclides, uranium, combined radium-226 and radium-228, and thorium-230. In addition, the non-metal and non-radiological constituents, chloride, nitrate, and sulfate, which are identified in the License groundwater monitoring requirements, are also above License groundwater protection standards in groundwater. Four additional constituents not addressed in License Condition 35B were identified; these constituents are arsenic, cadmium, fluoride, and boron. Arsenic, fluoride, and cadmium are listed constituents in Criterion 13 of Appendix A to 10 CFR 40. Boron is not listed in Criterion 13 or Criterion 5C but has promulgated groundwater protection standards by the State of New Mexico and is a constituent to be addressed in the ACL Application. These 13 constituents are the focus of the analyses in the ACL Application.

A review of historical groundwater corrective action performance and modeling of the long-term sources of groundwater contaminants (Large Tailings Pile seepage and back 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.

A range of groundwater corrective action alternatives has been developed to address the identified constituents 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. Based on the 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. The three alternatives evaluated include a) containment and removal of groundwater contaminants using the existing approved Groundwater Corrective Action Program (No Action alternative, assumes the 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 a revised groundwater monitoring program.

This Environmental Report has been developed considering the guidance presented in NUREG-1748 (NRC, 2003b). Section 1 of this report presents the GRP description and historical background, summarizes the current extent of groundwater constituents, the current License groundwater protection standards, and the proposed ACLs. Section 2 presents the Proposed Action and two alternative actions. Section 3 presents a description of the affected environment. Section 4 presents a summary of environmental impacts of the alternatives. Section 5 presents a summary of mitigation measures.

1.2 FACILITY DESCRIPTION

The GRP contains a former uranium mill (Homestake mill) in Cibola County, New Mexico that processed ore between 1958 and 1990. Figure 1-1 presents the location of the GRP within the State of New Mexico in relation to the Village of Milan and Albuquerque. The GRP is located 5.5 miles north of the City of Grants and the Village of Milan, New Mexico at 107 degrees 51.95 minutes west longitude and 35 degrees 14.501 minutes north latitude. The GRP occupies approximately 1,085 acres primarily in Section 26, Township 12 North, Range 10 West.

The area of the GRP includes the License boundary and the areas where corrective actions have occurred (Figure 1-2). Features currently existing at the GRP are the Large Tailings Pile, the Small Tailings Pile, groundwater restoration and monitoring wells, a reverse osmosis (RO) water treatment system, tailings flush and dewatering system, three lined evaporation ponds, two collection ponds, an office building and other support structures. The existing structures are related to the operation and maintenance of the groundwater restoration program.

1.2.1 Facility History

Uranium milling operations using alkaline leach circuits occurred at the Homestake mill between 1958 and February 1990 (Kleinfelder, 2007). 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 (tpd). The Homestake-Sapin Partners, a partnership between HMC and Sabre Pinon Corporation, in 1957 built a second, larger mill, with a nominal milling capacity of 1,750 tpd, 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 tpd (McLemore, 2007). The mills received ore mined in the Ambrosia Lake and Mount Taylor areas.

In 1962, United Nuclear Corporation merged with Sabre Pinon Corporation, but maintained the United Nuclear Corporation name. United Nuclear Corporation became a limited partner with HMC forming the United Nuclear-Homestake partnership and continued operating the Homestake mill. In March 1981, the United Nuclear-Homestake Partnership was dissolved and HMC became the sole owner.

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 mill closed soon after and was decommissioned in 1990. Reclamation of the mill, and some areas of surface soil contamination, was completed in 1994 with groundwater restoration and tailings reclamation activities ongoing at the GRP. Figures 1-3 and 1-4 show the Homestake mill facilities prior to decommissioning.

1.2.1.1 Mill Operations

The primary source of ore for the Homestake mill was from underground mines located within 30 miles 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 triuranium octoxide (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.

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).

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 repulper 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 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 yellowcake was packaged into 55-gallon drums for shipment.

1.2.1.2 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 1-5). Evaporation Pond 1 was used to hold water discharged from the groundwater restoration collection wells (AK Geoconsult et al, 1991), and continues to be used for storage and disposal by evaporation of reverse osmosis (RO) treatment system brine and other poor-quality water. 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 1-5). All ponds are expected to remain in service until groundwater restoration is complete.

1.2.1.3 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, and filtration, or ion exchange using zeolites, prior to re-injection. Non-compliant treated groundwater has been managed in three lined evaporation ponds (EP1, EP2, and EP3). Non-compliant treated groundwater is approximately 15 percent of the influent streams to both the RO and the zeolite treatment systems. This non-compliant effluent is managed by evaporation and is permanently removed from the groundwater system, while the remaining 85 percent of the influent streams is reinjected. At these pumping and treatment rates (740 gpm is 2018 average), approximately 80 million to 100 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 shut-off controls (APEX and Landshark brands). 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 the Small Tailings Pile for disposal (Figure 1-5).

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.

1.2.1.4 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.

1.2.1.4.1 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 NMED approved burial of the asbestos in the tailing impoundment (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 1-6). Residual byproduct and scale materials were removed from milling process components before those 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 burial. Demolition of milling facilities was accomplished using heavy equipment and was completed by March 1995 as documented in the Completion Report (AK Geoconsult, 1996) and approved by NRC in 1999 (NRC, 1999). Mill decommissioning at the GRP met applicable standards in 10 CFR Part 40 and applicable License conditions (HMC, 2013).

Mill debris was buried in pits located within the mill area or south of the Large Tailings Pile (refer to Figure 1-6). Burial pits were excavated using heavy equipment and debris was placed into pits in lifts up to 5 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 4 feet of soil (AK Geoconsult, 1996).

1.2.1.4.2 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). There was a period of inaction during soil cleanup due to decommissioning activities. After the mill decommissioning was complete, cleanup of the windblown contamination and other off-pile contaminated materials resumed in 1993 in accordance with License Condition 29C and10 CFR 40 Appendix A Criterion 6(6).

Surface soil from approximately 1,200 acres of land was removed (Figure 1-7). Most of the excavated soil was placed on the eastern 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.

1.2.1.4.3 Placement of Cover Material

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 after NRC approves the final cover design submitted March 21, 2022 (EA, 2022). 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 Homestake mill area, located southeast of the Large Tailings Pile (Figure 1-7), 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 1-8).

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 1-9.

1.2.1.5 Seepage Impacted Groundwater

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 groundwater as well as the alluvium.

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 feet higher than the phreatic surface at the toe of the Large Tailings Pile (D'Appolonia, 1980).

1.2.1.6 Water Treatment Systems

The first significant water treatment effort for collected groundwater occurred with the operation of the RO Plant in 1999. The RO Plant was significantly modified and expanded in 2014 and 2015 to improve treatment and increase capacity. Reverse osmosis can treat mildly to severely impacted groundwater and receives collected groundwater from the On-Site Area (Figure 1-2). Two field-scale pilot zeolite water treatment systems are present on the surface of the Large Tailings Pile. The RO Plant and related facilities are currently active and will be decommissioned after groundwater corrective actions cease. The zeolite treatment facilities are currently active and will be decommissioned to facilitate final Large Tailings Pile cover.

1.2.1.7 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 New Mexico Environmental Improvement Division 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 ten 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.

1.2.2 Previous and Current Corrective Action Programs

HMC in coordination with NRC, EPA, and NMED has progressively implemented most, if not all, general response actions and 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 non-compliant wastewater. Water management components of these corrective actions have included water storage in the Large Tailings Pile, reuse of collected waters in ore milling, storage and evaporation in lined evaporation ponds, land application, and treatment with reverse osmosis (RO), evaporation, and zeolites. 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. Figure 1-10 shows a timeline of corrective actions. 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 45 years. This groundwater CAP has been continuously expanded over the past 45 years.

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 shut down between 1981 and 1988, the corrective action groundwater collection waters were held in the Large Tailings Pile ponds, but the rate of collection necessitated additional water storage and evaporative treatment capacity. 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 1-5) 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. 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.

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).

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 tested 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. Continuous groundwater corrective action program expansion has occurred over the past 45 years (Figure 1-10). Appendix 4.1-A of the ACL Application 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 the past 45 years.

1.2.2.1 Source Control: Tailings Dewatering and Tailings Flushing

Source control of contaminants entering groundwater from 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.

1.2.2.1.1 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 1-11. These drains are connected to common sumps. Two additional sumps connected to the old tailings decant towers (East and West Reclaim sumps) are also shown on Figure 1-11. The cumulative volume of water removed by the toe drains and vertical tailings dewatering wells are shown in Figure 1-12. 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 2020 is approximately 394 million gallons, which is an average collection rate of

26 gallons per minute (gpm) for the past 29 years, although the average rate produced from the toe drains has declined with time and was 4 gpm in 2020 (Table 1-2).

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. 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 (Table 1-3). Water levels in the Large Tailings Pile have dropped dramatically since 2015 (Figure 1-13), but data from well locations presented in Figure 1-11 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 (Figure 1-14). The dewatering rates were restricted during a few years due to the limited available evaporation pond storage during those years.

1.2.2.1.2 Tailings Flushing

Testing of tailings flushing was deemed necessary to diminish the high groundwater 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 started in 2000 and ceased in mid-2015. Figure 1-11 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 2,000 to a peak of 308 gpm in 2014 and averaged 233 gpm over the 16-year period of operation of this program (Figure 1-14). 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 2018 of 5.4 and 13.7 mg/L, respectively. Tailings flushing was discontinued in mid-2015. Large Tailings Pile flushing ceased following investigations of the Large Tailings Pile that identified that flushing water primarily moved through the tailings sand material, which has been largely rinsed of dissolve constituents while the porewater within the tailings slimes was bound by capillary forces and thus inaccessible to the flushing program. It was therefore concluded that additional tailings flushing would have diminishing benefits in concentration reductions.

1.2.2.2 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 herein 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 areal extents and generally at concentrations closer to their respective groundwater protection limits than uranium. A more detailed description of the groundwater collection and injection program with associated data is included in the 2020 Annual Performance Report (HMC and Hydro-Engineering, 2021).

1.2.2.2.1 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 1-15 through 1-24 illustrate the configuration of the alluvial aquifer collection and injection systems from 1977 to the present. 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. A more detailed description of the groundwater collection and injection program with associated data are included in the 2020 Annual Performance Report (HMC and Hydro-Engineering, 2021).

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 1-16). 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 1-17). 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 & 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 1-18).

The main addition to the alluvial groundwater collection system during 2000-2004 and 2005-2009 was the collection of alluvial groundwater to feed the RO Plant and the collection of groundwater for land application, discussed in following sections (Figure 1-19 and 1-20). 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 (Figure 1-20).

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 1-19). The common water supply to the South Irrigation system connected the alluvial 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. 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 (Figure 1-21). Land application of collected groundwater, which effectively treated over 3.1 billion gallons of impacted water, ceased later in 2012 (HMC and Hydro-Engineering, 2021). 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 area collection and injection operations were similar for 2010-2012 and 2013-2015 (Figure 1-21 and Figure 1-22). The area (and rate) of off-site groundwater collection during 2013 through 2015 without the irrigation program was more limited than in previous periods, as shown by the data in Figure 1-22. The significant differences in the Off-Site collection shown in Figure 1-21 and Figure 1-22 reflect the cessation of collection for irrigation after 2012. From 2013 through 2015, the Off-Site collection was reduced to smaller areas in Sections 28, 34, and 35 and supplied water for the tailings flushing and testing of the zeolite treatment. Upgradient alluvial groundwater collection ended in 2013 and therefore is not shown on Figure 1-22.

From 2016 through 2018, alluvial collection supply wells for RO feed were added in the southwestern portion of the Large Tailings Pile area and between the Large Tailings Pile and evaporation ponds (Figure 1-23). Groundwater collection from the area southeast of the Small Tailings Pile (L Area) that had previously been used as an RO Plant feed source was redirected to treatment by the zeolite plant, after which it was used as a water source for reinjection near the Large Tailings Pile. Treated water injection locations are shown on Figure 1-23. The Off-Site collection water was treated through the zeolite systems to meet the uranium License groundwater protection standard and enable the reuse of this water for injection supply.

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, 2017) required that HMC provide an analysis of the collection for reinjection program and its impacts on restoration progress. This analysis was completed and reported in Hydro-Engineering LLC. (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 (2020) groundwater corrective action collection and injection system is illustrated in Figure 1-24. Currently, On-Site alluvial collection and injection wells with collection well operation are focused on the west and south sides of the Large Tailings Pile and the southwest portion of the top of the Large Tailings Pile. Collection operations are also occurring on the west and south sides of Evaporation Pond (EP1). This collection, in combination with injection downgradient of the collection wells, results in hydraulic control of alluvial groundwater flow gradients downgradient of the tailings seepage source area.

Off-Site 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. 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. Two collection wells in the central portion of Section 3 are also in the existing South Off-Site alluvial collection program to prevent continuing migration or expansion of the uranium plume in this area. A collection well is also operating in the northern portion of Felice Acres to capture seepage-impacted alluvial groundwater and reduce the relatively small uranium concentrations there to below the License groundwater protection standard. Two collection wells in the central portion of Section 3 are also in the existing South Off-Site alluvial groundwater collection program to prevent continuing migration or expansion of the uranium plume in this 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 (Figure 1-24).

1.2.2.2.2 Chinle Collection and Injection

Figure 1-25 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 alluvium 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.

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 provides the conduit to Chinle groundwater, have also evolved.

Figures 1-25 through 1-28 illustrate the sequence of Upper Chinle groundwater restoration efforts between 1984 and 2018. 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 1-25). 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 1-26). Some collected groundwater was used for the tailings flushing program (e.g., CW1, CW2, CW3, 929 and 934), some for the land application (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 1-27). 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.

The locations of collection and injection wells used in 2016 through 2018 in the Upper, Middle and Lower Chinle are presented on Figure 1-28. This period is characterized most 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 1-29) and injection into the Middle Chinle west of the West Fault splay. 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 existing remediation system are illustrated in Figures 1-29, 1-29A, and 1-29B. Upper Chinle groundwater collection is focused mainly near its subcrop area adjacent to the Large Tailings Pile as shown in Figure 1-29 and Figure 1-29A. Upper Chinle groundwater is also being collected from well CE15 which is located north of Broadview Acres in concert with injection into Upper Chinle well at CW5 (Figure 1-29B). The operation of collection wells located within and directly adjacent to the subcrop benefits both the Upper Chinle and the alluvium, 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 1-30 and Figure 1-30A, which also include 2019 uranium concentration contours and patterns indicating areas where the License groundwater protection standards are exceeded. Figure 1-30 shows the existing Middle Chinle wells west of the West Fault with only one operating collection well, CW62, and three operating injection wells. The collection and injection wells in the South Off-Site Area include five operating collection wells in South Felice Acres and six operating collection wells in the northeast corner of Section 3 (Figure 1-30A). Current Lower Chinle groundwater restoration did not include groundwater collection.

1.2.2.3 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 1-5 illustrates the location of the current water management and treatment systems. The location of the land application areas that ceased in 2012 are illustrated in Figure 1-20. Figure 1-31 presents a conceptual flow diagram for the water management system.

1.2.2.4 Evaporation

Evaporation was used to manage water at the GRP starting in 1986 with the construction of the West and East Collection Ponds (Figure 1-5) 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 Mill wastewater during the final years of the 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 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. 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. All evaporation ponds are currently operated by seasonal use of mechanical spray evaporators made by APEX or Land Shark 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.

The historical performance of the evaporation ponds is 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 (Figure 1-32 and Table 1-4). Recent Evaporation Pond 1 (EP1) liner maintenance has necessitated decreased storage and associated evaporative capacity since late 2018, which has contributed to lower reverse osmosis treatment rates.

1.2.2.5 Reverse Osmosis Treatment

The RO Plant (Figure 1-5) 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 reverse osmosis 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 reverse osmosis treatment was subsequently granted in 1998 as License Amendment 30. The original RO Plant consisted of a 300-gpm low pressure reverse osmosis which could be operated in series with a high pressure reverse osmosis unit to treat the brine from the low pressure reverse osmosis unit at maximum design rates of 75 gpm (Figure 1-32). 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 1-11, Figure 1-31, and Figure 1-32) 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 reverse osmosis 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 reverse osmosis pre-treatment system, and addition of a post treatment tank (PTT). The post treatment tank receives the reverse-osmosis 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.

A second high-pressure unit (HPRO-2) with a capacity of 250 gpm was added in 2016 (RO expansion 2, Figure 1-31 and Figure 1-32). HPRO-2 was configured to treat the brine from the three low-pressure units when they were all operating. The high-pressure reverse osmosis 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 reverse osmosis 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 Evaporation Pond 1 while liquids in the West Collection Pond are recycled to the RO Plant or pumped to the evaporation ponds.

Reverse osmosis treatment is used primarily, although not exclusively, for treatment of groundwater collected from On-Site wells due to the higher dissolved solids concentrations and multiple constituents requiring treatment, for which treatment with zeolites is not appropriate. Because the reverse osmosis product water has much lower total dissolved solids (TDS) and other constituent concentrations than the fresh water produced from the San Andres-Glorieta aquifer, injection of reverse osmosis product water or a mixture of reverse osmosis product water and fresh or other treated water is generally more effective in reducing the uranium and molybdenum concentrations within the alluvial groundwater (Hydro-Engineering, 1998) than fresh San Andres-Glorieta water injection alone because water with lower TDS concentrations tends to be more aggressive in removing sorbed contaminants on fine-grained solids than water with higher TDS concentrations. This efficacy is demonstrated by the groundwater restoration progress presented in annual monitoring reports (HMC and Hydro-Engineering, 2021).

1.2.2.5.1 Land Application

Land application of low concentration 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 (ERG and Hydro-Engineering, 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 1-20). 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. The irrigated area acreage was increased in 2002 by the addition of 60 acres in the North center pivot. 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 1-20. 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, 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 in water applied to the South and North irrigation areas were generally in the range of 0.1 mg/L to 0.35 mg/L; molybdenum concentrations were generally less than 0.05 mg/L; selenium concentrations were generally in the range of 0.05 mg/L to 0.1 mg/L; sulfate concentrations ranged from approximately 600 mg/L to 900 mg/L; and chloride concentrations ranged from 120 mg/L to 190 mg/L. The concentrations of other constituents (nitrate, vanadium, thorium-230, and combined radium-226 and radium-228) in the irrigation supply water were below the respective 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 1-20). 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.

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 (NRC, 2021a).

1.2.2.5.2 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 1-5 and Figure 1-32) 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 1-5). This system (abbreviated as 300Z; RIMCON and Hydro-Engineering, 2012), was tested with supply of both On-Site and Off-Site groundwater (RIMCON, 2013) 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 the Large Tailings Pile (Figure 1-5). The 1200Z system consists of four trains each with three sequential treatment cells and maximum design treatment capacity of 300 gpm for each train (Hydro-Engineering, 2017b). The water quality 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; 2018; 2019; 2020; 2021). Field-scale pilot testing of the 300Z and 1200Z zeolite beds has been used since 2016 to remove uranium from the Off-Site collected groundwater. Uranium is the only constituent that exceeds the License groundwater protection standard at that location. 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. Zeolite system annual water treatment rates have varied from 42 to 267 gpm. The effective continuous annual average zeolite treatment capacity is estimated to be approximately 250 gpm from the combination of the 300Z and 1200Z systems considering the time required to regenerate the zeolite beds and the removal of algae. The 300Z and 1200Z systems produce treated water that is piped to the post treatment tank where it is mixed with RO product water and fresh water prior to injecting it back into the groundwater.

1.2.2.6 Remediation Performance

Since 1978, remediation of the groundwater system has managed over 10.6 billion gallons of recovered groundwater. In that time, the On-Site corrective action program has removed and managed an estimated 6.2 billion gallons of water and removed an estimated 188,668,296 pounds of sulfate, 1,074,329 pounds of uranium, and 1,321,322 pounds of molybdenum from the groundwater system (HMC and Hydro-Engineering, 2021). Groundwater collection and treatment from Off-Site areas since 2018 has totaled over 814 million gallons and has removed an estimated 567 pounds of uranium from the groundwater system (HMC and Hydro-Engineering, 2021).

However, substantial constituent mass remains in the tailings and the groundwater system. Estimated changes in dissolved uranium mass remaining in the alluvial groundwater between 2009 and 2019, discussed further below, indicates that the most recent decade of groundwater remediation removed approximately 6.7 percent of the dissolved uranium mass in alluvial groundwater. This indicates that over 150 years would be required to recover all the remaining dissolved uranium in that groundwater. This conclusion is consistent with the results of an analysis of the changes in groundwater uranium concentrations from historical groundwater corrective actions to project the time 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.

The following sections discuss the overall performance of the source control and groundwater plume remediation efforts.

1.2.2.6.1 Source Control

Dewatering of the Large Tailings 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, 2020b). The toe drain and tailings well dewatering volumes are shown in Figure 1-12. These data indicate the declining rates of tailings fluid recovery since 2012. Tailings toe drain annual average recovery rates for 2020 are approximately 4.1 gpm for the entire tailings.

The effects of tailings dewatering and subsequent tailings drainage are evident in the water level or head changes in the tailings as illustrated in Figure 1-13, which illustrate a declining rate at which heads are dropping in most tailings wells and the near asymptotic flattening of heads in many wells. Currently, there is a maximum head of up to 52 feet of water in the center of slime tailings (base of tailings roughly 6575 feet above mean sea level [amsl], the maximum head in the slimes is approximately 6,627 feet amsl in well E14), but lower heads exist in the sand tailings due to higher sand hydraulic conductivities and faster draining than slime materials. Tailings dewatering has resulted in removal of approximately 200,000 pounds of uranium, 477,000 pounds of molybdenum and 5,600 pounds of selenium from the tailings.

Current Large Tailings Pile seepage rates have been estimated as approximately 11 gpm (HMC and Hydro-Engineering, 2021) and long-term seepage rates after final cover placement have been estimated to be approximately 0.6 gpm. The key factors in limiting long-term infiltration into the Large Tailings Pile are the semi-arid climate, the presence of a compacted clay radon barrier in the final cover, and the creation of a final reclamation topographic surface with positive drainage over the entire Large Tailings Pile.

Tailings flushing, tested in 1999, initiated in 2000 and terminated in mid-2015, substantially reduced tailings measured concentrations of uranium, molybdenum, and selenium concentrations. 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. Wells in the interior of the tailings generally have lower concentrations than the tailings margins and the sumps. This suggests that a substantial portion of the tailings footprint has seepage constituent concentrations lower than those represented by the sump data when evaluated on an area and volumetrically weighted basis.

Average tailings concentrations for uranium decreased by between threefold to sevenfold from pre-flushing levels, while molybdenum decreased by between three to fivefold, and selenium showed nominal change in tailings wells but an approximately fivefold decrease in tailings sumps. In addition, it is noted that six years of post-flushing monitoring does not indicate substantive 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 substantive 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.

1.2.2.6.2 Groundwater Remediation

Groundwater remediation efforts began over 45 years ago and have continually grown in spatial extent of collection and injection as well as in treatment and water management capacity. The objective of the groundwater remediation has been to return groundwater constituent concentrations to or below the License groundwater protection standards. The License groundwater protection standards were established by License Amendment 39 and are shown in Table 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).

The ACL Application presents performance data on the water management systems (i.e., evaporation, land application, RO, zeolites). The historical groundwater concentrations of uranium in alluvial groundwater and the three Chinle water-yielding units are illustrated in Figure 1-33 through Figure 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 more than 40 years of corrective action.

High uranium groundwater 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 (have not expanded) since 1999 (Figures 1-33 through 1-36). The iso-concentration 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 (have been reduced in total area) from the Rio San Jose drainage in the alluvial groundwater system since 1999, while the extent of the South Off-Site Area plume in the alluvial groundwater has been held constant and concentrations within that plume substantially reduced since 1999 (Figure 1-33).

The Upper Chinle, which receives recharge from the overlying alluvium 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 1-34), although elevated 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 1-35). The very limited impacts to Lower Chinle groundwater have been generally contained and reduced in size from their peak in approximately 1999 (Figure 1-36).

Over 10.6 billion gallons of water have been collected and treated since 1986, with roughly 3 billion gallons (28 percent) having been permanently removed from the groundwater system as untreatable wastewater. From these collected waters, approximately 1,276,437 pounds of uranium, 1,800,037 pounds of molybdenum, and approximately 73,743 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 201,000 pounds of uranium, 477,000 pounds of molybdenum, and 5,600 pounds of selenium.

1.3 OPERATIONS

The operations currently conducted at the GRP are associated with groundwater corrective action and environmental monitoring activities.

1.3.1 Monitoring Stations

Monitoring of groundwater, total suspended particulates, radionuclides, radon, and gamma exposure occurs as outlined in the License, the radiation protection program, standard operating procedures (SOPs), and the Environmental Monitoring Plan. HMC continuously samples total suspended particulates at seven locations (Table 1-5 and Figure 1-37). Radon-222 gas concentrations in ambient outdoor air are monitored on a continuous basis at the eleven locations identified in Figure 1-38. Annual radon flux measurements occur in the fall as two separate deployments, consisting of 100 canisters per deployment on the Large Tailings Pile and Small Tailings Pile, respectively.

Gamma dose rates are continuously monitored using optically stimulated luminescence dosimeter badges placed at ten locations identified in Figure 1-37. Occupational and public doses are monitored, and results presented semi-annually as required by the License. Table 1-6 and Table 1-7 outline the water quality sampling frequency and parameters monitored. The locations of the groundwater monitoring wells are provided in Figures 1-38 through 1-42.

1.3.2 Corporate Organization and Administrative Procedures

The Closure Manager has overall policy and management responsibilities for the GRP. The Closure Manager is responsible for enforcing the policies and procedures and has the ultimate on-site authority. Written standard operating procedures have been established for routine production activities involving the handling of radioactive materials and routine radiation safety practices. The GRP organizational chart is provided as Figure 1-43.

The Health, Safety and Environmental Compliance (HSE) Manager reports to the Closure Manager and has the authority and responsibility to ensure that GRP monitoring activities are compliant with the technical and quality assurance requirements in the Quality Assurance Plan. The HSE Manager maintains familiarity with the environmental and operational monitoring, remediation, and quality programs, and related documents and requirements.

The Quality Assurance staff reports directly to the HSE Manager and is responsible for ensuring that GRP monitoring activities are compliant with the technical and quality assurance requirements in the Quality Assurance Plan. The Quality Assurance staff will collect and review the relevant planning documents that identify the purpose and specifications for Site environmental compliance water sample collection. In addition, the QA staff will collect all data necessary to complete the review.

The Environmental Specialists report to the HSE Manager and have the responsibility to conduct GRP monitoring and sampling in accordance with the technical and quality assurance requirements in the Quality Assurance Plan and applicable standard operating procedures.

The Radiation Safety Officer (RSO) reports directly to the Closure Manager and is responsible for compliance with all environmental health and safety regulations, implementing all radiological and environmental monitoring procedures, and for compliance with the regulations and requirements administered by the NRC.

The Site Supervisor reports to the Closure Manager. The Site Supervisor has the authority and responsibility to ensure site operations are conducted in accordance with the quality assurance documents and standard operating procedures.

The Maintenance Technicians report to the Site Supervisor and have the responsibility to conduct GRP operations in accordance with the quality assurance documents and standard operating procedures.

The Radiation Safety Technician (RST) report to the Radiation Safety Officer and/ or the Alternate Radiation Safety Officer (ARSO) on all radiation safety matters and has the responsibility to conduct radiological field monitoring and sampling programs in accordance with the quality assurance procedures incorporated into applicable standard operating procedures. All activities related to assessing the environmental and health impacts from operations are conducted using standard operating procedures.

1.3.3 Personnel Qualifications and Training

Minimum education and experience qualifications for the GRP staff, including the Radiation Safety Officer and Radiation Safety Technician, are identified in the GRP Quality Assurance Plan (HMC, 2022).

The radiological protection training program for all workers includes providing basic radiation protection training for new employees and contractors, on-the-job training, and annual refresher training. The formal training includes the fundamentals of radiation, regulatory limits, methods for limiting radiation exposure, and personnel monitoring methods.

1.3.4 Security

The RO Plant, the office building, the collection ponds, the evaporation ponds, and the entire tailings disposal area are located within the controlled access area boundary of the GRP that is enclosed by a fence. The controlled access area is posted with "Caution Radioactive Materials" signs per 10 Code of Federal Regulations (CFR) 20.1902. Access to all areas is controlled by fences and gates. Warning and information signs are posted near the main gate. Perimeter checks of the fence are conducted monthly by HMC personnel. The RO Plant and the office building have alarms that notify law enforcement and HMC personnel.

1.3.5 Radiation Safety

The basis for the radiation safety program is to maintain radiation exposures to levels that are as low as reasonably achievable (ALARA) for all employees, contractors, visitors, and members of the general public per 10 CFR 20. The implementation of a successful ALARA program is the responsibility of management and all workers. Workers and management have the responsibility for developing work practices that minimize radiation exposure. ALARA is a primary consideration in worker training and developing work plans.

The Radiation Safety Program is implemented by the Radiation Safety Officer, the Alternate Radiation Safety Officer and the Radiation Safety Technician. The program consists of employee training, work-place monitoring, environmental and effluent monitoring, personnel monitoring and dose assessment, records management, and regulatory compliance. Supporting activities include job planning assistance, preparing radiation work permits, preparing, and maintaining standard operating procedures, monitoring equipment calibration and maintenance, and conducting audits.

1.4 THE PROPOSED ACTION

The Proposed Action includes the approval of alternate concentration limits, control over the long-term area of plume migration by land ownership, and annual monitoring and reporting of the groundwater conditions. The control boundary (Figure 1-44) circumscribes the area over which long-term control of access to and use of groundwater would be required under the Proposed Action. The control boundary represents the groundwater point of exposure (POE) for the proposed action and is a pragmatic construct, not a current physical or legal boundary, used to identify and conservatively estimate potential future exposure concentrations. Controls over access to and use of groundwater within the control boundary are assumed present for this alternative. This control and currently in-place alternative water supplies prevent current and potential future exposures.

Under the Proposed Action, 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 the Proposed Action is groundwater monitoring and reporting to confirm groundwater constituent concentrations remain below the approved ACLs. This alternative is modeled using natural attenuation of the current groundwater plumes.

1.5 PURPOSE AND NEED FOR THE PROPOSED ACTION

The past 45 years of investigation and corrective action have successfully mitigated groundwater impacts to as low as reasonably achievable while, at the same time, provided understanding of the hydrologic conditions and efficacy of groundwater corrective action systems. From 2000 through 2020, source control efforts in the Large Tailings Pile recovered over 412.2 million gallons of tailings pore water through collection at the Large Tailings Pile toe drains, which removed over 29.6 million pounds of sulfate, 125 thousand pounds of uranium, and 265.5 thousand pounds of molybdenum. Similarly, Large Tailings Pile dewatering wells removed over 456.8 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 1-3 and 1-4). Tailings flushing decreased tailings pore water uranium concentrations by between 14 percent and 38 percent and molybdenum by between 20 to 34 percent (Table 1-8).   The corrective action program has treated over 4.1 billion gallons of impacted groundwater with reverse osmosis, over 3.1 billion gallons with land application, over 658 million gallons through evaporation, and over 561 million gallons with zeolite treatment (Table 1-4). This treatment resulted in more than 818.8 million gallons permanently removed from the groundwater system as untreatable wastewater. This groundwater corrective action is the largest in scope and one of the longest running of any uranium mill site in the United States.

However, despite these efforts, mass balance calculations indicate that decades of large-scale groundwater removal and treatment and source control actions have only removed a small fraction of total contaminant mass from the affected groundwater systems. Further, predictive modeling of long-term groundwater contaminant sources (i.e., seepage from the Large Tailings Pile) and back-diffusion of constituent mass from the immobile domain in the water-yielding units demonstrates that long-term restoration of the groundwater to current License groundwater protection standards is technically impracticable and not reasonably achievable. Therefore, an alternative to groundwater restoration is needed to ensure long-term protection of public health, safety, and the environment. The purpose of the proposed action is to provide the requisite long-term protection of public health, safety, and the environment given the impracticability of groundwater restoration. Specifically, the proposed action establishes a) NRC-approved alternate concentrations limits in the License, b) controls on groundwater access and use to prevent unacceptable human health and environmental exposures and associated risks, c) and an appropriate monitoring program given the proposed alternate concentrations limits and groundwater access controls.

1.6 APPLICABLE REGULATORY REQUIREMENTS, PERMITS AND REQUIRED CONSULTATIONS

1.6.1 NRC Source Materials License SUA-1471

The HMC operates the GRP under NRC License SUA-1471 issued on November 10, 1986, as subsequently amended. The License authorizes HMC to possess, incidental to decommissioning, residual uranium and 11e.(2) Byproduct Material in the form of uranium waste tailings and other byproduct waste generated by past milling operations in accordance with their license.

Groundwater restoration is regulated under License Condition 35. Requirements specified in License Condition No. 35 include the following:

A. As Required in License Amendment No. 55, HMC shall implement the groundwater monitoring shown in Tables 2-1 and 2-2 of the Groundwater Monitoring Plan submitted by the licensee dated November 20, 2017 (ML18018A102), as updated by the licensee in correspondence dated October 8, 2019 (ML19281C055; Arcadis, 2019).

B. The groundwater protection standards *[Table 1-1]* for the GRP are established for each designated aquifer/zone as described in Ground-Water Hydrology for Support of Background Concentration at the Grants Reclamation Site (Hydro-Engineering, 2001) and Background Water Quality Evaluation of the Chinle aquifers (HMC and Hydro-Engineering, 2003). The constituents listed in *[Table 1-1]* for the alluvial aquifer must not exceed the specified concentration limit in any of the monitoring wells, except for the background alluvial and San Andres Limestone and Glorieta Sandstone monitoring wells as described in the Groundwater Monitoring Plan (ML19217A355).

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 358; 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 Numbers 1, 2, and 3 (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 License Condition 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.

License Conditions 15, 16, and 43 also apply to the CAP. License Condition 15 indicates that the results of all effluent and environmental monitoring required by this license and regulation shall be reported semi-annually, by March 31 and September 30. All groundwater monitoring data shall be reported per the requirements in License Condition 35.

License Condition 16 specifies that before engaging in any activity not previously assessed by the NRC, the licensee shall prepare and record an environmental evaluation of such activity. When the evaluation indicates that such activity may result in a significant adverse environmental impact that was not previously assessed, or that is greater than that previously assessed, the licensee shall provide a written evaluation of such activities and 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). In order 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.

1.6.2 NRC Confirmatory Order

The NRC issued a Confirmatory Order on March 28, 2017 in response to a records review that identified five apparent violations of the source materials license conditions. The order modified the radioactive materials license, in part to address the groundwater corrective action program, including:

- As required by Confirmatory Order Item 6, submit a revised Corrective Action Program to the NRC on which NRC and the GRP will work, aggressively and in good faith, toward a goal of final approval of the Corrective Action Program within a year from the date of submittal.

On October 11, 2018, HMC requested an extension of the Corrective Action Program deadline from the end of calendar year 2018 to December 18, 2019. On December 5, 2018, HMC provided additional justification for an extension in response to an NRC request for information dated November 28, 2018. NRC approved the CAP submittal date extension request on December 31, 2018. The Corrective Action Program was submitted December 18, 2019. In June 2020, the NRC performed an acceptance review and determined that the application needed additional technical detail and supplemental information. A revised CAP, providing the additional information requested, was submitted in November 2020.

1.6.3 U.S. Environmental Protection Agency

The EPA's role is as an oversight agency defined in the Memorandum of Understanding with the NRC, effective December 14, 1993, and amended in 2013. The EPA is responsible for monitoring all restoration activities and providing reviews and comments on submitted documents and proposed restoration approaches to the NRC so that the GRP is restored in a manner consistent with CERCLA requirements. The principal statutory authorities that govern EPA's role at the GRP include:

- Uranium Mill Tailings Reclamation and Control Act, as amended, which provides environmental standards under 40 CFR 192 that apply to the remediation of Title I and II sites for radon emissions and radiological and non-radiological standards for surface water and groundwater.

- 40 CFR 61, Subpart W, which are the National Emission Standards for Radon Emissions From Operating Mill Tailings. These standards relate to the management of conventional uranium mill tailings impoundment radon flux, including the monitoring and reporting of the measured fluxes. Authority for regulation of radon under this regulation has been delegated to the State of New Mexico.

- CERCLA, as amended, which provides federal authority to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment. The National Contingency Plan (NCP; 40 CFR 300) is the implementing regulation for CERCLA. Under the NCP, the GRP was added to the NPL in 1983 at the request of the State of New Mexico because of groundwater contamination discovered in 1974 (EPA, 1975). EPA is responsible for overseeing all reclamation activities carried out under the NRC's authority to ensure these actions will satisfy Applicable or Relevant and Appropriate Requirements (ARARs) under CERCLA.

The NPL deletion or partial deletion process begins when all response actions at the GRP have been deemed complete by EPA, pursuant to 40 CFR Parts 300.425(e) and 300.515(c)(3) and in consultation with the State of New Mexico. Requirements to delete the GRP from the NPL include preparing documentation that restoration and reclamation activities and decision making are complete and verified, the State's concurrence with deletion, and an opportunity for public notice and comment before the GRP is formally deleted from the NPL. Detailed guidance for deleting a site from the NPL is provided in *Close Out Procedures for National Priorities List Sites* (EPA, 2011).

1.6.4 State of New Mexico

The primary regulatory agencies for the State of New Mexico are the NMED and New Mexico Office of the State Engineer (NMOSE). The NMED regulates the GRP through Discharge Permit DP-200 issued by the Ground Water Quality Bureau. The New Mexico Office of the State Engineer regulates water appropriations through the Water Rights Division and surface impoundment dams through the Dam Safety Bureau. The State of New Mexico also regulates surface waters, well drilling, air quality, prehistoric and historic sites, and wildlife protection under the New Mexico Administrative Codes (NMAC) and New Mexico Statutes and Authorities (NMSA) cited below:

- NMAC Title 20.6.2 New Mexico Water Quality Control Commission regulations for Groundwater and Surface Water Protection
- NMAC Title 19.27.4 Well Driller Licensing; Construction, Repair and Plugging of Wells
- NMAC Title 4.10.12 New Mexico Prehistoric or Historic Sites Regulations
- NMSA 1978, 75-6-1 New Mexico Endangered Species Act
- NMAC Title 19.21, New Mexico Endangered Plant Regulations

Groundwater discharge at the GRP is regulated under NMED Discharge Permit DP-200, which was modified and renewed on September 18, 2014. Permit DP-200 authorizes specific discharges associated with ongoing closure and groundwater clean-up activities to protect public health, safety, and the environment, including for present and future groundwater and surface water uses. Permitted discharges include the ongoing seepage from the Large Tailings Pile and Small Tailings Pile and discharges from the groundwater treatment facilities.

DP-200 (NMED, 2014) increased the maximum treatment capacity and discharge to 5,500 gpm over the previous discharge permits (DP-200 and DP-725). It also allows pilot testing of alternate groundwater treatment technologies and an increase in evaporative capacity. DP-200 requires quarterly, semi-annual, and annual reporting of various groundwater restoration operational activities. The modification of DP-200 subsumed the conditions and requirements of previously issued Discharge Permit DP-725. NMED terminated Discharge Permit DP-725 by letter dated October 27, 2014.

Discharge permit DP-200 issued by the NMED and/or the impoundment embankment permits issued by the New Mexico Office of the State Engineer will either be transferred to Department of Energy, Office of Legacy Management or terminated, as appropriate.

1.6.5 Other Environmental Requirements

Final reclamation activities will require the NRC to perform an evaluation of the environmental impacts associated with reclamation activities to comply with the National Environmental Policy Act and NRC's regulations, found at 10 CFR Part 51. The evaluation will describe the affected environment, evaluate the potential environmental impacts of the proposed reclamation actions, and provide monitoring and mitigation measures. Groundwater corrective actions must also be protective of threatened and endangered species and prehistoric and historic sites that may be present at the GRP.

1.6.6 Decommission and Reclamation

Upon approval of ACLs, portions of the GRP previously not reclaimed will be decommissioned and reclaimed in accordance with the Decommissioning and Reclamation Plan (AK Geoconsult and Jenkins, 1993), or the most recent approved version of that plan. Decommissioning and reclamation will involve final closure of the Large and Small Tailings Piles, closure and demolition of the groundwater treatment systems, closure of the East and West Collection Ponds and Evaporation Pond 1, Evaporation Pond 2 and

Evaporation Pond 3, demolition of the remaining site structures, reclamation of the remaining contaminated soil including completion of a final radiological verification survey to demonstrate that the GRP meets final NRC cleanup criteria, completion of final surface contouring and installation of erosion control structures, application of topsoil and seed to reclaimed areas, and installation of final security features (e.g., fencing, gates, signage).

1.6.7 License Termination and Transition

After groundwater restoration, decommissioning, and reclamation are deemed complete by the NRC, with concurrence from EPA and NMED, the existing GRP radioactive materials license, SUA-1471, will be terminated and the GRP will be transferred to the Department of Energy, Office of Legacy Management for long-term custody and care under a General License for Custody and Long-Term Care of Uranium or Thorium Byproduct Materials Disposal Sites granted under 10 CFR 40.28. Department of Energy, Office of Legacy Management is then responsible for long-term surveillance and maintenance of the site to ensure protection of human health and the environment. The transition process is detailed in guidance titled *Process for Transition of Uranium Mill Tailings Radiation Control Act Title II Disposal Sites to the U.S. Department of Energy Office of Legacy Management for Long-Term Surveillance and Maintenance* (DOE, 2012).

1.6.8 Consultations

The online United States Fish and Wildlife Service project review process was accessed. The threatened and endangered species that may occur are discussed in Section 3.5. None of the threatened and endangered species were identified as having critical habitat within one mile of the proposed control boundary (Appendix A). Several migratory birds were identified as potentially using the area (Appendix A).

Congress enacted the National Historic Preservation Act of 1966, as amended to support and encourage the preservation of prehistoric and historic resources. Section 106 of the National Historic Preservation Act requires federal agencies to take into account the effects of their undertakings on historic properties and allow the Advisory Council on Historic Preservation an opportunity to review and comment on the undertaking. This process is undertaken by the NRC staff, which has not yet initiated a Section 106 consultation related to the reclamation licensing actions for the GRP.

2 ALTERNATIVES

This section discusses the alternatives considered for implementation as part of the ACL Application. These alternatives were developed by first screening potentially applicable technologies and process options. The treatment technologies and process options were screened against criteria of effectiveness, implementability, and relative cost to address seepage to groundwater from the Large Tailings Pile and the impacted groundwater plumes with regard to the following general response actions:

- No Action
- Natural Attenuation
- Institutional Controls
- Removal
- Containment
- Treatment (*in situ* and *ex situ*)

The ACL Application provides a detailed discussion of corrective measures undertaken to date and operational details for the existing collection, injection, and treatment systems as well as other treatment technologies previously considered for the GRP.

2.1 DETAILED DESCRIPTION OF ALTERNATIVES

Based on identified treatment technologies and process options, the groundwater corrective action alternatives identified below were developed and assessed considering several criteria.

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

Overall, the alternatives assessed below provide reasonable assurance of protection of public health, safety, and the environment and are technically feasible. All alternatives rely on control over access to and use of groundwater through land ownership, although the areas over which these controls are required and the durations over which they are required vary between alternatives. No uranium concentrations were predicted in San Andres-Glorieta groundwater above the 0.03 mg/L maximum contaminant level for drinking water at any time during the 1,000-year simulations for any alternative.

Alternatives 1 and 2 remove constituent mass from the groundwater through active and/or passive treatment, and, over one or more centuries, restore groundwater concentrations to License Condition 35B groundwater protective standards over varying areas, with Alternative 1 restoring essentially all the alluvial groundwater by 150 to 200 years and partially restoring Chinle groundwater within 1,000 years. Alternative 1 contains the long-term groundwater contaminant sources (seepage from the tailings piles and back diffusion from the alluvial fine-grained immobile domain) through long-term active removal, treatment and reinjection. Similarly, Alternative 2 restores essentially all of the alluvial groundwater by 150 to 200 years and partial restoration of Chinle groundwater within 1,000 years, but reduces long-term transport in alluvial groundwater through passive *in situ* treatment using a permeable reactive barrier after 35 years.

Alternatives 1 and 2 require tens of decades to centuries of active removal and treatment system operation, including evaporation ponds, which contain high concentrations of constituents in the water that are potentially available to wildlife, and which rely on mitigation to reduce potential wildlife exposures. This creates a potential exposure pathway to groundwater constituents that would not otherwise exist as local groundwater is not available to wildlife. Alternative 3 does not actively remove mass through treatment, but rather relies on natural attenuation and groundwater access controls through land ownership to ensure long-term public health protection.

Alternatives 1 and 2 involve long-term ownership of the affected area for groundwater access control to eliminate potential public exposures, and for operation and maintenance of active and passive treatment systems. The long-term active operation and maintenance of Alternatives 1 and 2 preclude license termination and transfer 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. Although long-term private ownership of the affected area is considered a sufficiently durable and enforceable control over access to and use of groundwater, long-term governmental custodial ownership and care is considered preferable due to a higher degree of reliability. This is clearly identified in the Criterion 11(c) of Appendix A to 10 CFR 40, which states, in part:

> *"Title to the byproduct material licensed under this Part and land, including any interests therein (other than land owned by the United States or by a State) which is used for the disposal of any such byproduct material, or 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. In view of the fact that physical isolation must be the primary means of long-term control, and Government land ownership is a desirable supplementary measure, ownership of certain severable subsurface interests (for example, mineral rights) may be determined to be unnecessary to protect the public health and safety and the environment. In any case, however, the applicant/operator must demonstrate a serious effort to obtain such subsurface rights, and must, in the event that certain rights cannot be obtained, provide notification in local public land records of the fact that the land is being used for the disposal of radioactive material and is subject to either an NRC general or specific license prohibiting the disruption and disturbance of the tailings."*

Further, Alternatives 1 and 2 involve the permanent and irretrievable removal of billions of gallons of groundwater from the local hydrologic basin as treatment waste that is evaporated for disposal.

Alternative 3 does not involve any additional groundwater collection, treatment or water injection and does not reduce groundwater concentrations but rather ceases all groundwater corrective action and relies on natural attenuation of contaminants in transport and control of access to and use of groundwater through land ownership. Alternative 3 does not require long-term operation and maintenance of corrective actions systems and does not remove any additional groundwater from the local hydrologic basins but does limit access to that groundwater over a finite area for the long-term. All groundwater exiting the control boundary under Alternative 3 remains in the local hydrologic basins for all potential beneficial uses outside the control boundary.

2.1.1 No Action Alternative

Alternative 1 assumes that the current groundwater corrective action program continues with the use of extraction wells, *ex situ* water treatment, injection wells, and injection trenches to hydraulically contain and remove the dissolved constituent plumes. Water treatment systems include reverse osmosis, zeolite, and evaporation. The zeolite treatment system would be relocated from the Large Tailings Pile (Figure 1-5) to a previously disturbed area adjacent to the collection ponds to allow placement of the final cover on the Large Tailings Pile by 2025 (Figure 2-1). The collection and injection corrective action would continue in the Off-Site areas (Figure 1-2) for 150 years and in the On-Site area for 1,000 years. Once the Off-Site alluvial groundwater is remediated to License groundwater protection standards after an estimated 150 years of corrective action, long-term containment of the Large Tailings Pile seepage and back-diffusion of contaminant mass in the immobile transport domain of the fine grained alluvial material under the Large Tailings Pile are required to keep alluvial groundwater constituent concentrations at or below the License groundwater protection standards. Figure 2-2 illustrates the predicted maximum extent of uranium above the License groundwater protection standards in 2019, and at 200 and 1,000 years. Table 2-1 summarizes the maximum predicted groundwater uranium concentrations from the calibrated model at POEs, shown in Figure 1-44.

Modeling of Alternative 1 groundwater corrective action, presented in Appendix 4.2-B of the ACL Application, indicates Off-Site groundwater restoration in the alluvium (alluvial groundwater relatively distant from the tailings in which uranium is the only contaminant currently above License groundwater protection standards) to below current License groundwater protection standards within 150 to 200 years. Continued reinjection of compliant treated water (meeting License groundwater protection standards) into the alluvium in Alternative 1 prevents the decreasing saturated extent of the alluvium. The modeling results indicate that the injection of water associated with the current groundwater corrective action, in combination with historically higher tailings seepage rates and upgradient water discharges to the alluvium from sources not related to the Homestake Mill activities, have artificially increased the saturation of the alluvium and when those artificial recharge sources are removed, the saturated extent of the alluvium decreases to extents lower than currently observed. The more continuous extents of alluvial saturation observed for Alternative 1 represent potentially longer, continuous flow paths for constituent transport.

Restoration of the Upper Chinle groundwater outside of the Large Tailings Pile footprint is achieved after approximately 300 years, with possible minor exceptions at the southern Broadview Acres area near Highway 605 and a very limited location east of Highway 605 and the Small Tailings Pile, where very limited extents of groundwater uranium concentrations above 0.09 mg/L may persist (See Appendix B of Appendix 4.2-B of ACL Application).

Restoration of the Middle Chinle groundwater outside of the Large Tailings Pile footprint is achieved after approximately 300 years, with the exception of a limited area near Murray Acres and Broadview Acres south of the Large Tailings Pile, where uranium concentrations above the 0.18 mg/L mixing zone standard and the 0.07 mg/L non-mixing zone standard may persist for 1,000 years (See Appendix B of Appendix 4.2-B of ACL Application).

Restoration of the Lower Chinle groundwater is generally not achieved under this alternative as recharge, through the subcrop, by alluvial groundwater which has uranium concentrations of less than 0.016 mg/L but above the Lower Chinle License groundwater protection standard of 0.03 mg/L, may allow persistence and even possible expansion of contaminant distributions above the 0.03 mg/L standard in the Lower Chinle over the 1,000 predictive period (See figures Appendix B of Appendix 4.2-B of ACL Application).

The maximum uranium concentration for this alternative for the 1,000-year predictive simulation is 0.146 mg/L and occurs at POE 4 in the alluvium (Table 2-1, Figure 1-44, Figure 2-2). This maximum groundwater uranium concentration is higher than either of the other two alternatives.

When the areas of restored groundwater in the alluvium, Lower Chinle, Middle Chinle, and Upper Chinle are overlain (Figure 2-2), Alternative 1 restores an estimated 828 acres at 200 years, but after 1,000 years the area of groundwater with constituent concentrations greater than the License groundwater protection standards is 2,326 acres, which represents an expansion of the current area of 1,404 acres (Table 2-2). This increase in area is a result of groundwater from a higher elevation hydrostratigraphic unit that is compliant with License groundwater protection standards for that unit (alluvial aquifer, 0.16 mg/L standard) entering the underlying hydrostratigraphic units, which have lower License groundwater protection standards.

2.1.2 Proposed Action

HMC and Barrick Gold Corporation, of which HMC is a wholly owned indirect subsidiary, are the names of the organizations sharing ownership of the Proposed Action. Under the Proposed Action, Alternative 3, in which the License is amended to incorporate the proposed ACLs, all corrective actions cease, and the proposed groundwater monitoring is implemented. Figure 2-3 illustrates the predicted maximum extent of uranium above the License groundwater protective standards in 2019, and at 200 and 1,000 years. Table 2-1 and Table 2-3 summarize the maximum predicted uranium concentrations at POEs shown in Figure 1-44.

The modeled Alternative 3 groundwater corrective action, presented in Appendix 4.2-B of the ACL Application, removes all the hydraulic stresses associated with corrective action (e.g., groundwater collection and injections), although municipal pumping of the San Andres-Glorieta groundwater for municipal water supply outside the control boundary continues at current rates. The modeling results indicate that the absence of injection of water associated with the current groundwater corrective action, in combination with diminished tailings seepage rates resulting from tailings drain down and cessation of historical discharges to the alluvium from upgradient sources not related to the Homestake mill activities, cause decreased saturation of the alluvium to areas smaller than currently observed. The less continuous extents of alluvial saturation observed for Alternative 3, and to a lesser degree, in Alternative 2, represent shorter, less continuous flow paths for constituent transport relative to conditions for Alternative 1. The reduced saturated extent of the alluvium, evident after approximately 200 years, restricts long-term groundwater constituent transport in the alluvium and generally precludes transport to the Rio San Jose alluvial system west and southwest of the GRP (See figures in Appendix B of Appendix 4.2-B of the ACL Application).

Groundwater constituent concentrations of uranium and molybdenum in Upper Chinle groundwater are predicted to generally migrate south, parallel to the subcrop strike, to where the subcrop abuts the East Fault splay just south of the Broadview Acres area near Highway 605. The extent of uranium in groundwater above the License groundwater protection standard of 0.09 mg/L after 200 years and 1,000 years are similar to those predicted for Alternative 2 and less extensive than that predicted for Alternative 1 at 1,000 years. (See figures in Appendix B of Appendix 4.2-B of the ACL Application.)

Uranium groundwater concentrations in Middle Chinle outside of the footprints of the tailings piles generally do not change substantially from current conditions by 200 years. However, predicted groundwater uranium concentrations from under the Large Tailings Pile footprint above the License groundwater protection standard of 0.07 mg/L migrate to the south. The source of this uranium is due to slow downward migration from the overlying Upper Chinle.

Uranium groundwater concentrations in the Lower Chinle outside of the tailings piles footprints generally do not change substantially from current conditions by 300 years. Predicted uranium concentrations west of the West Fault above the License groundwater protection standard of 0.03 mg/L become evident by 400 years and continue to expand to the west toward the Upper Chinle subcrop over the remaining 600 years. The source of this uranium is due to slow downward migration from the overlying Middle Chinle.

The maximum uranium concentration for Alternative 3 for the 1,000-year predictive simulation is 0.0250 mg/L and occurs at POE 7 in the Lower Chinle (Tables 2-1 and 2-4).

Alternative 3 does not restore groundwater to below License groundwater protection standards (Figure 2-3, Table 2-4). An increase of 498 acres where groundwater with constituent concentrations greater than the License groundwater protection standards after 1,000 years occurs compared to the 2019 area. This increase in area is a result of groundwater from a higher elevation hydrostratigraphic unit that is compliant with License groundwater protection standards for that unit entering the underlying hydrostratigraphic unit which has lower License groundwater protection standards. At 1,000 years, the total area of impacted groundwater under the Proposed Action is 424 acres smaller than the area under the No Action Alternative.

2.1.3 Monitoring Systems

2.1.3.1 Compliance Monitoring

Groundwater compliance monitoring as required by License Condition 35 will continue to be performed to establish impacted and nonimpacted areas and monitor unimpacted areas to demonstrate compliance with the License groundwater protection standards. Groundwater monitoring results would be used to determine groundwater constituent extents and concentrations over time. Monitoring results would also be used to assess groundwater constituent concentration trends, reductions in contaminant mass, and/or reductions in plume extent.

It is currently understood that NRC considers all wells in the compliance and corrective action monitoring programs points of compliance for the License groundwater protection standards. The proposed compliance monitoring program, as further discussed in Section 6, will include sampling and testing of the alluvial and Chinle monitoring wells identified in Table 2-5. Table 2-5 also specifies the parameter measurements, groundwater analytes and frequency of monitoring. Groundwater quality data will be collected in accordance with the approved Quality Assurance Plan (HMC, 2022).

Compliance monitoring results would be reported in the Annual Report to show where the License groundwater protection standards are met or exceeded. Comparison of changes in constituent concentrations and trends and dissolved constituent mass would help assess the performance and effectiveness of the implemented remedy. Groundwater compliance monitoring results would be used to demonstrate compliance with License Condition 35B, Criterion 7A, and NUREG-1620 Section 4.4.

2.1.3.2 Operational and Treatment System Monitoring

Operational and treatment system monitoring would cease with the approval of the Proposed Action.

2.1.3.3 Summary of Major Impacts of the Proposed Action

The major impacts associated with the Proposed Action are addressed in Section 4 of this Environmental Report. In general, the primary impact is removal of the right to access and use of permitted groundwater wells currently existing within the control boundary (Figure 1-44). Mitigation measures for the impacts associated with the Proposed Action are discussed in Section 5 of this Environmental Report.

2.1.4 Reasonable Alternatives

One alternative (Alternative 2) to the Proposed Action (Alternative 3) and the No Action Alternative (Alternative 1) was screened.

2.1.4.1 Alternative 2

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 On-Site area long-term collection, injection and *ex situ* treatment with an *in situ* hydroxyapatite permeable reactive barrier in year 36 of corrective action. Collection and injection in the North Off-Site and South Off-Site areas would continue for 150 years in the exact same manner as provided in Alternative 1. 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 to the point that concentrations above protective standards are contained to the Large Tailings Pile and Small Tailings Pile footprints, after which time, treatment by means of the permeable reactive barrier would continue. However, because the permeable reactive barrier would require replacement approximately every 50 years for the duration of the 1,000-year period, 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 occurs in the Off-Site areas for 150 years through collection and injection wells while 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 2-4). Figure 2-5 illustrates the predicted maximum extent of uranium above the License groundwater protection standard in 2019, and at 200 and 1,000 years. Table 2-1 summarizes the maximum predicted uranium concentrations at the representative POE.

As with Alternative 1, long-term contaminant sources to groundwater persist. Tailings draindown, seepage rates, and seepage constituent concentrations are the same as those for Alternative 1, described above. Also like Alternative 1, the zeolite treatment system is relocated from the top of the Large Tailings Pile and the final tailings cover would be placed on the Large Tailings Pile in year six (2025) of the predictive model runs (Figure 2-1). The Small Tailings Pile is not reclaimed and remains available to receive groundwater corrective action treatment wastes 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 the model 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 2-4), while the Off-Site groundwater corrective action program would continue.

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 the 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 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 and 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. As with Alternative 1, the zeolite treatment system is decommissioned in years 151 to 152 when Off-Site groundwater restoration is estimated to be complete and decommissioning wastes are placed in the Small Tailings Pile.

The maximum uranium concentration for Alternative 2 for the 1,000-year predictive simulation is 0.0567 mg/L and occurs at POE 9 in the alluvium (Table 2-1). This maximum groundwater uranium concentration is 61 percent lower than Alternative 1, while it is 53 percent higher than Alternative 3 (Table 2-3).

When the areas of restored groundwater in the alluvium, Lower Chinle, Middle Chinle, and Upper Chinle are overlain (Figure 2-5), Alternative 2 does not restore all areas of groundwater with constituent concentrations greater than the License groundwater protection standards to below License groundwater protection standards (Table 2-2). An increase of 378 acres of groundwater with constituent concentrations greater than the License groundwater protection standards occurs over the 2019 area. This increase in area is a result of groundwater from a higher elevation hydrostratigraphic unit that is compliant with License groundwater protection standards for that unit entering the underlying hydrostratigraphic unit which has lower License groundwater protection standards. However, the total area of impacted groundwater is 544 acres smaller after 1,000 years than the area of groundwater with constituent concentrations greater than the License groundwater protection standards under the No Action Alternative.

2.1.5 Alternatives Considered but Eliminated

Three alternatives including the No Action alternative were developed as part of the selection process for the Proposed Action. Although some technologies and process options were considered, but ultimately not incorporated into the three alternatives, no alternatives were considered but eliminated.

2.2 CUMULATIVE EFFECTS

The primary past, current, and potential future cumulative impact of the groundwater corrective actions and associated alternatives is the irretrievable commitment of groundwater resources through evaporation. To date, millions of gallons of groundwater have been removed from the groundwater system and evaporated as a method of treating the brine effluent and regeneration fluids associated with the reverse osmosis and the zeolite treatment systems. Continued pumping, while potentially restoring a portion of the area of impacted groundwater over which groundwater may be safely accessed, irretrievably decreases the total amount of this resource. Increasing constituent concentrations in the groundwater have been observed upgradient of the GRP. These elevated constituent concentrations in groundwater are migrating downgradient in the alluvium toward the GRP. Constituent concentrations in the groundwater beneath the GRP may contribute to a cumulative impact to groundwater.

Application of natural attenuation, ACLs, and control of access to and use of groundwater to ensure affected groundwater is not inappropriately accessed or used, allows the total volume of the resource to be preserved, and allows those resources to be accessed outside the area of restricted use. The potential area of restricted access is already serviced by a municipal water supply and under groundwater prohibition (Figure 2-6). This irretrievable consumption of the groundwater resource from the shallow and intermediate groundwater systems in the arid west may be a non-trivial cumulative effect of the proposed and potential future corrective actions.

3 DESCRIPTION OF THE AFFECTED ENVIRONMENT

3.1 LAND USE/LAND COVER

When the Homestake 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 for families working at the Homestake 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 cover within five miles of the GRP, and Colorado Plateau Pinyon-Juniper Shrubland, which comprises approximately 25 percent of the land cover (Table 3-1). Inter-Mountain Basins Semi-Desert Grassland includes dry grasslands and occurs on xeric sites within an elevation range of approximately 4,750 to 7,610 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.

The GRP is located in a semi-circular valley ringed by a series of mesas that are approximately 7,000 to 8,000 feet 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 3-1). The GRP is located near the confluence of the ephemeral Lobo Creek and San Mateo Creek drainages, both tributaries of the Rio San Jose.

Land use within five miles of the GRP License boundary is predominantly shrubland (Table 3-2). Shrubland comprises approximately 87 percent of the land use within five miles of the GRP (Figure 3-2). Developed land comprises approximately six percent of the land use within five miles of the GRP with pasture, water associated with the GRP and the former Bluewater Mill to the northwest, and undeveloped evergreen forest comprising the remaining seven percent of land use.

3.1.1 Land Use HMC Property

Some land in and around the GRP is owned and controlled by HMC. Some land owned by HMC is used for livestock grazing through a lessor/lessee tenant arrangement (Figure 3-3). 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.

HMC holds title to several lots within the GRP License boundary, which are idle and are not used except where treated and/or fresh groundwater injection and groundwater collection occurs as part of the ongoing groundwater restoration program. Several small lot or small acreage parcels held by HMC in the general area of the GRP are idle and are essentially not in use except in certain instances where treated and/or fresh-water injection and water collection is underway as part of the ongoing groundwater restoration program or are under agricultural use on selected lot(s). For example, Block 1 Lot 5 and Block 2 Lot 2 in Murray Acres were planted and irrigated in 2008 through 2018 with the Murray Acres San Andres Limestone and Glorieta Sandstone irrigation well (0806R).

3.1.2 Land Use Residential Subdivisions

Major land use outside HMC-owned property, immediately proximal to the GRP consists of residential development located in the Pleasant Valley Estates, Murray Acres, Broadview Acres, and Felice Acres residential subdivisions. An assessment of current land use in these four subdivisions was undertaken in January 2019 to provide an annual review of the present use, 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, vacant or permanently abandoned dwellings are present on several lots.

The 2020 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 the Village of Milan water during 2020. A 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. 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; exceptions to this overall status are discussed below.

In the Valle Verde residential area, one residence was previously identified as obtaining domestic-use water from private well supply. This property owner was connected to the Village of Milan water supply system in June 2020. HMC paid for the connection of this residence to the Village of Milan water supply system.

License Condition No. 42 requires the submittal of a land use survey with the annual report; the most recent detailed Land Use Review/Survey is provided in the 2019 Annual Report (HMC and Hydro-Engineering, 2020). Results of this reconnaissance effort are summarized in Table 3-3.

3.2 TRANSPORTATION

New Mexico State Highway 605 and Interstate 40 are the highway access routes near the GRP. The existing site transportation corridors are shown on Figure 3-4. The GRP is accessed from County Road 63. Site roads are predominantly dirt, unmaintained roads. Approximately 26 vehicle trips each day are made by GRP personnel. An additional eight trips each day are made to the GRP by contractors and other deliveries.

The nearest public use airport is the Grants-Milan Municipal Airport approximately five miles south of the GRP. This airport can serve planes up to 30,000 pounds. The nearest airport that is served by major air carriers is in Albuquerque, New Mexico, approximately 87 miles east of the GRP.

3.3 GEOLOGY AND SOIL

3.3.1 Geologic Setting

The GRP is located in the southeastern part of the Colorado Plateau physiographic province and is on the south flank of the San Juan Basin. This region experienced a minor degree of structural deformation (Figure 3-5) consisting of regional folding and block uplift associated with formation of the Zuni Uplift, which is characterized by a northwest-trending anticline composed of Precambrian crystalline basement rocks overlain by Permian to Jurassic sedimentary rocks (HDR, 2016). This uplift formed the Zuni Mountains (Figure 3-6), which consist of a northwest-trending monoclinal fold approximately 75 miles long and 30 miles wide to the southwest of Grants. The Zuni Uplift is composed of Precambrian crystalline basement rocks overlain by Permian to Jurassic sedimentary rocks (Langman et al., 2012). 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 3-5 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; Figure 3-5 and Figure 3-7).

The development of more recent northeast-trending, high-angle normal 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 (Figure 3-8). The San Mateo normal fault northeast of the GRP has a vertical displacement up to 450 feet (Arcadis, 2013). Evaluation of lithologic and geophysical logs from drilling investigations at the site indicate these two faults are located slightly farther to the west and to the east, respectively, than the locations shown on the geologic map (Figure 3-9). Structural offset generally increases to the north along both faults (NRC, 2004). In general, these two faults are approximately vertical (Figure 3-10), shear is east side down, and are relatively impermeable barriers to groundwater flow within the permeable units of the Chinle Formation near the GRP (Arcadis, 2013). Except for the ends of the East Fault, the permeable sandstones of the Chinle Formation are adjacent to the relatively impermeable mudstones and siltstones across the two faults

(Arcadis, 2013). The offset of the underlying San Andres-Glorieta regional aquifer is much lower than the vertical thickness of the unit and does not appear to alter 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, 2016). 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 to 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, some of which was 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 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 a combined thickness of up to 20 feet. Sand beds generally range from five to 20 feet. Microscopy and petrographic microscopy results also support the local origin of the sediment. 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.

The Quaternary alluvium directly overlies the Chinle Formation and San Andres Limestone above a pronounced angular unconformity (Figure 3-10). As a result, sandstone units within the underlying Chinle Formation are abruptly truncated at the base of the alluvium. The Chinle Formation sandstone units are laterally continuous and separated by thick sections of low permeability shale. These geologic and hydrogeologic relationships are depicted in detailed hydrogeological cross-sections A-A' through D-D' (Figures 3-11 through 3-14).

High resolution characterization techniques were used in two supplemental studies at the GRP; a study of background groundwater constituent concentrations in alluvial groundwater and a tripolyphosphate pilot study. 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 3-15) and the other is located downgradient of the Large Tailings Pile (Figure 3-16). Both cross sections illustrate the scale and degree to which the sediments vary, both spatially 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 at the GRP are illustrated on Figure 3-10.

3.3.2 Geologic Units

The GRP is located in the southernmost part of the San Mateo Creek basin (Figure 3-6). Four sedimentary geologic units are present beneath the GRP. From youngest to oldest these units are alluvium, the Chinle Formation, San Andres Limestone, and the Glorieta Sandstone. Figures 3-11 through 3-16 present geologic cross sections through the GRP. As shown on the cross sections, the geologic units dip to the east-northeast. Two north-northeast-trending normal faults are present at the GRP, known as the East Fault and West Fault (Figure 3-7). These faults are approximately vertical and down dropped on the east. The vertical displacement of the faults has juxtaposed the more permeable units of the Chinle Formation against less permeable mudstone layers, thus affecting the local flow regime. The San Andres Limestone and Glorieta Sandstone, although vertically displaced, maintain horizontal connectivity across the faults and flow is not affected.

3.3.2.1 Alluvium

Quaternary alluvium underlies the entire GRP, has variable hydraulic characteristics based on extensive testing, and is generally 50 to 100 feet thick.

HMC has drilled nearly 500 wells into the alluvium at the GRP. The geophysical and lithologic logs from these wells, as well as logs and information for residential wells not owned by HMC, have been used to define the base of the alluvium. The location of the alluvial wells that have been used to define the geology and groundwater conditions in the alluvium at the GRP are shown on Figure 3-17.

The contours of the base of the alluvium are shown on Figure 3-18. The deepest portion of the alluvium is present below the western portion of the Large Tailings Pile. It turns to the southwest near the southwest corner of the Large Tailings Pile. The land surface elevation in this area is approximately 6580 ft amsl, so the alluvium, at its thickest point, extends 120 feet below the ground surface.

The elevation of the base of the alluvium is shallower in an area extending from the eastern Murray Acres subdivision to the Small Tailings Pile. In this area, the alluvium is approximately 60 feet thick. The reduction in saturated thickness (Figure 3-19) and a generally lower permeability of the alluvial material in this area combine to decrease the rate of alluvial flow. The boundary of the alluvial aquifer is defined where the elevation of the base of the alluvium is equal to the water level elevation (see green line on Figure 3-19).

3.3.2.2 Volcanics

Widespread Quaternary andesite and basalt flows are interbedded with the 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 at the GRP are illustrated on Figure 3-10.

3.3.2.3 Chinle Formation

The Chinle Formation is up to 900 feet thick at the GRP. The Chinle Formation is a massive dark reddish shale. Although the Chinle Formation is dominated by low-permeability shale units, beneath the GRP, the Chinle Formation contains three water-bearing sandstone units of relatively higher permeability. These water-bearing units are referred to as the Upper Chinle Sandstone, Middle Chinle Sandstone, and Lower Chinle Mudstone. The extents of the Upper, Middle and Lower Chinle in the vicinity of the GRP are shown on Figure 3-20, Figure 3-21, and Figure 3-22, respectively.

3.3.2.4 San Andres Limestone and Glorieta Sandstone

The lowermost units of interest at the GRP are the San Andres Limestone and Glorieta Sandstone, which together are 200 to 225 feet thick. The San Andres Limestone and Glorieta Sandstone are overlain by an unconformity and underlain by the lower-permeability Yeso and Abo Formations. The extent of the San Andres Limestone and Glorieta Sandstone in the vicinity of the GRP is shown on Figure 3-23.

3.3.3 Hydrogeology

The hydrogeological framework at the GRP consists of a hydraulically unconfined, buried alluvium overlying and in hydraulic connection with discrete bedrock water-yielding units within the Chinle Formation and the San Andres Limestone and Glorieta Sandstone. The Chinle units are under partially confined conditions where they subcrop beneath the alluvium and confined conditions further downdip.

Though the Chinle Formation is largely comprised of shale, there are three water-bearing units within the Chinle, referred to as the Upper and Middle Chinle, both largely composed of sandstone, and the Lower Chinle, which consists of a zone of enhanced water yield within the shale formation. A regional aquifer, the Permian-age San Andres Limestone and Glorieta Sandstone, exists at depth below the GRP, and predominantly consists of limestone with subsidiary sandstones and shale.

Bedrock units have tilted and faulted near the GRP. As a result, all three Chinle units subcrop with the overlying alluvium. Groundwater exchange occurs between the alluvium and the Chinle units creating mixing zones. In the mixing zones, there is hydraulic communication between units (USACE, 2010).

3.3.3.1 Alluvial Aquifer

The unconfined alluvial aquifer is the principal aquifer of interest at the GRP. The alluvial aquifer is unconfined with saturated thickness ranging from zero to approximately 70 feet and is composed of three connected alluvial systems: San Mateo Creek, Lobo Canyon drainage, and Rio San Jose (HDR, 2016). The San Mateo Creek alluvium composes the north/northeastern branch and the central portion of the alluvial aquifer beneath the GRP; the Rio Lobo alluvium forms the eastern/southeastern branch of the alluvial aquifer; and the Rio San Jose alluvium forms the west-southwest portion of the alluvial aquifer (Figure 3-19). A local bedrock high causes the alluvial aquifer to branch to the west and south before the San Mateo Creek and Rio Lobo alluvial systems converge with the Rio San Jose alluvium.

The unconfined alluvial aquifer at the GRP is laterally bound by areas of higher bedrock elevation. 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.

The alluvial aquifer at the GRP is recharged from (1) upgradient inflows from the upper and middle San Mateo Creek basin, (2) surface streamflow infiltration losses and precipitation that collects in low-lying areas, (3) continued drain down of the Large Tailings Pile, (4) injection of treated groundwater and San Andres Limestone and Glorieta Sandstone groundwater through the site remediation system, and (5) discharge from the underlying Chinle and San Andres Limestone and Glorieta Sandstone aquifers at subcrops where heads in these aquifers are higher than alluvial aquifer heads. Discharge from the alluvial aquifer occurs by (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the underlying Chinle and San Andres Limestone and Glorieta Sandstone at subcrops where heads in the alluvial aquifer are higher than heads in these units, and (3) groundwater outflow downgradient (south) of the GRP. Groundwater levels within the alluvium are shown on Figure 3-24.

3.3.3.1.1 San Mateo Alluvium

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 in the area of the Large Tailings Pile. 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.

Since the inception of monitoring by HMC, saturation of the San Mateo alluvium has increased both upgradient and downgradient of the Large Tailings Pile. In the vicinity and downgradient of the Large Tailings Pile, groundwater restoration activities are likely a large contribution to increased saturation.

The San Mateo alluvial aquifer generally behaves as an unconfined aquifer with specific yields ranging from 0.038 to 0.28. A specific yield of 0.1 is assumed to best represent the alluvial aquifer at the GRP (HMC, 2019). Measured hydraulic conductivity values are relatively high, ranging from approximately 10 to more than 200 ft/day. These values are, in general, locally consistent and are likely derived from the depositional environment. Specific examples of this consistency are areas where basalt is interbedded within the alluvium and generates high hydraulic conductivities in the Rio San Jose alluvium and the western extents of the San Mateo Creek alluvium, and low values found in areas adjacent to the historical streambed during deposition that likely received finer grained material such as the area due west of the Large Tailings Pile. The water table ranges between 40 and 60 feet below the ground surface.

3.3.3.1.2 Rio Lobo Alluvium

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 background wells indicated that the confluence of the Lobo Creek and San Mateo Creek alluvial systems may be in the vicinity of the northwest License Boundary (HMC, 2019b). Based on the lack of alluvial saturation encountered in the Lobo drainage basin, the quantity of Lobo alluvial water entering the GRP, if any, is thought to be only a small fraction of the quantity from the San Mateo alluvial system.

3.3.3.1.3 Rio San Jose Alluvium

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 the Village of Milan (DOE, 2014). Groundwater flow direction is provided in Figure 3-25 (DOE, 2014).

3.3.3.2 Chinle Formation

The Chinle Formation in the vicinity of the GRP includes three water-bearing permeable sandstone horizons separated by shale, referred to as the Upper, Middle, and Lower Chinle. These units are generally confined. The Chinle groundwater is generally recharged from (1) injection of treated groundwater and San Andres Limestone and Glorieta Sandstone groundwater through the site remediation system operations and (2) recharge from the overlying alluvium at subcrops where groundwater potentiometric heads are greater than heads in the Chinle. Discharge from the Chinle occurs through (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the overlying alluvium at subcrops where heads in the Chinle are higher than alluvial heads, and (3) groundwater flow generally downdip away from the GRP to east-southeast.

3.3.3.2.1 Upper Chinle

The Upper Chinle is a northeast-dipping, confined laterally continuous sandstone. 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 is hydraulically bounded from other Chinle Formation 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 sandstone encountered in borehole BK4 is likely the same sandstone as what makes up the Upper Chinle but appears to be eroded between the ridge and the Upper Chinle subcrop.

The groundwater quality of the Upper Chinle is influenced by the alluvial groundwater quality 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).

Hydrogeologic 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, 2010). In contrast, estimated transmissivity values are much lower in the region between the West and East Faults, where the Upper Chinle is not fractured and finer grain size is noted. The hydraulic conductivity of the Upper Chinle ranges from less than 0.1 ft/day to more than 100 ft/day (HMC and Hydro-Engineering, 2010). 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 3-26). Groundwater at the GRP generally flows from areas mounding near the injection wells toward extraction wells.

3.3.3.2.2 Middle Chinle

The Middle Chinle is an east to northeast-dipping, laterally continuous sandstone with groundwater under confined conditions. The Middle Chinle is similar to the Upper Chinle and is hydraulically bounded from other Chinle Formation units by competent overlying and underlying shale. Generally, the Middle Chinle is the thickest of the Chinle sandstone units 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, 2010). All three systems of 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).

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, 2010). 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.

Groundwater flow in the Middle Chinle is shown on Figure 3-27. The figure shows that hydraulic head 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. The West Fault represents a significant barrier to groundwater flow within the Middle Chinle, with up to 110 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 intercepting much of the flow in the area of the Broadview Acres and South Felice Acres developments. A steep gradient was developed to the southeast of this well indicating potential recharge to the Middle Chinle groundwater 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 groundwater 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 groundwater 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.

3.3.3.2.3 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. The Lower Chinle is hydraulically isolated from the overlying Middle Chinle and underlying San Andres Limestone and Glorieta Sandstone aquifer. In contrast with the overlying Chinle units, the Lower Chinle is composed of shale with enough developed secondary permeability to behave as a limited water-yielding unit (HMC and Hydro-Engineering, 2010). The permeability of the Lower Chinle 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. 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 Lower Chinle 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 groundwater is much lower and less consistent than overlying Chinle sandstones. Hydraulic conductivity ranges from 0.1 to more than 50 ft/day (HMC and Hydro-Engineering, 2010). Estimated transmissivity values for the Lower Chinle are generally higher than 100 gpd/ft near subcrop locations (HMC and Hydro-Engineering, 2010). However, selected areas near subcrop locations exceed 1,000 gpd/ft.

The inferred direction of groundwater flow in the Lower Chinle is shown on Figure 3-28. 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. The northwesterly flow direction in this area indicates that the Lower Chinle groundwater moves across the West Fault in the area west of Broadview Acres. Hydraulic head is higher in the alluvial aquifer than in the Lower Chinle with the exception of the subcrop locations, where hydraulic communication occurs.

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

3.3.3.3 San Andres Limestone and Glorieta Sandstone Aquifer

The San Andres Limestone and Glorieta Sandstone aquifer is the most important 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, 2010). Similar to the Chinle Formation, the regional aquifer is mildly folded and dips to the east and northeast as a result of regional tectonic deformation. Refer to Figure 3-29 for a plan view of the GRP area showing well locations, measured groundwater elevations and inferred contours. The aquifer has been used by HMC as the source of unimpacted clean water used for hydraulic containment of the alluvial aquifer and Chinle Formation aquifers. Thus, some of the water level elevations shown on Figure 3-29 are depressed due to pumping. The contours shown are based in part on wells that are not shown on Figure 3-29, including well 951 and DOE wells further upgradient.

Groundwater elevations near the GRP ranged from 6,420.417 to 6,433.420 feet amsl during December 2010 (HMC and Hydro-Engineering, 2010). Flow direction is to the east-southeast. The water-level elevations measured during 2014 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

Limestone and Glorieta Sandstone 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 increase in gradient across the GRP also indicates a decrease in transmissivity in the area of the steeper gradient. The faults may cause a decrease in the transmitting ability of the San Andres Limestone and Glorieta Sandstone aquifer.

The U.S. Geological Survey suggested an average transmissivity of 374,000 gpd/ft (Baldwin and Anderholm, 1992; Frenzel, 1992). An average groundwater velocity of 4 ft/day is estimated based on a hydraulic conductivity of 615 ft/day, a gradient of 0.00086 foot per foot (ft/ft), and an assumed effective porosity of 0.1 (HMC and Hydro-Engineering, 2010). 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.

The San Andres Limestone and Glorieta Sandstone aquifer and the alluvial aquifer are separated by the Chinle formation that acts as an aquitard (approximately 800 feet) at the GRP. Refer to Figures 3-11 through Figures 3-14 for cross sections showing the bedrock formations across a portion of the GRP. The difference in the potentiometric head between the two aquifers confirms that the Chinle formation is acting as an aquitard. As shown on Figure 3-14, the San Andres Limestone and Glorieta Sandstone aquifer subcrops the alluvial aquifer in Sections 5 and 32 west of the GRP.

3.3.4 Soil

Available data from the Natural Resource Conservation Service was reviewed and twenty-one 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 3-30). Sparank and San Mateo soils are moderately alkaline and well drained. Sparank soil is clay loam overlying a silty clay loam and San Mateo soil is a loam (ERM, 2018).

3.4 WATER RESOURCES

3.4.1 Surface Water

The GRP area has very little 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 consists of the San Mateo Creek, Lobo Creek, and Rio San Jose. 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). During such events, the alluvial aquifer at the GRP is recharged from surface streamflow infiltration losses and precipitation that collects in low-lying areas. Maps showing upgradient drainage areas and surface water drainages in the vicinity of the GRP are presented in Figure 3-31 and Figure 3-32, 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; Figure 3-33). 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.

San Mateo Creek and Lobo Creek both drain onto the GRP. 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 mill site. Two Lobo Creek drainages enter the east side of the GRP.

HMC constructed a diversion levee north of the former Homestake mill area to divert surface water flows from the northern branch of Lobo Creek (Figure 3-32; AK Geoconsult and Jenkins, 1993). 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 Homestake 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 and is also diverted by the North Diversion Channel west around the Large Tailings Pile as shown on Figure 3-32.

3.4.2 Groundwater

Mining activities have affected groundwater quality in alluvium and bedrock in the vicinity of the GRP and surrounding mine and mill sites (Figure 3-34). In the Ambrosia Lake area, direct discharge and surface infiltration of mine dewatering flows and seepage from unlined evaporation ponds has resulted in elevated concentrations of constituents in alluvial groundwater including sulfate, uranium, radium, gross alpha, total dissolved solids, and selenium (Weston, 2016). Concentrations of these constituents have exceeded federal drinking water standards in both alluvial groundwater and within underlying bedrock units downgradient of historical mining and mill sites in the Ambrosia Lake area.

Activities at the former Bluewater Mill site affected groundwater within both alluvium, associated with the Rio San Jose, and the underlying San Andres Limestone and Glorieta Sandstone aquifer (DOE, 2014). Estimated pumping within the San Andres Limestone and Glorieta Sandstone aquifer is shown on Figures 3-35 and 3-36. Elevated levels of molybdenum, selenium, and uranium have been detected downgradient of the former Bluewater Mill site and historical tailings pond. Uranium has been identified as the primary constituent of concern, and uranium concentrations above the federal drinking water standard have been observed downgradient of the site.

Seepage from the GRP tailings piles has resulted in the contamination of groundwater in the alluvial aquifer and the Upper, Middle, and Lower Chinle at the GRP. HMC has operated a remediation system to mitigate the impact of seepage from tailings to groundwater since 1977 and has provided water from the Village of Milan drinking water system to the subdivisions south of the GRP since 1986. Groundwater in the San Mateo Creek Basin is utilized for a variety of sources as discussed in the following sections.

3.4.2.1 Alluvium

Pumping of alluvial groundwater occurs for domestic, irrigation, and industrial purposes. Significant pumping and injection occur in the alluvium associated with remediation at the GRP, which have generally increased saturated thicknesses in the alluvium near the GRP. The groundwater potentiometric surface map is provided as Figure 3-24.

Historical mine dewatering pumping has had a significant long-term effect on groundwater flows in the alluvium in the San Mateo Creek Basin. Mining of uranium occurred primarily in the Ambrosia Lake area of the San Mateo Creek Basin. Groundwater extracted from mine dewatering was either used in the mine process or discharged to local drainages or the ground surface. Much of this discharge flowed to the Arroyo del Puerto and recharged local alluvium. Alluvium in this area was likely unsaturated prior to mining (DOE, 1996; Weston, 2016). As such, most of the groundwater in alluvial sediments in the Arroyo del Puerto currently is a result of past mining activities and is not naturally occurring. Recharge of mine dewatering discharge over an approximately 25-year period resulted in increased flow downgradient in the Arroyo del Puerto and ultimately San Mateo Creek (Figure 3-25).

3.4.2.2 Upper Chinle

The water quality of the Upper Chinle is influenced by the water 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).

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 3-26). Groundwater at the GRP generally flows from areas mounding near the injection wells toward extraction wells.

3.4.2.3 Middle Chinle

Groundwater flow in the Middle Chinle is shown on Figure 3-27. The figure shows that hydraulic head 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. The West Fault represents a significant barrier to groundwater flow within the Middle Chinle, with up to 110 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 intercepting much of the flow in the area of the Broadview Acres and South Felice Acres developments. A steep gradient was 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, groundwater of the Middle Chinle is in hydraulic connection with the alluvial aquifer.

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.

3.4.2.4 Lower Chinle

The inferred direction of groundwater flow in the Lower Chinle is shown on Figure 3-28. 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. The northwesterly flow direction in this area indicates that the Lower Chinle water moves across the West Fault in the area west of Broadview Acres. Hydraulic head is higher in the alluvium than in the Lower Chinle with the exception of the subcrop locations, where 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).

3.4.2.5 San Andres Limestone and Glorieta Sandstone

The San Andres Limestone and Glorieta Sandstone aquifer represent the primary groundwater aquifer in the region surrounding the GRP and has historically been subject to significant pumping for irrigation, municipal, mining, and industrial water supplies (Figure 3-35 and Figure 3-36). Long-term pumping from the aquifer has resulted in localized drawdown and changes in groundwater flow conditions (Baldwin and Anderholm 1992). Data on historical pumping for irrigation are limited. Frenzel (1992) provides estimates for irrigation pumping from the early 1900s through 1985 based on streamflow data, acres of irrigated fields, and pumping records where available. Total irrigation pumping in the Bluewater-Toltec area was estimated to range between 3,500 acre-feet (ac-ft) per year in 1945 to a maximum of 12,600 ac-ft per year in 1954. Irrigation pumping declined to near zero after 1980 (Frenzel, 1992). Figure 3-35 presents Frenzel's estimate of groundwater pumped for irrigation use between 1900 and 1990.

3.4.3 Groundwater Quality

The areas of the Chinle Formation in which the chemical composition of water has been altered by inflow of alluvial water are identified as the mixing zone. The focus of the groundwater restoration in the Chinle Formation is within the mixing zone. Because of the common element of alluvial groundwater within the mixing zone, the mixing zone is considered a single groundwater unit. References to the mixing zone will be in singular terminology despite the fact that portions of the mixing zone exist within each Chinle water-yielding unit.

Stiff diagrams are used in the following sections to present the differences in water quality that exist in the different water-yielding units. The stiff diagrams are prepared using the concentrations of eight major constituents in milliequivalents per liter (meq/l). The four anions are plotted on the right side of a vertical line at four locations while the four cations are plotted on the left side at three locations. Sodium and potassium cations are combined for the plot. The shape of the resulting diagram indicates water composition while the magnitude or size relates to concentration.

3.4.3.1 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 (HMC, 2003a; 2003b; HMC and Hydro-Engineering 2003; 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.

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 groundwater restoration (EPA, 2005b). NMED approved these background values in alter dated August 18, 2005 (NMED, 2005). These background values are summarized in Table 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, those conditions represent baseline conditions for the GRP.

3.4.3.1.1 Alluvial Background Groundwater Quality

The prevalent cation is calcium and the prevalent anion is sulfate in background alluvial groundwater (Figure 3-37). 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.

Prevalent ionic constituent concentrations have been posted on Figure 3-38 to show the spatial variation in calcium, sodium, bicarbonate, and chloride concentration in the alluvial aquifer. These data are also tabulated in the upper left corner of Figure 3-38. The wells north of the Large Tailings Pile are all upgradient of the GRP and are 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 most prevalent ionic constituent concentrations for wells downgradient of the Large Tailings area are also presented on Figure 3-38. The locations and constituent concentrations are presented for the three Point of Compliance (POC) wells (S4, Di and X) and three wells in the adjacent subdivisions. Typical concentrations of prevalent ionic constituents in the San Andres deep groundwater, which is used in the groundwater restoration program for injection into the alluvial aquifer, are noted in the legend. Calcium concentrations in alluvial water are typically greater than 200 mg/L downgradient of the tailings, with the lowest concentrations being observed at the POC well X; however, the water quality near well X has been influenced by injection of reverse osmosis (RO) product water.

3.4.3.1.2 Upper Chinle Background 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 ten miles of the GRP (Figure 3-39). 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 this groundwater-quality data is useful in defining background concentrations of 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 3-40. 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 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 for groundwater from Upper Chinle wells 0931, 0934, CW13, and CW18, which are located east of the East Fault is presented on Figure 3-41. 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.

Upper Chinle well locations and selected ion constituent concentrations are presented in Figure 3-42 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 3-42 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 3-42 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.

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.

3.4.3.1.3 Middle Chinle Background Groundwater Quality

Stiff diagram comparisons of the groundwater quality composition for the Middle Chinle wells are presented on Figure 3-43 and Figure 3-44. 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 3-45. 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 the 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 the alluvial groundwater, 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 are presented on Figure 3-46 and 3-47. 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 groundwater 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 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 groundwater in this area. The mixing zone pattern on Figure 3-45 covers the entire portion of the Middle Chinle west of the West Fault. All of these Middle Chinle wells contain groundwater of a quality similar to that of the alluvium (Figure 3-45).

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.

3.4.3.1.4 Lower Chinle Background Groundwater Quality

The natural water composition in the Lower Chinle varies considerably, reflecting the limited permeability and dependence on fracture permeability within Chinle shale for groundwater conveyance. The chemical composition of water 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 3-46 and 3-47, respectively. Based on the calcium concentration, water of Lower Chinle well CW41 is similar to the typical water composition for the Upper and Middle Chinle non-mixing zones while water composition in samples from other wells varies widely. The calcium, sodium, bicarbonate, and chloride concentrations in the Lower Chinle wells are presented on Figure 3-48. Review of these data confirms that the range of concentrations of prevalent ion constituents in the Lower Chinle is relatively broad. Inflow of alluvial groundwater has probably affected some of the Lower Chinle groundwater near its subcrop area. It is also typical that prevalent constituent concentrations 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 a shale. Only well CW41 contains water with calcium concentrations less than 30 mg/L. The data from well CW41 indicates that the water 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 select the area of the mixing zone.

The concentrations of prevalent constituents in the alluvial water 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.

3.4.3.2 Groundwater Quality

Seepage from the tailings piles has resulted in the contamination of groundwater in the alluvial, Upper, Middle, and Lower Chinle units at the GRP. HMC has operated a remediation system to mitigate the impact of seepage from tailings to groundwater since 1977 and has provided water from the City of Milan drinking water system to the subdivisions south of the GRP since 1986.

3.4.3.2.1 Alluvial Aquifer

Figure 3-49 presents groundwater uranium concentration contours. The light yellow/green pattern on Figure 3-49 shows areas where groundwater uranium concentrations are elevated, which includes the Large Tailings Pile, the Small Tailings Pile, and the area to the west extending into Township 12 North, Range l0 West, and Section 28. Additional areas where uranium concentrations in the alluvium were greater than the License groundwater protection standards exist south of the Small Tailings Pile along Highway 605 and in Felice Acres. The area of elevated concentrations in Felice Acres extends southwest approximately 2,600 feet from the southwest corner of Felice Acres.

A closer look at the groundwater uranium concentrations in the Rio San Jose is provided in Figure 3-50, which presents the 2017 groundwater uranium concentrations measured for the Rio San Jose alluvial aquifer and the San Mateo alluvial aquifer in an area extending from the confluence of the alluvial aquifers to the south. Higher uranium concentrations exist in the Rio San Jose alluvial aquifer to the northwest of the San Mateo confluence, from the Bluewater Mill Tailings Site, which is under DOE long-term management. Uranium contamination has not been observed in the Rio Lobo Alluvial System.

Groundwater selenium concentrations are presented in Figure 3-51. Concentrations of selenium in the alluvial groundwater above the License groundwater protection standard are located within the GRP, with the exception of an area east of Highway 605 located southeast of the Large Tailings Pile. Selenium concentrations in the nearby subdivisions are below the License groundwater protection standard.

Figure 3-52 presents data and contours of molybdenum concentrations in the alluvial aquifer during 2019. The License groundwater protection standard for molybdenum is 0.10 mg/L. Significant groundwater molybdenum concentrations 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 3-53 presents radium-226 and radium-228 concentrations for the alluvial groundwater near the GRP. Radium-226 and radium-228 concentrations above the License groundwater protection standards in the alluvial aquifer are limited to areas directly underneath the Large Tailings Pile. Vanadium and thorium-230 concentrations are presented on Figures 3-54 and 3-55, respectively. Vanadium concentrations were above or equal to the License groundwater protection standard of 0.02 mg/L in four of the seven alluvial wells located within the footprint of the Large Tailings Pile, one well near the southwest corner of the Large Tailings Pile and three wells located near the perimeter of Small Tailings Pile. Thorium-230 was present above the License groundwater protection standards of 0.3 pCi/L in three of the five alluvial wells sampled within the footprint of the Large Tailings Pile. In addition, three wells near the perimeter of the Large Tailings Pile also exhibited thorium-230 concentrations above 0.3 pCi/L: one to the north, one to the east, and one near the southwest corner.

Sulfate concentration contours for the alluvial aquifer during 2019 are presented on Figure 3-56. Areas where sulfate exceeds the License groundwater protection standard include below the Large Tailings Pile, approximately 0.25 mile west of the Large Tailings Pile, within the 120-acre flood irrigation field, and south of the Murray Acres subdivision.

Nitrate concentrations measured in the alluvial aquifer in 2019 near the GRP are presented in Figure 3-57. Areas where the nitrate concentrations exceed the License groundwater protection standard of 12 mg/L include within the footprint of the Large Tailings Pile (6 out of 30 wells), between the Large Tailings Pile and Small Tailings Pile (three wells), and in one well located within the 120-acre flood irrigation field. 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 the ACL Application show little aerial extent in alluvial groundwater. Figures 3-58 through 3-61 present the current extent of arsenic, boron, cadmium, and fluoride in alluvial groundwater. Groundwater arsenic, cadmium, and fluoride concentrations above their respective protective levels are limited to the area directly under the Large Tailings Pile and Small Tailings Pile while boron has isolated (i.e., detached from the area under the Large Tailings Pile and Small Tailings Pile) but contiguous areas of concentrations above their respective protective levels exist to the south southwest in the vicinity of the Pleasant Valley Estates and Murray Acres subdivisions.

3.4.3.2.2 Upper Chinle

Impact to the Upper Chinle groundwater is limited to a mixing zone, adjacent to the subcrop area, where the alluvial aquifer has had a direct impact on groundwater quality in the Upper Chinle (Figure 3-62). Groundwater uranium concentrations exceeded the Upper Chinle mixing zone License groundwater protection standard of 0.18 mg/L in the Large Tailings Pile area extending down to the south of the collection ponds and in two isolated areas at the developments south of the GRP. One location exceeded the mixing zone License groundwater protection standard just north of Broadview Acres and two values exceeded the License groundwater protection standard at Felice Acres as shown on Figure 3-63 and Figure 3-63A. The License groundwater protection standard for uranium in the non-mixing zone was not exceeded.

Selenium concentrations in the Upper Chinle groundwater are presented on Figure 3-64 and Figure 3-64A. The selenium concentrations were less than the mixing-zone 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.

Figure 3-65 presents the molybdenum concentrations in the Upper Chinle groundwater during 2018. Molybdenum concentrations near and underlying the Large Tailings Pile exceeded both the mixing and non-mixing zone License groundwater protection standard of 0.1 mg/L. 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 was exceeded in one well north of Broadview Acres. Molybdenum concentrations from Broadview Acres to the south and east of the East Fault were equal or below License groundwater protection standards.

Groundwater vanadium concentrations measured are presented in Figure 3-66. A vanadium concentration of 0.02 mg/L, which is above the License groundwater protection standard of 0.01 mg/L, was detected in well CW3. Well CW3 is located northwest of the HMC office. Remaining measurements were equal to or less than the License groundwater protection standards. Figure 3-67 and Figure 3-67A present groundwater radium-226 and radium-228 concentrations. None of the values exceed the EPA MCL. The highest radium-226 concentration measured in the Upper Chinle wells was 0.2 pCi/L in well CW3. The largest radium-228 value was 1.4 pCi/L in well CE15.

Sulfate concentrations in Upper Chinle groundwater are presented in Figure 3-68. Only wells below and near the Large Tailings Pile area exceeded the License groundwater protection standard for the mixing zone of 1,750 mg/L. The non-mixing zone License groundwater protection standard of 914 mg/L in the Upper Chinle is also exceeded in groundwater in the eastern portion of the Large Tailings Pile and at well CW73 in the southern end of Felice Estates (922 mg/L). Nitrate concentrations in the Upper Chinle groundwater measured in 2019 are presented in Figure 3-69. All measured nitrate concentrations in Upper Chinle groundwater are less than the License groundwater protection standard except for well T32 at 18.7 mg/L.

Additional constituents identified through the screening of GRP data discussed further in Section 2.2 show little aerial extent in Upper Chinle groundwater. Figures 3-70 and 3-71 present the current extent of boron and fluoride in Upper Chinle groundwater. These concentrations are above their protective limits in groundwater south of the Large Tailings Pile and Small Tailings Pile and downgradient (east) of the mixing zone with the alluvial aquifer. However, it should be noted that there are no descriptive statistics of background for these constituents, complicating interpretation of their true extents.

3.4.3.2.3 Middle Chinle

The License groundwater protection standards were established for mixing zone and non-mixing zone in the Middle Chinle. The extent of the Middle Chinle mixing zone is shown on Figure 3-72. 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 uranium that exceeds the License groundwater protection standard in Middle Chinle groundwater is shown on Figure 3-73. Groundwater in areas in the southern portion of Felice Acres, extending into Section 3, west and northwest of the Large Tailings Pile exhibited concentrations greater than the mixing-zone License groundwater protection standards as a result of direct migration through the subcrop window. Uranium concentrations in Middle Chinle groundwater exceeded the non-mixing zone License groundwater protection standard in Broadview Acres and Felice Acres and show limited migration from the mixing zone.

Middle Chinle groundwater selenium concentrations are presented on Figure 3-74. An area northwest of the Large Tailings Pile exceeded the mixing zone License groundwater protection standard. The higher selenium concentrations in these wells follow the same path of downward movement of alluvial groundwater into the Middle Chinle groundwater as uranium. Groundwater in an area located in Felice Acres exceeded the non-mixing zone License groundwater protection standard in two wells, also consistent with uranium migration.

The molybdenum concentrations in the Middle Chinle groundwater are presented on Figure 3-75. 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 are presented in Figure 3-76. Concentrations ranged from 285 to a high of 1,860 mg/L in 2019. Mixing-zone sulfate concentrations in the Middle Chinle groundwater were above the License groundwater protection standard of 1,750 mg/L in two wells west of the West Fault. Sulfate concentrations in the non-mixing zone of the Middle Chinle were below the License groundwater protection standard of 867 mg/L.

Figure 3-77 presents the nitrate concentrations in the Middle Chinle groundwater. Groundwater nitrate concentrations exceed the mixing zone License groundwater protection standard in the same area west of the West Fault where other constituents exceeded the License groundwater protection standard in the Middle Chinle groundwater.

Additional constituents identified through the screening of GRP data show isolated exceedances of some constituents in the Middle Chinle groundwater. Figure 3-78 presents the current extent of boron in Middle Chinle groundwater. Boron has a single isolated exceedance in groundwater in the vicinity of well 434 under the northern portion of the Broadview Acres subdivision and is not present above the protective level of 0.75 mg/L in any other Middle Chinle well monitored.

3.4.3.2.4 Lower Chinle

The License groundwater protection standards for the Lower Chinle groundwater have been established for the mixing zone and the non-mixing zone (Table 1-1). The location of the Lower Chinle mixing zone is shown on Figure 3-79. Uranium concentrations in Lower Chinle groundwater collected in 2019 are shown on Figure 3-80. Uranium concentrations in Lower Chinle groundwater exceeded the mixing-zone License groundwater protection standard southwest of Felice Acres in Section 3. Groundwater in the non-mixing zone adjacent and northeast of the mixing zone also exceeded the uranium License groundwater protection standard.

Selenium concentrations in the Lower Chinle groundwater for 2019 are presented on Figure 3-81. None of the selenium concentrations obtained in 2019 from the Lower Chinle wells exceeded the License groundwater protection standard.

The 2019 groundwater molybdenum concentrations obtained from the Lower Chinle wells 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 2019 are presented in Figure 3-82. None of the Lower Chinle concentrations of sulfate are above the License groundwater protection standards in the mixing zone. Areas west of the West Fault and north of the Large Tailings Pile have sulfate concentrations greater than License groundwater protection standards in the non-mixing zone, which are thought to be naturally occurring levels.

Nitrate concentrations measured in 2019 are all significantly below License groundwater protection standards. Additional constituents identified through the screening of License data discussed further in the ACL Application do not show broad occurrences in the Lower Chinle. Boron has a single isolated occurrence in groundwater above the protective level of 0.75 mg/L in the vicinity of well CW32 west of the Large Tailings Pile (Figure 3-83).

3.4.3.2.5 San Andres-Glorieta Aquifer

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

Figure 3-84 provides concentrations versus time plots for uranium from San Andres-Glorieta wells that are routinely monitored by HMC. The location of these wells is shown on Figure 3-29. Highest uranium concentrations in the San Andres-Glorieta wells monitored during 2018 were 0.088 and 0.03 mg/L in wells 943 and 951R, respectively. The 2017 uranium value of 0.11 mg/L from well 806R appears to be an outlier. Uranium concentrations in well 943 are much greater than those in well 943M because leakage into well 943 from an overlying groundwater had affected the concentration in well 943 prior to its abandonment.

Selenium concentrations in San Andres groundwater vary from less than 0.005 to 0.011 mg/L except for the effected concentration in well 943 of 0.047 mg/L. All measured molybdenum concentrations are less than 0.03 mg/L. Uranium milling operations at the Bluewater Mill Site, which is located approximately four miles west north-west, directly upgradient (Figure 3-34), of the Large Tailings Pile released uranium to the San Andres-Glorieta groundwater. Figure 3-85 is an isoconcentration contour map for uranium in the San Andres-Glorieta groundwater. Based on this information, the increase in uranium concentration experienced in well 951R is interpreted to be the result of uranium releases from the Bluewater Mill site.

3.4.3.3 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 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 Homestake 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 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. NMED also 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). This order is included in Appendix 1.2-C of the ACL Application. A map illustrating the area of the groundwater addressed in the order is presented in Figure 2-6. 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. 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 licensed boundaries 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.

HMC uses bottled water for drinking. HMC also uses water from a production well completed in the San Andres-Glorieta aquifer for other domestic and sanitary uses. Prohibitions will be put in place for the former land application areas that will prohibit residential and agricultural use of the land application areas and use of groundwater for drinking beneath the land application areas until License transfer.

A query of the New Mexico Office of the State Engineer well records for the area within the proposed control boundary 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 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 21 domestic use well permits, two irrigation use well permits, and two sanitary well use permits (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 2-6). There is no documented groundwater use from any of the domestic or commercial well permits for properties connected to the municipal water supply. The current irrigation groundwater use rate is estimated to be 376.9 gpm over a six-month growing period (Appendix 4.4-A of the ACL Application).

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 2020 annual survey, all water users in the area of concern are supplied by the Village of Milan water supply.

3.4.3.4 Geochemistry

3.4.3.4.1 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)]. PHREEQC 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 3-86). The alluvial 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 analysis, and the sulfide as sulfur 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, 2018b). 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 X-ray diffraction 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 X-ray diffraction 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, oxidized conditions with abundant complexing anions (negative ions) are expected to afford relatively high contaminant solubilities with iron oxides providing the primary mechanism for contaminant transport retardation in groundwater transport.

3.4.3.4.2 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. 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. 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.

3.4.3.4.3 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 following 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 that is provided in Appendix 1.2-C (WME, 2021).

3.4.3.4.4 San Andres-Glorieta Aquifer Transport Assessment Approach

Constituent mobility is controlled by pH and redox conditions, which determine their dissolved forms in groundwater. The mineralogy of the bedrock 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 their concentrations upon migration into the San Andres-Glorieta aquifer.

3.4.3.4.5 Sample Collection and Analysis

The data for this assessment were collected as part of a geotechnical 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 X-ray diffraction (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.

3.4.3.4.6 San Andres-Glorieta Aquifer Mineralogy

Bulk X-ray diffraction 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 that could not be detected using X-ray diffraction 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.

3.4.3.4.7 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.

3.4.3.4.8 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., iron), whose respective minerals 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 $CaUO_2(CO_3)_3^{-2}$).

3.4.3.4.9 Implications for Constituent Transport San Andres-Glorieta Aquifer

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) or uraninite 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 ferrihydrite. 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 (0.01 to 0.38 percent as iron; ACL Application Appendix 1.2-C, WME, 2021). Considering this range in alluvial ferrihydrite content, a surface complexation mixing model (SCCM) was previously utilized to predict the adsorption behavior of constituents in the alluvial aquifer. Freundlich adsorption constants for constituents, 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, 2020b).

3.4.4 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 3-87). The sodium-sulfate tailings seepage contains elevated pH, total dissolved solids (TDS), and constituent 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 becomes partially diluted as 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 two constituents, uranium and molybdenum.

The affinity for adsorption of constituents 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^+, $UO2^{2+}$) below pH of 6 (Figure 3-88). 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 and anions at lower concentrations than in the solution (Figure 3-89). 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 3-87). 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 3-90). 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).

3.5 ECOLOGICAL RESOURCES

When the Homestake mill and tailings piles were constructed from 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 and EPA, 2010b). It 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 Table lands ecoregion lacks the dense pine forests typical of the higher elevation Arizona and New Mexico Mountains ecoregion (EPA, 2010a and EPA, 2010b). Recently, a survey was conducted in 2018 with a one-mile buffer around the GRP as shown in Figure 3-91 (ERM, 2018).

3.5.1 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 3-92. 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 3-4 lists 13 species of mammals, 36 species of birds, and 3 species of reptiles known to occur in the vicinity of the GRP.

The 2018 survey (ERM, 2018) identified several plant and wildlife species of interest (Table 3-5 and Table 3-6). 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, and mule deer were identified within the one-mile buffer around the GRP (Figures 3-93 through 3-96).

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 crucial habitats within one mile of the proposed control boundary (Appendix A).

3.5.2 Aquatic Ecology

The ephemeral San Mateo Creek exists within the GRP but 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 concentrate 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.

3.6 METEOROLOGY, CLIMATOLOGY AND AIR QUALITY

3.6.1 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 from 30 to 40 percent of the year's total moisture falling at that time. 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).

3.6.2 Local Meteorology and Climate

The climate at the GRP is arid to semi-arid and temperate typical of a high desert. Table 3-7 summarizes the average monthly temperature and precipitation at the Grants Airport located about 5.5 miles south of the site. Average temperatures range from a low of about 14 degrees Fahrenheit (°F) in January to a high of 89°F in July. The average annual precipitation is approximately 14 inches per year. Most of the precipitation, about 60 percent or 6 inches, 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.

The minimum and maximum temperatures measured at the GRP in 2020 ranged from 1°F to 93°F (Table 3-8). The annual precipitation measured at the GRP in 2018 was 7.38 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 3-97.

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 3-98 and 3-99, 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 (New Mexico Climate Center, 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).

3.6.3 Air Quality

No known monitoring stations are near the GRP. The nearest monitoring stations are outside of Albuquerque in Los Lunas and Bernalillo (http://nmaqinow.net, February 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. Radon emissions from the partially reclaimed tailings are the primary air emission at the GRP. In addition, there are odors that emanate from the brines in the evaporation ponds that are discernable and different from the surrounding area.

3.7 NOISE

The GRP is one half to three quarters of a mile from the nearest resident. Noise generated at the GRP is from vehicle traffic, pump operation, and monitoring well drilling activities. No sensitive noise receptors (e.g., schools and hospitals) are known to be located near the GRP.

3.8 HISTORIC AND CULTURAL RESOURCES

When the Homestake mill and tailings piles were constructed from 1956 to 1958, no surveys of historical and cultural resources were performed before disturbance. Since that time, several historic and cultural surveys have been conducted (Figure 3-100).

Cultural resource surveys were conducted at the site in 1993, 1994, 1995, 2006 and 2018 (SAC, 1993a, 1993b, 1994; CASA, 1994a, 1994b, 1994c, 1995; TEC, 2006). The extents of these surveys are shown on Figure 3-100. In 2017 and 2018, a cultural resource survey was completed on approximately 2,696 acres of the GRP (Lone Mountain, 2018) to survey areas not previously surveyed in preparation for GRP activities and eventual reclamation. All cultural surveys identified sites that were recommended eligible or had undetermined eligibility for nomination to the National Register of Historic Places.

The reports associated with these surveys recommended design of reclamation and corrective action activities to avoid the National Register of Historic Places eligible sites and the sites with undetermined eligibility by at least 100 feet (Lone Mountain, 2018). Additionally, it was noted that if cultural deposits were encountered during site GRP activities, work should stop immediately, and the state archaeologist notified.

3.9 VISUAL AND SCENIC RESOURCES

The buildings of the GRP are visible from County Road 63 and State Highway 605. Additionally, the GRP facilities are visible from the nearby subdivisions. The El Malpais National Monument is within 30 miles of the GRP. United States Forest Service national forests are located approximately two to five miles east and southwest of the GRP.

3.10 SOCIOECONOMIC

The population of New Mexico in 2010 was 2,389,039 (Census, 2019). This population represents an overall density of 29 persons per square mile or 8.9 persons per square kilometer (km^2).

Cibola County was formed in 1981 from part of Valencia County. The overall annual growth rate of Valencia County from 1900 through 2021 is 3.76 percent. Cibola County is approximately 4,542 square miles in size and the population was estimated to be 26,746 in 2019 (Census, 2019). The University of New Mexico Geospatial and Populations studies estimated the population to be 27,103.32 in 2018, or approximately six people per square mile. The population of Cibola County declined 1.7 percent between 2010 and 2018 (census, 2019). Cibola County population has declined an average of 0.25 percent per year since its creation in 1981.

The median household income for New Mexico for 2014 to 2018 was $49,754 with approximately 16.8 percent of the population living in poverty. The median household income for 2014 to 2018 in Cibola County was $37,368 with approximately 28 percent of the population living below the poverty threshold (Table 3-9). 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, the county immediately to the north of the GRP, includes portions of the Navaho and Zuni Nations. McKinley County has a median income of with approximately $33,834 and a poverty rate of 33.4 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 the Village of Milan, Grants, and San Rafael, near the GRP is provided in Table 3-9.

3.11 PUBLIC AND OCCUPATIONAL HEALTH

As presented in the 2018 Annual Report, the calculated annual total effective dose equivalent for occupational exposure was 53 mrem of which approximately 40 mrem was attributable to airborne particulates and radon decay products (HMC and Hydro-Engineering, 2019). Optically simulated luminescent badges were utilized to measure the maximum quarterly occupational radiation deep dose for 2018. It was measured to be 4 mrem. The 2018 Annual Report reported that "*nearly all the badges show doses below the reporting limit of 1 mrem in a quarter*" (HMC and Hydro-Engineering, 2019). Internal dose calculations were not available at the time of the 2018 Annual Report.

As discussed in Section 2, air particulate and radon concentrations and direct gamma radiation dose are measured at the GRP boundary and at identified locations for the nearest resident (Figure 1-37). The 2018 calculated total effective dose equivalent public dose assumed 75 percent total occupancy with 200 equivalent days per year indoors and 71 days per year outdoors. The public dose was calculated as 52 mrem/yr and 50 mrem/yr at HMC-4 and HMC-5, respectively. The 2018 Annual Report stated that "*The doses from inhalation of radionuclides in airborne particulate material are negligible at the nearest residences. The calculated doses are well within the 10 CFR 20.1301(a)(1) public dose limit of 100 mrem per year and the doses from airborne radionuclides, excluding radon, meet the ALARA constraint limit of 10 mrem per year (10 CFR 20.1101(d))* (HMC and Hydro-Engineering, 2019). Eighty percent of the total effective dose equivalent public dose was attributable to radon, with direct radiation accounting for twenty percent.

3.12 WASTE MANAGEMENT

Historical mill tailings and other 11e.(2) Byproduct Material wastes were placed in the Large Tailings Pile and Small Tailings Pile. Since milling was terminated, the processing facilities decommissioned and placed into the Small Tailings Pile, the principal waste management facilities are the radioactive waste disposal areas in the Small Tailings Pile and the evaporation ponds. Evaporation Pond (EP1) is a single lined impoundment approximately 30 acres in area located on the Small Tailings Pile (Figure 1-5). Evaporation Pond (EP2) is a double lined impoundment approximately 19 acres in area located due west of Evaporation Pond (EP1). Evaporation Pond (EP3) is a double lined impoundment of approximately 26 acres located north of the Large Tailings Pile. Two single lined collection ponds are located due east of the RO Plant. Non-compliant water (water pumped for corrective action but not meeting compliance limits in License Condition 35B) and solid effluents from the treatment systems are discharged to the East and West Collection Ponds, where solids settling occurs. Collected waters are then pumped to the evaporation ponds for management and disposal through evaporation. Solids retained in the collection ponds are periodically excavated from the collection ponds and placed in Evaporation Pond (EP1) for long-term disposal. All collection ponds and evaporation ponds will be decommissioned and reclaimed within the Small Tailings Pile upon approval for termination of groundwater corrective actions as required by the approved Decommissioning and Reclamation Plan (AK Geoconsult and Jenkins, 1993).

4 ENVIRONMENTAL IMPACTS

None of the alternatives are able to fully restore groundwater to the License groundwater protection standards in 1,000 years. Overall, all the alternatives analyzed below provide reasonable assurance of protection of public health, safety, and the environment and are technically feasible. 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 the No Action Alternative and Alternative 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. Long-term containment of contaminant mass back-diffusion from the immobile transport domain directly under the Large and Small Tailings Piles footprints and long-term seepage from the Large Tailings Pile is required to maintain alluvial groundwater restoration. Portions of the Chinle sandstone units are not remediated to License groundwater protection standards for the full compliance period with either the No Action Alternative 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. 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 land ownership 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 2-1).

Alternative 1 (No Action) is the least protective of the environment, as indicated by not achieving License groundwater protection standards in groundwater Off-Site or On-Site (Figure 2-2) over the largest area for the 1,000-year period (Table 2-2). The No Action Alternative will not provide reasonable assurance of protection in the long-term due to the current uncertainty with the future plume extents.

Although the onsite permeable reactive barrier in Alternative 2 provides long-term *in situ* treatment of groundwater constituents, the predictive model simulation indicates that Alternative 2 would not be able to restore groundwater to License groundwater protection standards within the License boundary (Figure 2-5).

The predictive model simulations for Alternative 3 indicate natural attenuation would not be able to manage and contain impacted groundwater within the current License boundary (Figure 2-3) and ACLs with groundwater access controls would be required to ensure the reasonable assurance of protection.

Overall, the No Action Alternative and Alternative 2 are less protective of the environment than the Proposed Action in that they afford an exposure pathway for wildlife through the 1,000-year or 150-year operation of evaporation ponds, respectively, that does not exist for the Proposed Action. In addition, Alternatives 1 and 2 result in the permanent and irretrievable removal of billions of gallons of groundwater as treatment wastewater, while the Proposed Action, although permanently restricting access to groundwater over a finite area, allows that groundwater to remain in the local hydrologic basins for beneficial use outside the area of restricted access. It is noted that the long-term control boundary that would be needed for any of the alternatives considered would be similar given the need to encompass uncertainty in predictions and the need to provide reasonable assurance of long-term protection.

The results of modeling the No Action Alternative and sensitivity modeling of long-term contaminant sources to groundwater demonstrate the impracticability of active corrective action to meet License groundwater protection standards and support the conclusion that ACLs are necessary to return to compliance with the requirements of 10 CFR 40, Appendix A, Criterion 5B(5).

4.1 LAND USE IMPACTS

All Alternatives require HMC to acquire property or restrict groundwater use for property it does not already control that would be impacted by groundwater flow and contaminant transport over the 1,000-year period to ensure groundwater is not inappropriately accessed or used. All Alternatives would also require the relocation of the zeolite treatment system from the Large Tailings Pile to a previously disturbed area near the existing water treatment plant to allow timely placement of the final cover on the Large Tailings Pile (Figure 2-1).

All Alternatives would reduce the residential population and eliminate the limited irrigation of lands for livestock forage crops on lands within the control boundary due to land acquisitions. Use of groundwater for agricultural or domestic purposes within the GRP and HMC-owned lands is currently prohibited by HMC policy. There are no permitted stock wells within the control boundary and the 2018 State Order prohibits the installation of new or replacement wells in this area. There are no current land use restrictions within the GRP outside of the License boundary, although the State of New Mexico has ordered restrictions for new and replacement groundwater wells (Figure 2-6).

The No Action Alternative continues the current groundwater restoration activities with no additional disturbance. The No Action Alternative requires reinstallation of collection and injection wells and capital replacement of the evaporation ponds every 50 years on currently disturbed areas (Table 4-1).

Alternative 2 would require installation of a road along the permeable reactive barrier and construction of a pipeline from the RO Plant to the permeable reactive barrier. The location of the permeable reactive barrier will be within the License boundary in an area of the GRP that has been previously disturbed (Figure 2-4). The permeable reactive barrier would need to be replaced every 50 years which would entail a disturbance of approximately 100 acres (Table 4-1).

Land use impacts associated with the Proposed Action are the smallest of all alternatives. The land use impacts for the Proposed Action are limited to those associated with decommissioning and reclamation of the groundwater corrective action infrastructure and reduced residential population on land within the control boundary due to land acquisitions, impacts which are shared by all Alternatives.

There are no identified adverse impacts from the land use changes under any alternative.

4.2 TRANSPORTATION IMPACTS

No additional construction or infrastructure is planned for the Proposed Action. The Proposed Action would not add to transportation requirements or number of vehicle trips to and from the GRP each year. Reclamation and decommissioning activities are common to all alternatives addressed under NRC approval of the Decommissioning and Reclamation Plan. Transportation to and from the GRP will primarily involve commuting GRP personnel and service providers, as well as delivery of consumable items and other materials associated with operating the GRP.

The No Action Alternative will result in additional vehicle traffic to the GRP by daily contractors and additional delivery of material for the relocation of the zeolite system, in addition to periodic capital equipment replacements for the corrective action infrastructure (e.g., zeolite system, evaporation pond liners, water collection and injection pipelines, groundwater wells, water treatment plan; see Table 4-1). Vehicle trips to the GRP would increase by approximately 150 percent for less than one year at the frequency for which capital equipment replacement is needed. Operation and maintenance of the No Action Alternative for 1,000 years would require between four and six vehicle round trips per weekday for 365,000 days (Table 4-1). No traffic data are available for Highway 605, and, based on HMC experience and qualitative assessment of local traffic, the increase would not result in substantial impacts to traffic as this volume is equal or less than current GRP-related vehicle traffic (Table 4-2).

Alternative 2 will result in additional vehicle traffic to the GRP by daily contractors and additional delivery of material for the relocation of the zeolite system, installation of the permeable reactive barrier, as well as periodic capital equipment replacements for the corrective action infrastructure (e.g., zeolite system, permeable reactive barrier, evaporation pond liners, water collection and injection pipelines, groundwater wells, water treatment plan; see Table 4-1). Operation and maintenance of Alternative 2 for 150 years would require six round trips per day for 54,750 days (Table 4-1). No traffic data are available for Highway 605 and, based on HMC experience and qualitative assessment of local traffic, the increase would not result in substantial impacts to traffic as this volume is equal or less than current GRP-related vehicle traffic (Table 4-2).

There are no identified adverse impacts from the changes in transportation on local roads under any alternative.

4.3 GEOLOGY AND SOIL IMPACTS

The Proposed Action would not require additional construction and no impacts to geology and soil are expected. The No Action Alternative and Alternative 2 would require relining of the evaporation ponds and relocation of the zeolite system. Both these activities would occur in previously disturbed areas.

Under Alternative 2, installation of the permeable reactive barrier would require construction of a pipeline from the RO Plant to the permeable reactive barrier, installation of 168 injection and monitoring wells into the alluvium nineteen times over the life of the permeable reactive barrier, and construction of a temporary unpaved access road to and along the wells of the permeable reactive barrier. The wells would be drilled and completed over the entire saturated thickness of the alluvium, which ranges from 30 to 80 feet and averages approximately 40 feet in the area of permeable reactive barrier installation. Installation of the wells for the permeable reactive barrier, construction of the pipeline to the permeable reactive barrier, and the road along the permeable reactive barrier would occur in areas of previous soil disturbance; therefore, no additional soil impacts are anticipated. Drilling of wells into the alluvium and Chinle would not impact the geology under Alternative 2. Installation of the reactive media for Alternative 2 would involve the injection of chemicals into the subsurface that, when combined through natural mixing in the subsurface, would form hydroxyapatite. This reactive media would encompass an area of approximately 50 acres over the 1,000-year period of permeable reactive barrier operation and replacement.

There are no identified adverse impacts to geology or soil under any alternative.

4.4 WATER RESOURCES IMPACTS

Figures 2-2, 2-3, and 2-5 illustrate the predicted maximum extent of uranium in all groundwater above the License groundwater protection standard for the periods 2019, year 200 and year 1,000 of the simulations 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 unit and represent the area over which control of access to groundwater would be needed for each alterative at each timeframe. The difference in area between the present period, represented by 2019 groundwater uranium concentration distributions at the end of the model calibration, and the predicted uranium distributions at 200 years and 1,000 years is used as a means for assessing the degree of groundwater restoration. This approach is based, in part, on the idea that a potential groundwater user could penetrate more than one hydrogeologic unit and, even if a single hydrogeologic unit is restored to its License groundwater protection standard concentration at a specific location, underlying or overlying groundwater that is not restored at that location would preclude use of groundwater from that area. For an area to be available for unrestricted access to groundwater, all groundwater in all hydrogeologic units at a given location must be below the License groundwater protection standards.

The No Action Alternative continues the current groundwater restoration activities and will increase the amount of groundwater injected and removed from the groundwater system. The No Action Alternative will continue to remove groundwater for more than 1,000 years and requires the restriction of access to groundwater over the largest area of 2,326 acres or 3.6 square miles (Figure 2-2 and Table 2-2). Of all the groundwater pumped for groundwater corrective actions, approximately 80 percent will be returned to the groundwater system as treated and compliant effluent. The remaining approximately 20 percent of pumped groundwater will be disposed of as a non-compliant waste stream in the lined evaporation ponds and constitute an irretrievable commitment of the groundwater resource. Over the 1,000-year period of the No Action Alternative, 85.7 billion gallons of groundwater are irretrievably removed from the local groundwater system (Table 4-3). These withdrawals from the alluvium and Upper, Middle, and Lower Chinle are not anticipated to have any local adverse effects on agricultural, industrial, or permitted residential water uses outside the control boundary. Although permitted well uses will be restricted inside the control boundary, all existing residential properties are connected to the Grants, New Mexico, municipal water supply.

Alternative 2 will continue the current groundwater restoration activities for 150 years in the Off-Site areas, and in the On-Site area for 35 years until the permeable reactive barrier is installed. As with the No Action Alternative, approximately 20 percent of pumped groundwater for Alternative 2 will be disposed of as a non-compliant waste stream in the lined evaporation ponds and constitute an irretrievable commitment of the groundwater resource. Over the 1,000-year period of Alternative 2, 9.8 billion gallons of groundwater are irretrievably removed from the local groundwater system (Table 4-3). Alternative 2 requires the restriction of access to groundwater over an area of 1,788 acres or 2.8 square miles (Figure 2-2 and Table 2-2). Although permitted well uses will be restricted inside the control boundary, all existing residential properties are connected to the Grants, New Mexico, municipal water supply.

Under the Proposed Action, groundwater corrective actions would cease, no additional groundwater would be pumped, no additional groundwater evaporated in the lined evaporation ponds, and 1,902 acres or 2.97 square miles would require restricted access to groundwater (Figure 2-3 and Table 2-2). Although groundwater above License groundwater protection standards will remain inside the control boundary and permitted well uses will be restricted inside the control boundary, HMC has provided access to Village of Milan municipal water to all properties with permitted groundwater wells and is working to acquire land ownership of properties within the control boundary. All groundwater exiting the control boundary under the Proposed Action will be protective of all beneficial uses and will remain in the local hydrologic basins, available for future use.

As a practical matter, the final area requiring restricted access to groundwater for the Proposed Action, as described by the control boundary is larger than 2.97 square miles identified above for Alternative 3. This is because the assessment and comparison of alternatives is based on base-case model results and the areas compared represent the minimum areas that would require access controls. The control boundary for the Proposed Action considers the results of a more conservative bounding-case model used to support calculation of ACLs and encompasses substantially more area than the minimum used for comparison of the alternatives to provide additional assurance that the Proposed Action will remain protective for the compliance period.

The irrevocable loss of billions of gallons of groundwater from the local hydrologic basin is considered an adverse impact from the No Action Alternative and Alternative 2. The control of access to and use of groundwater is common to all alternatives with the largest area requiring control for the No Action Alternative, the smallest for Alternative 2 with the area for Alternative 3 intermediate between the other two Alternatives. This removal of access to groundwater is a potential adverse environmental impact for all alternatives.

4.5 ECOLOGICAL RESOURCES IMPACTS

The No Action Alternative and Alternative 2 continue the current groundwater restoration activities and involve operation of evaporation ponds, generation and handling of treatment wastes, and relocation of the zeolite system to a previously disturbed area off the Large Tailings Pile. Potential wildlife receptor exposures associated with these alternatives relate primarily to access and use of the contaminated water in the evaporation ponds, to be operated for 1,000 years under the No Action Alternative and 150 years for Alternative 2. Potential for significant health risks to wildlife populations are considered to be low, as potential exposures would be sufficiently mitigated by best management practices for wildlife access deterrence (e.g., fencing, reflective flagging, and other deterrents). Additionally, a comparison of ecological effects estimated in the screening level risk assessment using maximum modeled groundwater concentrations at the POE and available ecological screening values for surface water and radioecological screening levels for drinking water in terrestrial systems concluded that no ecological hazard is indicated (Table 4-4 and Table 4-5). Therefore, the No Action Alternative and Alternative 2 include a wildlife exposure pathway for more than 1,000 years or 150 years, respectively, that does not exist for the Proposed Action, but that risk is low and largely mitigated by best management practices.

The Proposed Action would involve no additional surface disturbance and the evaporation ponds would be reclaimed after approval of the ACLs. Until approval of ACLs, waterfowl and other wildlife could be exposed to the brines in these ponds.

Ecological exposures to contaminants in the evaporation ponds are a potential adverse impact to ecological receptors for the No Action Alternative for 1,000 years and for 150 years until the ponds are decommissioned in Alternative 2. This potential adverse ecological impact exists for Alternative 3 in the short-term until ACLs are approved and the ponds are decommissioned.

4.6 AIR QUALITY IMPACTS

The primary air quality impacts are the release of radon gas from the Large Tailings Pile and the Small Tailings Pile and odors from the evaporation ponds. All alternatives involve prompt placement of the final tailings cover on the Large Tailings Pile, reducing those related radon emissions to below the regulatory standard of 20 pCi/m^2/second. Interim cover for the Small Tailings Pile is also required to limit radon flux to below the regulatory standard of 20 pCi/m^2/second.

The Proposed Action would end the current groundwater corrective action activities, allowing for prompt surface reclamation and placement of the final cover on the Small Tailings Pile which would remove all sources of air emissions in the shortest time frame.

The No Action Alternative and Alternative 2 would continue the current groundwater restoration activities but the final cover would not be placed on the Small Tailings Pile for the duration of those two alternatives as it would remain open with an interim cover to allow periodic disposal of treatment wastes and decommissioned equipment during the operational life of the alternatives. Odors from the evaporation ponds would remain for the duration of the No Action Alternative (1,000 years) and Alternative 2 (150 years). Minimal, short-term and transient impacts to air quality may occur from dust related to operations and maintenance, and periodic equipment replacement for both the No Action Alternative and Alternative 2. Alternative 2 would involve surface disturbance and drilling in previously disturbed areas within the License boundary for approximately thirteen months related to installation of the permeable reactive barrier, with minimal impacts to air quality.

There are no identified adverse impacts to air quality requiring mitigation under any alternative.

4.7 NOISE IMPACTS

The No Action Alternative continues the current groundwater restoration activities and there will be no increase in noise as a result of the ongoing routine activities. Operation of enhanced evaporation devices (e.g., TurboMisters) on the evaporation ponds are limited to daylight operating hours and operating noise levels at the margins of the ponds are below 90 decibels. Alternative 2 runs for 1,000 years with comparable levels of labor effort and site activities to the No Action Alternative for the first 36 years. The No Action Alternative requires full time staff and treatment facilities operations for the full 1,000 years, while Alternative 2 implements passive *in situ* treatment after year 36, allowing for substantially decreased surface activities and staff, but requiring periodic replacement of the permeable reactive barrier every 50 years, in addition to annual monitoring and inspections.

Alternative 2 would involve drilling of approximately 168 wells for permeable reactive barrier installation and pumping of calcium citrate and sodium phosphate solution into the injection wells. Drilling and vehicle traffic would be limited to daylight operating hours but pumping reactive media chemicals into the injection wells would occur 24 hours a day for approximately 8 months, although the noise impacts from the injections are not anticipated to have high noise levels (less than 90 decibels).

All activities other than monitoring would cease under the Proposed Alternative after decommissioning is complete. Noise impacts from groundwater corrective action system decommissioning are common to all alternatives and would be limited to daylight operating hours and operating noise levels would be below 90 decibels. Noise levels at the GRP would be reduced because of the elimination of corrective action activities.

There are no identified adverse impacts requiring mitigation from noise impacts under any alternative.

4.8 HISTORIC AND CULTURAL RESOURCES IMPACTS

All areas of potential disturbance under all alternatives have been surveyed for cultural resources (see Section 3.8). The No Action Alternative continues the current groundwater restoration activities and the additional surface disturbance for relocation of the zeolite system would occur in a previously disturbed and surveyed area (Figure 2-1). Alternative 2 requires surface disturbance within the License boundary in previously disturbed and surveyed areas (Figure 2-4). All On-Site corrective action activities with the exception of monitoring will cease under the Proposed Action. No impacts to cultural resources will occur under any of the alternatives. All alternatives would be implemented in conformance with the requirements in License Condition 43, which identifies actions to be taken to ensure no unapproved disturbance of cultural resources occurs.

There are no identified adverse impacts to historical or cultural resources under any alternative.

4.9 VISUAL/SCENIC RESOURCES IMPACTS

The No Action Alternative continues the current groundwater restoration activities and the additional surface disturbance for relocation of the zeolite system would occur in a previously disturbed area (Figure 2-1). Alternative 2 requires surface disturbance within the License boundary in a previously disturbed area (Figure 2-4). Alternative 2 implements passive *in situ* treatment after year 36, allowing for substantially decreased surface activities and staff, but requiring periodic replacement of the permeable reactive barrier every 50 years, in addition to annual monitoring and inspections, resulting in lower relative aesthetic impacts compared to the No Action Alternative. Implementation of the Proposed Action would allow for the least relative aesthetic impacts due to the timeliest completion of decommissioning and surface reclamation. All onsite corrective action activities with the exception of monitoring will cease under the Proposed Action. Any visual impacts for all alternatives would be short term, transient and small scale, related to periodic equipment replacement, systems operations, and monitoring activities. Given the scope, scale, and duration of these activities, no appreciable impacts to visual or scenic resources are expected in the intermediate to long-term.

There are no identified adverse impacts requiring mitigation to visual and scenic resources under any alternative.

4.10 SOCIOECONOMIC IMPACTS

The No Action Alternative continues the current groundwater restoration activities and includes relining of all evaporation ponds and well reinstallation every 50 years. Some residents will relocate from within the control boundary but, for 1,000 years, substantial changes to community, social, political or economic systems as a result of the No Action Alternative will not occur, as the scope of the alternative actions are not of sufficient magnitude (personnel, vehicle traffic, annual material or labor impacts to local economy, etc., see Table 4-1 and Table 4-2) to precipitate such changes. All onsite corrective action activities with the exception of monitoring will cease under the Proposed Action. A reduction in the workforce at the GRP would likely occur as staff are no longer needed for water treatment operations (Table 4-2). Alternative 2 would involve installation of the permeable reactive barrier, relining of all evaporation ponds, and well reinstallation every 50 years. These activities will require experienced drillers and contractors who would likely be contracted from outside the area for the 13 months of construction. It is not anticipated that any changes to community, social, political, or economic systems will occur under any of the three alternatives due to the limited scope and duration of the activities and limited changes in workforce between alternatives. There are no identified adverse socioeconomic impacts requiring mitigation under any alternative.

4.11 ENVIRONMENTAL JUSTICE

As discussed in Section 3.10, approximately 28 percent of the population of Cibola County lives below the poverty threshold (Table 3-9). Although Cibola County has a lower median income and higher rate of poverty than New Mexico as a whole, the median income and poverty rate are similar to other counties in New Mexico. McKinley County has a poverty rate of 33.4 percent. Of the 33 counties in New Mexico, McKinley, Socorro, and Cibola counties have the highest poverty rates in New Mexico. No data are available for the residential population within the control boundary. All persons currently living within the control boundary will relocate to areas outside the control boundary due to land acquisitions at purchase prices or above fair market value. There are no identified adverse impacts to populations living outside the control boundary. Therefore, although Cibola County as a whole has a 28 percent poverty rate, none of the alternatives would adversely impact individuals living in poverty.

HMC has obtained ownership of the substantial majority of property within the anticipated long-term care boundary and continues its efforts to obtain all property ownership within the control boundary. Access to the Village of Milan municipal water system was supplied to four residential subdivisions south and southwest of the Mill which were in the impacted groundwater area. Neither the Proposed Action nor the other alternatives would unfairly impact a specific population based on race, color, national origin, or income because of the limited scope and duration of the activities. Therefore, no potential adverse impacts related to environmental justice are identified.

There are no identified adverse impacts related to environmental justice under any alternative.

4.12 PUBLIC AND OCCUPATIONAL HEALTH IMPACTS

No measurable change to radon, airborne particulate, or gamma radiation exposure is anticipated for any of the alternatives. A radiation protection program is maintained at the GRP. The 2020 Annual Report stated that "*the calculated doses are well within the 10 CFR 20.1301(a)(1) public dose limit of 100 mrem per year and the doses from airborne radionuclides, excluding radon, meet the ALARA constraint limit of 10 mrem per year (10 CFR 20.1101(d))*" (HMC and Hydro-Engineering, 2021).

All the corrective action alternatives preclude public access to and use of contaminated groundwater and associated treatment waste streams. Therefore, there are no public impacts from radiological and non-radiological constituents. The risk assessment presented in Section 3.5 to the ACL Application identifies no systemic effects to the resident gardener and the estimated excess lifetime cancer risk for the resident gardener from maximum constituent concentrations in groundwater at the POE (Table 4-6) is less than that posed by the primary drinking water standard.

Workers at the GRP performing construction, operations and maintenance, and decommissioning activities have the potential for future exposure to licensed materials.   Impacts related to these potential exposures are discussed below.

Occupational exposures from alternative decommissioning is common to all alternatives and levels of potential exposures from decommissioning activities are of similar scope and duration. Overall worker risks from decommissioning activities, as well as construction and operations and maintenance activities for all alternatives are considered low, as best practices are implemented, including the use of standard operating procedures, radiation work permits, worker training, and occupational health monitoring in accordance with the GRP Radiation Protection Plan, which support reducing potential exposures to levels that are as low as reasonably achievable.

The No Action Alternative will result in the largest amount of pumped groundwater, water treatment, and related waste streams and will occur over the longest duration of the alternatives and will result in the greatest amount of waste generation and handling. These conditions result in the highest potential for occupational exposures to radiological and non-radiological constituents in groundwater.

There are no identified adverse impacts to public health requiring mitigation under any alternative. There are potential adverse impacts to occupational health for the No Action Alternative and Alternative 2.

4.13 WASTE MANAGEMENT

The No Action Alternative continues the current groundwater restoration activities. The 1,000-year duration of the No Action Alternative will result in the generation of approximately 86 billion gallons of non-compliant effluent for management in the evaporation ponds. In addition, 1,000 additional years of water treatment will result in 4 million tons of water treatment waste solids that will be disposed of in the Small Tailings Pile. No additional waste management facilities will be required to manage these wastes, which are the same wastes currently produced and managed as part of the licensed corrective action program. Therefore, there are no adverse impacts associated with waste management anticipated from the No Action Alternative.

Alternative 2 continues the current groundwater restoration activities for 150 years. The 150-year duration of this alternative will result in the generation of approximately 10 billion gallons of non-compliant effluent for management in the evaporation ponds. In addition, 36 additional years of *ex situ* water treatment will result in 600,000 tons of water treatment waste solids that will be disposed in the Small Tailings Pile. No additional waste management facilities will be required to manage these wastes, which are the same wastes currently produced and managed as part of the licensed corrective action program.

The Proposed Action would discontinue all GRP groundwater corrective action activities. No additional effluent or water treatment sold wastes would require management and disposal.

Therefore, there are no adverse impacts associated with waste management anticipated from the Proposed Action.

There are no identified adverse impacts related to waste management under any alternative, as all wastes generated would be licensed and managed in existing facilities on-site under existing procedures, monitoring, reporting and radiation protection plans.

5 MITIGATION MEASURES

Three areas of potential adverse impact are identified in Section 4, above, which include potential impacts to ecological receptors, the environment from water resources, and occupational workers. No mitigations are necessary for impacts from or changes to land use, transportation, geology and soils, air quality, noise, historical and cultural resources, visual and scenic resources, socioeconomic, environmental justice, or waste management as discussed in Section 4.

Potential adverse impacts to ecological receptors relate to potential access to and exposure to contaminants in brines stored and evaporated in the lined evaporation ponds under the No Action Alternative and Alternative 2. Until approval of ACLs and closure of the evaporation ponds under the Proposed Action, 1,000 years of duration under the No Action Alternative, and 150 years of duration under Alternative 2, mitigation of wildlife exposures in the evaporation ponds would be ongoing. Best management practices and potential mitigation measures include placement of reflective ribbon on T-posts and placement of predatory decoy birds (i.e., falcons and owls) around the pond perimeters to create visual deterrents for bird use of the ponds. Best management practices will continue to be implemented to ensure no adverse impacts to the other environmental media or receptors occur under the Proposed Action. Section 6.2 discusses ecological monitoring for the ponds.

No mitigation for the loss of the billions of groundwater under the No Action Alternative (85.7 billion gallons) and Alternative 2 (9.8 billion) is identified. These losses are an irrevocable commitment of groundwater resource under these alternatives. There is no incremental irrevocable commitment of groundwater resources for Alternative 3 relative to the other Alternatives.

Adverse impacts, related to restricted access to and use of groundwater under all alternatives, have already been largely mitigated by the connection to municipal water supply for all properties with permitted groundwater access. The remaining land acquisition by HMC will eliminate future groundwater demand for all alternatives.

Overall potential occupational worker risks from construction, operation, maintenance, and decommissioning associated with all the alternatives is considered low and potential exposures will be reduced to ALARA via the use of standard operating procedures, radiation work permits, worker training, and occupational health monitoring in accordance with the GRP Radiation Protection Plan.

6 ENVIRONMENTAL MEASUREMENTS AND MONITORING PROGRAMS

HMC has been monitoring groundwater quality at the GRP since 1961 when contamination was first discovered (Chavez, 1961). Under the Proposed Action, compliance, corrective action, and operational groundwater monitoring will continue be conducted at the GRP to satisfy the requirements of 10 CFR 40 Appendix A, Criterion 7A and to evaluate the performance and effectiveness of the Proposed Action. The proposed revision to the current groundwater monitoring plan under the Proposed Action includes modification of the analytes for which sampling and analysis are performed, the locations at which monitoring is performed, and the monitoring and reporting frequency.

The proposed groundwater monitoring program wells are identified in Table 2-5, as well as the analytes for which monitoring and reporting are proposed, the analytical methods and minimum reporting limits for each analyte, the proposed monitoring frequency, and appropriate field parameters. The locations of the proposed monitoring wells are illustrated in Figure 6-1. A revised Groundwater Monitoring Plan is included in the ACL Application as Appendix 5.2-A. Background wells are proposed to monitor and identify potential changes to groundwater upgradient of the GRP not related to 11e.(2) Byproduct Material. Annual sampling and reporting are proposed.

The monitoring program for the No Action Alternative is assumed to be similar to the current annual compliance monitoring program, which includes annual sampling and analysis of 101 wells (Tables 6-1 and 6-2). The monitoring program for Alternative 2 would include both the current annual compliance monitoring program, and approximately 30 additional monitoring wells associated with the permeable reactive barrier. Other monitoring programs as discussed below will be the same under all three alternatives.

6.1 RADIOLOGICAL MONITORING

6.1.1 Air Particulate Monitoring

HMC continuously samples total suspended particulates at seven locations around the GRP (Figure 1-37 and Table 1-5). Those locations identified as HMC-1, HMC-lA, HMC-2 and HMC-3 are areas at the property boundary expected to have the highest predictable concentrations of airborne radioactive particulates. The predominant wind direction is from the southwest; accordingly, HMC-1, HMC-2 and HMC-3 are generally located downwind from GRP reclamation activities. HMC-lA is northeast of Evaporation Pond 3 (EP3) located north of the former mill. The location identified as HMC-6 represents background conditions for air particulates and is located due west of the Large Tailings Pile at the western most side of the property boundary. Locations HMC-4 and HMC-5 are proximal to the nearest residences. HMC-1OFF and HMC-6OFF are north of the GRP outside the License boundary (Figure 1-37). HMC-7 is a blank Whatman filter that is analyzed as a lab and filter manufacturer quality check sample.

HMC uses high volume air samplers to continuously sample the ambient air at the locations shown in Figure 1-37. The samples are collected on 8-inch by 10-inch Whatman glass fiber filters (or equivalent), which are changed weekly or more frequently as required by dust loading. The collected samples are composited quarterly and analyzed for natural uranium, radium-226 and thorium-230 (Table 1-5). Air sampling flow volumes and run times are recorded by HMC and the data are reported to the laboratory for calculation of average radionuclide concentrations in air particulates.

6.1.2 Radon Monitoring

Radon-222 gas concentrations in ambient outdoor air are monitored on a continuous basis at the nine locations identified in Figure 1-37 and Table 1-5. The background location for radon gas is HMC-16, located northwest of the site. Rapidos high-sensitivity track-etch passive radon monitors from Radonova (formerly Landauer Radon), or equivalent, are used to continuously monitor radon gas at each sampling location (Table 1-5). Personnel place new passive radon monitors quarterly at the monitoring locations and the exposed detectors are retrieved and returned to the vendor for analysis. The passive radon detectors measure radon gas concentrations in ambient outdoor air by exposing a special alpha-particle sensitive plastic chip mounted inside a chamber with a membrane filter on one end that is permeable to air and radon gas, but not to dust or solid phase particulate radionuclides. Radon-222 gas from ambient air diffuses through the membrane, and the subsequent decay of radon gas inside the chamber causes imprint tracks on the alpha- sensitive plastic chip that can be enhanced by a chemical etching process and counted after collection. The radon gas concentration is calculated by determining the number of tracks per unit area of the plastic chip.

6.1.3 Radon Flux Monitoring

Regulation 10 CFR 40.65 requires licensees to estimate and report the quantities of principal radionuclides released to unrestricted areas in gaseous effluents every six months.

Radon-222 is typically the only gaseous-phase effluent radionuclide released to unrestricted areas. The principal sources of radon-222 at the GRP are the Large Tailings Pile and Small Tailings Pile. Radon-222 releases from components of the water treatment system (the reverse osmosis treatment plant and evaporation ponds) are insignificant relative to those of the Large Tailings Pile and Small Tailings Pile.

Annual flux measurements occur as two separate deployments, consisting of 100 canisters per deployment on the Large Tailings Pile and Small Tailings Pile respectively.

6.1.4 Direct Radiation

Gamma dose rates are continuously monitored using optically stimulated luminescence dosimeter badges placed at each of the eight locations identified in Figure 1-37. HMC-16 is considered the background location for direct radiation (Table 1-5). Each optically stimulated luminescence badge consists of an aluminum oxide detector within a plastic holder. The plastic provides adequate protection from weather for these badges to be used outdoors. The optically stimulated luminescence dosimeter badges are exchanged semi-annually and analyzed by an approved independent laboratory. The levels of direct environmental radiation are recorded for each of the eight locations.

6.1.5 Surface Contamination

The Occupational Monitoring Program requirements are summarized in Table 6-1. The monitoring of personnel for alpha contamination may be required by the Radiation Safety Officer depending on the nature of the work being performed as specified in the Radiation Protection Program Manual (ERG, 2019). Documentation for personnel contamination surveys is maintained in each specific radiation work permit documentation binder or in a binder for miscellaneous surveys as applicable.

Equipment surveys are required for all equipment that is to be removed from Restricted Areas as specified in the Radiation Protection Program Manual (ERG, 2019). Standard Operating Procedures are used for these surveys.

6.2 ECOLOGICAL MONITORING

Wildlife surveys of the evaporation ponds are conducted at the GRP. If wildlife is identified on the ponds, the presence of wildlife and the measures taken to deter wildlife from the ponds are noted on the Wildlife Observation and Dispersal Form. Any bird death is reported to the appropriate authorities.

7 COST BENEFIT ANALYSIS

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 (NRC, 2006c). Types of decommissioning costs and benefits that may be considered in ALARA analyses identified in NUREG-1757, Appendix N, Table N.1 (NRC, 2006c) 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 irrevocably lost as untreatable wastewater from collected groundwater treatment 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
    - Aesthetics
- Costs
    - Remediation Costs (capital, operation and maintenance, and decommissioning costs)
    - Additional Occupational/Public Dose
    - Occupational Non-radiological Risks
    - Transportation Direct Costs and Implied Risks
    - Environmental Impacts
    - Present value of Irretrievable Commitment of Groundwater
    - 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. This analysis of the costs and benefits for the corrective action alternatives addresses the acceptance criteria for corrective actions identified in through quantitative and, where appropriate, semi-quantitative and/or qualitative analysis of the costs and benefits of corrective action alternatives.

7.1 BENEFITS OF CORRECTIVE ACTION

Pursuant to Section 3.3.3.2 of the NRC ACL Guidance (NRC, 1996) and Section 4.3.3.3 of NUREG-1620 (NRC, 2003a), the benefits of implementing the identified corrective actions are weighed against the costs of performing (or not performing) such measures.

The following sections address quantifying the cost of an alternate domestic or municipal water supply as a measure of the direct benefit of groundwater restoration. Valuation of the pre-contaminated groundwater resources 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 essentially assumes that no alternate water supply is present and all permitted groundwater wells are used to meet estimated current and projected future groundwater demand for the next 1,000 years. Further, this analysis assumes that existing permitted groundwater wells in the affected area are functional for the entire 1,000-year period, despite the 2018 State of New Mexico Order prohibition on replacing these wells. HMC has obtained ownership of the substantial majority of property within the anticipated long-term care boundary and continues its efforts to obtain all property ownership within the control boundary. Once these land acquisitions are complete, there will be no future groundwater use demand for the affected area.

7.1.1 Current and Projected Future Water Demand

Although projection of hypothetical future groundwater use demands is a speculative endeavor because the future use of any the lands is uncertain, reasonable and conservative estimates of current and projected future water use demand are used to value the groundwater resource. Groundwater uses in the proposed control boundary outside land owned by HMC currently include:

- Irrigation for forage crops (e.g., alfalfa)
- Light industrial use
- Domestic use

Future groundwater use demand for the area within the proposed control boundary is projected from estimated current groundwater use demand assuming that demand change would be proportional to population change over the next 1,000 years. Cibola County area has experienced a long-term annual population growth rate of approximately 0.7 percent, while the short-term annual population change since Cibola County was formed in 1981 has been a decrease of 0.25 percent. Therefore, the projected future groundwater demand escalates the current estimated groundwater use demand for each water use type (e.g., domestic, irrigation, etc.) by the range of identified annual growth rates. Appendix C provides a detailed basis for estimating future groundwater use demand and the net present value of that projected future demand; the following 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 within the GRP is related solely to groundwater corrective action and monitoring. There will be no future groundwater use demand on the land associated with the GRP 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 groundwater use demand is illustrated in Figure 6-1.

Review of the New Mexico Office of State Engineer database and recent aerial photography using Google Earth and ArcGIS for the area inside the control boundary identified 23 active well permit files on land not controlled by HMC that have specified water diversion allocations, visible evidence of use, or evidence of infrastructure allowing beneficial use of groundwater from the associated wells (Figure 2-6). The number of wells for each well use type are summarized in Table 7-1 (See Appendix C for the New Mexico Office of the State Engineer data). 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 dataset.

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 and MUL)
- 2 Irrigation water supply well (IRR)
- 2 Sanitary well in conjunction with commercial use (SAN, considered for use with IND wells)

There are no permits for 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 (Figure 2-6). The State of New Mexico has established a legally enforceable prohibition on the drilling of new, replacement, or supplemental wells for all of the wells within the proposed control boundary, precluding installation of new wells and replacement of existing wells after their function life ends which is estimated to be approximately 50 years (Figure 2-6). However, 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 overestimate the 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 of New Mexico records. Therefore, estimates of current and projected future groundwater use rates for each use type are made based on the assumptions and approach in Table 7-2. Land owned by HMC is assumed to have no current or projected future groundwater use demand. For privately owned parcels without active well permits, it is assumed that there is no current or projected future groundwater use demand and no current groundwater access is available. For active well permits for irrigation wells as shown in Figure 2-6, a maximum of 226 acres were estimated to be privately owned land (non-HMC land) and available for irrigation with local groundwater. It is assumed that 1.5 square miles (960 acres) is the upper limit for arable land for projected future irrigation within the control boundary, although some of this land may be purchased by HMC in the future and may not be available for irrigation in the future. To identify the groundwater application rate, the irrigated crop is assumed to be alfalfa with an irrigation rate of 34.2 inches per season and an April through September, six-month growing season (Table 7-2). The acres under irrigation were escalated by population growth rates up to limit of available land for irrigation which is estimated to be 960 acres.

Table 7-3 summarizes the projected groundwater use demand rates for each category of well based on the assumptions and approach described above. These calculations indicate that approximately 96 percent of the projected future groundwater use demand comes from the assumed irrigation demand and between 83 and 90 percent of the present value of the groundwater use demand. Hypothetical domestic groundwater use demand accounts for approximately one and two percent of the total future demand and three to five percent of the present value of the projected groundwater use. Projected future commercial groundwater use demand accounts for one percent of projected demand and between 5 and 13 percent of the present value of the projected groundwater use.

7.1.2 Availability of Alternate Water Supplies

An alternate water supply is currently available and is supplied by the Village of Milan for all of the properties with permitted wells within the control boundary (Figure 2-6). The water supply wells for the Village of Milan are located several miles to the south and outside the area of the control boundary.

7.1.3 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. A range of potential future demand is considered assuming the long-term annual population growth rate of 3.76 percent and the short-term annual decrease of -0.3 percent.

Municipal water rates are assumed to annually increase over the next 1,000 years assuming an annual inflation rate of 1.5 percent which is the approximate annual average consumer price index change from 1913 through 2019. 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. Table 7-3 summarizes the nominal water use cost (total dollar amount) and present value of the monthly water use payments over the next 1,000 years, considering the range in potential population growth rates. Appendix C includes an electronic copy of the Microsoft Excel spreadsheet that develops the calculations.

These calculations indicate that the conservative upper bound on present value for the cost of supplying an alternate water supply for all the projected future water use demands over the next 1,000 years for the high growth rate assumption is approximately $6.7 million while the present value cost of supplying an alternate water supply for the low growth rate assumption is approximately $3.1 million. At the low end of the population change rate (-0.25 percent population change per year), groundwater demand for domestic uses ceases by 140 years, commercial demand ends by 356 years, and irrigation groundwater demand ceases by 214 years (Appendix C).

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 for 1,000 years despite a State of New Mexico prohibition on installing new wells or replacing the existing wells after their function life ends. Second, this analysis assumes that the current groundwater well permits for domestic and commercial use are the sole source of water supply when it is known that all properties within the proposed control boundary are connected to the municipal water supply and there is no evidence of groundwater well use. Third, the high estimate of projected peak total groundwater demand of 3,519 gallons per minute for all uses likely exceeds the reasonable yield of the existing 23 wells for the affected hydrostratigraphic units in the proposed control boundary (an average of 100 gallons per minute for each well screened in the alluvial aquifer and Chile sandstone units). Overall, this analysis of the projected groundwater demand and value of the uncontaminated groundwater essentially assumes that no alternate water supply is present, and all permitted wells are used for the next 1,000 years to supply projected demand.

7.1.4 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. Comparison of these benefits support assessment of the differences in indirect benefits between alternatives.

7.1.4.1 Avoided Adverse Health Effects: Radiological

Benefits of averted radiological dose from exposure to the constituents in groundwater are 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, 2006c). The benefit is calculated as present worth dollars from the averted dose to the entire affected population over 1,000 years from implementing a corrective action alternative. 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.

The most recent version of NUREG-1530 (NRC, 2022) identifies a value of a person-rem averted of $5,200 per person rem averted in 2014 dollars. This equates to approximately $6,250 in 2022 dollars using the Bureau of Labor Statistics inflation calculator.

The radiological constituents considered in the ACL Application above the License groundwater protection standards are combined radium-226 and radium-228, thorium-230, and uranium. Mapping of groundwater concentrations of thorium-230 and combined radium-226 and radium-228 identify that these radionuclides are only present in groundwater at concentrations above their respective License groundwater protective standards directly under the tailings piles or in the case of thorium-230, in two isolated wells at concentrations near their protective standards. Future transport of these constituents to the existing potential domestic well locations within the control boundary and within the functional life of those wells at concentrations above protective standards is not considered reasonable given the average groundwater flow rates and geochemical mobility in this geochemical environment. Therefore, uranium is the only radioisotope considered herein to contribute to averted dose from groundwater corrective action.

A review of the New Mexico Office of the State Engineer records identifies 29 active domestic well permits within the proposed control boundary, all of which have access to the existing municipal water supply lines (Figure 2-6). Each well is assumed to support a household of three persons, the average household population for New Mexico. Therefore, the estimated population with a current or potential future exposure potential within the control boundary is estimated to be 57 persons. This is the population for whom doses could be averted if the groundwater were remediated under each of the alternatives. However, it is noted that once HMC completes land acquisitions, there will be no exposed population within the control boundary. In addition, the wells currently present cannot be replaced because of the 2018 State of New

Mexico Order prohibiting new or replacement wells in this area (Figure 2-6). Therefore, the consideration of potential future exposures at these locations for 1,000 years is highly conservative and represents the maximum potential benefit to be derived if full groundwater restoration were to be permanently achieved.

The calculated dose and related risks from a unit concentration of exposure to uranium in groundwater are used to calculate the doses and risks from exposure to the predicted average concentrations over the next 1,000 years at the 19 wells identified from the records search. Table 7-4 summarizes the calculated total effective dose from exposures for each alternative, as developed in Appendix 4.4-B of the ACL Application. Table 7-4 also presents the calculated present worth of averted dose in person-rem as well as the calculated values of benefit of averted dose in dollars for each alternative.

The calculation of the benefit of averted dose for implementing each alternative identifies that the benefits range from $72,660 (Alternative 1) to $711,648 (Alternative 3). The calculations developed in Appendix C identify the present worth of averted dose for Alternative 1 to be $11.63 per person rem and $113.86 per person rem for Alternative 3.

7.1.4.2 Prevention of Land Depreciation

Assessment of the amount or likelihood of land value depreciation for various remedial action alternatives is problematic and considered a subjective and qualitative endeavor. The following assessment discusses factors affecting land value and their likelihood of and degree for adversely impacting land values.

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 impacted 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. Since the presence of reclaimed tailings impoundments 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 the potential presence of groundwater impacts, although not accessible by surface users.

The potential for adverse perception of land value based on the historical land use of milling also applies to all alternatives even though the surface will be remediated to free release standards for unrestricted surface use. As a result, this factor is also eliminated for discriminating between alternatives.

Therefore, the principal remaining factor considered as 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 are all within the control boundary.

Alternatives 2 and 3 result in long-term groundwater concentrations above License groundwater protection standards within the control boundary while No Action Alternative requires approximately 400 years to restore alluvial groundwater to the general limits of the Large Tailings Pile and Small Tailings Pile footprints, although portions of Chinle groundwater are not restored to License groundwater protection standards. 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. Therefore, the relative adverse impact of adjacent property values is, though not specifically quantified, considered moderate for all alternatives.

7.1.4.3 Other Potential Benefits of Corrective Action

An additional potential benefit is the timeliness of decommissioning and closure from an alternative. The No Action Alternative and Alternative 2 are operated for 1,000 years. Under these two alternatives final closure and License termination and transfer could not occur, due to 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 7-5.

7.1.5 Costs of Corrective Actions

Pursuant to NUREG-1757 Appendix N (NRC, 2006c), 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 including 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 Facility. In addition, groundwater removed from the hydrologic system that cannot be returned to the hydrologic system has value and its irretrievable loss has an associated cost. An example of such irretrievable waters are the waste brines produced from reverse osmosis water treatment. For the different alternatives, this represents permanent consumption of the groundwater resource for which a monetary value can be calculated.

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 soils cleanup derived concentration limit goals (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.

7.1.5.1 Direct Remedial Action Monetary Costs

Overall, present value costs for the alternatives range from $28.9 million for the Proposed Action to $324 million for the No Action Alternative (Table 7-5)). The No Action Alternative and Alternative 2 have present value costs more than ten times that of Alternative 3, do not support final site closure, License termination and transfer to the long-term custodian, and do not provide permanent groundwater restoration of all groundwater. Alternative 3 supports final site closure, License termination and transfer to the long-term custodian, and provides the requisite reasonable assurance of long-term protection through modified compliance limits, monitoring, restriction of groundwater use through control of access to and use of groundwater, and long-term governmental custodial care, but does not restore the groundwater inside the proposed control boundary.

7.1.5.2 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 occupation hazards of transporting equipment and materials to the GRP, as well as installing, operating, and decommissioning the equipment. Table 7-5 summarizes the capital costs, operation and maintenance costs, and periodic costs for each alternative. Relative occupational risk-related monetized 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.

The No Action Alternative and Alternative 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 the Proposed Action, which does not rely on long-term operation and maintenance of active or passive treatment systems, but rather on monitoring, inspections, and land ownership.

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 7-5. 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.

7.1.5.3 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.

The No Action Alternative and Alternative 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 the No Action Alternative and Alternative 2 permanently consume tens of billions of gallons of groundwater as treatment waste, which represent substantial portions of the potential future groundwater demand and substantial portions of the calculated groundwater resource value, as described in the following sections, while Alternative 3 has no further consumption of groundwater. The No Action Alternative 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 150 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 No Action Alternative 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 the Proposed Action 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 7-5. The Proposed Action is ranked as having the lowest relative environmental impacts (3) due to the smallest scope and duration of surface activities while the No Action Alternative and Alternative 2 are ranked as having low to moderate relative environmental impacts (2) due to their large scope and duration of surface activities.

7.1.5.4 Consumption of Groundwater Resources

While the No Action Alternative and Alternative 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. Operational performance data indicates that *ex situ* treatment of off-site groundwater with zeolite has an operational efficiency of 85 percent with 15 percent waste and reverse osmosis treatment has an operational efficiency of 75 percent with 25 percent waste. The wastewater volumes of untreatable groundwater are irretrievably lost from the hydrologic system. The No Action Alternative collects over 361 billion gallons of groundwater which results in approximately 85.7 billion gallons of waste groundwater permanently consumed from the hydrogeologic system while Alternative 2 collects approximately 48.6 billion gallons and results in approximately 9.7 billion gallons of wastewater. The Proposed Alternative does not result in any future consumption of groundwater from the hydrogeologic system.

Using the same methods applied for estimating the value of the uncontaminated water resource based on projected groundwater demand, the present value of groundwater permanently consumed as evaporated wastewater can be quantified as a potential cost. If the wastewater was replaced by municipal water supply at the municipal water rates, the present value of that future supply would be $5.4 million dollars for the No Action Alternative and $4.8 million dollars for Alternative 2 (Table 7-5).

Overall, this indicates that, for both the No Action Alternative and Alternative 2, a majority of 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 the high estimate of projected groundwater demand; for the low estimate of projected groundwater demand, the present value cost associated with the permanently consumed groundwater exceeds the calculated present value of the groundwater resource benefit.

7.1.5.5 Loss of Economic Use of Site/Facility

No alternative precludes HMC from future, post-reclamation economic use of the GRP and associated land 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 cost differentials between alternatives for loss of economic use are not considered a material discriminator between the alternatives and are not quantified herein.

8 SUMMARY OF ENVIRONMENTAL CONSEQUENCES

There are no identified adverse impacts to land use, transportation, geology and soil, air quality, visual or scenic resources, socioeconomics, or environmental justice. The potential for adverse impacts have been identified to ecological and occupational health from all alternatives has been identified (Table 8-1).

The potential for occupational health impacts is low for all alternatives. The No Action Alternative has the highest potential for occupational exposure due to the 1,000-year duration of corrective action. The potential for occupational exposure under Alternative 2 is intermediate based on the 150-year duration of active corrective action and periodic replacement of the permeable reactive barrier over the 1,000-year duration of that corrective action. The potential for occupational exposure will exist until the ACLs are approved and ponds are decommissioned. Best management practices and the use of personal protective equipment, worker training, and monitoring can be utilized to mitigate potential impacts.

Because there are no adverse impacts to any connected surface water, the only potential for adverse ecological impacts is from continued potential wildlife exposure to contaminated water in the evaporation and collection ponds. Under the Proposed Action, this potential for exposure and adverse impacts is limited to the time it would take for the ponds to be decommissioned and reclaimed upon cessation of groundwater pumping and treatment (approximately two years). Under the Proposed Action, these ponds would remain in operation for two years, while under the No Action Alternative and Alternative 2, these ponds would remain potential ecological exposure points for substantially longer periods, during which time the potential for exposure and adverse impacts would continue.

The primary point of environmental consequences comparison for the alternatives relates to groundwater resources. The Proposed Action does not afford additional reductions in contaminant volume, mass, mobility, or toxicity. On the other hand, the Proposed Action does not continue the irretrievable consumption of groundwater through evaporation. Conversely, with an additional 1,000 years of pumping, the No Action Alternative will permanently remove through evaporation approximately 85.8 billion gallons of groundwater from the hydrologic system. Alternative 2 will continue the current On-Site groundwater restoration activities for 36 years until the permeable reactive barrier is installed and will continue Off-Site groundwater restoration for 150 years which will result in the removal through evaporation of approximately 9.8 billion gallons of groundwater from the hydrogeologic system.

If the No Action Alternative or Alternative 2 were chosen, billions of gallons of groundwater would be permanently removed from the hydrogeologic system for an intermediate term restoration of access to and beneficial use of groundwater as a drinking water supply in an area that has an alternative water supply in place. The Proposed Action does not continue the irretrievable consumption of groundwater through evaporation and with control of access to and use of groundwater withing the proposed control boundary, the Proposed Action will be protective of health, safety, and the environment for 200 to 1,000 years.

9 LIST OF 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)

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.

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.

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)

Brown and Caldwell, 2018, San Mateo Creek Basin and HMC Mill Site Hydrogeologic Site Conceptual Models, Technical Memorandum, January 8. (ML18025B341)

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.

Complete Archaeological Service Associates. (CASA). 1994a. Cultural Resource Inventory Homestake Mining Company's Section 30 Borrow Pit Cibola County, New Mexico. CASA 94-77. August 28.

Complete Archaeological Service Associates. (CASA). 1994b. Cultural Resource Inventory, Homestake Mining Company's Section 30 Borrow Area (CASA 94-77). August 30.

Complete Archaeological Service Associates. (CASA). 1994c. Cultural Resource Inventory 85 Acre Parcel North of the Mill and Tailings Pile Homestake Mine, Cibola County, New Mexico. CASA 94-85. October 4.

Complete Archaeological Service Associates. (CASA). 1994d. Cultural Resource Inventory135 Acre Parcel Northeast of the Mill and Tailings Pile Homestake Mine, Cibola County, New Mexico. CASA 94-102. December 9.

Complete Archaeological Service Associates. (CASA). 1995. Cultural Resource Testing, Evaluation, and Monitoring of Eight Sites for Homestake Mining Company near Milan, Cibola County, New Mexico. May

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)

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.

Engineering Analytics, Inc. (EA). 2022. Grants Reclamation Project Large Tailings Pile Evapotranspiration Cover Project Design Report. March. (ML22080A186)

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) 2018. Radiation Protection Program Manual Homestake Grants Reclamation Project, Cibola County, New Mexico. Revision 1. March

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.

Environmental Restoration Group and Hydro-Engineering LLC (ERG and Hydro-Engineering). 2014. Evaluation Of Years 2000 Through 2013 Irrigation With Alluvial Ground Water; Section 4.0. (ML14120A174)

ERM. 2018. Environmental Report - Grants Homestake Site. February.

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.

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.

HDR. 2016. Draft Remedial Investigation Report. Homestake Mining Company Superfund Site. June.

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.

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). 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). 2014. Land Application Irrigation Report 2000-2013; (ML14120A174)

Homestake Mining Company of California (HMC). 2018b. 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. Groundwater Corrective Action Program. Grants Reclamation Project. November. (ML20358A152)

Homestake Mining Company of California (HMC). 2022. Environmental Report in Support of the Groundwater Corrective Action Program. Grants Reclamation Project. August.

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). 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.

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). 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, Hydro-Engineering, LLC, and Environmental Restoration Group (HMC et al). 2017. Land Application Impact. Assessment September.

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.

Hydro-Engineering, LLC (Hydro-Engineering). 1983. Ground-Water Discharge Plan for Homestake's Mill near Milan. (ML20217P436)

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. Personal Email Communication with Brown and Caldwell. September.

Hydro-Engineering, LLC (Hydro-Engineering). 2017b. 1200 GPM Zeolite System Construction Completion Report, Consultant's report for Homestake Mining Company, Grants, New Mexico.

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.

Idaho National Engineering and Environmental Laboratory (INEEL). 2002. Estimating uranium partition coefficients from laboratory adsorption isotherms. INEEL/CON-02-0016.

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.

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.

Kuhn, A.K. and W. E. Jenkins. (Kuhn and Jenkins). 1986. Tailings Stabilization and Site Reclamation Plan.

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.L. (Langmuir). 1997. Aqueous Environmental Chemistry. Prentice Hall, Inc., New Jersey. 600 pp.

Lone Mountain Archaeological Services, Inc. (Lone Mountain). 2018. An Intensive Cultural Resources Survey for Homestake Mining Company Grants Reclamation Project. March.

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

Natural 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.

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). 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/.

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/)

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.

PRISM Climate Group. (PRISM) 2004. Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004.

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)

Resource West. 2018. Evaporation Study Report.

Skiff, K.E. and J.P. Turner. (Skiff and Turner). 1981. A Report on Alkaline Carbonate Leaching at Homestake Mining Company. November 12.

Stantec. 2019. Grants Reclamation Project EP-1 Geotechnical Investigation Report. May

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.

Southwest Archaeological Consultants, Inc. (SAC). 1993a. A Cultural Resources Inventory for Homestake Mine Near Milan, New Mexico. SW 324. August 27.

Southwest Archaeological Consultants, Inc. (SAC). 1993b. Research Design and Data Recovery Plan for 4 Limited Activity Sites Adjacent to Homestake Mill Near Milan, New Mexico. SW 334. December 6.

Southwest Archaeological Consultants, Inc. (SAC). 1994. A Cultural Resources Inventory of 404 Acres Northeast of Milan, New Mexico for Homestake Mine. SW 354. April 8.

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.

Taschek Environmental Consulting. (TEC). 2006. Cultural Resources Inventory of 350 Acres for the Homestake Mining Company in Cibola County, New Mexico. July.

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). 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). 1996. Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Groundwater Project. Volume 1. October.

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 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). 2011. Close Out Procedures for National Priorities List Sites. OSWER Directive 9302-22. 51 pp. May

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). 2022. Ecotox knowledgebase https://cfpub.epa.gov/ecotox/search.cfm.

United States Nuclear Regulatory Commission (NRC). 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). 2006c. Consolidated Decommissioning Guidance Characterization, Survey, and Determination of Radiological Criteria. NUREG-1757, Vol. 2, Rev.1. September 2006.

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. United States Nuclear Regulatory Commission (NRC). 2017. 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.

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. (https://www.epa.gov/sites/default/files/2016-11/documents/epa_smcb_esi_phase1_.pdf)

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)

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.

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.

TABLES

FIGURES

APPENDIX A

APPENDIX B

APPENDIX C