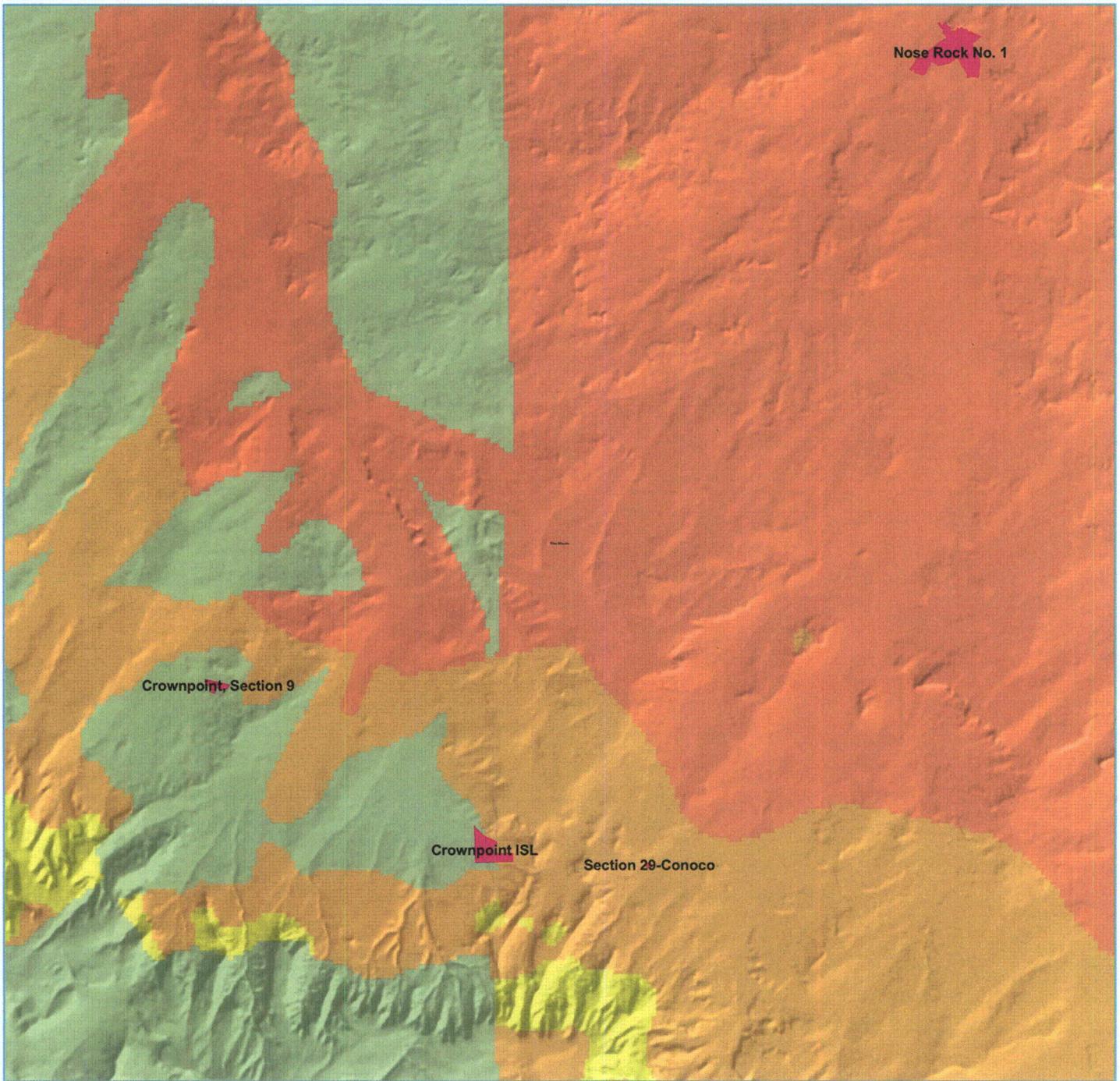


Crownpoint Area



Eastern Region
Becenti & Crown Point Areas

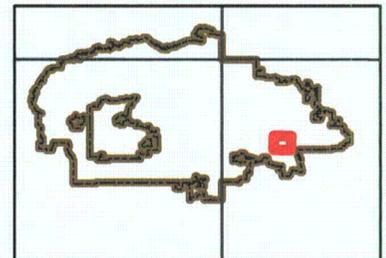
AQUIFER SENSITIVITY

Legend

• Abandoned Uranium Mines

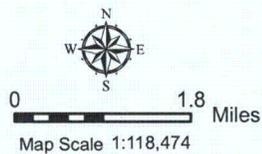
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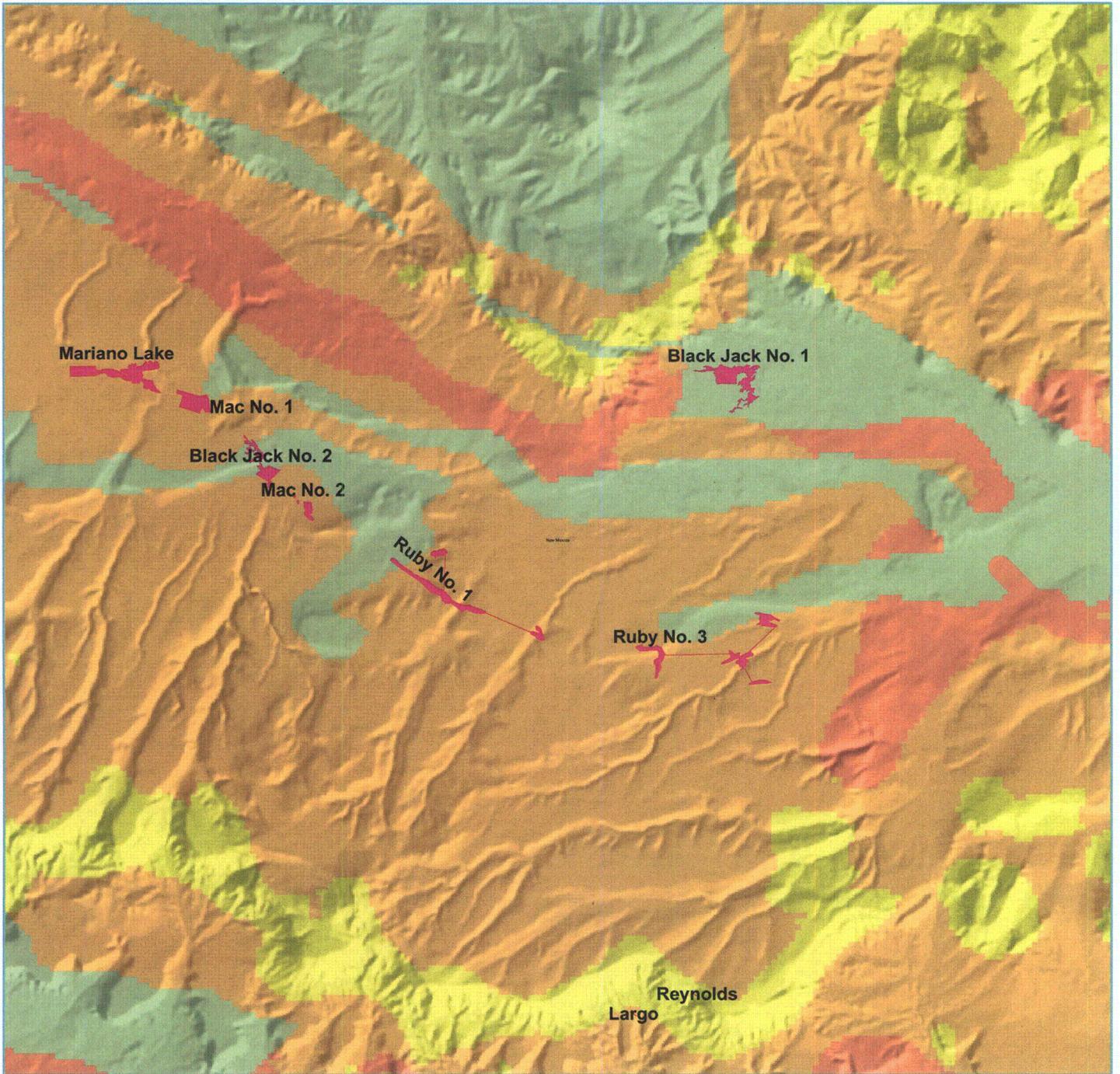
- 0 - Insignificant Potential
- 1 - Least Potential
- 2 - Intermediate Potential
- 3 - Most Potential



Sources

Aquifer sensitivity was developed and provided by Paul Blanchard (2002), U. S. Geological Survey, Water Resources Division in Albuquerque, New Mexico.





Eastern Region
Mariano Lake Area

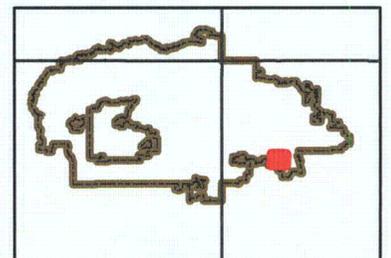
AQUIFER SENSITIVITY

Legend

• Abandoned Uranium Mines

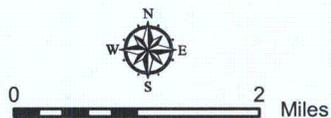
Aquifer Sensitivity Class

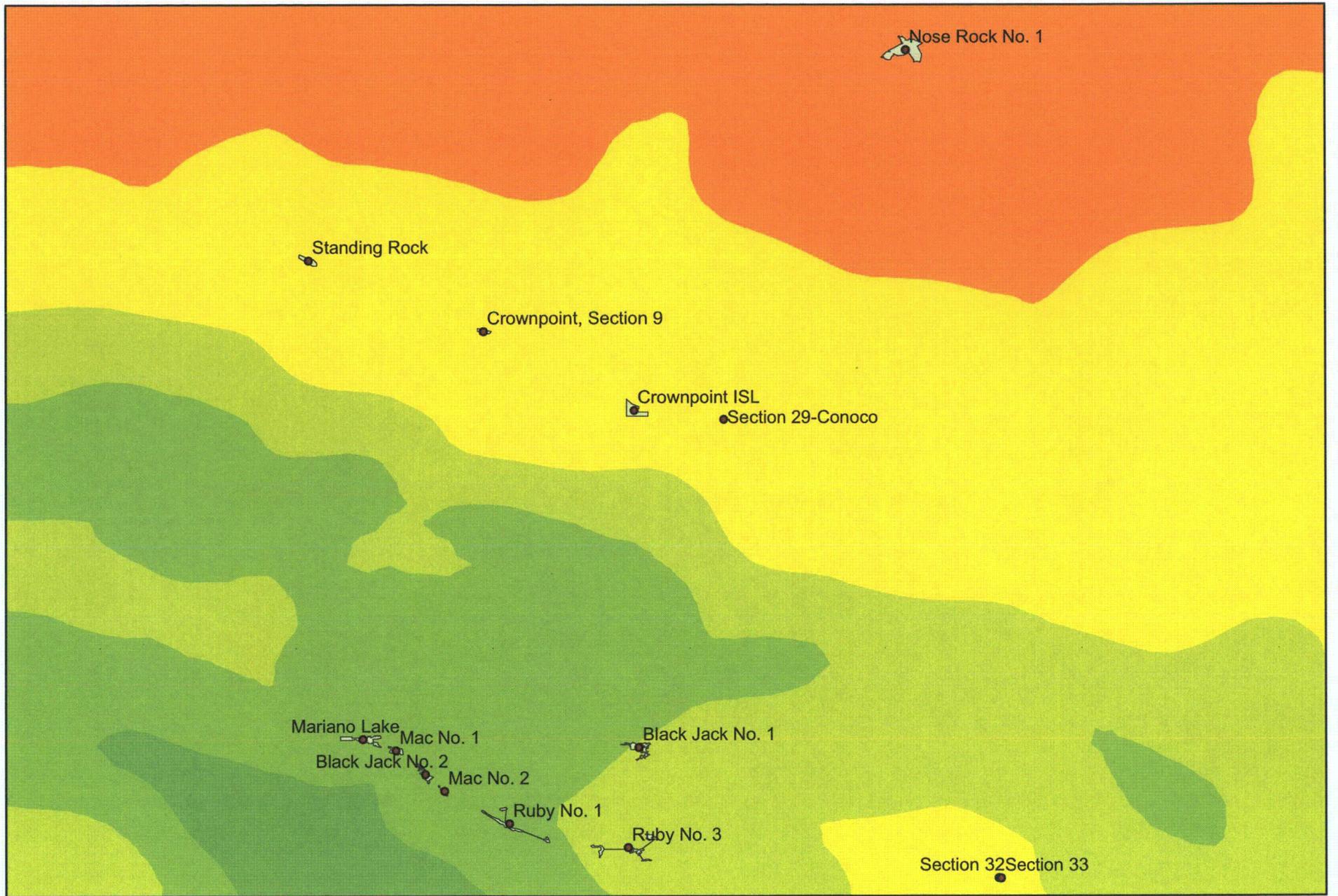
- 0 - Insignificant Potential
- 1 - Least Potential
- 2 - Intermediate Potential
- 3 - Most Potential



Sources

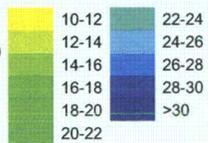
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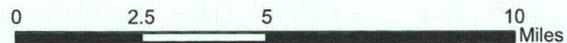


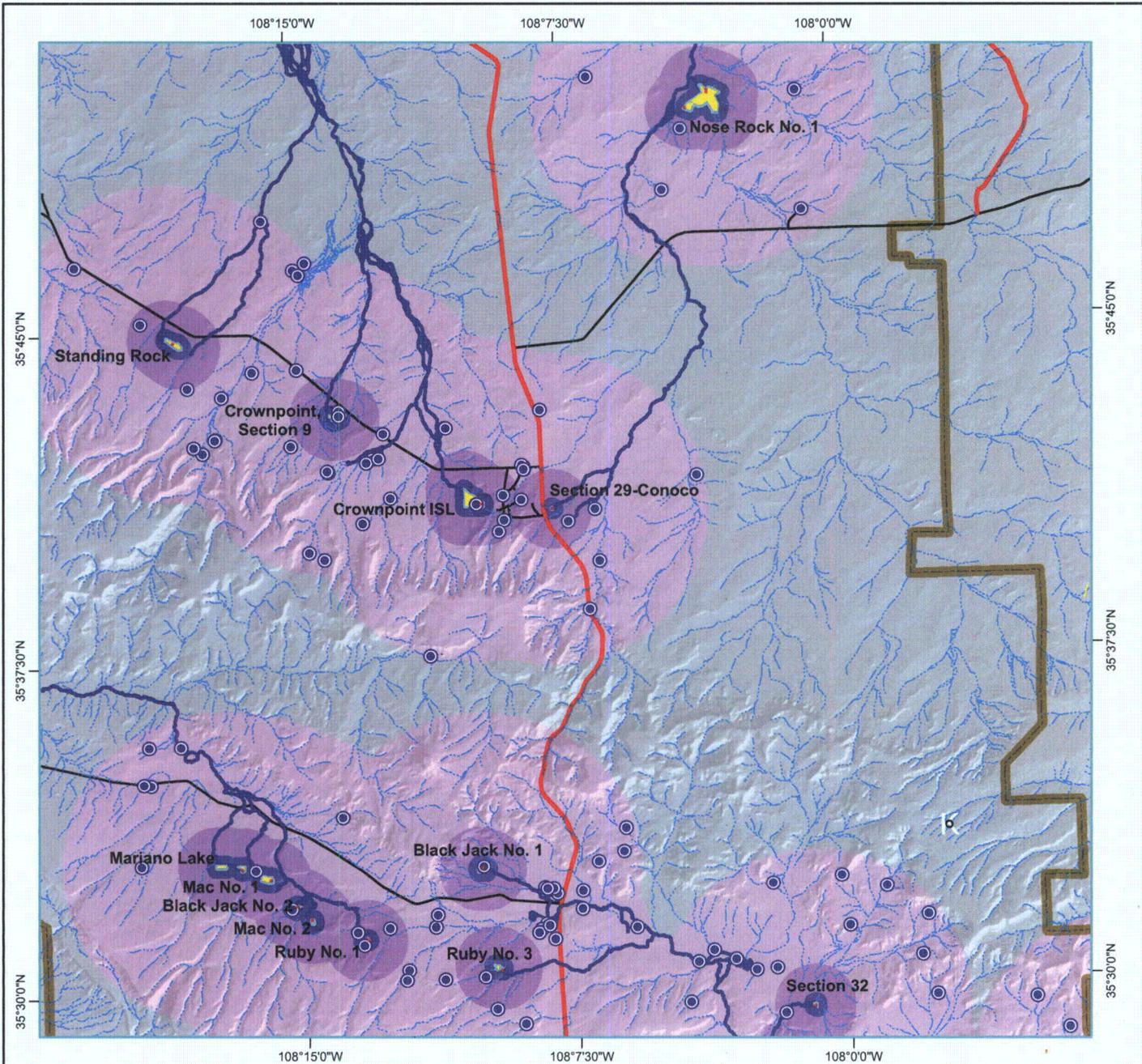
NN_Precipitation

Average Annual Precipitation (Inches)



**Average Annual Precipitation
Eastern Region
Crownpoint Area**



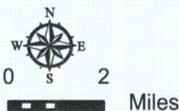


Eastern Region
Crownpoint Area

COMBINED PATHWAYS

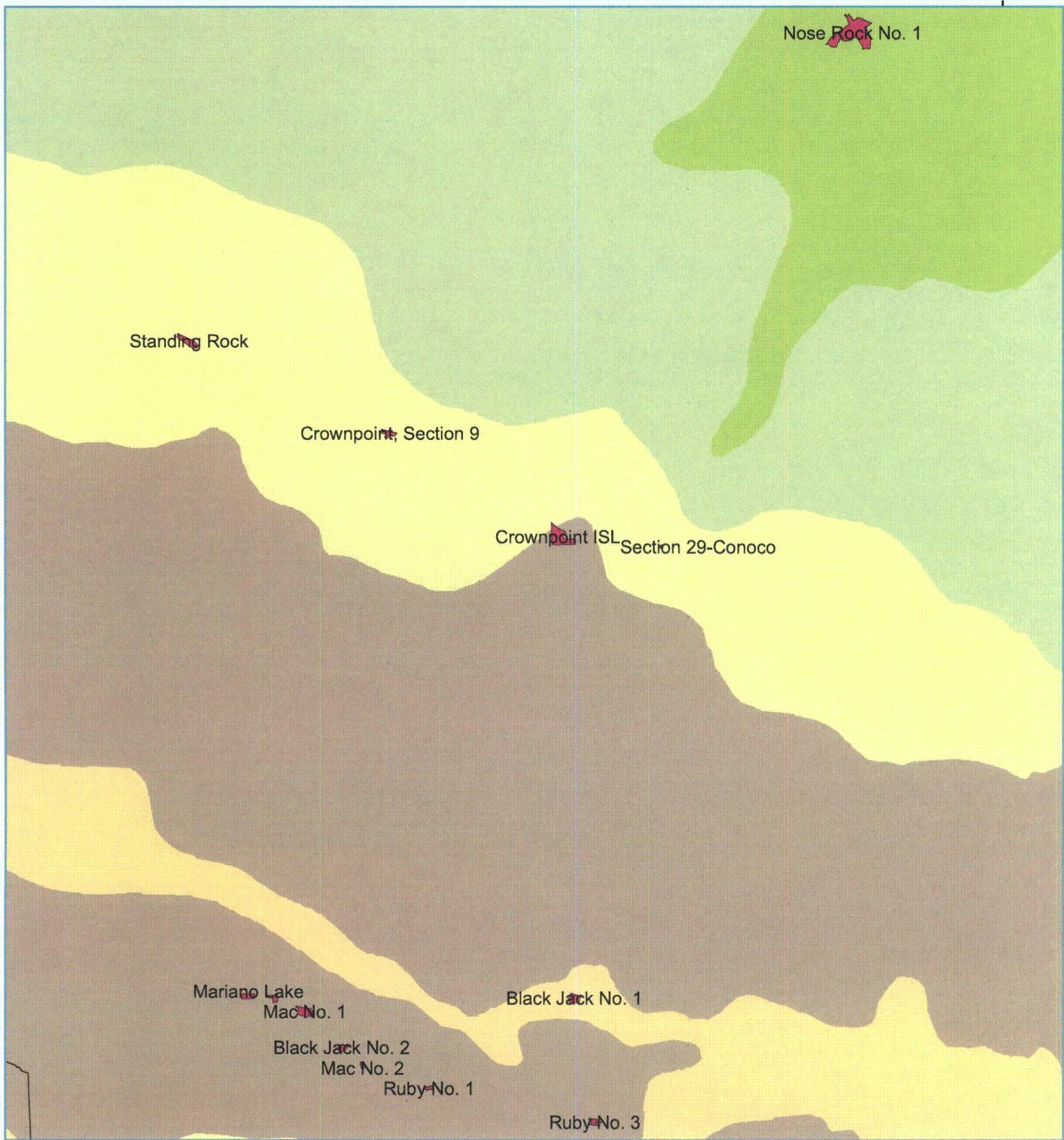
Legend

- | | | |
|---|--|--|
|  MAP-ID |  Downstream Water Pathway |  Abandoned Uranium Mine |
|  Mine Feature |  Intermittent Stream |  Mine Buffers |
|  Structure within 1 mile |  Highway |  200 Feet |
|  Well within 4 miles |  Paved Road |  1/4 Mile |
| | |  1 Mile |
| | |  4 Miles |
| | |  15 Miles |



Map Scale 1:80,000

108°0'W



108°0'W

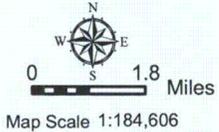
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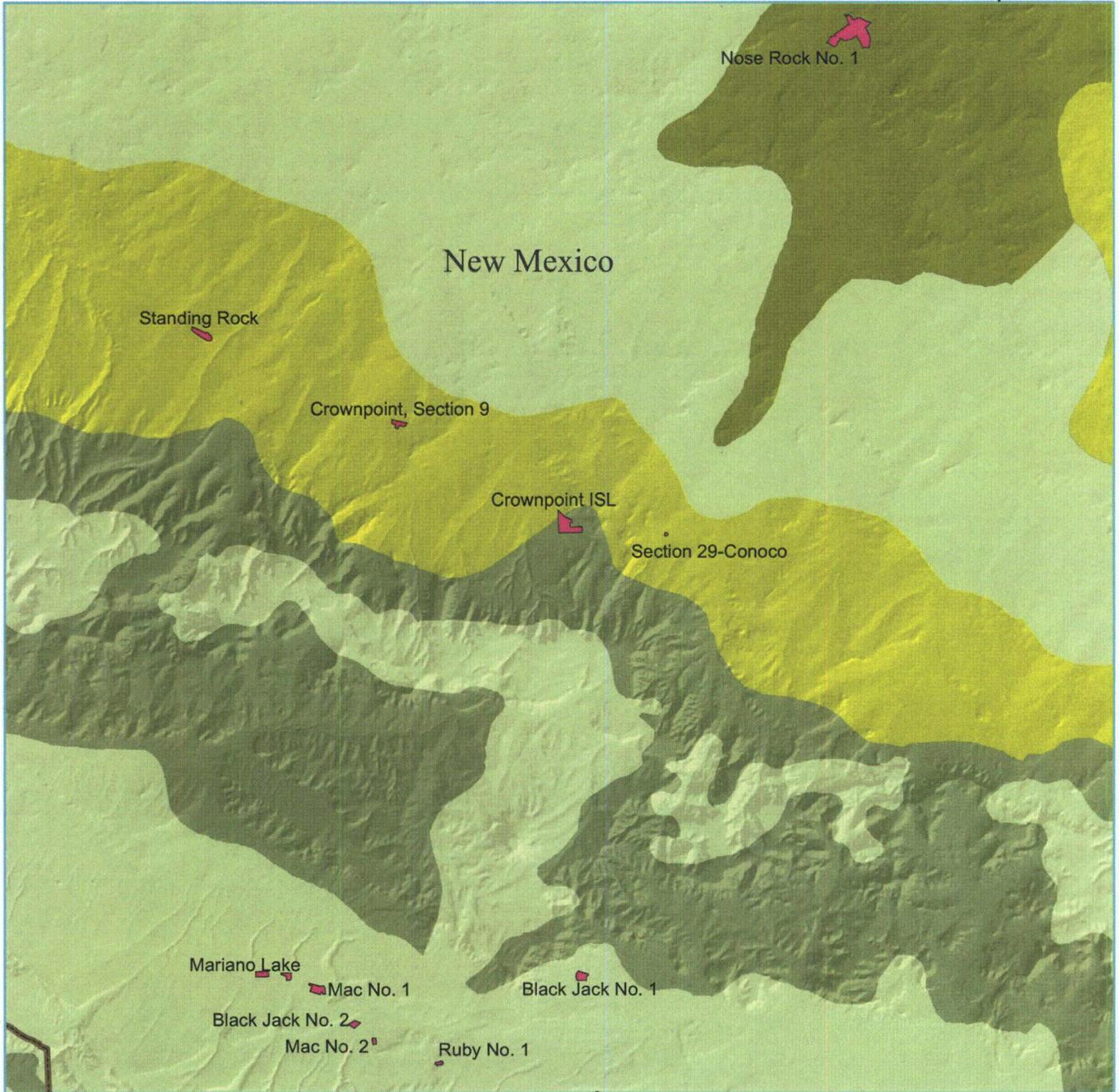
-  Water
- HYDROLOGIC GROUP INTERGRADES, Weighted Average**
-  A High infiltration, deep soils, well drained to excessively drained sands and gravels
-  A-
-  B+ Moderate infiltration rates, deep and moderately deep, moderately well and well drained soils with moderately coarse textures
-  B
-  B-
-  C+
-  C Slow infiltration rates, soils with layers impeding downward movement of water, or soils with moderately fine or fine textures
-  C-
-  D+ Very slow infiltration rates, soils are clayey, have a high water table, or are shallow to an impervious layer.
-  D

**Eastern Region
Crownpoint Area**

HYDROLOGIC GROUP

Sources
 Data are from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) data set. A code identifying the hydrologic characteristics of the soil was extracted from the STATSGO data.





Legend

-  Major Waters
- PERMEABILITY RATE (Inches/Hour)**
-  6.01 - 16.53; Rapid
-  2.01 - 6.00; Moderately Rapid
-  0.61 - 2.00; Moderate
-  0.21 - 0.60; Moderately Slow
-  0.07 - 0.20; Slow
-  0.01 - 0.06; Very Slow
-  0.00; Impermeable

**Eastern Region
Crownpoint Area**

PERMEABILITY

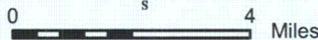
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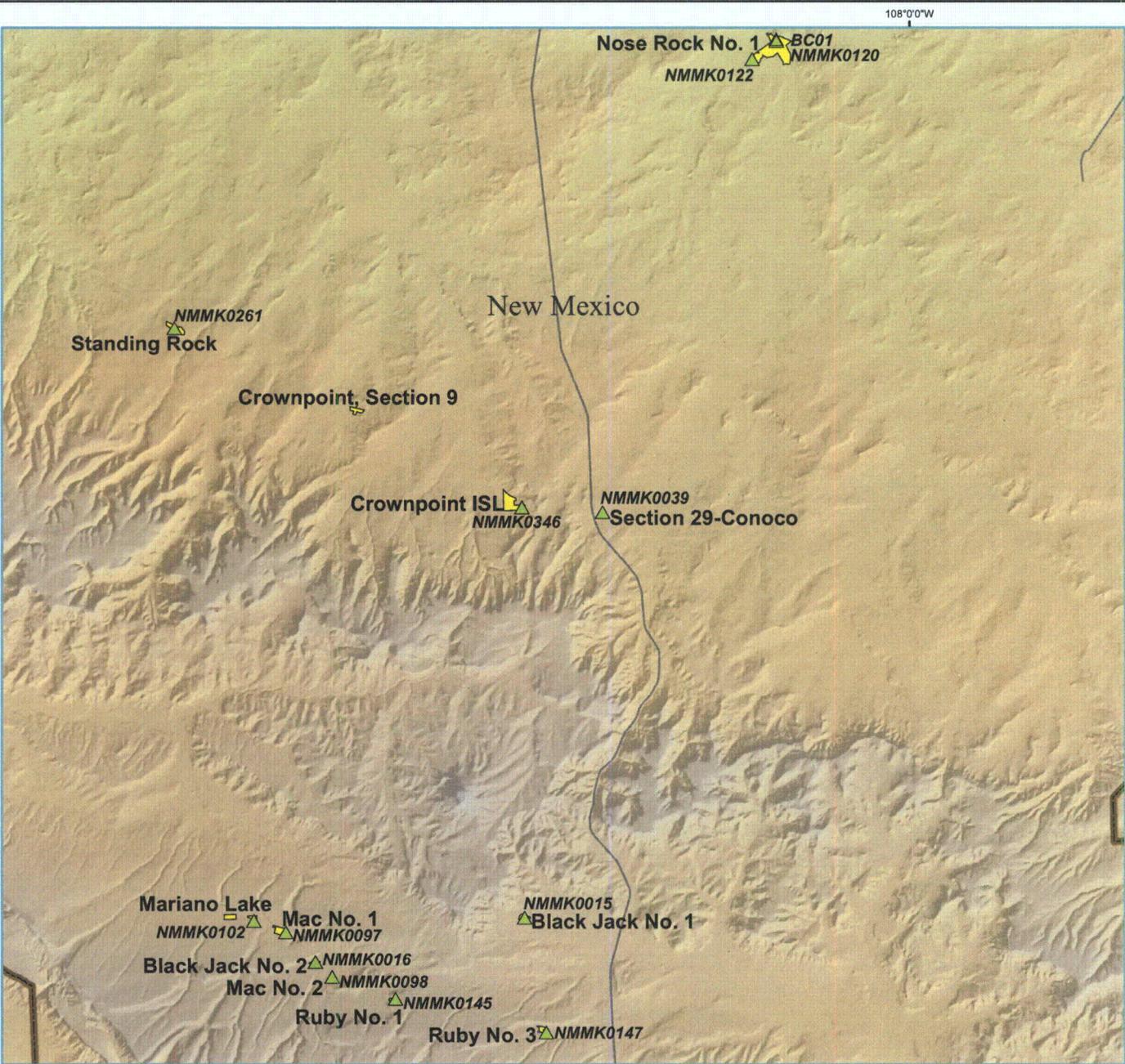
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Soil permeability is the quality of the soil that enables water or air to move through it. STATSGO weighted average soil permeability rate is expressed as inches per hour.

The STATSGO layer file "permh" and "perml" values were averaged across layers (by layer thickness) and components (by component percentage) as the depth- and area-weighting factors.

Filename: DB/Water/NN_STATSGO.shp (PERMWTAVG)





AUMs

Legend

RECLAMATION STATUS AND UNMAPPED WASTE PILES

RECLAIMED FEATURE

- Unreclaimed Waste Piles Present
- Presence of Unreclaimed Waste Piles Unknown
- No Unreclaimed Waste Piles

FEATURE RECLAMATION STATUS UNKNOWN

- ▲ Unreclaimed Waste Piles Present
- ▲ Presence of Unreclaimed Waste Piles Unknown
- ▲ No Unreclaimed Waste Piles

UNRECLAIMED FEATURE

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- No Unreclaimed Waste Piles
- NN_AUM_Poly_Surf

Eastern Region
Crownpoint Area

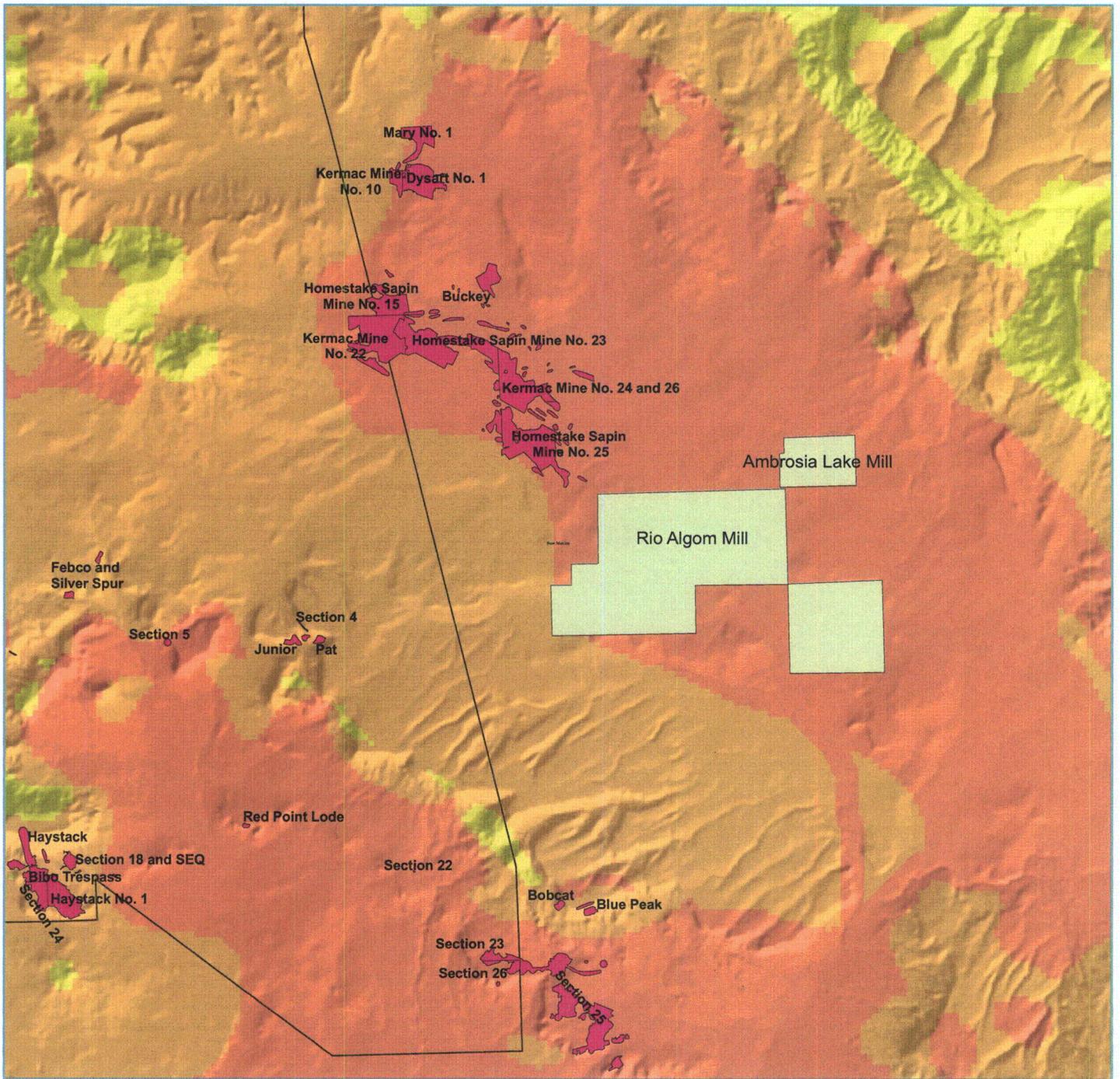
Sources

Reclaimed mine feature locations and status are from the Navajo Abandoned Mine Lands Reclamation Program. The presence of waste piles was determined by NAMLRP and TerraSpectra Geomatics.

Filenames: DB/AUM/NN_AUM_Pt_Features.shp

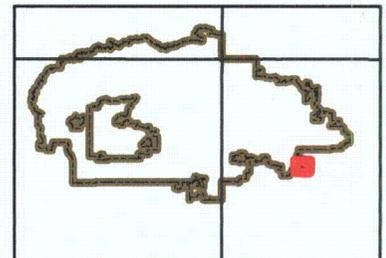


Ambrosia Lake Area



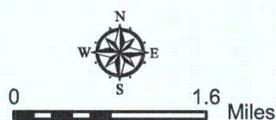
Eastern Region
Ambrosia Lake Area
AQUIFER SENSITIVITY

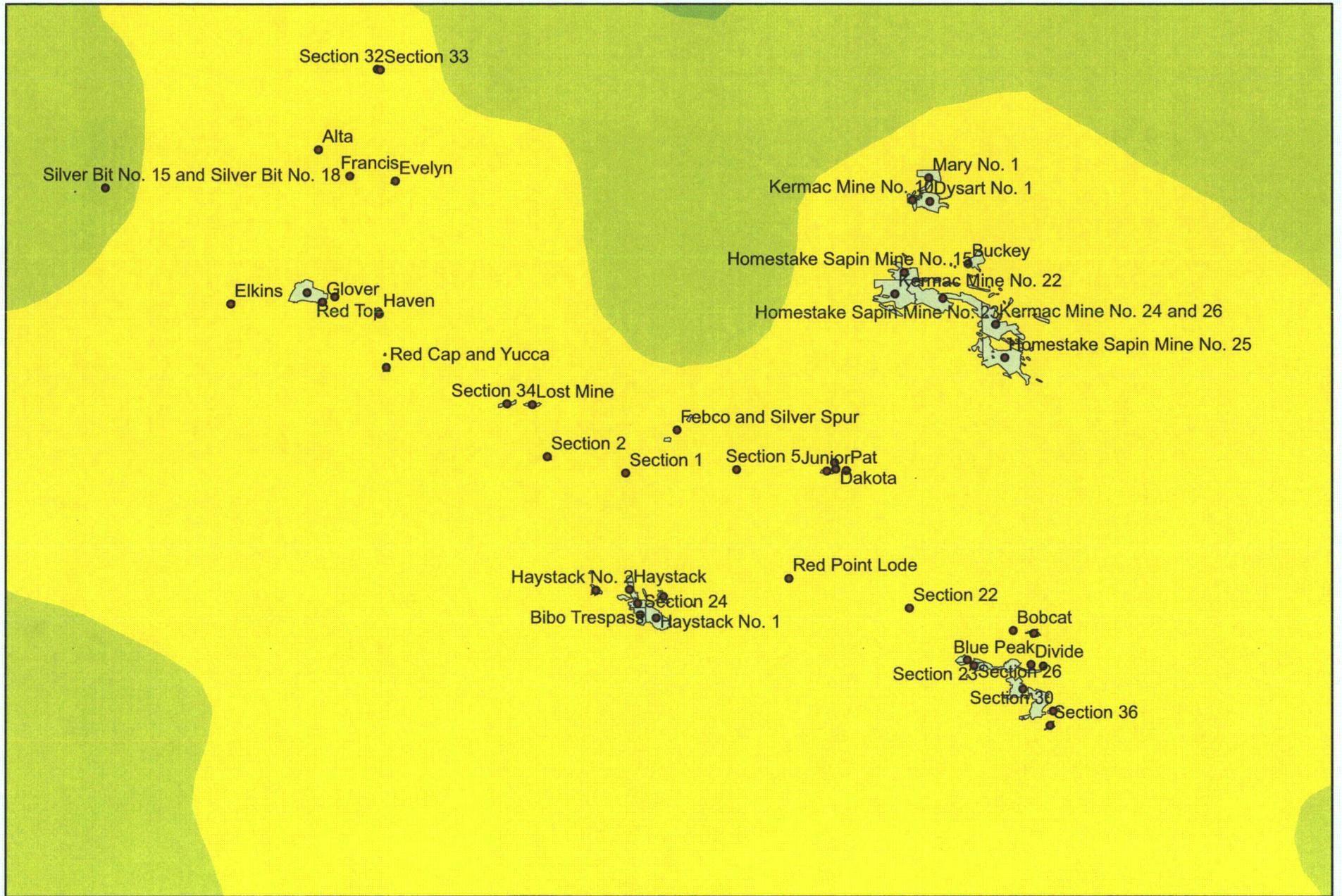
- Legend
- Abandoned Uranium Mines
- Aquifer Sensitivity Class
- 0 - Insignificant Potential
 - 1 - Least Potential
 - 2 - Intermediate Potential
 - 3 - Most Potential



Sources

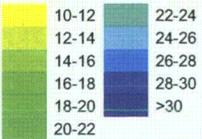
Aquifer sensitivity was developed and provided by Paul Blanchard (2002), U. S. Geological Survey, Water Resources Division in Albuquerque, New Mexico.



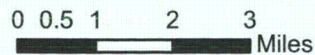


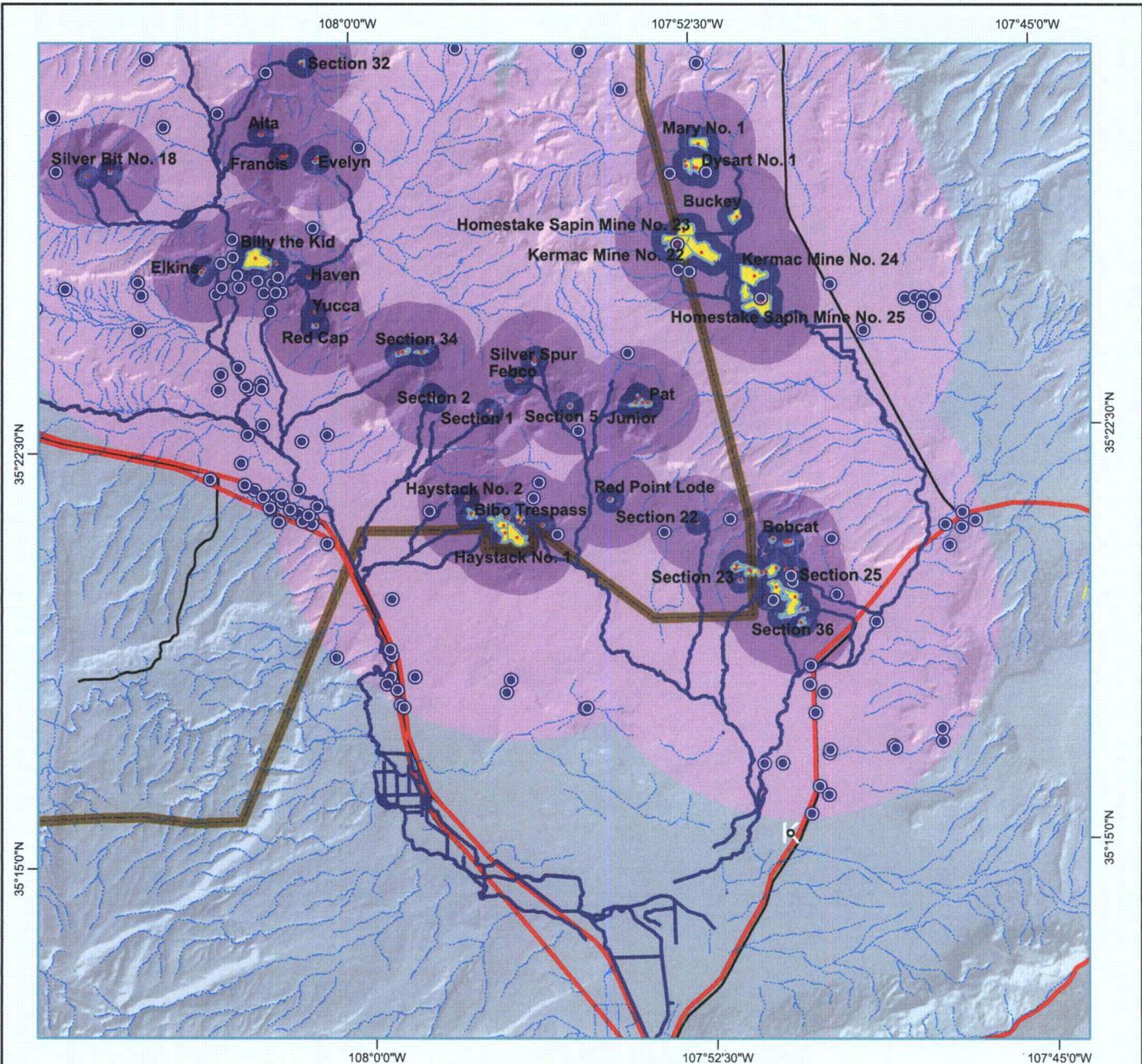
NN_Precipitation

Average Annual Precipitation (Inches)



**Average Annual Precipitation
Eastern Region
Ambrosia Lake Area**



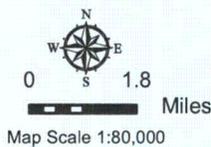


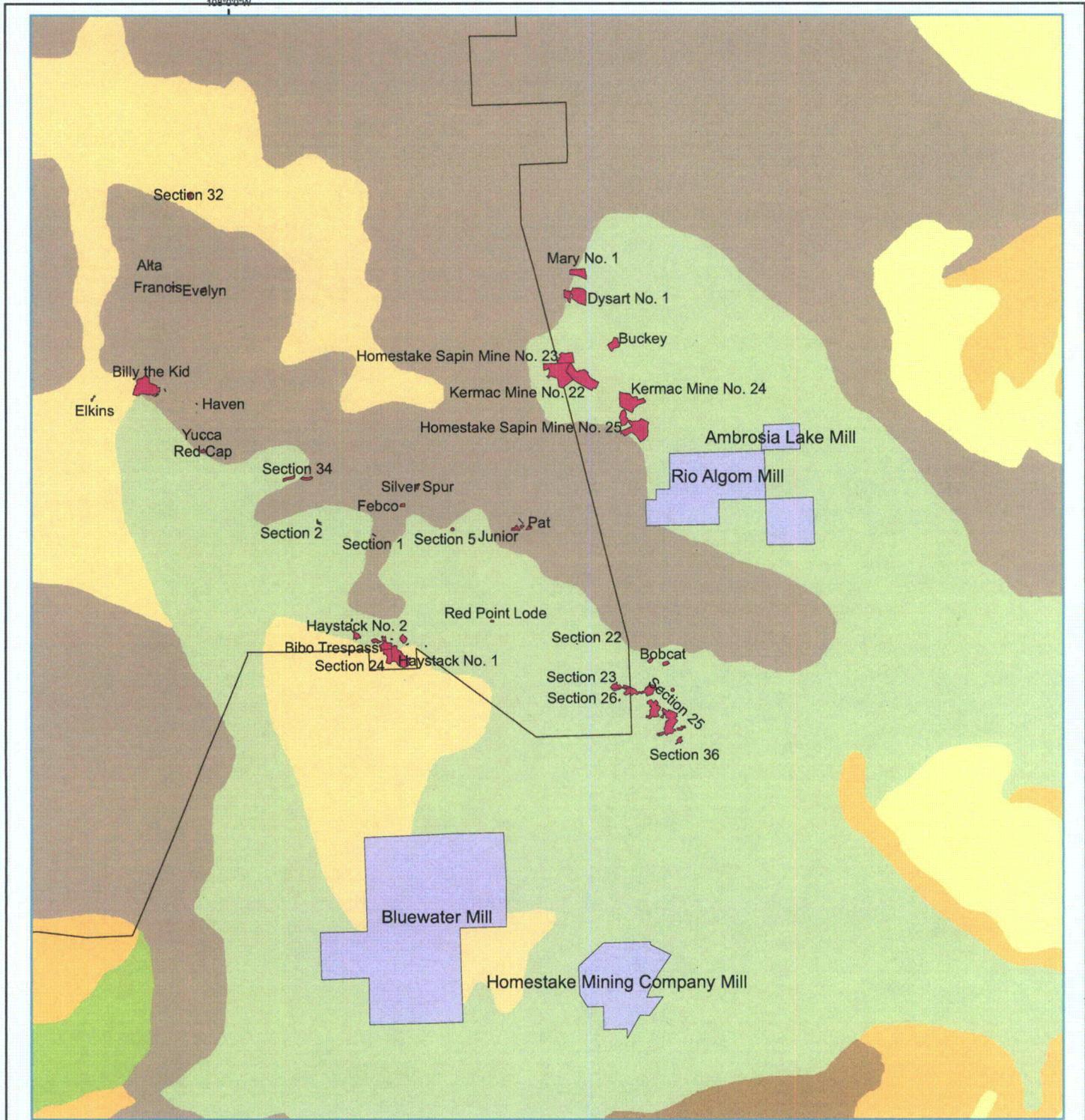
**Eastern Region
Ambrosia Lake Area**

COMBINED PATHWAYS

Legend

- | | | |
|---|--|---|
|  MAP-ID |  Downstream Water Pathway |  Abandoned Uranium Mine Mine Buffers |
|  Mine Feature |  Intermittent Stream |  200 Feet |
|  Structure within 1 mile |  Highway |  1/4 Mile |
|  Well within 4 miles |  Paved Road |  1 Mile |
| | |  4 Miles |
| | |  15 Miles |





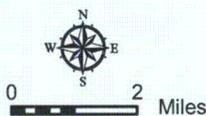
Legend 108°0'0"W

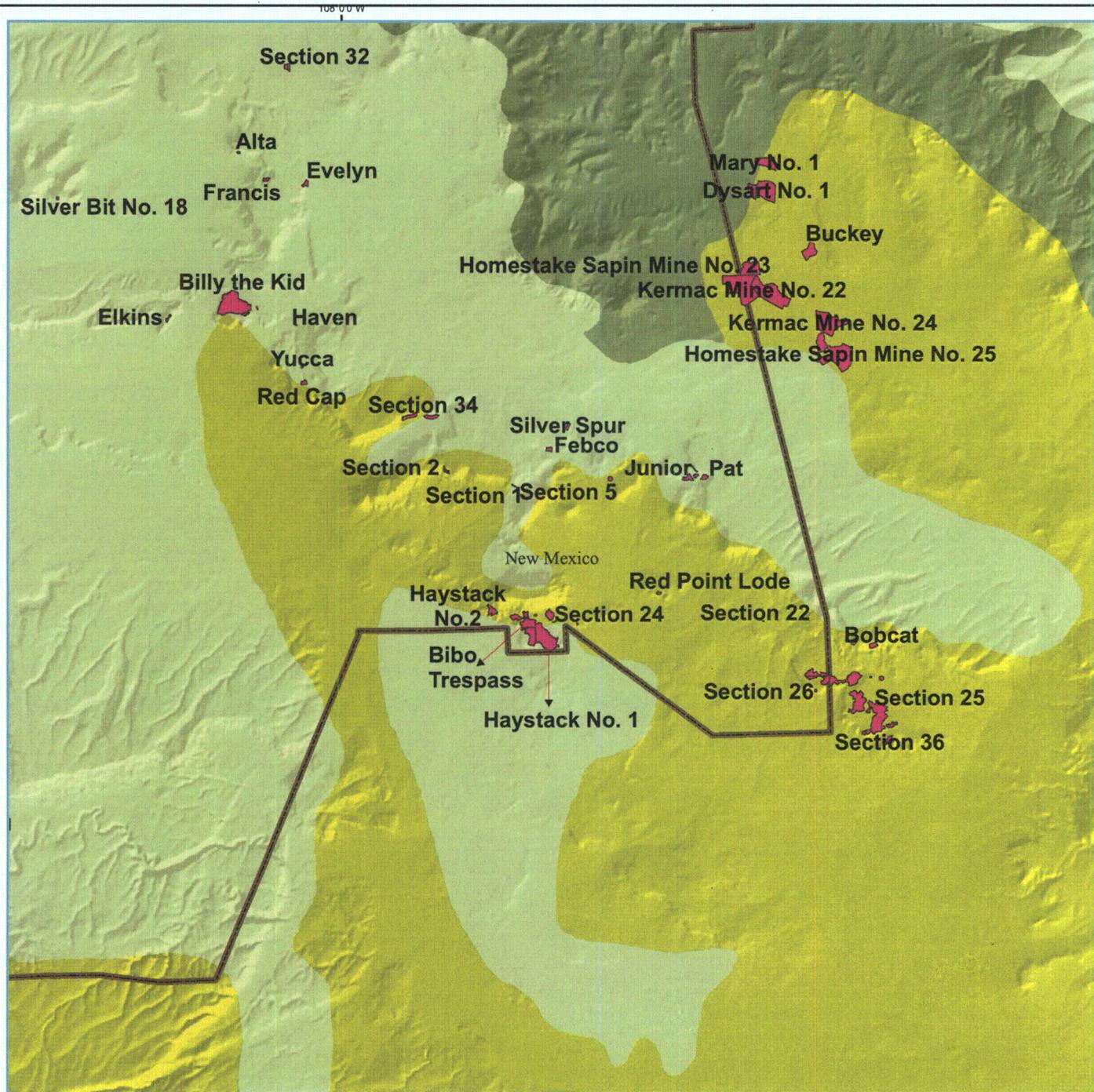
- Water
- HYDROLOGIC GROUP INTERGRADES, Weighted Average**
- A High infiltration, deep soils, well drained to excessively drained sands and gravels
- A-
- B+
- B Moderate infiltration rates, deep and moderately deep, moderately well and well drained soils with moderately coarse textures
- B-
- C+
- C Slow infiltration rates, soils with layers impeding downward movement of water, or soils with moderately fine or fine textures
- C-
- D+
- D Very slow infiltration rates, soils are clayey, have a high water table, or are shallow to an impervious layer.

**Eastern Region
Ambrosia Lake Area**

HYDROLOGIC GROUP

Sources
Data are from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) data set. A code identifying the hydrologic characteristics of the soil was extracted from the STATSGO data.





Legend

-  Major Waters
- PERMEABILITY RATE (Inches/Hour)**
-  6.01 - 16.53; Rapid
-  2.01 - 6.00; Moderately Rapid
-  0.61 - 2.00; Moderate
-  0.21 - 0.60; Moderately Slow
-  0.07 - 0.20; Slow
-  0.01 - 0.06; Very Slow
-  0.00; Impermeable

**Eastern Region
Ambrosia Lake Area
PERMEABILITY**

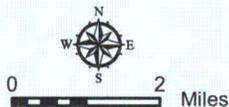
Sources

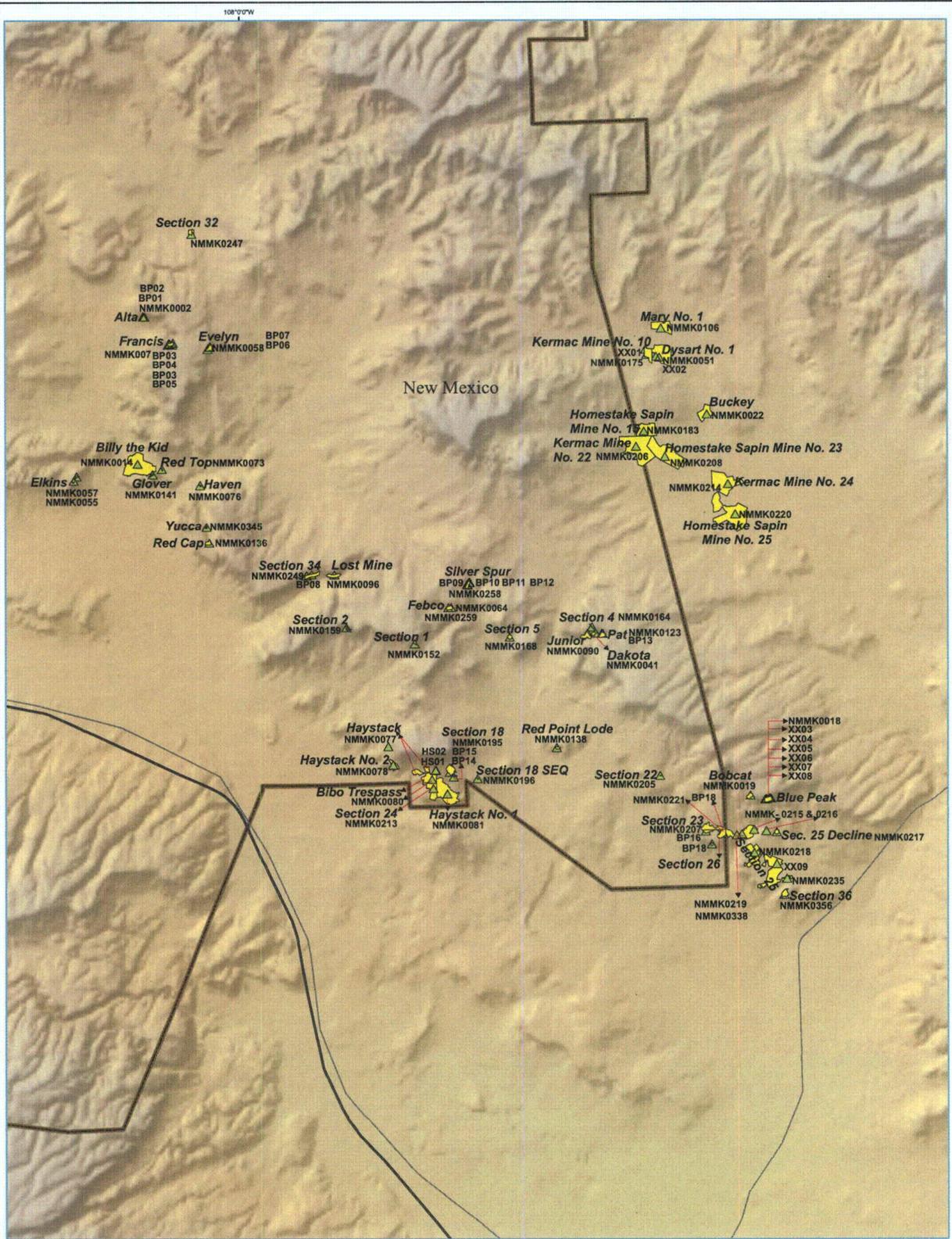
Data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) data set.

Soil permeability is the quality of the soil that enables water or air to move through it. STATSGO weighted average soil permeability rate is expressed as inches per hour.

The STATSGO layer file "permh" and "perml" values were averaged across layers (by layer thickness) and components (by component percentage) as the depth- and area-weighting factors.

Filename: DB/Water/NN_STATSGO.shp (PERMWTAVG)





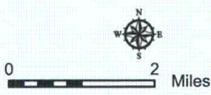
- AUMs Legend
- RECLAIMED FEATURE**
- Unreclaimed Waste Piles Present
 - Presence of Unreclaimed Waste Piles Unknown
 - No Unreclaimed Waste Piles
- FEATURE RECLAMATION STATUS UNKNOWN**
- ▲ Unreclaimed Waste Piles Present
 - ▲ Presence of Unreclaimed Waste Piles Unknown
 - ▲ No Unreclaimed Waste Piles
- UNRECLAIMED FEATURE**
- Unreclaimed Waste Piles Present
 - Presence of Unreclaimed Waste Piles Unknown
 - No Unreclaimed Waste Piles
 - NN AUM Surface

RECLAMATION STATUS AND UNMAPPED WASTE PILES

Sources

Reclaimed mine feature locations and status are from the Navajo Abandoned Mine Lands Reclamation Program. The presence of waste piles was determined by NAMLRP and TerraSpectra Geomatics.

FileNames: DB/AUM/NN_AUM_Pt_Features.shp



Appendix B. Utah No. 1 and Radium Hill No. 1 Mines Groundwater Pathway Assessment

Appendix B
Utah No. 1 and Radium Hill No. 1 Mines
Groundwater Pathway Assessment

April 2010

TDD No.: TO1-09-08-02-0001

Contract No.: EP-S9-07-01

Prepared for:

U.S. Environmental Protection Agency, Region 9
75 Hawthorne Street
San Francisco, CA 94105

Prepared by:



ERRG

Engineering/Remediation Resources Group, Inc.
4585 Pacheco Blvd., Suite 200
Martinez, California 94553
(925) 969-0750

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Section B1. Mine and Groundwater Investigation

B1.1. LOCATION OF ABANDONED URANIUM MINES

During U.S. Environmental Protection Agency's (EPA) screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, 31 AUMs (including 33 former uranium mining sites) were identified below the water table (Table 13 in EPA, 2007c). Two of the mining sites, the Utah No. 1 and Radium Hill No. 1 Mines (listed as one AUM in EPA, 2007c), are located in the North Central Region, approximately 3 miles south of Oljeto Trading Post in San Juan County of Utah (Chenoweth, 1991). These mines are located just north of the state line, in the SW1/4 and SE1/4 of Section 36, T.43S, R14E. The ore bodies for the Utah No. 1, Radium Hill No. 1, and Fern No. 1 Mines occur within the same channel (Chenoweth, 1994c). These mines are located in the Atene Mesa of the Monument Valley Mining District.

B1.1.1. Local Hydrogeology

The Utah No. 1 and Radium Hill No. 1 Mines are located in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley surrounding the two mines is 6 to 8 inches (see Average Annual Precipitation map for North Central Region in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the two mines is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

Aquifer sensitivity in the area surrounding the two mines ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the Oljeto Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Utah No. 1 and Radium Hill No. 1 Mines are located along a drainage system

feeding into the Oljeto Wash, which runs approximately south to north. Four water sources [well 8T-525, unnamed 6-inch well (08-0637), well 8K-433, and unnamed 4-inch well (08-0636)] are shown in Longworth (1994) as being located along the El Capitan and Oljeto Washes, upstream of where the drainage that the mine is on feeds into the Oljeto Wash. One mine shaft (Radium Hill) is shown in Longworth (1994) as being located on the Atene mesa above the Oljeto Wash adjacent to the mine. Depths to water and elevations of groundwater indicate a southeast to northwest gradient along the El Capitan Wash, feeding into the Oljeto Wash and then proceeding north (Figure 8). Some of these water sources can also be seen on the Surface Water Features Map for North Central Region in Appendix A. Water samples were collected from the Radium Hill No. 1 Mine Shaft and 8T-525 in 1991 (Longworth, 1994).

B1.2. DETAILED MINE BACKGROUND

Uranium ore deposits formed in the basal Shinarump Member of the Chinle Formation; the Shinarump is a fluvial channel deposit. The rocks of the Chinle Formation dip approximately 3 degrees to the southwest near the Utah No. 1 and Radium Hill No. 1 Mines. The channel deposit at the Fern Mine, which is the southern extension of the Radium Hill ore deposit and is physically connected to the Radium Hill No. 1 Mine, is approximately 200 feet wide, with a maximum depth of approximately 40 feet, and is composed of medium-to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the sediments (Chenoweth, 1994c). In the vicinity of the ore body, the channel at the Fern No. 1 Mine trends N15 degrees west. Uranium ore occurs along the banks of the channel (Chenoweth, 1994c) similar to ore at the Starlight East Mine (Figure 5).

Utah No. 1 Mine was initially mined from June 1944 to December 1944. A U.S. Geological Survey (USGS) engineer reported that uranium ore was mined by hand in and around chunks of silicified wood in conglomerate within the Shinarump Member. A total of 4,185.25 pounds of U_3O_8 was produced during this period (Chenoweth, 1991).

The mines were operated by Radium Hill Uranium, Incorporated. A 100-foot decline was sunk in 1955 to the first ore body at Utah No. 1 Mine. A second decline was started in 1956 and was known as Radium Hill No. 1. By December 1956, the mine workings of the second decline were connected with those of the Fern No. 1 Mine. The shipments from Utah No. 1 and Radium Hill No. 1 Mines were listed collectively as coming from School Section 36. A total of 126,702.74 pounds of U_3O_8 was produced from 1956 to 1961 (Chenoweth, 1994c).

B1.2.1. Utah No. 1 and Radium Hill No. 1 Ore Deposits

The water table in the Shinarump is perched, and ore deposits are unoxidized. During development of the Fern Mine, which is connected to the Radium Hill No. 1 Mine, groundwater entered the mine at a rate of 50 gallons per minute. Mining operations at Utah Mine, however, only encountered perched water

(Chenoweth, 1991). Uraninite (uranium oxide) was the principal uranium mineral, and copper sulfides, such as bornite, chalcocite, and chalcopyrite, were also present (Chenoweth, 1994c).

Drilling in the Fern Mine delineated an estimated 10,000 tons of high-grade uranium ore at an average depth of 200 feet and an average thickness of 5 feet; Radium Hill No. 1 was connected with the Fern No. 1 Mine. Mining operations at the Utah No. 1 and Radium Hill No. 1 Mines produced 12,776.09 tons of ore averaging 0.34 percent U_3O_8 , from 1955 to 1957 and from 1961 to 1962 (Chenoweth, 1994c). The adjacent Fern No. 1 mine was estimated to have 10,000 tons of high-grade uranium ore, of which 9,582.43 tons was mined. Based on the estimated sizes of the ore body, approximately 96 percent of the projected ore at Fern No. 1 Mine was mined.

Although mines in the area were often open pits, the Radium Hill ore body was at a depth of 200 feet, and room and pillar with underground equipment was used to mine the ore (Chenoweth, 1994). According to Chenoweth (1994c), Utah No. 1 and Radium Hill No. 1 Mines have been reclaimed, and no waste piles remain at the mines. No specific mine waste features were noted for the Utah No. 1 and Radium Hill No. 1 Mines during EPA's assessment (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c).

B1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

B1.3.1. Aerial Radiation Contours

In 2000, EPA produced the "Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas," herein referred to as "Project Atlas" (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley was created from data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory. The contour map is included in the Project Atlas and the portion of the data set that covers the Monument Valley mines of interest is shown on the Bismuth-214 Flyover Polygons map for North Central Region in Appendix A. The aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of surface ore deposits or surface mining-related activities. The map of the aerial radiation contour values in the Project Atlas illustrates higher bismuth-214 radiation for the Utah No. 1 and Radium Hill No. 1 Mines (up to 3.5 microRoentgens per hour [$\mu R/hr$] and up to 16.2 $\mu R/hr$, respectively) than for the immediate surrounding area. Neither Fern No. 1 Mine nor any other areas near these mines had bismuth-214 radiation higher than the surrounding area. An area to the west of Fern No. 1, Radium Hill No. 1, and Utah No. 1 Mines has background values of 2.4 to 3.5 $\mu R/hr$, while the bismuth-214 levels around Tract 24 Mine A and B to the southwest of the mines are not greater than bismuth-214 levels over the surrounding area (see the Bismuth-214 Flyover Polygons map for North Central Region in Appendix A; EPA, 2007c).

B1.3.2. Depth to Groundwater

In 1991 and 1992, USGS conducted a study in the Monument Valley and Cameron Mining Districts. Data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were measured in October 1991 from the following wells near the Utah No. 1 and Radium Hill No. 1 Mine:

- Radium Hill No. 1 Mine Shaft
- An unnamed 6-inch well near El Capitan Wash (08-0637 on geospatial maps in Appendix A)
- Artesian well 8T-525 (Appendix A; Longworth, 1994)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features map for North Central Region in Appendix A; Longworth, 1994)

The wells are located along the El Capitan/Oljetto Wash system, running from southeast at higher elevations (08-0636) to northwest at lower elevations (8T-525; Figure 8). The Radium Hill No. 1 Mine shaft is located on a drainage that feeds into the Oljetto Wash further downstream; however, the depth to water measured in the shaft does not necessarily represent groundwater levels as it is not known what portion of the groundwater reservoir that the shaft is connected with.

Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions at the 8T-525), indicating a southeast to northwest gradient along drainage. The elevation of water in the Radium Hill No. 1 mine shaft was estimated to be 5,158.2 feet above msl.

B1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. Water samples have been collected in the Monument Valley by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. These wells are unregulated water sources; therefore, limited or no information on well development is available, and groundwater samples are not collected regularly. Available analytical results summarized below are from limited grab groundwater sampling.

As stated in the main report, unregulated water sources in the Navajo Nation region are deemed unfit for human consumption; however, these water sources may still be used by the community, "either for cultural reasons, or because they prefer the taste" (Keller, 2007). These sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

B1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected groundwater samples from the water flooding the drill hole of the Radium Hill No. 1 Mine and from the artesian well 8T-525. The pH of the samples was measured at 7.2 and 7.5, respectively. Uranium-238, Uranium-234, and Uranium-235 concentrations in the water sample from the Radium Hill No. 1 Mine shaft were 210 picoCuries per liter (pCi/L), 230 pCi/L, and 12 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 690 micrograms per liter ($\mu\text{g/L}$); these concentrations were greater than the applicable maximum contaminant levels (MCLs) of 20 pCi/L (for uranium isotopes) and 15 pCi/L (for gross alpha). Uranium-238, uranium-234, and uranium-235 concentrations in the water sample from artesian well 8T-525 were 0.50 pCi/L, 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was $3.0 \mu\text{g/L}$ (Longworth, 1994). These concentrations were less than the applicable MCLs, and uranium concentrations were less than the estimated MCL of 20 pCi/L (based on the EPA MCL of $30 \mu\text{g/L}$ and conversion of 0.67 picocuries per microgram).

B1.3.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for the analysis of radioactive and stable metals and alpha and beta emitters. One sample was collected from each well identified as a potential source of water for human consumption, and samples were collected as a point-of-use sample designed to duplicate the most likely method in which people would obtain water. The concentrations of total uranium in three water samples collected in the North Central Region (sum of isotopes uranium-234, uranium-235, and uranium-238) were greater than the estimated MCL of 20 pCi/L:

- 36.29 pCi/L of uranium in one sample (Baby Rock Spring 8-44) collected in September 1998
- 40.00 pCi/L of uranium in one sample (Monument Pass Well) collected in January 2000
- 171.93 pCi/L of uranium in one sample (Tank 8A-299) collected in September 1998

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley Area. Well 8K-433 is categorized as a windmill well, and although it is not regulated for human consumption, locals indicate that the well is being used for drinking water and for watering livestock (EPA, 2009b).

Groundwater samples were also collected downgradient of the Utah No. 1 and Radium Hill No. 1 Mines approximately 0.8 miles northwest at spring 08GS-12-12 (also called Truck Cab Spring), approximately 1.5 mile to the north at spring 08GS-12-11, and approximately 1.5 miles to the north at windmill well 8-1A-1. The concentrations of uranium in water samples from spring 08GS-12-12, spring 08GS-12-11, and windmill well 8-1A-1 were 18.7 pCi/L, 4.24 pCi/L, and 5.08 pCi/L, respectively; these concentrations are less than the estimated MCL of 20 pCi/L. The concentration of uranium in a water

sample collected from well 08-27 (also called Shallow Well El Capitan), approximately 2.5 miles upstream of the Mine, was 10.6 pCi/L.

B1.3.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample in the North Central region. Gross alpha was 25.7 pCi/L, which exceeds the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not within 4 miles of the Utah No. 1 and Radium Hill No. 1 Mines.

B1.3.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentration of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 µg/L and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 µg/L and 15 pCi/L.

B1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels within the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Utah No. 1 and Radium Hill No. 1 Mines do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. These undisturbed deposits would be expected to be associated with extensive organic material in the channel sediments.

B1.5. MINED URANIUM DEPOSITS

Not enough data are available to determine the amount of uranium ore remaining at Utah No. 1 and Radium Hill No. 1 Mines. However, at the Fern No. 1 Mine, which is connected to Radium Hill No. 1 Mine, an estimated 96 percent of the ore body has been removed. The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body (Figure 22). Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted during operations at Fern No. 1 Mine might have destroyed organic material, as would mining operations. During mining operations in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface (Figure 22). Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Section B2. Hazard Ranking System and Summary

B2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, the migration of groundwater and surface water migration was investigated initially.

For HRS purposes, the main source of contamination to shallow water sources in the area is where a hazardous substance, in this case uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Utah No. 1 and Radium Hill No. 1 Mines include, but are not limited to:

- Disturbed soils and mine workings at the surface containing uranium ore are indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Remnants of uranium ore deposits below the surface and below the water table at the Utah No. 1 and Radium Hill No. 1 Mines.

Additional potential sources of hazardous substances not associated with the Utah No. 1 and Radium Hill No. 1 Mines but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in the channel sediments in the Shinarump Member of the Chinle Formation in the area surrounding the Utah No. 1 and Radium Hill No. 1 Mines, as mapped by Young, Malan, and Gray (1964).

B2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

B2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of and at the mines. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the Oljeto Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics are applicable to ore bodies remaining at the Utah No. 1 and Radium Hill No. 1 Mines and in the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed in the main report, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. The fresh oxidizing water likely infiltrates waste rock at the surface and at the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways, the Utah No. 1 and Radium Hill No. 1 ore bodies have likely been extensively mined, depleting them of significant volume of highest grade ore and probably destroying organic matter during water influx throughout mining operations. Uneroded ore deposits, as mapped on Figure 7, in the vicinity of and downstream of the two mines may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

B2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend to the north-northwest as the Oljeto wash and ephemeral creek beds do. Based on the noted influx of groundwater during mining at Fern No. 1 Mine and from the recorded depth to water at Radium Hill No. 1 Mine during the USGS sampling in 1991, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface (Figure 22); surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, allowing leaching of metals (including uranium) from the ore deposit. However, organics (carbonaceous material) and pyrite in the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 22). Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Uranium adsorbs onto clays in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter as it migrates downward to groundwater before it makes it outside the mined workings. However, given the mass of uranium remaining in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock. The pH of groundwater in the region is reported from 7.2 to 9.2, outside the optimal range of adsorption, further allowing the uranium in solution in oxidizing water to migrate/disperse.

Results of water sampling suggest that, while uranium may be leaching extensively upstream from other ore deposits (as evidenced by a uranium concentration of 171.9 pCi/L in the upgradient water sample from well 8K-433), leaching through the Utah No. 1 and Radium Hill No. 1 Mines is limited. This limited leaching is indicated by the downstream uranium concentration of 18.7 pCi/L at spring 08GS-12-12, which is less than the estimated MCL of 20 pCi/L. Some mobilization is suggested because the concentration in the water sample from 08GS-12-12 is higher than the uranium concentration of 10.6 pCi/L at the upstream well 08-27. Although uranium is being leached from the mines, secondary deposition and adsorption are probably keeping most of the uranium within the mined areas. In addition, water samples collected farther downstream at spring 08GS-12-11 and Wind Mill Tank 8-1A-1 had even lower concentrations of 4.23 pCi/L and 5.08 pCi/L, respectively.

B2.2.3. Groundwater Pathway Conclusion

Well 8K-433 is just inside a 4-mile radius of the mines but is located upstream from the mines, so groundwater flow from Utah No. 1 and Radium Hill No. 1 Mine would not affect the well (see the Combined Pathway-Oljato Map for North Central Region in Appendix A). Spring 08GS-12-12 is within a 1-mile radius of the mines and downgradient of the mines. The concentrations of radioactive metals in the water sample collected from this spring, which is the water source expected to be most influenced by the Utah No. 1 and Radium Hill No. 1 Mines, were less than MCLs. None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009a).

B2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Utah No. 1 and Radium Hill No. 1 Mines enters a drainage system that feeds to the southwest to the Oljeto Watershed, including the El Capitan Wash and the Oljeto Wash. The Oljeto Wash runs west of the mines toward the northeast and continues for approximately 15 miles until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storms, when slightly acidic and oxidizing rainwater interacts with waste rock on the surface. In semiarid to arid environments, evaporation is quick, and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds. However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

B2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash or the Oljeto Wash near the mines or within 15 miles downstream of the mines (NNEPA, 2006). Uranium was detected in the shallow water source downgradient of the mines but at a concentration less than the MCL.

B2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Utah No. 1 and Radium Hill No. 1 Mines for the following reasons:

- Most of the known contamination is confined to the mines, and concentrations of contaminants off-site that may be attributable to the mines are less than the respective MCLs
- Low to moderate radiation levels on aerial radiation maps and previous reports indicate the surface of the mine has been partially reclaimed and/or waste rock contains little uranium
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mine

B2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during this period. The Utah No. 1 and Radium Hill No. 1 Mines are located in the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined in this mine, primarily from channel deposits of the Shinarump Member of the Chinle Formation. Organic plant matter is abundant in the channel sediments. The Utah No. 1 and Radium Hill No. 1 Mines were listed by the EPA as productive AUM that has workings below the water table or were considered wet mines that required pumping (EPA, 2007c).

Monument Valley is drained by ephemeral streams forming tributaries to the San Juan River (Longworth, 1994). The Utah No. 1 and Radium Hill No. 1 Mines are located along a drainage system (part of the Oljeto Wash) that runs approximately southeast to northwest.

The following pertinent HRS factors are associated with the Utah No. 1 and Radium Hill No. 1 Mines:

- Aerial radiation surveys for bismuth-214 (a decay product of uranium) identify moderate radiation levels at the surface confined to the areas immediately around the Utah No. 1 and Radium Hill No. 1 Mines.
- Uranium was detected in samples collected from shallow water sources at concentrations greater than laboratory reporting limits but less than MCLs.

- Uranium concentrations in the downgradient spring closest to the Utah No. 1 and Radium Hill No. 1 Mines (approximately 0.5 mile west-northwest of Utah No. 1 and Radium Hill No. 1 Mines) are higher than uranium concentrations in wells upgradient of the mines (greater than 1 mile southwest of Utah No. 1 and Radium Hill No. 1 Mines) and farther downgradient of the mines (approximately 1.5 miles northeast of Utah No. 1 and Radium Hill No. 1 Mines). These results suggest limited uranium is migrating from the Utah No. 1 and Radium Hill No. 1 Mines.
- Uranium concentrations in the shaft at Radium Hill No. 1 mine were greater than MCLs.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Utah No. 1 and Radium Hill No. 1 Mines.

Appendix C. Fern No. 1 Mine Groundwater Pathway Assessment

Appendix C
Fern No. 1 Mine
Groundwater Pathway Assessment

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Section C1. Mine and Groundwater Investigation

C1.1. LOCATION OF ABANDONED URANIUM MINE

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining) occur below the water table (Table 13 in EPA, 2007c). One of these AUMs, the Fern No. 1 Mine, is located in the North Central Region, approximately 2.5 miles south of Oljeto Trading Post in Navajo County, Arizona. The AUM is located on the Atene Mesa of the Monument Valley Mining District, just south of the Arizona border with Utah. The ore bodies for the Fern No. 1, Utah No. 1, and Radium Hill No. 1 Mines occur within the same channel (Chenoweth, 1994c), with ore deposits contiguous between the mines.

C1.1.1. Local Hydrogeology

The Fern No. 1 Mine is located in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley around the mine is 6 to 8 inches (see Average Annual Precipitation Map for Monument Valley area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the two mines is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for the North Central Region in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for the North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

Aquifer sensitivity in the area around the mine ranges from intermediate potential for contaminant migration upgradient and surrounding the mine to the most potential for contaminant migration downgradient and to the west along the Oljeto Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Fern No. 1 Mine is located along a small drainage system, running west-southwest, feeding into the Oljeto Wash, which runs approximately south to north. Four water sources [well 8T-525, unnamed 6-inch well (08-0637), well 8K-433, and unnamed 4-inch well (08-0636)] are shown in Longworth (1994) as being located along the El Capitan and Oljeto Washes upstream of the where the drainage, which the mine is on, feeds into the Oljeto Wash. One mine shaft (Radium Hill) is shown in Longworth (1994) as being located on the Atene mesa above the Oljeto Wash adjacent to the mine. Depths to water and elevations of groundwater indicate a southeast to northwest gradient along the El Capitan Wash, feeding into the Oljeto Wash and then proceeding north (Figure 8). Some of these locations can also be seen on the Surface Water Features Map for North Central Region in Appendix A (EPA, 2007c). Water samples were collected from the Radium Hill No. 1 Mine Shaft and 8T-525 in 1991 (Longworth, 1994).

C1.2. DETAILED MINE BACKGROUND

Uranium ore deposits in the Fern No. 1 Mine are formed in the basal Shinarump Member of the Chinle Formation; the Shinarump is a fluvial channel deposit. The rocks of the Chinle Formation dip approximately 3 degrees to the southwest in the area near the Fern No. 1 Mine. The channel deposit at the Fern No. 1 Mine is approximately 200 feet wide, with a maximum depth of approximately 40 feet, and is composed of medium-to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the sediments (Chenoweth, 1994c). Near the ore body, the channel at the Fern No. 1 Mine trends N15°W. Uranium ore occurs along the banks of the channel (Chenoweth, 1994c) similar to ore at the Starlight East Mine (Figure 5).

C1.2.1. Fern No. 1 Ore Deposits

The water table in the Shinarump is perched, and ore deposits were unoxidized. During development of the Fern Mine, groundwater entered the mine at a rate of 50 gallons per minute. Uraninite (uranium oxide) was the principal uranium mineral found in the ore, and copper sulfides such as bornite, chalcocite, and chalcopyrite, were also present (Chenoweth, 1994c).

Drilling in the area of the Fern No. 1 Mine delineated an estimated 10,000 tons of high-grade uranium ore at an average depth of 200 feet and an average thickness of 5 feet. A 380-foot-long decline was used to reach the south end of the ore body (Figure C-1). When the Fern No. 1 Mine was closed in late 1962, it had produced 9,582.43 tons of ore, with an average grade of 0.66 percent U_3O_8 . The copper content of 1,998.41 tons averaged 0.42 percent copper, and the vanadium content of 7,584.02 tons averaged 0.37 percent V_2O_5 (Chenoweth, 1994c). Based on the estimated size of the ore body, approximately 96 percent of the projected ore at Fern No. 1 Mine was mined.

Although mines in the area were often open pits, the Fern Mine went to a depth of 200 feet, and a room and pillar system with underground equipment was used to mine the ore (Chenoweth, 1994c). According to Chenoweth (1994c), Fern No. 1 Mine has been reclaimed, and no waste piles remain at the mine. No specific mine waste features were noted for the Fern No. 1 Mine during EPA's assessment (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).

C1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

C1.3.1. Aerial Radiation Contours

In 2000, EPA produced the "Abandoned Uranium Mine Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas," herein referred to as "Project Atlas" (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley was created from data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory. The contour map is included in the Project Atlas, and the portion of the data set that covers the Monument Valley Areas mines of interest is shown on the Bismuth-214 Flyover Polygons Map for North Central Region in Appendix A. The aerial radiation contours identify concentrations higher than regional levels.

Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining. The map of the aerial radiation contour values in the Project Atlas illustrates higher bismuth-214 radiation for the Utah No. 1 and Radium Hill No. 1 Mines (up to 3.5 microRoentgens per hour [$\mu\text{R/hr}$] and 16.2 $\mu\text{R/hr}$, respectively) than for the immediate area. The bismuth-214 radiation levels around either the Fern No. 1 Mine or any other areas in the vicinity of these mines were not higher than the surrounding area. The background levels of an area to the west of Fern No. 1, Radium Hill No. 1, and Utah No. 1 Mines has was 2.4 to 3.5 $\mu\text{R/hr}$, while the bismuth-214 radiation levels for Tract 24 Mine A and B to the southwest of the mines were not greater than those measured above the surrounding area (see the Bismuth-214 Flyover Polygons map for North Central Region in Appendix A; EPA, 2007c).

C1.3.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) studied the Monument Valley and Cameron Mining Districts. Data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were collected in October 1991 (Longworth, 1994) from the following wells or mine shaft within 4 miles of the Fern No. 1 Mine:

- Radium Hill No. 1 Mine Shaft
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Map for North Central Region in Appendix A)
- Artesian well 8T-525

- Well 8K-433
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Map for North Central Region in Appendix A)

The wells are located along the El Capitan/Oljetto Wash system, running from southeast at higher elevations (08-0636) to northwest at lower elevations (8T-525; Figure 8). The Radium Hill No. 1 Mine shaft is located on a drainage that feeds into the Oljetto Wash farther downstream; however, the depth to water measured in the shaft does not necessarily represent groundwater levels as it is not known what portion of the groundwater reservoir that the shaft is connected with.

Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions at the 8T-525), indicating a southeast to northwest gradient along the drainage. Water elevation in the Radium Hill No. 1 mine shaft was estimated to be 5,158.2 feet above msl.

C1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Water samples have been collected in the Monument Valley by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. Limited or no information on well development is available, and groundwater samples are not collected regularly because these wells are unregulated water sources. Available analytical results summarized below are from limited grab groundwater sampling.

As stated in the main report, unregulated water sources within the Navajo Nation are deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

C1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected groundwater samples from the water flooding the drill hole of the Radium Hill No. 1 Mine and from the artesian well 8T-525. The pH of the samples was measured at 7.2 and 7.5, respectively. Uranium-238, uranium-234, and uranium-235 concentrations in the water sample from the Radium Hill No. 1 Mine shaft were 210 picoCuries per liter (pCi/L), 230 pCi/L, and 12 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 690 micrograms per liter ($\mu\text{g/L}$). Uranium-238, uranium-234, and uranium-235 concentrations in the water sample from artesian well

8T-525 were 0.50 pCi/L, 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 µg/L (Longworth, 1994). Uranium concentrations exceeded the estimated maximum contaminant level (MCL) of 20 pCi/L (based on the EPA MCL of 30 µg/L and conversion of 0.67 picocuries per microgram).

C1.3.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source for human consumption, and samples were collected as a point-of-use sample designed to duplicate the most likely method in which people would obtain water. The concentrations of total uranium (sum of isotopes uranium-234, uranium-235, and uranium-238) in three water samples collected within the North Central Region were greater than the estimated MCL of 20 pCi/L:

- The concentration of uranium in one sample (Baby Rock Spring 8-44) collected in September 1998 was 36.29 pCi/L
- The concentration of uranium in one sample (Monument Pass Well) collected in January 2000 was 40.00 pCi/L
- The concentration of uranium in one sample (Tank 8A-299) collected in September 1998 was 171.93 pCi/L

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley Area. Well 8K-433 is categorized as a windmill well and, although it is not regulated for human consumption, locals indicate that the well is used for drinking water and for watering livestock (EPA, 2009b).

Groundwater samples were also collected downstream of the Fern No. 1 Mine approximately 0.5 mile northwest at spring 08GS-12-12 (also called Truck Cab Spring), approximately 1.5 miles to the north at spring 08GS-12-11, and approximately 1.5 miles to the north at windmill well 8-1A-1. The concentrations of uranium in water samples from spring 08GS-12-12, spring 08GS-12-11, and windmill well 8-1A-1 were 18.7 pCi/L, 4.24 pCi/L, and 5.08 pCi/L, respectively; these concentrations are less than the estimated MCL of 20 pCi/L. The concentration of uranium in a water sample collected from well 08-27 (also called Shallow Well El Capitan), approximately 2.5 miles upstream of the mine, was 10.6 pCi/L.

C1.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample in the North Central Region. Gross alpha was present at 25.7 pCi/L, which exceeds the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not within 4 miles of the Fern No. 1 Mine.

C1.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 $\mu\text{g/L}$ and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 $\mu\text{g/L}$ and 15 pCi/L.

C1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels in the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Fern No. 1 Mine do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mine. Extensive organic material may persist in these undisturbed deposits in the channel deposits associated with the uranium deposition.

C1.5. MINED URANIUM DEPOSITS

Based on the estimated size of ore bodies at the mines, uranium ore deposits at the Fern No. 1 were significantly mined (96 percent). The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body (Figure 22). Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when operations began at the mine might have destroyed organic material, as would mining. During mining in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (Figure 22; EPA, 2007a).

Section C2. Hazard Ranking System and Summary

C2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at a site to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, groundwater and surface water migration were initially investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is where a hazardous substance, in this case, uranium has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Fern No. 1 Mine include, but are not limited to:

- Uranium ore in disturbed soils and mine workings at the surface as indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Uranium remaining in ore deposits below the surface and below the water table at the Fern No. 1 Mine.

Additional potential sources of hazardous substances not associated with the Fern No. 1 Mine but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in the channel sediments in the Shinarump Member of the Chinle Formation, as mapped by Young, Malan, and Gray (1964).

C2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

C2.2.1. Rainwater Infiltration

The average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of and at the mine. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mine along the Oljeto Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining Fern No. 1 Mine ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH that ranges from 5.5 to 6.0. As discussed in the main report, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. While yearly rainfall volumes are minimal, the influx of rainwater during annual thunderstorms can be rapid, allowing fresh oxidizing water to infiltrate waste rock at the surface and into subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mine provide preferential pathways, the Fern No. 1 ore body has been extensively mined (as much as 96 percent), depleting it of the highest grade ore and most of its mass, and probably destroying organic matter during water influx throughout mining operations at Fern No. 1 Mine. Uneroded ore deposits, as mapped on Figure 8, near and downstream of

the mine may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

C2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such, will likely trend to the north-northwest as the Oljeto Wash and ephemeral creek beds in the region do. Based on the noted influx of groundwater during mining at Fern No. 1 Mine and from the recorded depth to water at Radium Hill No. 1 Mine during the USGS sampling in 1991, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the waste rock into washes and ephemeral streams at the surface (Figure 22); surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit. However, organics (carbonaceous material) and pyrite in the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 22). Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Uranium adsorbs onto clays in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined workings. However, given the mass of uranium in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock. The pH of groundwater measured in the region is reported from 7.2 to 9.2, outside the optimal range of adsorption, further dispersing the uranium picked up in solution from oxidizing water.

Results of water sampling suggest that, while uranium may be leaching extensively upgradient of other ore deposits (as evidenced by a uranium concentration of 171.9 pCi/L in the upgradient water sample from well 8K-433), leaching through the Fern No. 1 Mine is limited. This limited leaching is manifested by the downstream uranium concentration of 18.7 pCi/L at spring 08GS-12-12, which is higher than the uranium concentrations of 10.6 pCi/L at the upstream well 08-27, but less than the estimated MCL of 20 pCi/L. Remnant uranium ore deposits in the adjacent Utah No. 1 and Radium Hill No. 1 Mines also likely contribute uranium to groundwater in this well. Although uranium likely leaches from the mine into oxidizing groundwater that flows through the mine, secondary deposition and adsorption is probably keeping most of the uranium within the mine. In addition, the concentrations of uranium in water

samples collected farther downstream at spring 08GS-12-11 and Wind Mill Tank 8-1A-1 were slightly lower at 4.23 pCi/L and 5.08 pCi/L, respectively.

C2.2.3. Groundwater Pathway Conclusion

Well 8K-433 is just inside a 4-mile radius of the mine but is located upstream, so groundwater flow from Fern No. 1 Mine would not affect the well (see the Combined Pathway-Oljetto Map for North Central Region in Appendix A). Spring 08GS-12-12 is within a 1-mile radius of the mine and downgradient of the mine. The concentrations of radioactive metals in samples from this spring, which is the water source expected to be most influenced by the Fern No. 1 and the Radium Hill No. 1 and Utah No. 1 Mines to which it adjoins, are less than MCLs. None of the wells are intended to be used for drinking water, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009a).

C2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the mine. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mine.

Surface water runoff from the Fern No. 1 Mine enters a drainage system within the Oljetto watershed, including the El Capitan Wash and the Oljetto Wash. The Oljetto Wash runs west of the mines toward the northeast and continues for approximately 15 miles until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles or flowing over the piles of waste rock may be directed into sediments rather than flowing to the creek beds.

C2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash or the Oljetto Wash near the mine or within 15 miles downstream of the mine (NNEPA, 2006). Uranium was detected in the shallow water source downgradient of the mine but at a concentration less than the MCL.

C2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Fern No. 1 Mine for the following reasons:

- Most of the known contamination is confined to the mine, and the concentrations of uranium in samples collected from shallow water sources that may be attributable to the mine are less than the respective MCLs
- Aerial radiation maps confirms that the surface of the mine has been reclaimed and/or does not have waste rock with high uranium concentrations
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mine

C2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during this period.

The Fern No. 1 Mine is located in the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined in this region, primarily from channel deposits of the Shinarump Member of the Chinle Formation. The channel deposit at the Fern No. 1 Mine is approximately 200 feet wide, approximately 200 feet below ground surface, and is composed of medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The Fern No. 1 Mine was listed by the EPA as a productive AUM (EPA, 2007c) at which workings are below the water table or were considered wet.

Monument Valley is drained by ephemeral streams forming tributaries to the San Juan River (Longworth, 1994). The Fern No. 1 Mine is located along a drainage system (part of the Oljeto Wash) that runs approximately southwest to northeast.

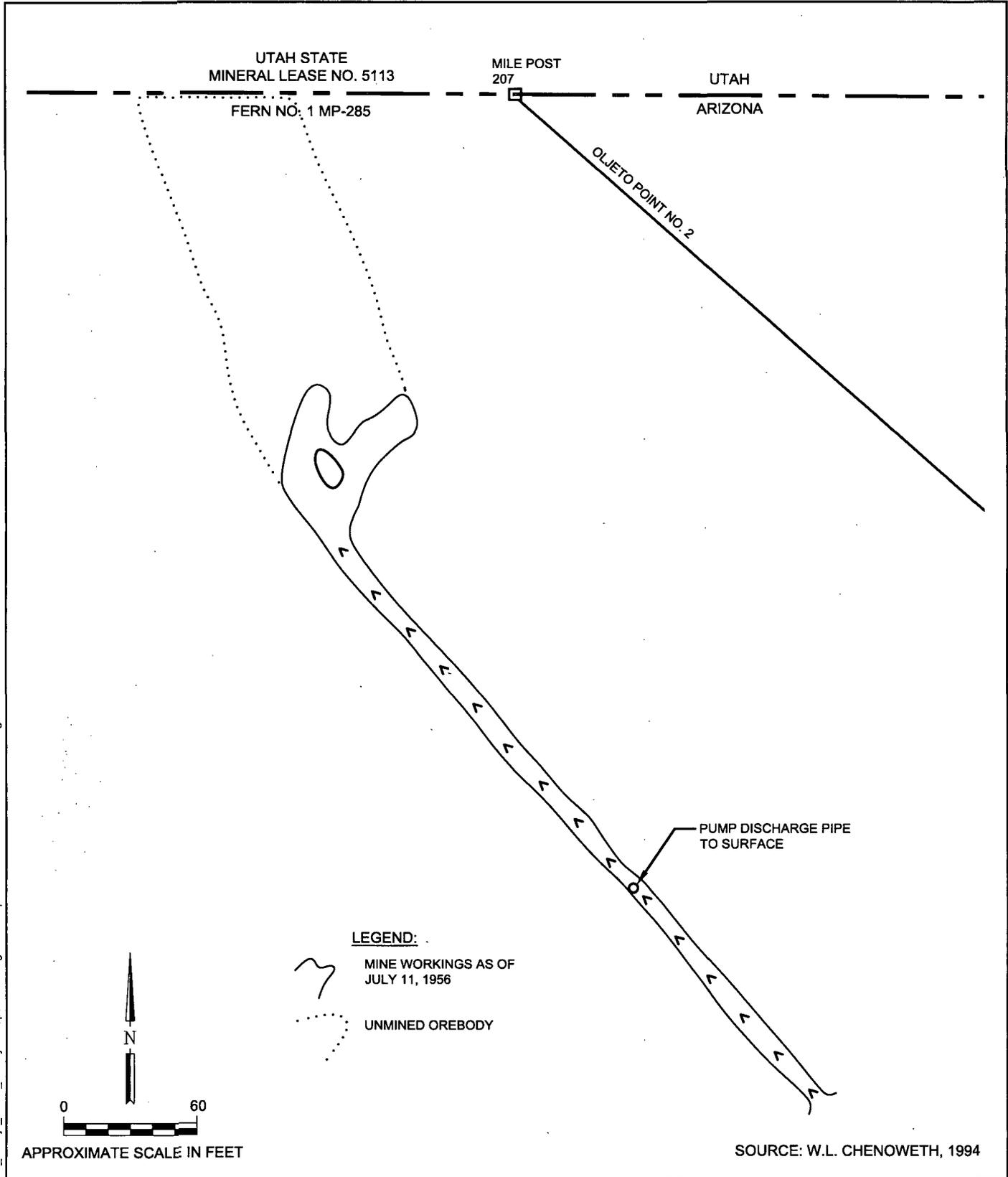
The following pertinent HRS factors are associated with the Fern No. 1 Mine:

- According to aerial radiation surveys for Bismuth-214 (a decay product of uranium), elevated uranium concentrations at the surface are indirectly shown to be confined to the areas immediately around the Radium Hill No. 1 Mine, which is connected to the Fern No. 1 Mine; no radiation levels greater than background were observed for Fern No. 1 Mine, and the mine was reported to be reclaimed (Chenoweth, 1994c).
- Uranium ore at Fern No. 1 Mine was extensively removed during mining

- Concentrations of uranium exceeded laboratory reporting limits but were less than MCLs.
- Uranium concentrations in the downgradient spring closest to the Utah No. 1, Radium Hill No. 1, and Fern No. 1 Mines (approximately 0.5 mile west-northwest of Utah No. 1 and Radium Hill No. 1 Mines) are higher than uranium concentrations in wells upgradient of the mines (greater than 1 mile southwest of Utah No. 1 and Radium Hill No. 1 Mines) and farther downgradient of the mines (approximately 1.5 miles northeast of Utah No. 1 and Radium Hill No. 1 Mines). These results manifest that uranium may be migrating from the Utah No. 1 and Radium Hill No. 1 Mines, and to a lesser extent, the Fern No. 1 Mine.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Fern No. 1 Mine.

Figures

P:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Plan Map of the Fern No. 1 Uranium Mine.dwg



SOURCE: W.L. CHENOWETH, 1994

 <p>Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750</p>	<p>CLIENT:</p> <p>EPA NAVAJO LANDS URANIUM STUDY</p>	<p>DESIGNED BY:</p> <p>RDB 5-20-09</p>	<p>PLAN MAP OF THE FERN NO. 1 URANIUM MINE</p>			
	<p>LOCATION:</p> <p>NAVAJO NATION, ARIZONA</p>	<p>CHECKED BY:</p> <p>JMD 5-21-09</p>				

Appendix D. Starlight and Starlight East Mines Groundwater Pathway Assessment

Appendix D
Starlight and Starlight East Mines
Groundwater Pathway Assessment

April 2010

TDD No.: TO1-09-08-02-0001
Contract No.: EP-S9-07-01

Prepared for:

U.S. Environmental Protection Agency, Region 9
75 Hawthorne Street
San Francisco, CA 94105

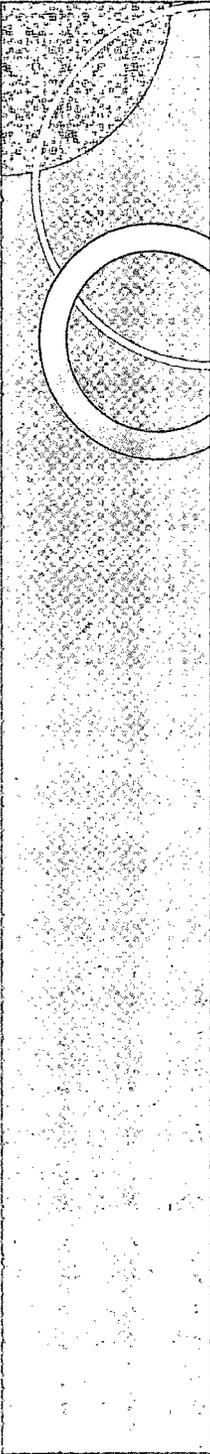
Prepared by:



ERRG

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Background

What are Tritium Exit Signs?

- Distributed as an NRC (or Agreement State) generally licensed device
- Can contain up to 25 Ci of tritium sealed in glass tubes
- Typical lifespan is 10 to 20 years depending on the initial activity of tritium (due to the short half-life of tritium)
- Self-illumination is the result of radioactive decay; tritium decays to helium, emitting electrons in the process. The emitted electrons (i.e., beta particles) energize a phosphorous coating inside the sealed glass tubes to light the sign.



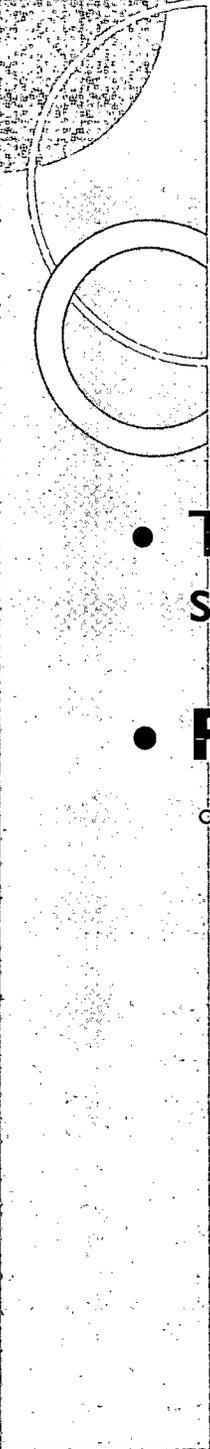
Request 1: Labeling should be in several locations on the sign with larger font.

- The rationale is that larger labeling will "improve recognition" and thus accountability.
- Nearly all commenters agreed with the petitioner. However NASA Center commented that it installed more visible labels on its signs and it was not completely successful. Another commenter suggested adding verbiage: "DO NOT THROW AWAY." SRB Technologies, INC (SRBT) commented that its exit signs have two labels on each sign; one on the outside frame and the other affixed inside the sign, so that should the frame be separated from the main body of the assembly, then a label is still visible within the sign.
- **Recommendation**
 - **DENY** Rulemaking.
 - **APPROVE** enhancements to regulatory guidance document (NUREG 1556, Volume 16, Appendix L, published December 2000). The Working Group (WG) agrees with the petitioner that labels should be more recognizable, although not necessarily by having several labels or by specifying minimum fonts. Improvements to labeling could be accomplished by enhancements to guidance.



Request 3: An expiration date should be distinctly legible to a fire or building inspector without taking down the sign.

- Rationale is that the fire or building inspector will be aware of an expired sign and request the replacement of the sign.
- SRBT commented that its exit signs clearly show the replacement date. However, it should also be noted that a replacement date of a sign does not fall under the jurisdiction of the NRC. Eli Lilly commented that when its records indicate that installed signs are close to expiration communication from tritium sign manufacturers would help prevent prolonged use and inadequate functionality in the case of an emergency.
- **Recommendation**
 - **DENY** Rulemaking.
- **APPROVE** enhancements to regulatory guidance documents. Although the actual expiration date is not under NRC purview, the location of the date is. This can be accomplished through guidance.



Request 4: National Collection effort with distinct milestones and goals on all expired and disused Tritium exit signs.

- This is a nonregulatory issue. Rationale is to provide a simpler method of disposal.
- **Recommendation**
 - **DENY** The (WVG) believes that such an effort is beyond the regulatory authority of the NRC, and therefore, neither a rulemaking nor modification to guidance would be appropriate.



Request 5: Organize a meeting with ASTSWMO and interested stakeholders to set a new path forward.

- Rationale is to gather all parties to hash out the issues to allow all parties to communicate their position.
- **Recommendation**
 - **DENY.** The WG believes that this is not a rulemaking issue.
 - **The WG agrees with the petitioner that a meeting with all interested stakeholders could prove beneficial.**



General Request: Improve regulations or guidance to improve labeling and accountability of signs.

- Rationale stated by the petitioner is that distributors do not always demonstrate accountability in dispensing exit signs to the proper recipients and that recipients are not informed of proper ownership and regulatory requirements.
- **Recommendation**
 - **DENY** Rulemaking.
- **APPROVE.** The WVG agrees with petitioner that the agency's guidance on this issue should be reviewed to ensure that the guidance adequately identifies for users and distributors of tritium exit signs responsibilities and obligations for accountability of signs. Additionally, the NRC public web site should be utilized in a manner similar to the EPA's to allow for additional information and education on the requirements for tritium exit signs.

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Section D1. Mine and Groundwater Investigation

D1.1. LOCATIONS OF ABANDONED URANIUM MINES

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). Two of the AUMs, the Starlight and Starlight East Mines, are in the Navajo County of Arizona, approximately 2.5 to 3 miles south of the Utah and Arizona border and 17 miles north of Kayenta, Arizona. The two AUMs are located within the El Capitan Flat of the Monument Valley Mining District (Figure 6).

D1.1.1. Local Hydrogeology

The Starlight and Starlight East Mines are located in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley area around the two mines is 6 to 8 inches (see Average Annual Precipitation Map for Monument Valley Area Map in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the two mines is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for North Central Region in Appendix A). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

Aquifer sensitivity in the area surrounding the two mines ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

The Starlight and Starlight East Mines are located along a drainage system (part of the El Capitan Wash) that runs approximately southeast to northwest. Two wells, 08-0637 and 08T-525, are shown in EPA's geographic information system geospatial database as being located along this section of the drainage, directly upstream and downstream of the mines, respectively (see the Surface Water Features Map for

North Central Region in Appendix A). Water samples were collected from 08T-525 in 1991 and 1998; no water samples were collected from 08-0637.

D1.2. DETAILED MINE BACKGROUND

Uranium ore deposits are formed in the basal Shinarump Member of the Chinle Formation; the Shinarump is a fluvial channel deposit. The rocks of the Chinle Formation dip approximately 2 degrees to the west in the area near the Starlight Mine. The channel deposit at the Starlight Mine is approximately 200 feet wide at a maximum depth of approximately 100 feet and is composed of medium-to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the sediments (Chenoweth, 1997a). The channel at the Starlight East Mine has a somewhat undulating but generally flat floor. Uranium ore occurs along the banks of the channel (Chenoweth, 1997a).

D1.2.1. Starlight and Starlight East Ore Deposits

The water table in the Shinarump is perched, and ore deposits are unoxidized. During development of the Starlight Mine, groundwater entered the mine at a rate of 50 gallons per minute. Uraninite (uranium oxide) was the principal uranium mineral; uraninite was accompanied by montrosite (vanadium oxide) and copper sulfides, such as bornite, chalcocite, and chalcopyrite. The rocks were principally sandstone, cemented with calcium carbonate (Chenoweth, 1997a).

Drilling in the area of the Starlight Mine delineated an estimated 65,000 tons of uranium ore, averaging 0.30 percent U_3O_8 at a depth of 170 feet and an average thickness of 2 feet. When the Starlight Mine was closed in late 1961, it had produced 40,378 tons of ore. Production began in 1961 at the Starlight East Mine on an estimated 50,000-ton ore body (Chenoweth, 1997a). When the Starlight East Mine closed in early 1964, it had produced 45,990 tons of ore. Based on the estimated sizes of the ore bodies, approximately 62 percent and 92 percent of the projected ore at Starlight Mine and Starlight East Mine, respectively, were mined.

Chenoweth (1997a) notes that the “two mines sites have been reclaimed.” No specific mine waste features were noted for the Starlight and Starlight East Mines during EPA’s assessment (EPA, 2007c). Although mines in the area were often open pits, the Starlight Mine ore body was at a depth of 170 feet, and a shaft was sunk to 190 feet to mine the ore. Similarly, the Starlight East Mine was mined along a 450-foot decline using underground equipment (Chenoweth, 1997a).

D1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

D1.3.1. Aerial Radiation Contours

In 2000, EPA produced the “Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas,” herein referred to as the “Project Atlas” (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley area was created from data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory. The contour map is included in the Project Atlas. The aerial radiation contours identify concentrations higher than regional levels.

Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. A map of the aerial radiation contour values in the Project Atlas illustrates higher bismuth-214 radiation (up to 34.9 microRoentgens per hour [$\mu\text{R/hr}$]) for the Starlight and Starlight East Mines than for the immediate surrounding area (EPA, 2007c). Similar values are shown for Sunlight, Sunlight South, Big Chief, and Big Four No. 2 Mines in Monument Valley and lower values at the Moonlight Mine and an area to the east of the Moonlight Mine (up to 3.5 $\mu\text{R/hr}$), also in Monument Valley. No contour value is shown for the Daylight Mine to the southwest of the Moonlight Mine.

A finer-scaled map shows that the bismuth-214 radiation count at the Starlight and Starlight East Mines is up to 23.6 to 34.9 $\mu\text{R/hr}$ at the center of the mined area, while the bismuth-214 radiation count at nearby Moonlight Mine ranges from 2.4 to 3.5 $\mu\text{R/hr}$ (see the Bismuth-214 Flyover Polygons map for North Central Region in Appendix A).

D1.3.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) conducted a study in the Monument Valley and Cameron Mining Districts. Site data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were measured in October 1991 (Longworth, 1994) from the following wells near the Starlight and Starlight East Mines:

- 8T-525
- 8K-433
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Maps for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Maps for North Central Region in Appendix A)

These wells are located along the same drainage, running from southeast at higher elevations (unnamed 4-inch well and 8K-433) to northwest at lower elevations (unnamed 6-inch well and 8T-525; Figure 8). Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions at the 8T-525), indicating a southeast to northwest gradient along drainage.

D1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. Water sampling has been conducted in the Monument Valley Area by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. Since these wells are unregulated water sources, limited or no information on well development is available and regular groundwater sampling is not conducted. Available analytical results summarized below are from limited grab groundwater sampling events.

As stated in the main report, water in unregulated water sources within the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). Since these sources have been historically used for drinking water purposes, it is hard for people to abandon using them (Keller, 2007).

D1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected a groundwater sample from well 8T-525. The pH of the sample was measured at 7.5. Uranium-238, uranium-234, and uranium-235 concentrations were 0.50 picoCuries per liter (pCi/L), 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 micrograms per liter ($\mu\text{g/L}$) (Longworth, 1994). Uranium concentrations were less than the estimated maximum contaminant level (MCL) of 20 pCi/L (based on EPA MCL of 30 $\mu\text{g/L}$ and conversion of 0.67 picocuries per microgram).

D1.3.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source of water for human consumption, and samples were collected as a point-of-use sample designed to duplicate the most likely method in which people would obtain water. The concentrations of uranium (sum of isotopes uranium-234, uranium-235, and uranium-238) in three water samples collected in the North Central Region were greater than the estimated MCL of 20 pCi/L:

- The concentration of uranium in sample from Baby Rock Spring 8-44 collected in September 1998 was 36.29 pCi/L
- The concentration of uranium in sample from Monument Pass Well collected in January 2000 was 40.00 pCi/L
- The concentration of uranium in sample from Tank 8A-299 collected in September 1998 was 171.93 pCi/L

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley. Well 8K-433 is categorized as a windmill well, and, although it is not regulated for human consumption, locals indicate that the well is being used for drinking water and for watering livestock (EPA, 2009b).

Well 8K-433 is located approximately 1.3 miles upstream of the Starlight and Starlight East Mines, adjacent to the Sunlight and Sunlight South Mines. Additionally, samples were collected downstream of the Starlight and Starlight East Mines at well 8T-525, approximately 0.25 mile northwest, and at Shallow Well El Capitan (well 08-27), approximately 6 miles farther to the northwest. The concentrations of uranium in water samples from well 8T-525 and from Shallow Well El Capitan were 1.68 pCi/L and 10.48 pCi/L, respectively; these concentrations are less than the estimated MCL of 20 pCi/L.

D1.3.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample in the North Central region. The gross alpha of the sample was 25.7 pCi/L, which exceeds the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not located within 4 miles of the Starlight and Starlight East Mines.

D1.3.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 µg/L and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 µg/L and 15 pCi/L.

D1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels within the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various size and grade (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Starlight and Starlight East Mines do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. Extensive organic

materials are present in these undisturbed deposits would be expected to also contain extensive organic material in the channel deposits associated with the uranium deposition (Figure 22).

D1.5. MINED URANIUM DEPOSITS

Based on estimated size of the ore bodies determined by exploration, uranium ore deposits at the Starlight and Starlight East Mines were significantly mined (62 percent and 92 percent, respectively). The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body. Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when operations began at the site might have destroyed organic material, as would mining operations. During mining operations in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (Figure 22; EPA, 2007a).

Section D2. Hazard Ranking System and Summary

D2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, the migration of groundwater and surface water was investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is where a hazardous substance, in this case uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Starlight and Starlight East Mines include, but are not limited to:

- Uranium ore in undisturbed soils and mine workings at the surface is indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Starlight and Starlight East Mines.

Additional potential sources of hazardous substances not associated with the Starlight and Starlight East Mines but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in channel sediments in the Shinarump Member of the Chinle Formation in the area around the Starlight and Starlight East Mines, as mapped by Young, Malan, and Gray (1964).

D2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is designed as a screening tool to give the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility were discussed in the Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

D2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of the mines and at the mine sites. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A). These characteristics are applicable to the remaining Starlight and Starlight East Mine ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH that ranges from 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. The fresh oxidizing water of a rainstorm likely infiltrates the waste rock at the surface and deeper into the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways, the Starlight and Starlight East ore bodies have been extensively mined (as much as 62 percent and 92 percent, respectively), probably depleting them of the highest grade ore and destroying organic matter during water influx throughout mining at Starlight Mine. Uneroded ore deposits, as mapped on Figure 7, near

and downstream of the two mines may provide more uranium- and organic-rich rock and sediment through which water infiltrates to mobilize and transport uranium.

D2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend to the north-northwest similar to the washes and ephemeral creek beds in the region. Based on artesian conditions at well 8T-525 and water levels of nearby wells observed during the 1991 sampling, the noted groundwater influx during mining at the Starlight Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the waste rock into washes and ephemeral streams at the surface (Figure 22); surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit (Figure 22). However, abundant organics (carbonaceous material) and pyrite in the rocks create reducing conditions, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally. Additionally, crossbedding, secondary calcium carbonate cementation, and clays in the sandstone may impede uranium dispersion. Uranium adsorbs onto clays in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium picked up from waste rock as rainwater (with pH of 5.5 to 6.0) infiltrates and runs over the waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the mass of uranium in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water sampling suggest that, while uranium may be extensively leaching upstream from other ore deposits or mines (as evidenced by a uranium concentration of 171.9 pCi/L in the upgradient water sample from well 8K-433), leaching through the Starlight and Starlight Mines is limited (as evidenced by the downstream water sample concentration of 1.68 pCi/L from well 8T-525). Although uranium is being leached from the mines, secondary deposition and adsorption is probably keeping most of the uranium within the mines. Additionally, the concentration of uranium in a water sample collected farther downstream at the Shallow Well El Capitan (08-27) was slightly higher at a concentration of 10.48 pCi/L, which suggests uranium is leaching into groundwater from either unmined ore deposits or other AUMs farther downstream or from adjacent drainages (Figure 22).

D2.2.3. Groundwater Pathway Conclusion

The Shallow Well El Capitan is outside the 4-mile radius of the Starlight and Starlight East Mines. Well 8K-433 is just outside a 1-mile radius of the mines but is located upstream from the mines, so groundwater flow would not affect the well (see the Combined Pathway-Oljato Map for North Central Region in Appendix A). Well 8T-525, is within a 0.25-mile radius of the mines, but concentrations of radioactive metals are less than MCLs. None of the wells are intended to be used for drinking water, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009b). Uranium was detected in the shallow water source immediately downgradient of the mines (well 8T-525) at a concentration less than the MCL; this is the water source expected to be most influenced by the Starlight and Starlight East Mines.

D2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the sites.

Surface water runoff from the Starlight and Starlight East Mines enters a drainage system within the Oljeto watershed, including the El Capitan Wash and the Oljeto Wash. The El Capitan Wash runs just south of the mines toward the northwest and meets up with the Oljeto Wash just west of the Starlight Mine. The Oljeto Wash continues for approximately 20 miles until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storms, when slightly acidic and oxidizing rainwater interacts with waste rock left on the surface. In semiarid to arid environments, evaporation is quick, and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds. However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

D2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash or the Oljeto Wash near the mines or within 15 miles downstream of the mines (NNEPA, 2006). Uranium was detected in the shallow water source downgradient of the mines but at a concentration less than the MCL.

D2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415(b)(2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Starlight Mine and Starlight East Mine for the following reasons:

- Most of the known contamination is confined to the mines, and the concentrations of uranium that have been measured in water sources away from the mines and that may be attributable to the mines are less than the MCLs
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mines

D2.5. SUMMARY

The Starlight and Starlight East Mines are located in the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined in this region, primarily from channel deposits of the Shinarump Member of the Chinle Formation. The channel deposit at the Starlight Mine is approximately 200 feet wide with maximum depth of 100 feet below ground surface, and is composed of medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The ore of the Starlight East Mine occurs along the banks of the channel. The Starlight and Starlight East Mines were listed by the EPA as productive AUMs (EPA, 2007c) that have workings below the water table or were considered wet mines that required pumping.

Monument Valley is drained by ephemeral streams forming tributaries to the San Juan River (Longworth, 1994). The Starlight and Starlight East Mines are located along a drainage system (part of the El Capitan Wash) that runs approximately southeast to northwest. The following pertinent HRS factors are associated with the Starlight and Starlight East Mines:

- According to aerial radiation surveys for bismuth-214 (a decay product of uranium), elevated uranium concentrations at the surface are indirectly shown to be confined to the areas immediately around the Starlight Mine and the Starlight East Mine.
- Soils typified by rapid infiltration but only during very infrequent precipitation events; the pH of rainwater is conducive to adsorption of uranium that is leached into oxidizing rainwater onto abundant inorganic and organic matter in channel deposits.
- Uranium concentrations in samples collected from water sources exceeded laboratory reporting limits but were less than MCLs.

- Uranium concentrations in samples from the downgradient well closest to the Starlight and Starlight East Mines (approximately 0.3 mile west-northwest of Starlight Mine) are lower than uranium concentrations in wells upgradient of the mines (greater than 1 mile southeast of Starlight East Mine) and farther downgradient of the mines (approximately 1.2 miles northwest of Starlight Mine). These results manifest that limited uranium is migrating from the Starlight and Starlight East Mines. None of these wells are regulated, although one well upgradient of the mines is being used for drinking water by humans.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Starlight and Starlight East Mines.

Appendix E. Sunlight and South Sunlight Mines Groundwater Pathway Assessment

Appendix E
Sunlight and South Sunlight Mines
Groundwater Pathway Assessment

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Section E1. Mine and Groundwater Investigation

E1.1. LOCATION OF ABANDONED URANIUM MINES

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). Two of these AUMs, the Sunlight and South Sunlight Mines, are located in the North Central Region of the Navajo Nation, in Navajo Nation District 8. Geographically, they are located on the South El Capitan Flat in the Monument Valley Mining District. The Sunlight and South Sunlight Mines are approximately 16 miles south of Kayenta, Arizona, and 4.5 miles west of U.S. Highway 163. The two mines have been reclaimed, but the mine waste from the South Sunlight decline is shown on the Boot Mesa topographic map (Figure 6; Chenoweth, 1997b).

E1.1.1. Local Hydrogeology

The Sunlight and South Sunlight Mines are in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley area around the two mines is 6 to 8 inches (see Average Annual Precipitation Map for Monument Valley Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the two mines is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

Aquifer sensitivity in the area surrounding the two mines ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

The Sunlight and South Sunlight Mines are located along a drainage system (part of the El Capitan Wash) that runs approximately southeast to northwest.

E1.2. DETAILED MINE BACKGROUND

The Sunlight and South Sunlight ore deposits are in the El Capitan Flat area of Monument Valley. El Capitan Flat is a large, sand-dune covered area on the eastern side of the Oljeto Wash (Figure 6). Oljeto Wash roughly follows the axis of the Oljeto syncline, between the Organ Rock anticline to the west and the crest of the Monument Uplift to the east. The dune sand in the area is underlain by the Upper Triassic Chinle Formation. Rocks of this formation dip approximately 2 degrees to the west into the Oljeto syncline (Chenoweth, 1997b).

E1.2.1. Sunlight and South Sunlight Ore Deposits

The ore bodies for the mines are formed in a paleochannel deposit in the basal portion of the Shinarump Member of the Chinle Formation. The channel was scoured into the underlying Moenkapi Formation of Lower Triassic age and is approximately 200 feet wide and 100 feet deep; the channel is filled with medium- to coarse-grained sandstone and conglomerate and carbonaceous plant materials, including fossil logs, are abundant (Chenoweth, 1997b).

The South Sunlight ore deposit occurs at the junction of the northwest-trending channel in which the Big Chief, Firelight No. 6, and Alma-Seegan Mines occur and the northeast trending channel in which the Big Four No. 2 Mine formed. The Sunlight ore deposit is in the north northwest trending channel formed by the merger of the other two channels (Figure 7; Chenoweth, 1997b).

The mine deposits were unoxidized because the water table in the basal Shinarump is shallow. Uraninite (uranium oxide) was the principal uranium mineral. Montrosite, a vanadium oxide, and copper sulfides, such as bornite, chalcocite, and chalcopyrite, are associated with the uranium mineralization. Calcium carbonate was the principal cementing agent of the sandstone (Chenoweth, 1997b).

E1.2.2. Production History

The Sunlight and South Sunlight Mines were 2 of 15 uranium deposits located by exploration drilling in the Oljeto syncline of Monument Valley. Of the deposits that were mined, the Sunlight Mine was the third largest, and the South Sunlight was the sixth (Chenoweth, 1997b).

E1.2.3. Sunlight Mine

Exploratory drilling at the Sunlight Mine delineated 54,000 tons of ore, with an average grade of 0.37 percent U_3O_8 . The ore ranged from 2 to 25 feet thick, averaging 12 feet. Installation of a 260-foot deep, two compartment shaft began in 1957. Two ore zones are at the Sunlight Mine; the upper ore zone was of lower grade than the lower ore zone (Chenoweth, 1997b). The deposit was mined by a modified room and pillar method.

The Sunlight Mine operated from 1957 until 1964. During that time, it produced 55,023.51 tons of ore averaging 0.26 percent U_3O_8 and containing 291,461.88 pounds U_3O_8 . The copper content of ore that was shipped to Mexican Hat (one of two mills used by mining interests at Sunlight Mine) averaged 1.05 percent copper (Chenoweth, 1997b).

E1.2.4. South Sunlight Mine

Very little information is available about the South Sunlight Mine. In 1961, a long decline was driven to develop the ore deposit and production began in 1962 (as production from the Sunlight Mine began to diminish). The mine was inactive for most of 1964, and cleanup mining was performed from late 1964 through 1965. Cleanup mining resulted in a decrease in ore grade from 0.34 percent U_3O_8 to 0.29 percent U_3O_8 . Total ore production from the South Sunlight Mine was 28,644.74 tons of ore, averaging 0.30 percent U_3O_8 and containing 171,459.83 pounds of U_3O_8 (Chenoweth, 1997b).

E1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

E1.3.1. Aerial Radiation Contours

In 2000, EPA produced the “Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas,” herein referred to as the “Project Atlas” (EPA, 2000a). The results of data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory are included in the Project Atlas as a contour map. The portion of the data set that covers the Monument Valley Areas mines of interest is shown on the Bismuth-214 Flyover Polygons Map for North Central Region in Appendix A (EPA, 2007c). The aerial radiation contours identify concentrations higher than regional levels.

Excess bismuth activity is a good indicator of the presence of old mines and mining-related activities. The bismuth-214 contours in the Project Atlas indicate the concentrations of bismuth-214 near the Sunlight and South Sunlight Mines range from 2.4 to 34.9 $\mu R/hr$, while the bismuth-214 levels over Tract 24 Mine A and B to the northwest of the mines are not greater than the levels in the surrounding area and over the Moonlight Mine to the east are limited, up to 3.5 $\mu R/hr$ (see the Bismuth-214 Flyover Polygons Map for North Central Region in Appendix A; EPA, 2007c).

E1.3.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) conducted a study in the Monument Valley and Cameron Mining Districts. Data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were measured in October 1991 (Longworth, 1994) from the following water sources near the Sunlight and South Sunlight Mines:

- Well 08T-525
- Well 08K-433 (formerly Tank 8A-299)
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Maps for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Maps for North Central Region in Appendix A)

These wells are located along the same drainage that runs from southeast at higher elevations (unnamed 4-inch well and 8K-433) to northwest at lower elevations (unnamed 6-inch well and 8T-525; Figure 8). Based on the elevations of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions at the 8T-525), indicating a southeast to northwest gradient along the drainage.

Based on the groundwater gradient, the Sunlight and South Sunlight Mines are downgradient from well 08-0636 and upgradient from wells 8T-525, 08-0637, and 08K-433.

E1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Water samples have been collected in the Monument Valley by the USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. These wells are unregulated water sources; therefore, limited or no information on well development is available, and groundwater samples are not collected regularly. Available analytical results summarized below are from limited grab groundwater samples.

As stated in the main report, water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been used historically for drinking water and, it is hard for people to abandon using them (Keller, 2007).

E1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected a groundwater sample from well 8T-525. The pH of the sample was measured at 7.5. Uranium-238, uranium-234, and uranium-235 concentrations were 0.50 picoCuries per liter (pCi/L), 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 micrograms per liter ($\mu\text{g/L}$) (Longworth, 1994). The results were all less than the respective

maximum contaminant levels (MCLs), and uranium concentrations were less than the estimated MCL of 20 pCi/L (based on EPA MCL of 30 µg/L and conversion of 0.67 picocuries per microgram).

E1.3.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source for human consumption, and samples were collected as a point-of-use sample to duplicate the most likely method in which people would obtain water. The concentrations of total uranium (sum of isotopes uranium-234, uranium-235, and uranium-238) in three water samples collected in the North Central Region were greater than the estimated MCL of 20 pCi/L:

- The concentration of uranium in the sample from Baby Rock Spring 8-44 collected in September 1998 was 36.29 pCi/L.
- The concentration of uranium in the sample from Monument Pass Well collected in January 2000 was 40.00 pCi/L.
- The concentration of uranium in a sample from Tank 8A-299 collected in September 1998 was 171.93 pCi/L.

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley. Well 8K-433 is categorized as a windmill well, and, although it is not regulated for human consumption, locals indicate that the well is being used for drinking water and for watering livestock (EPA, 2009b).

The wells from which the USACE collected samples in September 1998 included well 8K-433 (formerly Tank 8A-299), well 8T-525, and well 08-27 (also called Shallow Well El Capitan). Well 8K-433 is less than 0.1 mile to the west of the Sunlight and South Sunlight Mines, above the El Capitan Wash. Well 8T-525 is approximately 2 miles northwest and downstream of the Sunlight and South Sunlight Mines. Well 08-27 (Shallow Well El Capitan) is approximately 3 miles downstream of the mine (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c).

USACE collected the groundwater sample from well 8K-433 at an elevation of 5,100 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 155.00 pCi/L, greater than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at a concentration of 171.93 pCi/L, which exceeds the estimated MCL of 20 pCi/L. A groundwater sample was collected from well 8T-525 at an elevation of 5,011 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 1.59 pCi/L, which is less than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at a concentration of 1.68 pCi/L, which is less than the estimated MCL of 20 pCi/L. USACE collected the groundwater sample from Shallow Well El Capitan (08-27 on Surface Water Features Map for North Central Region in Appendix A; EPA,

2007c) at an elevation of 5,000 feet above msl; the pH of the sample was 7.84. Gross alpha (dissolved) as natural uranium was 8.41 pCi/L, which is less than the EPA MCL of 15 pCi/L (EPA, 2000b). Total uranium was detected in water sample from Shallow Well El Capitan at a concentration of 10.48 pCi/L, which is less than the estimated MCL of 20 pCi/L.

E1.3.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample from well 08T-522 in the North Central region. Gross alpha was measured at 25.7 pCi/L, which exceeds the EPA MCL of 15 pCi/L. Well 08T-522 is not located within 4 miles of the Sunlight and South Sunlight Mines.

E1.3.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 µg/L and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 µg/L and 15 pCi/L.

E1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels within the Shinarump Member of the Chinle Formation is likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at the Sunlight and South Sunlight Mines do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. Organic material likely occurs extensively in the channel sediments associated with the uranium deposition (Figure 22).

E1.5. MINED URANIUM DEPOSITS

Based on the estimated size of ore bodies determined by exploration, and the quantity of ore recovered during mining, it is likely that most of the ore body was removed at the Sunlight Mine; the estimated reserves at South Sunlight Mine are unknown. The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body.

Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted during mining might have destroyed organic material, as would mining operations. During mining in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (Figure 22; EPA, 2007a).

Section E2. Hazard Ranking System and Summary

E2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, the migration of groundwater and surface water was investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is where a hazardous substance, in this case, uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Sunlight and South Sunlight Mines include, but are not limited to:

- Uranium ore in undisturbed soils and mine workings at the surface are indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Remnants of uranium ore deposits below the surface and below the water table at the Sunlight and South Sunlight Mines.

Additional potential sources of hazardous substances not associated with the Sunlight and South Sunlight Mines but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in the channel sediments within the Shinarump Member of the Chinle Formation in the surrounding area as mapped by Young, Malan, and Gray (1964).

E2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is designed as a screening tool to give the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments. Uranium's toxicity and methods of mobility were discussed in the Section 2 of the main report [“Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)”].

E2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). Permeability is rapid, and an “intermediate potential” exists for contaminant migration in soils upgradient of the mine and at the mine site. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining Sunlight and South Sunlight Mines ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Due to the minimal yearly rainfall but rapid influx of rainwater during seasonal thunderstorms, the fresh oxidizing water likely infiltrates the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways, the Sunlight and South Sunlight ore bodies have been extensively mined, depleting the area of the highest grade ore and mass and probably destroying organic matter during water influx throughout mining operations. Uneroded ore deposits, as mapped on Figure 7,

near and downstream of the mine may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

E2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography, and as such, will likely trend to the north-northwest similar to the washes and ephemeral creek beds in the region. Based on artesian conditions at well 8T-525 and water levels of nearby wells observed during the 1991 sampling, the noted groundwater influx during mining at the Starlight Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface; surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit. However, organics (carbonaceous material) and pyrite in the rocks create a reducing environment, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally. Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Uranium adsorbs onto clays in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium that is picked up by rainwater (with pH of 5.5 to 6.0) as it passes over and through waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the mass of uranium in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water samples manifest that uranium is leaching from the Sunlight and South Sunlight Mines; the highest concentration of uranium was detected in the groundwater sample collected from well 08K-433 immediately adjacent to the Sunlight and South Sunlight mines. The much lower concentrations of uranium in the downstream water sample suggest the migration of uranium is limited in distance and that the Sunlight and South Sunlight Mines are the possible upstream source of uranium in the water samples.

E2.2.3. Groundwater Pathway Conclusion

The levels of radioactive metals in the groundwater sample collected from well 8K-433, adjacent to Sunlight and South Sunlight Mines, are elevated from the concentrations of radioactive metals in

groundwater samples collected downstream from the Sunlight and South Sunlight Mines at 08T-525 are much lower. It is likely that ore bodies and waste rock or an unmined uranium deposit remaining near the Sunlight and South Sunlight Mines contribute to the elevated concentrations.

None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009b).

E2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Sunlight and South Sunlight Mines enters the El Capitan Wash, which is west of the mine and flows in a southerly direction. The elevation of the wash is more than 100 feet lower than the elevation at the top of the mine shaft. The El Capitan Wash continues in a south/southeasterly direction until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storms, when slightly acidic and oxidizing rainwater interacts with waste rock left on the surface. In semiarid to arid environments, evaporation is quick, and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds. However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

E2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash near the mine or within 15 miles downstream of the mine (NNEPA, 2006). Uranium was detected in the shallow water source adjacent to the mines at a concentration greater than the MCL and may be driven by surface water flow of rainwater across the waste rock.

E2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites where contaminants pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Sunlight and South Sunlight Mines for the following reasons:

- The concentrations of radioactive metals in water samples collected downstream exceed their respective MCLs; it is possible that this contamination is from multiple sources, not solely the Sunlight and South Sunlight Mines. The potential for uranium contamination to the downgradient well is high because the mines are proximate.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mine.

E2.5. SUMMARY

The Sunlight and South Sunlight Mines are in the North Central Region, specifically the Monument Valley Mining District. Uranium and copper were mined from these mines, primarily from ore deposits in channel sediments of the Shinarump Member of the Chinle Formation. The ore deposit at the Sunlight and South Sunlight Mines is approximately 200 feet wide and 100 feet deep, hosted by medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The Sunlight and South Sunlight Mines were listed by the EPA as a productive AUM (EPA, 2007c) that had workings below the water table or was considered a wet mine that required pumping.

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Sunlight and South Sunlight Mines are located along a drainage system (part of the El Capitan Wash) that runs approximately southeast to northwest. The following pertinent HRS factors are associated with the Sunlight and South Sunlight Mines:

- According to aerial radiation surveys for bismuth-214 (a decay product of uranium), elevated uranium concentrations at the surface are indirectly shown to be confined to the areas around the Sunlight and South Sunlight Mines.
- Soils typified by rapid infiltration but only during very infrequent precipitation events; normal rainwater pH is conducive to adsorption of the uranium that is released into solution with introduction of oxidized rainwater onto abundant inorganic and organic matter in channel deposits.
- The concentrations of water samples collected from the water source adjacent the mines exceed their respective MCLs. The potential that the Sunlight and South Sunlight Mines contribute to the elevated concentrations of radioactive metals in groundwater is high.

- The water sources near the Sunlight and South Sunlight Mines are not regulated; however, records indicate that the water in some may be used for livestock or human consumption.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Sunlight and South Sunlight Mines.

Appendix F. Big Four No. 2 Mine Groundwater Pathway Assessment

Appendix F
Big Four No. 2 Mine
Groundwater Pathway Assessment

April 2010

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Section F1. Mine and Groundwater Investigation

F1.1. LOCATION OF ABANDONED URANIUM MINE

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). One of these AUMs, the Big Four No. 2 Mine, is in the North Central Region, approximately 15 miles north of Kayenta, Arizona and 4.5 miles west of U.S. Highway 163 (Chenoweth, 1994b). The AUM is in the El Capitan Flat of the Monument Valley Mining District (Figure 6).

F1.1.1. Local Hydrogeology

The Big Four No. 2 Mine is in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley area around the mine is 6 to 8 inches (see Average Annual Precipitation Map for Monument Valley Area map in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the mine is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

Aquifer sensitivity in the area around the mine ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

The Big Four No. 2 Mine is located along a drainage (part of the El Capitan Wash) that runs approximately southeast to northwest. One well, 08A-210, is shown in EPA's geographic information system geospatial database as being located along this section of the drainage, immediately adjacent to the mine. However no data have been found associated with this well, except for its elevation at 5,095 feet

above mean sea level (msl) and a depth to water of 8 feet below ground surface. Three wells, 08T-525, 08-0637, and 08-0636, are shown in EPA's geographic information system geospatial database as being located along this section of the drainage, downstream of the mine, (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c). Water samples were collected from 08T-525 in 1991 and 1998; no water samples have been collected from wells 08-0637 or 08-0636.

F1.2. DETAILED MINE BACKGROUND

Uranium ore deposits are formed in the basal Shinarump Member of the Chinle Formation; the Shinarump is a fluvial channel deposit scoured into the underlying Moenkopi Formation. The rocks of the Chinle Formation dip approximately 2 degrees to the west in the area near the Big Four No. 2 Mine. The channel deposit at the Big Four No. 2 Mine is approximately 200 feet wide, with a maximum depth of approximately 100 feet, and is hosted by medium-to-coarse-grained sandstone and conglomerate (Chenoweth, 1994b). Organic plant matter is abundant in the sediments.

F1.2.1. Big Four No. 2 Ore Deposits

Drilling in the area of the Big Four No. 2 Mine delineated an estimated 4,500 tons of uranium ore, averaging 0.25 percent U_3O_8 at a depth of 200 feet and an average thickness of 2 feet. The underground mine used a random room and pillar mining method with rubber-tired diesel equipment. A 450-foot-long decline with a 24 degree declination was completed to develop and mine the ore. When the Big Four No. 2 Mine was closed in late 1963, it had produced 3,929.7 tons of ore. Based on the estimated sizes of the ore bodies, approximately 87 percent of the projected ore at Big Four No. 2 Mine was mined.

Similar to other mines in the region, uranium was mined from the Shinarump Member of the Chinle Formation at the Big Chief Mine under wet conditions due to the presence of perched water at the AUM. During development of the Big Four No. 2 Mine, groundwater entered the mine at a rate of 50 gallons per minute (Chenoweth, 1994b).

According to Chenoweth (1994b), the mine has been reclaimed. No specific mine waste features were noted for the Big Four No 2 during the EPA's assessment (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c).

F1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

F1.3.1. Aerial Radiation Contours

In 2000, EPA produced the "Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas," herein referred to as the "Project Atlas" (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley area was created from data collected during an

aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory. The contour map is included in the Project Atlas. The aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities.

A map of the aerial radiation contour values in the Project Atlas illustrates higher bismuth-214 radiation (up to 7.4 excess microRoentgens per hour [$\mu\text{R/hr}$]) for the Big Four No 2 than for the immediate surrounding area. Increased values are shown for Sunlight, Sunlight South, Starlight, and Starlight East, and Big Chief Mines and lower values at the Moonlight Mine and an area to the east of the Moonlight Mine (up to 3.5 $\mu\text{R/hr}$). No contour value is shown for the Daylight Mine to the southwest of the Moonlight Mine.

Bismuth-214 at the Starlight, Starlight East, Big Chief, Sunlight, and South Sunlight Mines, north of Big Four No. 2 Mine, ranges from 2.4 to 34.9 $\mu\text{R/hr}$ on a finer scaled map. Bismuth-214 in areas around Big Four No. 2, toward the northwest, is at background values of 2 to 3 $\mu\text{R/hr}$ (see Bismuth-214 Flyover Polygons Maps for North Central Region in Appendix A; EPA, 2007c).

F1.3.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) studied the Monument Valley and Cameron Mining Districts. Data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were measured in October 1991 (Longworth, 1994) from the following wells near the Big Four No 2:

- 8T-525
- 8K-433(formerly Tank 8A-299)
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Maps for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Maps for North Central Region in Appendix A)

These wells are located along the same drainage, running from southeast at higher elevations (unnamed 4-inch well and 8K-433) to northwest at lower elevations (unnamed 6-inch well and 8T-525; Figure 8). Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above msl in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions) at 8T-525, indicating a southeast to northwest gradient along drainage.

F1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. Samples have been collected in the Monument Valley by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. These wells are unregulated water sources; consequently, limited or no information on well development is available, and groundwater samples are not collected regularly. Available analytical results summarized below are from limited grab groundwater sampling events.

As stated above, the water from unregulated water sources within the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). It is hard for people to abandon using them because the shallow water sources have been used historically for drinking water (Keller, 2007).

F1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected a groundwater sample from well 8T-525. The pH of the sample was measured at 7.5. Uranium-238, uranium-234, and uranium-235 concentrations were 0.50 picoCuries per liter (pCi/L), 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 micrograms per liter ($\mu\text{g/L}$) (Longworth, 1994). The results were less than the maximum contaminant levels (MCLs), and uranium concentrations were less than the estimated MCL of 20 pCi/L (based on the EPA MCL of 30 $\mu\text{g/L}$ and conversion of 0.67 picocuries per microgram).

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- The concentration of uranium in the sample from Tank 8A-299 collected in September 1998 was 171.93 pCi/L.

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley. Well 8K-433 is categorized as a windmill well and, although it is not regulated for human consumption, locals indicate that the well is being used for drinking water and for watering livestock (EPA, 2009b).

In September 1998, USACE collected samples from well 8K-433 (formerly Tank 8A-299), well 8T-525, and spring 8A-P.H.S.-22-Spring. Well 8K-433 is approximately 1 mile downstream of the Big 4 No. 2 Mine, above the El Capitan Wash and adjacent to the Sunlight and Sunlight South Mines. Well 8T-525 is approximately 2.5 miles northwest and downstream of the mine. Spring 08-220 is approximately 5.5 miles upstream of Big Four No. 2 Mine (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c).

USACE collected the groundwater sample from well 8K-433 at an elevation of 5,100 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 155.00 pCi/L, which exceeded the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8K-433 at concentration of 171.93 pCi/L, which exceeded the estimated MCL of 20 pCi/L. Groundwater was collected from well 8T-525 at an elevation of 5,011 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 1.59 pCi/L, which was less than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at a concentration of 1.68 pCi/L, which was less than the estimated MCL of 20 pCi/L. USACE collected the groundwater sample from spring 8A-P.H.S.-22-Spring (08A-220 on Surface Water Features Map for North Central Region in Appendix A) at an elevation of 5,257 feet above msl; the pH of the sample was 8.28. Gross alpha (dissolved) as natural uranium was 1.95 pCi/L, which was less than the EPA MCL of 15 pCi/L (EPA, 2000b). Total uranium was detected in water sample from 8A-P.H.S.-22-Spring at a concentration of 3.70 pCi/L, which was less than the estimated MCL of 20 pCi/L.

F1.3.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample in the North Central Region. Gross alpha was measured at a concentration of 25.7 pCi/L, which exceeded the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not within 4 miles of the Big Four No. 2 Mine.

F1.3.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 $\mu\text{g/L}$ and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 $\mu\text{g/L}$ and 15 pCi/L. However, this well is above the El Capitan Wash and immediately adjacent to the larger mines,

Sunlight and South Sunlight. Therefore, this increased uranium concentration is more likely to be associated with the Sunlight and South Sunlight Mines.

F1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels in the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Big Four No. 2 Mine do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. Organic material occurs extensively in the channel deposits associated with the uranium deposition.

F1.5. MINED URANIUM DEPOSITS

Based on estimated size of the ore bodies at the mines, uranium ore deposits at the Big Four No 2 were significantly mined (87 percent). The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body (Figure 22). Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when operations began at the mine might have destroyed organic material and oxidizing sulfides, as would mining operations. During mining in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Geologic studies indicated that the Big Four No. 2 deposit is in the same paleochannel as the Bootjack Mine to the south. This channel merges to the north with the channel in which the Big Chief, Firelight No. 6, Alma-Seegan Mines, and the South Sunlight Mine occur (Chenoweth, 1997a).

Section F2. Hazard Ranking System and Summary

F2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, the migration of groundwater and surface water was investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is where a hazardous substance, in this case, uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Big Four No. 2 Mine include, but are not limited to:

- Uranium ore in disturbed soils and mine workings at the surface is indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Uranium ore deposits remaining below the surface and below the water table at the Big Four No. 2 Mine.

Additional potential sources of hazardous substances not associated with the Big Four No. 2 Mine but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in the channel sediments in the Shinarump Member of the Chinle Formation in the area around the Big Four No. 2 Mines, as mapped by Young, Malan, and Gray (1964).

F2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool to give the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility are discussed in the Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

F2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of the mines and at the mine sites. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining Big Four No. 2 Mine ore body, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed in the main report, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. The fresh oxidizing water likely infiltrates the waste rock at the surface and ore deposits in the subsurface when seasonal rainwater, although minimal, infiltrates rapidly from the surface, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways directing water to the remnant ores, the Big Four No. 2 Mine ore body has been extensively mined (as much as 87 percent), depleting it of the highest grade ore and most of its mass; organic matter is also destroyed as water flows through the mine workings at Big Four No. 2 Mine. Uneroded ore deposits, as mapped on Figure 7, near and downstream

of the mine may provide more uranium- and organic-rich rock and sediment through which fresh water infiltrates to mobilize and transport uranium.

F2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend to the north-northwest as the washes and ephemeral creek beds do. Based on artesian conditions at well 8T-525 and water levels of nearby wells observed during the 1991 sampling, the noted groundwater influx during mining at the Big Four No. 2 Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface (Figure 22); surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit. However, organics (carbonaceous material) and pyrite in the rocks create a reducing environment, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 22). Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Uranium adsorbs onto clays in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the mass of uranium in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water samples suggest that uranium may be leaching downstream from the Big Four No. 2 Mine (as evidenced by a uranium concentration of 171.93 pCi/L in the water sample from well 8K-433 that is downgradient of the mine). However, well 8K-433 is also immediately adjacent to the larger uranium mines, Sunlight and South Sunlight, and is located above the wash; uranium in water from the well are more likely to be from the closer mines. No analytical data for surface water features are available for any points between Big Four No. 2 Mine and the two Sunlight Mines. It is very possible that the increased uranium concentrations detected at well 8K-433 are influenced more by leaching from the Sunlight Mines; however, without more information Big Four No. 2 Mine cannot be ruled out as a contributing source.

F2.2.3. Groundwater Pathway Conclusion

The Shallow Well El Capitan is outside the 4-mile radius of the Big Four No. 2 Mine, as is the spring 08A-220 (8A-P.H.S.-22 Spring). Well 8T-525, is outside the 1-mile radius of the mine, and concentrations of radioactive metals are less than MCLs. Well 8K-433 is at the 1-mile radius of the mine, and concentrations of radioactive metals are greater than MCLs. No analytical data are available for any wells within a 0.25-mile radius of the mine. None of the wells are intended to be used for drinking water, but community feedback has confirmed that the wells are being used (EPA, 2009b). Uranium was detected in the shallow water source (well 8K-433) downgradient of the mine but above the wash at a concentration exceeding the MCL; this is the water source expected to be most influenced by the Big Four No. 2 Mine if it is the same drainage. However, it is also the well immediately adjacent to the Sunlight and South Sunlight Mines, which are likely to be greater influences than Big Four No. 2 Mine.

Radioactive metals are detected in samples collected from the spring 08A-220 (8A-P.H.S.-22 Spring); however, the concentrations were less than the MCLs. This spring is upgradient to all of the AUMs that occur below the water table (EPA, 2007c), confirming that uranium is migrating into groundwater from uneroded channel deposits because no known AUMs are located upgradient of this spring.

No analytical data for surface water features are available for any points between Big Chief Mine and the two Sunlight Mines.

F2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Big Four No 2 enters a drainage system in the Oljeto watershed, including the El Capitan Wash and the Oljeto Wash. The El Capitan Wash runs just east of the mines toward the northwest and meets up with the Oljeto Wash northwest of the Big Four No. 2 Mine. The Oljeto Wash continues for approximately 20 miles until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during brief seasonal rainstorms, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid

environments, evaporation is quick, and water, limited in volume because most runs off at the surface infiltrates quickly through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds and adsorption of uranium to clays and organics is likely given the pH range of rainwater.

F2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash or the Oljeto Wash near the mines or within 15 miles downstream of the mines (NNEPA, 2006).

F2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Big Four No. 2 Mine for the following reasons:

- Most of the known contamination is confined to the mine, and the contamination that may be attributable to the mines has been found at concentrations less than the respective MCLs or are more likely attributable to the Sunlight and South Sunlight Mines, based on relative locations and elevations.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mine.

F2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during this period. The Big Four No. 2 Mine is within the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined in this region, primarily from channel deposits of the Shinarump Member of the Chinle Formation. The channel deposit at the Big Four No. 2 Mine is approximately 200 feet wide and 100 feet below ground surface and is hosted by medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The Big Four No. 2 Mine was listed by EPA as productive AUM (EPA, 2007c) that has workings below the water table or was considered a wet mine that required pumping.

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Big Four No 2 Mine is located along a drainage system (part of the El Capitan Wash) that runs approximately southeast to northwest.

The following are pertinent HRS factors for the Big Four No. 2 Mine:

- According to aerial radiation surveys for bismuth-214 (a decay product of uranium), slightly elevated uranium concentrations (between 2.4 to 7.4 $\mu\text{R/hr}$) at the surface are confined to the areas immediately around the Big Four No. 2 Mine; the mine was reported to be reclaimed (Chenoweth, 1994b).
- Soils are typified by rapid infiltration, but limited, fresh rainwater infiltrates only during very infrequent thunderstorms; the oxidizing rainwater that infiltrates through mine wastes and soils leaches uranium from these materials, and the uranium adsorbs readily to clays and residual organics because the pH of rainwater is optimal for adsorption.
- The concentrations of uranium in samples collected from water sources (wells) downgradient and along the same drainage of the mine were greater than laboratory reporting limits but were less than MCLs.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Big Four No. 2 Mine.

Appendix G. Big Chief Mine Groundwater Pathway Assessment

Appendix G
Big Chief Mine
Groundwater Pathway Assessment

April 2010

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Section G1. Mine and Groundwater Investigation

G1.1. LOCATION OF ABANDONED URANIUM MINE

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). One of these AUMs, the Big Chief Mine, is located in the North Central Region of the Navajo Nation, in Navajo Nation District 8. Geographically, it is located on the South El Capitan Flat in the Monument Valley Mining District (Figure 6). It is approximately 15 miles north of the junction of U.S. Highways 163 and 160 in Kayenta, Arizona.

G1.1.1. Local Hydrogeology

The Big Chief Mine is located in the San Juan subregion in the Upper Colorado watershed, specifically in the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley area surrounding the mine is 6 to 8 inches (see Average Annual Precipitation map for Monument Valley Area Map in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the mine is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for North Central Region in Appendix A). The moderately coarse soils are moderately deep to deep and moderately well- to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and produces more runoff than infiltration.

Aquifer sensitivity in the area around the mine ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

The Big Chief Mine is located along part of the El Capitan Wash that runs approximately southeast to northwest.

G1.2. MINE BACKGROUND

El Capitan Flat on the eastern side of Oljeto Wash in Monument Valley is covered by a large sand dune; Oljeto Wash roughly follows the axis of the Oljeto syncline. The dune sand is underlain by the Upper Triassic Chinle Formation. Rocks of the Chinle Formation dip approximately 5 degrees to the west into the Oljeto syncline (Chenoweth, 1992b).

The ore bodies at the Big Chief Mine were formed in a paleochannel deposit in the basal portion of the Shinarump Member of the Chinle Formation. The channel scoured into the underlying Middle Triassic Moenkopi Formation and was filled with medium- to coarse-grained sandstone and conglomerate, and carbonaceous plant materials are distributed abundantly in the sediments. The channel is approximately 300 feet wide and approximately 50 feet deep (Chenoweth, 1992b).

Uraninite was the principle uranium mineral mined at the Big Chief. Copper sulfides, such as chalcocite, bornite, and chalcopyrite, were also present in the ore. Oxidized copper minerals made up less than 5 percent of the total copper content of the ore, and calcium carbonate (CaCO_3) in the ore averaged less than 6 percent. The deposit was unoxidized because of the presence of a perched water table in the basal Shinarump conglomerate (Chenoweth, 1992b).

As with other mines in the region, uranium was extracted from the Shinarump Member of the Chinle Formation at the Big Chief Mine under wet conditions because of perched water at the AUM. During development of the Big Chief Mine, groundwater entered the mine at a rate of 80 gallons per hour (Chenoweth, 1992b).

G1.2.1. Production History

The Big Chief Mine operated between 1959 and 1961. The reserves of the ore bodies on Big Chief claims were estimated at approximately 38,000 tons. Between 1959 and 1961, approximately 32,834 tons of ore (151,221 pounds of U_3O_8) was extracted, which would be approximately 86 percent of the estimated reserves.

Mine development began in 1958 with installation of a 470-foot-long, 19-degree decline into the westernmost ore body identified during exploratory drilling. During active mining, a modified room-and-pillar method with on-level ore haulage along the working face was used to mine the ore; underground long-hole drilling continued to locate ore ahead of the working faces. Mining continued through 1960 at a rate of approximately 1,500 tons per month, and the grade of the mined ores averaged 0.24 percent U_3O_8 . Mining continued at a decreased rate during 1961; however, only 7,223.48 tons of ore, with an average grade of 0.20 percent U_3O_8 , was mined. The mine was closed in December 1961 after the economic ore had been mined out. All of the ore was processed at the TZM Mill at Mexican Hat (Chenoweth, 1992b).

G1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

G1.3.1. Aerial Radiation Contours

In 2000, the EPA produced the “Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas,” herein referred to as the “Project Atlas” (EPA, 2000a). The results of data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory are included in the Project Atlas. The data are presented on contour maps of excess bismuth-214.

Bismuth-214 radiation is associated with uranium decay, and excess bismuth activity is a good indicator of the presence of old mines and mining-related activities. The levels of bismuth-214 levels on a map of radiation contour levels near the Big Chief Mine range from 3.5 to 23.6 $\mu\text{R/hr}$ and are higher than surrounding areas (see Bismuth-214 Flyover Polygons maps for North Central Region in Appendix A; EPA, 2007c).

G1.3.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) studied the Monument Valley and Cameron Mining Districts. Data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were measured in October 1991 (Longworth, 1994) from the following wells near the Big Chief Mine:

- 8K-433 (formerly Tank 8A-299)
- 8T-525
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Maps for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Maps for North Central Region in Appendix A)

These wells are located along the El Capitan Wash that runs from higher elevations in the southeast (unnamed 4-inch well and 8K-433) to lower elevations in the northwest (unnamed 6-inch well and 8T-525; Figure 8). The Big Chief Mine is located at slightly high elevation to the east of the wash. Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions at the 8T-525), indicating a southeast to northwest gradient along drainage (Figure 8).

The Big Chief Mine shaft is at 5,187 feet above msl, and well 08-0636, immediately to the west of the mine along the El Capitan Wash, is at 5,090 feet above mean sea level. Based on topography, runoff near and from the mine is likely to flow to northwest into the wash.

G1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Samples were collected in the Monument Valley by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. Limited or no information on well development is available because the wells are unregulated sources of water, and groundwater samples are not collected regularly. Available analytical results summarized below are from limited grab groundwater samples.

As stated above, water in unregulated sources of water in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, "either for cultural reasons, or because they prefer the taste" (Keller, 2007). It is hard for people to abandon using them because these sources may have been used historically for drinking water (Keller, 2007).

G1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected a groundwater sample from well 8T-525. The pH of the sample was measured at 7.5. Uranium-238, uranium-234, and uranium-235 concentrations were 0.50 picoCuries per liter (pCi/L), 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 micrograms per liter ($\mu\text{g/L}$) (Longworth, 1994). The results were all less than the applicable maximum contaminant levels (MCLs), and uranium concentrations were less than the estimated MCL of 20 pCi/L (based on the EPA MCL of 30 $\mu\text{g/L}$ and conversion of 0.67 picocuries per microgram).

G1.3.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source for human consumption, and samples were collected as a point-of-use sample to duplicate the most likely method in which people would obtain water. Concentrations of total uranium (sum of isotopes uranium-234, uranium-235, and uranium-238) in three samples collected in the North Central Region were greater than the estimated MCL of 20 pCi/L:

- The concentration of uranium in the sample from Baby Rock Spring 8-44 collected in September 1998 was 36.29 pCi/L
- The concentration of uranium in the sample Monument Pass Well collected in January 2000 was 40.00 pCi/L
- The concentration of uranium in the sample Tank 8A-299 collected in September 1998 was 171.93 pCi/L

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley. Well 8K-433 is categorized as a windmill well, and, although it is not regulated for human consumption, locals indicate that the well is being used for drinking water and for watering livestock (EPA, 2009b).

In September 1998, water samples were collected by USACE at 8K-433 (formerly Tank 8A-299), well 8T-525, and spring 8A-P.H.S.-22-Spring. Well 8K-433 is located approximately 1.2 miles downstream of the Big Chief Mine, above the El Capitan Wash and adjacent to the Sunlight and Sunlight South Mines. Well 8T-525 is located approximately 3 miles northwest and downstream of the Big Chief Mine. Spring 8A-P.H.S.-22-Spring (08A-220) is approximately 6 miles upstream of Big Chief Mine (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c).

USACE collected the groundwater sample from well 8K-433 at an elevation of 5,100 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 155.00 pCi/L, which exceeded the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8K-433 at concentration of 171.93 pCi/L, which exceeded the estimated MCL of 20 pCi/L. Groundwater was collected from well 8T-525 at an elevation of 5,011 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 1.59 pCi/L, which was less than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at concentration of 1.68 pCi/L, which was less than the estimated MCL of 20 pCi/L. USACE collected the groundwater sample from spring 8A-P.H.S.-22-Spring (08A-220 on Surface Water Features Map for North Central Region in Appendix A) at an elevation of 5,257 feet above msl; the pH of the sample was 8.28. Gross alpha (dissolved) as natural uranium was 1.95 pCi/L, which was less than the EPA MCL of 15 pCi/L (EPA, 2000b). Total uranium was detected in water sample from 8A-P.H.S.-22-Spring at a concentration of 3.70 pCi/L, which was less than the estimated MCL of 20 pCi/L.

G1.3.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample within the North Central region. Gross alpha was present in the sample at 25.7 pCi/L, which exceeded the EPA MCL of 15 pCi/L. Well 08T-522 from which the sample was collected is not located within 4 miles of the Big Chief Mine.

G1.3.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 $\mu\text{g/L}$ and 40.9 pCi/L, respectively. Both of the concentrations exceeded the respective MCLs of 30 $\mu\text{g/L}$ and 15 pCi/L. This well is above the El Capitan Wash and immediately adjacent to the larger mines, Sunlight and South Sunlight. Thus, increased concentrations may be mostly associated with the Sunlight and South Sunlight Mines. The Big Chief Mine shaft is at an elevation of 5,187 feet above msl, and the ore bodies are at an average depth of 150 feet below ground surface (EPA, 2009d), suggesting the ore bodies were approximately below 5,030 feet. The elevation of well 8K-433 is 5,100 feet above msl; the total depth of the well is 46 feet below ground surface (EPA, 2009d), suggesting the well is higher than the main ore bodies.

G1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels in the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at the Big Chief Mine do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. These undisturbed deposits would be expected to also contain extensive organic material and sulfides in the channel deposits associated with the uranium deposition.

G1.5. MINED URANIUM DEPOSITS

Based on estimated size of the ore reserve at the mine, uranium ore deposits at the Big Chief Mine were significantly mined (approximately 86 percent). The economic ore was mined out (Chenoweth, 1992b), and the remaining uranium ore is lower in grade and likely scattered along the periphery of the original ore body (Figure 22). Mining would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when operations began at the mine might have leached uranium and also destroyed organic material and sulfides, as would mining operations. During mining operations in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a; Figure 22).

According to geologic studies, the Big Chief deposit is in the same paleochannel as the Firelight No. 6 and Alma-Seegan Mines to the South. This channel merges to the northwest with the channel in which the Bootjack and Big Four No. 2 Mines are hosted at the site of the South Sunlight Mine (Chenoweth, 1997a).

Section G2. Hazard Ranking System and Summary

G2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, groundwater and surface water migration was initially investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is a hazardous substance, in this case, uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Big Chief Mine include, but are not limited to:

- Disturbed soils and mine workings at the surface in which uranium occurs are indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Big Chief Mine.

Additional potential sources of hazardous substances not associated with the Big Chief Mine but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in the channel sediments within the Shinarump Member of the Chinle Formation in the area surrounding the Big Chief Mine as mapped by Young, Malan, and Gray (1964).

G2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility are discussed in the Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

G2.2.1. Rainwater Infiltration

The average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of the mine and at the mine site. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics apply to the remaining Big Chief Mine ore bodies and the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Based on the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing water likely infiltrates the waste rock at the surface, as well as ore deposits beneath the surface, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways, the Big Chief ore body has been extensively mined, depleting the highest grade ore and probably destroying organic matter during water influx throughout mining operations at Big Chief Mine. Uneroded ore deposits, as mapped on Figure 7, near and downstream of the mine may provide more uranium- and organic-rich rock and sediment through which fresh water infiltrates to mobilize and transport uranium.

G2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography, and as such, will likely trend to the northwest similar to the washes and ephemeral creek beds in the region. Based on artesian conditions at well 8T-525 and water levels of nearby wells observed during the 1991 sampling, the noted groundwater influx during mining at the Big Chief Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface (Figure 22); surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit. However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 22). Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Uranium adsorbs onto clays and organics in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the volume of uranium distributed in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water sampling are inconclusive regarding leaching of uranium from the Big Chief Mine because multiple sources (other mines in the region) may impact the water in locations where water samples have been collected. Uranium in the water samples collected downstream suggests the possibility of an upstream uranium source; the Big Chief Mine is a possible upstream source of uranium in the water.

G2.2.3. Groundwater Pathway Conclusion

Well 8K-433 is located approximately 2.25 miles downstream of the Big Chief Mine, and the concentrations of radioactive metals in samples collected near the mine exceeded MCLs. While analytical results of samples collected downstream from the mine may suggest that uranium may be leaching from Big Chief Mine (as evidenced by a uranium concentration of 171.93 pCi/L in the water sample from well 8K-433 downgradient of the mine), well 8K-433 is also immediately adjacent to the larger uranium mines, Sunlight and South Sunlight, and is located above the wash; concentrations of uranium in water samples from the well are more likely to be from the closer mines. As mentioned

above, the total well depth elevation for 8K-433 and for the Big Chief ore bodies suggests the well is higher than the main ore bodies and is probably not as influenced by uranium migration from the ore body, although the surface waste rock may still provide source of uranium migration to the underlying groundwater.

Radioactive metals are in the water source 08A-220 (8A-P.H.S.-22 Spring); however, the concentrations of these metals were less than the MCLs. This spring is upgradient to all of the AUMs that are below the water table (EPA, 2007c), confirming that uranium migrated into groundwater from uneroded channel deposits because no known AUMs are located upgradient of this sample location. Well 8T-525 is also located within a 4-mile radius of the Big Chief Mine, but concentrations of radioactive metals are less than applicable MCLs. None of the wells is intended to be used as drinking water wells, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009a). Well 8K-433 is the water source expected to be most influenced by the Big Chief Mine.

No analytical data for surface water features are available for any points between Big Chief Mine and the Sunlight and South Sunlight Mines.

G2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Big Chief Mine enters the El Capitan Wash, which flows in northwesterly direction. The elevation of the wash is approximately 120 feet lower than the elevation at the top of the mine shaft. The El Capitan Wash continues in a north-northwesterly direction until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is fast but limited through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds, and adsorption of uranium to clays and organics is likely given the pH range of rainwater.

G2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash within the vicinity of the mine or within 15 miles downstream of the mine (NNEPA, 2006).

G2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Big Chief Mine for the following reasons:

- Although the concentrations of radioactive metals in samples of groundwater collected downgradient of the mine exceeded their respective MCLs, it is likely that the contamination is from multiple sources, particularly from the Sunlight and South Sunlight Mines. Given that most of the ore body was removed from the mine during active mining, it is unlikely that the Big Chief Mine is a major contributor to the combined source.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site

G2.5. SUMMARY

The Big Chief Mine is in the North Central Region, specifically the Monument Valley Mining District. Uranium was mined primarily from paleochannel deposits of the Shinarump Member of the Chinle Formation. The channel deposit at the Big Chief Mine is approximately 300 feet wide and 50 feet deep, composed of medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The Big Chief Mine was listed by the EPA as a productive AUM (EPA, 2007c) that had workings below the water table or was considered a wet mine that required pumping.

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Big Chief Mine is located along the El Capitan Wash that runs approximately southeast to northwest.

The following are pertinent HRS factors for the Big Chief Mine:

- According to aerial radiation surveys for bismuth-214 (a decay product of uranium), elevated uranium concentrations at the surface are confined to the areas around the Big Chief Mine.
- Soils typified by rapid infiltration but only during very infrequent precipitation events; normal rainwater pH is conducive to adsorption of the uranium that is released into solution with introduction of oxidized rainwater onto abundant inorganic and organic matter in channel deposits.

- Radioactive metals were detected in samples collected from water sources downgradient of the mine at concentrations that exceeded their respective MCLs; however, it is not possible to isolate the Big Chief Mine as the source of the radioactive metals because other sources close by are more likely. Uranium concentrations in the downgradient well closest to the Big Chief Mine (approximately 2.25 miles downgradient) are higher than those in wells upgradient and those farther downgradient of the mine (approximately 3.75 south of the mine). This suggests that uranium is migrating from mines in the area but is more likely to be influenced by uranium at Sunlight and South Sunlight Mines. The water sources in the vicinity of the Big Chief Mine are not regulated; however, records indicate that some may be used for watering livestock or human consumption.
- Elevations of the well 8K-433 and the ore bodies at Big Chief Mine suggest the bottom of the well is higher than the main ore bodies, and water in this well is less likely to be influenced by underground mine workings at Big Chief Mine.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Big Chief Mine.

Appendix H. Bootjack Mine Groundwater Pathway Assessment

Appendix H
Bootjack Mine
Groundwater Pathway Assessment

April 2010

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Section H1. Mine and Groundwater Investigation

H1.1. MINE LOCATION

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that uranium ore deposits in 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). The 31 AUMs are found in the Eastern and North Central Regions of the investigation areas. One of these AUMs, the Bootjack Mine, is located in the North Central Region, 4 miles south of the Utah and Arizona border, and 13 miles north of Kayenta, Arizona. This AUM is located within the El Capitan Flat of the Monument Valley Mining District (Figure 6).

H1.1.1. Local Hydrogeology

The Bootjack Mine is in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley around the mine is 6 to 8 inches (see the Average Annual Precipitation Map for Monument Valley Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the mine is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well- to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and often produces more runoff than infiltration.

Aquifer sensitivity in the area around the mine has intermediate potential for contaminant migration upgradient and downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Bootjack Mine is located along the El Capitan Wash that runs approximately south to north. One well, 08T-525, is shown in EPA's geographic information system geospatial database

as being located along this section of the drainage, downstream of the mine (see the Surface Water Features Map for North Central Region in Appendix A; EPA, 2007c); samples were collected from well 08T-525 in 1991 and 1998. No wells are located upstream of Bootjack Mine.

H1.2. DETAILED MINE BACKGROUND

Uranium ore deposits are formed in the basal Shinarump Member of the Chinle Formation; the Shinarump is a fluvial channel deposit. The rocks of the Chinle Formation dip approximately 5 degrees to the west near the Bootjack Mine. The channel deposit at the Bootjack Mine is approximately 300 feet wide, is at a maximum depth of approximately 100 feet, and is composed of medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the sediments (Chenoweth, 1993). The channel at the Bootjack Mine heads east-west but then takes a sharp bend north-south (Figure H-1). Uranium ore occurs along the southern flank of the channel deposits (Chenoweth, 1993).

H1.2.1. Bootjack Ore Deposits

The water table in the Shinarump is perched, and ore deposits are unoxidized. The deepest ore deposits at the Bootjack Mine were 400 feet below ground surface, and the highest groundwater flow rate into the mine shaft was 500 gallons per minute. Uraninite (uranium oxide) was the principal uranium mineral; uraninite was accompanied by montrosite (vanadium oxide) and copper sulfides, such as bornite, chalcocite, and chalcopyrite. The host rocks were principally sandstone, cemented with calcium carbonate (Chenoweth, 1993).

Drilling in the area of the Bootjack Mine delineated an estimated 39,000 tons of uranium ore, averaging 0.80 percent U_3O_8 , 380 feet below ground surface, and 9.5 feet in thickness. When the Bootjack Mine was closed in late 1966, it had produced 36,236 tons of ore (Chenoweth, 1993). Based on the estimated size of the ore body, approximately 93 percent of the projected ore at Bootjack Mine was mined

Bootjack Mine was the deepest uranium ore mine in the region and had the highest groundwater flow. In 1959, groundwater flowed in the workings of the mine at an average rate of 200 gallons per minute; and by 1965, a year before the mine was abandoned, the flow rate of groundwater into the mine was recorded to be 500 gallons per minute. The water was collected in the shaft sump and pumped to an evaporation pond on the surface. The pond was located approximately 800 feet to the northeast of the mine shaft opening (Figure H-1; Chenoweth, 1993).

Other than the evaporation pond, no specific mine waste features were noted for the Bootjack Mine during EPA's assessment (EPA, 2007c). Bootjack Mine has been reclaimed, and no waste piles surround the mine (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c). However, a former mine pond was delineated, as shown on Figure H-1. Although mines in the area were

often open pits, the Bootjack ore body was 380 feet below ground surface, and a shaft was sunk to 437 feet to mine the ore (Chenoweth, 1993).

H1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

H1.3.1. Aerial Radiation Contours

In 2000, EPA produced the “Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas,” herein referred to as the “Project Atlas” (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley area was created from data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory. The contour map is included in the Project Atlas. The aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. The bismuth-214 radiation (up to 5.2 microRoentgens per hour [$\mu\text{R/hr}$]) on a map of the aerial radiation contour values in the Project Atlas is higher for the Bootjack Mine than for the immediate surrounding area. Similar values are shown for an area southeast of Bootjack Mine and for the Joe Rock #7-9 Mines to the southwest of Bootjack Mine (see Bismuth-214 Flyover Polygons Maps for North Central Region in Appendix A; EPA, 2007c). Elevated excess bismuth-214 corresponds with the evaporation pond formerly containing water pumped from the Bootjack Mine (Figure H-2; EPA, 2007c).

H1.3.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) conducted a study in the Monument Valley and Cameron Mining Districts. Site data were collected for shallow water sources, mine drill holes, wells, and auger holes. The nearest wells to Bootjack Mine are downstream and between 2 to 4 miles from the mine. Depths to groundwater were collected in October 1991 from the following wells:

- 8T-525
- 8K-433
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Maps for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Maps for North Central Region in Appendix A)

The wells are located along the same drainage, running from southeast at higher elevations (unnamed 4-inch well and 8K-433) to northwest at lower elevations (unnamed 6-inch well and 8T-525; Figure 8). Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed

6-inch well; and greater than 5,026 feet above msl (artesian conditions) at well 8T-525, indicating a southeast to northwest gradient along drainage. Although the wells are not in the immediate vicinity of the mine, based on the topography of area, groundwater most likely flows from Bootjack Mine to the northeast until it joins groundwater in other washes near Big Four No. 2 Mine and continues as described above in a northwest direction.

H1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Samples have been collected in the Monument Valley Area by USGS in 1991, U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. Limited or no information on well development is available, and groundwater samples are not collected regularly because the wells are unregulated. Available analytical results summarized below are from limited grab groundwater samples.

As stated above, water from unregulated sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). Since these sources may have been historically used for drinking water purposes, it is hard for people to abandon using them (Keller, 2007).

H1.3.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected a groundwater sample from well 8T-525. The pH of the sample was measured at 7.5. Uranium-238, uranium-234, and uranium-235 concentrations were 0.50 picoCuries per liter (pCi/L), 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 micrograms per liter ($\mu\text{g/L}$) (Longworth, 1994). The results were all less than the maximum contaminant levels (MCLs), and uranium concentrations were less than the estimated MCL of 20 pCi/L (based on the EPA MCL of 30 $\mu\text{g/L}$ and conversion of 0.67 picocuries per microgram).

H1.3.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source of water for human consumption, and samples were collected as a point-of-use sample designed to duplicate the most likely method in which people would obtain water. The concentrations of total uranium in three water samples collected in the North Central Region were greater than the estimated MCL of 20 pCi/L:

- The concentration of total uranium in one sample (Baby Rock Spring 8-44) was 36.3 pCi/L.
- The concentration of total uranium in one sample (Monument Pass Well) collected in January 2000 was 40.0 pCi/L.
- The concentration of total uranium in one sample (Tank 8A-299) collected in September 1998 was 171.9 pCi/L.

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley Area. Well 8K-433 is categorized as a windmill well, and, although it is not regulated for human consumption, locals indicate that the well is being used for drinking water and for watering livestock (EPA, 2009b).

In September 1998, USACE collected water samples from well 8K-433 (formerly Tank 8A-299), well 8T-525, and spring 8A-P.H.S.-22-Spring. Well 8K-433 is located approximately 2.9 miles downstream of the Bootjack Mine, above the El Capitan Wash and adjacent to the Sunlight and Sunlight South Mines. Well 8T-525 is located approximately 4 miles northwest and downstream of the Firelight No. 6 Mine. Spring 8A-P.H.S.-22-Spring (08A-220) is approximately 4.3 miles upstream of Firelight No. 6 Mine (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c).

USACE collected the groundwater sample from well 8K-433 at an elevation of 5,100 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 155.00 pCi/L, which exceeded the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8K-433 at concentration of 171.93 pCi/L, which exceeded the estimated MCL of 20 pCi/L. A groundwater sample was collected from well 8T-525 at an elevation of 5,011 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 1.59 pCi/L, which was less than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at concentration of 1.68 pCi/L, which was less than the estimated MCL of 20 pCi/L. USACE collected the groundwater sample from spring 8A-P.H.S.-22-Spring (08A-220 on Surface Water Features Map for North Central Region in Appendix A) at an elevation of 5,257 feet above msl; the pH of the sample was 8.28. Gross alpha (dissolved) as natural uranium was 1.95 pCi/L, which was less than the EPA MCL of 15 pCi/L (EPA, 2000b). Total uranium was detected in the water sample from 8A-P.H.S.-22-Spring at a concentration of 3.70 pCi/L, which was less than the estimated MCL of 20 pCi/L.

H1.3.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample within the North Central Region. Gross alpha was present at 25.7 pCi/L, which exceeded the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not within 4 miles of the Bootjack Mine.

H1.3.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 $\mu\text{g/L}$ and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 $\mu\text{g/L}$ and 15 pCi/L. This well is above the El Capitan Wash, immediately adjacent to the larger mines, Sunlight and South Sunlight, and is almost 3 miles from the Bootjack Mine. Thus, increased concentrations may be mostly associated with the Sunlight and South Sunlight Mines.

H1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels in the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Bootjack Mine do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mine. Organic materials and sulfides might also be extensive in these undisturbed deposits in the channel deposits associated with the uranium deposition.

H1.5. MINED URANIUM DEPOSITS

Based on the estimated size of the ore bodies at the mines, uranium ore deposits at the Bootjack Mine were significantly mined (93 percent). The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body (Figure 22). Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when operations began at the site might have destroyed organic material and sulfides, as would mine operations. During mining operations in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Geologic studies confirm that the Bootjack deposit is in the same paleochannel as one in which the Big Four No. 2 Mine is hosted to the north. This channel merges to the north with the channel in which the Big Chief, Firelight No. 6, and Alma-Seegan Mines at the site of the South Sunlight Mine (Chenoweth, 1997b) are hosted.

Section H2. Hazard Ranking System and Summary

H2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, groundwater and surface water migration was initially investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Bootjack Mine include, but are not limited to:

- Uranium in disturbed soils and mine workings at the surface is indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for the soil exposure pathway (EPA, 2007b). In addition, the evaporation pond for mine water exhibited elevated levels of bismuth-214 radiation (Figure H-2); see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Bootjack Mine.

Additional potential sources of hazardous substances not associated with the Bootjack Mine but found in the immediate area include:

- Undisturbed and uneroded ore deposits in the channel sediments within the Shinarump Member of the Chinle Formation in the area near the Bootjack Mine, as mapped by Young, Malan, and Gray (1964).

H2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering) because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact, as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility are discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

H2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of the mine and at the mine site. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps in Appendix A). These characteristics are applicable to the remaining Bootjack Mine ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed above in Subsection H2.1, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. The fresh oxidizing water that is minimal in volume, yet infiltrates rapidly likely infiltrates the waste rock at the surface, as well as the ore deposits beneath the surface, destroying organics and oxidizing sulfides, facilitating leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although open spaces associated with the mines provide preferential pathways, the Bootjack ore body has been extensively mined (as much as 93 percent), depleting it of the highest grade ore, other sulfide minerals, and organic matter during water influx throughout the workings. Uneroded ore deposits, as mapped on Figure 7, near and downstream of the mine may provide more uranium-, sulfide-, and organic-rich rock and sediment through which fresh water infiltrates to mobilize and transport uranium.

H2.2.2. Groundwater Flow

Groundwater flow has not been directly measured in the area; however, it is common for groundwater to follow topography, so groundwater will likely trend to the north-northwest along the washes and ephemeral creek beds. Based on artesian conditions at well 8T-525 and water levels of nearby wells observed during the 1991 sampling, the noted groundwater influx during mining at the Bootjack Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface (Figure 22); surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit (Figure 22). However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally. Additionally, crossbedding, secondary calcium carbonate cementation (which can raise pH, slowing adsorption but causing precipitation), and clays within the sandstone may impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the volume of uranium distributed in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water samples suggest that, while upstream uranium may be leaching extensively from other ore deposits or mines (as evidenced by a uranium concentration of 171.9 pCi/L in the upgradient water sample from well 8K-433), leaching through the Bootjack Mine is limited (as evidenced by the downstream water sample concentration of 1.68 pCi/L from well 8T-525). Although uranium is being leached from the mines, secondary deposition and adsorption is probably keeping most of the uranium within the mined areas. Additionally, the concentration of uranium in a water sample collected farther downstream at the Shallow Well El Capitan was slightly higher at 10.48 pCi/L, which suggests uranium is leaching into groundwater either from unmined ore deposits or other AUMs farther downstream or from adjacent drainages (Figure 22).

H2.2.3. Groundwater Pathway Conclusion

Well 8K-433 is outside a 1-mile radius of the mine and is downstream from the mine, positioned so that groundwater flow could potentially affect water in the well (see the Combined Pathway-Oljetto Map in Appendix A). Analytical results of samples collected from wells downstream from the Bootjack Mine suggest that uranium may be leaching (as evidenced by a uranium concentration of 171.93 pCi/L in the water sample from well 8K-433 downgradient from the mine). However, well 8K-433 is immediately adjacent to the larger uranium mines (Sunlight and South Sunlight) and is located above the wash, and concentrations of uranium in water samples from the well are more likely to be from the closer mines. Well 8K-433 is adjacent to the Sunlight Mine and is downstream from well 08-0636. Well 08-0636, the downgradient well closest to the mine, is located 2 miles downstream of the mine, but samples have not been collected from it. Based on the location of the well, uranium detected in well 8K-433 most likely originates from Sunlight Mine, South Sunlight Mine, or an unmined uranium deposit. None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that some of the wells are being used for drinking water (EPA, 2009b).

H2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Bootjack Mine enters a drainage in the Oljeto watershed, which includes the El Capitan Wash and the Oljeto Wash. The El Capitan Wash runs north of the mine toward the northwest and meets up with the Oljeto Wash just west of the Starlight Mine. The Oljeto Wash continues for approximately 20 miles until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is fast but limited through dry and porous soil because most precipitation falls as brief thunderstorms and runs off. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds, and adsorption of uranium to clays and organics is likely given the pH range of rainwater.

H2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash or the Oljeto Wash near the mine or within 15 miles downstream of the mine (NNEPA, 2006).

H2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Bootjack Mine for the following reasons:

- Although the concentrations of radioactive metals in samples collected from wells downgradient of the mine exceeded their respective MCLs, it is likely that this contamination is from the Sunlight and South Sunlight Mines, not the Bootjack Mine. Given the distance and conditions at the mine, it is unlikely that the Bootjack Mine contributes uranium to water in this well.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site

H2.5. SUMMARY

The Bootjack Mine is located in the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined in this region, primarily from channel deposits of the Shinarump Member of the Chinle Formation. The channel deposit at the Bootjack Mine is approximately 300 feet wide and approximately 100 deep and is composed of medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The ore of the Bootjack Mine occurs along the southern banks of the channel. The Bootjack Mine was listed by EPA as a productive AUM (EPA, 2007b) that has workings below the water table or was considered a wet mine that required pumping.

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Bootjack Mine is located along the El Capitan Wash that runs approximately southwest to northeast, then northwest.

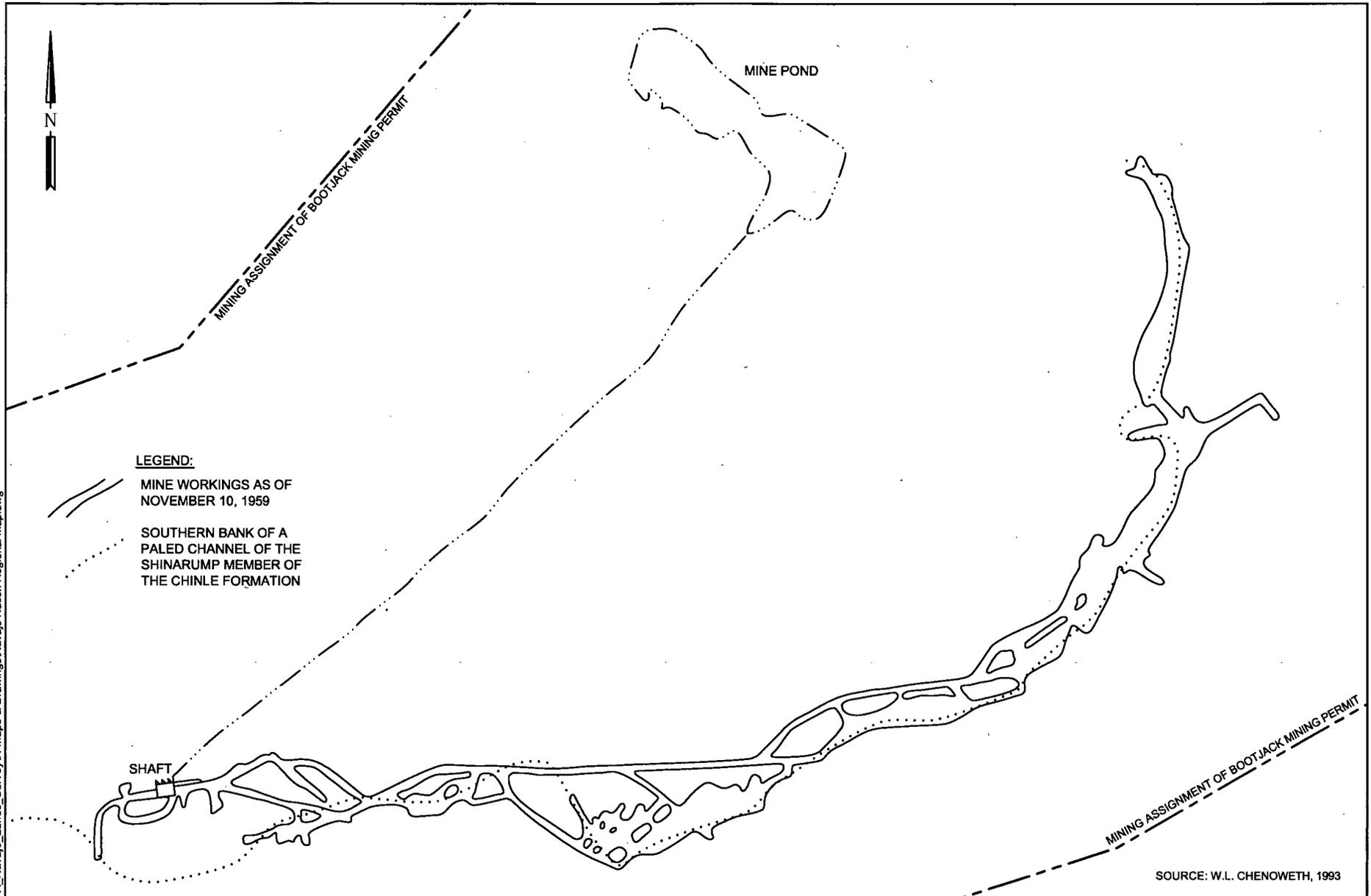
The following pertinent HRS factors are associated with the Bootjack Mine:

- Aerial radiation surveys for bismuth-214 (a decay product of uranium) identify elevated uranium concentrations at the surface confined to the areas immediately around the Bootjack Mine and the location of the former evaporation pond used for processing mine water.

- Uranium was detected in samples collected from water sources (wells) downgradient of the mine (approximately 3 miles north of Bootjack Mine) at concentrations greater than MCL; however, it is likely that this contamination is from the Sunlight and South Sunlight Mines, not the Bootjack Mine, given the distance and conditions at the mine;
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Bootjack Mine.

Figures

P:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Navajo Nation Regional Map.dwg



LEGEND:

MINE WORKINGS AS OF NOVEMBER 10, 1959

SOUTHERN BANK OF A PALED CHANNEL OF THE SHINARUMP MEMBER OF THE CHINLE FORMATION

SHAFT

MINE POND

MINING ASSIGNMENT OF BOOTJACK MINING PERMIT

MINING ASSIGNMENT OF BOOTJACK MINING PERMIT

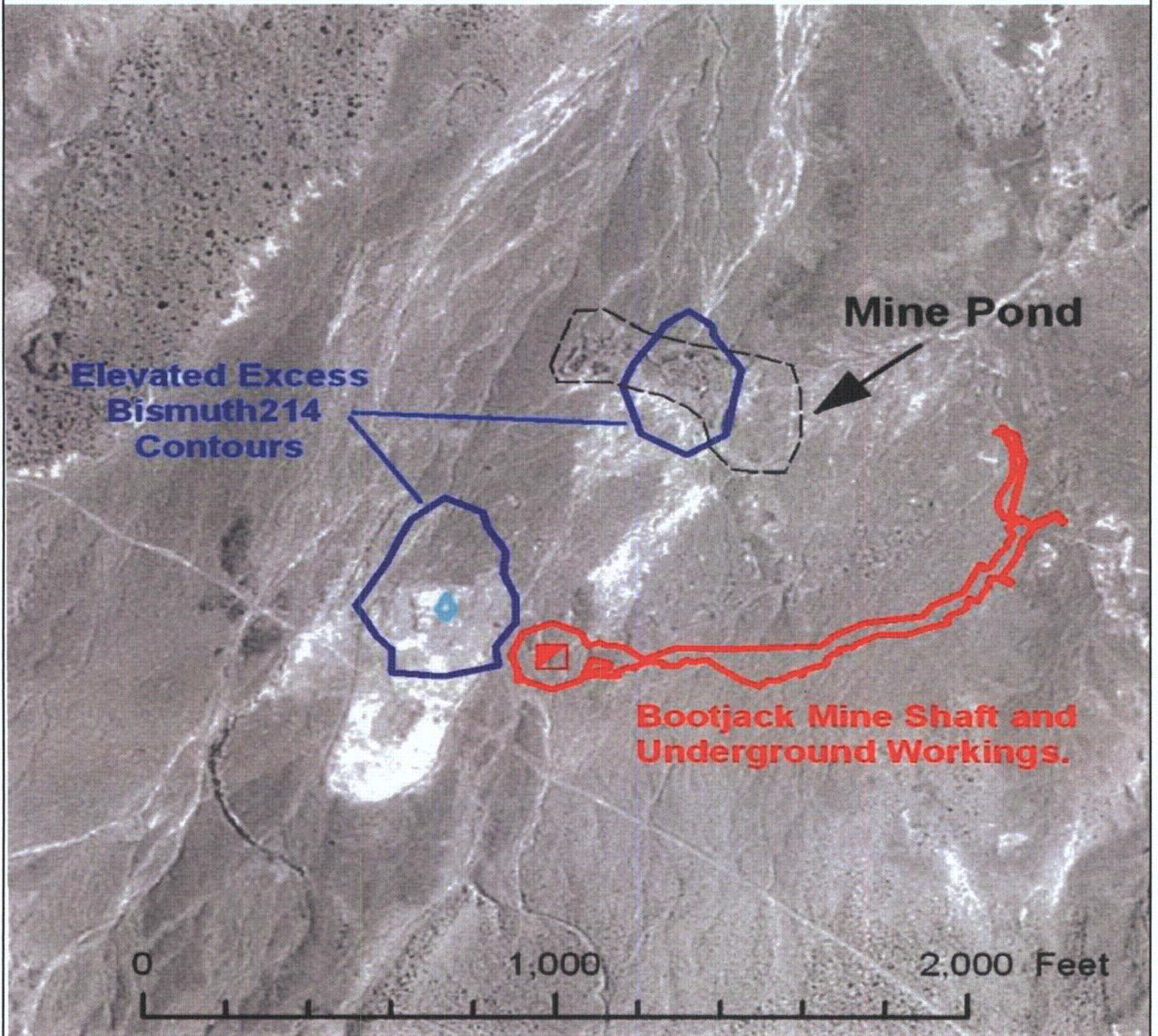
SOURCE: W.L. CHENOWETH, 1993

0 150
APPROXIMATE SCALE IN FEET



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CLIENT: EPA NAVAJO LANDS URANIUM STUDY	DESIGNED BY: RDB 5-21-09	PLAN MAP OF THE BOOTJACK MINE AND MINE EVAPORATION POND				
	CHECKED BY: JMD 5-22-09					
LOCATION: NAVAJO NATION	P.E.P.G.: -	ERRG PROJECT NO. 28-017	REVISION NO. 0	SHEET 1	OF 1	FIG NO. H-1



SOURCE: EPA, 2007c



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CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY	DESIGNED BY: RDB 5-20-09		BOOTJACK MINE WORKINGS AND PROXIMAL AREA WITH EXCESS BISMUTH-214 READINGS				
	CHECKED BY: JMD 5-21-09						
LOCATION: MONUMENT VALLEY AREA, NAVAJO NATION	P.E.P.G.: -		ERRG PROJECT NO. 28-017	REVISION NO. 0	SHEET 1	OF 1	FIG NO. H-2

Appendix I. Firelight No. 6 Mine Groundwater Pathway Assessment

Appendix I
Firelight No. 6 Mine
Groundwater Pathway Assessment

April 2010

TDD No.: TO1-09-08-02-0001
Contract No.: EP-S9-07-01

Prepared for:

U.S. Environmental Protection Agency, Region 9
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Section I1. Mine and Groundwater Investigation

I1.1. LOCATION OF ABANDONED URANIUM MINE

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) were below the water table (Table 13 in EPA, 2007c). One of these AUMs, the Firelight No. 6 Mine (also referred to as Naschoy or Noschoy Mine), is located in the North Central Region of the Navajo Nation, in Navajo Nation District 8. Geographically, it is located on the South El Capitan Flat in the Monument Valley Mining District. It is approximately 14 miles north of Kayenta, Arizona, approximately 7 miles south of the Arizona-Utah border. The mine is shown on the Boot Mesa topographic map, near latitude 36 55' North and longitude 110 15' West (Chenoweth, 1992a; Figure 6).

I1.2. LOCAL HYDROGEOLOGY

The Firelight No. 6 Mine is in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley area surrounding the mine is 6 to 8 inches (see the Average Annual Precipitation Map for Monument Valley Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the mine is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and produces more runoff than infiltration.

Aquifer sensitivity in the area surrounding the mine ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

The Firelight No. 6 Mine is located along a part of the El Capitan Wash that runs approximately southeast to northwest.

11.3. DETAILED MINE BACKGROUND

The El Capitan Flat of Monument Valley is a large area on the eastern side of the Oljeto Wash that is covered with a sand dune; Oljeto Wash roughly follows the axis of the Oljeto syncline. Underlying the dune sand is the Upper Triassic Chinle Formation. Rocks of this formation dip approximately 5 degrees to the west into the Oljeto syncline (Chenoweth, 1992a).

11.3.1. Firelight No. 6 Ore Deposits

The ore bodies at the Firelight No. 6 Mine were formed in a channel deposit in the basal portion of the Shinarump Member of the Chinle Formation. The channel, scoured into the underlying Middle Triassic Moenkopi Formation, was filled with medium- to coarse-grained sandstone and conglomerate. Carbonaceous plant materials were abundant in the channel sediments (Chenoweth, 1992a).

The deposit was unoxidized because of a perched water table in the Shinarump; during operation, approximately 50 gallons of water per minute was pumped from the mine (Chenoweth, 1992a). The ore was classified by the U.S. Atomic Energy Commission as low-vanadium ($<0.75\% \text{V}_2\text{O}_5$), low-lime ($<6\% \text{CaCO}_3$) uraninite. Although Monument Valley uranium ores are known to contain copper, no information is available on the copper content of the Firelight No. 6 Mine ore. The concentrations of U_3O_8 , copper, and vanadium in a sample of radioactive rock from the mine dump, collected during the National Uranium Resource Evaluation program of the Department of Energy, were 462 parts per million (ppm), 150 ppm, and 500 ppm, respectively (Chenoweth, 1992a).

Geologic studies of the channels in Monument Valley confirm that the Firelight No. 6 deposit is located in a north to northwest trending channel. The channel has been traced by drilling for approximately 6 miles before it merges with the Bootjack-Big Four channel at the Sunlight Mine (Chenoweth, 1992a).

11.3.2. Production History

The Firelight No. 6 Mine operated between 1959 and 1960. During that time, approximately 2,141 tons of ore, 7,611 pounds of U_3O_8 , were mined (August 2007).

The land included in the permit for the Firelight No. 6 Mine was first drilled in 1958 by the Climax Uranium Company of Grand Junction, Colorado. This initial drilling was done in a 50-foot grid pattern, with a total of 8,000 linear feet drilled. The deposit amounted to 6,040 tons of ore averaging 0.31% U_3O_8 and 1.02% V_2O_5 . The ore averaged about 170 feet in depth and ranged from 2 to 11.5 feet in thickness, averaging 4.5 feet. In the winter of 1958-1959, E.E. Lewis, Inc. advanced a 380-foot long, 31° decline into the ore body. Ore shipped from the drilling decline consisted of 29.44 tons that averaged 0.30% U_3O_8 and 0.74% V_2O_5 . Shipments for 1959 totaled 697.07 tons, averaging 0.20% U_3O_8 and 0.74% V_2O_5 . Mining was discontinued in early 1960 because of low grades and discontinuities in the ore. At the time

of closing, the mine workings consisted of about 600 feet of drifts, and 2,140.66 tons of ore had been mined, approximately 35% of the original estimated ore deposit. By June 1960, the equipment at the mine had been removed, and the mine portal had been filled with dune sand (Chenoweth, 1992a).

11.4. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

11.4.1. Aerial Radiation Contours

In 2000, the EPA produced the “Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas,” herein referred to as the “Project Atlas” (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley area was created from data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory; the portion of the map that covers the study AUMs is included in Appendix A.

The aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. Bismuth-214 radiation (up to 7.4 microRoentgens per hour [$\mu\text{R/hr}$]) on a map of the aerial radiation contour values in the Project Atlas are higher for the Firelight No. 6 mine than for the immediate surrounding area. Similar values are shown for Joe Rock #7-9 and Bootjack Mines to the west of Firelight No. 6 Mine (see Bismuth-214 Flyover Polygons Maps for North Central Region in Appendix A; EPA, 2007c).

11.4.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) conducted a study in the Monument Valley and Cameron Mining Districts. Site data were collected for shallow water sources, mine drill holes, wells, and auger holes. The nearest wells to Bootjack Mine are downstream and between two and four miles from the mine. The depths to groundwater that were measured in October 1991 (Longworth, 1994) in the following wells:

- 8T-525
- 8K-433
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Maps for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Maps for North Central Region in Appendix A)

These wells are located along the same drainage that runs from higher elevations at the southeast (unnamed 4-inch well and 8K-433) to lower elevations at the northwest (unnamed 6-inch well and 8T-525; Figure 8). Based on the altitude of the land surface (either surveyed or determined from USGS

topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions) at well 8T-525, indicating a southeast to northwest gradient along drainage. Although these wells are not in the immediate vicinity of the mine, based on the topography of area, groundwater most likely flows from Firelight No. 6 Mine northwest until it joins other washes near Big Four No. 2 Mine and continues as described above to the northwest.

11.4.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Samples have been collected in the Monument Valley Area by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. Limited or no information on well development is available, and groundwater samples are not collected regularly. Available analytical results summarized below are from limited grab groundwater sampling events.

As stated above, water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, "either for cultural reasons, or because they prefer the taste" (Keller, 2007). These sources may have been historically used for drinking water purposes, because it is hard for people to abandon using them (Keller, 2007).

11.4.3.1. Analytical Results for USGS 1991 Sampling

In December 1991, USGS collected a groundwater sample from well 8T-525. The pH of the sample was measured at 7.5. Uranium-238, uranium-234, and uranium-235 concentrations were 0.50 picoCurie per liter (pCi/L), 0.90 pCi/L, and <0.1 pCi/L, respectively, and gross alpha (dissolved) as natural uranium was 3.0 micrograms per liter ($\mu\text{g/L}$) (Longworth, 1994). The results were less than the maximum contaminant levels (MCLs), and uranium concentrations were less than the estimated MCL of 20 pCi/L (based on the EPA MCL of 30 $\mu\text{g/L}$ and conversion of 0.67 picocuries per microgram).

11.4.3.2. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source of water for human consumption, and samples were collected as a point-of-use sample to duplicate the most likely method in which people would obtain water. The concentrations of uranium in three samples collected in the North Central Region were greater than the estimated MCL of 20 pCi/L:

- Total uranium in one sample (Baby Rock Spring 8-44) collected in September 1998 was 36.3 pCi/L.
- The uranium in one sample (Monument Pass Well) collected in January 2000 was 40.0 pCi/L.
- Total uranium in one sample (Tank 8A-299, now called well 8K-433) collected in September 1998 was 171.9 pCi/L.

Of these samples, only one sample (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley Area. Well 8K-433 is categorized as a windmill well and, although it is not regulated for human consumption, locals indicate that the well is used for drinking water and for watering livestock (EPA, 2009b).

In September 1998, water samples were collected by USACE at well 8K-433 (formerly Tank 8A-299), well 8T-525, and spring 8A-P.H.S.-22-Spring. Well 8K-433 is located approximately 2.9 miles downstream of the Firelight No. 6 Mine, above the El Capitan Wash and adjacent to the Sunlight and Sunlight South Mines. Well 8T-525 is located approximately 4.7 miles northwest and downstream of the Firelight No. 6 Mine. Spring 8A-P.H.S.-22-Spring (08A-220) is approximately 4 miles upstream of Firelight No. 6 Mine (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c).

USACE collected the groundwater sample from well 8K-433 at an elevation of 5,100 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 155.00 pCi/L, which exceeded the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8K-433 at concentration of 171.93 pCi/L, which exceeded the estimated MCL of 20 pCi/L. Groundwater was collected from well 8T-525 at an elevation of 5,011 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 1.59 pCi/L, which was less than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at a concentration of 1.68 pCi/L, which was less than the estimated MCL of 20 pCi/L. USACE collected the groundwater sample from spring 8A-P.H.S.-22-Spring (08A-220 on Surface Water Features Map for North Central Region in Appendix A) at an elevation of 5,257 feet above msl; the pH of the sample was 8.28. Gross alpha (dissolved) as natural uranium was 1.95 pCi/L, which was less than the EPA MCL of 15 pCi/L (EPA, 2000b). Total uranium was detected in a water sample from 8A-P.H.S.-22-Spring at a concentration of 3.70 pCi/L, which was less than the estimated MCL of 20 pCi/L.

11.4.3.3. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample in the North Central region. Gross alpha was present at 25.7 pCi/L, which exceeded the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not within 4 miles of the Firelight No. 6 Mine.

11.4.3.4. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 $\mu\text{g/L}$ and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 $\mu\text{g/L}$ and 15 pCi/L. This well is above the El Capitan Wash, immediately adjacent to the larger mines, Sunlight and South Sunlight, and is almost 3 miles from the Firelight No. 6 Mine. Thus, the uranium may have dispersed from the Sunlight and South Sunlight Mines.

11.5. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels within the Shinarump Member of the Chinle Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at the Firelight No. 6 Mine do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. These undisturbed deposits would be expected to also contain extensive organic material in the channel deposits associated with the uranium deposition.

11.6. MINED URANIUM DEPOSITS

Based on estimated size of the ore bodies at the mine, uranium ore deposits at the Firelight No. 6 Mine were not significantly mined (only approximately 35 percent). The remaining uranium ore may be lower in grade and scattered along the periphery of the original ore body because the mine was shutdown in 1960 because grades were low and the ore was discontinuous (Chenoweth, 1992a). Uranium remaining at Firelight No. 6 Mine may also be discontinuous, as evidenced by exploratory drilling at the time that indicated greater amounts of viable ore that were not found once mining began.

Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when the mine operated might have destroyed organic material and oxidized sulfides, as would mine operations. During mining operations in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Geologic studies confirm that the Firelight No. 6 deposit is in the same paleochannel as are the Big Chief Mine to the northwest and the Alma-Seegan Mine to the southeast. This channel merges to the northwest with the channel that hosts the Bootjack and Big Four No. 2 Mines at the site of the South Sunlight Mine (Chenoweth, 1997a).

Section 12. Hazard Ranking System and Summary

12.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, groundwater and surface water migration was initially investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Firelight No. 6 Mine include, but are not limited to:

- Uranium in disturbed soils and mine workings at the surface are indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for North Central Region in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Firelight No. 6 Mine.

Additional potential sources of hazardous substances not associated with the Firelight No. 6 Mine but found in the immediate area include:

- Undisturbed and uneroded ore deposits in the channel sediments within the Shinarump Member of the Chinle Formation in the surrounding area as mapped by Young, Malan, and Gray (1964).

12.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering) because it is designed as a screening tool to give the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 22). Uranium's toxicity and methods of mobility were discussed in the Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

12.2.1. Rainwater Infiltration

The average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of the mine and at the mine site. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining Firelight No. 6 Mine ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Fresh oxidizing water from brief seasonal thunderstorms likely infiltrates the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways and the Firelight No. 6 ore body was not extensively mined, reports indicate the remaining ore is low grade. Uneroded ore deposits, as mapped on Figure 7, near and downstream of the mine may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

I2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography, and as such, will likely trend to the north-northwest as water flows in the washes and ephemeral creek beds in the region. Based on water levels of regional wells observed during the 1991 sampling, the noted groundwater influx during mining at the Firelight No. 6 Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface (Figure 22); surface water may also migrate down into groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1950s and 1960s are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit. However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, secondarily depositing uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 22). Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the volume of uranium distributed in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water samples are inconclusive regarding leaching of uranium from the Firelight No. 6 Mine because multiple sources (other mines in the region) may impact the water in wells where water samples have been collected. Results of samples collected downstream from the mine suggest the possibility of a uranium source upstream; the Firelight No. 6 Mine is a possible upstream source of uranium in the water samples.

I2.2.3. Groundwater Pathway Conclusion

Two other water samples were collected within 10 miles of the Firelight No. 6 Mine: a spring designated 8A-P.H.S.-22 Spring (08A-220 on one of the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c), which is approximately 4 miles south of the mine, and well 8K-433, which is approximately 3 miles northwest of the mine. The concentrations of radioactive metals in the sample collected from Well 8K 433 exceed MCLs. The concentrations of radioactive metals in the water source 08A-220 (8A-P.H.S.-22 Spring) were less than the MCLs. Therefore, 8A-P.H.S.-22 Spring is classified

in the less risk category. This spring is upgradient to all of the AUMs that occur below the water table (EPA, 2007c), suggesting that uranium migrated into groundwater from uneroded channel deposits because no known AUMs are located upgradient to this sample location.

None of the wells is intended to be used for drinking water, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009b).

12.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Firelight No. 6 Mine enters the El Capitan Wash, which is west of the mine and flows in a northwesterly direction. The elevation of the wash is approximately 100 feet lower than the elevation at the top of the mine shaft. The El Capitan Wash continues in a north-northwesterly direction until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during rainstorms, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, water infiltrates rapidly through dry and porous soil, and much of the incident rainfalls runs off into streams without contacting uranium in the wastes. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds, and adsorption of uranium to clays and organics is likely given the pH range of rainwater.

12.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash within the vicinity of the mine or within 15 miles downstream of the mine (NNEPA, 2006).

12.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that

pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Firelight No. 6 Mine for the following reasons:

- Although the concentrations of radioactive metals exceed their respective MCLs in water samples collected downstream of the mine, it is likely that the contamination is from the Sunlight and South Sunlight Mines, not the Firelight No. 6 Mine. Given the distance and conditions at the mine, it is unlikely that the Firelight No. 6 Mine is a major contributor to the possible combined source of the uranium in water in this well.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site

12.5. SUMMARY

The Firelight No. 6 Mine is in the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined here, primarily from channel deposits of the Shinarump Member of the Chinle Formation. Although not mined, copper is also present in the Firelight No. 6 ore bodies. The channel deposit at the Firelight No. 6 Mine is approximately 200 feet wide. The Firelight No. 6 ore body was approximately 170 feet below ground surface and varied from 2 to 12 feet thick. The channel that hosts the uranium ore is composed of medium- to coarse-grained sandstone and conglomerate. Organic plant matter is abundant in the channel sediments. The Firelight No. 6 Mine was listed by EPA as a productive AUM (EPA, 2007c) that had workings below the water table or was considered a wet mine that required pumping.

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Firelight No. 6 Mine is located along the El Capitan Wash that runs approximately southeast to northwest. The following pertinent HRS factors are associated with the Firelight No. 6 Mine:

- Aerial radiation surveys for bismuth-214 (a decay product of uranium) identify elevated uranium concentrations at the surface confined to the areas around the Firelight No. 6 Mine.
- A potentially significant portion of original ore body remains at the mine; however, reports are that remaining ore at the mine was low grade.
- Radioactive metal were detected in samples collected from water sources downgradient of the mine at concentrations that exceed their respective MCLs; however, due to the location of the water source it is not possible to isolate the Firelight No. 6 Mine as the source of the elevated concentrations and it is likely that concentrations are attributable to Sunlight and South Sunlight Mines.

- Uranium concentrations in water in the downgradient well closest to the Firelight No. 6 Mine (approximately 1.25 miles cross-gradient) are higher than those in water from wells upgradient and farther downgradient of the mine (approximately 8 miles south of the mine). This suggests that uranium is migrating from mines in the area, but the source cannot be limited to Firelight No. 6 Mine because multiple mines may contribute uranium to the water in the wells at elevated concentrations. The water sources near the Firelight No. 6 Mine are not regulated; however, records indicate that some water may be used for livestock or human consumption.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Firelight No. 6 Mine.

Appendix J. Alma-Seegan Mine Groundwater Pathway Assessment



Appendix J
Alma-Seegan Mine
Groundwater Pathway Assessment

April 2010

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Section J1. Mine and Groundwater Investigation

J1.1. LOCATION OF ABANDONED URANIUM MINE

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). One of these AUMs, the Alma-Seegan Mine, (also referred to as Alma-Seegin or Alma-Seggin Mine) is in the North Central Region of the Navajo Nation, in Navajo Nation District 8. Geographically, it is on the South El Capitan Flat in the Monument Valley Mining District. It is approximately 13 miles north of Kayenta, Arizona, and approximately 8 miles south of the Arizona-Utah border (Chenoweth, 1994a). The mine is shown on the Boot Mesa topographic map, near latitude 33° 53.56' North and longitude 110° 15.45' West (Figure 6).

J1.2. LOCAL HYDROGEOLOGY

The Alma-Seegan Mine is in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Average annual precipitation in the Monument Valley around the mine is 6 to 8 inches (see precipitation map for Monument Valley area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

Soil near the mine is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for North Central Region in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and produces more runoff than infiltration.

Aquifer sensitivity in the area surrounding the mine ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the El Capitan Wash (see the Aquifer Sensitivity Map for North Central Region in Appendix A; EPA, 2007c).

The Alma-Seegan Mine is located along part of the El Capitan Wash that runs approximately southeast to northwest (Figure 6).

J1.3. DETAILED MINE BACKGROUND

The El Capitan Flat of Monument Valley is a large area on the eastern side of the Oljeto Wash that is covered by a sand dune; El Capitan Flat roughly follows the axis of the Oljeto syncline (Figure 6). Underlying the dune sand is the Upper Triassic Chinle Formation. Rocks of this formation dip approximately 5 degrees to the west into the Oljeto syncline (Chenoweth, 1992b).

The ore bodies at the Alma-Seegan Mine formed in a channel deposit in the basal portion of the Shinarump Member of the Chinle Formation. The channel, scoured into the underlying Middle Triassic Moenkopi Formation, was filled with medium- to coarse-grained sandstone and conglomerate; abundant carbonaceous material also occurs with the coarse sediments. The channel was determined by drill hole information to be approximately 200 feet wide and approximately 50 feet deep. The channel trends approximately N40°W near the ore bodies. Drill hole logs describe ore 150 to 200 feet below ground surface, averaging 5 feet thick. Geological studies of the channels in Monument Valley indicate that the Alma-Seegan Mine deposit is located in a north to northwest trending channel. The deposit was unoxidized and occurs beneath the water table in the Shinarump. Water flowed into the mine workings at a rate of approximately 50 gallons per minute during mining. Uraninite is the principal uranium mineral. Copper sulfides, such as chalcocite, bornite, and chalcopyrite, are also present in the ore (Chenoweth, 1994a).

The Alma-Seegan Mine was a subsurface mine; however, it was labeled as an open pit mine on the 1988 U.S. Geological Survey topographical map. The reason attributed to this label is a description from 1966, which noted that the portal to the mine had been blocked, but the trench leading to the portal was a 200-foot-long, 15-foot-deep cut in the ground surface, which was partly filled with sand, giving the appearance of an open pit mining operation (Chenoweth, 1994a).

J1.4. PRODUCTION HISTORY

The Alma-Seegan Mine was one of several uranium deposits located by exploration drilling in the Oljeto syncline area of Monument Valley. The mine, which comprises ore bodies on two separate claims (Alma 4 and Seegan 2), was the last uranium mine to commence production in the area. The first mining permits for the area were issued in June, August, and September 1955. Under these permits, the area was drilled by several companies; however, drilling did not identify sufficient ore to develop a mine. The drilling and mining permits were abandoned by 1959 (Chenoweth, 1994a).

Under an allocation program that went into effect in 1962, allowing purchase of uranium concentrate discovered prior to 1958, the properties were reopened for mining in November 1962. As of 1963, 158 drill holes, totaling 25,200 feet, had been drilled on the property. Active mining began in July 1964. A 900-foot-long, minus 25-degree slope was sunk into the ore bodies near the claim line between two mining permit areas. Approximately 3,384 tons of ore that averaged 0.21 percent U_3O_8 was recovered in 1965; approximately 3,385 tons of ore averaging 0.16 percent U_3O_8 was mined in 1966. The mine was closed in 1966; the total production from the mine was approximately 6,769 tons of ore containing 25,540.90 pounds of U_3O_8 and averaging 0.19 percent U_3O_8 (Chenoweth, 1994a).

J1.5. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

J1.5.1. Aerial Radiation Contours

In 2000, the EPA produced the "Abandoned Uranium Mines Project, Arizona, New Mexico, Utah-Navajo Lands, 1994-2000, Project Atlas," herein referred to as the "Project Atlas" (EPA, 2000a). A contour map showing excess bismuth activity in the Monument Valley area was created from data collected during an aerial radiation survey flown by the United States Department of Energy Remote Sensing Laboratory; the portion of the map that covers the study AUMs is included in Appendix A.

The aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. The bismuth-214 radiation on a map of the aerial radiation contour values in the Project Atlas near the Alma-Seegan Mine range from 3.5 to 10.9 $\mu R/hr$ (see Bismuth-214 Flyover Polygons maps for North Central Region in Appendix A; EPA, 2007c).

J1.5.2. Depth to Groundwater

In 1991 and 1992, the U.S. Geological Survey (USGS) conducted a study in the Monument Valley and Cameron Mining Districts. Data were collected for shallow water sources, mine drill holes, wells, and auger holes. Depths to groundwater were measured in October 1991 from the following locations near the Alma-Seegan Mine:

- 8K-433 (formerly Tank 8A-299)
- 8T-525
- An unnamed 6-inch well near El Capitan Wash (08-0637 on Surface Water Features Map for North Central Region in Appendix A)
- An unnamed 4-inch well near El Capitan Wash (08-0636 on Surface Water Features Map for North Central Region in Appendix A; Longworth, 1994)

These wells are located along the El Capitan Wash, which runs from higher elevations in the southeast (unnamed 4-inch well and 8K-433) to lower elevations in the northwest (unnamed 6-inch well and 8T-525; Figure 8). The Alma-Seegan Mine is located at a slightly higher elevation to the east of the wash. Based on the altitude of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 5,084.2 feet above mean sea level (msl) in the unnamed 4-inch well and well 8K-433; 5,030.2 feet above msl in the unnamed 6-inch well; and greater than 5,026 feet above msl (artesian conditions) at well 8T-525, indicating a southeast to northwest gradient along drainage (Figure 8).

Based on the groundwater gradient, the Alma-Seegan Mine is downgradient from the 8A-P.H.S.-22 Spring (08A-220 on Surface Water Features Map for North Central Region in Appendix A). The elevations for the mine and spring confirm the following: the Alma-Seegan Mine is approximately 5,241 feet above msl, and the 8A-P.H.S.-22 Spring (08A-220) is approximately 5,360 feet above msl.

J1.5.3. Groundwater

As stated above, water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. Samples have been collected in the Monument Valley Area by USGS in 1991, EPA/U.S. Army Corps of Engineers (USACE) in 1998 and 2000, Navajo Nation Environmental Protection Agency (NNEPA) in 2004, and EPA in 2008. Since these wells are unregulated water sources, limited or no information on well development is available and regular groundwater sampling is not conducted. Available analytical results summarized below are from limited grab groundwater sampling events.

J1.5.3.1. Analytical Results for EPA/USACE 1998 and 2000 Sampling

USACE, under an EPA grant, collected samples in 1998 for analysis of radioactive and stable metals, as well as alpha and beta emitters. One sample was collected from each well identified as a potential source for human consumption, and samples were collected as a point-of-use sample designed to duplicate the most likely method in which people would obtain water. The total uranium (sum of isotopes uranium-234, uranium-235, and uranium-238) in three water samples collected in the North Central Region contained total uranium were greater than the estimated maximum contaminant level (MCL) of 20 picoCuries per liter (pCi/L), based on the EPA MCL of 30 microgram per liter ($\mu\text{g/L}$) and conversion of 0.67 picocuries per microgram:

- The concentration of uranium in one sample (Baby Rock Spring 8-44) collected in September 1998 was 36.29 pCi/L.
- The concentration of one sample (Monument Pass Well) collected in January 2000 was 40.00 pCi/L.
- The concentration of uranium in one sample (Tank 8A-299, now called well 8K-433) collected in September 1998 was 171.93 pCi/L.

Of these samples, only one of the samples (from Tank 8A-299, now called well 8K-433) was collected in the Monument Valley Area. Well 8K-433 is approximately 4.4 miles downgradient from the Alma-Seegan Mine, but above the stream bed and adjacent to the Sunlight and South Sunlight Mines. Well 8K-433 is categorized as a windmill well and, although water from it is not regulated for human consumption, locals indicate that the well is used for drinking water and for watering livestock (EPA, 2009b).

In September 1998, water samples were collected by USACE near the Alma-Seegan Mine at 8K-433 (formerly Tank 8A-299), well 8T-525, and spring 8A-P.H.S.-22-Spring. Well 8T-525 is approximately 5.8 miles northwest and downstream of the Alma-Seegan Mine. Spring 8A-P.H.S.-22-Spring (08A-220) is approximately 2.7 miles upstream of Alma-Seegan Mine (see the Surface Water Features Maps for North Central Region in Appendix A; EPA, 2007c).

USACE collected the groundwater sample from well 8K-433 at an elevation of 5,100 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 155.00 pCi/L, which exceeded the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at concentration of 171.93 pCi/L, which exceeded the estimated MCL of 20 pCi/L. Groundwater was collected from well 8T-525 at an elevation of 5,011 feet above msl; the pH of the sample was 8.94. Gross alpha (dissolved) as natural uranium was 1.59 pCi/L, which was less than the EPA MCL of 15 pCi/L. Total uranium was detected in the water sample from well 8T-525 at concentration of 1.68 pCi/L, which was less than the estimated MCL of 20 pCi/L. USACE collected the groundwater sample from spring 8A-P.H.S.-22-Spring (08A-220 on Surface Water Features Map for North Central Region in Appendix A) at an elevation of 5,257 feet above msl; the pH of the sample was 8.28. Gross alpha (dissolved) as natural uranium was 1.95 pCi/L, which was less than the EPA MCL of 15 pCi/L (EPA, 2000b). Total uranium was detected in a water sample from 8A-P.H.S.-22-Spring at a concentration of 3.70 pCi/L, which was less than the estimated MCL of 20 pCi/L.

J1.5.3.2. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample in the North Central region. Gross alpha radiation was present at 25.7 pCi/L, which exceeded the EPA MCL of 15 pCi/L. The sample location, well 08T-522, is not within 4 miles of the Alma-Seegan Mine.

J1.5.3.3. Analytical Results for EPA 2008 Sampling

EPA collected water samples from well 8K-433 between February and March 2008. The concentrations of uranium and the gross alpha count (listed on EPA tables as excluding uranium) were 130 micrograms per liter ($\mu\text{g/L}$) and 40.9 pCi/L, respectively. Both of the concentrations exceeded their respective MCLs of 30 $\mu\text{g/L}$ and 15 pCi/L.

J1.6. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the network of uneroded channels within the Shinarump Member of the Chinle Formation are likely to be higher than background concentrations because uranium is present in ore bodies of various sizes and grades (Figure 7). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at the Alma-Seegan Mine do, but most may not extend to the surface, as indicated by the lower aerial radiation signatures around the mines. Organic material is extensively abundant in the channel deposits that host the uranium ores.

J1.7. MINED URANIUM DEPOSITS

Exploratory drilling near the Alma-Seegan Mine defined approximately 8,000 tons of ore averaging 0.22 percent U_3O_8 . However, mining operations recovered 6,769 tons of ore that averaged 0.19 percent U_3O_8 . Based on the estimated tonnage at the mine, approximately 16 percent of the original uranium ore may remain in the subsurface. The remaining uranium ore may be discontinuous, located at the edges of the former active mining, or of low quality.

Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water noted when operations were occurring at the site might have destroyed organic material, as would mining operations. During mining operations in the 1950s and 1960s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Geologic studies indicated that the Alma-Seegan deposit is in the same paleochannel as the Firelight No. 6 and Big Chief Mines to the northwest. This channel merges to the northwest with the channel containing the Bootjack and Big Four No. 2 Mines at the site of the South Sunlight Mine (Chenoweth, 1997a).

Section J2. Hazard Ranking System and Summary

J2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, groundwater and surface water migration was initially investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Alma-Seegan Mine include, but are not limited to:

- Uranium in disturbed soils and mine workings at the surface are indicated by the aerial radiation contours. The radiation levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, no specific waste rock or tailings were noted during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Alma-Seegan Mine.

Additional potential sources of hazardous substances not associated with the Alma-Seegan Mine but found in the surrounding area include:

- Undisturbed and uneroded ore deposits in the channel deposits in the Shinarump Member of the Chinle Formation in the surrounding area.

J2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering) because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments. Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

J2.2.1. Rainwater Infiltration

The average annual precipitation in the area is low, approximately 6 to 8 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for North Central Region in Appendix A; EPA, 2007c). Permeability is rapid, and an "intermediate potential" exists for contaminant migration in soils upgradient of the mine and at the mine site. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the El Capitan Wash (see the Permeability and Aquifer Sensitivity Maps for North Central Region in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining Alma-Seegan Mine ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. While yearly rainfall is minimal, the influx of rainwater during annual thunderstorms can be rapid but limited in volume because the rain falls in brief, seasonal thunderstorms, allowing fresh oxidizing water to infiltrate the waste rock at the surface and into subsurface ore deposits, destroying organics, oxidizing sulfides, and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 22). Although the open spaces associated with the mines provide preferential pathways, the Alma-Seegan ore body has been extensively mined, depleting the area of the highest grade ore and probably depleting organic matter and sulfides during water influx throughout the mine. Uneroded ore deposits in the vicinity of and downstream of the mine may provide more uranium-

and organic- and sulfide-rich rock and sediment through which fresh water infiltrates to mobilize and transport uranium.

J2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography, and as such, will likely trend to the north-northwest similar to the washes and ephemeral creek beds in the region. Based on water levels of regional wells observed during the 1991 sampling, the noted groundwater influx during mining at the Alma-Seegan Mine, and the depth of the mine, groundwater levels are likely above the main mine workings. Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Chinle Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface; surface water may migrate down into the groundwater as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out in the 1960s are likely below the oxidizing groundwater table, allowing leaching of metals (including uranium) from the ore deposit. However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 22). Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the volume of uranium distributed in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of water sampling are inconclusive regarding leaching of uranium from the Alma-Seegan Mine because multiple sources (other mines in the region) may impact the water at locations where water samples have been collected. Results of samples collected downstream of the mine suggest the possibility of an upstream uranium source; the Alma-Seegan Mine is a possible upstream source of uranium in the water samples.

J2.2.3. Groundwater Pathway Conclusion

The two locations from which water samples were collected are within 5 miles of the Alma-Seegan Mine: a spring designated 8A-P.H.S.-22 Spring, which is approximately 2 miles southeast of the mine, and well 8K-433, which is approximately 4.25 miles northwest of the mine. The concentrations of radioactive metals in Well 8K-433 contains exceed MCLs. The concentrations of radioactive metals in samples from

water source 08A-220 (8A-P.H.S.-22 Spring) were less than MCLs. Therefore, 8A-P.H.S.-22 Spring is classified in the less risk category. This spring is upgradient to all of the AUMs that occur below the water table (EPA, 2007c), confirming that uranium migrated into groundwater from uneroded channel deposits because no known AUMs are located upgradient to this sample location.

None of the wells are intended to be used for drinking water, but community feedback has confirmed that the wells are used for drinking water (EPA, 2009a).

J2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Alma-Seegan Mine enters the El Capitan Wash, which is located west of the mine and flows in a northwesterly direction. The elevation of the wash is greater than 100 feet lower than the elevation at the top of the mine shaft. The El Capitan Wash continues in a north-northwesterly direction until it empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during rainstorms, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is fast but limited in volume through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds.

J2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the El Capitan Wash near the mine or within 15 miles downstream of the mine (NNEPA, 2006).

J2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Alma-Seegan Mine for the following reasons:

- Although the concentrations of radioactive metals in a water sample collected downstream of the mine exceed their respective MCLs, the well is located above the wash, over 4 miles downstream, and it is likely that the contamination is from the adjacent Sunlight and South Sunlight Mines, not from the Alma-Seegan Mine.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site

J2.5. SUMMARY

The Alma-Seegan Mine is located in the North Central Region, specifically the Monument Valley Mining District. Uranium was mined primarily from channel deposits of the Shinarump Member of the Chinle Formation. The channel deposit at the Alma-Seegan Mine is approximately 200 feet wide and is composed of medium- to coarse-grained sandstone and conglomerate. The ore is approximately 150 to 200 feet below ground surface, averaging 5 feet thick. Organic plant matter is abundant in the channel sediments. The Alma-Seegan Mine was listed by EPA as a former productive AUM (EPA, 2007c) that had workings below the water table or was considered a wet mine that required pumping.

Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longworth, 1994). The Alma-Seegan Mine is located along a drainage system (part of the El Capitan Wash) that runs approximately southeast to northwest. The following pertinent HRS factors are associated with the Alma-Seegan Mine:

- According to aerial radiation surveys for bismuth-214 (a decay product of uranium), elevated uranium concentrations at the surface are indirectly shown to be confined to the areas around the Alma-Seegan Mine.
- Soils typified by rapid infiltration but only during very infrequent rainfalls; normal rainwater pH is conducive to adsorption of the uranium that is released into solution with introduction of oxidized rainwater onto abundant inorganic and organic matter in channel deposits.
- Radioactive metals were detected in samples collected from water sources downgradient of the mine at concentrations greater than their respective MCLs; however, due to the location of the water source it is not likely that the Alma-Seegan Mine is a source of the elevated concentrations.
- Uranium concentrations in samples of water collected from the mine well closest to the Alma-Seegan Mine (4 miles downgradient) are higher than those upgradient of the mine; however, this well (08K-433) is above the stream bed and immediately adjacent to the Sunlight and South Sunlight Mines. The analytical results from samples collected from the well suggest that uranium is migrating from mines in the area, but the source is likely the Sunlight and South Sunlight Mines. The water sources in the vicinity of the Alma-Seegan Mine are not regulated; however, records indicate that some may be in use for livestock or human consumption.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Alma-Seegan Mine.

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Appendix K. Grace ISL and Section 13 Mines Groundwater Pathway Assessment

**Appendix K
Grace ISL and Section 13 Mines
Groundwater Pathway Assessment**

April 2010

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Section K1. Mine and Groundwater Investigation

K1.1. LOCATIONS

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). The 31 AUMs are found in the Eastern and North-Central Regions of the study area. Two AUMs, Grace ISL Mine (where ISL stands for “in-situ leaching”) and Section 13 Mine, were only exploratory workings, in the Eastern Region of the Navajo Nation, approximately 5 miles northeast of Church Rock and 10 miles northeast of Gallup, New Mexico. The two AUMs are in the Grants Uranium Region on the western edge of the Church Rock Mining District, Section 13, T. 16 N., R. 17 W., in McKinley County, New Mexico (Peterson, 1980). The locations by township and range for each of the mines (with northings and eastings for the Section 13 Mine) are as follows:

- Grace ISL Mine at 16N.17W.23 (northeast quarter; Holen and Hatchell, 1986)
- Section 13 Mine at 16N.17W.13.411 (35°37'00"N, 108°35'25"W; McLemore, 1983)

K1.1.1. Local Hydrogeology and Geology

The Grace ISL and Section 13 Mines are in the Little Colorado subregion in the Lower Colorado watershed, specifically within the Upper Puerco hydrologic unit. The north fork of the Rio Puerco (Puerco River), an ephemeral stream, is east of the mines and runs northeast to southwest. The ephemeral stream drains more than 3,000 square miles in northwestern New Mexico and northeastern Arizona (Southwest Research and Information Center [SRIC], 1992).

K1.1.1.1. Precipitation

Average annual precipitation in the area surrounding the two mines is 12 to 14 inches (see Average Annual Precipitation Map for Church Rock Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007b).

K1.1.1.2. Soil and Permeability

Soil near the two mines is characterized hydrologically by very slow infiltration rates (see the Hydrologic Group Map in Appendix A). Soil in this area is either clayey with a high water table or shallow soil overlying an impervious layer. Permeability in the area is moderately slow on average, between 0.21 and 0.60 inches per hour (see the Permeability Map in Appendix A; EPA, 2007b). In addition, the volume of rainfall during storms can exceed the capacity of soil to transmit water and produce more runoff than infiltration.

K1.1.1.3. Aquifer Sensitivity

The Grace ISL and Section 13 Mines are located along a drainage system (part of the Rio Puerco) that runs approximately northeast to southwest. Drainage in the immediate area of the mines, however, run approximately northwest to southeast into the north fork of the Rio Puerco. The aquifer sensitivity for the Grace ISL and Section 13 Mines ranges from insignificant potential for contaminant migration upstream and surrounding the mine to most potential downstream from the mine in the Rio Puerco basin (see the Aquifer Sensitivity Map for Church Rock Area in Appendix A; EPA, 2007b)..

K1.1.1.4. Dewatering

Beginning in 1960, uranium was mined near the north fork of the Rio Puerco and the Pipeline Arroyo, the small tributary to the Rio Puerco northeast of Gallup, New Mexico. Because the mined ore deposits were below the regional water table, water seeping into shafts was pumped out to prevent flooding. From 1967 to 1986, the discharge rate from mine dewatering averaged approximately 0.25 cubic meters per second, which created continuous flow in the Rio Puerco from the mouth of the Pipeline Arroyo to as far as a few kilometers downstream of Chambers, Arizona (Van Metre et al., 1997). Before the mid-1970s, untreated effluent was discharged directly to Pipeline Arroyo. From August 1988 until June 1991, the base flow was observed and estimated to be less than 0.01 cubic meter per second in the Rio Puerco near Church Rock, where bedrock crops out in the channel and forms a waterfall from 2 to 3 meters high (Van Metre et al., 1997).

Grace ISL Mine only produced approximately 200 pounds of U_3O_8 during 1975, and Section 13 was never a producing mine; thus, dewatering would have been minimal during 1975 at Grace ISL and unlikely at Section 13.

On July 16, 1979, a tailings pond dike failed at the United Nuclear Corporation uranium mill upstream from the Church Rock Mines and adjacent to the Pipeline Arroyo. An estimated 360,000 cubic meters of mine-tailings liquid and 1,000 metric tons of tailings were discharged into the north fork of the Rio Puerco via the Pipeline Arroyo. The pH of the liquid was about 1.9 (highly acidic), and the total gross alpha activity was estimated at 130,000 picocuries per liter (pCi/L). Uranium was detected in samples of

water from the tailings pond and from the Rio Puerco at concentrations of 4,100 $\mu\text{g/L}$ on February 5, 1979, prior to failure of the dike, and at 6,500 $\mu\text{g/L}$ on July 16, 1979, respectively (Van Metre et al., 1997). The volume of the spill was about 6 percent of the volume released in a typical year by mine dewatering and about 28 percent of the average annual runoff in 1990 and 1991 at the Church Rock gauging station. The average annual volume of dewatering effluent from 1967 to 1986 (6.4×10^6 cubic meters) was about five times the average runoff per year (1.3×10^6 cubic meters) at the Church Rock gauging station for 1990 to 1991 (Graf, et al., 1996).

K1.1.1.5. Surface Water and Groundwater

The Grace ISL and Section 13 Mines are located adjacent to and just west of the north fork of the Rio Puerco, which runs approximately northeast to southwest. Under natural conditions, the Rio Puerco is an ephemeral stream with runoff in response to spring snowmelt and to brief, intense summer thunderstorms. As mentioned in Subsection K1.1.1.4, flow in some reaches of the river changed from ephemeral to perennial in response to effluent discharge from the uranium mines and the sewage treatment plant at Gallup, New Mexico (Van Metre et al., 1997).

Mine dewatering caused large drawdowns in bedrock formations underlying the alluvial aquifer in the Church Rock reach. In 1968, the water level in an abandoned mine shaft near Pipeline Arroyo in the Dakota and Morrison Formations was reported to be 35 meters below the land surface (Hiss, 1977). Water had to be pumped from the mines continuously to keep the tunnels and shafts dry for work to proceed. For example, groundwater was pumped at rate of approximately 3,000 gallons per minute (gpm) from the Morrison Formation at NE Church Rock and NE Church Rock No. 1 Mines in November 1973 and increased to 4,400 gpm by 1977. The water was pumped to the land surface and into settling ponds, where it was treated with barium chloride to remove suspended solids; it was then allowed to flow from ponds into formerly dry tributaries of the Rio Puerco (Hiss, 1977).

Groundwater Flow Direction

Data are insufficient to accurately determine the direction of groundwater flow around the mines in the Church Rock Mining District. Some depth-to-water measurements have been recorded, but determining the groundwater gradient is difficult because the wells were screened in different aquifers and measurements were collected on different dates, often years apart. For example, depths to water were measured in wells 14K-313, KM CR II G-1, and 15T-303, which are all drilled into the aquifer listed as 211GLLP (probably the Gallup Sandstone). The dates of measurement, however, are September 2, 1953; April 24, 1980; and January 1, 1953, respectively.

Similarly, depths to water were measured in two wells, 16T-510 and 16T-606, accessing the 211DKOT aquifer (EPA, 2009d); the 211DKOT aquifer probably refers to the Dakota Sandstone. Kerr-McGee (1976) also lists wells 16T-513 and 16T-534 as accessing the Dakota Sandstone and the Westwater

Canyon Member of the Morrison Formation. The measurements for the four wells were taken many years apart: on August 30, 1960; July 3, 1980; July 27, 1959; and July 29, 1965, respectively. Thus, the lack of measurements from similar dates in wells drilled in the same aquifers makes calculating the groundwater gradient and flow direction difficult. Depths to water were measured in three of the wells (16T-510, 16T-513, and 16T-534) during summer months within a 6-year period prior to the height of mining in the area. Based on well elevations and depths to water, the groundwater elevations in the three wells were 6,714.5 feet above mean sea level (msl), 6,693 feet above msl, and 6,575 feet above msl, respectively. The elevations suggest that groundwater flows generally in a south-to-southwest direction.

Groundwater water contours in surrounding drainage basins for the Rio Puerco tend to be aligned with the flow direction of the drainage basin. As a result, it is possible that the near-surface groundwater and rainfall infiltration around Grace ISL and Section 13 Mines flows toward the southwest.

Groundwater Wells and Water Sources

The following wells or sampling locations are in the area (Figure 16):

- Wells KM CR II G-1, KM CR II G-2, KM CR II G-3, and KM CR II W-2 at NE Church Rock No. 2 Mine
- Well 15T-303 (Pipeline Canyon Well) along Pipeline Arroyo upstream of the north fork of Rio Puerco
- Sample location 1082213, approximately 6.25 miles upgradient of well 15T-303 on a separate drainage running north
- Well 14K-586 (G00012; Friendship I; probably same as 14T-586) near the NE Church Rock Mine
- Church Rock Mill Well adjacent to Church Rock Mill and Pipeline Arroyo
- Sample location 1082366 on the drainage feeding into Pipeline Arroyo, to the east of Church Rock Mill
- Wells 16T-606 (probably the same as G00026) and 16T-532 at Church Rock Mine, downgradient of Church Rock ISL Mine and in adjacent drainage to Grace ISL and Section 13 Mines
- Well 16T-513 (16N 16W 15 4322; Uphill Road Windmill; sample location 1081952)
- Wells Grey, 16-3-4 (Keith Begay Well; possibly the same as sample location 1081851), and 16T-348 (Lobo Valley; sample location 1082365) along the north fork of Rio Puerco before it meets with Pipeline Arroyo (east of Grace ISL and Section 13 Mines)
- Well 16T-514 (Pinedale Chapter House) south of the north fork of Rio Puerco before it meets up with Pipeline Arroyo
- Becenti Trail Spring, approximately 1 mile downstream of the Section 13 Mine along the north fork of Rio Puerco but approximately 0.8 mile upstream from the drainage system on which the Grace ISL Mine is located

- Wells G 01100S-2, G 01100S, G 01100 (sample location 1081956), and 16-4-10 (Lime Ridge) and sample location 1081955, along the drainage system running north into Rio Puerco and downgradient of where the Pipeline Arroyo runs into Rio Puerco
- Well 16K-340 (sample location 1081954) along the Rio Puerco, downstream of where both drainage systems on which the Grace ISL and Section 13 Mines are located meet the north fork of Rio Puerco
- Well 16K-336 (Puerco North Fork) along Rio Puerco, farther downstream of the Grace ISL and Section 13 Mines
- Well 14K-313 (Brown Bull; sample location 1082210) in adjacent Hard Ground Canyon to the west of the NE Church Rock Mine and Pipeline Arroyo
- Sample location 1081950 on the drainage feeding into Hard Ground Canyon to the west of NE Church Rock and Pipeline Arroyo
- Well 16T-510 (Nose Rock; sample location 1081953) in adjacent Hard Ground Canyon to the west of the Section 13 Mine and the Rio Puerco
- Well 16T-534 (Superman Cyn.; NR106.0820X1070) on the hillside northwest of where Hard Ground Canyon meets Rio Puerco (EPA, 2009d)

Groundwater Chemistry

Water samples were collected from some of the wells in the area, and pH and conductivity were measured in 1977, 1978, 1979, and 2008. The pH of the water samples ranged from 5.5 in sample 1082366 (although the pH appears anomalous in comparison with other pHs measured) to 9.01 in the sample from well 16T-510, averaging approximately 7.5. Specific conductivity ranged from 5 micromhos per centimeter in sample 1082365 collected in 1979 (which may be inaccurately reported) to 2,890 micromhos per centimeter in a sample collected from well 15T-303 in 2008, averaging approximately 1,170 micromhos per centimeter (EPA, 2009d).

The underground mine workings were flooded when mining and associated dewatering were discontinued at the mines in the area (Figure 23). At that time, oxidized surfaces of the mine workings could have potentially released soluble constituents, including uranium, into groundwater causing a temporary local impact to water quality. The leachates injected as part of the ISL often did not successfully liberate uranium from the ore deposits because of the presence of humate, therefore not much uranium was put into solution for subsequent dispersion and/or migration. The dissolution would have been temporary because resaturation of the mine workings would convert the exposed surfaces from unsaturated to saturated, limiting further dissolution (MWH, 2003), and the prior reduced environment equilibrium would be reestablished. The humates that characterize these deposits often fix uranium in place and limit dispersion from the ore deposit. Only Grace ISL Mine is listed as having produced a small amount of uranium ore in 1975, which may have required the use of leachates and pumping, but the amounts injected and recovered are not known. Subsequent flooding when mining ceased in the Grace ISL and

nearby mines would have re-established reducing conditions around the mines, limiting mobility of the uranium because sulfides and organic materials would fix the uranium in place near the mines.

Water parameters and chemistry were measured for snowmelt and storm runoff in Rio Puerco; U.S. Geological Survey (USGS) collected the surface runoff samples as composite cross-section samples or point samples at stream-flow gauging stations near Church Rock and Manuelito, New Mexico, and Chambers, Arizona, between August 31, 1988, and October 20, 1990. Specific conductivity, pH, gross alpha activity, and uranium concentrations ranged from 456 to 1,980 microSiemens per centimeter, 7.4 to 8.1, 4.4 to 2.1 pCi/L, and 1.9 to 13 µg/L, respectively (Graf, et al., 1996).

Geology and Groundwater

Uranium ore deposits of the Grants Uranium Region are found in the sandstones of the Westwater Canyon and Brushy Basin Members of the Morrison Formation, which were deposited during the Jurassic Period. The Westwater Canyon Member was deposited as a broad alluvial fan by aggrading braided streams and ranges from 220 to 270 feet thick. The Brushy Basin Member overlies the Westwater Canyon Member and consists of mudstone formed from volcanic ash falls. The member is very thin near the mines in the Church Rock area, and is not considered a major source of uranium, unlike other areas in the Grants Region Mining District. Overlying the Morrison Formation with a slight angular unconformity is the 70- to 180-foot-thick Dakota Sandstone, which was deposited during the Cretaceous Period. The rocks of the Morrison Formation dip less than 5 degrees to the north and are exposed at the surface near Hwy 40, approximately 2 miles south of the Church Rock Mines within the Church Rock Mining District.

The regional dip of the sedimentary rocks is northward. The Nutria monocline, which is a secondary feature that aligns east to west in the southern part of T. 17 N., R. 16 W., forms the southern edge of Mesa de los Lobos. The rock sequence has been fractured by faults that strike northeasterly and trend slightly to the northwest. Displacement of stratigraphy varies but in general is less than a few tens of feet (Kerr-McGee Corporation, 1976). Kerr-McGee Corporation (1976) describes the Nutria monocline as being in the southern part of T. 17 N., R. 16. W. Van Metre et al. (1997), however, describe the Nutria monocline as being about 5 kilometers east of Gallup, where it forms a groundwater divide for regional flow. Recharge that occurs east of the monocline flows in a north-to-northeast direction toward the San Juan Basin, and recharge west of the monocline flows in westward direction (Van Metre et al., 1997).

Groundwater occurs in most of the Cretaceous Sandstones (i.e., Dakota, Gallup, and Crevasse Canyon Formations) beneath the Mesa de los Lobos, and nearly all sandstones yield some water, but the amount is variable. The pre-Cretaceous rock outcrops comprise a narrow east-to-west belt that forms the southern outline of the San Juan Basin. The narrow exposures are tilted northward, ranging from 3 to 30 degrees and occur at elevations of 6,500 feet above msl. Recharge from rainfall infiltrates downward to the water table and then downgradient, generally northward in the areas north of the mines, similar to the regional

dip to the north. In general, pre-Cretaceous sandstone aquifers have a low permeability, and the yields are relatively small (Kerr-McGee Corporation, 1976).

A historic piezometric surface map for Upper Gallup Sandstone shows a northeast flow direction (EPA, 2010). The flow direction illustrated on the piezometric surface map for deeper aquifers might suggest that, although surface and shallow subsurface water flow might follow topography, deeper groundwater flow trends toward the north, following the regional dip in the area of the NE Church Rock Mines. South of the mines, the regional dip is more gentle (EPA, 2010), and groundwater may not be as affected by the dip. Near the Church Rock Mines, the direction of surface water flow, when present, would be from northwest to southeast along unnamed washes near the mines into the northeast- to southwest-trending north fork of the Rio Puerco.

The recharge and groundwater response to regional dip and the historic piezometric map suggest that groundwater flows in a northeast direction in the Church Rock Mining District, which is counter to suggestions that groundwater flow tends to be aligned with the flow direction of the drainage basin and the general flow direction derived from depths to water measured in the Dakota Formation wells. Since the depths to water were collected during different years and the tendency for groundwater to flow in the direction of drainage basins is not confirmed, the direction of groundwater flow to the northwest cannot be discounted.

K1.2. REGIONAL AND DETAILED MINE BACKGROUND

As mentioned in Subsection K1.1.1.4, uranium was mined near Pipeline Arroyo beginning in 1960. The area is known locally as the Church Rock Mining District (Figure 9). Uranium mine shafts near Pipeline Arroyo averaged 500 meters (or 1,640 feet) deep (Van Metre et al., 1997). The uranium deposits in the Grace ISL and Section 13 Mine are hosted in the Westwater Canyon Member. Uranium deposits in the Westwater Canyon Member, in which the greatest number and the largest ore deposits were hosted, were formed as paleo-stream channels and are associated with lenses of carbonaceous matter. The uranium ore deposits in the Westwater Canyon Member are unoxidized. Uraninite (uranium oxide) was the principal uranium mineral; uraninite was accompanied by montrosite (vanadium oxide) and coffinite (uranium-bearing silicate mineral) (Granger, 1963). The rocks of the Westwater Canyon Member were principally medium- to coarse-grained, arkosic sandstones.

The ore deposits in the Grace ISL and Section 13 Mines are hosted in the Westwater Canyon Member of the Morrison Formation. The estimated depth of the Grace ISL deposit is 500 feet, from which approximately 200 pounds of U_3O_8 were produced. The reserves for the Section 13 Mine, including adjacent sections, are listed as 41.9 million pounds of U_3O_8 with an average grade of 0.12 percent (McLemore and Chenoweth, 1991). Most of the uranium deposits in Section 13, T. 16 N., R. 17 W.

(Section 13 Mine) are in elongated tabular masses associated with humate, which may be indicative of primary deposition (Holen and Hatchell, 1986).

K1.2.1. In-Situ Leach at Grace ISL and Section 13 Mines

Grace Nuclear used ISL at the Grace ISL Mine in 1975. ISL consists of injecting a leachate into a mineralized zone through injection wells. The solution migrates through the zone, dissolving the uranium, and is subsequently pumped to the surface through production wells. Uranium is recovered from the uranium-bearing solution using a conventional recovery system, in this case ion exchange. Suitable leaching chemicals are then be added to the barren solution and recirculated to the wells. At the Grace ISL Mine, six injection wells and two production wells were completed into the Westwater Canyon Member approximately 500 feet bgs; the production wells were pumped at approximately 40 gpm (Holen and Hatchell, 1986).

Teton Exploration carried out a pilot ISL (push-pull) project to an approximate depth of 1,300 feet at the Section 13 deposit in 1980. Teton injected approximately 4,500 gallons of water into the uranium-bearing zone of the Westwater Canyon Member at depth of approximately 600 feet. The ore deposit occurs at depths ranging from 675 to 725 feet bgs (Holen and Hatchell, 1986).

The humate present in the primary ores of the Grants Uranium region significantly reduces permeability, which may affect the effectiveness of ISL for uranium extraction. It has been noted that “the shielding of coffinite by organic material would be expected to adversely affect leachate contact of the uranium mineral and reduce leaching efficiency.” Remnant bodies of primary ore can be found completely surrounded by oxidized rock for a distance of over half a mile beyond the regional oxidation front, illustrating how resistant primary ore can be to dissolution by geochemical processes (Holen and Hatchell, 1986).

K1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

K1.3.1. Aerial Radiation Contours

In 1988, USGS produced an aerial gamma-ray contour map of regional surface concentrations of uranium (Duval, 1988). A contour map delineating excess gamma-ray activity in the Eastern Region was created from data collected during an aerial gamma-ray survey flown by USGS (Figure 21). To investigate regional surface concentrations of uranium, the aerial gamma-ray contour map (Figure 21) was studied, where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU) (Duval, 1998). The map contours represent values in percent.

The aerial gamma-ray contours identify concentrations across the region. Gamma-ray radiation is associated with uranium, and excess levels of gamma-ray activity are a good indicator of old mines and mining-related activities. A map of the aerial gamma-ray contour values illustrates higher gamma-ray radiation (up to 3.75 percent in the vicinity of the Church Rock area). Background concentrations within McKinley County and adjacent counties ranged from 1.00 to 2.75 percent.

K1.3.2. Groundwater

Water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, the water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). The sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. From 1977 to 1979, Los Alamos Scientific Laboratory collected samples in the Church Rock area as part of the National Uranium Resource Evaluation Program (NURE) during the hydrogeochemical and stream sediment reconnaissance phase. In July 2002, a water quality sample was collected from a domestic well in the Westwater Canyon Member in the area of the Church Rock Mill. In 2003 and 2004, Navajo Nation Environmental Protection Agency (NNEPA) collected samples under the CRUMP. EPA collected additional samples in the Church Rock area in 2008 and 2009. Limited or no information on well development is available, and groundwater samples were not collected regularly because the wells are unregulated sources of water. Available analytical results summarized below are from limited grab groundwater samples.

K1.3.2.1. Analytical Results for NURE 1977 to 1979 Sampling Event

From September 1977 to October 1979, NURE collected water samples in the Church Rock area; data from the samples have been compiled and transferred to a database by USGS. Samples 1081950, 1081951, 1081952, 1081953, 1081954, 1081955, and 1081956 were collected in September 1977; samples 1082210 and 1082213 were collected in October 1978; and samples 1082365 and 1082366 were collected in October 1979 (Figure 16; EPA, 2009d). Samples 1082365 and 1082366 were collected after the tailings spill in July 1979 from the Church Rock Mill (EPA, 2009d).

Sample 1081954, collected in 1977 from well 16K-340 along the Pipeline Arroyo and approximately 1.2 miles downstream of Grace ISL Mine, had a uranium concentration of 2.4 µg/L (EPA, 2009d). Sample 1082213, collected in 1978 almost 14 miles upstream of Grace ISL Mine, had a uranium concentration of 0.17 µg/L; the uranium does not appear to be associated with any AUMs in the area and may be background. Sample 1082366, collected in 1979 from the drainage system directly across Pipeline Arroyo from the Church Rock Mill and approximately 7 miles northeast from Grace ISL Mine

(Figure 16), had a uranium concentration of 1,007.4 $\mu\text{g/L}$, which exceeded the maximum contaminant level (MCL) of 30 $\mu\text{g/L}$. The exceedance was the highest concentration detected in water samples collected from the Church Rock area.

The following samples were collected in adjacent drainage systems:

- Samples 1081953, 1081950, and 1082210 collected in Hard Ground Canyon with uranium concentrations of 0.64 $\mu\text{g/L}$, 0.89 $\mu\text{g/L}$, and 1.46 $\mu\text{g/L}$, respectively
- Samples 1082365 and 1081951 collected along the north fork of the Rio Puerco to the east of the mines with uranium concentrations of 0.95 $\mu\text{g/L}$ and 0.22 $\mu\text{g/L}$, respectively
- Samples 1081952, 1081955, and 1081956 collected along drainage systems to the east and southeast feeding into the north fork of Rio Puerco with uranium concentrations of 0.18 $\mu\text{g/L}$, 1.24 $\mu\text{g/L}$, and 2.62 $\mu\text{g/L}$, respectively (EPA, 2009d)

Locations where samples 1081950, 1081954, 1081955, and 1081956 were collected are within 4 miles of the Grace ISL and Section 13 Mines, while locations where samples 1081951, 1081952, 1081953, 1082366, 1082365, 1082210, and 1082213 were collected are between approximately 4 to 14 miles from the mines. Uranium mines in the Church Rock Mining District were still operating when the water samples were collected in 1977, 1978, and 1979.

K1.3.2.2. Analytical Results for 2002 Church Rock Mill Sampling Event

In July 2002, a water quality sample was collected from the Westwater Canyon Member in the area of the Church Rock Mill from a domestic well located in Section 2. Dissolved uranium was detected at a concentration of 70 $\mu\text{g/L}$, and gross alpha activity was not measured at a level greater than the laboratory reporting limit of 1.0 pCi/L (MWH, 2003).

K1.3.2.3. Analytical Results for CRUMP 2003 and 2004 Sampling Events

NNEPA and EPA collected water samples near the Church Rock and NE Church Rock Mines in October 2003 under CRUMP. Ten of the wells are within 8 miles of the Church Rock Mines, and the following samples were collected for analysis of uranium:

- Sample collected from well 15T-303 (listed as 15K-303) with a uranium concentration of 0.69 $\mu\text{g/L}$
- Sample collected from well 14K-586 with a uranium concentration of 3 $\mu\text{g/L}$
- Sample collected from well 16T-606 with a uranium concentration of 6.99 $\mu\text{g/L}$
- Sample collected from shallow well Grey with a uranium concentration of 14.84 $\mu\text{g/L}$
- Sample collected from well 16T-348 with a uranium concentration of 0.29 $\mu\text{g/L}$
- Sample collected from 16K-340 with a uranium concentration of 2.92 $\mu\text{g/L}$

- Sample collected from 16-4-10 with a uranium concentration of 69.37 µg/L
- Sample collected from well 14K-313 with a uranium concentration of 0.05 µg/L
- Sample collected from well 16T-534 with a uranium concentration of 0.15 µg/L
- Sample collected from 16K-336 with a uranium concentration of 0.57 µg/L (EPA, 2009d)

Wells 16T-606, 16K-340, 16-4-10, 16T-534, and 16K-336 are also within a 4-mile radius of Grace ISL and Section 13 Mines. The uranium concentration in only 1 groundwater sample collected for this study, from well 16-4-10, exceeded the MCL of 30 µg/L. Well 16-4-10 is less than 2.8 miles downgradient of the Grace ISL Mine. The samples were collected after mining had been discontinued in the Church Rock Mining District.

During the CRUMP study, the water from many of the wells sampled was deemed unsuitable for human and domestic uses based on various pollutants in and water quality parameters of the samples, not just uranium. The pollutants and water quality parameters included arsenic, iron, and selenium and sulfate, pH, total hardness, fluoride, chloride, and total dissolved solids. CRUMP recommended that water in well 16T-606 be considered unsuitable for any use in all three categories—human drinking water, domestic water, and livestock water (CRUMP, 2007). Well 16T-606 is approximately 2.5 miles northeast of Grace ISL Mine and east of Section 13 Mine.

In 2004, NNEPA collected one water sample in the Eastern Region. The gross alpha activity of the sample was 6.5 pCi/L, which is less than the EPA MCL of 15 pCi/L. The sample was collected from water in the public water system at the Crownpoint Chapter House, and the source of water in the system is not within 4 miles of the Church Rock Mines and is in a different watershed.

K1.3.2.4. Analytical Results for EPA 2006 to 2009 Sampling Event

EPA collected and analyzed water samples from 2006 to 2009 from the following wells:

- Well 15K-303 with a uranium concentration of 0.38 µg/L
- Well 14T-586 with a uranium concentration of 1.5 µg/L
- Well 14K-313 with no concentration of uranium equal to or greater than the laboratory reporting limit
- Well Grey with a uranium concentration of 5.2 µg/L
- Well 16-4-10 with a uranium concentration of 260 µg/L
- Well 16-3-4 with no concentration of uranium equal to or greater than the laboratory reporting limit
- Well 16T-513 with no concentration of uranium equal to or greater than the laboratory reporting limit
- Becenti Trail Spring with a uranium concentration of 110 µg/L

The uranium concentrations in the samples collected from well 16-4-10 in 2008 and from Becenti Trail Spring in 2009 exceeded the MCL of 30 $\mu\text{g/L}$. Both of the locations from which the samples were collected are less than 4 miles from the Grace ISL and Section 13 Mines. Well 16-4-10 is downstream of the mines; however, it is along a different drainage system running northwest into the Rio Puerco. Without more information on the direction of groundwater flow, the relationship between the Grace ISL and Section 13 Mines and the elevated uranium concentration in well 16-4-10 is difficult to establish. However, the lower uranium concentrations detected in samples collected between well 16-4-10 and the mines and a location on a separate drainage system suggest that a direct relationship is unlikely.

Becenti Trail Spring is immediately downstream of Section 13 Mine and may be influenced by surface runoff at the mine site. It is unlikely the ISL pilot test at Section 13 Mine would have produced much surface disturbance. Becenti Trail Spring is a shallow water source with an aquifer listed as 231CHNL, which could be an abbreviation for the Chinle Formation, although the spring depth does not correlate well with the expected formation depth. The measured depth to water at the Becenti Trail Spring was reported as 12 feet bgs. The spring is approximately 1 mile downstream of the Section 13 Mine and upstream of where drainage from Grace ISL Mine meets the north fork of the Rio Puerco.

K1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the undiscovered and undisturbed deposits in the Westwater Canyon Member of the Morrison Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 10). Some of the undisturbed uranium deposits may also extend below the water table, similar to the deposits at Grace ISL and Section 13 Mines; however, most may not extend to the surface because they are covered by the Dakota Sandstone. Extensive redistributed organic material is expected in the undisturbed uranium-bearing lens deposits.

K1.5. MINED URANIUM DEPOSITS

The scale and duration of the mining operations at the two mines suggest that very little ore, if any, has been removed. Mining operations may have left some open spaces and conduits, such as shafts, wells, and exploratory holes. The deposits are largely intact, and the reducing conditions and significant organics and sulfides have likely prevented uranium from being leached and migrating in solution very far.

Section K2. Hazard Ranking System and Summary

K2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Grace ISL and Section 13 Mines include, but are not limited to:

- Uranium ore deposits remaining below the surface and below the water table at the two AUMs.

The following additional potential sources of hazardous substances are not associated with the Grace ISL and Section 13 Mines but are found in the surrounding area:

- Undisturbed and uneroded uranium deposits within the Westwater Canyon and Brushy Basin Members of the Morrison Formation in the Church Rock Mining District.

K2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS

emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

K2.2.1. Rainwater Infiltration

As discussed above in Subsection K1.1.1.1, average annual precipitation in the area is low, approximately 12 to 16 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through soil surrounding the mines are very slow (see the Hydrologic Group Map for Church Rock Area in Appendix A). Permeability is moderately slow, and contaminant migration in soil has "intermediate potential" upgradient of the mines and "insignificant potential" downgradient of the mines and at the mine sites. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the Rio Puerco (see the Permeability and Aquifer Sensitivity Maps for Church Rock Area in Appendix A). The characteristics are applicable to the largely intact ore bodies of the Grace ISL and Section 13 Mines, as well as the uneroded ore deposits in the area not associated with an established mine site.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed above in Subsection K2.1, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Normally if not limited by unfavorable soil conditions, fresh oxidizing water from the rapid influx of rainwater from seasonal storms can infiltrate the waste rock at the surface and into ore deposits beneath the surface, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23). However, infiltration rates for soil at the Grace ISL and Section 13 Mines are particularly slow. Some open spaces associated with ISL mining may provide preferential pathways; however, the ore deposits are largely undisturbed, and the humate which hinders the ISL process contribute to reducing conditions that limit the dispersion of any uranium that might be leached to the areas immediately around the undisturbed ore deposit.

K2.2.2. Groundwater Flow

Groundwater flow has not been directly measured in the area, but it is common for groundwater to follow topography. If so, groundwater flow would likely trend to the southeast to southwest similar to the

washes and ephemeral creek beds around the Grace ISL and Section 13 Mines and to the Rio Puerco. The southeast-to-southwest flow direction would be most true for very shallow groundwater and surface water infiltration. However, it has been noted that the regional dip to the north and a northeasterly striking fracture system influence groundwater flow in the area around and north of the mines. An historic piezometric map for the upper Gallup also suggests a northeasterly flow direction. The regional dip lessens just south of the NE Church Rock Mines, and groundwater may then follow the direction of drainage basins to the south and toward the Rio Puerco. However, depth to water data are insufficient around and to the south of the mines to conclusively determine the directional flow and gradient of groundwater.

Under normal favorable conditions such as coarse soil, fresh oxidizing rainwater can leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down to groundwater. Given the very slow infiltration rates and shallow impermeable rock immediately beneath the thin mantle of soil in the Church Rock Mining District and the lack of surface disturbance at Grace ISL and Section 13 Mines, very little uranium is likely to be picked up from waste rock and infiltrate down to groundwater in the Morrison Formation.

Rainwater and mine waters can also flow through the wastes and into washes and ephemeral streams at the surface, which then may migrate down into the groundwater as it flows through the creeks. While this effect is less likely at Grace ISL and Section 13 Mines because of their limited dewatering, the creeks downgradient of the mines that were extensively dewatered are particularly susceptible because water pumped from the mines was discharged directly to the streams without treatment. Sediment may have been deposited in the streams and may persist as a long-term source of uranium to surface water. The water itself might also infiltrate to groundwater and disperse with regional flow.

When operations were discontinued, rainwater and groundwater refill the mine workings, allowing some leaching and transport of uranium. The dissolution would have been temporary because resaturation of the mine workings would convert the exposed surfaces from unsaturated to saturated, limiting further dissolution (MWH, 2003), and the prior reduced environment, in which uranium is at equilibrium with the chemistry of the rock and water, would be reestablished. Uneroded ore deposits near and downstream of the mines may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

Remnants of the original ore deposits that were not completely mined out in the 1970s and 1980s are likely below the oxidizing groundwater table, allowing leaching of metals (including uranium) from the ore deposit (Figure 23). However, organic- (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidation/reduction interface and redistributing uranium locally. Additionally, cross-bedding, secondary

calcium carbonate cementation, and clays within the sandstone may impede dispersion of uranium. Adsorption of uranium onto clays occurs in the pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. Given the relative small volume of uranium distributed in the deposits at the Grace ISL Mine and these conditions, little uranium is likely to migrate far from the site. Ore at the Section 13 Mine is somewhat larger in scale, so that some uranium resulting from the groundwater interaction with ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

No water samples were collected adjacent to or directly upstream from the Grace ISL and Section 13 Mines. Uranium concentrations downstream of the Church Rock Mines but upstream of the Grace ISL and Section 13 Mine indicate that uranium is leaching, as evidenced by uranium concentrations of 110 µg/L in the sample from Becenti Trail Spring and 6.99 µg/L in the sample from well 16T-606. Results of the water samples from the main drainage system suggest that little uranium is leaching downstream of the mines, as evidenced by a uranium concentration of 2.92 µg/L in the downgradient water sample from well 16K-340 along the north fork of Rio Puerco. Some uranium may be leaching from mines; however, secondary deposition and adsorption is probably keeping most of the uranium within areas immediately around the mines.

The higher uranium concentration in the sample collected upstream from where the drainage on which Grace ISL Mine is situated meets the Rio Puerco and downstream of where the drainage on which the Section 13 Mine is situated meets the Rio Puerco (Becenti Trail Spring) may suggest stratigraphic variance of water flow. The depth to water at the Becenti Trail Spring is only 12 feet bgs, and the water source is likely to be influenced by surface runoff from sediment nearby and from along the Rio Puerco. Little surface disturbance is expected at the Grace ISL and Section 13 Mines because of the limited mining and method of extraction, thus the uranium concentration may reflect surface runoff from sediment off of the Church Rock Mine and possibly from uranium-bearing sediment along the Rio Puerco deposited from previous dewatering.

Well 16T-606 is drilled into the Dakota Sandstone to a depth of 417 feet, and the depth to groundwater was measured at 79 feet bgs in July 1980. Potential sources for uranium migration into the well may be from neighboring groundwater, rather than surface and rainwater recharge because infiltration rates in the area are slow. Uranium concentrations probably reflect the uranium being carried in solution from the ore at Church Rock Mine and Section 16 Deposit because of the proximity of well 16T-606 to the mines and are not likely to be attributable to the Grace ISL and Section 13 Mines.

Uranium concentrations exceeding the MCL were detected in samples collected from Becenti Trail Spring (110 µg/L), from location 1082366 (1,007.4 µg/L), from the well at Church Rock Mill (70 µg/L), and from well 16-4-10 (69.37 µg/L and 260 µg/L). As discussed above, uranium in the Becenti Trail Spring sample is likely influenced by surface runoff, sediments in the stream deposited when mine waters were pumped directly to the stream, and sporadic flow along Rio Puerco. Well depths are unknown for sample location 1082366, well at Church Rock Mill, and well 16-4-10. One of the four water sources in the area with a uranium concentration greater than the MCL (well 16-4-10 with a uranium concentration of 260 µg/L) is less than 3 miles southeast of the Grace ISL Mine. Although this location may be in the direction of flow of surface waters and groundwater, the lower concentration of uranium detected in samples collected from well 16K-340 (2.92 µg/L) less than 1 mile south of the Grace ISL Mine and from sample location 1081956 (2.62 µg/L) just over 2 miles southeast of the Grace ISL Mine indicates elevated concentrations of uranium in well 16-4-10 are likely from a different source, either unmined ore deposits or other AUMs from adjacent drainages.

K2.2.3. Groundwater Pathway Conclusion

Data are insufficient to accurately determine the direction of groundwater flow around the mines; however, it may flow down dip to the north or northeast in deep aquifers beneath and to the north of the mines, where the regional dip to the north is pronounced, and to the southwest in flow in the shallow subsurface and in deeper units to the south of the mines, where the regional dip to the north is not as pronounced.

Groundwater contours in drainage basins for the Rio Puerco tend to be aligned with the flow direction of the drainage basin. As a result, it is likely that the direction of shallow groundwater flow south of the Grace ISL and Section 13 Mines is toward the southwest. The boundary of the watershed is north of the mines, and the proximity of the mines to the boundary is likely the cause of the low upstream uranium concentrations, where little upstream contribution to uranium concentrations would be expected and little uranium would leach from the reduced environment of mine workings in deeper units where groundwater flows to the northeast.

The uranium concentrations of samples from close wells (such as well 16K-340) southeast of the mines have uranium concentrations exceed possible background concentrations but are less than the MCL. Well 16-4-10, with a uranium concentration exceeding the MCL, is less than 4 miles southeast of the Grace ISL and Section 13 Mines. However, water samples from sample location 1081956 and well 16K-340, collected between the mines and well 16-4-10, had lower uranium concentrations than the sample from well 16-4-10. Well 16-4-10 is also south of the Rio Puerco in a different drainage basin.

If groundwater flow follows topography and trends to the south-southwest, the lower concentration (2.92 µg/L) of uranium detected in well 16K-340, located less than 1 mile south of the Grace ISL Mine,

indicates the elevated concentration of uranium in well 16-4-10 is from a different source (e.g., unmined ore deposits or other AUMs farther downstream or from adjacent drainages). If the groundwater flow is to the northeast, as indicated by regional dip effect and historic piezometric map, then samples collected from location 1082366 and Church Rock Mill may reflect some influence from uranium migrating from the southwest (including the Church Rock Mine), as well as some effect from Church Rock Mill. The distance from the sample locations and geologic conditions at the Grace ISL and Section 13 Mines make them less likely to contribute to the elevated uranium concentrations in the locations sampled. None of the wells are intended to be used for drinking water, although community feedback has confirmed that the wells are used for drinking water (EPA, 2009a).

K2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Grace ISL and Section 13 Mines enters a drainage system within the Lower Colorado, including the Rio Puerco. The Rio Puerco runs just southeast of the mines toward the west, where it meets up with the Little Colorado River and eventually with the Colorado River.

As discussed above in Subsection K2.2.2, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick and water infiltration is fast but limited in volume through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediment rather than running off into the creek beds. The area is characterized by slow to very slow infiltration and moderate to moderately slow permeability; as a result, runoff to streams is possible, rather than infiltrating deeper. Sediment from water discharged directly to the streams from dewatering the mines likely persists throughout the drainage, and subsequent stream flow may leach uranium from the sediment. However, surface disturbances or waste rock piles are not expected to be present at the Grace ISL and Section 13 Mines, limiting the source for uranium to migrate in surface water.

K2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the Pipeline Arroyo or the north fork of the Rio Puerco near the mines or within 4 miles downstream of the mines. However, the unincorporated town of Church Rock is less than 5 miles to the south; no known drinking water intakes or fisheries are listed for Church Rock.

Uranium was detected in the sample from the shallow water source (Becenti Trail Spring) downstream of the Section 13 Mine at a concentration exceeding the MCL. The exceedance suggests that uranium is present in solution in the near subsurface. The Becenti Trail Spring is approximately 1 mile downstream of the Section 13 Mine, suggesting the potential exists for uranium migration from the Section 13 Mine; however, very little surface disturbance would be expected in association with the limited ISL mining at Grace ISL and Section 13 Mines.

K2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Grace ISL and Section 13 Mines for the following reasons:

- Most of the known contamination is confined to the site, and concentrations off site that may be attributable to the mines are less than the respective MCLs.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site.

K2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during that period.

The Grace ISL and Section 13 Mines are in the Eastern Region, specifically the Church Rock Mining District of the Grants Uranium Region. Mining in the area peaked in the 1970s and 1980s. Uranium and vanadium were mined in this region, primarily from ore deposits of the Dakota Sandstone and Westwater Canyon and Brushy Basin Members of the Morrison Formation. The Westwater Canyon Member was created by aggrading braided streams, which formed an alluvial plain and ranges from 0 to 220 feet thick. Uranium ore deposits in the shape of lenses can be found in the ancient channels. Organic plant matter is

present in the channel sediment. EPA lists the Grace ISL Mine as very small productive mine (with production limited to 1975) and the Section 13 Mine as a non-productive AUM (EPA, 2007c); both mines were considered to have ore deposits below the water table or were considered wet mines that required pumping.

The Church Rock Mining District is drained by ephemeral streams forming tributaries to the Rio Puerco. The Grace ISL and Section 13 Mines are west of the north fork of the Rio Puerco that runs approximately northeast to southwest.

The following pertinent HRS factors are associated with the Grace ISL and Section 13 Mines:

- Uranium migration is expected to be minimal in surface flow and at depth because of the type of mining at the mines, the low permeability and slow infiltration rates of soil, and limited scale of operations at the mines.
- Deep groundwater may flow down a regional dip toward the north beneath and north of the Church Rock Mines, and an historic piezometric map of upper Gallup shows flow toward the northeast. A review of groundwater analytical results from wells collected to the north of the mines (16T-606 and 14K-586) indicated uranium concentrations are orders of magnitude less than the MCL and are likely to be more influenced by Church Rock Mine and NE Church Rock Mine, respectively.
- The pilot tests for ISL may not have been highly efficient because the humates associated with the primary ore deposit prevented uranium from leaching; these same humates may also limit uranium that might otherwise leach into groundwater from dispersing far from the ore deposit itself.
- Uranium concentrations exceeding the MCL were detected in groundwater samples in four water sources (sample location 1082366, well at Church Rock Mill, well 16-4-10, and Becenti Trail Spring) to the northeast and southwest of the mines. Sample location 1082366 and well 16-4-10 are on adjacent drainage systems, at elevations above the Pipeline Arroyo or Rio Puerco and of unknown depths. The conflicting groundwater flow directions make it difficult to determine which of the locations is downgradient from the mines.
- The shallow Becenti Trail Spring is downstream of the Section 13 Mine and upstream of the drainage system on which the Grace ISL Mine is situated that feeds into Rio Puerco. Results indicated that some uranium may be migrating from the surface of mines in the area through shallow subsurface and surface flow to the southwest to this spring. The lack of surface sources, however, expected at the Section 13 and Grace ISL Mines make them unlikely sources for the uranium contamination.
- None of the wells are regulated.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Grace ISL and Section 13 Mines.

**Appendix L. NE Church Rock, NE Church Rock No. 1,
NE Church Rock No. 1 East and NE
Church Rock No. 2 Mines Groundwater
Pathway Assessment**

Appendix L
NE Church Rock, NE Church Rock No. 1, NE Church Rock
No. 1 East and NE Church Rock No. 2 Mines
Groundwater Pathway Assessment

April 2010

TDD No.: TO1-09-08-02-0001

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Prepared for:

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Section L1. Mine and Groundwater Investigation

L1.1. LOCATIONS

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). Four of these AUMs (NE Church Rock, NE Church Rock No. 1, NE Church Rock No. 1 East, and NE Church Rock No. 2 Mines, collectively referred to as the NE Church Rock Mines) are located in Eastern Region of the Navajo Nation in McKinley County of New Mexico, approximately 11 miles northeast of Church Rock and 16 miles northeast of Gallup, New Mexico. The four AUMs are in the Church Rock Mining District of the Grants Uranium Region (Figure 9). The specific locations by township and range (with latitudes and longitudes) for each of the mines are as follows:

- NE Church Rock Mine at 17N.16W.35.200 (35°39'30"N 108°30'30"W)
- NE Church Rock No. 1 Mine at 17N.16W.35.200 (35°40'00"N 108°30'5"W)
- NE Church Rock No. 1 East Mine at 17N.16W.36.100 (35°39'55"N 108°29'50"W)
- NE Church Rock No. 2 Mine at 17N.16W.27.200 (35°40'45"N 108°31'40"W)

L1.1.1. Local Hydrogeology and Geology

The NE Church Rock Mines are in the Little Colorado subregion in the Lower Colorado watershed, specifically within the Upper Puerco hydrologic unit. The Pipeline Arroyo, an ephemeral stream, is just east of the mines and runs northeast to southwest into the north fork of the Rio Puerco (Puerco River), another ephemeral stream that drains more than 3,000 square miles in northwestern New Mexico and northeastern Arizona (Southwest Research and Information Center [SRIC], 1992).

L1.1.1.1. Precipitation

Average annual precipitation in the area around the four mines is 12 to 16 inches (see Average Annual Precipitation Map for Church Rock Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

L1.1.1.2. Soils and Permeability

Soil near the four mines is characterized hydrologically by very slow infiltration rates (see the Hydrologic Group Map for Church Rock Area in Appendix A). Soil in this area is either clayey with a high water table or shallow soil overlying an impervious layer. Permeability in the area is moderately slow on average, between 0.21 and 0.60 inches per hour (see the Permeability Map for Church Rock Area in Appendix A; EPA, 2007c). In addition, the volume of rainfall during storms can exceed the capacity of soil to transmit water and produce more runoff than infiltration.

L1.1.1.3. Aquifer Sensitivity

Aquifer sensitivity within the area of the NE Church Rock Mines ranges from insignificant potential to intermediate potential for contaminate migration (see the Aquifer Sensitivity Map for Church Rock area in Appendix A; EPA, 2007c). The NE Church Rock Mines are located along a drainage system (part of the Rio Puerco) that runs approximately northeast to southwest. Aquifer sensitivity for the NE Church Rock Mines ranges from insignificant contaminant migration upstream and surrounding the mines to intermediate potential downstream of the mines. Aquifer sensitivity for NE Church Rock Mine No. 1 and NE Church Rock Mine No.1-East Mines is of insignificant potential around and downstream of the mines. The aquifer sensitivity for the NE Church Rock No. 2 Mine ranges from insignificant potential for contaminant migration upstream and surrounding the mine to intermediate potential downstream from the mine.

L1.1.1.4. Dewatering

Beginning in 1960, uranium was mined near Pipeline Arroyo, the small tributary to the Rio Puerco northeast of Gallup, New Mexico. Because the ore deposits that were mined were below the regional water table, water seeping into shafts was pumped to prevent flooding. From 1967 to 1986, the discharge rate from mine dewatering averaged approximately 0.25 cubic meters per second, which created continuous flow in the Rio Puerco from the mouth of the Pipeline Arroyo to as far as a few kilometers downstream of Chambers, Arizona (Van Metre et al., 1997).

Before the mid-1970s, untreated effluent was discharged directly to Pipeline Arroyo. During the mid-1970s, effluent was treated to improve the quality of discharged mine waters. Effluent was treated using a flocculent to reduce suspended solids, and dissolved uranium was removed by using ion-exchange treatment. The treatment reduced concentrations of uranium by approximately 85 percent from a flow-weighted average of 7,250 micrograms per liter ($\mu\text{g/L}$) in 1975 to 1,000 $\mu\text{g/L}$ in 1982. Mining ceased in 1985, and mine dewatering subsequently ceased in February 1986. Approximately 140 million cubic meters of mine-dewatering effluent was discharged to Pipeline Arroyo from 1960 to 1961 and 1967 to 1986; the mine dewatering was primarily from the Westwater Canyon Member of the Morrison

Formation (Van Metre et al., 1997). Since 1986, when discharges of uranium mine-dewatering effluent ceased, the Rio Puerco has resumed its ephemeral nature (SRIC, 1992). From August 1988 until June 1991, the base flow was observed and estimated to be less than 0.01 cubic meter per second at Rio Puerco location near Church Rock, where bedrock crops out in the channel and forms a waterfall from 2 to 3 meters high (Van Metre et al., 1997).

On July 16, 1979, a tailings pond dike failed at the United Nuclear Corporation uranium mill downgradient from the NE Church Rock Mines and adjacent to the Pipeline Arroyo. An estimated 360,000 cubic meters of mine-tailings liquid and 1,000 metric tons of tailings were discharged into the Rio Puerco via the Pipeline Arroyo. The pH of the liquid was about 1.9 (highly acidic), and the total gross alpha activity was estimated at 130,000 picocuries per liter (pCi/L), greater than EPA's maximum contaminant level (MCL) of 15 pCi/L (EPA, 2009e). Uranium was measured in samples of water from the tailings pond and in the Rio Puerco at concentrations of 4,100 $\mu\text{g/L}$ on February 5, 1979, prior to failure of the dike, and at 6,500 $\mu\text{g/L}$ on July 16, 1979, respectively (Van Metre et al., 1997). The volume of the spill was about 6 percent of the volume released in a typical year by mine dewatering and about 28 percent of the average annual runoff in 1990 and 1991 at the Church Rock gauging station. The average annual volume of dewatering effluent from 1967 to 1986 (6.4×10^6 cubic meters) was about five times the average runoff per year (1.3×10^6 cubic meters) at the Church Rock gauging station for 1990 to 1991 (Graf, et al., 1996).

L1.1.1.5. Surface Water and Groundwater

The mines are located upgradient or adjacent to the Pipeline Arroyo which feeds into the north fork of the Rio Puerco; the north fork of the Rio Puerco runs approximately northeast to southwest. Under natural conditions, the Rio Puerco is an ephemeral stream that flows with runoff from spring snowmelt and brief, intense summer thunderstorms. As in Subsection L1.1.1.4, flow in some reaches of the river changed from ephemeral to perennial when effluent from the uranium mines and the sewage treatment plant at Gallup, New Mexico were discharged into it (Van Metre et al., 1997).

Mine dewatering caused large drawdowns in bedrock formations underlying the alluvia aquifer in the Church Rock reach. In 1968, the water level in an abandoned mine shaft near Pipeline Arroyo in the Dakota and Morrison Formations was reported to be 35 meters (approximately 115 feet) below the land surface (Hiss, 1977). Water had to be pumped from the mines continuously to keep the tunnels and shafts dry. Groundwater was pumped at rate of approximately 3,000 gallons per minute (gpm) from the Morrison Formation at NE Church Rock and NE Church Rock No. 1 Mines in November 1973; pumping had increased to 4,400 gpm by 1977. The water was pumped to the land surface and into settling ponds, where it was treated with barium chloride to remove suspended solids; it was then allowed to flow from ponds into formerly dry tributaries of the Rio Puerco (Hiss, 1977).

Water levels in the shaft of Church Rock Mine to the south declined from between 220 and 230 feet below ground surface (bgs) in January 1970 to greater than 320 feet bgs by January 1975. The water levels are listed for United Nuclear Corp. Northeast Church Rock Mine by Hiss (1977), but the location is in Section 17 of Township 16 North, Range 16 West, which is the location of Church Rock Mine. The water level prior to the start of dewatering in October 1968 during sinking of a new uranium mine shaft in Section 35 of Township 17 North, Range 16 West (which is consistent with location and development of the NE Church Rock Mine) was reported to be 144 feet bgs (Hiss, 1977).

Data are insufficient to accurately determine the direction of groundwater flow surrounding the mines. While some depth-to-water readings have been recorded, determining the groundwater gradient is difficult because the wells were screened in different aquifers and measurements were collected on different dates, often years apart. For example, depths to water were measured in wells 14K-313, KM CR II G-1, and 15T-303, which are all drilled into the aquifer listed as 211GLLP (probably the Gallup Sandstone). The dates of measurement, however, are September 2, 1953; April 24, 1980; and January 1, 1953, respectively.

Similarly, depths to water were measured in two wells, 16T-510 and 16T-606, accessing the 211DKOT aquifer (EPA, 2009d); the 211DKOT aquifer probably refers to the Dakota Sandstone. Kerr-McGee Corporation (1976) also list wells 16T-513 and 16T-534 as accessing the Dakota Sandstone along with the Westwater Canyon Member. The measurements for the four wells were taken many years apart: on August 30, 1960; July 3, 1980; July 27, 1959; and July 29, 1965, respectively. Thus, the lack of measurements from similar dates in wells drilled in the same aquifers makes the groundwater gradient and flow direction difficult to calculate. Depths to water were measured in three of the wells (16T-510, 16T-513, and 16T-534) during summer months within a 6-year period prior to the height of mining activities in the area. Based on well elevations and depths to water, the groundwater elevations in the three wells were 6,714.5 feet above mean sea level (msl), 6,693 feet above msl, and 6,575 feet above msl, respectively. The elevations suggest groundwater flows in a general south-to-southwest direction.

Groundwater contours in surrounding drainage basins for the Rio Puerco tend to be aligned with the flow direction of the drainage basin. As a result, it is likely that, at a minimum, near-surface groundwater and rainfall infiltration around the Church Rock Mines flow toward the southwest.

Groundwater Wells and Water Sources

Several wells or locations from which samples were collected in the area (Figure 16), include the following:

- Wells KM CR II G-1, KM CR II G-2, KM CR II G-3, and KM CR II W-2 at NE Church Rock No. 2 Mine
- Well 15T-303 along Pipeline Arroyo upgradient of NE Church Rock No. 1 East Mine
- Sample location 1082213, approximately 6.25 miles upgradient of well 15T-303 on a separate drainage running north
- Well 14K-586 (G00012; Friendship I; possibly same as 14T-586) in the vicinity of NE Church Rock Mine
- Church Rock Mill Well adjacent to Church Rock Mill and Pipeline Arroyo
- Sample location 1082366 on the drainage feeding into Pipeline Arroyo, to the east of Church Rock Mill
- Wells 16T-606 (probably the same as G00026) and 16T-532 at Church Rock Mine, downgradient of Church Rock ISL (“in-situ leaching”) Mine
- Well 16T-513 (16N 16W 15 4322; Uphill Road Windmill; sample location 1081952)
- Wells Grey, 16-3-4 (Keith Begay Well; possibly the same as sample location 1081851), 16T-348 (Lobo Valley; sample location 1082365) along Rio Puerco before it meets with Pipeline Arroyo (south of NE Church Rock Mines and northeast of Church Rock Mine)
- Well 16T-514 (Pinedale Chapter House) south of Rio Puerco before it meets up with Pipeline Arroyo
- Becenti Trail Spring, approximately 2.5 miles southwest and downstream of Church Rock Mine along North Fork of Rio Puerco
- Wells G 01100S-2, G 01100S, G 01100 (sample location 1081956), and 16-4-10 (Lime Ridge), and sample location 1081955, along the drainage system running north into Rio Puerco and downgradient of where the Pipeline Arroyo runs into Rio Puerco
- Well 16K-340 (sample location 1081954) along Rio Puerco, downgradient of Church Rock, Section 16, Grace ISL, and Section 13 Mines and where it meets Pipeline Arroyo
- Well 16K-336 (Puerco No. Fork) along Rio Puerco, farther downgradient of Church Rock Mine
- Well 14K-313 (Brown Bull; sample location 1082210) in adjacent Hard Ground Canyon to the west of the NE Church Rock Mine and Pipeline Arroyo
- Sample location 1081950 on the drainage feeding into Hard Ground Canyon to the west of NE Church Rock and Pipeline Arroyo
- Well 16T-510 (Nose Rock; sample location 1081953) in adjacent Hard Ground Canyon to the west of the Section 13 Mine and the Rio Puerco
- Well 16T-534 (Superman Cyn.; NR106.0820X1070) on the hillside northwest of where Hard Ground Canyon meets Rio Puerco (EPA, 2009d)

Groundwater Chemistry

Water samples were collected from some of the wells in the area, and pH and conductivity were measured in 1977, 1978, 1979, and 2008. The pH of the water samples ranged from 5.5 in sample 1082366 (although this appears anomalous in comparison with other pHs measured) to 9.01 in the sample from

well 16T-510, averaging approximately 7.5. Specific conductivity ranged from 5 micromhos per centimeter in sample 1082365 collected in 1979 (which may be inaccurately reported) to 2,890 micromhos per centimeter in a sample collected from Well 15T-303 in 2008 (EPA, 2009d), averaging approximately 1,170 micromhos per centimeter.

When mining and associated dewatering were discontinued at the mines, the underground mine workings were flooded (Figure 23). At that time, oxidized surfaces of the mine workings could have potentially released soluble constituents, including uranium, into groundwater causing temporary local impact to water quality. This dissolution would have been temporary because resaturation of the mine workings would convert the exposed surfaces from unsaturated to saturated, limiting further dissolution (MWH, 2003), and prior reduced environment equilibrium would be reestablished.

Water parameters and chemistry were measured for snowmelt and storm runoff in Rio Puerco; these surface runoff samples were collected by U.S. Geological Survey as composite cross-section samples or point samples at stream-flow gauging stations near Church Rock and Manuelito, New Mexico, and Chambers, Arizona, between August 31, 1988 and October 20, 1990. Specific conductivity, pH, gross alpha activity, and uranium concentration ranged from 456 to 1,980 microSiemens per centimeter, 7.4 to 8.1, 4.4 to 21 pCi/L, and 1.9 to 13 µg/L, respectively (Graf, et al., 1996).

Geology and Groundwater

Uranium ore deposits of the Grants Uranium Region are found in the sandstones of the Westwater Canyon and Brushy Basin members of the Morrison Formation, which is from the Jurassic Period. The Westwater Canyon Member was deposited as a broad alluvial fan by aggrading braided streams and ranges from 220 to 270 feet thick. The Brushy Basin Member overlies the Westwater Canyon member and consists of mudstone formed from volcanic ash falls. The member is very thin near the Church Rock Mines, and is not considered a major source of uranium, unlike other areas in the Grants Region Mining District. Overlying the Morrison Formation with a slight angular unconformity is the 70- to 180-foot-thick Dakota Sandstone, which is from the Cretaceous Period. The rocks of the Morrison Formation dip less than 5 degrees to the north and are exposed at the surface near Hwy 40, approximately 2 miles south of the Church Rock Mines.

The regional dip of the sedimentary rocks is northward, the Nutria monocline, which is a secondary feature that aligns east-west in the southern part of T. 17 N., R. 16 W, forms the southern edge of Mesa de los Lobos. The rock sequence has been fractured by faults that strike northeasterly strike and trend slightly to northwest. Displacement of stratigraphy varies but in general is less than a few tens of feet (Kerr-McGee Corporation, 1976). Kerr-McGee Corporation (1976) describe the Nutria monocline as being in southern part of T. 17 N., R. 16. W. Van Metre et al. (1997), however, describe the Nutria monocline as being about 5 kilometers east of Gallup where it forms a groundwater divide for the

regional flow systems. Recharge that occurs east of the monocline flows in a north-northeastward direction toward the San Juan Basin, and recharge west of the monocline flows in westward direction (Van Metre et al., 1997).

Groundwater occurs in most of the Cretaceous sandstones (i.e., Dakota, Gallup, and Crevasse Canyon Formations) beneath the Mesa de los Lobos, and nearly all yield some water, although the amount is variable. The pre-Cretaceous rock outcrops comprise a narrow east-west belt that forms the southern outline of the San Juan Basin. The narrow exposures are tilted northward, ranging from 3 to 30 degrees and occur at elevations of 6,500 feet above mean sea level (msl). Recharge water from rainfall infiltrates downward to the water table and then downgradient, generally northward in the areas north of the mines, similar to the regional dip to the north. In general, pre-Cretaceous sandstone aquifers have a low permeability and the yields are relatively small (Kerr-McGee Corporation, 1976).

A historic piezometric surface map for Upper Gallup Sandstone shows a northeast flow direction (EPA, 2010). The flow direction illustrated on the piezometric surface map for deeper aquifer might suggest that, although surface and shallow subsurface water flow might follow topography, deeper groundwater flow trends toward the north, following the regional dip in the area of the NE Church Rock Mines. South of the mines, the regional dip is more gentle (EPA, 2010), and groundwater is not as likely to be affected by the dip. Near the NE Church Rock Mines, the direction of surface water flow, when present, would be from west to east along an unnamed wash near the mines into the northeast- to southwest-trending Pipeline Arroyo.

L1.2. REGIONAL AND DETAILED MINE BACKGROUND

The uranium ore deposits in the Westwater Canyon Member are unoxidized. Uraninite (uranium oxide) is the principal uranium mineral and is accompanied by montrosite (vanadium oxide) and coffinite (uranium-bearing silicate mineral) (Granger, 1963).

L1.2.1. NE Church Rock Mines Ore Deposits

Uranium from the NE Church Rock No. 1 and NE Church Rock No. 1 East was mined from one ore body that runs approximately east to west. Fishman and Reynolds (1983) state that ore in the NE Church Rock No. 1 and NE Church Rock No. 1 East Mines occurs in three sandstone units in the upper portion of the Westwater Canyon Member of the Morrison Formation, all of which occur below the pre-mining groundwater table (Fishman and Reynolds, 1983). The rocks of the Westwater Canyon Member are principally medium- to coarse-grained, arkosic sandstones. Each unit is separated from others by mudstone units of variable thicknesses. According to the Church Rock Uranium Monitoring Project (CRUMP), the Westwater Canyon Member is also known as a high-quality drinking water aquifer that serves at least 13,145 people (CRUMP, 2007).

The organic carbon contents of the ore samples are uniformly low, in contrast with primary (tabular) uranium ore bodies in the Grants Uranium Region. The differences, together with radiometric dating, suggest ore of the NE Church Rock Mines is redistributed. However, the concentration of sulfur and vanadium in the deposits differ geochemically from other redistributed ore bodies in the Westwater Canyon Member, and the deposits are thought to be somewhat younger than other redistributed ore bodies in the Westwater (Fishman and Reynolds, 1983).

L1.2.2. NE Church Rock Mines

Uranium mining began as early as the 1950s in the Church Rock Mining District, often as open pit or “caved pits” or underground declines that followed the northward and downward tilt of the sedimentary rocks near the surface. Development of the NE Church Rock Mine began in 1968 and in the other NE Church Rock mines in the 1970s (CRUMP, 2007).

NE Church Rock Mine operated as an underground “room-and-pillar” mine accessed by two vertical shafts; the production start date is listed as 1972 (EPA, 2007c). NE Church Rock No. 1 Mine was an underground mine that operated from 1972 to 1986. Uranium was mine at the NE Church Rock No. 1 East from 1979 to 1985 through the eastern shaft, which connected to continuous underground complex with NE Church Rock No. 1 Mine. NE Church Rock No. 2 Mine was for waste dumps only and operated from 1978 to 1982 (CRUMP, 2007). EPA (2007c) lists the production periods for the NE Church Rock No. 1 Mine and NE Church Rock No. 1 East Mine as 1976 to 1985 and 1978 to 1983, respectively. Discrepancies may be due to mining operations occurring simultaneously for one underground complex through the two mines.

L1.2.2.1. NE Church Rock Mine

The NE Church Rock Mine covers approximately 150 acres on a mesa to the south of 14 residences in the Red Water Pond Road area (SRIC, 2007). The NE Church Rock Mine is located at an elevation of 7,040 feet above msl (McLemore, 1983).

NE Church Rock Mine operated as an underground “room-and-pillar” mine accessed by two vertical shafts; the production start date is listed as 1972 (EPA, 2007c). The mine comprises a 1,793-foot-deep main shaft and a second shaft that were mined with tracked equipment. Ore is redistributed or “stack,” down dip from and adjacent to oxidized sandstone; the ore is fracture- and fault-related and trends N45°E. It is cumulatively approximately 9 to 26 feet thick in two horizons. The ore is mostly coffinite and has an average grade of 0.20 percent U_3O_8 . Groundwater flow was measured at 2,000 gpm (McLemore, 1983).

NE Church Rock Mine produced 3,498,648 tons of ore, with an average grade of 0.14 percent U_3O_8 . Production at the mine started in 1972, and the mine was closed in 1982 (EPA, 2007c). The reclamation

status for the NE Church Rock Mine is unknown; it is also unknown whether any unreclaimed waste piles remain at the mine (see the Reclamation Status and Unmapped Waste Piles Map for the Church Rock area in Appendix A; EPA, 2007c). However, it has been noted that the buildings and tailings at the NE Church Rock Mine were removed in the 1990s and that waste dumps and mine ponds still remain (CRUMP, 2007). Closure consisted of removing buildings, sealing shafts, and removing uranium mill tailings that had been brought to the site from the nearby Church Rock Mill. The waste dumps at the site are uncovered and unreclaimed. They form a bench about 50 feet high and are between 500 and 600 feet from the nearest Navajo residence (SRIC, 2007).

L1.2.2.2. NE Church Rock No. 1 and NE Church Rock No. 1 East Mines

The NE Church Rock Mine No. 1 Mine covers approximately 80 acres on a ledge on the northeast side of the valley and is located approximately 1,000 feet east of one of the 14 residences in the area (SRIC, 2007). The NE Church Rock No. 1 Mine is located at an elevation of 7,112 feet above msl (McLemore, 1983).

NE Church Rock No. 1 Mine was an underground mine that operated from 1972 to 1986; ore at the NE Church Rock No. 1 East was mined from 1979 to 1985 through the eastern shaft which connected to continuous underground complex with NE Church Rock No. 1 Mine (CRUMP, 2007). The mine comprises a 1,851-foot deep shaft, mined with track equipment with room and pillar design. Ore is primarily multilayered and flat-lying, with a primary tabular trend of coffinite deposits in reduced sandstones; deposits are approximately 8 feet thick, 100 to 500 feet long, and 50 to 250 feet wide. NE Church Rock No. 1 Mine produced 836,570 tons of uranium ore, with an average grade of 0.18percent U_3O_8 (McLemore, 1983). The mine opened in 1976 and closed in 1985.

The NE Church Rock No. 1 East Mine is located at an elevation of 7,110 feet above msl. The mine comprises a 1,635-foot-deep shaft, mined with track equipment. Ore is primarily multilayered and flat-lying, with a primary tabular trend of coffinite deposits in reduced sandstones; deposits are approximately 8 to 15 feet thick. NE Church Rock No. 1 East Mine produced 322,602 tons of ore, with an average grade of 0.19percent U_3O_8 (McLemore, 1983). The mine opened in 1978 and closed in 1983 (EPA, 2007c).

The reclamation statuses for the NE Church Rock No. 1 and NE Church Rock No. 1 East and whether any unreclaimed waste piles remain at the mines are unknown (see the Reclamation Status and Unmapped Waste Piles Map for Church Rock area in Appendix A; EPA, 2007c). However, it has been noted that NE Church Rock Mine No. 1 had been reclaimed by Quivira Mining pursuant to the Bureau of Land Management, and that the headframe for NE Church Rock No. 1 East Mine had been removed (CRUMP, 2007).

L1.2.2.3. NE Church Rock No. 2 Mine

Although a deep shaft was proposed at the NE Church Rock No. 2 Mine site, the ore body was never developed (EPA, 2007c). NE Church Rock No. 2 Mine is at an elevation of 7,350 feet above msl. The mine was proposed as a 2,300-foot-deep four-compartment shaft. Ore is primarily multilayered and flat-lying coffinite deposits in a tabular trend occur in reduced sandstones and have an average grade of 0.19 percent U_3O_8 (McLemore, 1983). NE Church Rock No. 2 Mine was used for waste removal and dumping only and operated from 1978 to 1982 (CRUMP, 2007).

L1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

L1.3.1. Aerial Radiation Contours

In 1988, the U.S. Geological Survey (USGS) produced an Aerial Gamma-Ray Contour Map of Regional Surface Concentrations of Uranium (Duval, 1988). A contour map delineating excess gamma ray activity in the Eastern Region was created from data collected during an aerial gamma-ray survey flown by USGS (Figure 21). To investigate regional surface concentrations of uranium, the aerial gamma-ray contour map (Figure 21) was studied, where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU) (Duval, 1998). The map contours represent values in percent.

The aerial gamma-ray contours identify concentrations across the region. Gamma-ray radiation is associated with uranium, and excess levels of gamma-ray activity are a good indicator of old mines and mining-related activities. A map of the aerial gamma-ray contour values illustrates higher gamma-ray radiation (up to 3.75 percent) in the vicinity of the NE Church Rock Mines. Background concentrations within McKinley County and adjacent counties ranged from 1.00 to 2.75 percent.

L1.3.2. NE Church Rock Mine Gamma Scan

In 2003, gamma radiation surveys were also performed by EPA's Radiation & Indoor Environments laboratory in Las Vegas, Nevada, using truck-mounted sodium-iodide detectors that "scan" the ground surface up to 200 feet from the van. During the surveys, gamma rates ranged from 10 to 15 microRoentgens per hour ($\mu R/hr$) in areas of the community, where no impacts from sources of radiation, particularly uranium ore or uranium mine wastes, were observed. Gamma rates increased around the north face of the mine waste dump, ranging from 30 $\mu R/hr$ around residences 600 feet from the waste dump to 300 $\mu R/hr$ at the base of the waste dump. Gamma rates ranged from 25 $\mu R/hr$ 1,000 feet from the waste dump to 120 $\mu R/hr$ within 150 feet of the waste dump along an unnamed arroyo into which mine water discharged during mining (SRIC, 2007).

The levels of gamma rays on the road running through the park were shown ranging from green to red; green represents the average background levels, and red represents levels higher than background; yellow is in between these two variables (Figure L-1). The elevated levels could be due to naturally occurring radioactive material or mining or both. The NE Church Rock Mine covers almost an entire drainage basin, and the survey crossed the mouth of the basin. The truck crossed an area immediately north of the NE Church Rock Mine and downstream of the drainage that drains the area around the mines. Figure L-1 indicates that average levels are found upstream of the creek that drains the area around the mines. However, after crossing the creek at the location where it enters a larger tributary, the gamma levels spike to red and remain at that level until the scan ends at the northeastern edge of the mine. The spike indicates high levels of uranium are in soil around the northern edge of the mine. The elevated levels could be from mining, but they could also be due to naturally high uranium levels in rocks. However, the elevated levels do not confirm that uranium is leaching into groundwater or finding its way into surface water. The limited scale of the scan makes it difficult to determine the extent of elevated gamma ray levels.

L1.3.3. Groundwater and Mine Water

Water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. W.L. Hiss collected water samples from NE Church Rock and NE Church Rock No. 1 Mines area in November 1973. From 1977 to 1979, Los Alamos Scientific Laboratory collected samples in the Church Rock Area at the NE Church Rock and NE Church Rock No. 1 Mines, as part of the National Uranium Resource Evaluation Program (NURE) during the hydrogeochemical and stream sediment reconnaissance phase. In July 2002, a water quality sample was collected from a domestic well in the Westwater Canyon Member in the area of the Church Rock Mill. In 2003 and 2004, Navajo Nation Environmental Protection Agency (NNEPA) collected samples under the CRUMP, and EPA collected samples in 2008 and 2009. Because the wells are unregulated water sources, limited or no information on well development is available and regular groundwater sampling is not conducted. Available analytical results summarized below are from limited grab groundwater sampling events.

L1.3.3.1. Analytical Results for 1973 Water Sampling in Vicinity of Church Rock

W.L. Hiss collected water samples from NE Church Rock and NE Church Rock No. 1 Mines area in November 1973. The samples were described as (1) a sample from a drill hole at end of C-3 drift, about

2,000 feet southwest of the mine shaft; (2) a sample from a drill hole near No. 1 vent hole in A-1 drift; and (3) a very turbid sample from the end of the wastewater discharge line at the settling pond. The concentrations of dissolved uranium in the samples were 264 µg/L, 31 µg/L, and 1,210 µg/L, respectively. All of the concentrations exceeded EPA's established MCL of 30 µg/L for uranium in drinking water; however, none of water from which the samples were collected was considered to be drinking water. The latitude and longitudes for the sample locations are listed as 35°39'26"N 108°30'28"W, 35°39'26"N 108°38'28"W, and 35°39'26"N 108°30'28"W, respectively (Hiss, 1977).

L1.3.3.2. Analytical Results for NURE 1977, 1978, and 1979 Sampling

From September 1977 to October 1979, NURE collected water samples in the Church Rock area; data from the samples have been compiled and transferred to a database by USGS. Samples 1081950, 1081951, 1081952, 1081953, 1081954, 1081955, and 1081956 were collected in September 1977; samples 1082210 and 1082213 were collected in October 1978; and samples 1082365 and 1082366 were collected in October 1979 (Figure 16; EPA, 2009d). Samples 1082365 and 1082366 were collected after the tailings spill in July 1979 from the Church Rock Mill (EPA, 2009d).

The sample (1082213) collected upgradient of the NE Church Rock Mines had a uranium concentration of 0.17 µg/L; the concentration does not appear to be associated with any AUMs in the area and may be background. Sample 1082366 was collected in 1979 from the drainage directly across Pipeline Arroyo from the Church Rock Mill (Figure 16); the concentration of uranium in the sample was 1,007.4 µg/L, which exceeded the MCL of 30 µg/L. The exceedance was the highest concentration detected in water samples collected from in the Church Rock area. Sample 1081954, collected in 1977 from well 16K-340 along the Pipeline Arroyo and downstream of the mines, had a uranium concentration of 2.4 µg/L (EPA, 2009d).

The following samples were collected in adjacent drainages:

- Samples 1081953, 1081950, and 1082210 collected in Hard Ground Canyon with uranium concentrations of 0.64 µg/L, 0.89 µg/L, and 1.46 µg/L, respectively
- Samples 1082365 and 1081951 collected along the north fork of the Rio Puerco to the southeast of mines with uranium concentrations of 0.95 µg/L and 0.22 µg/L, respectively
- Samples 1081952, 1081955, and 1081956 collected downstream in drainages feeding into the Pipeline Arroyo with uranium concentrations of 0.18 µg/L, 1.24 µg/L, and 2.62 µg/L, respectively (EPA, 2009d)

Sample locations for 1082366, 1081951, 1081952, 1081950, and 1082210 are within 4 miles of the NE Church Rock Mine, while sample locations for 1082365, 1081956, 1081955, 1081954, 1081953, and 1082213 are between approximately 4 to 8 miles from NE Church Rock Mine. The uranium mines were still operating when the water samples were collected in 1977, 1978, and 1979.

L1.3.3.3. Analytical Results for Church Rock Mill Sampling

In July 2002, a water quality sample was collected from a domestic well in the Westwater Canyon Member in the area of the Church Rock Mill, in Section 2. Dissolved uranium was detected at a concentration of 70 µg/L, and gross alpha activity was not measured at a level greater than the laboratory reporting limit of 1.0 pCi/L (MWH, 2003).

L1.3.3.4. Analytical Results for CRUMP 2003 Sampling

NNEPA and EPA collected 13 water samples near the Church Rock and NE Church Rock Mines in October 2003 under CRUMP. Ten of the wells are within 10 miles of the NE Church Rock Mines and were sampled for uranium. The following samples were collected from the 10 wells:

- Sample collected from well 15T-303 (listed as 15K-303) with a uranium concentration of 0.69 µg/L
- Sample collected from well 14K-586 with a uranium concentration of 3 µg/L
- Sample collected from well 16T-606 with a uranium concentration of 6.99 µg/L
- Sample collected from shallow well Grey with a uranium concentration of 14.84 µg/L
- Sample collected from well 16T-348 with a uranium concentration of 0.29 µg/L
- Sample collected from 16K-340 with a uranium concentration of 2.92 µg/L
- Sample collected from 16-4-10 with a uranium concentration of 69.37 µg/L
- Sample collected from well 14K-313 with a uranium concentration of 0.05 µg/L
- Sample collected from well 16T-534 with a uranium concentration of 0.15 µg/L
- Sample collected from 16K-336 with a uranium concentration of 0.57 µg/L (EPA, 2009d)

Wells 15T-303, 14K-586, 16T-606, Grey, and 14K-313 are within 4 miles of the mines, while the rest of the wells are between 4 and 10 miles from the mines. Of the samples collected from 13 wells for this study, only 1 groundwater sample, collected at well 16-4-10, had a uranium concentration greater than the MCL of 30 µg/L. Well 16-4-10 is approximately 7 miles downgradient of the NE Church Rock Mines. The samples were collected after mining had been discontinued at the NE Church Rock Mines.

During the CRUMP study, the water in many of the wells sampled was deemed unsuitable for human and domestic uses, based on various pollutants in and water quality parameters of the samples, not just uranium concentrations. These pollutants and water quality parameters included arsenic, iron, and selenium and sulfate, pH, total hardness, fluoride, chloride, and total dissolved solids (CRUMP, 2007).

L1.3.3.5. Analytical Results for NNEPA 2004 Sampling

NNEPA collected one water sample within the Eastern AUM Region. The gross alpha activity of the sample was 6.5 pCi/L, which is less than the EPA MCL of 15 pCi/L. The sample was collected from

water in the public water system at the Crownpoint Chapter House, and the source of water in the system is not within 4 miles of the NE Church Rock Mines and is within a different watershed.

L1.3.3.6. Analytical Results for EPA 2006 to 2009 Sampling

EPA collected and analyzed water samples from 2006 to 2009 from the following wells:

- Well 15K-303 with a uranium concentration of 0.38 µg/L
- Well 14T-586 with a uranium concentration of 1.5 µg/L
- Well 14K-313 with a uranium concentration less than the laboratory reporting limit
- Well Grey with a uranium concentration of 5.2 µg/L
- Well 16-4-10 with a uranium concentration of 260 µg/L
- Well 16-3-4 with a uranium concentration less than the laboratory reporting limit
- Well 16T-513 with uranium concentration less than the laboratory reporting limit
- Becenti Trail Spring with a uranium concentration of 110 µg/L

The uranium concentration in the sample collected from well 16-4-10 in 2008 exceeded the MCL of 30 µg/L, as did the Becenti Trail Spring sample collected in 2009. Both of the locations from which the samples were collected are outside a 4-mile radius from the NE Church Rock Mines. While Well 16-4-10 is downstream of the mines, it is along a different drainage running northwest into Rio Puerco. Without more information on the direction of groundwater flow, the relationship between the NE Church Rock Mines and the elevated uranium concentration in well 16-4-10 is difficult to establish. However, the distance from the mines, the lower uranium concentrations detected in samples collected between well 16-4-10 and the mines, and a location on a separate drainage suggest that a direct relationship is unlikely.

Becenti Trail Spring is a shallow water source with aquifer listed as 231CHNL (EPA, 2009d), which could be an abbreviation for the Chinle Formation, although the depths do not correlate. The measured depth to water at the Becenti Trail Spring was reported as 12 feet bgs. The spring is almost 6 miles downgradient of the NE Church Rock Mines and the Church Rock Mill and less than 2.5 miles downgradient of the Church Rock Mine and the Section 16 Deposit Mine, thus making it difficult to directly correlate uranium content with uranium from workings and conditions at NE Church Rock Mines.

L1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the undiscovered and undisturbed deposits in the Westwater Canyon-Brushy Basin members of the Morrison Formation are likely to be higher than background because uranium is present in ore bodies of various sizes and grades (Figure 23). Some of the undisturbed uranium deposits may also extend below the water table, as the deposits NE Church Rock Mines do;

however, most may not extend to the surface because they are covered by the Dakota Sandstone. Extensive redistributed organic material is expected in the undisturbed uranium-bearing lens deposits.

L1.5. MINED URANIUM DEPOSITS

The size and duration of mining operations at NE Church Rock Mine, NE Church Rock No. 1 Mine, and NE Church Rock No. 1 East Mine suggest that the mines were significantly mined. Any remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body. Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The influx of water that would have resulted during mining operations might have destroyed organic material and oxidized sulfides. During mining operations in the 1970s and 1980s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mines and placed at the surface. Mine wastes were typically discarded within a few feet to hundreds of feet from the mine opening (EPA, 2007a). NE Church Rock No. 2 Mine was not developed.

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Section L2. Hazard Ranking System and Summary

L2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial, limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium, has been deposited, stored, disposed of, or placed at the surface. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the NE Church Rock Mines include, but are not limited to:

- Uranium in disturbed soils and mine workings at the surface are possibly indicated by the vehicle gamma-ray scan. The gamma-ray levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). The presence of unreclaimed waste piles is unknown (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c).
- Uranium ore deposits remaining below the surface and below the water table at the NE Church Rock Mines.

Additional potential sources of hazardous substances not associated with the NE Church Rock Mines but found in the surrounding area include:

- Undisturbed and uneroded uranium deposits in the Westwater Canyon Member of the Morrison Formation in the area around the NE Church Rock Mines.

L2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

L2.2.1. Rainwater Infiltration

As discussed above in Subsection L2.2.2, average annual precipitation in the area is low, approximately 12 to 16 inches, and is mostly characterized by brief thunderstorms. While uranium can be carried by rainwater infiltration, infiltration rates through soil surrounding the NE Church Rock Mines are very slow, making this unlikely (see the Hydrologic Group Map for the Church Rock Area in Appendix A; EPA, 2007c). Permeability is moderately slow, and contaminant migration in soil has "insignificant potential" upgradient and at the mines and "intermediate potential" downgradient of the mines. Based on the Permeability and Aquifer Sensitivity Maps for the Church Rock Area in Appendix A, the potential for the relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the Rio Puerco. The hydrologic characteristics are applicable to the areas overlying remnant ore bodies of the NE Church Rock Mines, as well as the uneroded ore deposits in the area not associated with an established mine site.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed above in Subsection L2.1, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Because of the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing water can infiltrate the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23). However, infiltration rates for the NE Church Rock Mines are particularly slow. Although the open spaces associated with the mines provide a preferential pathway, extensive mining of the ore bodies

would deplete the uranium deposits of the highest grade ore, and an influx of water during mining probably destroyed organic matter.

L2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend to the south-southwest as the washes and ephemeral creek beds do. This south-southwest flow direction would be most true for shallow groundwater and surface water infiltration. However, it has been noted that the regional dip to the north and a northeasterly striking fracture system influence groundwater flow in the area around and north of the mines. An historic piezometric map for the upper Gallup suggests a northeasterly flow direction. The regional dip lessens just south of the mines, and groundwater may then follow the direction of drainage basins to the south and toward the Rio Puerco. However, depth to water data are insufficient surrounding the mines and to the south to conclusively determine the directional flow and gradient of groundwater.

Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down but given the very slow infiltration rates, very little rainwater is likely to make to the Morrison Formation. Rainwater will also flow through the wastes into washes and ephemeral streams at the surface (Figure 23); surface water may migrate down into the groundwater as it flows through the creeks. When operations were discontinued, the rainwater and groundwater would refill the mine workings, allowing some leaching and transport of uranium. This dissolution would have been temporary because resaturation of the mine workings would convert the exposed surfaces from unsaturated to saturated, limiting further dissolution (MWH, 2003), and the prior reduced environment would be reestablished, in which uranium is at equilibrium with the chemistry of the rock and water. Uneroded ore deposits in the vicinity of and downstream of the four mines may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

Remnants of the original ore deposits that were not completely mined out in the 1970s and 1980s are likely below the groundwater table, which may allow leaching of metals (including uranium) from the ore deposit with oxidizing water influx (Figure 23). However, organic-(carbonaceous material) and pyrite-rich zones within the rocks can create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally. Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, because of the

volume of uranium distributed in the deposits and the organic content of the ore deposits as compared with other Grant Uranium Region deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Groundwater likely flows down regional dip to the north from the mines, and low concentration of uranium in water samples suggest that little to no uranium is leaching from ore deposits or mines, as evidenced by uranium concentrations of 0.38 $\mu\text{g/L}$ in an upstream water sample collected from well 15T-303 in 2008 and 0.17 $\mu\text{g/L}$ in water sample 1082213 collected in 1978 approximately 8 miles northeast of NE Church Rock Mine.

Uranium concentrations downstream of the NE Church Rock Mines indicate uranium is leaching and dispersing in that direction. The leaching and dispersion are evidenced by uranium concentrations of 5.2 $\mu\text{g/L}$ and 14.84 $\mu\text{g/L}$ in samples from well Grey and 6.99 $\mu\text{g/L}$ in sample from well 16T-606. However, both of these concentrations may be due to uranium in solution from other mines and/or ore deposits along the drainage. Grey well is located along the north fork of the Rio Puerco to the southeast of the mines, and well 16T-606 is more likely to be influenced by Church Rock and Section 16 Deposit Mines because it is located between them.

Although uranium may leach from the mines, secondary deposition and adsorption is probably keeping most of the uranium within the mined areas. One of the three water sources in the area with a uranium concentration greater than the MCL (well 16-4-10 with a uranium concentration of 260 $\mu\text{g/L}$) is located 7 miles southwest of the mines. Although this location may be in the direction of surface and subsurface groundwater flow, the lower concentration of uranium detected in well 16T-606 (4.68 pCi/L), located approximately 4 miles southwest of the NE Church Mines, indicates elevated concentrations of uranium in well 16-4-10 are likely from a different source, either unmined ore deposits or other AUMs farther downstream or from adjacent drainages (Figure 23).

L2.2.3. Site Conditions and Local Community

Mining at the NE Church Rock Mines produced waste piles, settling ponds, and mine debris left at the sites. Some mine waste piles were returned to shafts, while others were contoured to reduce movement of the waste material. Low-grade uranium and associated radioactive metals, such as radium, might be in the waste piles. The ponds were drained though sediment that settled out of them may contain some uranium.

A small community of residents is immediately adjacent to the NE Church Rock Mine, downstream and downwind of the mine waste piles. Sheep, cattle, and horses graze in the area (EPA, 2009c). An estimated 50 families live in two valleys that are close to the NE Church Rock Mines (in an area locally

called Red Water Pond Rock community), and 14 of the families live between NE Church Rock Mine and NE Church Rock Mine No. 1. The Church Rock Mill is 1.0 to 1.5 miles south of some residences, and NE Church Rock No. 1 East Mine is approximately 0.25 mile from the nearest residence (CRUMP, 2007).

L2.2.4. Groundwater Pathway Conclusion

Data are insufficient to accurately determine the direction of groundwater flow around the mines; however, it may be to the north or northeast in deep aquifers beneath and to the north of the mines where the regional dip is pronounced, and to the southwest in shallow subsurface and in deeper units to the south of the mines where regional dip is minimal.

Groundwater contours in surrounding drainage basins for the Rio Puerco tend to be aligned with the flow direction of the drainage basin. As a result, it is likely that the direction of shallow groundwater flow south of the NE Church Rock Mines is toward the southwest. The boundary of the watershed is just north of the mines, and the proximity of the mines to the boundary is likely the cause of the low upstream uranium concentrations, where little upstream contribution to uranium concentrations would be expected and little uranium would leach from the reduced environment of mine workings in deeper units where groundwater flows to the northeast.

Samples from wells to the southwest of the mines, such at wells Grey and 16T-606, have elevated uranium concentrations, but the concentrations are less than the MCL. Well 16-4-10, with a uranium concentration exceeding the MCL, is located approximately 7 miles southwest of the NE Church Rock Mines, and there are water samples with concentrations less than that in well 16-4-10 collected between the NE Church Rock Mines and well 16-4-10. Well 16-4-10 is also south of the Rio Puerco in a different drainage basin. None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009b).

L2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the NE Church Rock Mines enters a drainage system in the Lower Colorado that includes the Rio Puerco. The north fork of the Rio Puerco runs west then southwest before joining with the south fork of the Rio Puerco, where the Rio Puerco runs toward the west, meeting up with the Little Colorado River and eventually with the Colorado River.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration can be fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments and waste piles rather than flowing to the creek beds. However, clayey soil below would limit this infiltration.

L2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the Pipeline Arroyo or the North Fork of the Rio Puerco near the mines or within 4 miles downstream of the mines. The unincorporated town of Church Rock is approximately 10 miles to the northwest; no known drinking water intakes or fisheries are listed for Church Rock.

Uranium was detected in samples from the shallow water source (Becenti Trail Spring) downgradient of the mines at concentrations exceeding the MCL. The exceedances suggest that uranium is present in solution in the near subsurface. However, the Becenti Trail Spring is almost 6 miles downgradient of the NE Church Rock Mines and the Church Rock Mill but less than 2.5 miles downgradient of the Church Rock Mine and the Section 16 Deposit Mine, making it difficult to directly correlate the content of uranium with uranium from workings and conditions at the NE Church Rock Mines.

L2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the NE Church Rock Mines for the following reasons:

- Most of the known contamination is confined to the site and concentrations off site that may be attributable to the mines are less than the respective MCLs
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site; the waste dumps are approximately 500 to 600 feet from the nearest Navajo residence (SRIC, 2007)

L2.5. SUMMARY

The general area of study is the Navajo Nation, which covers more than 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). The study area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining. The NE Church Mines—which consist of the NE Church Rock Mine, the NE Church Rock No. 1 Mine, the NE Church Rock No. 1 East Mine, and the NE Church Rock No. 2 Mine—are in the Eastern Region, specifically the Church Rock Mining District of the Grants Uranium Region. Mining in the NE Church Rock Mines area peaked in the 1970s and 1980s. Uranium and vanadium were mined in this region, primarily from ore deposits of the Westwater Canyon Member of the Morrison Formation. The sandstone was created by aggrading braided streams, which formed an alluvial plain. The Westwater Canyon Member ranges from 0 to 220 feet thick, and uranium ore deposits in the shape of lenses can be found in the channels. Organic plant matter is present in the channel sediments. The NE Church Rock Mines, except NE Church Rock No. 2 Mine, were listed by EPA as productive AUMs (EPA, 2007c) that have workings below the water table or were considered wet mines that required pumping.

The Church Rock area is drained by ephemeral streams forming tributaries to the Rio Puerco. The NE Church Rock Mines are located along a minor drainage running northwest to southeast into the Pipeline Arroyo that runs approximately northeast to southwest. The Pipeline Arroyo meets up with the north fork of the Rio Puerco to the south of the mines.

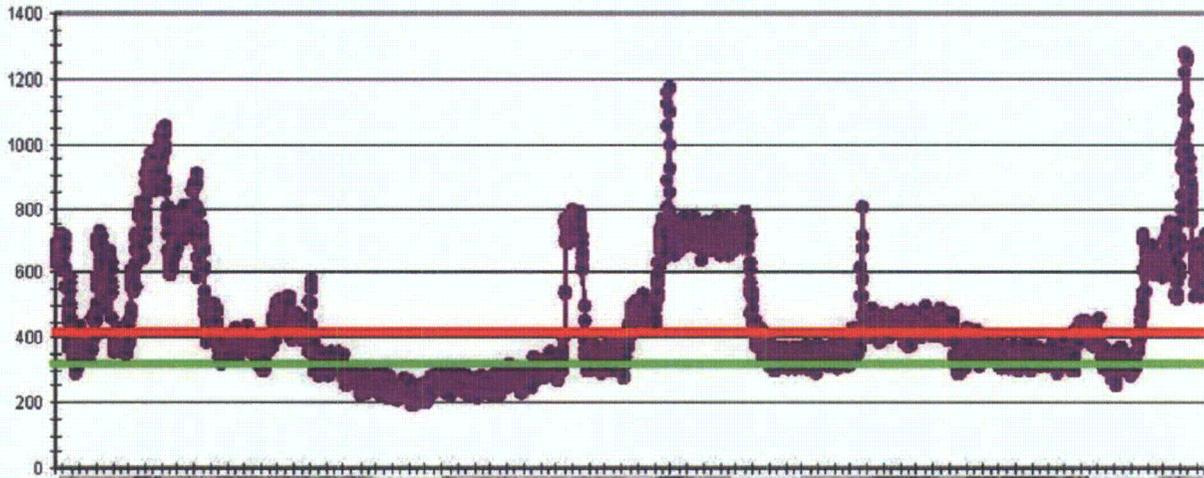
The following pertinent HRS factors are associated with the NE Church Rock Mines:

- According to a vehicular gamma-ray survey (a decay product of uranium), elevated uranium concentrations at the surface appear to occur immediately north of the NE Church Rock Mines boundaries and downgradient of the mines and specifically near waste piles. However, the area is characterized by very slow infiltration rates and moderately slow permeability.
- Geologically, the ore deposits are not as organic-rich, and, if oxidizing groundwater were introduced, loci are insufficient for reducing conditions, facilitating the distribution of uranium locally, which may redistribute uranium.
- Deep groundwater likely flows down regional dip toward the north beneath and north of the NE Church Rock Mines, and an historic piezometric map of upper Gallup shows flow toward the northeast. A review of groundwater analytical results from well 15T-303 and sample 1082213 collected downgradient of the mines reveal uranium concentrations are orders of magnitude less than the MCL.

- Uranium concentrations exceeding the MCL were detected in groundwater samples in three water sources (sample location 1082366, well 16-4-10, and Becenti Trail Spring) to the southeast and southwest of the mines. Sample location 1082366 and well 16-4-10 are on adjacent drainages and possible “upgradient” from the NE Church Rock mines, at elevations above the Pipeline Arroyo and of unknown depths. The shallow Becenti Trail Spring is downstream of the NE Church Rock Mines, as well as Church Rock Mine, Church Rock ISL Mine, Section 13 Mine, and the Church Rock Mill.
- Uranium concentrations in the downstream (and possibly upgradient) wells closest to the NE Church Rock Mines (approximately 2.5 miles southwest of the NE Church Rock Mine) are higher than concentrations in wells upstream of the mines (approximately 0.5 miles northeast NE Church Rock Mine No. 1 East Mine). The results suggest that some uranium may be migrating from the surface of NE Church Rock Mines through shallow subsurface and surface flow to the southwest, but not at concentrations high enough to exceed the MCL.
- None of the wells are regulated.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the NE Church Rock Mines; waste dumps are between 500 and 600 feet from the nearest Navajo residence (SRIC, 2007).

Figures

- Det1 C/S
- Avg Bg+2SD
- Avg Bg+7SD



SOURCE: EPA, 2007

N:\2008_Projects\28-017_EPA_Navejo_Lands_Survey\N Maps & Drawings\NE Church Rock Mine Gamma Radiation Scan.dwg



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CLIENT:
U.S. ENVIRONMENTAL
PROTECTION AGENCY

LOCATION:
NEW MEXICO,
NAVAJO NATION

DESIGNED BY:
RDB 6-11-09

CHECKED BY:
JMD 6-12-09

P.E.P.G.:
-

NE CHURCH ROCK MINE
RADIATION SCAN, 2003

ERRG PROJECT NO.	REVISION NO.	SHEET	OF	FIG NO.
28-017	0	1	1	L-1

Appendix M. Church Rock, Church Rock ISL, and Section 16 Deposit Mines Groundwater Pathway Assessment

Appendix M
Church Rock, Church Rock ISL,
and Section 16 Deposit Mines
Groundwater Pathway Assessment

April 2010

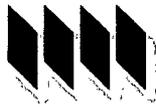
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Section M1. Mine and Groundwater Investigation

M1.1. LOCATIONS

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). The 31 AUMs are found in the Eastern and North Central Regions of the study area. Three of the AUMs—Church Rock Mine, Church Rock ISL Mine (where ISL stands for “in-situ leaching”), and Section 16 Deposit Mine (herein collectively referred to as the “Church Rock Mines”)—are located in the Eastern Region of the Navajo Nation in McKinley County of New Mexico, approximately 7 miles northeast of Church Rock and 14 miles northeast of Gallup, New Mexico. The three AUMs are in the Church Rock Mining District of the Grants Uranium Region (Figure 9). The specific locations by township and range (with latitudes and longitudes) for each of the mines are as follows:

- Church Rock Mine (also called Old Church Rock Mine) at 16N.16W.17.212
- Church Rock ISL Mine at 16N.16W.8.422 (35°37'45"N 108°33'8"W)
- Section 16 Deposit Mine at 16N.16W.16.110 (35°37'15"N 108°32'55"W)

The Church Rock Mine was a productive mine on and off from 1960 to 1982, but no production is listed for the Church Rock ISL and Section 16 Deposit Mines. They may have just been used as haulage drifts for Church Rock Mine (Church Rock ISL) and exploratory drilling (Section 16 Deposit).

M1.1.1. Local Hydrogeology and Geology

The Church Rock Mines are in the Little Colorado subregion in the Lower Colorado watershed, specifically within the Upper Puerco hydrologic unit. The north fork of the Rio Puerco (Puerco River), an ephemeral stream, is east of the mines and runs northeast to southwest. The ephemeral stream drains more than 3,000 square miles in northwestern New Mexico and northeastern Arizona (Southwest Research and Information Center [SRIC], 1992).

M1.1.1.1. Precipitation

Average annual precipitation in the area around the three mines is 12 to 16 inches (see Average Annual Precipitation Map for Church Rock Area in Appendix A; PRISM Group of Oregon State University,

2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

M1.1.1.2. Soils and Permeability

Soil near the Church Rock ISL Mine and the northern portion of the Church Rock Mine is characterized hydrologically by very slow infiltration rates (see the Hydrologic Group Map for Church Rock Area in Appendix A; EPA, 2007c). Soil in this area is either clayey with a high water table or overlies an impervious unit. Soil near the Section 16 Deposit Mine and the southern portion of the Church Rock Mine is also characterized hydrologically by slow infiltration rates. Soil in the area is either layered, which impedes downward movement of water, or has moderately fine to fine textures that impede infiltration of water.

Permeability in the area of the Church Rock ISL Mine and the northern portion of the Church Rock Mine is moderately slow on average, between 0.21 and 0.60 inches per hour. In addition, the volume of rainfall during storms can exceed the capacity of soil to transmit water and produce more runoff than infiltration. Permeability in the area of the Section 16 Deposit Mine and the southern portion of the Church Rock Mine is moderate on average, between 0.61 to 2.00 inches per hour (see the Permeability Map for Church Rock Area in Appendix A; EPA, 2007c).

M1.1.1.3. Aquifer Sensitivity

Aquifer sensitivity within the area of the Church Rock Mines varies considerably, ranging from insignificant potential to most potential for contaminant migration (see the Aquifer Sensitivity Map for Church Rock area in Appendix A; EPA, 2007c). The Church Rock Mines are along a drainage feeding into the north fork of the Rio Puerco that runs approximately northeast to southwest.

The aquifer sensitivity surrounding the Church Rock Mine has insignificant potential for contaminant migration and intermediate potential downgradient of the mine along the drainage system for the north fork of the Rio Puerco. The aquifer sensitivity for the Church Rock ISL Mine ranges from least potential for contaminant migration upgradient and surrounding the mine to insignificant potential downgradient of the mine. The aquifer sensitivity for the Section 16 Mine Deposit Mine ranges from insignificant potential for contaminant migration upgradient of the mine to most potential in the immediate vicinity of the mine and downgradient along the drainage for the Rio Puerco.

M1.1.1.4. Dewatering

Beginning in 1960, uranium was mined near the north fork of the Rio Puerco and the Pipeline Arroyo, the small tributary to the Rio Puerco northeast of Gallup, New Mexico. Water filled the mine shafts because the ore deposits were beneath the regional water table and had to be pumped to prevent flooding. From

1967 to 1986, the discharge rate from mine dewatering averaged approximately 0.25 cubic meters per second, which created continuous flow in the Rio Puerco from the mouth of the Pipeline Arroyo to as far as a few kilometers downstream of Chambers, Arizona (Van Metre et al., 1997).

Before the mid-1970s, untreated effluent was discharged directly to Pipeline Arroyo. During the mid-1970s, effluent was treated to improve the quality of discharged mine waters. Effluent was treated using a flocculent to reduce suspended solids, and dissolved uranium was removed by using ion exchange. The treatment reduced concentrations of uranium by approximately 85 percent from a flow-weighted average of 7,250 micrograms per liter ($\mu\text{g/L}$) in 1975 to 1,000 $\mu\text{g/L}$ in 1982. Mining ceased in 1985, and mine dewatering ceased in February 1986. Approximately 140 million cubic meters of mine-dewatering effluent was discharged to Pipeline Arroyo from 1960 to 1961 and 1967 to 1986; the mine dewatering was primarily from the Westwater Canyon Member of the Morrison Formation (Van Metre et al., 1997). Since 1986 when discharges of uranium mine-dewatering effluent ceased, flow in the Rio Puerco has resumed being ephemeral (SRIC, 1992).

From August 1988 until June 1991, the base flow was observed and estimated to be less than 0.01 cubic meter per second in the Rio Puerco at a location near Church Rock, where bedrock crops out in the channel and forms a waterfall 2 to 3 meters high (Van Metre et al., 1997).

On July 16, 1979, a tailings pond dike failed at the United Nuclear Corporation uranium mill upstream from the Church Rock Mines and adjacent to the Pipeline Arroyo. An estimated 360,000 cubic meters of mine-tailings liquid and 1,000 metric tons of tailings were discharged into the north fork of the Rio Puerco via the Pipeline Arroyo. The pH of the liquid was about 1.9 (highly acidic), and the total gross alpha activity was estimated at 130,000 picocuries per liter (pCi/L), greater than EPA's maximum contaminant level (MCL) of 15 pCi/L (EPA, 2009e). Uranium was detected in samples of water from the tailings pond and from the Rio Puerco at concentrations of 4,100 $\mu\text{g/L}$ on February 5, 1979, prior to failure of the dike, and at 6,500 $\mu\text{g/L}$ on July 16, 1979 (Van Metre et al., 1997). The volume of the spill was about 6 percent of the volume released in a typical year by mine dewatering and about 28 percent of the average annual runoff in 1990 and 1991 at the Church Rock gauging station. The average annual volume of dewatering effluent from 1967 to 1986 (6.4×10^6 cubic meters) was about five times the average runoff per year (1.3×10^6 cubic meters) at the Church Rock gauging station for 1990 and 1991 (Graf, et al., 1996).

M1.1.1.5. Surface Water and Groundwater

The mines are located adjacent to and just west of the north fork of the Rio Puerco, which runs approximately northeast to southwest. Under natural conditions, the Rio Puerco is an ephemeral stream with runoff in response to spring snowmelt and to brief, intense summer thunderstorms. As mentioned in Subsection M1.1.1.4, flow in some reaches of the river changed from ephemeral to perennial in response

to effluent discharge from the uranium mines and the sewage treatment plant at Gallup, New Mexico (Van Metre et al., 1997).

Mine dewatering caused large drawdowns in bedrock formations underlying the alluvial aquifer in the Church Rock reach. In 1968, the water level in an abandoned mine shaft near Pipeline Arroyo in the Dakota and Morrison Formations was reported to be 35 meters below the land surface (Hiss, 1977). Water had to be pumped continuously from the mines to keep the tunnels and shafts dry for work to proceed. Groundwater was pumped at rates of approximately 3,000 gallons per minute (gpm) from the Morrison Formation at NE Church Rock and NE Church Rock No. 1 Mines in November 1973, and the rates increased to 4,400 gpm by 1977. The water was pumped to the land surface and into settling ponds, where it was treated with barium chloride to remove suspended solids; it was then allowed to flow from the ponds into formerly dry tributaries of the Rio Puerco (Hiss, 1977).

Water levels in the shaft of Church Rock Mine declined from between 220 and 230 feet below ground surface (bgs) in January 1970 to greater than 320 feet bgs by January 1975. The water levels are listed for United Nuclear Corp. Northeast Church Rock Mine by Hiss (1977), but the location is in Section 17 of Township 16 North, Range 16 West, which is the location of Church Rock Mine. Prior to the start of dewatering in October 1968 as the new uranium mine shaft was sunk in Section 35 of Township 17 North, Range 16 West (which is consistent with location and development of the NE Church Rock Mine), the water level was reported to be 144 feet bgs (Hiss, 1977).

Groundwater Flow Direction

Data are insufficient to accurately determine the direction of groundwater flow surrounding the mines. Some depth-to-water measurements have been recorded; however, determining the groundwater gradient is difficult because the wells were screened in different aquifers and measurements were collected on different dates, often years apart. For example, depths to water were measured in wells 14K-313, KM CR II G-1, and 15T-303, which are all drilled into the aquifer listed as 211GLLP (probably the Gallup Sandstone). The dates of measurement, however, are September 2, 1953; April 24, 1980; and January 1, 1953, respectively.

Similarly, depths to water were measured in two wells, 16T-510 and 16T-606, accessing the 211DKOT aquifer (EPA, 2009d); the 211DKOT aquifer probably refers to the Dakota Sandstone. Kerr-McGee Corporation (1976) also list wells 16T-513 and 16T-534 as accessing the Dakota Sandstone along with the Westwater Canyon Member. The measurements for the four wells were taken many years apart: on August 30, 1960; July 3, 1980; July 27, 1959; and July 29, 1965, respectively. Thus, the lack of measurements from similar dates in wells drilled in the same aquifers makes the groundwater gradient and flow direction difficult to calculate. Depths to water were measured in three of the wells (16T-510, 16T-513, and 16T-534) during summer months within a 6-year period prior to the height of mining

activities in the area. Based on well elevations and depths to water, the groundwater elevations in the three wells were 6,714.5 feet above mean sea level (msl), 6,693 feet above msl, and 6,575 feet above msl, respectively. The elevations suggest groundwater flows in a general south-to-southwest direction.

Groundwater contours in surrounding drainage basins for the Rio Puerco tend to be aligned with the flow direction of the drainage basin. As a result, it is likely that, at a minimum, near-surface groundwater and rainfall infiltration around the Church Rock Mines flow toward the southwest.

Groundwater Wells and Water Sources

The following wells or water sampling locations are in the area (Figure 16):

- Wells KM CR II G-1, KM CR II G-2, KM CR II G-3, and KM CR II W-2 at NE Church Rock No. 2 Mine
- Well 15T-303 (Pipeline Canyon Well) along Pipeline Arroyo upstream of the Church Rock Mines
- Sample location 1082213, approximately 6.25 miles upgradient of well 15T-303 on a separate drainage running north
- Well 14K-586 (G00012; Friendship I; probably the same as 14T-586) near the NE Church Rock Mine
- Church Rock Mill Well adjacent to Church Rock Mill and Pipeline Arroyo
- Sample location 1082366 on the drainage feeding into Pipeline Arroyo, to the east of Church Rock Mill
- Wells 16T-606 (probably the same as G00026) and 16T-532 at Church Rock Mine, downgradient of Church Rock ISL Mine
- Well 16T-513 (16N 16W 15 4322; Uphill Road Windmill; sample location 1081952)
- Wells Grey, 16-3-4 (Keith Begay Well; possibly the same as sample location 1081851), and 16T-348 (Lobo Valley; sample location 1082365) along the north fork of Rio Puerco before it meets with Pipeline Arroyo (east of Church Rock Mines)
- Well 16T-514 (Pinedale Chapter House) south of the north fork of Rio Puerco before it meets up with Pipeline Arroyo
- Becenti Trail Spring, approximately 2.5 miles southwest and downstream of Church Rock Mine along the north fork of Rio Puerco
- Wells G 01100S-2, G 01100S, G 01100 (sample location 1081956), and 16-4-10 (Lime Ridge) and sample location 1081955 along the drainage running north into Rio Puerco and downgradient of where the Pipeline Arroyo runs into Rio Puerco
- Well 16K-340 (sample location 1081954) along the Rio Puerco, downstream of Church Rock, Church Rock ISL, Section 16, Grace ISL, and Section 13 Mines, and where Pipeline Arroyo meets the north fork of Rio Puerco

- Well 16K-336 (Puerco North Fork) along the Rio Puerco, farther downstream of Church Rock Mines
- Well 14K-313 (Brown Bull; sample location 1082210) in adjacent Hard Ground Canyon to the west of the NE Church Rock Mine and Pipeline Arroyo
- Sample location 1081950 on the drainage feeding into Hard Ground Canyon to the west of NE Church Rock and Pipeline Arroyo
- Well 16T-510 (Nose Rock; sample location 1081953) in the adjacent Hard Ground Canyon to the west of the Section 13 Mine and the Rio Puerco
- Well 16T-534 (Superman Cyn.; NR106.0820X1070) on the hillside northwest of where Hard Ground Canyon meets the Rio Puerco (EPA, 2009d)

Groundwater Chemistry

Water samples were collected from some of the wells in the area, and pH and conductivity were measured in 1977, 1978, 1979, and 2008. The pH of the water samples ranged from 5.5 in sample 1082366 (although this result appears to be anomalous in comparison with other pHs measured) to 9.01 in the sample from well 16T-510, averaging approximately 7.5. Specific conductivity ranged from 5 micromhos per centimeter in sample 1082365 collected in 1979 (which may be inaccurately reported) to 2,890 micromhos per centimeter in a sample collected from well 15T-303 in 2008 (EPA, 2009d), averaging approximately 1,170 micromhos per centimeter.

When mining and associated dewatering were discontinued at the mines, the underground mine workings were flooded (Figure 23). At that time, oxidized surfaces of the mine workings could have potentially released soluble constituents, including uranium, into groundwater causing temporary local impact to water quality. The dissolution would have been temporary because resaturation of the mine workings would convert the exposed surfaces from unsaturated to saturated, limiting further dissolution (MWH, 2003), and prior reduced environment equilibrium would be reestablished.

Water parameters and chemistry were measured for snowmelt and storm runoff in Rio Puerco; U.S. Geological Survey (USGS) collected the surface runoff samples as composite cross-section samples or point samples at stream-flow gauging stations near Church Rock and Manuelito, New Mexico, and Chambers, Arizona, between August 31, 1988, and October 20, 1990. Specific conductivity, pH, gross alpha activity, and uranium concentrations ranged from 456 to 1,980 microSiemens per centimeter, 7.4 to 8.1, 4.4 to 21 pCi/L, and 1.9 to 13 µg/L, respectively (Graf, et al., 1996).

Geology and Groundwater

Uranium ore deposits of the Grants Uranium Region are found in the sandstones of the Westwater Canyon and Brushy Basin Members of the Morrison Formation, which were deposited during the Jurassic Period. The Westwater Canyon Member was deposited as a broad alluvial fan by aggrading braided streams and ranges from 220 to 270 feet thick. The Brushy Basin Member overlies the Westwater

Canyon Member and consists of mudstone formed from volcanic ash falls. The member is very thin near the Church Rock Mines and is not considered a major source of uranium, unlike other areas in the Grants Region Mining District. Overlying the Morrison Formation with a slight angular unconformity is the 70- to 180-foot-thick Dakota Sandstone, which was deposited during the Cretaceous Period. The rocks of the Morrison Formation dip less than 5 degrees to the north and are exposed at the surface near Hwy 40, approximately 2 miles south of the Church Rock Mines.

The regional dip of the sedimentary rocks is northward. The Nutria monocline, which is a secondary feature that aligns east to west in the southern part of T. 17 N., R. 16 W., forms the southern edge of Mesa de los Lobos. The rock sequence has been fractured by faults that strike northeasterly and trend slightly to the northwest. Displacement of stratigraphy varies but in general is less than a few tens of feet (Kerr-McGee Corporation, 1976). Kerr-McGee Corporation (1976) describes the Nutria monocline as being in the southern part of T. 17 N., R. 16. W. Van Metre et al. (1997), however, describe the Nutria monocline as being about 5 kilometers east of Gallup, where it forms a groundwater divide for the regional flow systems. Recharge that occurs east of the monocline flows in a north-to-northeast direction toward the San Juan Basin, and recharge west of the monocline flows in westward direction (Van Metre et al., 1997).

Groundwater occurs in most of the Cretaceous sandstones (i.e., Dakota, Gallup, and Crevasse Canyon Formations) beneath the Mesa de los Lobos, and nearly all sandstones yield some water, although the amount is variable. The pre-Cretaceous rock outcrops comprise a narrow east-to-west belt that forms the southern outline of the San Juan Basin. The narrow exposures are tilted northward, dipping from 3 to 30 degrees, and occur at elevations of 6,500 feet above msl. Recharge water from rainfall infiltrates downward to the water table and then downgradient, generally northward in the areas north of the mines, following the regional dip. In general, pre-Cretaceous sandstone aquifers have a low permeability, and the yields are relatively small (Kerr-McGee Corporation, 1976).

A historic piezometric surface map for Upper Gallup Sandstone shows a northeast flow direction (EPA, 2010). The contours on the piezometric surface map for deeper aquifers identify gradients that, although surface and shallow groundwater flow might follow topography, deeper groundwater flow trends toward the north, following the regional dip in the area of the NE Church Rock Mines. South of the mines, the regional dip is more gentle (EPA, 2010), and groundwater may not be as affected by the dip. Near the Church Rock Mines, the direction of surface water flow, when present, would be from northwest to southeast along unnamed washes near the mines into the northeast- to southwest-trending north fork of the Rio Puerco.

The recharge and groundwater response to regional dip and the historic piezometric map suggest groundwater flows in a northeast direction in the Church Rock Mining District, which is counter to suggestions that groundwater flow tends to be aligned with the flow direction of the drainage basin and

the general flow direction derived from depths to water measured in the Dakota Formation wells. The northwest direction of groundwater flow cannot be discounted because the depths to water were measured during different years and the tendency for groundwater to flow in the direction of drainage basins is not confirmed.

M1.2. REGIONAL AND DETAILED MINE BACKGROUND

As mentioned in Subsection M1.1.1.4, uranium was mined near Pipeline Arroyo beginning in 1960. The area is known locally as the Church Rock Mining District (Figure 9). Uranium mine shafts near Pipeline Arroyo averaged 500 meters (or 1,640 feet) deep (Van Metre et al., 1997). Uranium deposits in the Westwater Canyon Member, which hosted the greatest number and the largest ore deposits, were formed as paleo-stream channels and are associated with lenses of carbonaceous matter. The uranium ore deposits in the Westwater Canyon Member are unoxidized. Uraninite (uranium oxide) was the principal uranium mineral; uraninite was accompanied by montrosite (vanadium oxide) and coffinite (uranium-bearing silicate mineral) (Granger, 1963). The rocks of the Westwater Canyon Member were principally medium- to coarse-grained, arkosic sandstones.

Although it was typically not mined, several ore deposits have been found in the 70-to 180-foot-thick Dakota Sandstone. The Church Rock Mine was the only mine in the area to have produced uranium from the Dakota Sandstone, although uranium in the Section 16 Deposit was found in the Dakota Sandstone. The Church Rock Mine was also the only mine in the area to produce uranium ore through ISL, although other deposits in the Church Rock Mining District were tested using ISL (e.g., Grace ISL Mine).

M1.2.1. Church Rock Mine Ore Deposits and Mine

The Church Rock Mine is at an elevation of 6,810 feet above msl (McLemore, 1983). The ore deposit in the Dakota Sandstone at the Church Rock Mine appears to be in a channel that incised into the Brushy Basin Member of the Morrison Formation. The ore is associated with organic debris at contact of Dakota and Brushy Basin Sandstone along several horizons. The ore is redistributed and sandstone fracture-controlled (McLemore, 1983).

The Church Rock Mine first developed and produced uranium ore between 1960 and 1962; it was reopened in 1977. Church Rock Mine is an underground “room-and-pillar” mine, accessed by a vertical shaft. The mine ranges from 700 to 900 feet bgs (Church Rock Uranium Monitoring Project [CRUMP], 2007). The Church Rock Mine had produced 292,604 tons of ore with an average grade of 15 percent when the mine closed in 1982. The presence of unreclaimed waste piles is listed as unknown for Church Rock Mine (see Reclamation Status and Unmapped Waste Piles Map for Church Rock area in Appendix A; EPA, 2007c). The only specific mine waste features noted for the Church Rock Mine were settling and holding ponds (Figure M-1; EPA, 2007c).

M1.2.2. Church Rock ISL Ore Deposit and Mine

The Church Rock ISL Mine is described as being haulage drifts connected to the Church Rock Mine and production of ore, if any, is confidential. The ore deposit is in the Westwater Canyon and Brushy Basin Members of the Morrison Formation. The ore deposit is described as 800 to 870 feet deep and 5 to 36 feet thick; six horizons cover the entire thickness of the Westwater Canyon Member. The most continuous ore body is 2 to 10 feet thick in the middle of Westwater Canyon Member (McLemore, 1983). No specific mine wastes were noted for the Church Rock ISL Mine during EPA's assessment (EPA, 2007c).

M1.2.3. Section 16 Deposit Ore Deposit and Mine

The Section 16 Deposit Mine is described as a 5- to 11-foot-thick horizon that is 320 to 480 feet deep in the Dakota Sandstone. Uranium mineralization is also listed as being present in the Westwater Canyon Member. Exploratory holes were drilled from 319 to 721 feet deep (McLemore, 1983). No production information is available for the mine, and no specific mine wastes were noted for the Section 16 Deposit Mine during EPA's assessment (EPA, 2007c).

M1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

M1.3.1. Aerial Radiation Contours

In 1988, USGS produced an aerial gamma-ray contour map of regional surface concentrations of uranium (Duval, 1988). A contour map delineating excess gamma-ray activity in the Eastern Region was created from data collected during an aerial gamma-ray survey flown by USGS (Figure 21). To investigate regional surface concentrations of uranium, the aerial gamma-ray contour map (Figure 21) was studied, where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU) (Duval, 1988). The map contours represent values in percent.

The aerial gamma-ray contours identify concentrations across the region. Gamma-ray radiation is associated with uranium, and excess levels of gamma ray activity are a good indicator of old mines and mining-related activities. A map of the aerial gamma-ray contour values illustrates higher gamma-ray radiation (up to 3.75 percent in the vicinity of the Church Rock Mines. Background concentrations within McKinley County and adjacent counties ranged from 1.00 to 2.75 percent.

M1.3.2. Church Rock Mine Gamma Scan

In 2003, gamma radiation surveys were also performed by EPA's Radiation & Indoor Environments Laboratory in Las Vegas, Nevada, using truck-mounted sodium-iodide detectors that scan the ground surface up to 200 feet from the van. The 2003 surveys established that gamma radiation concentrations in

non-impacted areas of the Church Rock Mine ranged from 10.7 to 13.2 microRoentgens per hour ($\mu\text{R/hr}$), based on monitoring in two areas not affected by uranium mining. The concentrations are slightly lower than the average background concentration of 16.7 $\mu\text{R/hr}$ derived from data in Hydro Resources, Inc.'s (HRI) 1993 environmental report about the Church Rock Mine (HRI, 1993). In comparison, average gamma concentrations on both sides of State Route 566 (at 34.5 $\mu\text{R/hr}$) and on grazing land used by the King Family (at 28 $\mu\text{R/hr}$) were more than 2 times the background concentrations, and maximum gamma concentrations were more than 16 times background (SRIC, 2007). SRIC (2007) suggest that elevated gamma concentrations near State Route 566 may from spillage of ore from trucks during mining (1960–1962 and 1977–1982), and elevated gamma concentrations on grazing land may be from deposition of uraniferous materials by wind.

The elevated concentrations could be from surface disturbances and waste disposal during mining operations, but they could also be from naturally high uranium concentrations in native rocks. The elevated concentrations do not confirm that uranium is leaching into groundwater or finding its way into surface water but rather that a potential source of uranium in water exists. The limited scale of the scan makes it difficult to determine the extent of elevated gamma-ray concentrations.

M1.3.3. Groundwater

Water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, the water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). The sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. From 1977 to 1979, Los Alamos Scientific Laboratory collected samples in the Church Rock area as part of the National Uranium Resource Evaluation Program (NURE) during the hydrogeochemical and stream sediment reconnaissance phase. In July 2002, a water quality sample was collected from a domestic well in the Westwater Canyon Member in the area of the Church Rock Mill. In 2003 and 2004, Navajo Nation Environmental Protection Agency (NNEPA) collected samples under the CRUMP. EPA collected additional samples in the Church Rock area in 2008 and 2009. Limited or no information on well development is available, and groundwater samples were not collected regularly because the wells are unregulated sources of water. Available analytical results summarized below are from limited grab groundwater samples.

M1.3.3.1. Analytical Results for NURE 1977 to 1979 Sampling Event

From September 1977 to October 1979, NURE collected water samples in the Church Rock area; data from the samples have been compiled and transferred to a database by USGS. Samples 1081950,

1081951, 1081952, 1081953, 1081954, 1081955, and 1081956 were collected in September 1977; samples 1082210 and 1082213 were collected in October 1978; and samples 1082365 and 1082366 were collected in October 1979 (Figure 16; EPA, 2009d). Samples 1082365 and 1082366 were collected after the tailings spill in July 1979 from the Church Rock Mill (EPA, 2009d).

Sample 1081954, collected in 1977 from well 16K-340 along the Pipeline Arroyo and approximately 3 miles downstream of the mines, had a uranium concentration of 2.4 µg/L (EPA, 2009d). Sample 1082213, collected in 1978 over 11 miles upstream of the Church Rock Mine, had a uranium concentration of 0.17 µg/L; the uranium does not appear to be associated with any AUMs in the area and may be attributed to background. Sample 1082366, collected in 1979 from the drainage directly across Pipeline Arroyo from the Church Rock Mill and approximately 4.5 miles northeast from Church Rock Mine (Figure 16), had a uranium concentration of 1,007.4 µg/L, which exceeded the MCL of 30 µg/L. The exceedance was the highest concentration detected in water samples collected from the Church Rock area.

The following samples were collected in adjacent drainages:

- Samples 1081953, 1081950, and 1082210 collected in Hard Ground Canyon with uranium concentrations of 0.64 µg/L, 0.89 µg/L, and 1.46 µg/L, respectively
- Samples 1082365 and 1081951 collected along the north fork of the Rio Puerco to the east of the mines with uranium concentrations of 0.95 µg/L and 0.22 µg/L, respectively
- Samples 1081952, 1081955, and 1081956 collected along drainages to the east and southeast feeding into the north fork of Rio Puerco with uranium concentrations of 0.18 µg/L, 1.24 µg/L, and 2.62 µg/L, respectively (EPA, 2009d)

Locations where samples 1081950, 1081951, 1081952, 1081953, 1081954, 1081956, and 1082210 were collected are within 4 miles of the Church Rock Mine, while locations for samples 1082366, 1082365, 1081955, and 1082213 are between approximately 4 to 12 miles from Church Rock Mine. The uranium mines were still operating when the water samples were collected in 1977, 1978, and 1979.

M1.3.3.2. Analytical Results for 2002 Church Rock Mill Sampling Event

In July 2002, a water quality sample was collected from the Westwater Canyon Member in the area of the Church Rock Mill from a domestic well located in Section 2. Dissolved uranium was detected at a concentration of 70 µg/L, and gross alpha activity was not measured at a level greater than the laboratory reporting limit of 1.0 pCi/L (MWH, 2003).

M1.3.3.3. Analytical Results for CRUMP 2003 and 2004 Sampling Events

NNEPA and EPA collected water samples near the Church Rock and NE Church Rock Mines in October 2003 under CRUMP. Ten of the wells are within 6 miles of the Church Rock Mines, and the following samples were collected for analysis of uranium:

- Sample collected from well 15T-303 (listed as 15K-303) with a uranium concentration of 0.69 µg/L
- Sample collected from well 14K-586 with a uranium concentration of 3 µg/L
- Sample collected from well 16T-606 with a uranium concentration of 6.99 µg/L
- Sample collected from shallow well Grey with a uranium concentration of 14.84 µg/L
- Sample collected from well 16T-348 with a uranium concentration of 0.29 µg/L
- Sample collected from 16K-340 with a uranium concentration of 2.92 µg/L
- Sample collected from 16-4-10 with a uranium concentration of 69.37 µg/L
- Sample collected from well 14K-313 with a uranium concentration of 0.05 µg/L
- Sample collected from well 16T-534 with a uranium concentration of 0.15 µg/L
- Sample collected from 16K-336 with a uranium concentration of 0.57 µg/L (EPA, 2009d)

All of the wells are within 4 miles of the mines, except 16T-534, 16K-340, 16K-336, and 16T-348. Of the 13 wells sampled for this study, only 1 groundwater sample, collected at well 16-4-10, contained uranium at a concentration greater than the MCL of 30 µg/L. Well 16-4-10 is approximately 3.7 miles downgradient of the Church Rock Mines. The samples were collected after mining operations had been discontinued at the Church Rock Mines.

During the CRUMP study, many of the wells sampled were deemed unsuitable for human and domestic uses based on various pollutants in and water quality parameters of the samples, not just uranium concentrations. The pollutants and water quality parameters included arsenic, iron, and selenium concentrations and sulfate, pH, total hardness, fluoride, chloride, and total dissolved solids. CRUMP recommended that water in well 16T-606 be considered unsuitable for any use in all three categories—human drinking water, domestic water, and livestock water (CRUMP, 2007). Well 16T-606 is less than 0.5 mile south of Church Rock Mine and west of Section 16 Deposit Mine.

NNEPA collected one water sample within the Eastern Region. The gross alpha activity of the sample was 6.5 pCi/L, which is less than the EPA MCL of 15 pCi/L. The sample was collected from water in the public water system at the Crownpoint Chapter House, and the source of water in the system is not within 4 miles of the Church Rock Mines and is in a different watershed.

M1.3.3.4. Analytical Results for EPA 2006 to 2009 Sampling Event

EPA collected and analyzed water samples from 2006 to 2009 from the following wells:

- Well 15K-303 with a uranium concentration of 0.38 µg/L
- Well 14T-586 with a uranium concentration of 1.5 µg/L
- Well 14K-313 with no concentration of uranium equal to or greater than the laboratory reporting limit
- Well Grey with a uranium concentration of 5.2 µg/L
- Well 16-4-10 with a uranium concentration of 260 µg/L
- Well 16-3-4 with no concentration of uranium equal to or greater than the laboratory reporting limit
- Well 16T-513 with no concentration of uranium equal to or greater than the laboratory reporting limit
- Becenti Trail Spring with a uranium concentration of 110 µg/L

The uranium concentrations in the samples collected from well 16-4-10 in 2008 and the Becenti Trail Spring in 2009 exceeded the MCL of 30 µg/L. Both of the locations from which the samples were collected are less than 4 miles from the Church Rock Mines. Well 16-4-10 is downstream of the mines; however, it is along a different drainage running northwest into the Rio Puerco. Without more information on the direction of groundwater flow, the relationship between the Church Rock Mines and the elevated uranium concentration in well 16-4-10 is difficult to establish. However, the lower uranium concentrations detected in samples collected between well 16-4-10 and the mines and a location on a separate drainage suggest that a direct relationship is unlikely.

Becenti Trail Spring is immediately downstream of Church Rock Mine and is likely to be influenced from surface runoff at the mine site. Becenti Trail Spring is a shallow water source with an aquifer listed as 231CHNL, which could be an abbreviation for the Chinle Formation, although the spring depth does not correlate well with the expected formation depth. The measured depth to water at the Becenti Trail Spring was reported as 12 feet bgs. The spring is approximately 2.3 miles downstream of the Church Rock Mines and the Section 16 Deposit Mine.

M1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in the undiscovered and undisturbed deposits in the Westwater Canyon and Brushy Basin Members of the Morrison Formation are likely to be higher than background concentrations because uranium is present in ore bodies of various sizes and grades (Figure 10). Some of the undisturbed uranium deposits may also extend below the water table, similar to the deposits at the Church Rock Mines; however, most may not extend to the surface because they are covered by the

Dakota Sandstone. Extensive redistributed organic material is expected in the undisturbed uranium-bearing lens deposits.

M1.5. MINED URANIUM DEPOSITS

The scale and duration of the mining operations at the Church Rock Mine suggest that the mine was significantly mined. Any remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body (Figure 23). Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The influx of water that would have resulted during mining operations might have destroyed some of the organic material and oxidized sulfides. During mining operations in the 1970s and 1980s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a). Church Rock ISL Mine was not developed, and no information was available about either reserves mined or resources remaining in the Section 16 Deposit.

Section M2. Hazard Ranking System and Summary

M2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is where a hazardous substance, in this case uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Church Rock Mines include, but are not limited to:

- Uranium in disturbed soils and mine workings at the surface are possibly indicated by the vehicle gamma-ray scan. The gamma-ray levels were orders of magnitudes higher than much of the surrounding area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for the soil exposure pathway (EPA, 2007b). The presence of unreclaimed waste piles is unknown (see the Reclamation Status and Unmapped Waste Piles Map for Church Rock area in Appendix A; EPA, 2007c).
- The holding and settling ponds for mine water extracted from Church Rock Mine are currently visible from the surface. However, no information is available to assess possible contamination relating to these ponds. The ponds may potentially meet the EPA's HRS criteria on the definition of "area of observed contamination" for the soil exposure pathway (EPA, 2007b).

- Uranium ore deposits remain below the surface and below the water table at the Church Rock Mines.
- Sediments from water pumped from the mines might have been deposited in drainages downgradient from the mines. Until the water was treated to remove sediment and dissolved uranium, water pumped from the mines was discharged directly to the streams.

The following additional potential sources of hazardous substances are not associated with the Church Rock Mines, but are found in the surrounding area:

- Undisturbed and uneroded uranium deposits within the Westwater Canyon and Brushy Basin Members of the Morrison Formation in the area surrounding the Church Rock Mines.

M2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility are discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

M2.2.1. Rainwater Infiltration

As discussed above in Subsection M1.1.1.1, average annual precipitation in the area is low, approximately 12 to 16 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through soil surrounding the mines are slow to very slow (see the Hydrologic Group Map for Church Rock Area in Appendix A; EPA, 2007c). Permeability is moderately slow, and contaminant migration in soil has "least potential" upgradient of the mines and "most potential" downgradient of the mines and at the mine sites. The potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along the Rio Puerco (see the Permeability and Aquifer Sensitivity Maps for Church Rock Area in Appendix A; EPA, 2007c). The

characteristics are applicable to the remaining ore bodies of the Church Rock Mines, as well as the uneroded ore deposits in the area not associated with an established mine site.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed above in Subsection M2.1, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Because of the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing water can infiltrate the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23). However, infiltration rates for the Church Rock Mines are particularly slow. Although the open spaces associated with the mines provide preferential pathways, extensive mining of the ore bodies would deplete the uranium deposits of the highest grade ore.

M2.2.2. Groundwater Flow

Groundwater flow has not been directly measured in the area, but it is common for groundwater to follow topography; as a result, groundwater flow would likely trend to the south-southwest similar to the washes and ephemeral creek beds in the area. This south-southwest flow direction would be most true for very shallow groundwater and surface water infiltration. However, it has been noted that the regional dip to the north and a northeasterly striking fracture system influence groundwater flow in the area around and north of the mines. An historic piezometric map for the upper Gallup also suggests a northeasterly flow direction. The regional dip lessens just south of the NE Church Rock Mines, and groundwater may then follow the direction of drainage basins to the south and toward the Rio Puerco. However, depth-to-water data are insufficient around and to the south of the mines to conclusively determine the directional flow and gradient of groundwater.

Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down to groundwater. Given the very slow infiltration rates and shallow impermeable rock beneath the surface, however, very little rainwater is likely to make it down to the Morrison Formation. Rainwater will also flow through the wastes and into washes and ephemeral streams at the surface (Figure 23); surface water may migrate down into groundwater as it flows through the creeks. The creeks downgradient of the mines are particularly suspect because water pumped from the mines was discharged directly to the streams without treatment. Sediment potentially deposited in the streams may persist as a long-term source of uranium to surface water. The water itself might also infiltrate to groundwater and disperse with regional flow. When operations were discontinued, rainwater and groundwater would refill the mine workings, allowing some leaching and transport of uranium. The dissolution would have been temporary because resaturation of the mine workings would convert the exposed surfaces from unsaturated to saturated, limiting further dissolution (MWH, 2003), and the prior reduced environment, in which uranium is at

equilibrium with the chemistry of the rock and water, would be reestablished. Uneroded ore deposits near and downstream of the mines may provide more uranium- and organic-rich rock and sediment through which fresh water infiltrates to mobilize and transport uranium.

Remnants of the original ore deposits that were not completely mined out in the 1970s and 1980s are likely below the oxidizing groundwater table, allowing leaching of metals (including uranium) from the ore deposit (Figure 23). However, organic- (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidation/reduction interface and redistributing uranium locally. Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede dispersion of uranium. Adsorption of uranium onto clays occurs in the pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. However, given the volume of uranium distributed in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock.

Results of the water sampling suggested that little uranium is leaching upstream of the ore deposits or mines, as evidenced by uranium concentrations of 5.2 µg/L in the upgradient water sample from well Grey along the north fork of Rio Puerco and 3 µg/L in the upgradient water sample from well 14K-586 along Pipeline Arroyo. Uranium concentrations downstream of the Church Rock Mines also indicate that uranium is leaching, as evidenced by uranium concentrations of 110 µg/L in the sample from Becenti Trail Spring and 6.99 µg/L in the sample from well 16T-606. Although uranium is being leached from the mines, secondary deposition and adsorption is probably keeping most of the uranium within areas immediately around the mines.

The higher concentration in the sample (Becenti Trail Spring) collected farther downstream from the Church Rock Mines may suggest stratigraphic variance of water flow. The depth to water at the Becenti Trail Spring is only 12 feet bgs, and this water source is likely to be influenced by surface runoff from sediments nearby and from along the Rio Puerco. Well 16T-606 is drilled to a depth of 417 feet bgs, into the Dakota Sandstone, and the depth to groundwater was measured at 79 feet bgs in July 1980. Potential sources for uranium migration into the well may be from neighboring groundwater, rather than surface and rainwater recharge because infiltration rates in the area are slow. Uranium concentrations probably reflect the uranium being carried in solution from the ore at the mines because of the proximity of well 16T 606 to Church Rock Mine and Section 16 Deposit.

Uranium concentrations exceeding the MCL were detected in samples collected from Becenti Trail Spring (110 µg/L), from location 1082366 (1,007.4 µg/L), from the well at Church Rock Mill (70 µg/L), and from well 16-4-10 (69.37 µg/L and 260 µg/L). As discussed above, uranium in sample from the Becenti Trail Spring is likely influenced by surface runoff, sediment in the stream deposited when mine water was pumped directly to the stream, and sporadic flow along the Rio Puerco. Well depths are unknown for sample location 1082366, well at Church Rock Mill, and well 16-4-10. Only well 16-4-10 (with an exceedance of 260 µg/L) is located just less than 4 miles southwest of the Church Rock Mine. This location may be in the direction of surface water and groundwater flow; however, the lower concentration of uranium detected in samples collected from well 16T-606 (6.99 µg/L) less than 0.5 mile south of the Church Rock Mine and from sample location 1081956 (2.62 µg/L) approximately 3 miles southwest of the Church Rock Mine indicates elevated concentrations of uranium in well 16-4-10 are likely from a different source (e.g., unmined ore deposits or other AUMs from adjacent drainages).

M2.2.3. Site Conditions and Local Community

Mining at the Church Rock Mines has resulted in waste piles, sediment in streams, sediment in settling ponds, and potential mine debris. Low-grade uranium and associated radioactive minerals (such as radium) may persist in the piles, and oxidizing rainwater may leach the radioactive metals from the rock in the piles. The ponds were drained, but sediment persists in the ponds.

A small community of residents lives within 0.25 to 1.5 miles of the Church Rock Mines: to the west is the Livingston Camp, and to the east is the King Family Ranch area. The King Family Ranch's homes and grazing areas cover parts of Section 7 with Church Rock Mine. The northeastern quarter of Section 17 and southeastern quarter of Section 8 to the north contain the proposed uranium ISL mines (including the Church Rock ISL Mine).

An estimated 50 families live in two valleys that are close to the NE Church Rock Mines (north of the Church Rock Mines), and 14 of the families live between NE Church Rock Mine and NE Church Rock Mine No. 1. The Church Rock Mill is 1.0 to 1.5 miles south of some residences, and NE Church Rock No. 1 East Mine is approximately 0.25 mile from the nearest residence (CRUMP, 2007).

M2.2.4. Groundwater Pathway Conclusion

Data are insufficient to accurately determine the direction of groundwater flow around the mines; however, it may down dip to the north or northeast in deep aquifers beneath and to the north of the mines, where the regional dip to the north is pronounced, and to the southwest in flow in the shallow subsurface and in deeper units to the south of the mines, where regional dip to the north is not as pronounced.

Groundwater contours in drainage basins for the Rio Puerco tend to be aligned with the flow direction of the drainage basin. As a result, it is likely that the direction of shallow groundwater flow south of the Church Rock Mines is toward the southwest. The boundary of the watershed is just north of the mines, and the proximity of the mines to the boundary is likely the cause of the low upstream uranium concentrations, where little upstream contribution to uranium concentrations would be expected and little uranium would leach from the reduced environment of mine workings in deeper units where groundwater flows to the northeast.

Samples from close wells adjacent to and east of the mines, such as at wells Grey and 16T-606, had uranium concentrations exceeding possible background concentrations, but less than the MCL. Well 16-4-10, with a uranium concentration exceeding the MCL, is less than 4 miles southwest of the Church Rock Mines. However, uranium concentrations in samples from sample location 1081956 and well 16T-606 (collected between the Church Rock Mines and well 16-4-10) were lower than the concentration from well 16-4-10. Well 16-4-10 is also south of the Rio Puerco in a different drainage basin.

If groundwater flow follows topography and trends to the south-southwest, the lower concentrations of uranium detected in well 16T-606 (6.99 $\mu\text{g/L}$), located less than 0.5 mile south of the Church Rock Mine, and in well 16K-340 (2.92 $\mu\text{g/L}$), located approximately 3.5 miles southwest of the Church Rock Mines, indicate the elevated concentration of uranium in well 16-4-10 are from a different source (e.g., either unmined ore deposits or other AUMs farther downstream or from adjacent drainages). If the groundwater flow is to the northeast, as indicated by regional dip effect and historic piezometric map, then samples collected from sample location 1082366 and Church Rock Mill may reflect some influence from uranium migrating from Church Rock Mines, as well as some effect from Church Rock Mill. None of the wells are intended to be used as drinking water wells, although community feedback has confirmed that the wells are being used for drinking water (EPA, 2009a).

M2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Church Rock area enters a drainage system in the Lower Colorado, including the Rio Puerco. The Rio Puerco, east of the mines, runs from northeast to southwest, where it meets up with the Little Colorado River and eventually with the Colorado River.

As discussed above in Subsection M2.2.2, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. In semiarid to arid environments, however, evaporation is quick and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediment rather than flowing to the creek beds. The area is characterized by slow to very slow infiltration and moderate to moderately slow permeability; as a result, runoff to streams is substantial, rather than infiltrating deeper. Sediment from water discharged directly to the streams from dewatering the mines likely persists throughout the drainage, and stream flow may subsequently leach uranium from the sediment.

M2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the Pipeline Arroyo or the north fork of the Rio Puerco near the mines or within 4 miles downstream of the mines. The unincorporated town of Church Rock is less than 7 miles to the southwest; no known drinking water intakes or fisheries are listed for Church Rock.

Uranium was detected in the sample from the shallow water source (Becenti Trail Spring) downstream of the Church Rock Mines at a concentration exceeding the MCL. The exceedance suggests that uranium is present in solution in the near subsurface. The Becenti Trail Spring is approximately 2.5 miles downstream of the Church Rock Mines, suggesting uranium could migrate from the Church Rock Mines.

M2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Church Rock Mines for the following reasons:

- Most of the known contamination from subsurface ore deposits is confined to the site and concentrations off site that may be attributable to the mines are less than the respective MCLs.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site.

M2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and

production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during that period.

The Church Rock Mines—which consist of the Church Rock Mine, the Church Rock ISL Mine, and the Section 16 Deposit Mine—are in the Eastern Region, specifically the Church Rock Mining District of the Grants Uranium Region. Mining in the Church Rock Mines area peaked in the 1970s and 1980s. Uranium and vanadium were mined in this region, primarily from ore deposits of the Dakota Sandstone and Westwater Canyon and Brushy Basin Members of the Morrison Formation. The Westwater Canyon Member was created by aggrading braided streams, which formed an alluvial plain, and ranges from 0 to 220 feet thick. Uranium ore deposits in the shape of lenses can be found in the ancient channels. Organic plant matter is present in the channel sediment. EPA listed the Church Rock Mine as a productive AUM, the Church Rock ISL Mine as non-productive AUM, and Section 16 Deposit as unknown (EPA, 2007c) that have workings below the water table or were considered wet mines that required pumping.

The Church Rock area is drained by ephemeral streams forming tributaries to the Rio Puerco. The Church Rock Mines are east and north of the north fork of the Rio Puerco that runs approximately northeast to southwest.

The following pertinent HRS factors are associated with the Church Rock Mines:

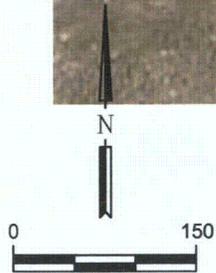
- According to a vehicular gamma-ray survey (a decay product of uranium), elevated uranium concentrations at the surface appear to occur at and around the Church Rock Mines. However, the area is characterized by very slow infiltration rates and moderately slow permeability.
- Deep groundwater likely flows down a regional dip toward the north beneath and north of the NE Church Rock Mines, and an historic piezometric map of upper Gallup shows flow toward the northeast. A review of groundwater analytical results from well 15T-303 and sample 1082213 collected downgradient of the mines indicated uranium concentrations are orders of magnitude less than the MCL.
- Uranium concentrations exceeding the MCL were detected in groundwater samples in four water sources (sample location 1082366, well at Church Rock Mill, well 16-4-10, and Becenti Trail Spring) to the northeast and southwest of the mines. Sample location 1082366 and well 16-4-10 are on adjacent drainages, at elevations above the Pipeline Arroyo or Rio Puerco and of unknown depths. The conflicting groundwater flow directions make it difficult to determine which of the locations are downgradient from the Church Rock Mines.
- The shallow Becenti Trail Spring is downstream of the Church Rock Mines. The results indicated that some uranium may be migrating from the surface of the Church Rock Mines through shallow subsurface and surface flow to the southwest to the spring.
- None of the wells are regulated.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Church Rock Mines.

Figures

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SOURCE: GOOGLE EARTH, 2009 AND as EPA, 2001



APPROXIMATE SCALE IN METERS



ERRG

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4585 Pacheco Blvd., Suite 200
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CLIENT:

U.S. ENVIRONMENTAL
PROTECTION AGENCY

LOCATION:

NEW MEXICO,
NAVAJO NATION

DESIGNED BY:

RDB 6-11-09

CHECKED BY:

JMD 6-12-09

P.E.P.G.:

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**CHURCH ROCK MINE HOLDING AND
SETTLING PONDS AERIAL VIEW**

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**Appendix N. Section 29 - Conoco, Crownpoint
Section 9, and Crownpoint ISL Mines
Groundwater Pathway Assessment**

Appendix N
Section 29-Conoco, Crownpoint Section 9,
and Crownpoint ISL Mines:
Groundwater Pathway Assessment

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Section N1. Mine and Groundwater Investigation

N1.1. LOCATION OF ABANDONED URANIUM MINES

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) were identified below the water table (Table 13 in EPA, 2007c). Three of the AUMs—Section 29-Conoco Mine, Crownpoint Section 9 Mine, and Crownpoint ISL Mine (Crownpoint Mines)—are in the Eastern Region, in McKinley County, New Mexico. Section 29-Conoco Mine is immediately east of the small town of Crownpoint, and Crownpoint Section 9 and Crownpoint In-Situ Leaching (ISL) Mines are west of Crownpoint. Section 29-Conoco and Crownpoint ISL Mines are 125 miles northwest of Albuquerque. The three AUMs are in the west-central portion of the Grants Uranium Region.

The locations by township and range for each of the mines are as follows:

- Section 29-Conoco Mine at 17N,12W.29 (Wentworth, Porter, and Jensen, 1980)
- Crownpoint Section 9 Mine (listed as Insitu Leaching Pilot Plant) at 17N.13W.9.211 and 17N.13W.16 (McLemore and Chenoweth, 1991)
- Crownpoint ISL Mine at 17N.12W.24 (McLemore and Chenoweth, 1991)

N1.1.1. Local Hydrogeology and Geology

The Section 29-Conoco Mine, Crownpoint Section 9 Mine, and the Crownpoint ISL Mine are drained by tributaries that eventually flow into the San Juan River in the north. The Crownpoint Mining District lies on the Chaco Slope of the San Juan sedimentary basin, a large regional depression approximately 100 miles in diameter. The asymmetric basin's southern limb (Chaco Slope) dips gently to the north, and its northern limb dips steeply to the south. The Crownpoint Mining District is along the southern limb. The area around the mines does not have any known structural complexity because of faulting or folding of the sedimentary package (Myers, 2006a).

The Grants Uranium Region, including the Crownpoint Mining District, occurs in and along the southern border of the San Juan Basin. In the Crownpoint Section 9 Mine and Crownpoint ISL Mine areas, the uranium deposits are hosted in sandstones of the Westwater Canyon-Brushy Basin members of the Morrison Formation (Figure 14). During the Jurassic era, three broad alluvial fans, constituting the majority of the Morrison Formation, were deposited in the basin. Southern outcrops of the Morrison

Formation were partially eroded, and later tectonic activity caused a slightly northward tilt (<5 degrees) to the Morrison Formation. The formation is up to 180 meters thick and comprises, from top to bottom, the Brushy Basin Member (comprising the Jackpile sandstone and the Poison Canyon sandstone), the Westwater Canyon Member, and the Recapture Member.

The Morrison Formation is the primary host for uranium mineralization in the Crownpoint Mining District. The Recapture Member shale is the basal unit of the Morrison and consists of siltstone and mudstone, with no significant uranium occurrences. The overlying Westwater Member, fine-grained to coarse-grained sandstone with conglomeritic zones, is the most important uranium mineralization host. The Brushy Basin Shale Member overlies the Westwater and consists mostly of mudstone with thin sandstone lenses that occasionally host uranium mineralization. Generally Westwater Canyon sandstone units to the south of the mineralized zone are oxidized, and the sandstone down dip to the north is reduced (Figure 17; Myers, 2006a).

The Section 29-Conoco Mine property occurs on the northern flank of an unnamed mountain range, which consists of rimrock plateaus and steep, incised canyons. The property is north of the Puerco River and Hosta Butte, the most prominent geographic features in the area. The mountain peaks within 2 miles south of the property are up to 7,900 feet in elevation, with elevations in the immediate area of about 6,700 feet above mean sea level (Myers, 2006b).

N1.1.1.1. Precipitation

Average annual precipitation in the area around the mines is 10 to 12 inches (see the Average Annual Precipitation Map for the Crownpoint Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007b).

N1.1.1.2. Permeability and Aquifer Sensitivity

Soil near the three mines is characterized hydrologically by slow to very slow infiltration rates (see the Hydrologic Group Map for Crownpoint Area in Appendix A; EPA, 2007c). The very slow infiltration rates around Crownpoint ISL are either due to clayey soils, "a high water table, or are shallow to an impervious layer." Permeability in the area ranges between moderately rapid on average, between 2.01 to 6.00 inches per hour, around Crownpoint Section 9 Mine and Section 29-Conoco, and moderately slow, between 0.21 to 0.60 inches per hour, around Crownpoint ISL Mine (see the Permeability Map for Crownpoint Area in Appendix A; EPA, 2007c). Aquifer sensitivity in the area surrounding the mine ranges from insignificant potential to intermediate potential for contaminant migration downgradient along the unnamed washes (see the Aquifer Sensitivity Map for Crownpoint Area in Appendix A; EPA, 2007c).

N1.1.1.3. Dewatering

As described in the main report, uranium ore occurs in reduced anaerobic environments, in which pyrite, uranium, and other metals are relatively stable. As dewatering during mining progressed, the ore bodies were exposed to oxygen and pyrite was oxidized. The resultant sulfate ions and acid dissolved metals, including uranium, selenium, and molybdenum, increasing the concentrations of metals in groundwater (Erskine and Ardito, 2008).

N1.1.1.4. Surface Water and Groundwater

The Crownpoint Section 9 and Crownpoint ISL Mines are located along two unnamed drainage systems that run approximately south-southwest to north-northeast and southeast to northwest, respectively, before joining together approximately 4 miles north of Crownpoint Section 9 Mine. Section 29-Conoco Mine is located on separate drainage system to the east that runs southwest to northeast before eventually joining the Kim-me-vi-oli Wash near Nose Rock No. 1 Mine and then emptying into the San Juan River much farther to the north.

Two wells, SJ 01624 and SJ-823, are within a 4-mile radius of and along the section of the same drainage as Crownpoint ISL Mine, one upstream and one downstream (Figure 17); however, there is no analytical data for either of the wells.

Four wells are located along the section of the drainage near Crownpoint Section 9 Mine, within 0.25-mile radius of the mine; three apparently upstream or at the mine and one downstream or at the mine. No wells are shown in EPA's geographic information system geospatial database located within 4 miles downstream of the mine along this drainage (Figure 17).

Although no wells are located on the ephemeral wash east of Crownpoint where Section 29-Conoco Mine is located, wells 15-UNK-0009, 15-UNK-0010, 28U-321P, and SJ 01338 are within 0.5 mile to the east-southeast in adjacent drainage and well 15B-19 is just over 1 mile east and two drainages over from the mine. No others wells are located within 4 miles downstream of this wash.

There are other wells located along separate drainages from the three mines, several in the town of Crownpoint and between Crownpoint ISL Mine and Crownpoint Section 9 Mine. These wells include Crwnpt PM 5, 15K-202, 15-0579, Crwnpt PM6, Crwnpt PM7, 15-0580, 15-0581, 15T-534, 15-0593, SJ 01023, 15T-554, 15L-73, 16P-101, 15R-318A, Begay Well, Path 320, and SJ-936. Additional wells located farther out from the mines include 15B-33, 15T-559, and 15T-560 and sample location 1081987.

Groundwater Chemistry

Water samples were collected from some of the wells in the area in 1977, 1979, and 2008, and pH and conductivity were measured. The pH of the water samples ranged from 6.7 in sample 1081980 to 9 in

samples 1082344 and 1082345, with an average of approximately 8.4. Specific conductivity ranged from 480 micromhos per centimeter in sample 1081981 to 2,860 micromhos per centimeter in 1081976, with an average of approximately 1242 micromhos per centimeter.

N1.2. DETAILED MINE BACKGROUNDS

The Westwater Canyon Member is approximately 250 to 350 feet thick near Section 29-Conoco Mine and is composed of poorly sorted, cross-bedded fine- to very coarse-grained arkosic to feldspathic sandstone; variable amounts of humate and organic plant material are distributed through the sandstone. The sandstone is intercalated with mudstone and interfingers with the Brushy Basin Member. The sandstone and mudstone of the Westwater Canyon Member were deposited primarily by braided streams. The Point Lookout Sandstone and Menefee Formation are found as surface rocks at the Nose Rock No. 1, Crownpoint ISL, and Section 29-Conoco mines (Chapman, Wood, and Griswold, Inc., 1979).

Storage and mine support buildings and a few lined settling ponds were constructed at Section 29-Conoco Mine in the late 1970s in preparation for mining in the late 1970s but were never used. Three shafts were sunk in the late 1970s, and mining was originally planned to be by underground extraction with surface processing. Current studies for mining at the site propose the use of ISL technology, which would leave minimal footprint on the surface because extraction would be through injection of oxygenated water, which does not generate mine tailings or waste dumps (Myers, 2006b).

A plant facility, leach ponds, and access and production shafts to mineralized horizons were also constructed at the Crownpoint ISL mine but because of falling uranium prices, development was terminated in the early 1980s (Myers, 2006a).

N1.2.1. Crownpoint Ore Deposits

The ore deposits around the Crownpoint Mining District are similar to each other, with ore being from same trend (Figure 11), although not contiguous between the mines. The uranium ore deposits discovered in the 1970s are found in four vertically separate sandstone units in the Westwater Canyon Member of the Morrison Formation. The rocks in the area near the Crownpoint Mines consist of gentle north-northeast dipping strata, with no known faulting. The strata in Section 29-Conoco Mine dip north-northeast between 1 and 2 degrees (Wentworth, Porter, and Jensen, 1980).

Uranium deposits at the Section 29 Conoco Mine average approximately 2,000 feet below ground surface (bgs) and are composed of medium-to-coarse-grained sandstone and conglomerate. Mineralized horizons in the Westwater Canyon Member ranged from a few inches thick to more than 50 feet thick and range from nearly horizontal to moderately dipping up to 10 degrees. The mineralization is associated with the porous and permeable sandstone, in which the concentrations of organic material, often as coatings on

sand grains, are elevated. This organic material controlled the shape of the ore zones (Myers, 2006a), as uranium-bearing groundwater and elongate humate masses reacted along the southern margins of several east-southeast trending channels (Wentworth, Porter, and Jensen, 1980).

Uranium mineralization at Crownpoint mines is secondarily enriched, having formed stacked, elongated lenses approximately 2,900 feet long by 2,500 feet wide. Individual mineralized horizons are generally a few hundred to a thousand feet long, up to 300 feet wide, and 0.5 foot to over 50 feet thick. A 2006 estimate puts the ore at the Crownpoint ISL Mine at 4.75 million tons and 9.966 million pounds of U_3O_8 (Myers, 2006a). Ore resources for the Section 29-Conoco Mine are estimated at 7.06 million tons with 13.672 million pounds of U_3O_8 (Myers, 2006b).

The reclamation statuses of the mines are unknown and are also listed as unknown as to whether any unreclaimed waste piles remain (see the Reclamation Status and Unmapped Waste Piles Map in Appendix A; EPA, 2007c).

N1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

N1.3.1. Regional Aerial Radiation Contours

Aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. An aerial radiation survey has not completed for the Eastern Region so a review of surface radiation at a scale to discern specific mines was not possible. To investigate regional surface concentrations of uranium, an aerial gamma-ray contour map (Figure 21) was studied, where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU; Duval, 1988). The map contours represent values in percent. A regional high occurs just south of the McKinley County border with Cibola County, outside the study area around the Bluewater and Grants uranium mill sites (up to approximately 5.75%). Local highs just north of the border (up to 4.25%) appear to be in the vicinity of the Haystack and Ambrosia Lake areas. Background concentrations within McKinley County and adjacent counties ranged from 1.00 to 2.75%. Another area of high uranium contours appears to the northwest of the other areas, around the Church Rock area, with concentrations up to 4.75%. A regional high does not appear in the Crownpoint Mining District, where Section 29-Conoco, Crownpoint Section 9 and Crownpoint ISL Mines are located, roughly in the middle of McKinley County. This could be partly due to the great depths of the ore bodies at these mines and the lack of extensive surface disturbance.

N1.3.2. Depth to Groundwater

EPA-compiled water data on Google Earth™ shows the locations of water samples and depth to water measurements that have been collected for shallow wells, mine drill holes, wells, and auger holes; the well locations have been transferred to a topographic map for the Crownpoint area (Figure 17).

N1.3.2.1. Crownpoint ISL and Section 29-Conoco Mines

Depths to groundwater were measured at wells near the Crownpoint ISL and Section 29-Conoco Mines including (but not limited to):

- 15-0579 at elevation of 6,950 feet above msl with depth to groundwater of 423 feet bgs on March 13, 1975
- SJ 00823 at elevation of 6,710 feet above msl with depth to groundwater of 40 feet bgs on December 19, 1978
- 15K-303 at elevation of 6,985 feet above msl with depth to groundwater of 225 feet bgs on June 1, 1932
- CRWNPT PM5 at elevation of 7,034 feet above msl with depth to groundwater of 335 feet bgs on September 15, 1958
- CRWNPT PM6 at elevation of 6,950 feet above msl with depth to groundwater of 350 feet bgs on September 25, 1961
- 15-UNK-0010 at elevation of 6,820 feet above msl with depth to groundwater of 371.4 feet bgs on June 25, 1985

These wells are located within an approximate 4-mile radius of Crownpoint ISL Mine, running from southeast at higher elevations (15K-303 and CRWNPT PM5) to northwest at lower elevations (SJ 00823; Figure 17). However, depths to water were measured during different years, and well screens are placed in different aquifers from one well to the next. Of these, the well screens for wells 15K-303, CRWNPT PM5, and CRWNPT PM6 are placed in the same aquifer, listed as 221MRSN (probably particular unit of the Morrison Formation).

Of these, only the depths to groundwater measured in CRWNPT PM5 and CRWNPT PM6 were recorded during a similar time period. Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 6,699 feet above msl in CRWNPT PM5 and 6,600 feet above msl in SJ 00823, indicating a general south to north groundwater flow (EPA, 2009d).

N1.3.2.2. Crownpoint Section 9 Mine

Depths to groundwater were collected from wells in the vicinity of the Crownpoint Section 9 Mine including (but not limited to):

- Begay Well at elevation of 6,830 feet above msl with depth to groundwater of 125 feet bgs on January 1, 1963
- 94-202 at elevation of 6,699 feet above msl with depth to groundwater of 269.7 feet bgs on June 28, 1985
- PU-279 at elevation of 6,702 feet above msl with depth to groundwater of 274.2 feet bgs on June 28, 1985
- SJ-936 at elevation of 7,090 feet above msl with depth to groundwater of 333.4 feet bgs on June 26, 1985
- SJ-00823 at elevation of 6,710 feet above msl with depth to groundwater of 40 feet bgs on December 19, 1978
- 15T-560 at elevation of 6,760 feet above msl with depth to groundwater of 200 feet bgs on June 10, 1979

These wells are located within an approximate 4-mile radius of Crownpoint Section 9 Mine, running from higher elevations in the southwest (SJ-936) to lower elevations in the north and northeast (SJ 00823 and 15T-560; Figure 17). Depths to water were measured during different years, and well screens are placed in different aquifers from one well to the next. However, the well screens for wells SJ-936, SJ 00823, and 15T-560 are placed in the same aquifer, listed as 211GLLP (probably the Gallup Formation), and depths to groundwater were measured during a similar time period. Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 6,756.6 feet above msl in SJ-936, 6,670 feet above msl in SJ 00823, and 6,560 feet above msl in 15T-560, indicating a general south to north groundwater gradient (EPA, 2009d).

N1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. Water samples were collected in the Crownpoint area in 1977 and 1979 as part of the National Uranium Resource Evaluation Program (NURE) in the hydrogeochemical and stream sediment reconnaissance phase and in 2008 by EPA. No information on well development is available, and groundwater samples are not collected regularly because these wells are unregulated water sources. Available analytical results summarized below are from limited grab groundwater samples.

As stated above, water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been historically used for drinking water purposes, and it is hard for people to abandon using them (Keller, 2007).

N1.3.3.1. Analytical Results for 1977 and 1979 Sampling

In September 1977 and October 1979, four water samples were collected within a 4-mile radius of Section 29 Conoco and Crownpoint ISL Mines. The concentration of uranium in sample 1082353, possibly collected at well 15K-303, upgradient from Crownpoint ISL mine, was 2.36 micrograms per liter ($\mu\text{g/L}$), and the pH was 8.6 and the specific conductivity 750. The uranium concentration and the pH in sample 1081981, north of well 15K-303 and also upgradient of Crownpoint ISL, were 0.2 $\mu\text{g/L}$ and 8.2, respectively, and the specific conductivity was 480. The uranium concentration and pH in sample 1081978 collected in 1977 from well 15B-19 were 1.47 $\mu\text{g/L}$ and 8.3, respectively, and the specific conductivity was 1,300. Sample 1082352 collected in 1979 from well 15B-19 had a uranium concentration of 0.25 $\mu\text{g/L}$.

Additional samples were collected from wells farther than 4 miles from the mines. These samples include:

- Sample 1081976 collected in 1977 from well 15B-33 the uranium concentration, pH, and specific conductivity were 2.38 $\mu\text{g/L}$, 8.6, and 2,860, respectively.
- Sample 1082345 collected in 1979 from well 15B-33 - the uranium concentration, pH, and specific conductivity were 1.69 $\mu\text{g/L}$, 9, and 858, respectively.
- Sample 1081987 collected in 1977 from well north of Crownpoint the uranium concentration, pH, and specific conductivity were 1.21 $\mu\text{g/L}$, 8.7, and 1,820, respectively.
- Sample 1082344 collected in 1979 from well north of Crownpoint - the uranium concentration, pH, and specific conductivity were 1.46 $\mu\text{g/L}$, 9, and 673, respectively.
- Sample 1082007, collected in 1977 almost 6 miles to the northwest along the same drainage system as Crownpoint ISL Mine - the uranium concentration, pH, and specific conductivity were 1.91 $\mu\text{g/L}$, 8.9, and 2,120, respectively.

In September 1977 and October 1979, three water samples were collected within a 4-mile radius of Crownpoint Section 9 Mine. The uranium concentration, pH, and specific conductivity in sample 1081980, collected in 1977 from adjacent drainage to the mine, were 0.17 $\mu\text{g/L}$, 6.7, and 1,600, respectively. The pH of the water sample collected from well 15T-560 in 2008 from adjacent drainage to the mine, was 8.1, and the specific conductivity was 806; uranium was not detected at a concentration equal to or greater than the laboratory reporting limit (EPA, 2009d).

N1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

None of the mines have been uranium producers, although exploratory drilling has discovered large ore reserves and extensive associated organic material. As detailed on Figure 11, uranium ore still remains at and between the three mines. Pre-mining operations may have left some open spaces and conduits, such as shafts and exploratory holes. While early pre-mining operations may have disturbed surface soil and

generated waste material at the site, both are likely to be minimal. Undisturbed and unmined deposits in the area are very deep, such that rainwater infiltration is a less likely pathway of concern, and groundwater is more likely to mobilize uranium.

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Section N2. Hazard Ranking System

N2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial, limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Crownpoint Mines include, but are not limited to:

- Uranium ore deposits below the surface and below the water table at the mines.

Additional potential sources of hazardous substances not necessarily associated with the Crownpoint Mines but found in the surrounding area include:

- Undisturbed deposits within the Westwater Canyon Sandstone in the area surrounding the Crownpoint Mines.

N2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS

emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

N2.2.1. Rainwater Infiltration

As discussed above in Subsection N1.1.1.1, average annual precipitation in the area is approximately 10 to 12 inches and is mostly characterized by brief thunderstorms. Infiltration rates through fine-grained soils are slow to very slow (see the Hydrologic Group Map for Crownpoint area in Appendix A; EPA, 2007c). Permeability is moderately rapid, and an 'insignificant to intermediate potential' exists for contaminant migration in soils around the mine sites. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest increases downgradient of the mines along an unnamed wash (see the Permeability and Aquifer Sensitivity Maps for Crownpoint area in Appendix A; EPA, 2007c). These characteristics are applicable to the Crownpoint Mine ore bodies, as well as the uneroded deposits in the surrounding area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Because of the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing water likely infiltrates the waste rock at the surface, as well as the subsurface ore deposits, destroying organics, oxidizing sulfides, and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23). Although the open spaces associated with the mines provide preferential pathways, neither of the Crownpoint Mines ore bodies have been extensively mined, meaning the highest grade ore is still in place at the mine. Uneroded ore deposits, in the vicinity of and downstream of the mine may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium. However, because the uranium deposits are approximately 2,000 feet below the surface, rainwater is less of a concern than in mines with shallower deposits.

N2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend to the north-northwest from Crownpoint ISL, northwest

then north from Crownpoint Section 9, and northeast from Section 29-Conoco Mine as surface waters in the unnamed washes and ephemeral creek beds do. Depth-to-groundwater measurements identify a general south to north gradient. Based on the depth of the uranium ore and from the recorded depth to waters around the mine, groundwater levels are likely above the ore deposits. Recharge of fresh oxidizing rainwater to the groundwater table is less likely to leach uranium because of the depth of the deposits; however, it could have a minor effect.

Oxidizing groundwater leaches metals (including uranium) from the ore deposit in the presence of oxidizing conditions. However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 23).

In addition, unoxidized zones within the ore deposits are controlled by organic accumulations deposited adjacent to zones of higher groundwater flow, the insoluble nature of the intermixed uranium and humate, lower groundwater transmissivity at the stratigraphic pinch outs, and the hydrologic influence of bounding faults. Crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may also impede uranium dispersion. Adsorption of uranium onto clays occurs in the pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. It is also noted that the overlying strata in the Section 29 Conoco area have slow infiltration rates, with moderately rapid to moderately slow permeability into Westwater Canyon Member where the uranium deposits are located. Groundwater is more likely to be affected by recharge from the adjacent arroyos during thunderstorms. Measured groundwater pH in the region averages 8.4, which is outside the optimal adsorption range and may allow uranium to be picked up in solution from oxidizing water to migrate.

Results of water sampling suggest that uranium is not leaching from ore deposits and dispersing downstream from any of the Crownpoint Mines. The uranium concentrations in two water samples collected upstream of Crownpoint ISL Mine were 0.2 µg/L and 2.36 µg/L. The concentration of uranium in one water sample, almost 6 miles downstream from the Crownpoint ISL Mine, was 1.91 µg/L. All of these concentrations are less than the maximum contaminant level (MCL) of 30 µg/L and may define background concentrations of uranium in groundwater for the area.

In general, no upstream water samples were available for comparison against water quality standards. Two data sets are available for a sample location downstream from Section 29-Conoco Mine, within approximately 1 mile of the mine. The uranium concentrations were 0.25 µg/L and 1.47 µg/L. Two data sets are also available for the sample collected downgradient from the mine but in a different wash. The uranium concentrations in these data sets were 1.69 µg/L and 2.38 µg/L. All of the concentrations are less than the MCL of 30 µg/L and are consistent with background concentrations for uranium in groundwater of between 0.25 to 2.38 µg/L.

N2.2.3. Groundwater Pathway Conclusion

Uranium was not detected in any of the groundwater samples within a 4-mile radius of the Crownpoint Mines at concentrations greater than the MCL of 30 µg/L. None of the wells are intended to be used for drinking water, but community feedback has confirmed that the wells are being used for drinking water purposes (EPA, 2009a).

N2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Crownpoint Mines enters two unnamed drainage systems that join and feed into the San Juan River. Surface water runoff from the Section 29-Conoco Mine enters an unnamed drainage system that feeds into the Kim-me-vi-oli Wash to the north-northeast. The wash eventually empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick and water infiltration is fast but limited in volume through dry and porous soil. As a result, only minor amounts of surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds.

N2.3.1. Surface Water Pathway Conclusion

Some regulated drinking water intakes are likely located within the vicinity of the mines or within 15 miles downstream of the mines because of the mines proximity to the town of Crownpoint. However, uranium concentrations in samples collected from the water source downgradient of the mines are much less than the MCL, and the depth of the ore bodies makes direct interaction with surface waters unlikely.

N2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that

pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Crownpoint Mines for the following reasons:

- No known contamination is near the mines, and concentrations of uranium in samples from wells upgradient and downgradient of the mines that may be attributable to the mines are less than their respective MCLs.
- Low to moderate radiation levels were seen on aerial radiation maps, and no waste rock with significant uranium content is present.
- Residences, schools, and/or daycare centers are within 200 feet of contamination associated with the site; however, that uranium concentration are less than the respective MCLs.

N2.5. SUMMARY

The general area of the study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining starting in the 1900s. Substantial tracks of land were disturbed by surface and underground mining during this period. The Crownpoint Mines are located within the Eastern Region, specifically the Grants Uranium Region. The Grants Uranium Region, located on the southeastern Colorado Plateau in northwestern New Mexico, covers an area 150-kilometers long running east-southeast and up to approximately 30 kilometers wide (Dahlkamp, 1993) and spans three counties (Cibola, McKinley, and San Juan). Uranium was mined in this region, primarily from channel deposits of Westwater Canyon Member of the Morrison Formation. The channel deposits at the Crownpoint Mines are still being explored, but the ore depths are approximately 2,000 feet bgs.

Section 29-Conoco Mine, Crownpoint Section 9 Mine, and Crownpoint ISL Mine are listed by the EPA as non-productive AUMs (EPA, 2007c) that have workings below the water table. There is potential that human receptors might be exposed to uranium through groundwater and surface water pathways because of the proximity of Crownpoint ISL mine to the town of Crownpoint and unidentified structures seen on aerial maps within a 4-mile radius. However, the geologic setting of the mines and analytical results for groundwater samples suggest that contamination is unlikely.

The area surrounding Crownpoint Section 9 Mine and Crownpoint ISL Mine is drained by ephemeral streams forming tributaries that eventually flow to the San Juan River in the north. The Section 29-Conoco area is also drained by ephemeral streams running southwest to northeast that feed into the Kimme-vi-oli Wash farther to the north and eventually flow into San Juan River.

The following pertinent HRS factors are associated with the Crownpoint ISL Mine and the Crownpoint Section 9 Mine:

- According to aerial radiation surveys for Bismuth-214 (a decay product of uranium), no elevated uranium concentrations at the surface are associated with either Crownpoint Mine.
- Uranium was present in samples collected from shallow sources of water, but the concentrations were less than MCLs.
- Uranium concentrations in the downgradient well where the drainage systems for the mines join (approximately 4 miles north-northeast of Crownpoint Section 9 Mine) are less than MCLs.
- Uranium concentrations in the downgradient well closest to the Section 29-Conoco Mine (approximately 1 mile north-northeast of Section 29-Conoco Mine) are less than e MCLs.
- Residences, schools, and/or daycare centers are within 200 feet of mines; however, uranium concentrations are less than the MCL.

Appendix O. Nose Rock No. 1 Mine Groundwater Pathway Assessment

Appendix O
Nose Rock No. 1 Mine:
Groundwater Pathway Assessment

April 2010

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Section 01. Mine and Groundwater Investigation

01.1. LOCATIONS

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mines) occur below the water table (Table 13 in EPA, 2007c). One of these mines, the Nose Rock No. 1 Mine, is located in the Eastern Region, within north-central McKinley County approximately 12 miles northeast of the town of Crownpoint in New Mexico and 30 miles northwest of the Ambrosia Lake area, within the Grants Uranium Region. The mine is located in Section 31 of Township 19 North, Range 11 West (sec. 31, T. 19 N., R. 11 W.) and Sections 1 and 36 of Township 18 North, Range 12 West (McLemore and Chenoweth, 1991). The surface elevation of the mine is approximately 6,350 to 6,360 feet above mean sea level at latitude and longitude of approximately 35.8363°N and 108.0537°W (Figure 18).

01.1.1. Local Hydrogeology

The Nose Rock No. 1 Mine is located in the San Juan River Basin system. The Nose Rock No. 1 Mine is located along the Kim-me-vi-oli Wash that runs approximately south-southeast to north-northwest.

01.1.1.1. Precipitation

Average annual precipitation in the area surrounding the mine is 8 to 10 inches (see Average Annual Precipitation Map for the Crownpoint area of the Eastern Region in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c). The annual evaporation rate is reported to reach 100 inches per year and suggests that much of the area lacks supplies of surface water to support basic human needs; thus, residents and industry in the area are dependent upon groundwater (Brod, 1979).

01.1.1.2. Permeability and Aquifer Sensitivity

Soil near the mine is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for Crownpoint area in Appendix A). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is rapid on average, between 6.01 to 16.53 inches per hour (see the Permeability Map for Crownpoint area in Appendix A; EPA, 2007c).

However, the volume of rainfall during storms can exceed the capacity of soils to transmit water and force more runoff than infiltration.

Aquifer sensitivity in the area surrounding the mine has the most potential for contaminant migration along the unnamed wash (see the Aquifer Sensitivity Map for Becenti and Crownpoint areas in Appendix A; EPA, 2007c).

01.1.1.3. Dewatering

As described in the main report, uranium ore occurs in reduced anaerobic environments, in which pyrite, uranium, and other metals are relatively stable. As dewatering during mining activities progressed, the ore bodies were exposed to oxygen and pyrite was oxidized. The resultant sulfate ions and acid dissolved the metals, including uranium, selenium, and molybdenum, causing increases in metal concentrations in groundwater. For the mines that have reflooded after mining was discontinued, the oxygen would be consumed and subsurface conditions within the mines would return to a more reduced state, allowing for redeposition of uranium and other metals (Erskine and Ardito, 2008).

01.1.1.4. Surface Water and Groundwater

The mine is located along the Kim-me-vi-oli Wash that runs approximately south-southeast to north-northwest. Several wells or water data locations are scattered throughout the area along drainages that flow into the Kim-me-vi-oli Wash, including the following:

- Well Pitt #2 (sample location 1081933) and sample location 1082346 in drainages to the southeast and upgradient of the mine
- Well SJ-01586 to the east of the mine and well 15T-517 (sample location 1081994) to the west of the mine in adjacent drainage systems, which feed into the Kim-me-vi-oli Wash downgradient of the mine
- Sample location 1082342, well SJ02230 (sample location 1081991), and sample location 1081990 in drainages to the southwest and south of the mine, which feed into the Kim-me-vi-oli Wash downgradient of the mine
- Well 15-UNK-0007 either located in adjacent drainage immediately to the west of the mine or just upgradient of the mine at sample location 1081992 (these may be inaccurately located in database; Figure 18)

Well Pitt #2 is an active domestic well, while wells SJ02230, SJ01586, and 15T-517 are listed as livestock wells. Well 15-UNK-0007, approximately 1 mile south-southeast of the Nose Rock No. 1 mine, is an observation well installed by Phillips Uranium Corporation in association with the mine. The known well depths range from 700 and 701 feet below ground surface (bgs) for Pitt #2 and 15T-517, respectively, to 1,725 feet bgs for 15-UNK-0007. The only reported depths to water were 153.7 feet bgs taken on October 18, 1985, in 15T-517 and -58 feet bgs on September 1, 1976 (the negative value may be

a typographic error or indicate semi-confined conditions). The well depths and depths to water for the remaining wells listed here are unknown.

01.2. DETAILED MINE BACKGROUND

The Grants Uranium Region including the Nose Rock area occurs within and along the southern border of the San Juan Basin. In the Nose Rock area, the uranium deposits are hosted in sandstones of the Westwater Canyon-Brushy Basin members of the Morrison Formation (Figure 14). During the Jurassic, three broad alluvial fans, constituting the majority of the Morrison Formation, were deposited in the basin. Southern outcrops of the Morrison Formation were partially eroded in the Upper Cretaceous and tectonic activity in the Laramide caused a slightly northward tilt (<5 degrees) to the Morrison Formation. The formation is up to 180 meters thick and is comprised of, from top to bottom, the Brushy Basin Member (comprising the Jackpile sandstone and the Poison Canyon sandstone), the Westwater Canyon Member, and the Recapture Member (Chapman, Wood, and Griswold, Inc., 1979). The structure of the area consists of a gentle homocline dipping N. 70 E. at about 120 feet per mile (Clark, 1980).

The Westwater Canyon Member is composed of poorly sorted, cross-bedded fine- to very coarse-grained arkosic to feldspathic sandstone; humate and organic plant material occur in variable amounts in the sandstone. The sandstone is intercalated with mudstone and interfingers with the Brushy Basin Member. These sandstone and mudstone of the Westwater Canyon Member were deposited primarily by braided streams. The Point Lookout Sandstone and Menefee Formation are found as surface rocks at the Nose Rock No. 1, Crownpoint ISL, and Section 29-Conoco Mines (Chapman, Wood, and Griswold, Inc., 1979).

In 1973, Phillips Uranium Corporation began drilling in the Nose Rock area and, by December 1975, they discovered approximately 25 million pounds of uranium oxide contained within a 1,920-acre tract. The Westwater Canyon Member in the northwest portion of sec. 31, T. 19 N., R. 11 W. is approximately 170 meters thick in this area and thickens markedly northward into the San Juan Basin (Clark, 1980).

The hosting units of the Westwater Canyon Member are a series of stacked fluvial quartz-arkosic sandstones separated by clay and shale beds. The mineralization was generated by the down-dip movement of groundwater flowing through the sands and the inter-formational and overlying tuffaceous sediments. The ore deposits in Section 31 are 11 miles down dip of the present redox interface, and the Westwater Canyon Sandstone is gray and unoxidized (Clark, 1980). Uranium was precipitated in reducing environment produced by the reaction of pyrite-rich sediments and humates with groundwater at the oxidation-reduction front. Uranium ore occurs as tabular and roll front deposits (Alief, 2009).

Strathmore Minerals Corporation currently holds the mineral leases, or claim stakes, of Section 36, as well as an additional seven sections contiguous or near the Section 36 lease (Strathmore, 2007). Phillips

Uranium Corporation estimated the resource of Sections 1 and 36 to be 6,694,217 tons of ore or 18,230,955 pounds of U_3O_8 (Alief, 2009).

01.2.1. Nose Rock No. 1 Ore Deposits

Exploratory drilling in the Nose Rock area has found uranium ore at an approximate depth of 3,100 feet. There are three distinct front rolls of uranium and in areas where two or all three of them are superimposed, ore thickness may be in excess of 50 feet. Coffinite has been observed to be the principal uranium mineral and it is coextensive and intimately associated with black carbonaceous matter. There has been speculation that the Nose Rock and Ambrosia Lake deposits are connected in some manner and further drilling may prove this in the future.

01.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

01.3.1. Regional Aerial Radiation Contours

Aerial radiation contours identify concentrations higher than regional levels. Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. An aerial radiation survey was not completed for the Eastern Region by the DERSL, so a review of surface radiation at a scale to discern specific mines was not possible. In order to investigate regional surface concentrations of uranium, an aerial gamma-ray contour map (Figure 21) was studied where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU; Duval, 1988). The map contours represent values in percent. A regional high occurs just south of the McKinley County border with Cibola County, outside the study area around the Bluewater and Grants uranium mill sites (up to approximately 5.75%). Local highs just north of the border (up to 4.25%) appear to be in the vicinity of the Haystack and Ambrosia Lake areas. Background concentrations within McKinley County and adjacent counties range from 1.00 to 2.75%. Another area of high uranium contours appears to the northwest of the other areas, around the Church Rock area with concentrations up to 4.75%. There does not appear to be a regional high in the Crownpoint area, where Nose Rock No. 1 Mine is located, roughly in the middle of McKinley County. This could be partly due to the great depths of the ore bodies in this mine and due to the minor surface disturbances associated with exploratory drilling at the mine.

01.3.2. Depth to Groundwater

Several wells are located in the Nose Rock area; however, well data are scarce and depth to water measurements have been recorded for only a few wells. Depth to groundwater was measured at well 15T-517 in October 1985 and at well 15-UNK-0007 in September 1976. In addition to the time difference between measurements, the wells are installed to very different depths and thus different aquifers. Well 15T-517 is drilled to 701 feet bgs into the Point Lookout Sandstone, and well 15-UNK-0007 is drilled to 1725 feet bgs into the Gallup Sandstone.

These wells are located within a four mile radius of Nose Rock No. 1 Mine (Figure 18). Based on the altitude of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 6,302 feet above msl in 15-UNK-007 (or 6,418 feet above msl if artesian conditions indicated by the reading listed in the database are accurate) and 6,236.3 feet above msl in 15T-517, indicating a general southeast to northwest flow (EPA, 2009d).

01.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation region at many unregulated wells and springs. Water samples were collected in the Nose Rock area in 1977 and 1979 as part of the National Uranium Resource Evaluation Program (NURE) during the hydrogeochemical and stream sediment reconnaissance phase. Because these wells are unregulated water sources, no information on well development is available and regular groundwater sampling is not conducted. Available analytical results summarized below are from limited grab groundwater sampling events.

As stated above, unregulated water sources within the Navajo Nation are deemed unfit for human consumption; however, these water sources may still be in use by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been historically used for drinking water purposes and it is hard for people to abandon using them (Keller, 2007).

01.3.3.1. Analytical Results for 1977 and 1979 Sampling

In September 1977 and October 1979, water sampling for NURE was conducted in the Nose Rock area; data from this sampling event have been compiled and transferred to a database by the U.S. Geological Survey (USGS) (1997). In September 1977, four water samples were collected within a 4-mile radius of Nose Rock No. 1 Mine. Sample 1081994 at livestock well 15T-517 in adjacent drainage to the mine had a uranium concentration of 0.48 micrograms per liter ($\mu\text{g/L}$), pH of 8.9, and specific conductivity of 3,620. Sample 1081991 at livestock well SJ02230 in adjacent drainage to the mine had a uranium concentration of 0.53 $\mu\text{g/L}$, pH of 8.9, and specific conductivity of 1,320. Sample 1081992, likely collected from observation well 15-UNK-0007 and immediately upgradient of the mine, had a uranium concentration of 1.68 $\mu\text{g/L}$, pH of 8.8, and specific conductivity of 2,900. Sample 1081993 collected at domestic well PITT #2 and upgradient of the mine, had a uranium concentration of 1.1 $\mu\text{g/L}$, pH of 8.5, and specific conductivity of 2,850 (EPA, 2009c).

Water sample 1081990 collected approximately 5.9 miles to the south of the mine in adjacent drainage system had a uranium concentration of 1.32 $\mu\text{g/L}$, pH of 8.5, and specific conductivity of 1,750, while sample 1081996 collected approximately 6.5 miles downstream from Nose Rock No. 1 Mine along the

Kim-me-vi-oli Wash had a uranium concentration of 2.92 $\mu\text{g/L}$, pH of 8.3, and specific conductivity of 3,000 (EPA, 2009c).

In October 1979, three water samples were collected in the vicinity of Nose Rock No. 1 Mine but outside a 4-mile radius. Sample 1082342 collected in adjacent drainage to the mine had a uranium concentration of 2.14 $\mu\text{g/L}$, pH of 9, and specific conductivity of 797. Sample 1082346 collected upgradient of the mine had a uranium concentration of 0.26 $\mu\text{g/L}$, pH of 9, and specific conductivity of 761. Another sample, 1082341, was collected at the same location as sample 1081996; sample 1082341 had a uranium concentration of 2.19 $\mu\text{g/L}$, pH of 8.5, and specific conductivity of 913 (EPA, 2009c).

O1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

Nose Rock No. 1 Mine has not produced uranium ore, although exploratory drilling has discovered large ore deposits with extensive organic material associated with uranium deposition. As illustrated on Figure 12, the ore bodies are scattered throughout the area, with large deposits to the northeast and smaller deposits to the west and southwest of the mine; ore bodies in the vicinity of the mine appear to be interconnected. Since mining operations have not begun at the mine, the only potential open spaces and conduits are from the exploratory drill holes. As such, the deposits should still be in a reduced environment. Aerial views of the mine indicate that pre-mining and exploratory operations may have disturbed the surface, with the possibility that minor volumes of overburden, drill core and cuttings, and waste rock may have been removed from the mine and placed at the surface (Figure 23).

Section O2. Hazard Ranking System and Summary

O2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial, limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium, has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and sampled uranium deposits.

Potential sources of hazardous substances associated with the Nose Rock No. 1 Mine include, but are not limited to:

- Uranium ore deposits remain below the surface and below the water table at the Nose Rock No. 1 Mine.

Additional potential sources of hazardous substances not necessarily associated with the Nose Rock No. 1 Mine but found in the surrounding area include:

- Undisturbed and uneroded channel deposits within the Westwater Canyon Sandstone in the area surrounding the Nose Rock No. 1 Mine (Figure 12).

O2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS

emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is designed as a screening tool to give the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

O2.2.1. Rainwater Infiltration

As discussed above in Subsection O1.1.1.1, average annual precipitation in the area is low, approximately 8 to 10 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep moderately-grained soils are moderate (see the Hydrologic Group Map for Crownpoint area in Appendix A). Permeability is rapid, and the "most potential" exists for contaminant migration in soils upgradient at the mine site. This potential for relative ease at which a contaminant applied on or near the land surface can migrate to the aquifer of interest remains the same downgradient of the mine along the Kim-me-vi-oli Wash (see the Permeability and Aquifer Sensitivity Maps for Becenti and Crownpoint areas in Appendix A). These characteristics are applicable to the remaining Nose Rock No.1 Mine ore body, as well as the uneroded ore deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. Adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Due to the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing water likely infiltrates the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23). Although the open spaces associated with the mines provide a preferential pathway, the Nose Rock ore body has not been mined, meaning the ore is still in place at the mine. Uneroded ore deposits, in the vicinity of and downstream of the mine may also provide uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium. However as the uranium deposits are approximately 3,000 feet below the surface, rainwater is less of a concern than in mines with shallower deposits.

O2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend to the north-northwest as the Kim-me-vi-oli Wash and the other ephemeral creek beds do. Based on the depth of the uranium ore and from the recorded depth to waters around the mine, groundwater levels are likely above the ore deposits. Recharge of fresh oxidizing

rainwater to the groundwater table is less likely to leach uranium due to the depth of the deposits however it could have a minor effect. The ore deposits are likely below the oxidizing groundwater table, allowing leaching of metals (including uranium) from the ore deposit. However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 23). In addition, unoxidized zones within the ore deposits are controlled by organic accumulations deposited adjacent to zones of higher groundwater flow, the insoluble nature of the intermixed uranium and humate, lower groundwater transmissivity at the stratigraphic pinch outs, and the hydrologic influence of bounding faults. Crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may also impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. It is also noted that the overlying strata in the Nose Rock area have moderate infiltration rates with rapid permeability into Westwater Canyon Member where the uranium deposits are. Groundwater is more likely to be affected by recharge from the adjacent arroyos during thunderstorms. Measured groundwater pH in the region is reported from 8.5 to 8.8, outside the optimal adsorption range, which may allow uranium to be picked up in solution from oxidizing water to migrate.

Results of water sampling illustrate similar uranium concentrations throughout the area, suggesting the concentrations may reflect the background concentration of uranium in groundwater in the area. Upstream water samples have uranium at concentrations less than the maximum contaminant level (MCL) of 30 $\mu\text{g/L}$ (0.53 $\mu\text{g/L}$ to 2.14 $\mu\text{g/L}$). Two samples collected approximately 6.5 miles downstream of Nose Rock No. 1 Mine along the Kim-me-vi-oli Wash had uranium concentrations of similar magnitude. These concentrations are also less than the MCL of 30 $\mu\text{g/L}$, and the concentrations would reflect the summation of water from multiple drainages collecting into this wash such that any uranium present is not necessarily associated with Nose Rock No. 1 Mine. The analytical result for the sample collected adjacent to the mine is similar in magnitude to the other results, which also suggests that no significant uranium leaching is occurring from ore deposits at Nose Rock No. 1 Mine.

02.2.3. Groundwater Pathway Conclusion

There are no water samples containing uranium above the MCL of 30 $\mu\text{g/L}$ within the 4-mile radius of Nose Rock No. 1 Mine. Samples collected from wells within the 4-mile radius are from upstream or adjacent drainages, so groundwater flow from the mines would not affect these wells or springs (see the Combined Pathway for Eastern Region in Appendix A). None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that the wells are used for drinking water (EPA, 2009b).

02.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Nose Rock No. 1 Mine enters a drainage system that feeds into the Kim-me-vi-oli Wash to the north-north west. This eventually empties into the San Juan River.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds.

02.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the Kim-me-vi-oli Wash in the vicinity of the mine or within 15 miles downstream of the mines. Uranium was detected in the water sources upgradient and downgradient of the mine but at concentrations less than the applicable MCL.

02.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary at this time for the Nose Rock No. 1 Mine for the following reasons:

- There is no known contamination near the site, and concentrations off site that may be attributable to the mines are less than the respective MCLs
- Background levels of low to moderate radiation were seen on aerial radiation maps and the mine has never been productive, and there is little or no waste rock expected at the surface
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site

O2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s. Substantial tracts of land were disturbed by surface and underground mining during this period. The Nose Rock No. 1 Mine is in the Eastern Region, specifically the Grants Uranium Region. The Grants Uranium Region, on the southeastern Colorado Plateau in northwestern New Mexico, covers an area 150km long that runs east-southeast and is up to approximately 30 kilometers wide (Dahlkamp, 1993) and spans three counties, Cibola, McKinley, and San Juan. Uranium was mined in this region, primarily from channel deposits of Westwater Canyon Member of the Morrison Formation. The channel deposit at the Nose Rock No. 1 Mine is still being explored but is at an approximate depth of 3,100 feet. Organic matter is abundant in the channel sediments. The Nose Rock No. 1 Mine was listed by EPA as a non-productive AUM (EPA, 2007c) that has ore deposits below the water table.

The Nose Rock area is drained by ephemeral streams that form tributaries to the San Juan River. The Nose Rock No. 1 Mine is located along the Kim-me-vi-oli Wash that runs approximately southeast to northwest.

The following pertinent HRS factors are associated with the Nose Rock No. 1 Mine:

- According to aerial radiation surveys for Bismuth-214 (a decay product of uranium), no elevated uranium concentrations at the surface are associated with Nose Rock No. 1 Mine.
- Uranium concentrations in samples collected from water sources (wells) near the mine were less than MCLs.
- Uranium concentrations in samples collected from the downgradient well closest to the Nose Rock No. 1 Mine (approximately 6.5 miles north-northwest of Nose Rock No. 1 Mine) are similar in magnitude to uranium concentrations in wells upgradient of the mine, which are less than MCLs.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Nose Rock No. 1 Mine.

Appendix P. Mariano Lake Mines Groundwater Pathway Assessment

Appendix P
Mariano Lake Mines
Groundwater Pathway Assessment

April 2010

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Section P1. Mine and Groundwater Investigation

P1.1. LOCATION OF ABANDONED URANIUM MINES

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). Two of these AUMs—both listed as Mariano Lake Mine in Table 8 in EPA, 2007c—are located within the Eastern Region, approximately 1.5 miles south of Highway 11 in McKinley County of New Mexico. The mines are located within the Mariano Lake chapter of the Navajo Nation, west of Smith Lake, east of Mariano Lake, and approximately 9 miles southwest of Crownpoint.

The Mariano Lake Mine(s) are in Sections 11 and 12, T. 15 N., R. 14 W., in McKinley County, New Mexico (Jenkins and Cunningham, 1980; McLemore and Chenoweth, 1991). The township and range for the Mariano Lake Mine in Section 12 are listed as 15N.14W.12.134 (McLemore, 1983). The mine is listed at latitude of longitude of 35.54708 and 108.2780 (McLemore, 2007). The Mariano Lake mines are listed as one mine in most literature and were operated by Gulf Mineral Resources Company from 1977 to 1982.

These AUMs are in the Rio Puerco drainage basin of the Smith Lake Mining District of the Grants Uranium Region.

P1.1.1. Local Hydrogeology and Geology

The Mariano Lake mines are in the Smith Lake Mining District on the eastern flank of the San Juan River Basin. Hydrologically, the mines are in the Rio Puerco drainage basin (Busby, 1979); drainages from the mines feed into North Fork of the Rio Puerco, which runs east to west and then into the Rio Puerco, running west to southwest out of New Mexico into the Little Colorado River in Arizona (Busby, 1979).

P1.1.1.1. Precipitation

Average annual precipitation in the area around the mines is 14 to 16 inches (see Average Annual Precipitation Map for Crownpoint Area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007c).

While surface water and groundwater are commonly considered to be separate resources, they generally are closely interconnected. Much of the annual rainfall flows over the land as runoff in washes and ephemeral stream channels or is used by plants. In arid areas, a large portion of the rainfall is lost by evaporation, such that only a fraction of the rainwater infiltrates the soil below the root zone to become groundwater. In fine-grained sediments, water may move at rates as slow as 1 inch per year, but in coarser sediments, it may travel as fast as tens of feet per day. In the Rio Puerco basin, the shallow aquifer is river-deposited alluvium consisting of fine sand interfingering with silty clay. Shallow groundwater moves at rates ranging from 0.10 inch to 3 feet per day (Wirt, 1994).

P1.1.1.2. Permeability and Aquifer Sensitivity

The mines are characterized hydrologically by very slow infiltration rates, either caused by clayey soil, a high water table, or shallow to impervious soil layers (see the Hydrologic Group Map for Crownpoint Area in Appendix A; EPA, 2007c). Permeability in the area is moderate, between 0.61 to 2.00 inches per hour (see the Permeability Map for Crownpoint Area in Appendix A; EPA, 2007c). However, the volume of rainfall during storms can exceed the capacity of soil to transmit water and produce more runoff than infiltration.

Cementation in the Brushy Basin sandstones ranges from slight to extreme. Montmorillonite and hematite coatings contribute significantly to grain cementation. Often these montmorillonite grain coatings are also comprised of pyrite, mixed organic materials, and uranium minerals. Silica cement is locally extensive, and kaolinite is commonly mixed with, or appears to grade into, silica cement. Both of these cements occur only within primary pore spaces. Coatings and cements can provide barriers to extensive water infiltration and impede further uranium dissolution and dispersion. According to Jenkins and Cunningham (1980), precipitation of uranium minerals along geochemical boundaries was followed by silica and kaolinite cementation, which protected the ore minerals from subsequent remobilization.

Aquifer sensitivity in the area around the mines ranges from insignificant potential for contaminant migration east of the mines to intermediate potential for contaminant migration at the mines and immediately downgradient (see the Aquifer Sensitivity Map for Crownpoint Area in Appendix A; EPA, 2007c).

P1.1.1.3. Dewatering

As described in the main report, uranium ore occurs in reduced anaerobic environments, in which pyrite, uranium, organics, and other metals are relatively stable. As dewatering during mining progressed, the ore bodies were exposed to oxygen, and pyrite was oxidized. The resultant sulfate ions and acid leached metals from ore bodies and other occurrences in the host formations; metals include uranium, selenium, and molybdenum, increasing the solute content of groundwater. For the mines that have since reflooded

after mining was discontinued, oxygen is not quickly replenished, and subsurface conditions within the mines return to a more reduced state, redepositing uranium and other metals (Erskine and Ardito, 2008).

P1.1.1.4. Surface Water and Groundwater

The mines are located along a drainage that feeds into larger drainage to the north; the drainage runs southeast to northwest and ultimately feeds into the north fork of the Rio Puerco, which runs approximately east to west (Figure 19). The following wells or water data locations are in the area:

- Lance BJ-2 Well in the drainage to the southeast and adjacent to Black Jack No. 2 Mine
- Wells 16-649, 16-UNK-0002, and 16T-519 in adjacent drainages to the east that join downstream of the drainage that mine is on
- Spring 16-41 (sample location 1082357; “Leo House Family Well”) adjacent to a lake, spring 16-31 upstream of the lake, and well 16T-591 within a separate drainage to the east (on the other side of the Continental Divide)
- Wells Lance #1 and Lance #2 are in a separate drainage to the east that runs west to east (on the other side of the Continental Divide)
- Wells 16K-318, Mariano-1, 16K-303, and Tidewater 001 in an adjacent drainage and on ridge to the east
- Spring at sample location 1082369 adjacent to the Mariano Lake Mine
- Wells 16T-558 and 16T-610 in the hills to the northeast on the opposite side of a larger drainage
- Well 16T-596, a municipal water well to the northwest above Mariano Lake
- Anderson Well (sample locations 1081964 and 1082370), Red Willow Spring (sample location 1081965), and Chapter House Well (sample location 1081963) in drainages to the northwest, also running off of Fallen Timber Ridge into the town of Mariano Lake
- St. George Well (sample location 1081968) and sample location 1081967 in a separate drainage west of Mariano Lake that runs southeast to northwest
- Sample locations 1081966 and 1082329 to the far northwest adjacent to the Rio Puerco

Some of these locations can also be seen on the Surface Water Features Map for Crownpoint Area in Appendix A (EPA, 2007c).

Wirt (1994) noted that during the 19th century, river water was available only during periods of seasonal runoff, while small springs, catch basins, and shallow hand-dug wells were used as more dependable water supplies. During the 20th century, wells were drilled and equipped with windmills capable of pumping water to the surface. The wells were drilled in shallow rock and alluvium along the Rio Puerco (Wirt, 1994).

Groundwater Chemistry

Water samples were collected from some of the wells in the Mariano Lake area in 1977, 1979, and 2008, and pH and conductivity were measured. The pH of the water samples ranged from 6.5 in sample location 1081964 to 8.95 in Chapter House Well, averaging approximately 7.8. Specific conductivity ranged from 399 micromhos per centimeter in Chapter House Well to 2,900 micromhos per centimeter in sample location 1081968, averaging approximately 953 micromhos per centimeter (EPA, 2009d).

P1.2. DETAILED MINE BACKGROUND

The Mariano Lake mines are in the Smith Lake District of the Grants Uranium Region. In 1983, eight mines (Mariano Lake [listed as one mine]; Mac No. 1, Black Jack No. 2; Mac No. 2; Ruby Nos. 1, 2, and 3; and Black Jack No. 1) were described as having produced ore from this district in the past, and two additional ore bodies (Section 20 and Ruby No. 4) were found within the district. Ore in Black Jack No. 1 occurs in the Westwater Canyon Member of the Morrison Formation; all the other ore deposits occur in the Brushy Basin Member and are aligned in a northwest-southeast trend (Figure 13). The thickness of the Brushy Basin Member ranges from 80 to 180 feet, and sandstones make up almost half of that thickness. Ore deposits occur in the two lowermost sandstone units of the Brushy Basin Member. The two mineralized sandstones are separated by 10 feet of shale and may be stratigraphically equivalent to the Poison Canyon sandstone in the Ambrosia Lake District (McLemore, 1983).

The Smith Lake-Mariano Lake area produced uranium from 1951 to 1986 from sandstone uranium deposits in the Morrison Formation and from limestone uranium deposits in the Todilto Formation (McLemore, 2007). Uranium ore was produced from the Mariano Lake Mine from 1977 to 1982 through a 519-foot deep shaft. The Mariano Lake Mine was estimated to have 3.5 million pounds of uranium ore reserves with 0.24% U₃O₈ (McLemore, 1983).

P1.2.1. Mariano Lake Ore Deposits

The Mariano Lake uranium deposit is hosted by the lowermost arkosic fluvial sandstone of the Brushy Basin Member of the Morrison Formation and occurs in the trough of an east-west trending syncline at the western end of the Smith Lake-Mariano Lake group of uranium deposits near Crownpoint, New Mexico. The sandstones in the Mariano Lake Mine area are lithologically and stratigraphically similar to the Poison Canyon sandstone in the Ambrosia Lake Mine district.

Near the Mariano Lake Mine, the Brushy Basin Member is approximately 120 feet thick; the thickness of sandstone average 100 feet, and interbedded in the sandstone is 20 feet of bentonitic mudstone. The sandstones occur as lenticular stacked sandstone bodies with sharp contacts with the underlying mudstone and sharp to gradational contacts with overlying mudstone. The uranium ore occurs in the lowest sandstone which averages 25 feet in thickness and is sandwiched between fairly continuous mudstones. Uranium occurred in both the tabular-crossbedded and parallel-laminated facies, though more commonly

in the tabular-crossbedded facies. In the tabular-crossbedded facies, uranium ore is associated with coarse-grained sandstone in scour fills and crossbed sets which provide zones of greater porosity and permeability. These zones provided conduits for uranium-rich groundwater and as sites for uranium precipitation under favorable reducing conditions (Jenkins and Cunningham, 1980).

Sorting and cementation of the sandstone are poor to fair, and locally the host sandstone can be well-cemented. Authigenic cements include clays (montmorillonite, chlorite, and kaolinite), silica, potassium feldspar, organic material, iron disulfides, calcite, barite, and dolomite. Detrital carbonaceous (organic) material in the host sandstone includes coalified plant debris and possible animal (dinosaur) remains. Relatively low porosity in mineralized samples is attributed to the presence of organic material that coated detrital grains (Fishman and Reynolds, 1982; Sachdev, 1980). Montmorillonite and hematite coatings also contribute significantly to grain cementation (Jenkins and Cunningham, 1980). Pyrite varies in form and abundance throughout the Mariano Lake area but is concentrated in the ore zone; it also acts as cement in the host rocks (Sachdev, 1980).

The Mariano Lake deposit closely resembles other tabular uranium deposits in the Grants Uranium Region. Early authigenic smectite clays are typical of tabular deposits, and similar mixed layer smectite-illite layers are found the Mariano Lake deposit. Dissolved feldspars succeeded by authigenic potassium feldspar and quartz overgrowths are common in tabular deposits of Grants Uranium Region and specific in Mariano Lake area (Fishman and Reynolds, 1982).

The ore body is situated on the reduced side of a regional reduction-oxidation (redox) interface (Figure P-1), and amorphous organic material which is diagnostic characteristic of tabular uranium deposits in the Grants Uranium region is abundant. Some organic material has the capacity to adsorb large amounts of uranium; consequently, the tabular ore bodies likely formed from concentration of soluble uranium ions by the organic material. Redistributed deposits are formed by oxidation-reduction processes similar to those responsible for forming roll-type uranium deposits; oxygen-rich groundwater leaches uranium from tabular ore bodies, flows down the hydraulic gradient through the sandstone, and invades pyrite-bearing reduced areas where the dissolved uranium precipitates as secondary mineralization (Fishman and Reynolds, 1982). Hansley (1988) identifies three types of ore: primary, secondary, and diagenetically altered primary ore in cores from the Mariano Lake area. In the primary ores, uranium occurs in amorphous carbonaceous material; most ore with low carbon content was interpreted to be diagenetically altered primary ore.

In the Mariano Lake area, nearly equal concentrations of uranium and organic carbon and anomalously high concentrations of vanadium that are lower than concentrations of uranium are indicative of primary ore. Low concentrations of organic carbon and vanadium concentrations in excess of uranium are indicative of secondary origin. Uranium and carbon concentrations vary widely in the Mariano Lake ore body, though the organic carbon concentrations correlate closely with uranium concentrations.

Detections of uranium in amorphous organic material suggest that coffinite resided even in organic material far from the redox interface (Fishman and Reynolds, 1982).

Although rock updip from the Mariano Lake ore body is oxidized, oxidation does not appear to have redistributed uranium to the rock within or adjacent to the Mariano Lake ore body. Stagnation of waters by the structures in the Mariano deposits and the deflection of waters by the lowered ore body porosity may have preserved the Mariano Lake Deposit (Fishman and Reynolds, 1982).

Uranium was mined from the Mariano Lake mines from 1977 to 1982 by Gulf Mineral Resources Company; total production from this period was 505,489 tons of uranium. EPA (2007c) noted that uranium was recovered from mine water at the Mariano Lake mines by pumping recirculated mine water along with air to facilitate oxidation through injection drill holes into old uranium mine stopes. The injected water that was uranium-rich was collected in sumps and pumped to the surface into settling and holding ponds. When settling is complete, uranium is removed from the waters at an ion exchange facility.

P1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

P1.3.1. Aerial Radiation Contours

Unlike the North Central Region, an aerial radiation survey was not completed for the Eastern Region, so a review of surface radiation at a scale to discern specific mines was not possible. An aerial gamma-ray contour map (Figure 21) was studied where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU) (Duval, 1988). Local highs just north of the McKinley and Cibola County border (up to 4.25%) appear to be near the Haystack and Ambrosia Lake areas, with a slight elevated ridge of 2.75 to 3.00% continuing to the northwest into the Smith Lake and Mariano Lake areas. Background concentrations within McKinley County and adjacent counties range from 1.00 to 2.75%.

P1.3.2. Depth to Groundwater

Several wells are in the Mariano Lake area; however, well data are scarce, and depth-to-water measurements have been recorded at only a few wells. Most of these measurements are from the 1970s and 1980s and were not taken on the same date for calculation of groundwater direction. Where information is available, it is noted that the wells are often drilled to various depths and screened in different aquifers. Groundwater from two of the wells, 16-UNK-0002 and 16T-596, is from the same aquifer, listed as '221ENRD' in the database. Water elevations calculated from the depths to water were 6,933.9 feet above mean sea level and 6,625 feet above mean sea level (msl), respectively. Although the wells were installed in two different years (on January 28, 1982, and July 31, 1978, respectively), the

water elevations calculated from the depths to water indicate a general southeast to northwest gradient, which is consistent with the direction of surface flow in the drainage.

The well screens for wells Lance BJ-2 and 16T-558 are in the aquifer listed as 221 WSRC (probably Westwater Canyon Member). Based on the elevation of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 7,216 feet above msl in Lance BJ-2 and 6,795 feet above msl in 16T-558, indicating a general south-to-north groundwater gradient (EPA, 2009d). The groundwater gradient mimics the general trend of drainages that run toward the Rio Puerco in the north. A more thorough or detailed comparison of the depths to water measured in the wells is not feasible because of the different measurement dates and the different aquifers in which the wells are completed.

Recorded depths to water range from 210 feet below ground surface (in Lance BJ-2 on July 11, 1961) to 972 feet below ground surface (in well 16T-610 on September 17, 1981).

P1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Water samples were collected in the Mariano Lake area in 1977 and 1979 as part of the National Uranium Resource Evaluation Program (NURE) during the hydrogeochemical and stream sediment reconnaissance phase and in 2008 by EPA. No information on well development is available, and groundwater samples are not collected regularly because these wells are unregulated sources of water. Available analytical results summarized below are from limited grab groundwater samples.

As stated in the main report, water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, “either for cultural reasons, or because they prefer the taste” (Keller, 2007). These sources may have been used historically for drinking water, and it is hard for people to abandon using them (Keller, 2007).

P1.3.3.1. Analytical Results for NURE 1977 and 1979 Sampling

In September 1977 and October 1979, water samples for NURE were collected in the Smith Lake-Mariano Lake area; data from this sampling as been compiled and transferred to a database by the U.S. Geological Survey (USGS, 1997). Samples 1082329, 1082357, 1082369, 1082370, 1081964, 1081965, 1081963, 1081966, 1081967, and 1081968 were collected from the wells in the area (Figure 14). One sample, 1082369, was collected at a spring near the western shaft of the Mariano Lake Mine. The uranium concentration in Sample 1082369 was 716.2 micrograms per liter ($\mu\text{g/L}$). Several samples (1081964, 1082370, 1081965, 1081963, 1081967, and 1081968) were collected from adjacent drainages to the west. Uranium concentrations for the samples ranged from 2.07 $\mu\text{g/L}$ (sample 1081964) to 6.51 $\mu\text{g/L}$

(sample 1081967). However, many of the drainages feed to the west and do not join downstream of drainages adjacent to the mine. The uranium concentrations in samples 1081966 and 1082329, collected approximately 4.8 miles downgradient to the northwest of the Mariano Lake Mine were 0.54 µg/L and 0.52 µg/L, respectively.

The drainage from which sample 1082357 was collected from spring 16-41 to the east of the mine does not appear to be same drainage in which the mines occur because the drainage feeds to the east. The uranium concentration in sample 1082357 collected in October 1979 was 16.96 µg/L. The Ruby No. 1 Mine is located approximately 1.9 miles to the west of the sample location, and the Black Jack No. 1 Mine is located approximately 2 miles to the north (Figure 19). Based on the higher elevation of Ruby No. 1 Mine and the sample location being on the same side of the valley to the mine, the uranium concentration is likely to be related to this mine or unmined deposits nearby.

The concentration of uranium in the sample 1082369 near the western shaft of Mariano Lake Mine was greater than the maximum contaminant level (MCL) of 30 µg/L, while the samples from adjacent drainages and approximately 4.8 miles downstream (1082329 and 1081966) were less than the MCL. Sample 1082369 was collected in October 1979 while Mariano Lake Mine operated and was being dewatered. Mining at Mariano Lake Mine were discontinued in 1982.

The uranium mines in the area still operated at the time of the water sampling between 1977 and 1979.

P1.3.3.2. Analytical Results for EPA 2008 Sampling

EPA collected samples in 2008 for analysis of radioactive and stable metals and alpha and beta emitters. EPA collected water samples from wells 16T-519 (upstream of Mariano Lake Mine) and 16K-528 (in adjacent drainage) in February and March 2008. The concentrations of uranium and gross alpha count in the water sample from 16T-519, upgradient of the Mariano Lake Mine, were 34 µg/L and 1.420 pCi/L, respectively; the gross alpha count did not include uranium. The concentration of uranium in the water sample exceeded the MCL of 30 µg/L; the gross alpha count was less than the MCL of 15 pCi/L. This sample was collected to the southeast of Ruby No. 1 Mine.

The concentrations of uranium and gross alpha count in the water sample from 16K-528, in the drainage to the west of the Mariano Lake Mine, were 25 µg/L and 8.550 pCi/L, respectively; both of the concentrations are less than MCLs. Well 16T-519 is listed as an active livestock well, and well 16K-528 is listed as inactive municipal well Mariano PM2 (EPA, 2009d).

P1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in unmined uranium deposits within the Brushy Basin Member are likely to be higher than background because uranium is present in ore bodies of various sizes and grades

(Figure 13). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Mariano Lake Mine do, but most may not extend to the surface unless the Brushy Basin Member crops out there. Extensive organic material and pyrite are expected in the primary ore deposits and along the redox boundary of the redistributed ore deposits.

P1.5. MINED URANIUM DEPOSITS

Not enough data are present to determine the amount of uranium ore remaining at Mariano Lake mines. Given the interconnected nature of the ore bodies in the area and the irregular shapes formed, it is likely that uranium ore still remains at and between mines in the area. The remaining uranium ore, however, is likely lower in grade and scattered along the periphery of the original ore bodies (Figure 23). Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. The large influx of water that would have come with the start of mining operations in ore bodies below the water table would require the dewatering at the mines, which might have destroyed organic material, as would mining operations. During mining operations between 1977 and 1982, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface (Figure 23). Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

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Section P2. Hazard Ranking System and Summary

P2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial, limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Mariano Lake mines include, but are not limited to:

- Uranium in disturbed soil and mine workings at the surface is indicated by the aerial radiation contours. The aerial gamma-ray contour map illustrates a very minor ridge of elevated aerial radiation, only 2.75% to 3.00% compared with the 1.75% to 2.00% to the northeast and southwest, along the trend of the Smith Lake and Mariano Lake ore deposits. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, the presence of unreclaimed waste rock or tailings at these mines is unknown, as determined during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for Crownpoint Area in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Mariano Lake mines.

Additional potential sources of hazardous substances not associated with the Mariano Lake mines but found in the surrounding area include:

- Undisturbed and uneroded uranium ore deposits within the Brushy Basin Member of the Morrison Formation in the area surrounding the Mariano Lake mines (Figure 13).

P2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within four miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

P2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 14 to 16 inches, and falls mostly during brief, seasonal thunderstorms (see the Average Annual Precipitation Map for Crownpoint Area of Eastern Region in Appendix A; EPA, 2007c). Infiltration rates through clayey soil are very slow (see the Hydrologic Group Map for Crownpoint Area of Eastern Region in Appendix A; EPA, 2007c). Permeability is moderate, and an "intermediate potential" exists for contaminant migration in soil at the mines and upgradient and downgradient of the mines (see the Permeability and Aquifer Sensitivity Map for Crownpoint Area of Eastern Region in Appendix A; EPA, 2007c). Permeability through host strata may be limited by the montmorillonitic and hematitic coatings, as well as silica and kaolinite cementation of the Brushy Basin Member.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed above in the main report, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Fresh oxidizing water likely infiltrates the waste rock at the surface but does not infiltrate quickly through the soils. Conceivably some rainwater may infiltrate to the remnant ore deposits deeper beneath the surface. The rainwater destroys organics and leaches and transports uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23).

Although the open spaces associated with the mines provide preferential pathways, the Mariano Lake Mine ore bodies have likely been extensively mined, depleting them of the highest grade ore and probably organic matter; uranium is leached and additional organic material is depleted as water migrates

throughout the mine workings. Uneroded ore deposits in the vicinity of and downstream of the mines may provide more uranium- and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

P2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography and as such will likely trend as surface flow in ephemeral creek beds does. As a result, groundwater flow will likely trend to the north-northwest in the immediate area and generally to the north toward Rio Puerco, as indicated by the groundwater gradient (Subsection P1.3.2). Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Morrison Formation. However, the transport of uranium in solution may be limited by the clay-rich rocks in Brushy Basin Member in which the remaining uranium deposits are hosted. Rainwater will flow through the wastes and then into washes and ephemeral streams at the surface (Figure 23). Surface water may migrate down into groundwater as it flows through the creeks; however, depths to groundwater are generally several hundred feet, so this is a less likely pathway.

Remnants of the original ore deposits that were not completely mined out are likely below the oxidizing groundwater table, leaching metals (including uranium) from the ore deposit. However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones where uranium will deposit secondarily, thereby moving the oxidizing/reduction interface and redistributing uranium locally (Figure 23). Overlying and underlying mudstones, secondary calcium carbonate cementation, and clay cements within the sandstone may also impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. Measured groundwater pH in the region is reported from 6.85 to 8.95, outside the optimal adsorption range, which may allow uranium picked up in solution from oxidizing water to migrate.

Fishman and Reynolds (1982) noted that the preservation of the Mariano Lake deposit may have been due to the presence of the Mariano structures. The Mariano syncline and anticline may have impeded groundwater flow because their axial trend (east-west) is perpendicular to the regional hydraulic gradient. The structures impedance of the northward flowing groundwater may have served to stagnate waters in the synclinal trough, retarding future encroachments of oxidizing groundwater. Additionally, the lower porosity of the ore body, resulting from abundant ore-stage authigenic minerals, may have partially deflected oxidizing groundwater around the ore body, preserving the deposit.

Results of water samples suggest that uranium could be leaching downstream from Mariano Lake mines, as evidenced by a uranium concentration of 25.000 µg/L in the downgradient water sample from well 16K-528, located less than 3 miles to the northwest of Mariano Lake Mine in Section 11. In addition, analytical results of water sampling at Mariano Lake Mine (sample 1082369) also suggest that leaching is occurring at the spring, as evidenced by a uranium concentration of 35 µg/L. While uranium appears to be leaching from the mines, limited permeability and porosity and adsorption is probably keeping some of the uranium within the mined areas.

P2.2.3. Groundwater Pathway Conclusion

Well 16T-519 is just inside a 4-mile radius of the eastern edge of the Mariano Lake mines but is located upstream from the mines, so groundwater flow from the Mariano Lake mines would not affect the well (see the Combined Pathway for Crownpoint Area in Appendix A). Well 16K-528 is within the 4-mile radius of the Mariano Lake mines and downgradient of the mines, but in an adjacent drainage. Samples 1081966 and 1082329 collected in September 1977 and October 1979, respectively, are approximately 4.8 miles downgradient of the mines. The concentrations of radioactive metals in the samples from the well, which is the water source expected to be most influenced by the Mariano Lake mines, were orders of magnitude less than the concentrations in a sample collected from the spring adjacent to the western edge of the Mariano Lake mines and less than MCLs. These wells are not intended to be used for drinking water; however, community feedback has confirmed that some wells are used for drinking water (EPA, 2009a).

P2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Mariano Lake mines enters drainage within the Rio Puerco watershed. One shallow water source, the spring from which sample 1082369 was collected, is noted along this drainage; it meets up with the larger southeast-to-northwest drainage where municipal water well 16T-595 is located, just over 3 miles northwest of Mariano Lake Mine in Section 11. This larger drainage feeds into the Rio Puerco, which runs east to west in the area. The Rio Puerco eventually empties into the Little Colorado River in Arizona.

As discussed above, uranium may be introduced to surface water during storms, when slightly acidic rainwater interacts with waste rock left on the surface. In semiarid to arid environments, evaporation is quick, and water infiltration is moderately rapid through dry and porous soil in the waste piles. Some of the surface water infiltrating the waste rock piles may be directed into subsurface sediments rather than flowing to the creek beds but this will be minimal due to poor permeability in the area around the mines. However, the volume of rainfall during sudden storms can exceed the capacity of soil to transmit water and force more runoff than infiltration.

P2.3.1. Surface Water Pathway Conclusion

No known fisheries are within 15 miles of the Mariano Lake mines, but two regulated drinking water wells (municipal water wells 16T-595 and 16T-696) are just over 3 miles to the northwest of the mines, along drainage that is fed by the drainage in which the Mariano mines are located. The wells are over 1,600 feet deep and are not likely to be influenced significantly by surface water pathway. However, Mariano Lake is located downgradient of the mines, and surface water from areas near Mariano Lake mines may flow into the lake

Uranium was detected in the water source adjacent to the mines and in drainages adjacent the mines at concentrations exceeding the MCL. The adjacent water source to the Mariano Lake Mine located in Section 11 is likely influenced by surface disturbances and waste rock and/or dewatering.

P2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Mariano Lake mines for the following reasons:

- Most of the known contamination is confined to the site, and concentrations off site that may be attributable to the mines are less than the respective MCLs.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site.

P2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during this period. The Mariano Lake Mine(s) are in the Eastern Region, specifically the Grants Uranium Region. Uranium and vanadium were mined primarily from deposits of the Brushy Basin Member of the Morrison Formation. The Mariano Lake mines were listed by the EPA

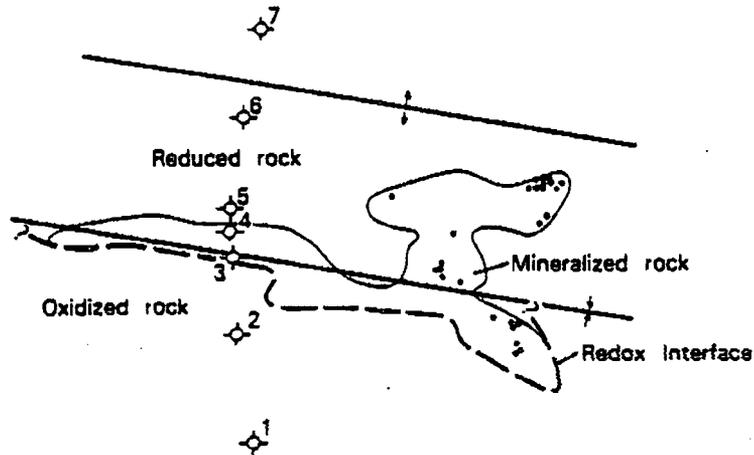
as productive AUMs (EPA, 2007c) that have workings below the water table or were considered wet mines that required pumping.

The Smith Lake Area, where the Mariano Lake mines are located, is drained by ephemeral streams that form tributaries to the Rio Puerco. The mines are located along a drainage that runs approximately southeast to northwest.

The following pertinent HRS factors are associated with the Mariano Lake mines:

- Low to moderate radiation levels on regional aerial radiation maps identify minor uranium content at the surface, although no known waste rock features are noted for the mines.
- Uranium was detected in samples collected from a water source (spring) within 0.25 mile of the Mariano Lake Mine in Section 11 at concentrations exceeding the MCL; the spring is located immediately adjacent to the mine and is likely influenced by surface conditions at the time of the sampling (during mining).
- Uranium was detected in samples collected from water sources downgradient of the mines at concentrations less than MCLs; these results suggest a limited amount of uranium disperses from the Mariano Lake mines – the mineralogy of the host rocks (clay and organic cements) and persistent reducing environments limit the extent that uranium that leaches from remnant ore deposits into groundwater might disperse.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Mariano Lake mines.

Figures

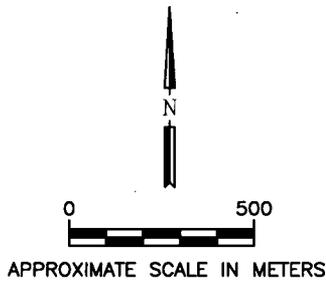


SOURCE: MODIFIED FROM SACHDEV, 1980,
TAKEN FROM FISHMAN AND REYNOLDS, 1982

EXPLANATION

- SAMPLING LOCATION
- ◊² CORE LOCATION AND NUMBER
- |— MARIANO SYNCLINE
- |— MARIANO ANTICLINE

NOTE THE PRESENCE OF OXIDIZED ROCK
SOUTH AND REDUCED ROCK NORTH OF
THE ORE BODY.



P:\2008_P\Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Depth to Water for Selected Wells 2.dwg



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CLIENT:
U.S. ENVIRONMENTAL
PROTECTION AGENCY

LOCATION:
MONUMENT VALLEY AREA,
NAVAJO NATION

DESIGNED BY:
RDB 7-7-09

CHECKED BY:
RLM 7-7-09

P.E.P.G.:
-

**PLAN MAP OF THE MARIANO LAKE
DEPOSIT SHOWING SAMPLING
LOCALITIES AND CORE HOLE LOCATIONS**

ERRG PROJECT NO.	REVISION NO.	SHEET	OF	FIG NO.
28-017	0	1	1	P-1

Appendix Q. Black Jack No. 2 Mine Groundwater Pathway Assessment

Appendix Q
Black Jack No. 2 Mine:
Groundwater Pathway Assessment

April 2010

TDD No.: TO1-09-08-02-0001
Contract No.: EP-S9-07-01

Prepared for:

U.S. Environmental Protection Agency, Region 9
75 Hawthorne Street
San Francisco, CA 94105

Prepared by:



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Section Q1. Mine and Groundwater Investigation

Q1.1. LOCATIONS

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, the U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mining sites) occur below the water table (Table 13 in EPA, 2007c). One of the AUMs, the Black Jack No. 2 Mine, is in the Eastern Region, in the Smith Lake District of the Grants Uranium Region (Figure 13). It is southwest of Crownpoint and north of Thoreau, approximately 8 miles west of Smith Lake, in McKinley County, New Mexico, and 9 miles north of U.S. Highway 40. This AUM is located at an elevation of 7,420 feet above mean sea level (msl) in township and range of 15N.13W.18.223 and latitude and longitude of 35°31'58"N, 108°15'12"W (McLemore, 1983).

Q1.1.1. Local Hydrogeology and Geology

The Black Jack No. 2 Mine is located in the Upper Puerco subregion within the Little Colorado watershed, specifically within the Lower Colorado hydrologic unit. Black Jack No. 2 Mine is within a drainage system of ephemeral creeks that feed into the Rio Puerco drainage system (part of the Little Colorado River), which runs approximately east to west north of the mine.

Q1.1.1.1. Precipitation

Average annual precipitation in the Smith Lake area surrounding the mine is 14 to 18 inches (see Average Annual Precipitation Map for Crownpoint area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007b).

Q1.1.1.2. Permeability and Aquifer Sensitivity

Soil near the mine is characterized hydrologically by very slow infiltration rates (see the Hydrologic Group Map for Crownpoint area in Appendix A; EPA, 2007c). The clayey soil either has a high (shallow) water table or is immediately above an impervious layer that is very slow to drain. Permeability in the area is moderate, between 0.61 to 2.00 inches per hour (see the Permeability Map for Crownpoint

area in Appendix A; EPA, 2007c). The volume of rainfall during storms can exceed the capacity of soils to transmit water and produces more runoff than infiltration.

Aquifer sensitivity in the area surrounding the mine has insignificant to intermediate potential for contaminant migration downgradient along the Rio Puerco drainage (see the Aquifer Sensitivity Map for Mariano Lake area in Appendix A; EPA, 2007c).

Q1.1.1.3. Dewatering

As described in the main report, uranium ore occurs in reduced anaerobic environments, in which pyrite, uranium, and other metals are relatively stable. As dewatering during mining activities progressed, the ore bodies were exposed to oxygen and pyrite was oxidized. The resultant sulfate ions and acid dissolved the metals, including uranium, selenium, and molybdenum, causing increases in metal concentrations in groundwater. For the mines that have reflooded after mining was discontinued, the oxygen would be consumed and subsurface conditions within the mines would return to a more reduced state, allowing for redeposition of uranium and other metals (Erskine and Ardito, 2008).

Q1.1.1.4. Surface Water and Groundwater

The mine is located along a drainage system running northeast of the Fallen Timber Ridge then north into larger ephemeral creek bed running southeast to northwest and feeding into the Rio Puerco, which runs approximately east to west in the area (Figure 19). The following wells or water data locations are in the area:

- Lance BJ-2 Well adjacent to the mine (only well on same drainage as mine)
- Wells 16-649, 16-UNK-0002, and 16T-519 in adjacent upgradient drainages that join downstream of the drainage that mine is on
- Spring 16-41 (sample location 1082357; "Leo House Family Well") adjacent to a lake, spring 16-31 upstream of the lake, and well 16T-591 within a separate drainage system to the east (on the other side of the continental divide)
- Wells Lance #1 and Lance #2 are in separate drainage system to the east that runs west to east (on the other side of the continental divide)
- Wells 16K-318, Mariano-1, 16K-303, and Tidewater 001 are to the north and on the opposite ridge to the mine
- Spring at sample location 1082369 adjacent to the Mariano Lake Mine on the adjacent drainage to the northwest, which also feeds into a large drainage to the north
- Wells 16T-558 and 16T-610 in hills on the opposite side of a larger drainage
- Well 16T-596, a municipal water well to the northwest above Mariano Lake

- Anderson Well (sample locations 1081964 and 1082370), Red Willow Spring (sample location 1081965), and Chapter House Well (sample location 1081963) located in drainages to the northwest, also running off of Fallen Timber Ridge into the town of Mariano Lake
- St. George Well (sample location 1081968) and sample location 1081967 in a separate drainage system west of Mariano Lake that runs southeast to northwest
- Sample locations 1081966 and 1082329 to the far northwest adjacent to the Rio Puerco

Groundwater Chemistry

Water samples were collected from some of the wells in the area in 1977, 1979, and 2008, and pH and conductivity were measured. The pH of the water samples ranged from 6.5 in sample location 1081964 to 8.95 in Chapter House Well, with an average of approximately 7.8. Specific conductivity ranged from 399 micromhos per centimeter in Chapter House Well to 2,900 micromhos per centimeter in sample location 1081968, with an average of approximately 953 micromhos per centimeter (EPA, 2009d).

Q1.2. DETAILED MINE BACKGROUND

Black Jack No. 2 Mine is in the Smith Lake District of the Grants Uranium Region. In 1983, eight mines (Mariano Lake; Mac No. 1, Black Jack No. 2; Mac No. 2; Ruby Nos. 1, 2, and 3; and Black Jack No. 1) were listed as having produced ore from this district in the past and two additional ore bodies (Section 20 and Ruby No. 4) were found within the district. Ore in Black Jack No. 1 occurs in the Westwater Canyon Member of the Morrison Formation, while all other deposits occur in Brushy Basin Member and are aligned in a northwest-southeast trend (Figure 13). The Brushy Basin Member in the area ranges from 80 to 180 feet thick, and sandstones make up almost half of that. Ore deposits occur in the two lowermost sandstone units of the Brushy Basin Member. The two mineralized sandstones are separated by 10 feet of shale and may be stratigraphically equivalent to the Poison Canyon sandstone in the Ambrosia Lake District (McLemore, 1983).

Ore was extracted from a 330-foot-deep vertical shaft with drifts (McLemore, 1983); the estimated depth of the ore was 303 feet below ground surface (bgs) (McLemore and Chenoweth, 1991). The ore was mined by driving 14-foot by 18-foot drifts and cross-cutting on 50-foot centers. Production at Black Jack No. 2 Mine began in 1960 and, when it was closed in 1970, it had produced 247,613 tons of ore yielding 1,129,004 pounds of U_3O_8 (McLemore and Chenoweth, 1991; McLemore, 1983).

Aerial views of the mine site show some surface disturbance but no large-scale disturbances such as tailings ponds or waste piles. A large building is still visible on aerial maps.

Q1.2.1. Black Jack No. 2 Mine Ore Deposits

Uranium ore deposits are formed in the Brushy Basin Member of the Morrison Formation; the Brushy Basin Member is approximately 150 feet thick and consists of greenish-gray mudstone. The ore is

located in a medium- to course-grained sandstone lens called the Poison Canyon tongue. This lens is approximately 60 feet thick at the northwestern end of the mine and thins to approximately 18 feet thick at the southern end of the mine; it thickens and thins locally but pinches out 2 to 3 miles east of the mine. The sandstone ranges from medium-grained to very coarse-grained (Hoskins, 1963).

The mine lies on the axis of a syncline formed between regional dip and the Mariana anticline; the regional dip of beds ranges from 3 to 5 degrees to the northeast, while the ore body plunges with syncline to northwest. The rocks in the mine have been cut by a set of steeply dipping fractures that strike north 55° west. and dip slightly to the northeast; the fractures are locally filled with clayey gouge material (Hoskins, 1963).

Ore deposits are typically lenticular in shape and pinch out rapidly on the northeastern side of the mine. Some of the lenticular bodies interconnect and overlap, but they are generally of low grade. Most of the ore occurs in the lower part of the ore-bearing mudstone, usually lying directly on the lowest mudstone, although there are three ore horizons. Permeability probably influenced the shapes of the ore bodies with higher grade, and thicker ore occurs near highly cross-bedded sandstone and becomes less mineralized as the sand becomes less coarse. The highest grade of ore is usually in very coarse-grained sandstone and has a black oily color. The lower mudstone acts as barrier for the ore body (Hoskins, 1963).

Brick-red sandstone occurs along the northeastern edge of the mine and is the ore boundary. This sandstone is also cross-bedded and of similar quality to the ore-bearing sandstone; however, no mineralization has occurred.

The ore at the mine occurs below the water table in the sandstone that is interbedded with mudstone lenses and consists of unoxidized uranium and vanadium minerals. The overall outline of the ore body is described as having the appearance of a stream channel. The ore minerals are probably low-valence orders coffinite and vanadium silicates. No woody material was observed, but the black ore is probably due to either carbonaceous material or the mineralogy of the uranium minerals (Hoskins, 1963).

The reclamation status of this mine is unknown, and the presence of unreclaimed waste piles is unknown (see the Reclamation Status and Unmapped Waste Piles Map for Crownpoint area in Appendix A; EPA, 2007c). No specific mine waste features were noted for the Black Jack No. 2 Mine during EPA's assessment (EPA, 2007c).

Q1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

Q1.3.1. Aerial Radiation Contours

Unlike the North-Central Region, an aerial radiation survey was not completed for the Eastern Region, so a review of surface radiation at a scale to discern specific mines was not possible. In 1988, USGS

produced an aerial gamma-ray contour map of regional surface concentrations of uranium for New Mexico (Duval, 1988). The aerial gamma-ray contour map (Figure 21) was studied where aerial gamma-ray systems were calibrated, so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU) (Duval, 1988). Gamma ray radiation is associated with uranium, and excess levels of gamma ray activity are a good indicator of old mines and mining-related activities. A map of the aerial gamma-ray contour values illustrates higher gamma-ray radiation up to 2.75 in the vicinity of the Black Jack No. 2 Mine than for the surrounding area. Background concentrations within McKinley County and adjacent counties range from 1.00 to 2.75 percent.

A ridge of increased gamma-ray values is seen at all surrounding mines (Figure 21), approximately along the mineralized zone in the Smith Lake district (Figure 13), so the increased values may also be due to geology rather than just mining activity.

Q1.3.2. Depth to Groundwater

EPA compiled water data on Google Earth™ that shows the locations of water samples and depth to water that have been collected for shallow wells, mine drill holes, wells, and auger holes; the wells and sample locations have been transferred to topographic maps (Figure 19). Depths to groundwater were measured in wells in the vicinity of the Black Jack No. 2 Mine, including (but not limited to):

- Lance BJ-2 at an elevation of 7,426 feet above msl with depth to groundwater of 210 feet bgs on July 11, 1961 (aquifer 221WSRC)
- 16-UNK-0002 at an elevation of 7,610 feet above msl with depth to groundwater of 676.1 feet bgs on January 28, 1982 (aquifer 221ENRD)
- 16T-519 at an elevation of 7,510 feet above msl with depth to groundwater of 502 feet bgs on December 3, 1963 (aquifer 221CSPG)
- 16T-591 at an elevation of 7,480 feet above msl with depth to groundwater of 562 feet bgs on March 23, 1977 (aquifer 221CSPG)
- Lance #1 and Lance #2 at an elevation of 7,434 feet above msl with depth to groundwater of 800 feet bgs on July 11, 1961 (aquifer 221CSPG)
- 16T-318 at an elevation of 7,410 feet above msl with depth to groundwater of 230 feet bgs on October 3, 1948 (aquifer 211DKOT)
- 16T-558 at an elevation of 7,585 feet above msl with depth to groundwater of 790 feet bgs on August 5, 1971 (aquifer 221WSRC)
- 16T-610 at an elevation of 7,500 feet above msl with depth to groundwater of 972 feet bgs on September 17, 1981 (unknown aquifer)
- 16T-596 at an elevation of 7,160 feet above msl with depth to groundwater of 535 feet bgs on July 31, 1978 (aquifer 221ENRD)

Wells Lance BJ-2, 16-UNK-0002, 16T-519, 16-591, 16K-318, and 16T-610 are located within an approximate 4-mile radius of Black Jack No. 2 Mine, while the others are within a 4- to 6-mile radius of the mine (Figure 19). Depths to water were measured during different years, and well screens were placed in different aquifers from one well to the next. Of these, the well screens for wells 16T-519, 16T-591, Lance #1, and Lance #2 are apparently placed in the same aquifer, listed as 221CSPG (probably Cow Springs sandstone below the Morrison Formation). Based on the altitude of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 7,008 feet above msl in 16T-519, 6,918 feet above msl in 16T-591, and 6,634 feet above msl in Lance #1 and Lance #2, indicating a south-to-north groundwater flow (EPA, 2009d).

The well screens for wells Lance BJ-2 and 16T-558 are placed in aquifer listed as 221 WSRC (probably Westwater Canyon Member), and screens for wells 16-UNK-0002 and 16T-596 are placed in an aquifer listed as 221ENRD (probably Entrada sandstone below the Cowsprings sandstone and above Chinle Formation). Based on the altitude of the land surface (either surveyed or determined from USGS topographic maps) and the measured depths to groundwater, groundwater elevations were estimated to be 7,216 feet above msl in Lance BJ-2, 6,795 feet above msl in 16T-558, 6,933.9 feet above msl in 16-UNK-0002, and 6,625 feet above msl in 16T-596, indicating a general south-to-north groundwater flow (EPA, 2009d). These groundwater flow directions mimic the general trend of drainage systems that run toward the Rio Puerco in the north.

While no depth to water was listed, the developed spring 16-31, at elevation of 7,620 feet msl, was measured at 10 feet deep.

Q1.3.3. Groundwater

Under various investigations and programs, water samples have been collected throughout the Navajo Nation at many unregulated wells and springs. Water samples were collected in the Smith Lake area in 1977 and 1979 as part of the National Uranium Resource Evaluation Program (NURE) in the hydrogeochemical and stream sediment reconnaissance phase and in 2008 by EPA. These wells are unregulated water sources, so no information on well development is available and groundwater samples are not collected regularly. Available analytical results summarized below are from limited grab groundwater samples.

As stated above, water from unregulated water sources within the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, "either for cultural reasons, or because they prefer the taste" (Keller, 2007). These sources may have been historically used for drinking water, and it is hard for people to abandon using them (Keller, 2007).

Q1.3.3.1. Analytical Results for 1977 and 1979 Sampling

In October 1979, two water samples were collected within a 4-mile radius of Black Jack No. 2 Mine. Sample 1082357, collected at spring 16-41, from an adjacent drainage system across the Continental Divide, had a uranium concentration of 16.96 micrograms per liter ($\mu\text{g/L}$). Sample 1082369 from spring adjacent to the Mariano Lake Mine in the drainage system to the northwest of the mine had a uranium concentration of 716.2 $\mu\text{g/L}$, pH of 7.8, and specific conductivity of 800 (EPA, 2007c).

In September 1977 and October 1979, eight groundwater samples were collected within a 4- to 6-mile radius of Black Jack No. 2 Mine. These samples included:

- Sample 1081964 collected in 1977 from Anderson well with a uranium concentration of 2.07 $\mu\text{g/L}$, pH of 6.5, and specific conductivity of 550
- Sample 1082370 collected in 1979 from Anderson well with a uranium concentration of 3.19 $\mu\text{g/L}$, pH of 7.6, and specific conductivity of 471
- Sample 1081965 collected in 1977 from Red Willow spring with a uranium concentration of 4.98 $\mu\text{g/L}$, pH of 7.1, and specific conductivity of 700
- Sample 1081963 collected in 1977 from well 16K-528 with a uranium concentration of 5.26 $\mu\text{g/L}$, pH of 8.8, and specific conductivity of 850
- Sample 1081967 collected in 1977 from well west of Mariano Lake with a uranium concentration of 6.51 $\mu\text{g/L}$, pH of 7.3, and specific conductivity of 1,100
- Sample 1081968 collected in 1977 from St. George well with a uranium concentration of 3.21 $\mu\text{g/L}$, pH of 6.7, and specific conductivity of 2,900
- Sample 1081966 collected in 1977 from well north of Mariano Lake and adjacent to the Rio Puerco with a uranium concentration of 0.54 $\mu\text{g/L}$, pH of 8.6, and specific conductivity of 1,450
- Sample 1082329 collected in 1979 from well north of Mariano Lake and adjacent to the Rio Puerco with a uranium concentration of 0.52 $\mu\text{g/L}$, pH of 8.8, and specific conductivity of 458 (EPA, 2007c)

Q1.3.3.2. Analytical Results for EPA 2008 Sampling

In 2008, the EPA collected water samples from wells surrounding the Black Jack No. 2 Mine. Samples were collected and analyzed for two wells, 16K-528 and 16T-519, which are within a 6-mile radius of the mine. The alpha activity in groundwater samples collected from wells 16K-528 and 16T-519 were 8.550 picocuries per liter (pCi/L) and 1.420 pCi/L, respectively; these activities are less than the maximum contaminant level (MCL) of 15 pCi/L. Analytical results for the groundwater samples collected from the two wells indicated the concentrations of uranium were 25.0 $\mu\text{g/L}$ and 34.0 $\mu\text{g/L}$, respectively. Only the concentration at 16T-519 exceeded the MCL of 30 $\mu\text{g/L}$ for uranium. This well, however, is located upgradient of the Black Jack No. 2 Mine.

Q1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in trend of uranium ore along the redox interface within the Brushy Basin Member of the Morrison Formation is likely to be higher than background because uranium is present in ore bodies of various size and grade (Figure 13). Most if not all of the undisturbed uranium deposits are likely to extend below the water table, as the deposits at Black Jack No. 2 Mine do, and are unlikely to extend to the surface. The undisturbed deposits also would be expected to contain extensive organic material in the lens deposits associated with the uranium deposition.

Q1.5. MINED URANIUM DEPOSITS

Based on a description of mining, uranium ore deposits at the Black Jack No. 2 Mine were significantly mined (Hoskins, 1963). The remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore body. Mining operations would have left open spaces and conduits, such as shafts, drifts, adits, inclines, and exploratory holes. Mining operations at the site and a large influx of water during these operations might have destroyed organic material. During mining operations, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface. Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Section Q2. Hazard Ranking System

Q2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial, limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, the migration of groundwater and surface water migration was initially investigated.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed at the surface. Sources of contamination include NORM and TENORM associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Black Jack No. 2 Mine include, but are not limited to:

- Uranium in disturbed soils and mine workings at the surface are indicated by the aerial radiation contours. The aerial gamma-ray contour map illustrates a slight ridge in the vicinity of the Smith Lake district. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, the presence of unreclaimed waste rock or tailings at these mines is unknown, as determined during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for Crownpoint area in Appendix A; EPA, 2007c).
- Uranium ore deposits remain below the surface and below the water table at the Black Jack No. 2 Mine.

Additional potential sources of hazardous substances not associated with the Black Jack No. 2 Mine but found in the surrounding area include:

- Undisturbed and uneroded uranium ore deposits in the Brushy Bush Member of the Morrison Formation in the area surrounding the Black Jack No. 2 Mine (Figure 13).

Q2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering), because it is designed as a screening tool to give the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). Uranium's toxicity and methods of mobility were discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

Q2.2.1. Rainwater Infiltration

As discussed above in Subsection Q2.2.2, average annual precipitation in the area is low, approximately 14 to 16 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through clayey soils with a high water or shallow soil to an impervious layer are characterized by very slow infiltration rates (see the Hydrologic Group Map for Crownpoint area in Appendix A; EPA, 2007c). Permeability in the area is moderate on average, between 0.61 to 2.00 inches per hour, and the "most potential" exists for contaminant migration in soils downgradient along the Rio Puerco drainage (see the Permeability Map for Crownpoint area and Aquifer Sensitivity Map for Mariano Lake area in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining Black Jack No. 2 Mine ore bodies, as well as the uneroded channel deposits in the area.

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed above in Subsection Q2.1, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Because of the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing water likely infiltrates the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as UO_2^{2+} (Figure 23). Although open spaces associated with the mines provide a preferential pathway, the Black Jack No. 2 Mine ore body has been extensively mined, depleting it of the highest grade ore and probably destroying organic matter during water influx throughout mining operations at the mine. Uneroded ore deposits in the vicinity of and downstream of the mine may provide more uranium-

and organic-rich rock and sediment through which freshwater infiltrates to mobilize and transport uranium.

Q2.2.2. Groundwater Flow

Although groundwater flow has not been directly measured in the area, it is common for groundwater to follow topography. As a result, groundwater flow will likely trend to the north-northeast in the immediate area surrounding the mine as the washes and ephemeral creek beds do, and generally to the north toward Rio Puérco as indicated by depths to groundwater (Subsection Q1.3.2). Recharge of fresh oxidizing rainwater to the groundwater table will also likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the Morrison Formation. Rainwater will flow through the wastes into washes and ephemeral streams at the surface (Figure 23). Surface water may migrate down into groundwater as it flows through the creeks; however, groundwater depths are generally several hundred feet down, so this is a less likely pathway.

Remnants of the original ore deposits that were not completely mined out are likely below the oxidizing groundwater table, allowing leaching of metals (including uranium) from the ore deposit (Figure 23). However, high organic content (carbonaceous material) and pyrite-rich zones within the rocks create reduced zones, causing secondary deposition of uranium, thereby moving the oxidizing/reduction interface and redistributing uranium locally. Additionally, crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may impede uranium dispersion. Adsorption of uranium onto clays occurs in pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. Given the volume of uranium distributed in the deposits, some uranium resulting from the groundwater interaction with residual ore bodies at the mine may stay in solution and flow more easily through the mine voids and rock, but the depth to groundwater will make contribution of uranium in solution to groundwater minor.

Results of water sampling suggest that uranium could be leaching downstream from Black Jack No. 2 Mine, as evidenced by a uranium concentration of 25.000 $\mu\text{g/L}$ in the downgradient water sample from well 16K-528. Well 16K-528, however, is downstream of numerous mines, including the Mariano Lake Mine, and the well is located approximately 5 miles downstream of Black Jack No. 2 Mine. In addition, analytical results of water sampling at Mariano Lake Mine (sample 1082369) also suggest that leaching is occurring at the spring between Black Jack No. 2 Mine and well 16K-528, as evidenced by a uranium concentration of 35.000 $\mu\text{g/L}$. No analytical data for groundwater are available for any points between Black Jack No. 2 and Mariano Mines or directly downstream of Black Jack No. 2 Mine.

Q2.2.3. Groundwater Pathway Conclusion

Well 16K-528 is outside of the 4-mile radius of the mine, at a distance of approximately 5 miles to the northwest, while well 16T-519 is within a 4-mile radius of the mine, located approximately 4 miles to the west. Sample 1082369 collected from the spring adjacent to Mariano Lake Mine is approximately 2 miles to the northwest. The analytical results for samples collected at well 16K-528, well 16T-519, and the spring adjacent to Mariano Lake Mine were 25 µg/L, 34 µg/L, and 716.2 µg/L, respectively. The uranium concentrations at well 16T-519 and the spring adjacent to Mariano Lake Mine exceed the MCL of 30 µg/L. Well 16T-519 is in a separate drainage system on the other side of the Continental Divide and is unlikely to be directly influenced by groundwater flow from Black Jack No. 2 Mine. Given the location on a different drainage and proximity to Mariano Lake Mine, the spring is likely influenced by surface waste at the Mariano Lake Mine. No analytical data are available for any wells within a 0.25-mile radius of the mine.

None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009a). No wells are located directly upstream or downstream in the same drainage as Black Jack No. 2 Mine. Uranium was detected in the shallow water source (sample 1082369 from spring at Mariano Lake Mine) at a concentration exceeding the MCL, but the exceedance is unlikely to reflect potential contamination to groundwater from ore deposits at Black Jack No. 2 Mine.

Q2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Black Jack No. 2 Mine enters a drainage system within the Rio Puerco watershed. No wells or shallow water sources are noted along this drainage system until it meets up with the larger southeast-to-northwest drainage system where municipal water well 16T-595 is located, just over 5 miles northwest of Black Jack No. 2 Mine. This larger drainage feeds into the Rio Puerco, which runs east to west in the area. The Rio Puerco eventually empties into the Little Colorado River in Arizona.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is fast through dry and porous soil. As a result, some of the surface water entering the waste rock piles may be directed into sediments rather than flowing to the creek beds.

Q2.3.1. Surface Water Pathway Conclusion

No known regulated drinking water intakes or fisheries are associated within the vicinity of the Black Jack No. 2 Mine within 4 miles of the mine but two municipal water wells (16T-595 and 16T-696) are located just over 5 miles to the northwest of the mine, along drainage that is feed by drainage that mine is located on. Uranium was detected in the water sources in adjacent drainages to the mine at concentrations exceeding the MCL but appear to be influenced by other contaminant sources rather than from the Black Jack No. 2 Mine. A developed spring to the east of the mine is too shallow (depth at 7,610 feet above msl) to be influenced by the deeper deposits and groundwater at Black Jack No. 2 Mine, where groundwater has been measured at 7,216 feet above msl.

Q2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Black Jack No. 2 Mine for the following reasons:

- Known contamination appears to be confined to the site and concentrations of contaminants off site that may be attributable to the mines are less than the respective MCLs
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site

Q2.5. SUMMARY

The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during this period. The Black Jack No. 2 Mine is located within the Eastern Region, specifically the Grants Uranium District. Uranium and vanadium were mined in this region, primarily from mud lens deposits of the Brush Basin Member of the Morrison Formation. The Black Jack No. 2 Mine was listed by the EPA as productive AUMs (EPA, 2007c) that have workings below the water table or were considered wet mines that required pumping.

The Smith Lake Area, where the Black Jack No. 2 Mine is located, is drained by ephemeral streams forming tributaries to the Rio Puerco. The mine is located along a drainage that runs approximately southeast to northwest.

The following pertinent HRS factors are associated with the Black Jack No. 2 Mine:

- Low to moderate radiation levels on regional aerial radiation maps identify minor uranium content at the surface, although no known waste rock features are noted for the site.
- Uranium was detected in samples collected from water sources (wells and spring) within 6 miles of the mine at concentrations exceeding the MCL, but distances and locations in relation to drainages suggest other influences for the uranium concentrations.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Black Jack No. 2 Mine.

**Appendix R. Kermac Mine No. 22, Homestake-Sapin
Mine No. 23, Kermac Mine No. 24, and
Homestake-Sapin Mine No. 25
Groundwater Pathway Assessment**

Appendix R
Kermac Mine No. 22, Homestake Sapin Mine No. 23,
Kermac Mine No. 24, and Homestake Sapin Mine No. 25
Groundwater Pathway Assessment

April 2010

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Section R1. Mine and Groundwater Investigation

R1.1. LOCATIONS OF ABANDONED URANIUM MINES

During their screening assessment of abandoned uranium mines (AUMs) in the Navajo Nation, U.S. Environmental Protection Agency (EPA) determined that 31 AUMs (including 33 former uranium mines) occur below the water table (Table 13 in EPA, 2007c). Four of these mines, Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25, are located in the Eastern Region, approximately 1 to 2 miles west of Highway 509 in McKinley County of New Mexico. The Kermac No. 22 Mine is partially located on the Baca/Prewitt chapter of the Navajo Nation, and the other three mines are located off Navajo Nation lands. The four mines are at the western side of the Ambrosia Lake area in Township 14 North, Range 10 West, in McKinley County, New Mexico (Gould, et al., 1963). The locations by township and range (with northings and eastings) for each of the mines are as follows:

- Kermac Mine No. 22 at 14N.10W.22.223 (N35E 25.973' W107E 52.855')
- Kermac Mine No. 24 at 14N.10W.24.332 (N35E 25.340' W107E 51.168')
- Homestake-Sapin Mine No. 23 at 14N.10W.23.134 (N35E 25.788' W107E 52.337')
- Homestake Sapin Mine No. 25 at 14N.10W.25.144 (N35E 24.871' W107E 51.048')

R1.1.1. Local Hydrogeology and Geology

The Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 are in the Ambrosia Lake area on the southern flank of the San Juan Basin in an area representative of the groundwater recharge zone for the basin (Brod, 1979). Hydrologically, the mines are in the Rio Puerco Basin and the Rio San Jose watershed; drainages adjacent to the mines feed into Arroyo del Puerto, which runs south into the San Mateo Creek, then into the Rio San Jose and Rio Puerco, and ultimately into the Rio Grande (Popp, 1983). During mining, large-scale dewatering was necessary, and more than 250,000 acre-feet of water was pumped from the Ambrosia Lake Valley, resulting in more than 500 feet of drawdown in the potentiometric surface. In 1979, Brod noted that the Arroyo del Puerto had been perennial since large amounts of mine wastewater were discharged to it, starting in the 1950s. Since mining activities ended in 1989 at Homestake Sapin Mine No. 23, water levels are recovering, but according to Eskine and Ardito (2008), full recovery may take hundreds to thousands of years.

R1.1.1.1. Precipitation

Average annual precipitation in the area around the four mines is 10 to 12 inches (see Average Annual Precipitation Map for Ambrosia Lake area in Appendix A; PRISM Group of Oregon State University, 2007). Precipitation is generally in the form of localized, short-duration, high-intensity thunderstorms, and approximately one-half of the annual precipitation occurs from July to October (EPA, 2007b). The annual evaporation rate is reported to reach 100 inches per year and suggests that much of the area lacks supplies of surface water to support basic human needs; thus, residents and industry in the area depend on groundwater (Brod, 1979).

R1.1.1.2. Permeability and Aquifer Sensitivity

Soil near the four mines is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map for Ambrosia Lake area in Appendix A; EPA, 2007c). The moderately coarse soils are moderately deep to deep and moderately well to well-drained. Permeability in the area is moderately rapid on average, between 2.01 to 6.00 inches per hour (see the Permeability Map for Ambrosia Lake area in Appendix A; EPA, 2007c). Based on data from the 1950s, permeability ranged from 0.1 to 3,220 millidarcies, and porosity ranged from 2.6 and 27.4 percent in Homestake-Sapin No. 23 Mine. According to pumping tests in the Sabre Pinon well at Kermac No. 25 Mine, the average permeability of Westwater Canyon sandstone in the vicinity of the well was approximately 780 millidarcies; the average porosity was approximately 22 percent (Granger and Santos, 1982). However, it has been noted that little precipitation enters bedrock outcrops because the permeability is generally low, so water evaporates soon after it falls. It is likely that limited runoff on outcrops crosses fractures, which allows some recharge, and recharge occurs through the creek and arroyo beds. The two largest drainages, San Mateo Creek and Arroyo del Puerto, may be considered the major sources of recharge for the area (Brod, 1979).

The Westwater Canyon Member is directly overlain and underlain by impermeable montmorillonitic strata of the Brushy Basin Member and by clay- and silt-rich strata of the Recapture Member, respectively; therefore, there is little intermixing between waters of aquifers above and below the Westwater Canyon Member. Large faults and fault systems may provide vertical channels through impermeable units, but the swelling properties of montmorillonite and clay-rich gouge generally seal off faults to migration. Present recharge into uranium host strata is relatively meager because rainfall in the area is low and strata outcrops along steep slopes and cliff face above major drainages (Granger and Santos, 1982).

Aquifer sensitivity in the area surrounding the four mines ranges from intermediate potential for contaminant migration west of the mines to most potential for contaminant migration at the mines and downgradient along the Arroyo del Puerto (see the Aquifer Sensitivity Map for Ambrosia Lake area in Appendix A; EPA, 2007c).

R1.1.1.3. Dewatering

As described in the main report, the uranium ore occurs in reduced anaerobic environments, in which pyrite, uranium, and other metals are relatively stable. As dewatering during mining progressed, the ore bodies were exposed to oxygen, and pyrite was oxidized. The resultant sulfate ions and acid dissolved metals from the ore deposit, including uranium, selenium, and molybdenum. Increased concentrations of metals in groundwater result. For the mines that have reflooded after mining was discontinued, the oxygen would be consumed and subsurface conditions within the mines would return to a more reduced state, re-depositing uranium and other metals (Erskine and Ardito, 2008).

R1.1.1.4. Surface Water and Groundwater

The mines are located along a drainage system which feeds into the Arroyo del Puerto; the Arroyo del Puerto runs approximately northwest to southeast. Several wells or water data locations are in the area, including the following:

- Spring 16-26 (sample 1081345), well B01246, well Karmac 002, well 1081335, well R.D.O. 001, well 1081712, and sample location SMC-07 in drainages to the north and east of the mines
- Karmac 003, Karmac 004, Karmac 005, and Sabre Pinon wells and sample location SMC-32 (1081739) along the same drainage as the mines
- Karmac 001, Homestake 001, Homestake 002, Homestake 620, and Homestake 635 wells and sample locations SMC-17, SMC-18, and SMC-21 (RH08-0056) adjacent to the Arroyo del Puerto
- Sample locations for SMC-28, SMC-26 (1081337, 1081742, RH08-0069), wells B00415 O-5, B00415 O-6, B00415 O-7), SMC-39, SMC-20 (well B01115 and sample RH08-0055), SMC-23 (well B00659; sample RH08-0059), RH08-0071, SMC-24 (RH08-0074), and SMC-25 (RH08-0072) along San Mateo Creek (Figure 20)

It is unclear whether the list of well names for the Homestake wells is for just one or multiple wells, similarly for the wells with the B00415 prefix. Depths to water and elevations indicate a northwest to southeast gradient along the Arroyo del Puerto, feeding into the San Mateo Creek and then proceeding southwest (Figure 20). Some of these locations can also be seen on the Surface Water Features Map for Ambrosia Lake area in Appendix A. Water samples 1081345, 1081335, 1081712, and 108739 were collected from a spring and three wells along drainages feeding into and along the Arroyo del Puerto (EPA, 2009d). Water samples SMC-07, SMC-17, SMC-32, and SMC-18 were also collected from wells along drainages which feed into and along the Arroyo del Puerto. The other SMC water samples were collected from wells along the San Mateo Creek.

Groundwater Chemistry

The chemical characteristics of mine waters in the Ambrosia Lake area were reported by Granger and Santos (1982). The pH of mine waters from underground sump, underground drill hole, and fracture and fault flow averaged approximately 8.3 and ranged from 7.7 to 9.0. Uranium concentrations ranged from

1.9 micrograms per liter ($\mu\text{g/L}$) to 1,260 $\mu\text{g/L}$. The one sample collected from the Kermac Mine No. 24 had pH of 7.8 and uranium concentration of 82 $\mu\text{g/L}$. However, mine waters emerging from drill holes and fractures were tested in several mines using pH-sensitive papers and yielded pH values near 6.5, suggesting underground waters initially have a lower pH than those determined in the laboratory because CO_2 loss increases pH (Granger and Santos, 1982).

R1.2. DETAILED MINE BACKGROUND

The structural configuration of the deposits in the Ambrosia Lake area is described in one of two ways:

- By form: ore is termed “trend” if the form of the deposit is tabular; the long dimensions nearly parallel bedding. Ore is termed “stack,” if the deposit has sizeable vertical extent.
- By timing: ore is described as “prefault” and “postfault.”

Trend ore tends to be more or less equivalent to prefault ore, and stack ore tends to be redistributed, postfault ore (Corbett, 1963). Trend ore was controlled by sedimentary structures, and redistributed stack ore was controlled by a combination of sedimentary and tectonic structures. Individual ore bodies may consist entirely of one or the other, but more often than not, the ore body is a combination of the two types. Uranium in the area was mined by conventional room and pillar methods, and deposits are not confined to section boundaries, resulting in an extensive network of interconnected mine workings.

R1.2.1. Kermac Mine No. 22 Ore Deposit

The Kermac Mine No. 22 ore bodies are a very large cluster of multilayered deposits in the Westwater Canyon Member of the Morrison Formation, which extend into Sections 15 and 23. The continuity of the cluster and considerable thickness of the deposits suggest that it is principally redistributed or “stack” ore. Access to the ore deposits is through a vertical shaft, which was installed in 1958 (Hilpert, 1969).

Pitchblende (a massive, possibly impure version of the uranium-bearing mineral uraninite) is found below the water table at Kermac Mine No. 22, although it is extremely rare in the sandstones of the Westwater Canyon Member elsewhere. It is considered an unoxidized mineral and is likely to be a postfault mineral. It occurs at the 6,400-foot level in the mine as a hard botryoidal vug lining along fractures. Another comparatively scarce mineral to deposits in the Westwater Canyon Member, the secondary mineral carnotite (a uranium vanadate), was found in the mine, approximately 100 feet below the groundwater table in a faulted area; carnotite usually occurs at or near an outcrop, well above the water table. If vanadium is abundant in an oxidizing environment, low solubility uranium vanadate minerals can be formed (Granger, 1963). The presence of both primary (unoxidized) and secondary (oxidized) uranium minerals suggest that the presence of oxidizing groundwater does not necessarily produce a completely oxidized environment. The presence of other metals, such as vanadium, can precipitate uranium minerals,

even in oxidizing groundwater because the solubility of minerals such as uranium vanadate is lower than uranium minerals.

Corbett (1963) studied uranium and vanadium minerals at the Kermac Mine No. 22 and found at least 10 different minerals with different characteristics and valence. In 1961, he noted that Eh, pH, and oxidation potential of waters coming from drill holes in the mine was such that only high-valent minerals appeared to be stable. Some of these high-valent minerals form as crusts on the mine workings. He suggested that the groundwater was sufficiently oxidizing and slightly alkaline, favorable for leaching of uranium and vanadium.

According to the EPA, total uranium production from 1958 to 1985 at Kermac Mine No. 22 was 3,851,523 tons (EPA, 2007c).

R1.2.2. Kermac Mine No. 24 Ore Deposit

Kermac Mine No. 24 Mine is also a very large multilayer cluster of deposits, located principally in the Westwater Canyon Member but partly in the lower portion of the Brushy Basin Member. The cluster is largely in the western half of the section but locally extends into the eastern half, into adjoining Sections 23 and 25. Access to ore deposits is also through a vertical shaft, installed in 1959 (Hilpert, 1969). According to EPA (2007c), total uranium production from 1959 to 1983 at Kermac Mine No. 24 was 2,894,860 tons.

R1.2.3. Homestake Sapin Mine No. 23 Ore Deposit

Homestake Sapin Mine No. 23 is a very large multilayer cluster of deposits, principally in the middle of the Westwater Canyon Member. The cluster trends eastward across the northern part of the section and southward across the eastern part, into adjoining Sections 15, 22, 24, and 25. Access to ore deposits is through a vertical shaft, which was installed in 1959 (Hilpert, 1969).

A study of the geology and ore bodies at the Homestake Sapin Mine No. 23 was published in 1982 to present the geology of the deposits developed in the mine and to relate it to the geologic framework of the other mines in the area. Homestake Sapin Mine No. 23 has a variety of features and types of ore typical of the district. As discussed in the main report, there are two types of ore: (1) primary (prefault) trend ore as peneconcordant layers of uranium-rich organic matter that impregnates parts of the reduced sandstone and that is typically elongate subparallel to sedimentary trends; and (2) regional strike and redistributed (postfault) stacked ore from destruction of primary ore and redistributed as lower grade ore along the redox interface (Granger and Santos, 1982).

Most of the uranium deposits occur in sandstone within the main body of the Westwater Canyon Member, but some ore is found in the Poison Canyon sandstone in the Ambrosia Lake area. During diagenesis,

these sandstones became very light gray reduced rock containing disseminated pyrite and scattered fragments of coalified fossil wood. Humate is coextensive with uranium ore and is the primary control of the shapes and positions of uranium ore; uraniferous humate coats sand grains, fills interstices, and locally replaced detrital grains. In Homestake Sapin Mine No. 23, humate layers are typically 0.3 to 1.0 meter (1 foot to 3.3 feet) thick and do not exceed 1.5 meters (4.9 feet); the coffinite dispersed in the humate is extremely fine-grained. Remnants of ore extend to southeast corner of Section 23, into Section 24, northwest part of Section 25, and northeast of Section 26. The primary ore contains more iron, mostly as pyrite, than the surrounding barren rock (Granger and Santos, 1982).

The Westwater Canyon Member was subsequently oxidized by infiltrating meteoric water, producing a tongue of oxidized rock into the basin. The ore in Homestake-Sapin Mine No. 23 occurs mostly below the pre-mining water table at depths ranging from about 170 to 250 meters (558 to 820 feet). Within the oxidized tongue, most primary ore was destroyed and redistributed as secondary ore bodies along the leading edge of the tongue as the waters moved slowly down dip. During infiltration of oxidizing water, pyrite was progressively converted to hematite or hydrous iron oxides, and sulfur was removed as sulfate. Organics are likely oxidized to carbon dioxide and water or reconstituted humic acids. Uranium and other metals in primary ore bodies were oxidized and dissolved. The front probably moved through the rocks at a rate several orders of magnitude slower than the groundwater flow rate (Granger and Santos, 1982).

The irregularities in the Westwater Canyon Member caused variations in permeability and affected the symmetry of the leading edge of the tongue. Permeabilities range from those that might be expected typical of conglomerate to those more typical of mudstone, and pores are choked by calcite and clay cements. Structural features such as faults, fractures, and joints also contribute to the variability in permeability and flow of groundwater through the Westwater Canyon Member. Materials such as pyrite and organic matter that readily oxidize control the shape of the front, deflecting it around both sides. While the fractures around major faults can increase transmissivity, minor faults and fractures tend to decrease the transmissivity because thin layers of gouge and clay restrict passage of water (Granger and Santos, 1982). The increase in permeability from a joint system is evident in the southwest part of the mine. The depositional pattern in the Westwater Canyon Member is erratic, and there are indications that ore was dissolved where water flowed freely and was re-deposited nearby where flow was restricted by joint intersections. The result is triangular-shaped, high-grade ore bodies (Gould, et al., 1963).

The first effect of oxidizing water as it infiltrates the ore body is the dissolution and removal of molybdenum; selenium then moves to the redox interface. More thorough oxidation, related to removal of uranium and organic carbon, tends to remove the reconcentrated selenium. Initial oxidation removes the uranium in the coffinite, but the uranium associated with organics is likely retained until oxidation is complete when uranium leaches. Vanadium is leached at this stage at a slower rate than uranium; lead and organic carbon persist the longest but may ultimately be oxidized and removed depending on the

amount of infiltration of oxidizing water. Postfault ores consisted of coffinite aggregates that coat sand grains as a thin film, filled small interstices, and partly replace highly altered feldspar and detrital grains. Pyrite formed in the redistributed ore before and after the coffinite, along joints, and in fractures, and disseminated throughout the sandstone. A large variety of oxidized uranium minerals occur in near-surface and deeper subsurface deposits, some deposited prior to mining and some as post-mining efflorescent (Granger and Santos, 1982).

According to EPA (2007c), total uranium production from 1958 to 1985 at Homestake Sapin Mine No. 23 was 4,811,351 tons.

R1.2.4. Homestake Sapin Mine No. 25 Ore Deposit

The Homestake Sapin Mine No. 25 is a large series of lenses and pods in the Westwater Canyon Member that extend linearly southeastward across Section 25 into Sections 23, 24, 26, and 36. Deposits are mostly "stack" ore, but trend ore occurs near the base. The stack ore is up to 100 feet thick and is controlled by a northwest-trending fracture system. Ore deposits here are also mined through a vertical shaft, which was installed in 1959 (Hilpert, 1969).

The Section 25 ore body is approximately 5,800 feet long and 300 to 1,200 feet wide. Evidence exists that fracturing occurred after the trend ore was deposited and that it provides more permeable zones through which oxidizing solutions can flow, removing uranium from trend ore until conditions more favorable for redeposition are encountered. The distance the uranium is carried may vary from a few feet to as much as 1 mile and, although the bulk of the uranium occurs along fractures, ore is also disseminated in the surrounding rock. Uranium apparently was taken into solution by formation waters and migrated down dip in Homestake Sapin Mine No. 25, leaving an insoluble black residue. Conclusive evidence exists that secondary deposition was controlled in large part by northwest-southeast fractures and that fracturing was not involved with the deposition of east-west trending roll deposits (Gould, et al., 1963).

Uranium removal is evident in some areas of increased fracture density; other fracture zones appear to have localized uranium. Several factors can affect permeability and influence the localization of secondary deposits, including increased fracture density, abrupt changes in grain size and sorting of sediments in the host rock, and the presence or absence of intraformation mudstone layers. Permeability through overlying strata to the Westwater Canyon Member is limited by the overlying montmorillonitic strata of the Brushy Basin Member thus limiting water recharge to uranium-bearing strata of the Westwater (Granger and Santos, 1982).

According to EPA (2007c), total uranium production from 1959 to 1983 at Homestake Sapin Mine No. 25 was 3,145,969 tons.

R1.3. PREVIOUS SAMPLING AND DISTRIBUTION OF URANIUM

R1.3.1. Aerial Radiation Contours

Unlike the North Central Region, an aerial radiation survey was not completed for the Eastern Region, so a review of surface radiation at a scale to discern specific mines was not possible. An aerial gamma-ray contour map (Figure 21) was studied where aerial gamma-ray systems were calibrated so that the measurements could be expressed as the apparent surface concentrations of equivalent uranium (parts per million eU) (Duval, 1988). Local highs just north of the McKinley and Cibola County border (up to 4.25 percent) appear to be near the Haystack and Ambrosia Lake areas. Background concentrations within McKinley County and adjacent counties range from 1.00 to 2.75 percent.

R1.3.2. Depth to Groundwater

Although several wells are in the Ambrosia Lake area, well data are scarce, and only a few wells have depth to water measurements. Most of the water measurements were from the 1950s and were not collected on the same date so that a groundwater gradient could be calculated. Depth to water was measured in two wells, Karmac 001 and Homestake 635, on April 30, 1957. Groundwater from both of these wells is from the same aquifer, listed as '221WSRC' in the database. The well elevations are 6,984 feet above mean sea level (msl) and 6,942 feet above msl, respectively. Using the elevations (and the depths to water measured 443 feet and 412 feet below ground surface [bgs], respectively) and elevations of groundwater in the wells, the groundwater elevations are 6,541 feet above msl at well Karmac 001 and 6,530 feet above msl at well Homestake 635. However, it is not possible to calculate the flow direction without a third elevation. These elevations would be consistent with groundwater flow in the drainage direction. A comparison of the depths with water levels measured in other wells is not feasible because of the different measurement dates and the different aquifers sourced by the wells.

The calculated groundwater elevations for Karmac 001 and Homestake 635 wells are consistent with groundwater elevations measured in the Westwater Canyon Member in Homestake Sapin Mine No. 23 in 1958. Elevations, measured in eight wells, ranged from 6,543 feet above msl to 6,558 feet above msl. The ground surface is at an elevation of approximately 7,000 feet above msl throughout the mine, and the static water table is approximately 450 feet bgs (Granger and Santos, 1982). The water table dropped precipitously after mid-1958 when dewatering commenced but seems to have largely rebounded since the end of mining operations.

R1.3.3. Groundwater

As stated in the main report, water from unregulated water sources in the Navajo Nation is deemed unfit for human consumption; however, these water sources may still be used by the community, "either for cultural reasons, or because they prefer the taste" (Keller, 2007). Since these sources may have been historically used for drinking water purposes, it is hard for people to abandon using them (Keller, 2007).

Under various investigations and programs, water samples have been collected throughout the Navajo Nation from many unregulated wells and springs. Water samples were collected in the Ambrosia Lake area in 1978 and 1979 as part of the National Uranium Resource Evaluation Program (NURE) in the hydrogeochemical and stream sediment reconnaissance phase and in 2008 by EPA. No information on well development is available, and groundwater samples are not collected regularly because these wells are unregulated water sources. Available analytical results summarized below are from limited grab groundwater samples.

R1.3.3.1. Analytical Results for NURE 1978 and 1979 Sampling

From May 1978 to October 1979, water samples for NURE were collected in the Ambrosia Lake area; data from this sampling have been compiled and transferred to a database by the U.S. Geological Survey (USGS) (1997). Samples 1081345, 1081335, 1081712, 1081739, 1081711, 1081708, and 1081243 were collected from the wells in the area (Figure 20). Samples upgradient of the study AUMs, 1081345, 1081335, and 1081712, had uranium concentrations of 4.05 $\mu\text{g/L}$, 37.05 $\mu\text{g/L}$, and 19.22 $\mu\text{g/L}$, respectively. The farthest upgradient sample, 1081345, does not appear to be associated with any AUMs in the area and may be indicative of a background concentration. Sample 1081335 was collected at Kermac Mine No. 10, and sample 1081712 was collected downslope from Dysart Mine No. 1 (Figure 20). The concentration of uranium in the sample at Kermac Mine No. 10 (1081335) exceeded the maximum contaminant level (MCL) of 30 $\mu\text{g/L}$; the uranium concentration in a sample collected approximately 1 mile downstream (1081712) was less than the MCL.

In June 1978, sample 1081739 was collected from a well over 5 miles downstream to the southeast of the study mines (Figure 20); the concentration of uranium was elevated at 49.48 $\mu\text{g/L}$, which exceeded the MCL of 30 $\mu\text{g/L}$. The concentration of uranium in additional samples collected farther downstream (approximately 1.2 miles at a 114 degree heading from sample location 1081739; not shown on the figure) declined with distance from the mines, down to 17.91 $\mu\text{g/L}$ in June 1978 and 32.83 $\mu\text{g/L}$ in October 1979.

In a drainage adjacent to the west of the Ambrosia Lake area (near Haystack mining district), samples 1081343, 1081708, and 1081711 were collected from local windmill wells. The windmill wells from which sample 1081343 was collected in October 1979 and from which sample 1081708 was collected in May 1978 are upstream of all AUMs in the area. However, uranium was detected in the water samples at concentrations of 35.78 $\mu\text{g/L}$ and 10.67 $\mu\text{g/L}$, respectively.

The uranium mines in the area were still in operation at the time of the water samples were collected in 1978 and 1979.

R1.3.3.2. Analytical Results for EPA 2008 Sampling

EPA collected samples in 2008 for analysis of radioactive and stable metals and alpha and beta emitters. EPA collected water samples from wells 16B-38 and 16T-521 on February 27, 2008, from an adjacent drainage to the Ambrosia Lake area (near Haystack area mines). The concentrations of uranium and gross alpha count in the water sample from 16B-38, upgradient of the Junior, Section 4, Dakota, and Pat Mines, were 54 µg/L and 0.00 picoCuries per liter (pCi/L), respectively. The concentration of uranium in the water sample exceeded the MCL of 30 µg/L; the gross alpha count was less than the MCL of 15 pCi/L. The concentrations of uranium and gross alpha count in the water sample from 16T-521, downgradient of the Febco, Silver Spur, and Section 5 mines, were 63 µg/L and 20.69 pCi/L, respectively; both of the concentrations exceeded MCLs. Both wells are listed as active livestock wells (EPA, 2009d) and appear on topographic maps as windmill wells.

R1.3.3.3. Analytical Results for New Mexico Environment Department 2008 and 2009 Sampling

New Mexico Environment Department (NMED) collected water samples in August and September 2008 (samples identifiers starting with RH08-00 and in March and April 2009 (sample identifiers starting with SMC) for analysis of radioactive and stable metals, as well as groundwater parameters and isotopes, in the vicinity of the Ambrosia Lake mines. All, except one, of the sample locations are downstream and more than 4 miles from the most southernmost of the four mines, Homestake Sapin Mine No. 25. SMC-07 was collected in 2009 along an adjacent drainage and upgradient from the Kermac Mine No. 24 and Homestake Sapin Mine No. 25 (Figure 20).

The depths of the wells from which the samples were collected ranged from 87 feet bgs (sample SMC-39) to 1,249 feet bgs (sample SMC-07). Most wells were a few hundred feet deep.

One sample, SMC-07, was collected east of the mines on Julian Hill. The dissolved uranium concentration in the sample was 2.5 µg/L, an order of magnitude less than the EPA MCL of 30 µg/L. This sample location appears to be upgradient of any known producing or non-producing mines and may reflect influence of background uranium content of aquifer rock.

Analytical results for dissolved uranium in the downgradient samples ranged from less than the reporting limit of 2 µg/L (in samples SMC-18 and SMC-32) to 188 µg/L (in sample SMC-26). The sample location for SMC-32 is along the drainage bed of the Arroyo del Puerto downgradient from the mines, but upgradient from the confluence of the Arroyo del Puerto with the San Mateo Creek. Several samples were collected to the southeast along San Mateo Creek before it meets the Arroyo del Puerto. The highest dissolved uranium concentrations were detected in samples collected farthest up San Mateo Creek from the confluence of the two drainages (SMC-28 at 46.4 µg/L, RH08-0055 at 62.5 µg/L, RH08-0069 at 170 µg/L, and SMC-26 at 188 µg/L). A decrease in concentration was observed in samples collected in vicinity of the confluence in 2009 (SMC-24 at 13.8 µg/L and SMC-23 at 10.1 µg/L).

Analytical results for gross alpha in the downgradient samples collected in 2008 ranged from 2.5 pCi/L (in sample RH08-0069) to 55.0 pCi/L (in sample RH08-0055). Five of the seven samples collected in 2008 in the area near the confluence of the Arroyo del Puerto with the San Mateo Creek had gross alpha activities greater than the MCL of 15 pCi/L; these included samples RH08-0055, RH08-0072, RH08-0071, RH08-0059, and RH08-0074.

R1.4. UNDISTURBED OR UNMINED URANIUM DEPOSITS

The concentrations of uranium in unmined uranium deposits within the Westwater Canyon Member area are likely to be higher than background because uranium is present in ore bodies of various size and grade (Figure 23). Some of these undisturbed uranium deposits may also extend below the water table, as the deposits at Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 do, but most may not extend to the surface unless the Westwater Canyon Member outcrops at the location. These undisturbed deposits would be expected to also contain extensive organic material and pyrite in the primary ore deposits and along the redox boundary of the redistributed ore deposits.

A uranium deposit to the southwest of the major uranium ore bodies of the Ambrosia Lake area (which includes the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25) is described as a relict uranium deposit (Smith and Peterson, 1980). Redistribution of uranium and humate during the migration of oxidizing conditions through the fluvial sediments was controlled by differences in transmissivity within the host rock. In areas of low permeability/transmissivity, remnant zones of primary and redistributed uranium mineralization occur as islands of reduced ground referred to as relict uranium deposits. The localization of uranium is thought to be controlled mainly by organic accumulations deposited adjacent to zones of higher groundwater flow. Preservation of the deposit was aided by the insoluble nature of the intermixed uranium and humate, lower groundwater transmissivity at the stratigraphic pinch out, and the hydrologic influence of bounding faults. This deposit, located to the southwest of the Homestake Sapin Mine No. 23 (in Section 28, above Section 33 shown in the middle of Figure 20), is quite extensive in scope (Figure R-1). Please note that this deposit may be upgradient of well 16B-38 to the southwest, as well as upgradient to drainage to the east that feeds into Arroyo del Puerto.

R1.5. MINED URANIUM DEPOSITS

Not enough data are present to determine the amount of uranium ore remaining at Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 after mining ended in the 1980s. However, given the extensiveness of the ore bodies in the area, that they are interconnected, and the irregular shapes formed, it is likely that uranium ore still remains at between the four mines; the remaining uranium ore is likely lower in grade and scattered along the periphery of the original ore bodies (Figure 23). Mining operations would have left open spaces and conduits, such as

shafts, drifts, adits, inclines, and exploratory holes. The large influx of water that came with the start of mining operations, would have required extensive dewatering as noted at the mines, likely destroying organic material. During mining operations from the 1950s to 1980s, protore (i.e., ore not rich enough to meet market demand and price), overburden, drill core and cuttings, and waste rock would have been removed from the mine and placed at the surface (Figure 23). Early small mining operations typically discarded the waste within a few feet to hundreds of feet from the mine opening (EPA, 2007a).

Section R2. Hazard Ranking System and Summary

R2.1. SOURCES OF CONTAMINATION

The Hazard Ranking System (HRS) is the principal mechanism EPA uses to place uncontrolled waste sites on the National Priorities List. The HRS uses information from initial limited investigations to assess the relative potential of contaminants at sites to pose a threat to human health or the environment. Four pathways can be scored under the HRS: (1) groundwater migration (drinking water); (2) surface water migration (drinking water, human food chain, and sensitive environments); (3) soil exposure (resident population, nearby population, and sensitive environments); and (4) air migration (population and sensitive environments). For this desktop study, an initial limited investigation of groundwater and surface water migration was conducted.

For HRS purposes, the main source of contamination to shallow water sources in the area is uranium that has been deposited, stored, disposed of, or placed at the surface. Sources of contamination include naturally occurring radioactive material and technologically enhanced naturally occurring radioactive material associated with undisturbed and mined uranium deposits.

Potential sources of hazardous substances associated with the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 include, but are not limited to:

- Disturbed soils and mine workings at the surface containing uranium ore are indicated by the aerial radiation contours. The aerial gamma-ray contour map illustrates a local high in the vicinity of the Haystack and Ambrosia Lake area. The measurements may meet EPA's HRS criteria on the definition of "area of observed contamination" for soil exposure pathway (EPA, 2007b). However, the presence of unreclaimed waste rock or tailings at these mines is unknown, as determined during EPA's investigation (see the Reclamation Status and Unmapped Waste Piles Map for Ambrosia Lake area in Appendix A; EPA, 2007c).
- Remaining uranium ore deposits below the surface and below the water table at the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25.

Additional potential sources of hazardous substances not associated with the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 but found in the surrounding area include:

- Undisturbed and uneroded uranium ore deposits within the Westwater Canyon Member of the Morrison Formation in the area around the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25.

R2.2. GROUNDWATER PATHWAY

The HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to groundwater; (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, mobility, and quantity); and (3) the people (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are within 4 miles of the site. The HRS emphasizes drinking water usage over other uses of groundwater (e.g., food crop irrigation and livestock watering) because it is a screening tool that gives the greatest weight to the most direct and extensively studied exposure route.

Uranium can migrate into groundwater from the surface, carried by rainwater as it infiltrates through uranium-bearing rocks, sediments, and wastes. Uranium can also disperse into groundwater through direct contact as groundwater flows through ore deposits and uranium-bearing rocks and sediments (Figure 23). However, hydrologic and geologic conditions preclude significant infiltration in the Ambrosia Lake area. Uranium's toxicity and methods of mobility are discussed in Section 2 of the main report ["Groundwater Pathway Analysis Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)"].

R2.2.1. Rainwater Infiltration

Average annual precipitation in the area is low, approximately 10 to 12 inches, and is mostly characterized by brief thunderstorms. Infiltration rates through deep coarse-grained soils are moderate (see the Hydrologic Group Map for Ambrosia Lake area of Eastern Region in Appendix A; EPA, 2007c). Permeability is moderately rapid, and an "intermediate potential" exists for contaminant migration in soils at the mines and upgradient and downgradient of the mines (see the Permeability and Aquifer Sensitivity Map for Ambrosia Lake area of Eastern Region in Appendix A; EPA, 2007c). These characteristics are applicable to the remaining ore bodies at Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25, as well as the unmined uranium deposits in the area. Permeability through overlying strata to the Westwater Canyon Member is limited by montmorillonitic clays in the Brushy Basin Member, limiting recharge to uranium-bearing strata beneath (Granger and Santos, 1982).

Normal rainwater is slightly acidic, with a pH range of 5.5 to 6.0. As discussed in the main report, adsorption of uranium on organic and inorganic substances is maximized in a similar pH range. Due to the minimal yearly rainfall but rapid influx of rainwater during annual thunderstorms, the fresh oxidizing

water likely infiltrates the waste rock at the surface, as well as the subsurface ore deposits, destroying organics and leaching and transporting uranium in the hexavalent form as $(\text{UO}_2)^{2+}$ (Figure 23). However, it has been noted that little precipitation enters bedrock and considerable recharge likely occurs through the creek and arroyo beds, specifically along Arroyo del Puerto in the Ambrosia Lake area (Brod, 1979).

Although the open spaces associated with the mines provide preferential pathways, the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 ore bodies have likely been extensively mined, depleting them of the highest grade ore and probably organic matters. Uneroded ore deposits such as those that occur in Section 28 in the vicinity of and downstream of the four mines may provide more uranium- and organic-rich rock and sediment through which fresh water infiltrates to mobilize and transport uranium. The trend ore extend between the four mines and throughout the areas as shown on Figure R-1.

R2.2.2. Groundwater Flow

Groundwater flow has not been directly measured in the area; however, it is common for groundwater to follow topography and as such it will likely trend to the southeast as surface water flows in the Arroyo del Puerto and ephemeral creek beds. Considering that dewatering was conducted during mining at Homestake Sapin Mine No. 23 and the recorded depth to waters at the mine, the main mine workings are likely beneath the groundwater table, which is also true for the three other mines. Fresh oxidizing rainwater will likely leach some uranium from the waste rock piles at the surface and transport the uranium as $(\text{UO}_2)^{2+}$ down through the overlying soils, however, further infiltration of the oxidizing water may be limited by the clay-rich rocks directly above the Westwater Canyon Member that hosts the remaining uranium deposits. Rainwater will also likely flow through the wastes into washes and ephemeral streams at the surface (Figure 23); surface water may infiltrate to groundwater further downstream as it flows through the creeks.

Remnants of the original ore deposits that were not completely mined out are likely below the groundwater table, normally availing metals (including uranium) to leaching from the ore deposit. However, high organic content (carbonaceous material) and pyrite-rich zones at the peripheries of the ore deposits in these mines create reduced zones, causing secondary deposition of uranium, thereby limiting the extent to which uranium might migrate (Figure 23). In addition, unoxidized zones in the ore deposits are controlled by (1) organic accumulations deposited adjacent to zones of higher groundwater flow, (2) the insoluble nature of the intermixed uranium and humate, (3) the lower groundwater transmissivity at the stratigraphic pinch outs, and (4) the hydrologic influence of bounding faults. Crossbedding, secondary calcium carbonate cementation, and clays within the sandstone may also impede uranium dispersion. The presence of ore with uranium vanadates (which are less soluble than other uranium minerals), pitchblende, and humate suggest reduced conditions that limit uranium migration and demonstrate that uranium probably hasn't moved far past the outer edges of the ore deposit as the variable

permeability created by mineralogy and structure limits the movement of groundwater and thus the dispersion of uranium

Adsorption of uranium onto clays occurs in the pH range of 4.5 to 7.5, and maximum adsorption of uranium onto organic matter occurs in the pH range of 3.5 to 6.0. Much of the uranium in rainwater (with pH of 5.5 to 6.0) picked up from waste rock will likely adsorb to clays and organic matter during its migration downward to groundwater before it makes it outside the mined areas. It is also noted that the overlying strata in the Ambrosia Lake area impedes infiltration into Westwater Canyon Member where the uranium deposits are hosted. Groundwater is more likely to be affected by recharge from the adjacent arroyos during thunderstorms. Measured groundwater pH in the region is reported from 7.7 to 9.0, outside the optimal adsorption range, which may allow uranium to be picked up in solution from oxidizing water to migrate.

Results of water sampling suggest that, while uranium is leaching upstream from other ore deposits (as evidenced by uranium concentrations of 37.05 $\mu\text{g/L}$ and 19.22 $\mu\text{g/L}$ in the upgradient water samples 1081335 and 1081712 adjacent to Kermac Mine No. 10 and Dysart No. 1 Mine), the amount of leaching through the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 is unknown because the closest downstream water sample location is over 5 miles to the southeast; and the location where sample SMC-17 was collected is over 4 miles along a separate drainage.

In addition, several former mills and processing plants are in between the mines and where the samples were collected downstream from the mines (Figure 20). Based on the extensive surface disturbance and tailings generated by mill operations, the former mill sites are likely potential sources of uranium contamination to groundwater. The highest uranium concentration detected along the Arroyo del Puerto was 49.48 $\mu\text{g/L}$ in a water sample from well (sample 1081739) over 5 miles downgradient from the mines and just over 3 miles downstream from Kermac Nuclear Fuels Processing Plant. Higher concentrations of uranium, 63.9 $\mu\text{g/L}$ in SMC-20 and 188 $\mu\text{g/L}$ in SMC-26, were detected in samples collected along the San Mateo Creek, upgradient of the confluence of the Arroyo del Puerto and the San Mateo Creek. These higher concentrations suggested other sources of uranium were present to the southeast of the mines. Although uranium is being leached from the ore bodies at the mines, secondary deposition and adsorption may keep much of the uranium within the mined areas.

R2.2.3. Groundwater Pathway Conclusion

The location of the water sample (1081739) with the highest concentration along the Arroyo del Puerto is outside the 4-mile radius of the mines and downstream of the mill site, and the other sample locations with water samples containing uranium above the MCL of 30 $\mu\text{g/L}$ are either upstream (1081335) or outside the 4-mile radius (1081337). In fact, higher concentrations of uranium are found in groundwater

samples collected along the San Mateo Creek to the southeast and along adjacent drainages, which suggests alternative sources of uranium.

Samples collected from wells within the 4-mile radius are from upstream or adjacent drainages, so groundwater flow from the mines is less likely to affect these wells or springs (see the Combined Pathway for Ambrosia Lake area of Eastern Region in Appendix A). None of the wells are intended to be used as drinking water wells, but community feedback has confirmed that the wells are being used for drinking water (EPA, 2009a).

R2.3. SURFACE WATER PATHWAY

In appraising the surface water pathway, the HRS evaluates (1) the likelihood that sources at a site have actually released, or potentially could release, hazardous substances to surface water (e.g., streams, rivers, lakes, and oceans); (2) the characteristics of the hazardous substances that are available for a release (i.e., toxicity, persistence, bioaccumulation potential, and quantity); and (3) the people or sensitive environments (targets) who actually have been, or potentially could be, affected by the release. The HRS focuses on the number of people who regularly obtain their drinking water from wells that are located within 4 miles of the site. The HRS focuses on drinking water intakes, fisheries, and sensitive environments associated with surface water bodies within 15 miles downstream of the mines.

Surface water runoff from the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 enters a drainage system that feeds to the east into the Arroyo del Puerto. The Arroyo del Puerto runs toward the south-southwest and continues into other ephemeral creeks before ultimately feeding into the Rio Grande.

As discussed above, uranium may be introduced to surface water during storm events, when slightly acidic rainwater interacts with waste rock left on the surface. However, in semiarid to arid environments, evaporation is quick, and water infiltration is limited because even though the soils are capable of moderate infiltration, the volume of rainfall during thunderstorms often exceeds the capacity of the soil to transmit the water and most runs off. As a result, some uranium may leach from wastes and enter into the surface water that is subsequently directed into subsurface soils, ultimately flowing to the creeks and drainages. Surface waters infiltrating through waste piles and other soils are further constrained from infiltrating to groundwater by bedrock rich in clays.

R2.3.1. Surface Water Pathway Conclusion

No regulated drinking water intakes or fisheries are associated with the Arroyo del Puerto near the mines or within 4 miles downstream of the mines (NNEPA, 2006). Uranium was detected in the shallow water source over 5 miles downgradient of the mines at a concentration exceeding MCLs.

R2.4. EMERGENCY RESPONSE CONSIDERATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan [Title 40 Code of Federal Regulations § 300.415 (b) (2)] authorizes EPA to consider emergency response actions at those sites that pose an imminent threat to human health or the environment. Referral to EPA Region 9's Emergency Response Office does not appear to be necessary for the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 for the following reasons:

- Most likely uranium sources are confined to the surface features such as waste piles. Uranium observed off site may be attributable to other mines with associated mills and processing plants as the mills and plants lie between these mines and the locations from which water samples were collected.
- Low to moderate radiation levels on regional aerial radiation maps indicate minor uranium content in surface though no known waste rock features are noted for the site.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the site.

R2.5. SUMMARY

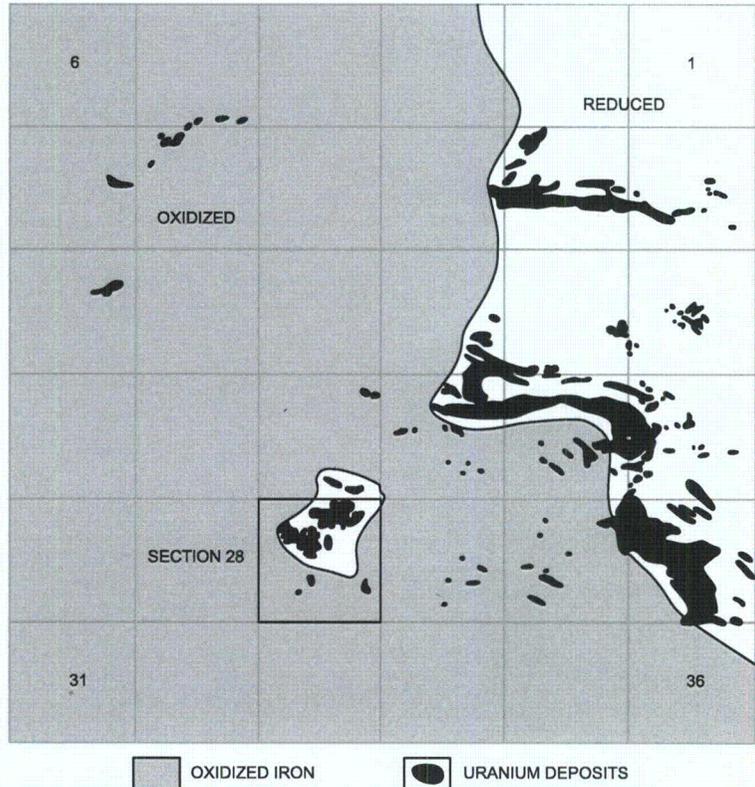
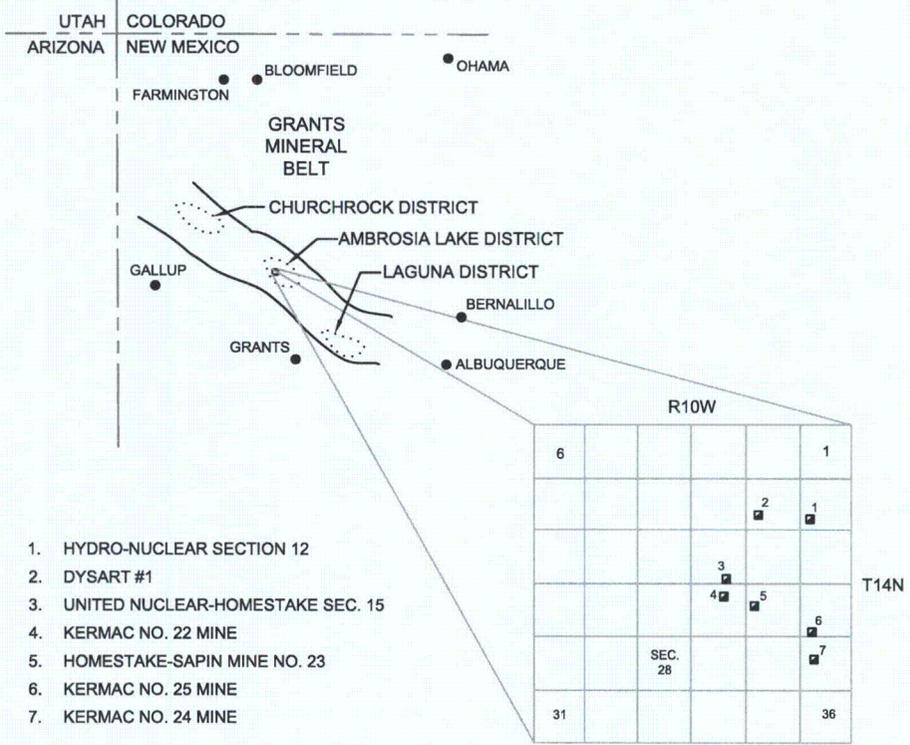
The general area of study is the Navajo Nation, which covers over 27,000 square miles in Arizona, New Mexico, and Utah (Figure 1). This area was heavily mined for uranium; mining started in the 1900s, and production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mining during this period. The Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 are in the Eastern Region, specifically the Ambrosia Lake mining district within the Grants Uranium Region. Uranium and vanadium were mined primarily from the Westwater Canyon Member of the Morrison Formation between the 1950s and 1980s. Organic plant matter is abundant in the channel sediments, providing reducing conditions for uranium precipitation and limiting uranium migration. The Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 were listed by the EPA as productive AUMs (EPA, 2007c) that have workings below the water table or were considered wet mines that required pumping.

Hydrologically, the mines are located in the Rio Puerco Basin and within the Rio San Jose watershed; drainages adjacent to the mines feed into Arroyo del Puerto which runs south into the San Mateo Creek and the Rio San Jose and Rio Puerco, ultimately into the Rio Grande (Popp, 1983). During mining, large-scale dewatering was necessary.

The following pertinent HRS factors are associated with the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25:

- According to aerial radiation survey for New Mexico, there is a regional high just north of the McKinley and Cibola County border (up to 4.25 percent) in the vicinity of the Haystack and Ambrosia Lake areas, in vicinity of Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25.
- The concentrations of uranium in samples from shallow water sources (wells) over 5 and 6 miles downgradient of the mines exceeded MCLs; the concentration of uranium in samples collected from a well more than 6 miles downgradient did not exceed MCLs.
- Uranium concentrations in groundwater samples collected at wells adjacent to similar uranium mines (Kermac Mine No. 10 and Dysart Mine No. 1) 1.5 to 3 miles north of the four study mines were less than or slightly exceeded the MCL of 30 µg/L, indicating a potential for uranium to be released in solution; these proximal wells are not used for drinking water and, based on their proximity to the mines, represent the highest concentrations expected to be associated with remaining uranium at those two mines.
- Uranium concentration in samples of water from the downgradient well closest to Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 (over 5 miles southeast of the mines) is higher than uranium concentrations in wells upgradient of the mines (greater than 1 mile northwest of the mines) and farther downgradient (approximately 1.2 miles southeast); however, the presence of several mills and processing plant in between the mines and the well locations makes it difficult to attribute uranium levels solely, if at all, to the mines.
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the Kermac Mine No. 22, Kermac Mine No. 24, Homestake Sapin Mine No. 23, and Homestake Sapin Mine No. 25 Mines.

Figures



SOURCE: SMITH AND PETERSON, 1980

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CLIENT:
U.S. ENVIRONMENTAL PROTECTION AGENCY

LOCATION:
NEW MEXICO, NAVAJO NATION

DESIGNED BY:
 RDB 6-11-09

CHECKED BY:
 RLM 6-12-09

P.E.P.G.:
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GENERALIZED LOCATION MAP AND REDOX INTERFACE MAP FOR URANIUM DEPOSITS IN SECTION 28, AMBROSIA LAKE AREA				
ERRG PROJECT NO.	REVISION NO.	SHEET	OF	FIG NO.
28-017	0	1	1	R-1

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