# Groundwater Pathway Assessment Report: Uranium Migration in the Navajo Nation and Shallow Water Sources (Eastern and North Central Region Mines)

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# Acronyms and Abbreviations

| | |
|---|---|
| ATSDR | Agency for Toxic Substances and Disease Registry |
| AUMs | abandoned uranium mines |
| bgs | below ground surface |
| DERSL | U.S. Department of Energy Remote Sensing Laboratory |
| EPA | U.S. Environmental Protection Agency |
| eU | equivalent uranium |
| GPAR | Groundwater Pathway Analysis Report |
| gpm | gallons per minute |
| HRI | Hydro Resources, Inc. |
| HRS | Hazard Ranking System |
| ISL | in-situ leaching |
| MCLs | maximum contaminant levels |
| mg/L | milligrams per liter |
| msl | mean sea level |
| NMED | New Mexico Environment Department |
| NNEPA | Navajo Nation Environmental Protection Agency |
| NNPDWR | Navajo Nation Primary Drinking Water Regulations |
| NORM | Naturally Occurring Radioactive Material |
| NURE | National Uranium Resource Evaluation Program |
| pCi/L | picocuries per liter |
| pCi/µg | picocuries per microgram |
| ppb | parts per billion |
| SRIC | Southwest Research and Information Center |
| START | Superfund Technical Assessment and Response Team |

## Acronyms and Abbreviations *(continued)*

| | |
|---|---|
| TDD | Technical Direction Document |
| TENORM | Technologically Enhanced Naturally Occurring Radioactive Material |
| USACE | U.S. Army Corps of Engineers |
| USGS | U.S. Geological Survey |
| μg | micrograms |
| μg/L | micrograms per liter |
| μR/hr | microRoentgens per hour |

# Section 1. Introduction

This Groundwater Pathway Analysis Report (GPAR) presents the results of a desktop study of uranium deposits and mining in the Navajo Nation and the potential for migration of uranium into water sources within the Navajo Nation. Engineering/Remediation Resources Group, Inc. performed the study for the U.S. Environmental Protection Agency (EPA) as an ongoing assessment of abandoned uranium mines (AUMs) in the region and their effects on the Navajo Nation under Superfund Technical Assessment and Response Team (START) contract number EP-S9-07-01. The work was conducted under Technical Direction Document (TDD) number TO1-09-08-02-0001 issued to ERRG in support of EPA's Chemical Emergency Preparedness and Prevention activities.

Uranium and its decay products are radioactive; consequently, uranium in water sources may pose a risk to human health if the water is consumed by human or domestic animals. The EPA has delineated six regions across the Navajo Nation where AUMs occur: Northern Region, Western Region, North Central Region, Central Region, Southern Region, and Eastern Region (Figure 1; EPA, 2007c). The desktop study specifically focused on uranium occurrences and water wells (including shallow sources of water) in the North Central Region and the Eastern Regions because deposits of uranium at AUMs in these two regions remain beneath the groundwater table.

Uranium deposits in the Navajo Nation occur broadly within the Colorado Plateau uranium province. The North Central Region deposits fall within the Monument Valley Mining District and the Eastern Region uranium deposits fall within what is referred to as the "Grants Uranium Region" (Figure 2). Dispersion of uranium into groundwater from these natural uranium occurrences may be accelerated in areas of historical mining (i.e., AUMs) because most uranium in water comes from uranium-bearing rocks and piles of waste rock and soil on the surface and from rocks in the subsurface through which either surface water or groundwater passes, leaching and mobilizing the uranium.

This GPAR discusses the uranium geology and hydrogeology, regional geology and hydrogeology, methods of mining, and conditions resulting from mining. This GPAR also discusses the generalized distribution of uranium in and around native deposits and the migration of uranium from these deposits, particularly migration that might be accelerated from AUMs where ore remains below the groundwater table, leading to potential exposure to dissolved uranium in shallow wells of the region. Groundwater pathway assessments were completed for 30 AUMs listed by EPA as having uranium ore deposits below

the groundwater table; a Preliminary Assessment Report was completed earlier for another AUM with ore deposits below groundwater table (Moonlight Mine in the North Central Region). Specific mine histories, previous investigations, and hazard ranking analyses are provided in Appendices B through J for the AUMs in the North Central Region (except for the Moonlight Mine) and in Appendices K through R for the AUMs in the Eastern Region. References and acronyms for this GPAR and the appendix reports are included in this GPAR to avoid redundancy. Based on the research and resources available, this GPAR summarizes the AUMs with elevated, limited, or undefined potentials for contaminating unregulated wells near the mines.

## 1.1. PROBLEM ASSESSMENT

The Safe Drinking Water Act was passed in 1974 to protect public health and authorizes the EPA to set national health-based standards for drinking water to protect against naturally occurring and man-made contaminants. Materials that may contain any of the primordial radionuclides[1] or radioactive elements, such as uranium, radium, thorium, and their radioactive decay products, as they occur in nature and that are undisturbed as a result of human activities are referred to as Naturally Occurring Radioactive Material (NORM). NORMs that have been concentrated or exposed to the accessible environment as a result of human activities such as uranium mineral extraction are defined as Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) (EPA, 2007a). Both TENORM and NORM can contaminate drinking water and fall under applicable regulatory health-based standards.

Uranium is mildly radioactive, and people are exposed to low amounts of uranium, in air, food, and water; however, ingestion of large amounts of uranium can cause kidney disease. Uranium and its radioactive decay products contribute to natural background radiation. Uranium decays into other radioactive elements, such as radium, which can cause cancer if a person is exposed to enough of the decay products for a long enough period of time. Studies have reported lung and other cancers in uranium miners, but it is not possible to directly correlate the cases of cancer with the uranium exposure because the workers also smoked and were exposed to other substances that cause cancer, such as radon and silica dust.

Uranium mining may disperse radioactive-contaminated dusts, sediments, groundwater, and surface water, depending on site conditions, mining practices, and the amount and grade of material extracted. In August 2007, EPA presented the results of a screening assessment of AUMs in the Navajo Nation in the "Abandoned Uranium Mines and the Navajo Nation: Navajo Nation AUM Screening Assessment Report and Atlas with Geospatial Data," herein referred to as the "AUM Report and Atlas" (EPA, 2007c). The assessment determined that 31 AUMs hosted uranium ore deposits below the water table, from which uranium from the AUMs may disperse into shallow groundwater. It was noted from the results of

[1] An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

analyses of the water samples collected from some of these mines (Moonlight and Radium Hill Mines) that radionuclides may concentrate in water that partially fills the AUMs (EPA, 2007c). Reclaimed AUMs should pose little risk of health hazards; however, unreclaimed AUMs may pose some risk because mining disturbs mineralization and increases the probability of exposures. Activities can include removal of overburden, tunneling, and transporting ore.

EPA and the Navajo Nation EPA issued a health advisory in 2001 recommending people drink from regulated drinking water sources, which are routinely sampled and tested. However, some unregulated water wells and shallow water sources have been historically used for watering livestock and possibly for human consumption; thus, EPA collected samples from 226 of the sources to investigate the concentrations of uranium in the water.

### 1.1.1. Water Quality Objectives

#### 1.1.1.1. Maximum Contaminant Levels

EPA has established standards, maximum contaminant levels (MCLs), for uranium, radium, and alpha particle activity in drinking water throughout the United States. The MCL for uranium in drinking water is 30 micrograms per liter (μg/L), and the MCLs for radium-226 and radium-228 combined and gross alpha particle activity are 5 picocuries per liter (pCi/L) and 15 pCi/L, respectively (EPA, 2009e). As long as concentrations of uranium and the gross alpha activity in drinking water are less than the MCL, the water is considered safe to drink. Uranium in native rocks and soils, undisturbed ore deposits, partially mined deposits, and waste piles at AUMs may migrate to local shallow water sources by leaching into surface water and groundwater that together mingle in shallow water sources. The concentrations of uranium in these waters depend on (1) the form in which the uranium occurs (its ionic state, mineral form, and degree of weathering or oxidation), (2) the concentrations at which uranium occurs in the natural deposits, and (3) the environmental conditions of the water and AUM (pH, oxidation/reduction potential, etc). The relationship between concentration (μg/L) and activity (pCi/L) is dependent upon the relative mix of the radioactive isotopes (e.g., uranium-234, uranium-235, and uranium-238) that comprise uranium at a particular drinking water source. Uranium ore has a very low specific activity of 0.68 microcurie per gram or picocurie per microgram (pCi/μg) (Agency for Toxic Substances and Disease Registry [ATSDR], 1999). Using this conversion factor, the equivalent activity for a concentration of 30 μg/L would be approximately 20 pCi/L.

#### 1.1.1.2. Navajo Nation

The Navajo Nation Primary Drinking Water Regulations (NNPDWR) were formally adopted by the Resources Committee of the Navajo Nation Council, Navajo Nation Environmental Protection Agency's (NNEPA) legislative oversight, pursuant to the Navajo Nation Safe Drinking Water Act. The purpose of these

regulations is to promote the protection of the health and welfare of the Navajo people and the environment, and the regulations are applicable to public water systems. The NNPDWR MCL for uranium is 30 μg/L, and the gross alpha particle activity MCL is 15 pCi/L (including radium-226 but excluding radon and uranium; NNEPA, 2007).

# Section 2. Chemistry, Toxicology, and Regional Background

## 2.1. URANIUM BACKGROUND

Uranium is fairly ubiquitous in nature and is found in varying but small amounts in rocks, soils, water, air, plants, and animals and in all human beings. On average, approximately 90 μg (micrograms) of uranium exists in the human body from normal intakes of water, food, and air (World Health Organization, 2009). The greatest health risk from large intakes of uranium is toxic damage to the kidneys because, in addition to being weakly radioactive, uranium is a toxic metal. ATSDR notes in its *Toxicological Profile for Uranium* (ATSDR, 1999) that health effects associated with oral or dermal exposure to natural uranium appear to be solely chemical in nature and not radiological; they also note that the Committee on the Biological Effects of Ionizing Radiation concluded that ingesting food or water with uranium at normal concentrations will most likely not result in cancer or cause other health problems in most people. However, excessive uranium exposure may increase the risk of cancer because it is radioactive, and exposure to radioactivity has been shown to cause cancer. Uranium tends to concentrate in specific areas of the body, and the risks of bone cancer, liver cancer, and blood diseases (such as leukemia) increase with concentration (EPA, 2009a).

Uranium is found naturally as three different isotopes: uranium-238, uranium-235, and uranium-234. Uranium-238 is the most abundant of the isotopes. Natural uranium, including uranium ore, comprises 99.284 percent uranium-238, 0.711 percent uranium-235, and 0.005 percent uranium-234 by mass. Combining the mass percentages with the unique half-life of each isotope converts mass into radioactivity units such that uranium ore is 48.9 percent uranium-238, 48.9 percent uranium-234, and 2.25 percent uranium-235. As mentioned in Subsection 1.1.1, uranium ore has a very low specific activity of 0.68 pCi/μg.

Uranium-238 undergoes radioactive decay into a series of 13 different radionuclides before ending in the stable lead isotope, lead-206. As the radionuclides progressively decay, alpha or beta radiation, and occasionally gamma radiation, is emitted. A few of these radionuclides, including radium and radon, are very radioactive and can be a human health hazard. Cancer is a major concern from the radionuclides because oral exposure to radium is known to cause bone, head, and nasal passage tumors in humans (EPA, 1992).

Uranium is present in minerals in its hexavalent ($U^{6+}$) and tetravalent ($U^{4+}$) states of oxidation, although tetravalent uranium is only stable under reducing conditions. Hexavalent uranium occurs as individual ions and complex ions, uranyl complex $(UO_2)^{2+}$, in minerals. Both uranium ions, $U^{4+}$ and $(UO_2)^{2+}$ are strongly adsorbed by many inorganic and organic substances. As pH increases to approximately 7.5, sorption capacities of both inorganic and organic substances rise; the sorption capacities for inorganic substances reach a maximum in the pH range of 4.5 to 7.5. For humic substances (organic matter), the maximum sorption capacities are reached in the pH range of 3.5 to 6.0.

Uranium is normally highly insoluble under reducing conditions. Upon oxidation by through-flowing groundwater, dissolution can increase markedly. Uranium-decay products generally do not form soluble compounds. Uranium will generally be more dispersed than radium because radium is relatively immobile in the surficial environment, and radon decays too rapidly to move far from its parent, radium. Additionally, the two isotopes of thorium in the uranium-238 decay series are extremely immobile in the surficial environment. Lead-210, another uranium-decay product, usually forms rather insoluble sulfides and sulfates. Helium, given off during the decay of uranium-238, uranium-235, and thorium-232, does not react chemically because it is inert and is a very small molecule by size, often escaping through fissures into groundwater regime (Devoto, et al., 1980). Helium that leaks to the surface may be a good indicator of faults and fracture zones where metals can concentrate.

### 2.1.1. Uranium Geology

Uranium deposits are found in a variety of geologic settings. In the United States, most uranium was mined from epigenetic (i.e., a mineral deposit of later origin than its enclosing rocks) uranium deposits in Mesozoic and Cenozoic sandstone. Mineralization occurs in a variety of spatial configurations in the sandstone, but the host sandstone is generally reduced at the point of ore deposition, characterized by disseminated pyrite and carbonaceous (humate) material (Kimberley, 1978).

Uranium deposits can broadly be broken into three categories: (1) primary uranium deposits formed by hydrothermal fluids that originate from molten rock; (2) secondary uranium deposits formed by weathering or from sedimentary processes; and (3) tertiary uranium deposits formed by metamorphic processes. Three host environments or subtypes of sandstone-type uranium deposits are tabular/peneconcordant, rollfront, and tectonic-lithologic. The tabular/peneconcordant host environment is further subtyped into extrinsic carbon, vanadium-uranium, and basal channel deposits.

Of the 33 AUMs hosting uranium ore deposits below the water table, 13 of them are in the Monument Valley Mining District (in the North Central Region), and 20 of them are located in the Grants Uranium Region (in the Eastern Region). EPA lists the Utah No. 1 and Radium Hill No. 1 mines in the North Central Region together and the Kermac No. 24 and Kermac No. 25 mines together in the Eastern Region. The Monument Valley uranium deposits are secondary basal channel deposits. The Grants Uranium

Region deposits are dominantly secondary extrinsic carbon deposits and less frequently tectonic-lithologic deposits. These deposits are generated by the progressive infiltration and migration of groundwater through sandstones until uranium in the water interacts with reductants in the sandstone and concentrates/fixes in-place (Dahlkamp, 1993).

Generally, the host sandstone is fluvial, has been subjected to reducing diagenesis (i.e., chemical, physical, and biological changes after a sedimentary rock has been deposited) and extensive pyrite growth, and often contains abundant organic matter. The sediments containing sulfides (such as pyrite) constitute a reducing environment with anaerobic conditions producing the reductant hydrogen sulfide, capable of reducing large amounts of uranium. Uranium deposits are located at or near oxidation-reduction interfaces generated by the influx of oxygenated uranium-bearing (as $U^{6+}$) groundwater. Oxidizing groundwater destroys organics, oxidizes pyrite, leaches calcite, and alters feldspar and ferriferous silicates The groundwater leaches and transports metals that include uranium, molybdenum selenium, and vanadium, as either individual or complex ions. The oxidizing groundwater passes through an oxidation-reduction interface zone in the sandstone, decreasing the pH, causing metals to precipitate as reduced solid species, often precipitating uraninite or coffinite (as $U^{4+}$). Uranium, selenium, molybdenum, and vanadium mineralization occurs in or near this oxidation-reduction interface (Figure 3; Kimberley, 1978). This interface between the oxidized and reduced sandstone is generally the prime location for uranium mineralization, but some epigenetic uranium deposits are found within the pyritiferous-reduced sandstone. Deposits in reduced sandstone occur when subsequent burial and changes in groundwater hydrology and chemistry cause formerly oxidized areas to be re-reduced, leaving a uranium deposit that originally was at the oxidation-reduction interface to be encased within pyritiferous sandstone (Kimberley, 1978).

#### 2.1.1.1. Monument Valley Uranium Mineralization

Uranium deposits in the Navajo Nation are predominantly secondary deposits created by supergene processes after the enclosing sediments were deposited and lithified. The host rock is a fluvial, medium- to coarse-grained, poorly sorted, conglomeratic sandstone. Uranium in the Monument Valley Mining District is typically associated with pockets of plant fragments and trees that are concentrated in the basal portion of the fluvial channel (Figure 4). Uranium was deposited preferentially along the base of channels or cuts that were scoured into the underlying formations, forming small lenticular deposits of low to medium grade, as typified in deposits of the Starlight East Mine (Figure 5). Principal uranium minerals are uraninite, pitchblende, and coffinite. These minerals impregnate the host sandstone, coating sand grains; replacing quartz grains, clay particles, and specifically fossil plant debris; and filling vertical fissures beneath the base of the scours (Dahlkamp, 1993).

Individual deposits may be only a few meters long, but some are up to 300 meters long. The deposits are also less than 1 meter across to more than 100 meters wide and less than 0.2 meters thick to 3 meters thick.

As mentioned above, uranium deposition is associated with plant fragments in the basal portions of the fluvial channels (Figure 4). These deposits form small low- to medium-grade reserves; the mineralization crosscuts the sandstone bedding and extends from overlying horizons (conglomerates) to underlying less-permeable horizons. The contact zones are sharp; hematite and limonite occur in the sandstone upgradient of the interface (except where the sands have been re-reduced), and carbon and pyrite occur in the sandstone downgradient of the interface, becoming more diffuse farther away from the interface (Dahlkamp, 1993). The deposits in the Chinle Formation of southeastern Utah are principally vertical-edge tabular bodies that are elongated parallel to the historic direction of flow in the sandstone (Figure 4; Kimberley, 1978).

#### 2.1.1.2. Grants Uranium Region Uranium Mineralization

The uranium in the Grants Uranium Region is typically associated with redistributed carbonaceous matter in lenses in the continental sandstone, and the bulk of the ore is in unoxidized deposits. The reduced deposits are separated into primary and redistributed mineralization. The structural configuration of the deposits in the Grants Uranium Region is described in one of two ways:

- By form with ore being termed "trend" if the form of the deposit is tabular, with long dimensions nearly parallel to bedding, or ore termed "stack" if the deposit has sizable vertical extent
- By timing with ore broken up into "prefault" and "postfault"

Trend ore tends to be more or less equivalent to prefault ore and stack ore to redistributed postfault ore (Corbett, 1963). Trend-type ore was controlled by sedimentary structures, while redistributed stack ore was controlled by 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. Redistributed ore bodies form from oxidation and removal of uranium from primary deposits and subsequent reprecipitation of reduced uranium at an oxidation-reduction boundary or along a geologic structure.

Principal uranium minerals are coffinite, pitchblende (a massive, possibly impure version of uraninite), sooty pitchblende, and black amorphous urano-organic complexes/uraniferous humate. These minerals impregnate the host sandstone and are interstitially distributed to the sand grains (Dahlkamp, 1993). Primary reduced mineralization of uranium is found in urano-organic compounds. The individual ore lenses range in length from tens of meters up to about 2,000 meters and in width from several meters to hundreds of meters. Thicknesses are usually less than 2.5 meters but range from centimeters to over

5 meters. Coffinite is the principal uranium mineral in redistributed reduced mineralization, and pitchblende is rare. Unlike primary ore where humate occurs in approximately 1:1 ratio with uranium, the ratio is highly variable in redistributed unoxidized mineralization.

### 2.1.2. Uranium Hydrogeology

Just as it is fairly ubiquitous in rock and soil, uranium is found in most natural waters at various concentrations. Variations in concentrations in water reflect the overall variations of original concentrations in bedrock or soils. Concentrations of uranium in sea and ocean waters generally range between 0.5 and 10 parts per billion (ppb), whereas concentrations in surface waters are generally low, from less than 0.1 ppb to more than 1 ppb (generally equivalent to micrograms per liter [μg/L]). However, concentrations in groundwater range from 0.5 ppb to 10 ppb but may increase to greater than 100 ppb. Concentrations in water in conglomerate sandstones can range from 0 to 2,100 ppb, averaging 2.2 to 26.2 ppb. Higher concentrations of uranium in groundwater are associated with terranes underlain by uraniferous lithologies. Particularly high uranium concentrations in groundwater are generated from those rich in dissolved salts such as carbonate, chloride, sulfate, nitrate, and phosphate. Groundwater richer in dissolved salts is typically encountered in arid to semiarid environments (Dahlkamp, 1993), similar to the setting in the Monument Valley Mining District.

Water is a significant method of dispersal of uranium and related TENORM in mining areas. (EPA, 2008). Uranium can be mobilized by either acidic or alkaline solutions and can be leached or remobilized from uranium deposits and waste, depending on local geology and climate. Water can travel underground through mines and drill holes, leaching uranium from either undisturbed deposits, from residuals left in the wallrock after mining, or from debris in the mine workings and ultimately mingling with groundwater. Precipitation can leach uranium from waste piles near old mine workings and from tailings from mineral extraction; this contaminated water can either percolate down to mingle with groundwater or flow over the surface into streams or other bodies of water at the surface.

## 2.2. REGIONAL AND SITE BACKGROUNDS

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, starting in the 1900s; production peaked between the 1940s and the 1960s. Substantial tracts of land were disturbed by surface and underground mine operations (EPA, 2007c). The uranium deposits from which uranium was mined in the Navajo Nation occur in what is referred to generally as the Colorado Plateau uranium province.

Uranium in the Navajo Nation was produced significantly from deposits in the Chinle and Morrison formations and from minor deposits in the Bidahochi, Dakota Sandstone; Todilto Limestone; Navajo Sandstone; and the Kayenta, Moenkopi, and Toreva formations (EPA, 2007c). The original source of

uranium is igneous rocks; uranium has been mobilized from the original source, transported by water, and deposited in sedimentary rocks at an oxidation-reduction interface.

Only a limited supply of water is available in relation to the demand of water for industry and domestic use because the Navajo Nation is semiarid. Most surface waters in the Navajo Nation (and the San Juan Basin) are either intermittent or ephemeral (EPA, 2006). Intermittent streams have defined channels formed by the flow of water part of the time in most years; ephemeral streams do not have defined stream channels and are created in response to heavy rainfall events. Flow in the channels and washes of the basin is sporadic and results from the localized, short-duration, high-intensity thunderstorms in late spring and summer. Perennial streams have visible water year-round. It has been reported that radiochemical constituents are fairly low in most of the natural stream flow in the area, although the concentrations are higher than in streams outside of the San Juan Basin (Busby, 1979).

### 2.2.1. Monument Valley Mining District

Specifically, the Starlight, Starlight East, Sunlight, South Sunlight, Big Four No. 2, Big Chief, Bootjack, Firelight No. 6, Alma-Seegan, Utah No. 1, Radium Hill No. 1, and Fern No. 1 Mines are in the Monument Valley Mining District (Dahlkamp, 1993) in the Colorado Plateau uranium province (Figure 1; North Central Region). The Monument Valley landscape is formed by differential erosion of the nearly horizontal stratigraphy, forming numerous canyons, mesas, and monuments (Figure 6). Land in the Monument Valley Mining District is generally used for sheep grazing and tourism and is typified by sparse grasses and desert shrubs at the lower elevations and pinyon-juniper forest at higher elevations (Longsworth, 1994).

#### 2.2.1.1. Regional Geology

In the Monument Valley Mining District, uranium is produced from the Shinarump Member of the Chinle Formation. Young, Malan, and Gray mapped out the uranium-bearing channels of the Shinarump, illustrating the uneroded channels and the estimated eroded channels (Figure 7; Young, Malan, and Gray, 1964). Most of the AUMs occur along the uneroded channels, and significant portions of the uneroded channels appear to have not been mined.

The host rock for the uranium deposits is fluvial medium- to coarse-grained conglomeratic, crossbedded, poorly sorted, lenticular arkosic sandstone. The unit is yellowish-gray and red to brown in color and contains interbeds of greenish-gray mudstone and siltstone. Carbonaceous matter is locally abundant, especially at bends, paleochannel meanders, in mud bars, or where changes in stream load carrying ability occurred. Reduction is seen as bleaching of the originally red and brown sandstone to light gray. The sandstone is cemented by calcite, up to 15 percent calcium carbonate.

### 2.2.1.2. Hydrology and Hydrogeology

The mines within the North Central Region are located in the San Juan subregion in the Upper Colorado watershed, specifically within the Lower San Juan hydrologic unit. Historic measurements of depths to water and elevations in along the El Capitan Wash indicated a general southeast to northwest gradient (Figure 8). Monument Valley is drained by ephemeral streams that form tributaries to the San Juan River (Longsworth, 1994).

*Precipitation*

Average annual precipitation in the Monument Valley ranges between 4 and 8 inches (see precipitation map covering the 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). Rainfall during thunderstorms can cause flooding that may be of large magnitude but local in extent. It is not uncommon for discharges of several hundred to several thousand cubic feet per second to occur from drainages of only a few square miles (Busby, 1979).

*Infiltration*

Soil near the mines in the Monument Valley area is characterized hydrologically by moderate infiltration rates (see the Hydrologic Group Map in Appendix A). The moderately coarse soils are moderately deep to deep and moderately well to well drained. This hydrologic classification is based on properties that include depth to water table, intake rate and permeability after prolonged wetting, depth to a very slowly permeable layer, and wetness. Permeability in the Monument Valley area is rapid on average, between 6.01 to 16.53 inches per hour. The variations are illustrated on the Permeability Map for North Central Region in Appendix A; EPA, 2007c).

*Aquifers*

As discussed in the AUM Report and Atlas (EPA, 2007c), aquifer sensitivity is defined by Blanchard as "the relative ease with which a contaminant applied on or near a land surface can migrate to the aquifer of interest" and "[a]quifer sensitivity is a function of the intrinsic characteristics of the geological materials, and the overlying unsaturated zone" (Blanchard, 2002). Blanchard has developed a model of aquifer sensitivity for the Navajo Nation. Aquifer sensitivity in the Monument Valley area ranges from intermediate potential for contaminant migration upgradient to most potential for contaminant migration downgradient along the drainages (see the Aquifer Sensitivity Map for North Central in Appendix A; EPA, 2007c).

The Monument Valley Mining District is in the Monument Valley hydrogeologic subdivision of the Navajo Indian Reservation that is part of the Henry hydrologic basin. This subdivision is mentioned as

one of the driest and least favorable areas for development of groundwater in the Navajo Nation (Longsworth, 1994). The consolidated sedimentary rocks consist of eolian and fluvial deposits, including the Shinarump Member of the Chinle Formation, the Moenkopi Formation, and the De Chelly Sandstone Member and Organ Rock Tongue of the Cutler Formation, which are part of the C aquifer system in Monument Valley (Longsworth, 1994).

Although groundwater may be found in unconsolidated alluvium and in all consolidated sedimentary rocks, it is predominantly available to wells only in the alluvium and in the relatively more permeable units of the C aquifer. The alluvium may yield more than 10 gallons per minute (gpm) to wells. In the C aquifer, the Shinarump Member may yield 5 to 10 gpm; the De Chelly Sandstone Member may yield 5 gpm, and the Organ Rock Tongue may yield 1 to 2 gpm. The Moenkopi Formation generally does not yield water to wells (Longsworth, 1994).

Recharge to the alluvium and to the C aquifer is directly from rainfall, from ephemeral streams, or from leakage from underlying water-bearing units. In outcrop areas, recharge to the C aquifer may occur through fractures and along bedding planes, while high rates of evaporation and low permeabilities limit the amount in the nonfractured parts of the aquifer (Longsworth, 1994).

### *Monument Valley Area Groundwater Wells and Flow*

Groundwater wells and surface water sources vary in type throughout the region. Many wells have unknown origins with undocumented histories regarding installation, development, depths, water levels, and sampling. Some monitoring wells have been installed in relationship with mining operations at uranium mines, while other water wells, often shallow, serve as water resources for livestock.

Few well depth and depth to groundwater data are available for the region. However, depths to groundwater were collected in October 1991 from the following wells in the vicinity of the Monument Valley area mines:

- 8T-525
- 8K-433
- 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; Longsworth, 1994)

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 altitude of the land surface (either surveyed or determined from U.S. Geological Survey [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 8T-525, indicating a southeast to northwest flow along drainage.

Elevations measured at the wells and springs along the El Capitan Wash confirm a southeast-to-northwest gradient. Starting southeast of Alma-Seegan, as seen on Surface Water Features Map for North Central Region (Appendix A), the measured wells and springs are:

- 08A-220 (developed spring for livestock use) at 5,360 feet above msl (also known as 8A-P.H.S.-22 Spring)
- 8-5-9 at 5,148 feet above msl with depth of 10.6 feet below ground surface (bgs)
- 08A-210 (abandoned) at 5,095 feet above msl
- 08-0636 (inactive well) at 5,090 feet above msl with depth of 14 feet bgs
- 08-0612 (used for livestock) at 5,095 feet above msl with depth of 560 feet bgs
- 08K-433(inactive well used for livestock) at 5,100 feet above msl with depth of 46 feet bgs (also known as Tank 8A-299)
- 08-0637 (inactive well) at 5,040 feet above msl with depth of 151 feet bgs
- 08T-525 (active artesian well used for livestock) at 5,026 feet above msl with depth of 383 feet bgs
- 08-27 (active well used for livestock) at 5,000 feet above msl (also known as Alvin Billy Well and Shallow Well El Capitan)

Wells 8K-433 and 8T-525 are both perforated in the Shinarump Member of the Chinle Formation. Well 8T-525 is also perforated in the De Chelly Sandstone. The perforated or screened intervals are not known for the two unnamed wells near El Capitan Wash. The depths of the wells suggest that they are also drilled into the Shinarump Member (Longsworth, 1994). Longsworth (1994) notes that groundwater generally moves from recharge areas toward the Oljeto and El Capitan Washes in the area near the Moonlight and Radium Hill mines, and eventually flows north to discharge to the San Juan River. More detailed discussions regarding groundwater wells and flow directions for each mine and/or area are provided in Appendix B through Appendix J.

### *Groundwater Parameters*

Based on measurements in the wells listed above, pH in groundwater samples from the Monument Valley area ranges from 7.85 in Shallow Well El Capitan (at same location at 08-27) to 8.94 in well 08T-525 (EPA, 2009d).

#### 2.2.1.3. Regional Aerial Radiation Contours

Bismuth-214 radiation is associated with uranium, and excess bismuth activity is a good indicator of old mines and mining-related activities. 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 U.S. Department of Energy Remote Sensing Laboratory (DERSL). The contour map is included in the Project Atlas. A gamma-ray detector was mounted in an aircraft that was flown over an area at a certain altitude with most of the gamma-ray signal derived from the upper 20 to 25 centimeters of surficial materials. Equivalent uranium (eU) was calculated from the counts received by the gamma-ray detector in the energy window corresponding to bismuth-214; this technique assumed that uranium and its decay products were in secular equilibrium (USGS, 1995). The aerial radiation contours identified surface concentrations higher than regional levels.

### 2.2.2. 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. The principal mining districts within the Grants Uranium Region are Church Rock, Crownpoint, Smith Lake-Mariano Lake, Ambrosia Lake, and Laguna (Figure 9). The 19 AUMs in the Eastern Region are in 4 mining districts of the Grants Uranium Region:

1. Church Rock Mining District (Figure 10): Grace ISL Mine, Section 13 Mine, NE Church Rock No. 2 Mine, NE Church Rock No. 1 Mine, NE Church Rock No. 1-East Mine, NE Church Rock Mine, Church Rock ISL Mine, Church Rock Mine, and Section 16 Deposit Mine
2. Crownpoint Mining District (Figure 11): Crownpoint Section 9 Mine, Nose Rock No. 1 Mine (Figure 12), Crownpoint ISL Mine, and Section 29 – Conoco Mine
3. Smith Lake-Mariano Lake Mining District (Figure 13): Mariano Lake Mine and Black Jack No. 2 Mine
4. Ambrosia Lake Mining District: Kermac Mine No. 22, Homestake Sapin Mine No. 23, and Kermac Mine Nos. 24 and 25

#### 2.2.2.1. Regional Geology

The Grants Uranium Region occurs in and along the southern border of the San Juan Basin. Most of the uranium deposits are hosted in sandstones of the Westwater Canyon-Brushy Basin members of the Morrison Formation (Figure 14). During the Jurassic period, three broad alluvial fans, constituting most 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 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 Westwater Canyon Member is the host for ore in the Church Rock District, Ambrosia Lake District, and most of the other districts in the Grants Region. The Jackpile sandstone hosts uranium deposits in the Laguna District, and the Poison Canyon sandstone hosts deposits in the Mt. Taylor District and Ambrosia Lake District. The Westwater Canyon Member is approximately 15 meters thick in the Laguna District to 80 meters thick in the Ambrosia Lake District and is composed of poorly sorted, cross-bedded fine- to very coarse-grained arkose to feldspathic sandstone; the content of humate and organic plant material varies throughout. 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 structural configuration of the deposits in the Ambrosia Lake area is described in one of two ways:

- By form with ore being termed "trend" if the form of the deposit is tabular, with long dimensions nearly parallel to bedding, or ore termed "stack" if the deposit has sizable vertical extent
- By timing with ore broken up into "prefault" and "postfault"

Trend ore tends to be more or less equivalent to prefault ore and stack ore to redistributed postfault ore (Corbett, 1963). Trend-type ore was controlled by sedimentary structures, while redistributed stack ore was controlled by 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.

Based on the geologic maps for the Grants Uranium Region, surface rocks at the Grace ISL, Section 13, Church Rock ISL, Church Rock, Section 16 Deposit, Mariano Lake, Black Jack No. 2, Kermac No. 22, Kermac No. 24, Kermac No. 25, and Homestake-Sapin No. 23 mines are from the Dakota Sandstone and lower Mancos Shale. The surface rocks in the NE Church Rock mines and Crownpoint No. 9 Mine are from Gallup Sandstone and Mulatto Tongue of Mancos Shale. 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).

#### 2.2.2.2. Hydrology and Hydrogeology

The mines within the Eastern Region are located within the San Juan River, Colorado River, and Rio Grande Drainages. The northern portion, including the Crownpoint area, is drained by tributaries of the San Juan River Drainage. The western and southwestern parts, including the Church Rock and Mariano

Lake areas, are drained by the Rio Puerco Drainage. The eastern and southeastern parts, including the Ambrosia Lake area and the Black Jack Mine in the Smith Lake area, are drained by tributaries of the Rio Grande. The Eastern Region is characterized by intermittent and ephemeral streams; the only perennial stream is Bluewater Creek within the southern portion of the Baca/Prewitt Chapter of the Navajo Nation (EPA, 2006).

Dewatering of mines with ore bodies beneath the groundwater table is necessary because it facilitates stoping and increases the strength of the sandstone (Hohne, 1963). Wet ores are encountered in the sandstone mines at depths ranging from 80 to more than 500 feet below shaft collars. Although historically a greater number of mines are in ore bodies above the groundwater table, the greatest tonnage of ore has come from deposits beneath the groundwater table. Dewatering is accomplished by the pumping of water through large wells or pumps in the workings, lowering the groundwater table to below the ore extraction zone (Figure 15).

### *Precipitation*

Average annual precipitation varies throughout the Grants Uranium Region, ranging from 8 to 18 inches in the vicinity of the AUMs discussed in this report (see three precipitation maps covering 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). Rainfall during thunderstorms can cause flooding that may be of large magnitude but local in extent. It is not uncommon for discharges of several hundred to several thousand cubic feet per second to occur from drainages of only a few square miles (Busby, 1979). Streams in the Ambrosia Lake area, and likely in much of the Grants Uranium Region, are intermittent and are sediment-laden during the brief periods of storm runoff (John, E.C., and S.W. West, 1963).

### *Infiltration*

Soil near the mines in the Ambrosia Lake, Crownpoint, and Smith Lake area is characterized hydrologically by very slow to moderate infiltration rates (see the Hydrologic Group Map for Ambrosia Lake Area and Crownpoint Area of Eastern Region in Appendix A). Soil in the Church Rock Area is characterized by very slow to slow infiltration rates (see the Hydrologic Group Map for Church Rock Area of Eastern Region in Appendix A). Very slow infiltration rates are attributed to clayey soils, high water table, or the presence of an impervious layer, while slow infiltration rates are generally due to downward movement of water being impeded by soil layers with moderately fine or fine textures. The moderately coarse soils are moderately deep to deep and moderately well to well-drained. This hydrologic classification is based on properties that include depth to water table, intake rate and permeability after prolonged wetting, depth to a very slowly permeable layer, and wetness.

Permeability in the Ambrosia Lake area varies from moderately slow (0.21 to 0.60 inches per hour) to moderately rapid (2.01 to 6.00 inches per hour), while permeability in the Crownpoint area similarly varies from moderately slow to rapid (6.01 to 16.53 inches per hour). Permeability in the Church Rock area only varies from moderately slow to moderate (0.61 to 2.00 inches per hour). The variations are illustrated on the Permeability Maps in Appendix A; EPA, 2007c).

### *Aquifers*

As discussed in the AUM Report and Atlas (EPA, 2007c), aquifer sensitivity is defined by Blanchard as "the relative ease with which a contaminant applied on or near a land surface can migrate to the aquifer of interest" and "[a]quifer sensitivity is a function of the intrinsic characteristics of the geological materials, and the overlying unsaturated zone" (Blanchard, 2002). Blanchard has developed a model of aquifer sensitivity for the Navajo Nation. Aquifer sensitivity in the Grants Uranium Region ranges from insignificant potential to most potential, varying significantly across the region and the individual mining districts (see the Aquifer Sensitivity maps in Appendix A; EPA, 2007c).

The principal aquifers in the Grants District and Ambrosia Lake District are the Glorieta Sandstone, San Andres Limestone, Westwater Canyon Member of Morrison Formation, Dakota Sandstone, and Quaternary alluvium and basalt. The Westwater Canyon Member supplies most of the water supply near Ambrosia Lake; the Dakota Sandstone is used less because larger supplies of better quality water can be obtained from the Westwater Canyon Member. However, hydrologic properties of the Westwater Canyon vary widely over short distances, with poor-sorting in coarser sands but improving sorting as grain-size diminishes. The aquifers represent the sole source of water for the area, except for the occasional small diversions of irrigation water from Bluewater Creek (John, E.C., and S.W. West, 1963).

Mine dewatering and groundwater withdrawal in the Grants Uranium Region has caused water levels to decline significantly since measurements began in 1946. North of Bluewater, groundwater levels declined approximately 40 to 45 feet between the start of measurements and 1963 (John, E.C., and S.W. West, 1963). Throughout uranium mining, large-scale dewatering was necessary and more than 250,000 acre-feet of water was pumped from Ambrosia Lake Valley, resulting in more than 500 feet of drawdown in the potentiometric surface. Water levels have been recovering since mining ended in 1986; however, according to Erskine and Ardito (2008), it may take hundreds to thousands of years for them to fully recover.

### *Grants Uranium Region Groundwater Wells and Flow*

The Grants Uranium Region covers a broad area, including several mining districts (Church Rock, Crownpoint, Smith Lake-Mariano Lake, and Ambrosia Lake) (Figure 9). Wells and springs in the area have been identified by various sources, and limited sampling has been conducted. Mine, sampling, and well locations are shown on topographic maps covering each of the areas (Figures 16, 17, 18, 19, and 20).

While some depth to water readings have been recorded, determining the groundwater gradient is difficult because the wells can be screened in different aquifers and measurements were collected on different dates, often years apart. Although groundwater flow has not been directly measured in the areas, it is common for groundwater to follow topography. Discussions regarding groundwater wells and flow directions for each mine and/or area are provided in Appendix K through Appendix R. Well and sample locations can also be seen on the Surface Water Features Maps in Appendix A.

*Groundwater Parameters*

Based on samples collected from selected wells completed in the Morrison Formation of the Grants Uranium region, pH of water in the vicinity of the study AUMs mostly ranged from 7.2 to 9.2 throughout area, while temperature ranged from 14.5 to 17.5°C near Ambrosia Lake area, 33.5 to 35.5°C near Crownpoint area, and 10.5 to 17.0°C near Church Rock area. Total dissolved solids in samples collected near the study AUMs ranged from 280 to 310 milligrams per liter (mg/L) near Crownpoint area, from 480 to 2,300 mg/L near Ambrosia Lake area, and was 360 mg/L closest to the Church Rock area AUMs (Dam, et al., 1990).

#### 2.2.2.3. Regional Aerial Radiation Contours

As mentioned above, bismuth-214 radiation is associated with uranium, excess bismuth activity is a good indicator of old mines and mining-related activities, and aerial radiation contours can identify surface concentrations higher than regional levels. DERSL did not complete an aerial radiation survey 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 eU (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 percent). Local highs just north of the border (up to 4.25 percent) 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 percent. 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 percent. A regional high does not appear in the Crownpoint area, located roughly in the middle of McKinley County.

### 2.2.3. Mine Site Background

In the Monument Valley Mining District, uranium and vanadium were mined primarily from fluvial channel deposits of the Shinarump Member of the Chinle Formation (Figure 4). In the Grants Uranium Region, most of the uranium deposits are hosted in sandstones of the Westwater Canyon-Brushy Basin

members of the Morrison Formation. Thirty of the 31 AUMs discussed below are listed by EPA as AUMs that have workings below the water table or were considered wet mines that required pumping (EPA, 2007c).

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# Section 3. Mine Groundwater Pathways

## 3.1. REGIONAL LOCATIONS

The study AUMs in the Monument Valley area with workings below the water table are located in Navajo County, Arizona, and San Juan County, Utah. The study AUMs in the Grants Uranium Region are located in McKinley County. Although these AUMs are inoperative, the disturbance of deposits at the surface and in the subsurface can make the remaining uranium in rocks at the mine less stable and more accessible for redistribution.

## 3.2. GROUNDWATER PATHWAY ASSESSMENTS

EPA's screening assessment of AUMs in the Navajo Nation determined that uranium ore deposits in 31 AUMs occurred below the water table (EPA, 2007c). The 31 AUMs are in the Eastern and North Central Regions (Figure 1). Groundwater pathway assessments were completed for 30 of the AUMs during this study; a Preliminary Assessment Report has been previously completed for the Moonlight Mine in the North Central Region. Specific mine histories, previous investigations, and hazard ranking analyses are provided in Appendices B through J for the AUMs within the North Central Region, except for Moonlight Mine, and in Appendices K through R for the AUMs within the Eastern Region. Based on regional settings for the two uranium regions (Monument Valley area and Grants Uranium Region) and the mine histories, generalized cross sections with pathways for uranium in solution are illustrated on Figures 22 and 23. References and acronyms for this GPAR, and all appendix reports are included in this GPAR.

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# Section 4. 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 tracks of land were disturbed by surface and underground mining. In August 2007, EPA presented the results of a screening assessment of AUMs in the Navajo Nation in its AUM Report and Atlas (EPA, 2007c). The assessment determined that 31 AUMs hosted uranium ore deposits below the water table, which may aid dispersion of uranium from the AUMs into shallow groundwater. These AUMs were listed by the EPA as either productive or non-productive mines that have ore bodies below the water table or were considered wet mines that required pumping. Productive mines are mines that have produced uranium ore while non-productive mines have not and can include exploratory drilling sites and pilot-test sites such as for in-situ leaching.

The Utah No. 1 Mine, Radium Hill No. 1 Mine, Fern No. 1 Mine, Starlight Mine, Starlight East Mine, Moonlight Mine, Sunlight Mine, South Sunlight Mine, Big Four No. 2 Mine, Big Chief Mine, Bootjack Mine, Firelight No. 6 Mine, and Alma-Seegan Mine are located within the North Central Region, specifically the Monument Valley Mining District. Uranium and vanadium were mined in this district, primarily from channel deposits of the Shinarump Member of the Chinle Formation. Organic plant matter is abundant in the channel sediments and the ore generally occurs along the banks of the channel.

The Grace ISL Mine, Section 13 Mine, NE Church Rock No. 2 Mine, NE Church Rock No. 1 Mine, NE Church Rock No. 1-East Mine, NE Church Rock Mine, Church Rock ISL Mine, Church Rock Mine, Section 16 deposit Mine, Crownpoint Section 9 Mine, Nose Rock No. 1 Mine, two Mariano Lake Mines, Black Jack No. 2 Mine, Crownpoint ISL Mine, Section 29-Conoco Mine, Kermac Mine No. 22, Homestake Sapin Mine No. 23, and Kermac Mine Nos. 24 and 25 are located within the Eastern Region, specifically the Grants Uranium Region. Most of the uranium deposits in this region are hosted in sandstones of the Westwater Canyon-Brushy Basin members of the Morrison Formation, where uranium is typically associated with redistributed carbonaceous matter in lenses in the continental sandstone and the bulk of the ore is in unoxidized deposits.

## 4.1. POTENTIAL FOR URANIUM MIGRATION TO SHALLOW GROUNDWATER SOURCES IN THE NORTH CENTRAL REGION

This desktop study investigated 12 mines with ore bodies beneath the groundwater table, and Groundwater Pathway Assessments were completed for each mine (see Appendices B through J); some mines were grouped together because of proximity and lack of local data. The mines investigated were:

- Utah No. 1 and Radium Hill No. 1 Mines (Appendix B)
- Fern No. 1 Mines (Appendix C)
- Starlight and Starlight East Mines (Appendix D)
- Sunlight and South Sunlight Mines (Appendix E)
- Big Four No. 2 Mine (Appendix F)
- Big Chief Mine (Appendix G)
- Bootjack Mine (Appendix H)
- Firelight No. 6 Mine (Appendix I)
- Alma-Seegan Mine (Appendix J)

A Preliminary Assessment Report was submitted for the Moonlight Mine in September 2008 (Weston Solutions, Inc., 2008). Based on the regional and local uranium geology, hydrogeology, mine histories, and previous mine investigations and surveys, assessments for potential contamination were done using the hazard ranking system. The following subsections summarize the AUMs with elevated, limited, or undefined potentials for contaminating unregulated wells in the vicinity of the Monument Valley mines.

### 4.1.1. Elevated Potential for Uranium Migration to Groundwater Sources

Mines with elevated potential of releasing uranium to groundwater and to unregulated wells near the mines may have combinations of several factors, which may include but are not limited to:

- Uranium concentrations greater than the MCL in groundwater samples collected from downgradient wells
- Depth to water sources in relation to depth of ore deposits
- Higher than average radiation at the surface
- Potentially sizeable mass of uranium ore remaining at the mine
- Extensive unreclaimed waste piles
- Hydrologic conditions, such as rainfall, infiltration, aquifer sensitivity, and permeability, conducive to accelerated uranium migration
- Residences, schools, or daycare centers are within 200 feet of contamination associated with the mine.

The following mines have an elevated potential for releasing uranium to groundwater sources, specifically unregulated water sources:

- Utah No. 1 and Radium Hill No. 1 Mines, because concentrations of uranium from sample collected in Radium Hill No. 1 mine shaft is much greater than the MCL although samples collected at downgradient water sources were less than the MCL. This suggests limited uranium migration; however, no samples were collected in the closest downgradient water source, and sampling at 08GS-12-12 might provide further information on the trend in uranium concentration. The moderate aerial radiation signature may indicate that surface water is less of an influence on uranium migration than groundwater.
- Sunlight and South Sunlight Mines, because of elevated surface radiation and concentrations of alpha radiation, beta radiation, radium-226, uranium-234, and uranium-238 exceeded MCLs in well 08K-433, immediately adjacent to the mines.
- Moonlight Mine, because elevated uranium concentrations were measured in groundwater samples collected from within 4 miles of the mine in well 8K-433 in 1998 and 2008, and from standing water in the mine pit in 1991; however well 8K-433 is not supposed to be actively used for drinking water and the mine pit was backfilled in 1994. In addition, gamma radiation was measured at the site in July 2008 and certain areas of the mine were twice the presumed background radiation measurements though values are still much less than for other mines in the area.

### 4.1.2. Limited Potential for Uranium Migration to Groundwater Sources

Mines with limited potential of releasing uranium to groundwater sources near the mines may have combinations of several factors, which may include but are not limited to:

- Uranium concentrations less than the MCL in groundwater samples collected from downgradient wells
- Shallow depth to water relative to depth of ore deposits
- Moderate to low aerial radiation at the surface
- Limited uranium ore remaining at the mine
- Limited or no unreclaimed waste piles
- Mine reclaimed
- Hydrologic conditions, such as rainfall, infiltration, aquifer sensitivity, and permeability, unfavorable to extensive uranium migration
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mine

The following mines have a limited potential for releasing uranium to groundwater sources:

- Fern No. 1, based on the background level surface radiation at the mine, original ore body being significantly mined, reported reclaimed status, and hydrologic setting (with very limited precipitation), and because concentrations of uranium in downgradient water sources were less than the MCL.
- Starlight and Starlight East Mines, based on the hydrologic setting (with limited precipitation) and because uranium concentrations significantly less than the MCL were measured in the groundwater sample from the closest downgradient well to the mines while higher concentrations were detected in groundwater sample from well further downgradient, suggestive of a source downgradient or from adjacent drainage to the Starlight and Starlight East Mines;
- Big Four No. 2 Mine, based on low to moderate aerial radiation levels and hydrologic setting (with limited precipitation), where uranium is unlikely to travel far from mine because of rainwater chemistry and uranium adsorption properties at shallow depths. The mine may contribute to uranium concentrations found in groundwater samples from 08K-433; however, Sunlight and South Sunlight Mines are more likely to influence this well, given its location above the El Capitan Wash. Sampling at a closer downgradient well (such as 08A-210 or 08-0636) might provide further confirmation of this determination.
- Bootjack Mine, based on low aerial radiation at surface; hydrologic setting (with limited precipitation), where uranium is unlikely to travel far from mine because of rainwater chemistry and uranium adsorption properties at shallow depths; high percentage of ore body removed; and lack of water sources in the vicinity of and downgradient of the mine.
- Alma-Seegan Mine, based on moderate aerial radiation at surface and small percentage of ore, which may contribute to uranium concentrations found in groundwater samples from 08K-433; however, the hydrologic setting suggests that uranium is unlikely to travel far from the mine site because of rainwater chemistry and uranium adsorption properties. Sampling at closer downgradient well (such as 8-5-9) might provide further confirmation of this determination.

### 4.1.3. Undefined Potential for Uranium Migration to Groundwater Sources

Mines with undefined potential of releasing uranium to groundwater sources in the vicinity of the mines may have combinations of several factors, which may include but are not limited to:

- Insufficient analytical results at geographically relevant locations to the mine
- Aerial radiation greater than background levels at the surface
- Possibly high or unknown mass of uranium ore remaining at the mine

The following mines have undefined potential for releasing uranium to groundwater sources because data sources are limited:

- Big Chief Mine, based on high aerial radiation suggesting some remaining uranium contamination on the surface for migration though the hydrologic setting is characterized by limited precipitation, and the lack of analytical data from water sources directly attributable to the Big Chief Mine; the closest water sources are wells 08-0636 and 08A-210 which are adjacent to Big Four No. 2 Mine.
- Firelight No. 6 Mine, based on moderate aerial radiation at surface; hydrologic setting (with limited precipitation), where uranium is unlikely to travel far from mine site because rainwater chemistry and uranium adsorption properties at shallow depths; low percentage of ore body removed; and lack of analytical data from water sources directly attributable to the Firelight No. 6 Mine; closest water source is well 8-5-9.

## 4.2. POSSIBLE SAMPLING LOCATIONS FOR FURTHER INVESTIGATION IN THE NORTH CENTRAL REGION

Sampling at downgradient wells to Utah No. 1 and Radium Hill No. 1 Mines, Sunlight and South Sunlight Mines, Big Four No. 2 Mine, Big Chief Mine, Firelight No. 6 Mine, and Alma-Seegan Mine may provide further confirmation on the potential for uranium migration from these sources. The suggested sampling locations include 08GS-12-12, 08K-433, 08A-210, 08-0636, and 8-5-9. Sampling locations would have to be assessed because some of the locations (wells or springs) may no longer be accessible.

## 4.3. POTENTIAL FOR URANIUM MIGRATION TO SHALLOW GROUNDWATER SOURCES IN THE EASTERN REGION

This desktop study investigated 20 mines within the Eastern Region with ore bodies beneath the groundwater table, and Groundwater Pathway Assessments were completed for each mine (see Appendices K through R); some mines were grouped together because of proximity and lack of local data. The mines investigated were:

- Grace ISL and Section 13 Mines (Appendix K)
- NE Church Rock, NE Church Rock No. 1, NE Church Rock No.1 East, and NE Church Rock No. 2 Mines (Appendix L)
- Church Rock, Church Rock ISL, and Section 16 Deposit Mines (Appendix M)
- Section 29-Conoco, Crownpoint Section 9, and Crownpoint ISL Mines (Appendix N)
- Nose Rock No. 1 Mine (Appendix O)
- Mariano Lake Mines (Appendix P)
- Black Jack No. 2 Mine (Appendix Q)
- Kermac No. 22, Homestake-Sapin No. 23, Kermac No. 24, and Homestake-Sapin No. 25Mines (Appendix R)

Based on the regional and local uranium geology, hydrogeology, mine histories, and previous mine investigations and surveys, assessments for potential contamination were done using the hazard ranking system. The following subsections summarize the AUMs with elevated, limited, or undefined potentials for contaminating unregulated wells in the vicinity of the mines.

### 4.3.1. Elevated Potential for Uranium Migration to Groundwater Sources

Mines with elevated potential of releasing uranium to groundwater sources in the vicinity of the mines may have combinations of several factors, which may include but are not limited to:

- Uranium concentrations greater than the MCL in groundwater samples collected from downgradient wells
- Shallow depth to water sources relative to depth of ore deposits
- Higher than average radiation at the surface
- Sizeable mass of uranium ore remaining at the mine
- Extensive unreclaimed waste piles
- Hydrologic conditions, such as rainfall, infiltration, aquifer sensitivity, and permeability, conducive to extensive uranium migration
- Residences, schools, or daycare centers are within 200 feet of contamination associated with the mine

The following mines have an elevated potential for releasing uranium to groundwater sources:

- Church Rock, (and to lesser degree) Church Rock ISL, and Section 16 Deposit Mines, because the concentration of uranium in the shallow sample from Becenti Trail Spring downstream of the mines exceeded the MCL. However, the sample collected from well 16T-606 closer to the mines was less than the shallow sample farther downstream, which may suggests a stratigraphic control on uranium migration where uranium is sourced from surface waste at the mines and in the channels of the Rio Puerco from previous dewatering. The lower concentrations in deeper wells may suggest that little uranium is migrating through groundwater pathway. However, the groundwater flow direction is not fully delineated in the area, making attribution of sources difficult.
- Mariano Lake Mine(s), because the concentration of uranium in the sample collected in the spring immediately adjacent to the Mariano Lake Mine in Section 11 exceeded the MCL. However, samples collected at downgradient water sources had uranium concentrations less than the MCL. As a result, it is likely uranium migration is limited. Additionally, the spring sample was collected in 1979 during mining operations and the exceedance may have been influenced by water from mine dewatering entering the spring. Further sampling at the spring and at well 16T-553 adjacent to the Mariano Lake Mine in Section 12 might provide further information on the trend in uranium migration. The moderate aerial radiation signature may indicate that surface water is less of an influence now on uranium migration than groundwater, and the permeability and porosity conditions around the ore deposits may minimize groundwater contamination.

### 4.3.2. Limited Potential for Uranium Migration to Groundwater Sources

Mines with limited potential of releasing uranium to groundwater sources in the vicinity of the mines may exhibit several combinations of factors, which may include but are not limited to:

- Uranium concentrations less than the MCL in groundwater samples collected from downgradient wells
- Shallow depth to water sources relative to depth of ore deposits
- Moderate to low aerial radiation at the surface
- Limited mass of uranium ore remaining at the mine
- Limited or no unreclaimed waste piles
- Mine reclaimed
- Hydrologic conditions, such as rainfall, infiltration, aquifer sensitivity, and permeability, unfavorable to extensive uranium migration
- No water sources within influence of mine
- No residences, schools, or daycare centers are within 200 feet of contamination associated with the mine

The following mines have a limited potential for releasing uranium to groundwater sources:

- Grace ISL and Section 13 Mines, based on the likelihood that very little uranium is leaching from the mines because of the small size of the deposits at depth, the permeability and infiltration rates, and geologic characteristics of the deposits; in addition, little to no surface disturbances would be expected because both mines were briefly tested or mined using ISL techniques, which leaves minimal surface impact. The groundwater sample from well 16K-340, closest to the mines, had a uranium concentration less than the MCL, and wells in the area where uranium was detected in samples at concentrations exceeding the MCL were likely attributably to other mines in the Church Rock area.
- NE Church Rock, NE Church Rock No. 1, NE Church Rock No. 1 East, and NE Church Rock No. 2 Mines have limited potential for releasing uranium to deep groundwater sources because uranium concentrations were orders of magnitude less than the MCL in groundwater samples in two downgradient water sources to the north (sample location 1082213 and well 15T-303). It is also likely that reducing conditions have returned in ore deposits after mine operations were discontinued in 1980s, limiting the dispersion of uranium in solution. The hydrologic setting at the mines is that of limited precipitation, characterized by very slow infiltration rates and moderately slow permeability.
- Nose Rock No. 1 Mine, based on low aerial radiation at surface; hydrologic setting (with limited precipitation), where uranium is unlikely to travel far from mine site because of rainwater chemistry and uranium adsorption properties at shallow depths; uranium concentrations of groundwater samples within 4-mile radius of the mine and downstream of the mine; and lack of water sources in the vicinity of and downgradient of the mine.

- Section 29-Conoco, Crownpoint Section 9, and Crownpoint ISL Mines, based on low aerial radiation at surface; hydrologic setting (with limited precipitation), where uranium is unlikely to travel far from the mine because of rainwater chemistry and uranium adsorption properties at shallow depths; depth of uranium deposits; and lack of water sources in the vicinity of and downgradient of the mine. Although residences and schools are within 200 feet of the mine, no uranium concentrations greater than the MCL have been measured in groundwater samples.
- Black Jack No. 2 Mine, based on minor surface disturbance; insignificant potential for aquifer sensitivity; hydrologic setting (very slow infiltration rates with moderate precipitation and permeability), where uranium is unlikely to travel far from mine site because of rainwater chemistry and uranium adsorption properties at shallow depths; depth of uranium deposits; and lack of water sources in the vicinity of and downgradient of the mine that would be influenced by potential uranium contamination from mine.

### 4.3.3. Undefined Potential for Uranium Migration to Groundwater Sources

Mines with undefined potential of releasing uranium to groundwater sources near the mines may have combinations of several factors, which may include but are not limited to:

- Insufficient analytical results at geographically relevant locations to the mine
- Unknown depth to water sources relative to depth of ore deposits
- Conflicting geological settings that may be conducive to meteoric waters picking up uranium but impeding uranium in solution from large-scale migration
- Aerial radiation greater than background levels at the surface
- Possibly large or unknown mass of uranium ore remaining at the mine

The following mines have undefined potential for releasing uranium to water sources:

- NE Church Rock, NE Church Rock No. 1, NE Church Rock No. 1 East, and NE Church Rock No. 2 Mines have undefined potential for releasing uranium to shallow water sources through the surface water pathway because local radiation levels suggest significant uranium concentrations in the surface that could migrate, even though the hydrologic setting has limited precipitation, characterized by very slow infiltration rates and moderately slow permeability. Ore deposits with low organics suggest the potential for uranium to be transported farther distances if oxidizing groundwater introduced. Elevated uranium concentrations exceeding the MCL were detected in groundwater samples in three downstream water sources (sample location 1082366, well 16-4-10, and Becenti Trail Spring); these three locations may be upgradient of the mines, if wells are deep and regional dip influences deep groundwater, or may be downgradient if they are shallow water sources and influenced by surface runoff. Sample location for 1082366 and well 16-4-10 are on adjacent drainages, at elevations above the Pipeline Arroyo with unknown well depths. Shallow Becenti Trail Spring is downstream of NE Church Rock Mines, as well as Church Rock Mine, Church Rock ISL Mine, Section 13 Mine and the Church Rock Mill, suggesting cumulative sources for uranium to leach into surface water.

- Kermac No. 22, No. 24, and No. 25 Mines and Homestake Sapin Mine No. 23, because regional aerial radiation levels suggest remaining uranium could migrate although the hydrologic setting is that of limited precipitation, percentage of the ore bodies have been removed is unknown, and there is a lack of analytical data from water sources directly attributable to the Kermac No. 22, No. 24, and No. 25 Mines and Homestake Sapin Mine No. 23. Elevated uranium concentrations in water samples collected upstream, in adjacent drainage systems, and downstream suggest uranium leaching is common in this area, consistent with extensive uranium mineralization in the mining district. The percentage, if any, of the measured uranium concentrations in water samples that resulted from leaching from the Kermac No. 22, No. 24, and No. 25 Mines and Homestake Sapin Mine No. 23 is difficult to determine because while geological conditions may impede leaching from the area, extensive volumes of uranium remaining in the mines may allow some uranium in solution to migrate downstream, and no water samples have been collected adjacent to or immediately downstream of each of the mines.

## 4.4. POSSIBLE SAMPLING FOR FURTHER INVESTIGATION IN THE EASTERN REGION

Based on either the elevated potential or undefined potential for uranium to migrate to water sources, additional sampling and investigation may be warranted for some of the 31 AUMs in the Eastern Region discussed in this GPAR. These mines include the (1) Church Rock, Church Rock ISL, and Section 16 Deposit Mines for their elevated potential to release uranium to nearby shallow water sources in the Church Rock area; (2) the NE Church Rock Mines for their undefined potential to release uranium into shallow water sources in the Church Rock area; (3) the Mariano Lake Mines for their elevated potential to release uranium into water sources in Mariano Lake area; and (4) the Kermac No. 22, No. 24, and No. 25 Mines and Homestake Sapin Mine No. 23 for their undefined potential to release uranium into groundwater and shallow water sources in the Ambrosia Lake area.

### 4.4.1. Church Rock Area Sampling

Additional measurement of depths to groundwater and collection of samples at and downstream of Church Rock, Church Rock ISL, and Section 16 Deposit Mines and the NE Church Rock Mines may provide further confirmation on the direction of groundwater flow in the area and the potential for uranium migration from the mines. The following wells are suggested for measuring well and groundwater depths and determining groundwater flow directions in shallow and deep aquifers:

- Wells 14K-313, KM CR II G-1, and 15T-303 (drilled into Gallup Sandstone aquifer)
- Wells 16T-534, 16T-513, and any other wells drilled into the Westwater Canyon Member
- Wells 16T-510, 16T-606, and any other wells drilled into the Dakota Formation
- Sample location 1082366 (unknown aquifer and depth)
- Shallow water sources 16K-340 and Becenti Trail Spring

Analysis of groundwater samples from the wells listed above may help to illustrate the groundwater conditions at, downgradient, and downstream of the mines. The groundwater flow directions will help determine which sources are plausible (i.e., deep aquifer migration to the north and/or shallow or surface migration to the south or all groundwater flow to the southwest). Sampling locations would have to be assessed because some of the sample locations (wells or springs) may no longer be accessible.

### 4.4.2. Mariano Lake Area Sampling

Collection of samples at the spring and well adjacent to the Mariano Lake Mines (sampling location for sample 1082369 and well 16T-553, respectively) may provide further confirmation on the potential for uranium migration from these sources. Collection of additional samples from municipal wells 16T-595 and 16T-696 and Chapter House Well (16K-628) at the same time will help to illustrate the downgradient distribution of uranium in groundwater. Sampling locations would have to be assessed because some of the sample locations (wells or springs) may no longer be accessible.

### 4.4.3. Ambrosia Lake Area Sampling

Sampling at downgradient wells to Kermac No. 22, No. 24, and No. 25 Mines and Homestake Sapin Mine No. 23 may provide further confirmation on the potential for uranium migration from these sources. The suggested sampling locations include KARMAC 003, KARMAC 004, KARMAC 005, and Sabre Pinon, and additional sampling at sample location 1081739. Sampling locations would have to be assessed because some of the sample locations (wells or springs) may no longer be accessible.

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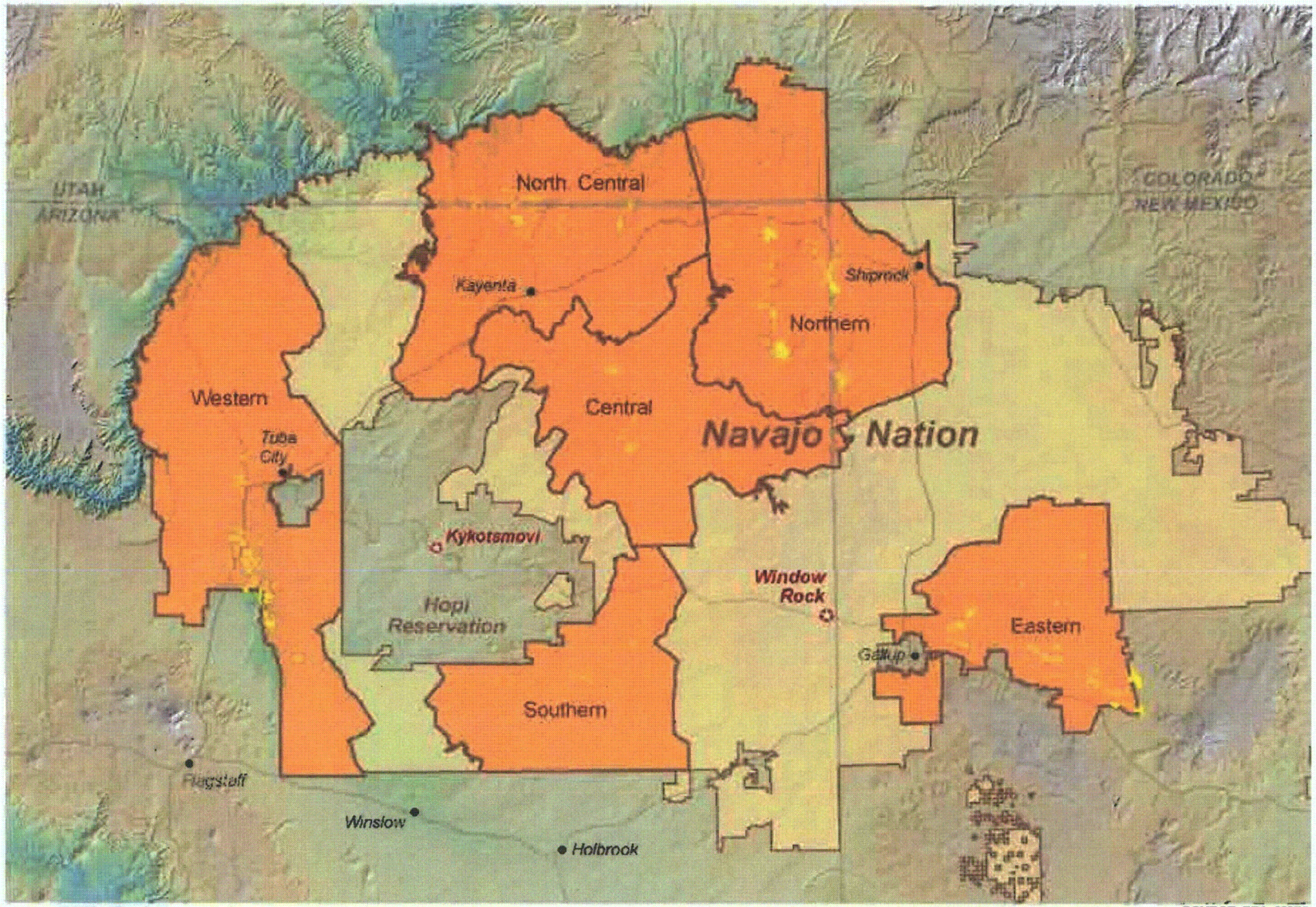
# Figures




SOURCE: EPA, 2007C

**LEGEND:**

URANIUM DEPOSITS

N

NOT TO SCALE

ERRG

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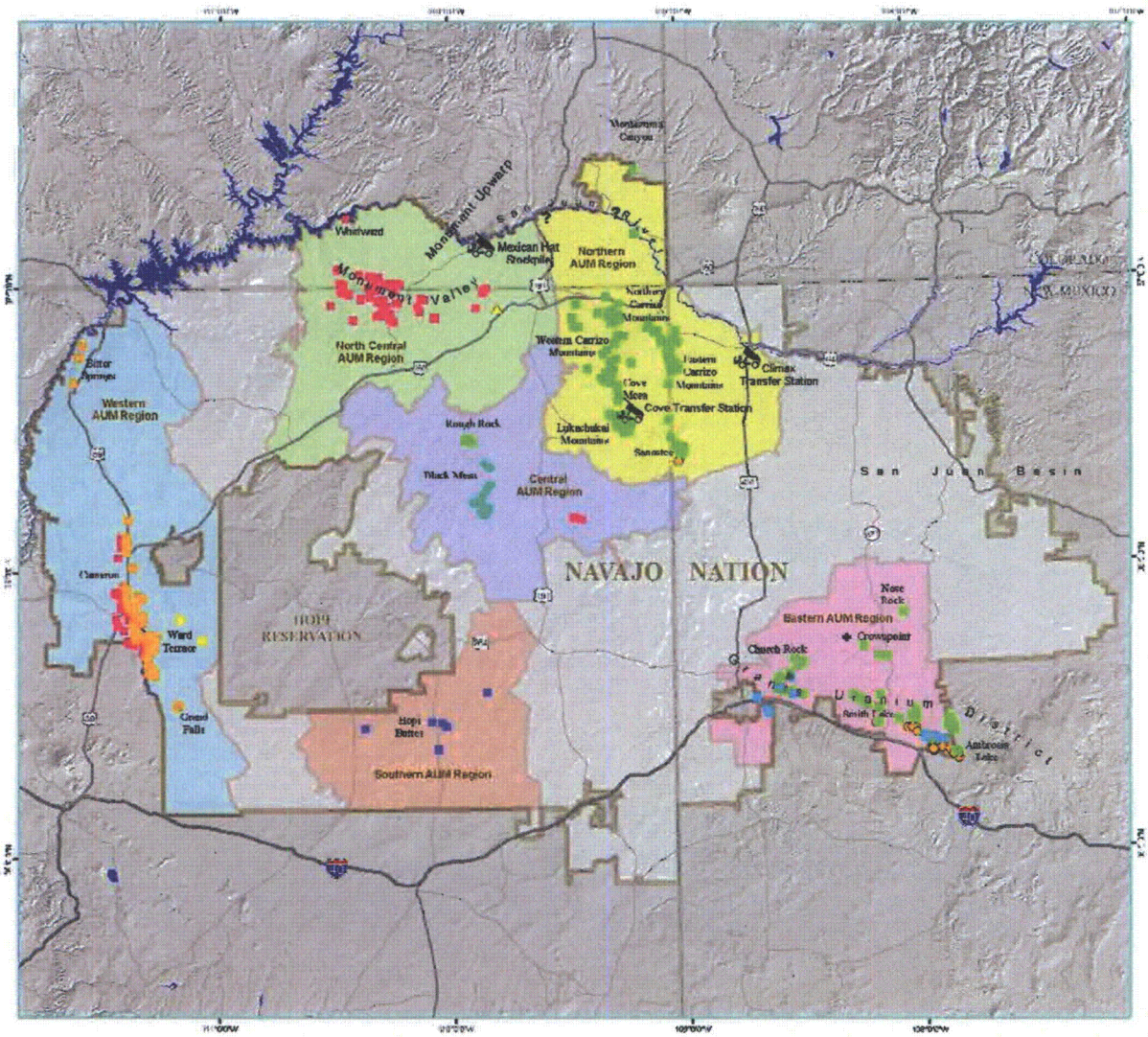
|---|---|---|---|---|---|---|
| CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 3-31-09 | NAVAJO NATION REGIONAL MAP | | | | |
| | CHECKED BY: RLM 3-31-09 | | | | | |
| LOCATION: NAVAJO NATION | P.E.P.G.: – | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 1 |

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




Legend

Abandoned Uranium Mine Host Rock

- Tertiary Bidahochi Formation
- Cretaceous Dakota Sandstone
- Cretaceous Toreva Formation
- Cretaceous Point Lookout Sandstone
- Cretaceous Dakota Sandstone and Jurassic Morrison Formation
- Jurassic Morrison Formation
- Jurassic Kayenta
- Jurassic Navajo
- Jurassic Todilto Limestone
- Triassic Petrified Forest Member, Chinle Formation
- Triassic Shinarump Member, Chinle Formation
- Transfer Station
- ? Unknown

N

0 40

APPROXIMATE SCALE IN MILES

Source

Abandoned Uranium Mine locations and host rock types were produced from Navajo Abandoned Mine Lands Reclamation Program maps and sources by William L. Chenoweth, Virginia McLemore, US Atomic Energy Commission/US Department of Energy Documents, and other sources.

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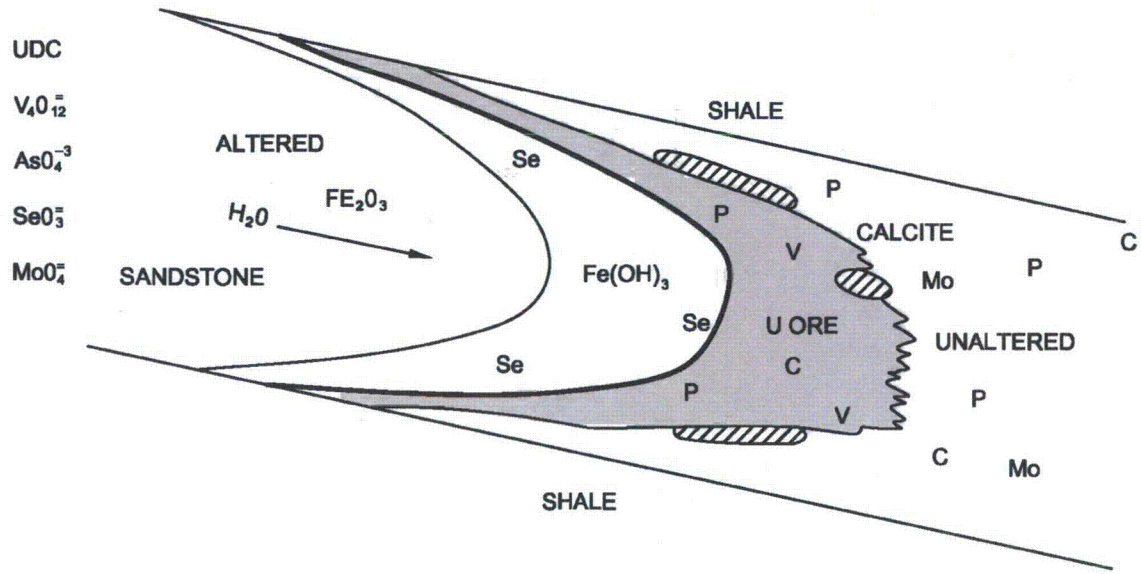
| CLIENT: | DESIGNED BY: | ABANDONED URANIUM MINES SHOWN BY GEOLOGIC HOST ROCK FORMATION | | | | |
|---|---|---|---|---|---|---|
| U.S. ENVIRONMENTAL PROTECTION AGENCY | RDB 5-26-09 | | | | | |
| LOCATION: | CHECKED BY: RLM 5-26-09 | | | | | |
| NAVAJO NATION | P.S.P.G.: - | ERRG PROJECT NO. 26-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 2 |

P:\2008_Projects\26-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Abandoned Uranium Mines Shown by Geologic Host Rock Formation.dwg




**LEGEND:**

| | |
|---|---|
| $AsO_4^{-3}$ | ARSENIC IN SOLUTION |
| C | CARBONACEOUS MATERIAL |
| P | PYRITE |
| UDC | URANYL DICARBONITE |
| V | VANADIUM MINERALIZATION |
| $V_4O_{12}^{=}$ | VANADIUM IN SOLUTION |
| Se | SELENIUM MINERALIZATION |
| $SeO_3^{=}$ | SELENIUM IN SOLUTION |
| Mo | MOLYBDENUM MINERALIZATION |
| $MoO_4^{=}$ | MOLYBDENUM IN SOLUTION |
| (hatched) | CALCITE |
| U | URANIUM |

MODIFIED FROM: DEVOTO, R.H., 1978

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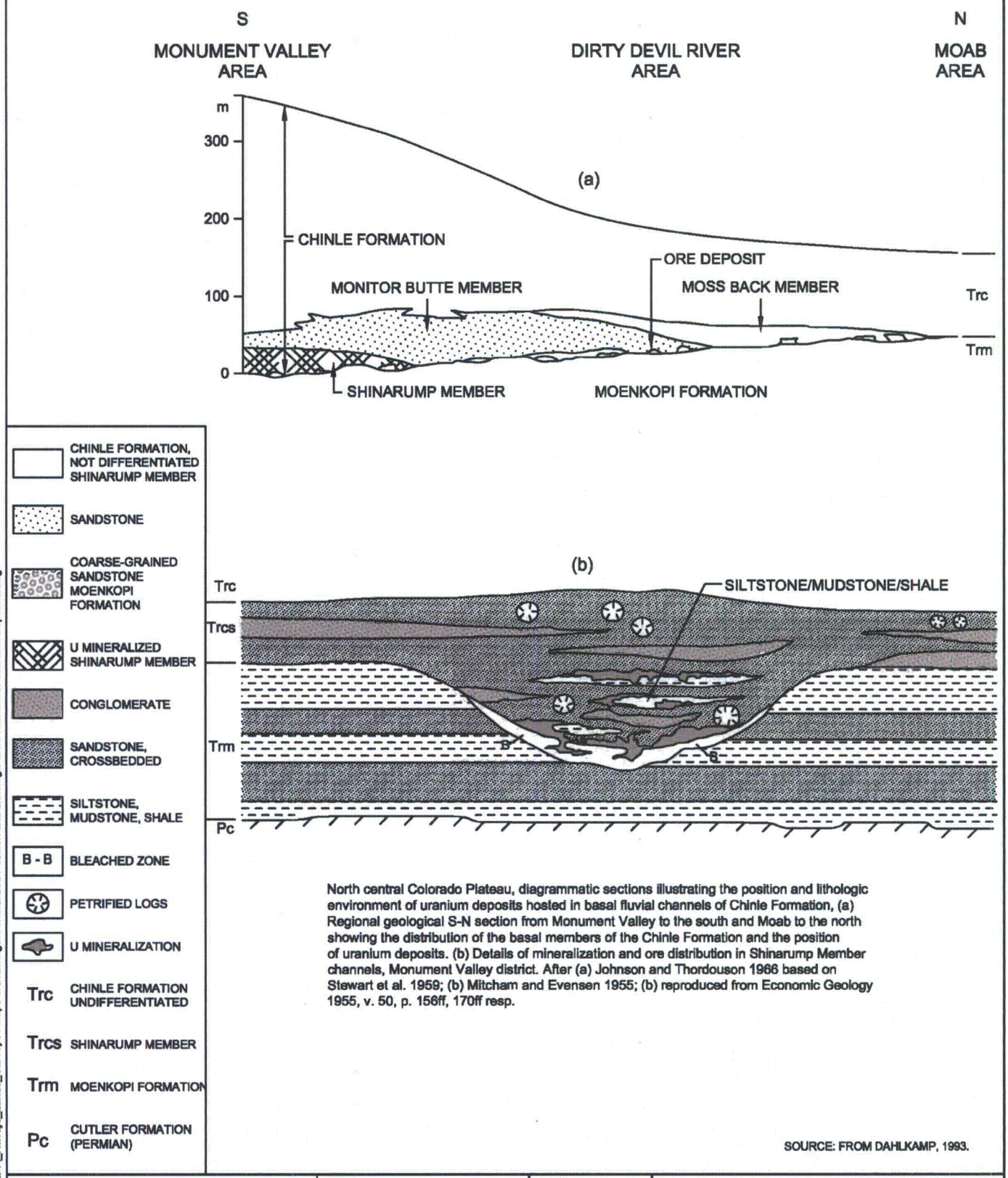
| CLIENT: | DESIGNED BY: | URANIUM DEPOSITION IN SANDSTONE AT OXIDATION-REDUCTION INTERFACE | | | | |
|---|---|---|---|---|---|---|
| U.S. ENVIRONMENTAL PROTECTION AGENCY | RDB 5-26-09 | | | | | |
| | CHECKED BY: RLM 5-26-09 | | | | | |
| LOCATION: NAVAJO NATION | P.E/P.G.: – | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 3 |

N:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Uranium Deposition in Sandstone.dwg




North central Colorado Plateau, diagrammatic sections illustrating the position and lithologic environment of uranium deposits hosted in basal fluvial channels of Chinle Formation, (a) Regional geological S-N section from Monument Valley to the south and Moab to the north showing the distribution of the basal members of the Chinle Formation and the position of uranium deposits. (b) Details of mineralization and ore distribution in Shinarump Member channels, Monument Valley district. After (a) Johnson and Thordouson 1966 based on Stewart et al. 1959; (b) Mitcham and Evensen 1955; (b) reproduced from Economic Geology 1955, v. 50, p. 156ff, 170ff resp.

SOURCE: FROM DAHLKAMP, 1993.

P:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Generalized Position and Lithologic Environment of Uranium Deposits.dwg

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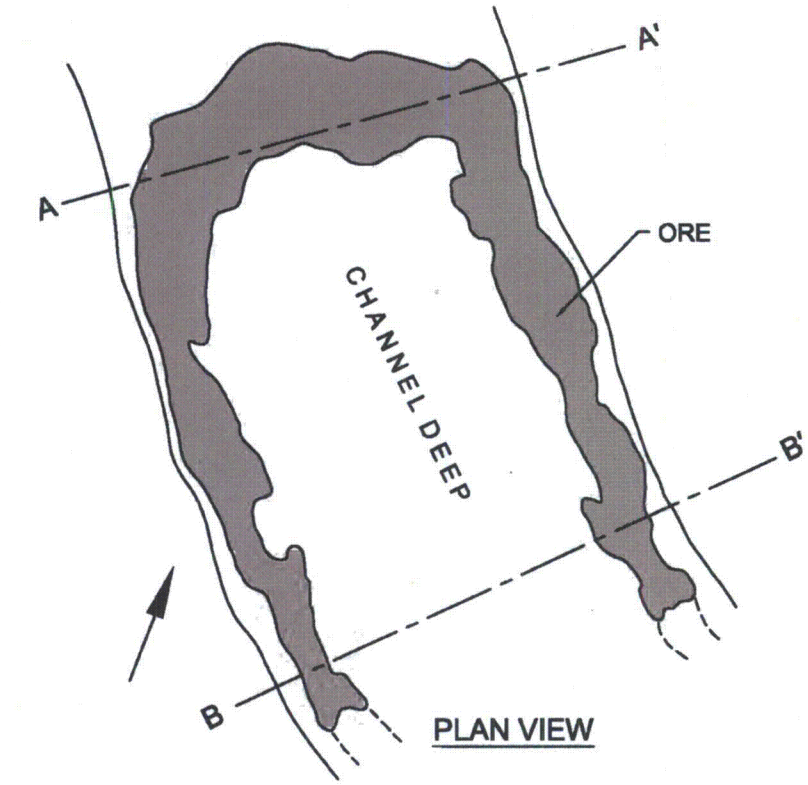
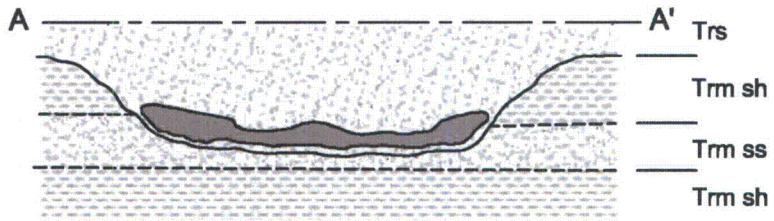
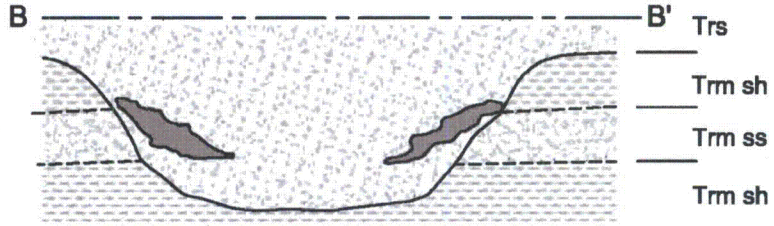
| CLIENT: | DESIGNED BY: | GENERALIZED POSITION AND LITHOLOGIC ENVIRONMENT OF URANIUM DEPOSITS HOSTED IN CHINLE FORMATION | | | | |
|---|---|---|---|---|---|---|
| U.S. ENVIRONMENTAL PROTECTION AGENCY | VZC 3-26-09 | | | | | |
| | CHECKED BY: RLM 3-26-09 | | | | | |
| LOCATION: MONUMENT VALLEY AREA, NAVAJO NATION | P.E/P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 4 |




CROSS SECTION A-A'




CROSS SECTION B-B'

Trs-Shinarump Member, Chinle Formation; Trm sh-Moenkopi Formation, shale; Trm ss-Moenkopi Formation, sandstone. Geology by K.G. Hatfield, 1961.

NOT TO SCALE

SOURCE: FROM W.L. CHENOWETH, 1997

P:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Plan and Cross-sections of Ore Bodies.dwg

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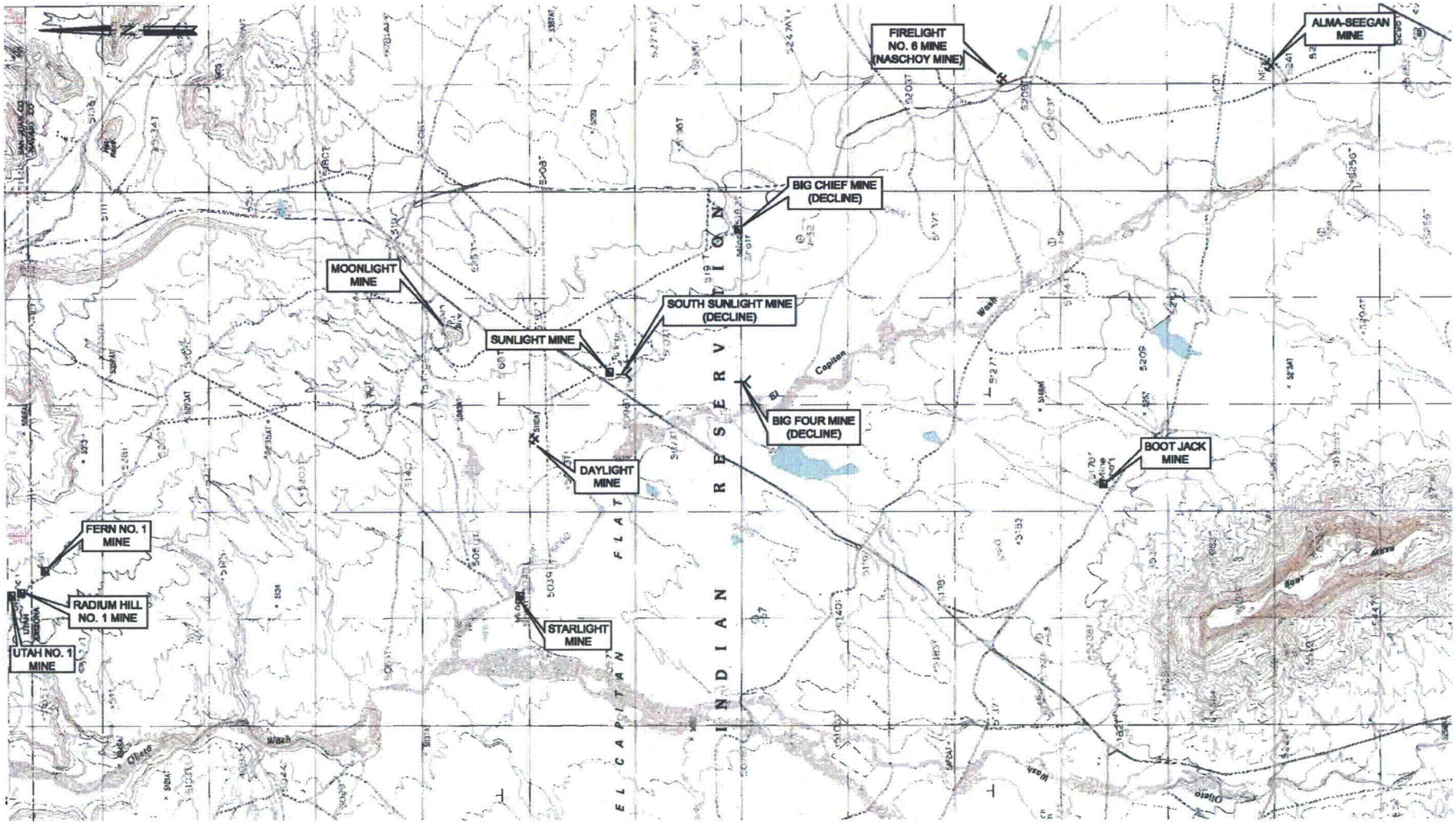
| CLIENT: | DESIGNED BY: | PLAN VIEW AND CROSS SECTIONS OF ORE BODIES AT STARLIGHT EAST MINE | | | | |
|---|---|---|---|---|---|---|
| U.S. ENVIRONMENTAL PROTECTION AGENCY | VZC 3-26-09 | | | | | |
| LOCATION: | CHECKED BY: RLM 3-26-09 | | | | | |
| STARLIGHT MINE, ARIZONA NAVAJO NATION | P.E/P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 5 |




**LEGEND:**

- MINE
- MINE DECLINE
- MINE ADIT/SHAFT

0 3000
APPROXIMATE SCALE IN FEET

SOURCE: 7.5' USGS QUADRANGLE OF BOOT MESA, AZ–UTAH, DATED: 1968

| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |

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CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

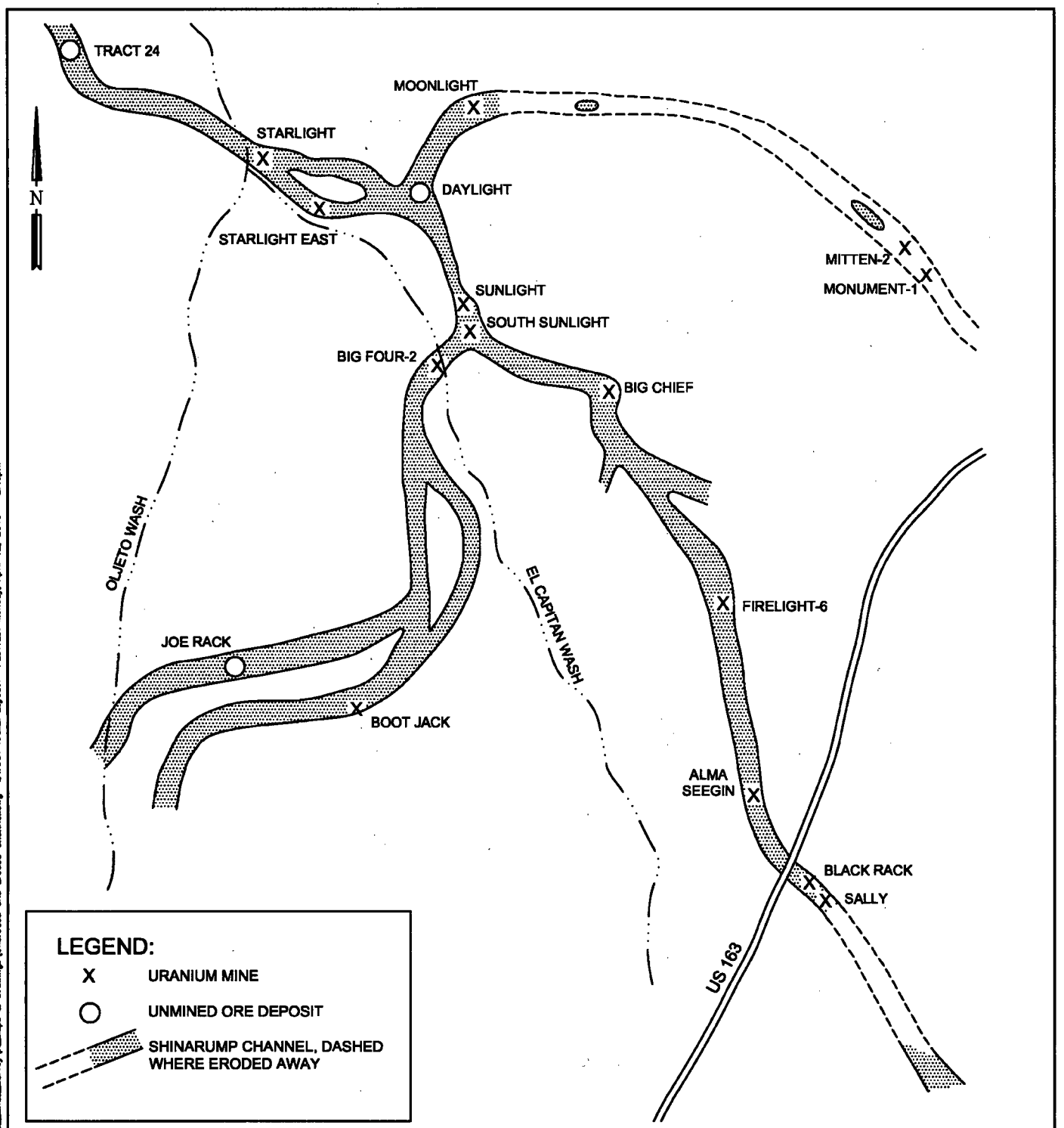
LOCATION: MONUMENT VALLEY AREA, ARIZONA NAVAJO NATION

DESIGNED BY: RDB 5-18-09
CHECKED BY: RLM 5-19-09
P.E./P.G.: –

# TOPOGRAPHIC MAP WITH MINE LOCATIONS IN MONUMENT VALLEY AREA

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | SHEET NO. |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 6 |

P:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\4_Maps & Drawings\Location of Mines.dwg




Map of the El Capitan Wash Area, Navajo County, Arizona showing Shinarump channels and uranium deposits. After Young and others (1964).

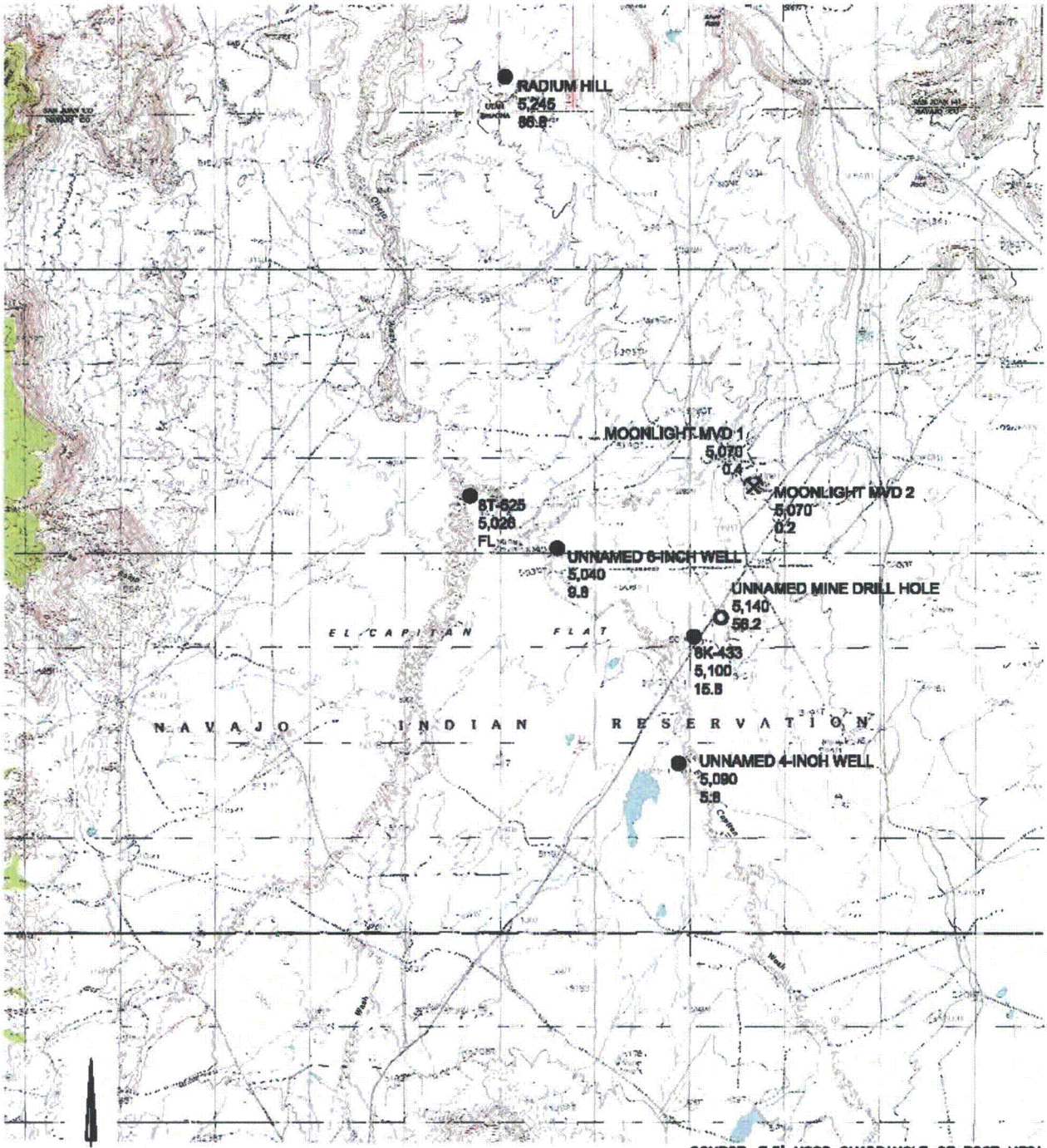
0 1

APPROXIMATE SCALE IN MILES

SOURCE: FROM W.L. CHENOWETH, 1997a

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: VZC 3-25-10 | UNERODED AND ERODED CHANNEL DEPOSITS OF EL CAPITAN WASH AREA | | | | |
| | LOCATION: MONUMENT VALLEY AREA, NAVAJO NATION | CHECKED BY: RLM 3-25-10 | | | | | |
| | | P.E/P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 7 |

FILE NAME: H:\projects\2008 Projects\28-017_EPA_Navajo_Lands_Survey\Maps & Drawings\Uneroded and Eroded Channel.dwg LAYOUT NAME: Layout1 PLOTTED: Monday, April 12, 2010 - 2:45pm




N

0 1

APPROXIMATE SCALE IN MILES

**LEGEND:**

- ● WELL
- ○ MINE DRILL HOLE
- ⚒ OPEN PIT MINE (DEPTH TO WATER MEASURED THROUGH SHALLOW WELL)
- 6K-433 SITE NAME
- 5,100 ALTITUDE OF LAND SURFACE IN FEET ABOVE SEA LEVEL
- 15.8 DEPTH TO GROUND WATER
- FL FLOWING

SOURCE: 7.5' USGS QUADRANGLE OF BOOT MESA, ARIZONA–UTAH, DATED: 1988
DATA SOURCE: LONGSWORTH, 1994

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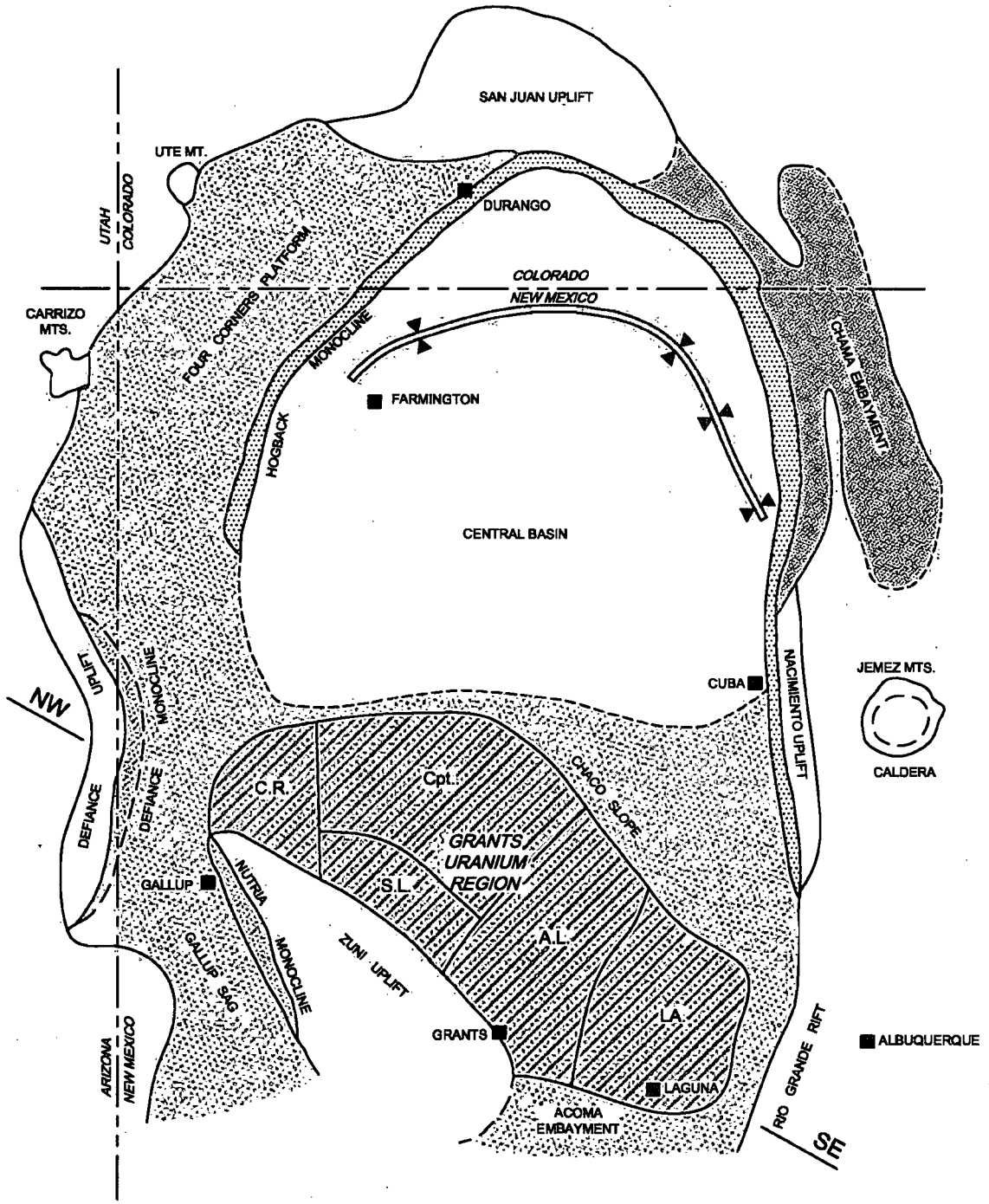
| CLIENT: | DESIGNED BY: | DEPTH TO WATER FOR SELECTED WELLS IN THE MONUMENT VALLEY AREA | | | | |
|---|---|---|---|---|---|---|
| U.S. ENVIRONMENTAL PROTECTION AGENCY | RDB 3-25-10 | | | | | |
| LOCATION: | CHECKED BY: RLM 3-25-10 | | | | | |
| MONUMENT VALLEY AREA, NAVAJO NATION | P.E.P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 8 |

FILE NAME: N:\projects\2028 Projects\28-017_EPA_Navajo_Lands_Survey\Maps & Drawings\Depth to Water for Selected Wells 2.dwg LAYOUT NAME: Layout1 PLOTTED: Monday, April 12, 2010 - 3:17pm




INDIVIDUAL DISTRICTS OF THE URANIUM REGION ARE OUTLINED. PRINCIPAL DISTRICTS: C.R.=CHURCH ROCK; Cpt.=CROWNPOINT; S.L.=SMITH LAKE - MARIANO LAKE; A.L.=AMBROSIA LAKE; LA.=LAGUNA. (AFTER SANTOS AND TURNER PETERSON 1986 BASED ON KELLY 1951) (REPRINTED BY PERMISSION OF AAPG).

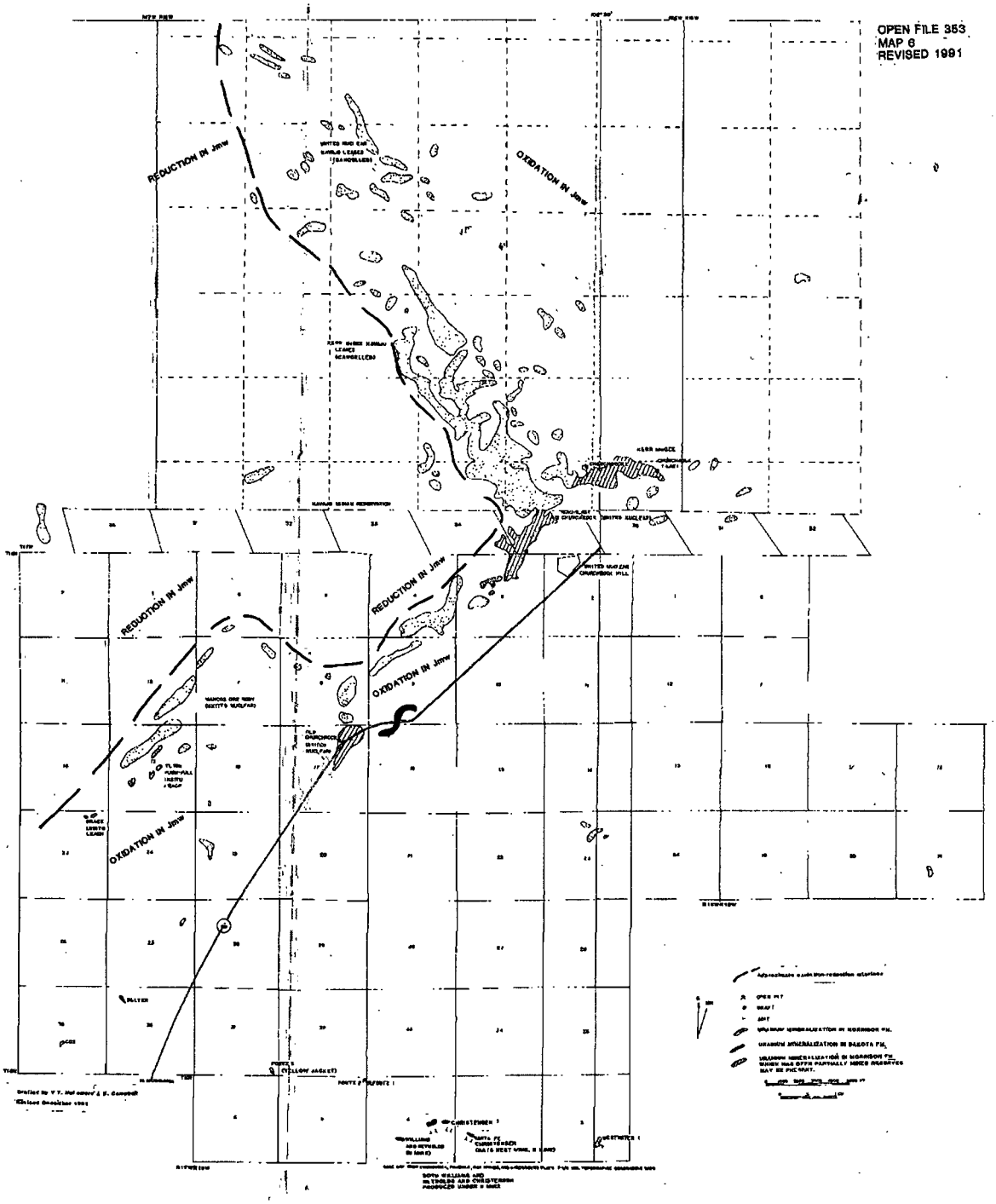
0 40

APPROXIMATE SCALE IN KM.

FROM DAHLKAMP, 1993

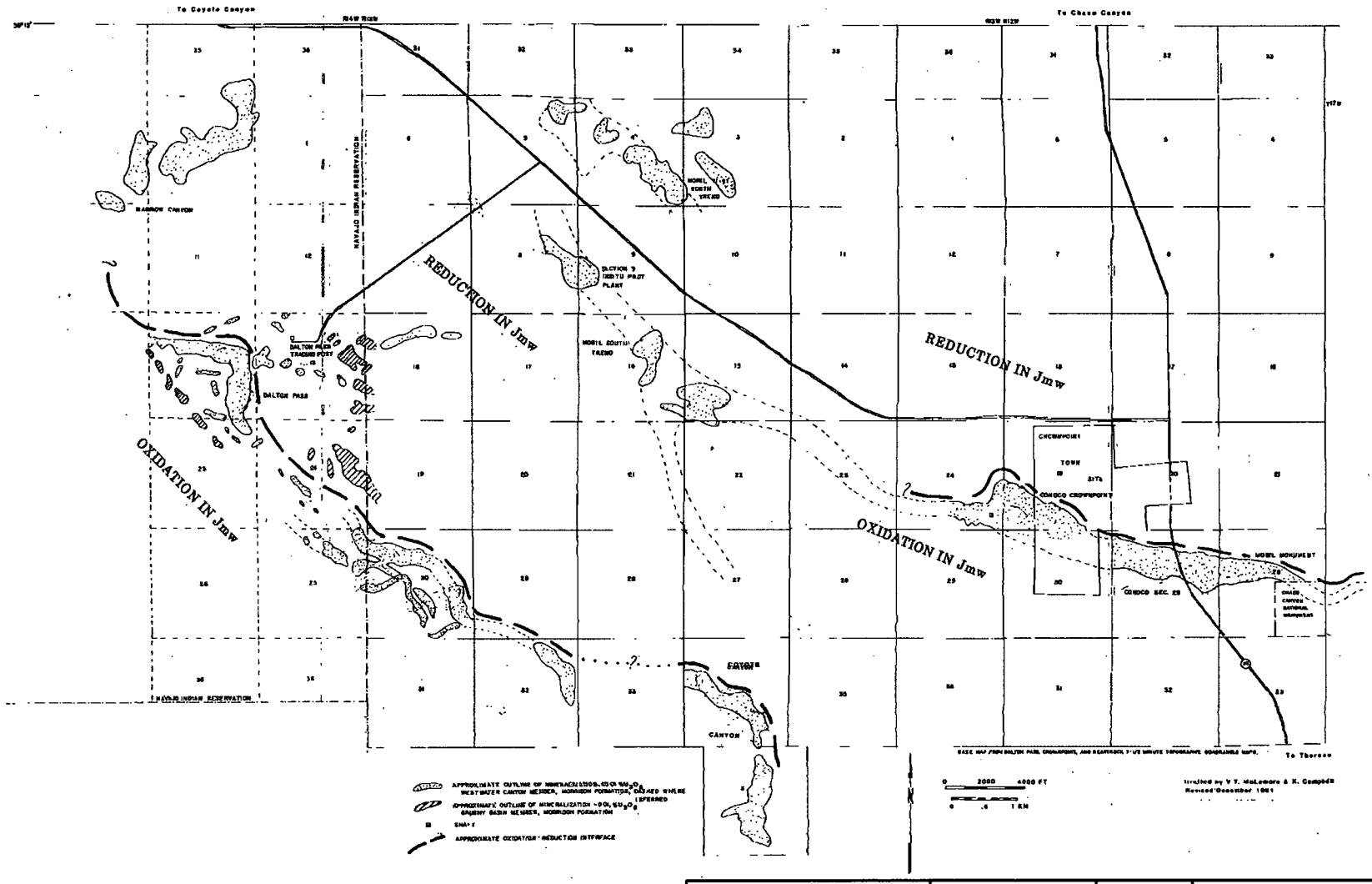
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: VZC 3-25-10 | MINING DISTRICTS OF GRANTS URANIUM REGION | | | | | |
| | LOCATION: NEW MEXICO, NAVAJO NATION | CHECKED BY: RLM 3-25-10 | | | | | | |
| | | P.E/P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 9 | |

FILE NAME: M:\projects\2008 Projects\28-017_EPA_Navajo_Lands_Survey\N_Maps & Drawings\Grants Uranium Region.dwg LAYOUT NAME: Layout1 PLOTTED: Monday, April 12, 2010 - 3:19pm



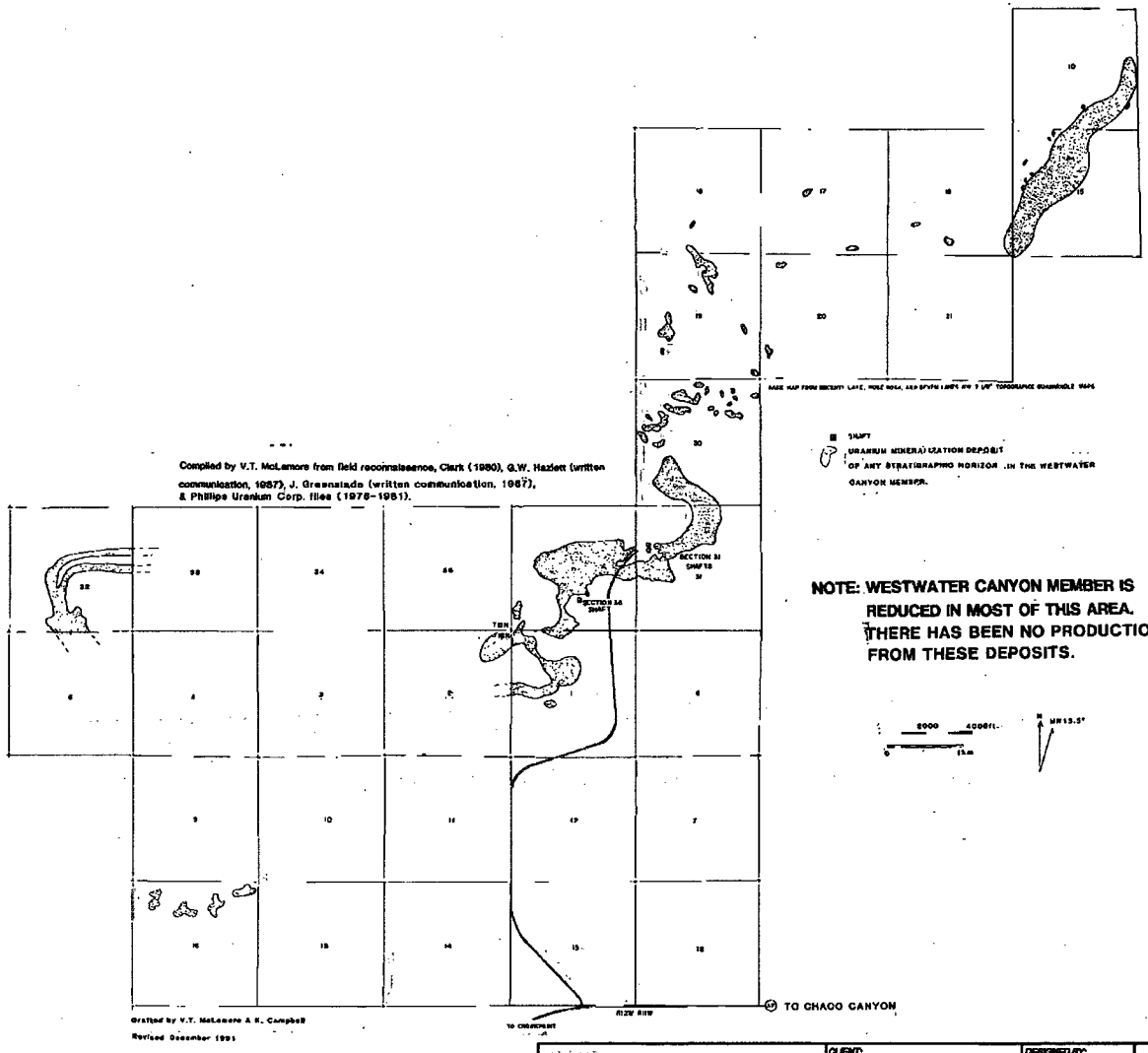

TAKEN FROM McLEMORE AND CHENOWETH, 1991

| | | | | |
|---|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 4-7-10 | URANIUM DEPOSITS AND MINES IN CHURCH ROCK DISTRICT, GRANTS URANIUM REGION, McKINLEY COUNTY, NEW MEXICO | |
| | LOCATION: NEW MEXICO, NAVAJO NATION | CHECKED BY: RLM 4-7-10 | | |
| | | P.E.P.G.: – | ERRG PROJECT NO. 28-017 | REVISION NO. 0 / SHEET 1 OF 1 / FIG NO. 10 |




TAKEN FROM McLEMORE AND CHENOWETH, 1991

| | | | |
|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0760 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 4-7-10 | URANIUM DEPOSITS AND MINES IN CROWNPOINT DISTRICT, GRANTS URANIUM REGION, McKINLEY COUNTY, NEW MEXICO |
| | LOCATION: NEW MEXICO, NAVAJO NATION | CHECKED BY: RLM 4-7-10 | |
| | | P.E.P.G.: – | ERRG PROJECT NO. 28-017 / REVISION NO. 0 / SHEET 1 OF 1 / FIG NO. 11 |




TAKEN FROM McLEMORE AND CHENOWETH, 1991

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(925) 969-0750
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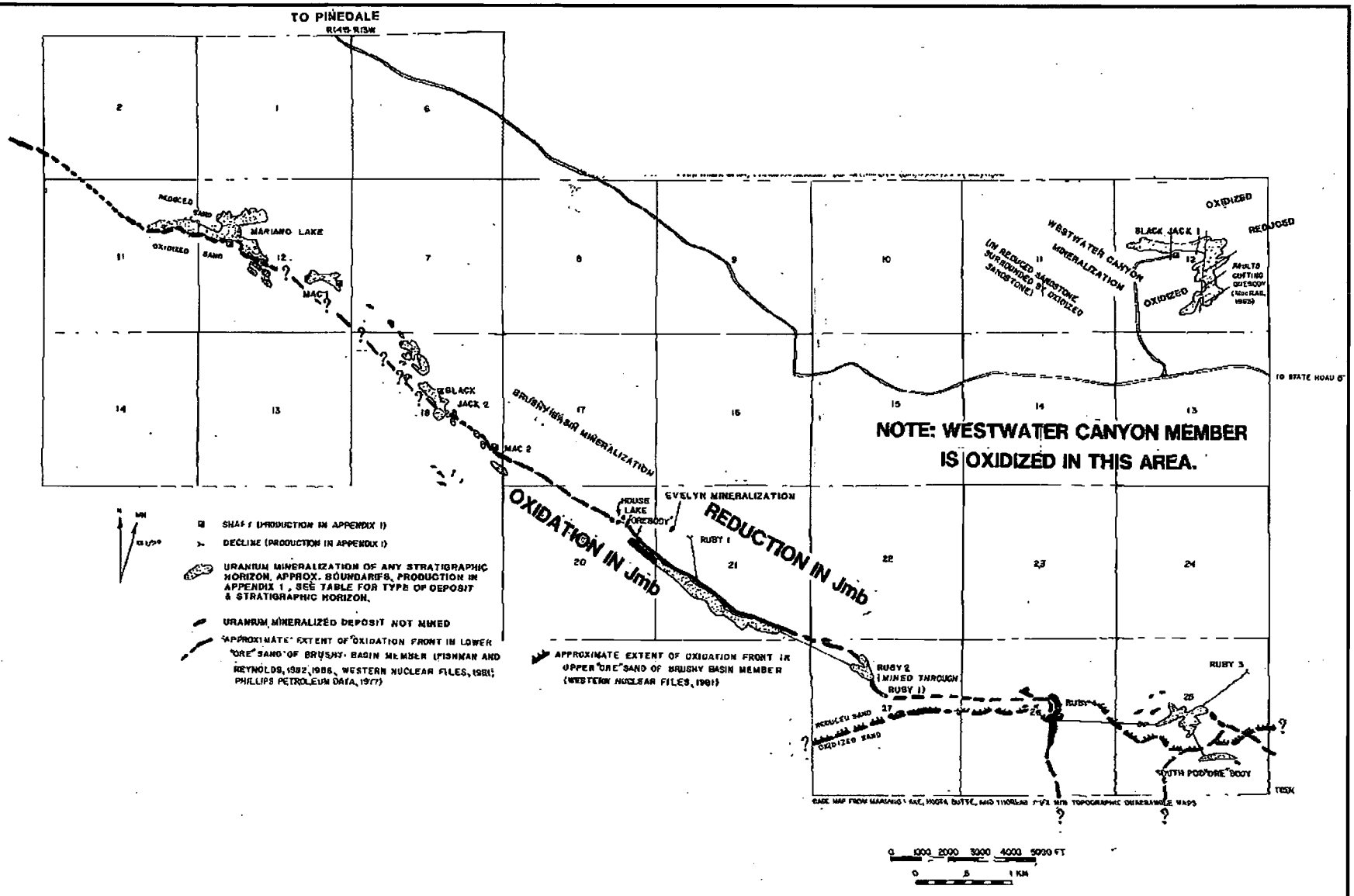
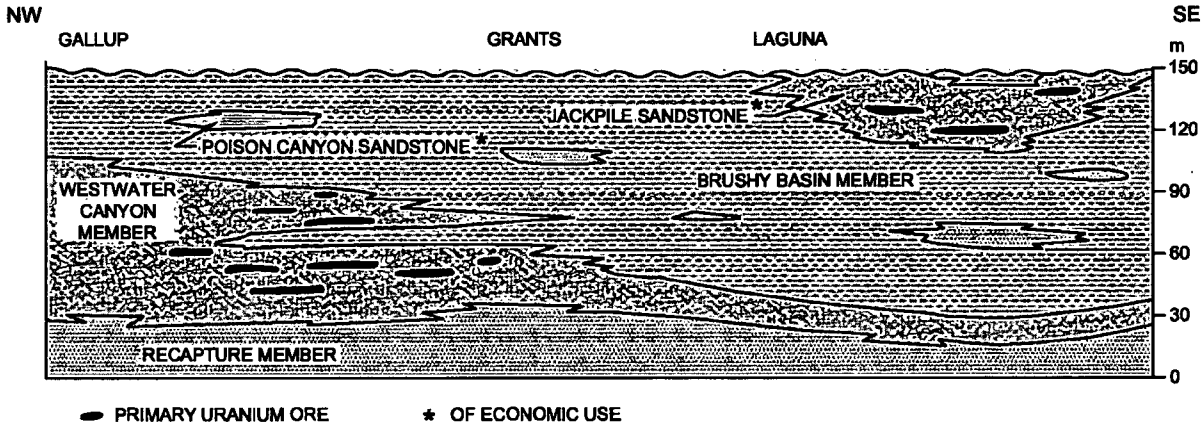
| | | | |
|---|---|---|---|
| CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 4-7-10 | URANIUM DEPOSITS AND MINES IN NOSE ROCK AREA, GRANTS URANIUM REGION, McKINLEY COUNTY, NEW MEXICO | |
| LOCATION: NEW MEXICO, NAVAJO NATION | CHECKED BY: RLM 4-7-10 | | |
| | P.E.P.G.: – | ERRG PROJECT NO. 28-017 | REVISION NO. 0 |
| | | SHEET 1 OF 1 | FIG NO. 12 |




TAKEN FROM McLEMORE AND CHENOWETH, 1991

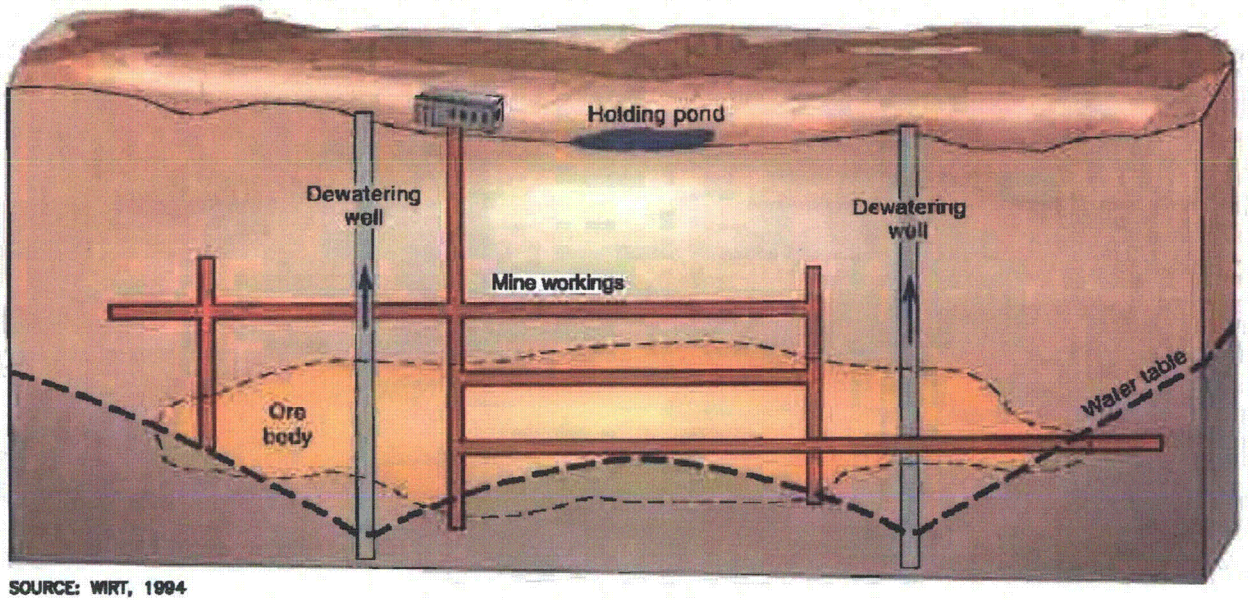
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 4-7-10 | URANIUM DEPOSITS AND MINES IN SMITH LAKE DISTRICT, GRANTS URANIUM REGION, McKINLEY COUNTY, NEW MEXICO | | | | | |
| | LOCATION: NEW MEXICO, NAVAJO NATION | CHECKED BY: RLM 4-7-10 | | | | | | |
| | | P.E.P.G.: – | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 13 | |




GRANTS URANIUM REGION: SCHEMATIC NW-SE STRATIGRAPHIC SECTION OF THE MORRISON FORMATION.
(AFTER TURNER-PETERSON AND FRISHMAN 1986, BASED ON HILPERT 1963)(REPRINTED BY PERMISSION OF AAPG)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 3-25-10 | GRANTS URANIUM REGION STRATIGRAPHIC SECTION | | | | | |
| | LOCATION: GRANTS URANIUM REGION, NAVAJO NATION | CHECKED BY: RLM 3-25-10 | | | | | | |
| | | P.E/P.G.: – | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 14 | |

FILE NAME: H:\projects\2008 Projects\28-017_EPA_Navajo_Lands_Survey\Vi_Maps & Drawings\Stratigraphic Section.dwg LAYOUT NAME: Layout1 PLOTTED: Monday, April 12, 2010 - 3:22pm

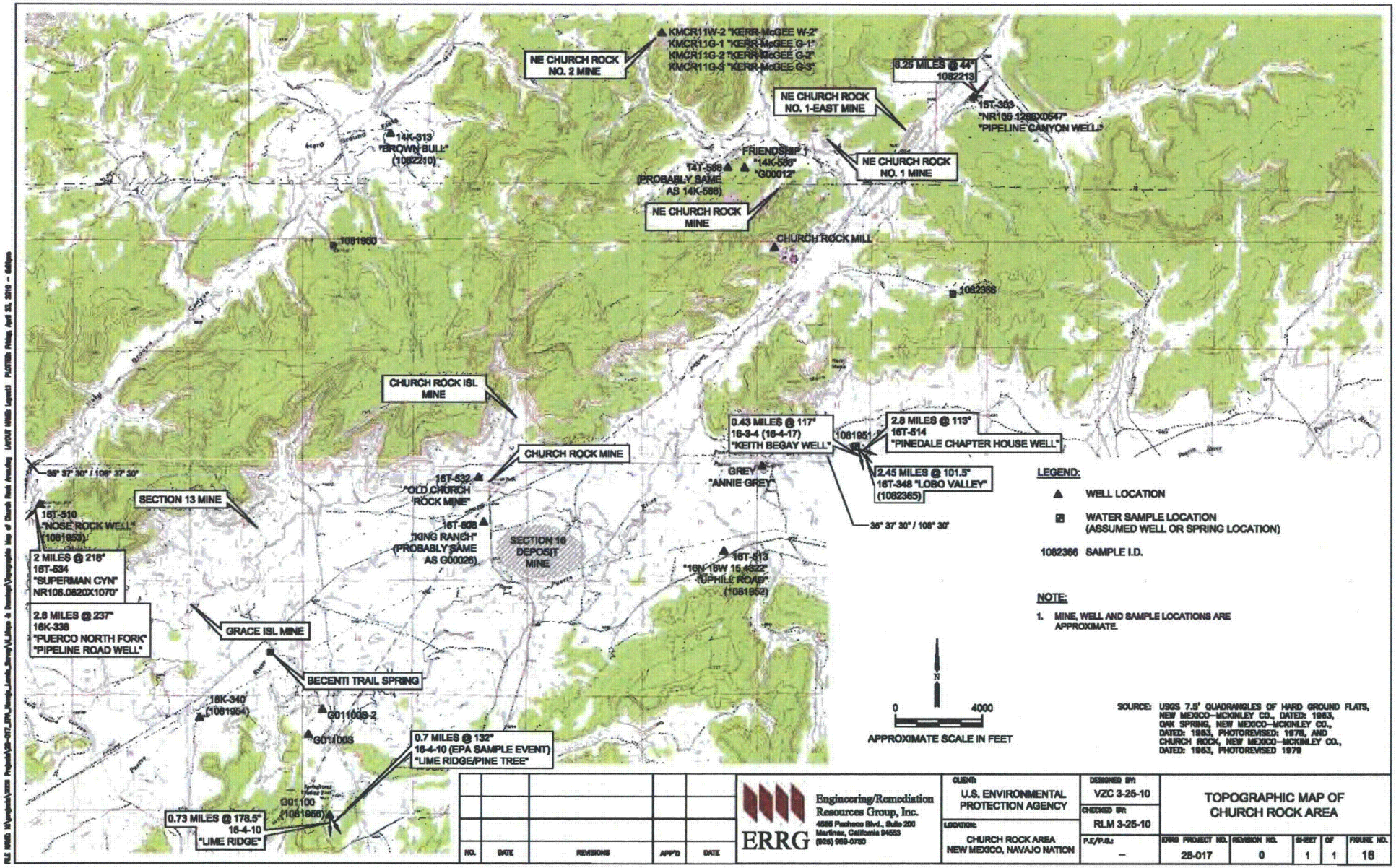



SOURCE: WIRT, 1994

MINE DEWATERING: WATER IS PUMPED THROUGH LARGE WELLS TO THE SURFACE IN ORDER TO LOWER THE WATER TABLE SURROUNDING THE UNDERGROUND TUNNELS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ERRG Engineering/Remediation Resources Group, Inc. 4585 Pacheco Blvd., Suite 200 Martinez, California 94553 (925) 969-0750 | CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: RDB 7-7-09 | MINE DEWATERING | | | | | |
| | LOCATION: MONUMENT VALLEY AREA, NAVAJO NATION | CHECKED BY: RLM 7-7-09 | | | | | | |
| | | P.E/P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 | SHEET 1 | OF 1 | FIG NO. 15 | |

N:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\N Maps & Drawings\Mine Dewatering.dwg




| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |

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4585 Pacheco Blvd., Suite 200
Martinez, California 94553
(925) 969-0780

CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

LOCATION: CHURCH ROCK AREA NEW MEXICO, NAVAJO NATION

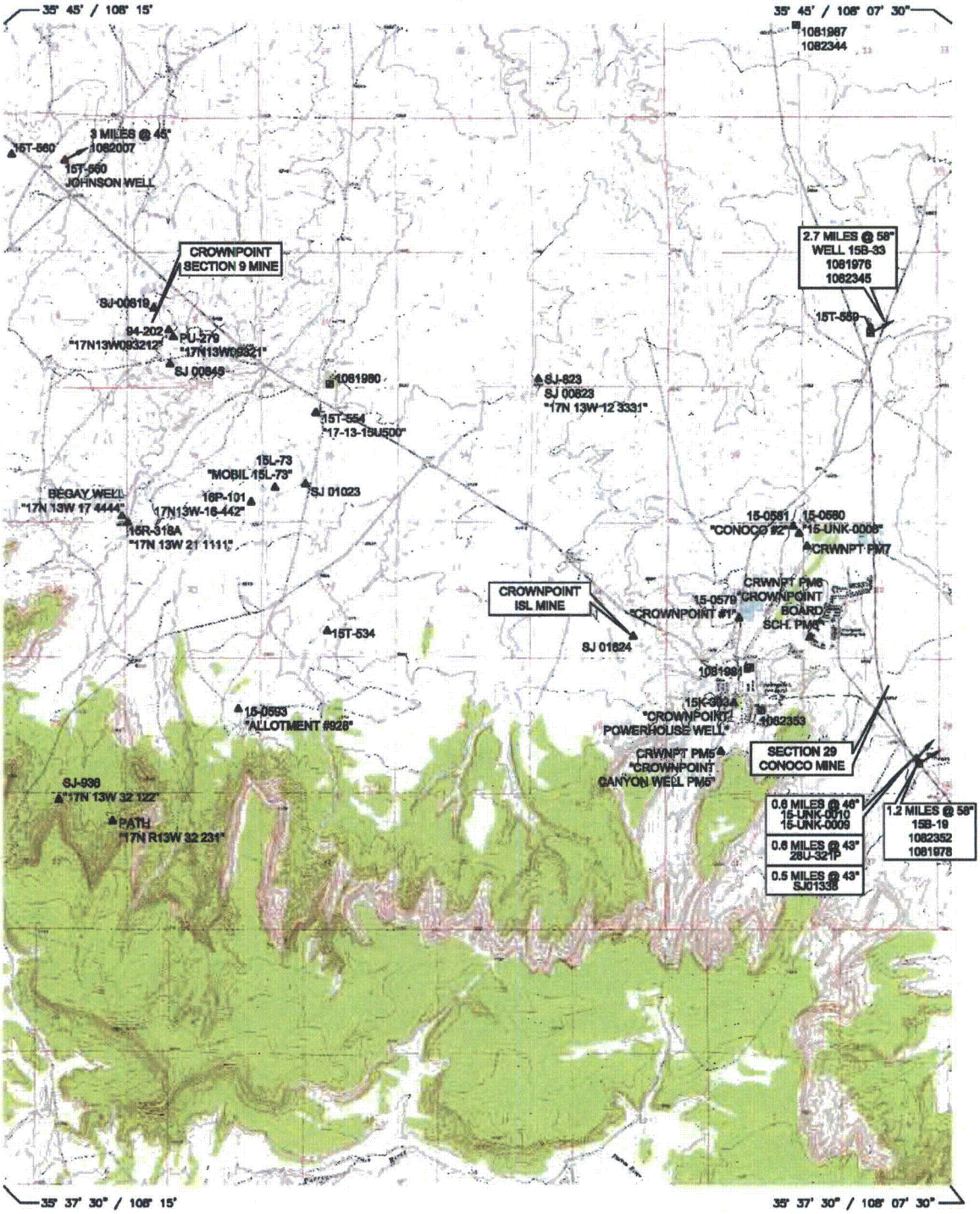
DESIGNED BY: VZC 3-25-10

CHECKED BY: RLM 3-25-10

P.E./P.G.: –

# TOPOGRAPHIC MAP OF CHURCH ROCK AREA

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE NO. |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 16 |




SOURCE: USGS 7.5' QUADRANGLE OF CROWNPOINT, NEW MEXICO--MCKINLEY CO., DATED: 1963

**LEGEND:**

▲ WELL LOCATION

▣ WATER SAMPLE LOCATION (ASSUMED WELL OR SPRING LOCATION)

1081712 SAMPLE I.D.

**NOTES:**

1. MINE, WELL AND SAMPLE LOCATIONS ARE APPROXIMATE.

N

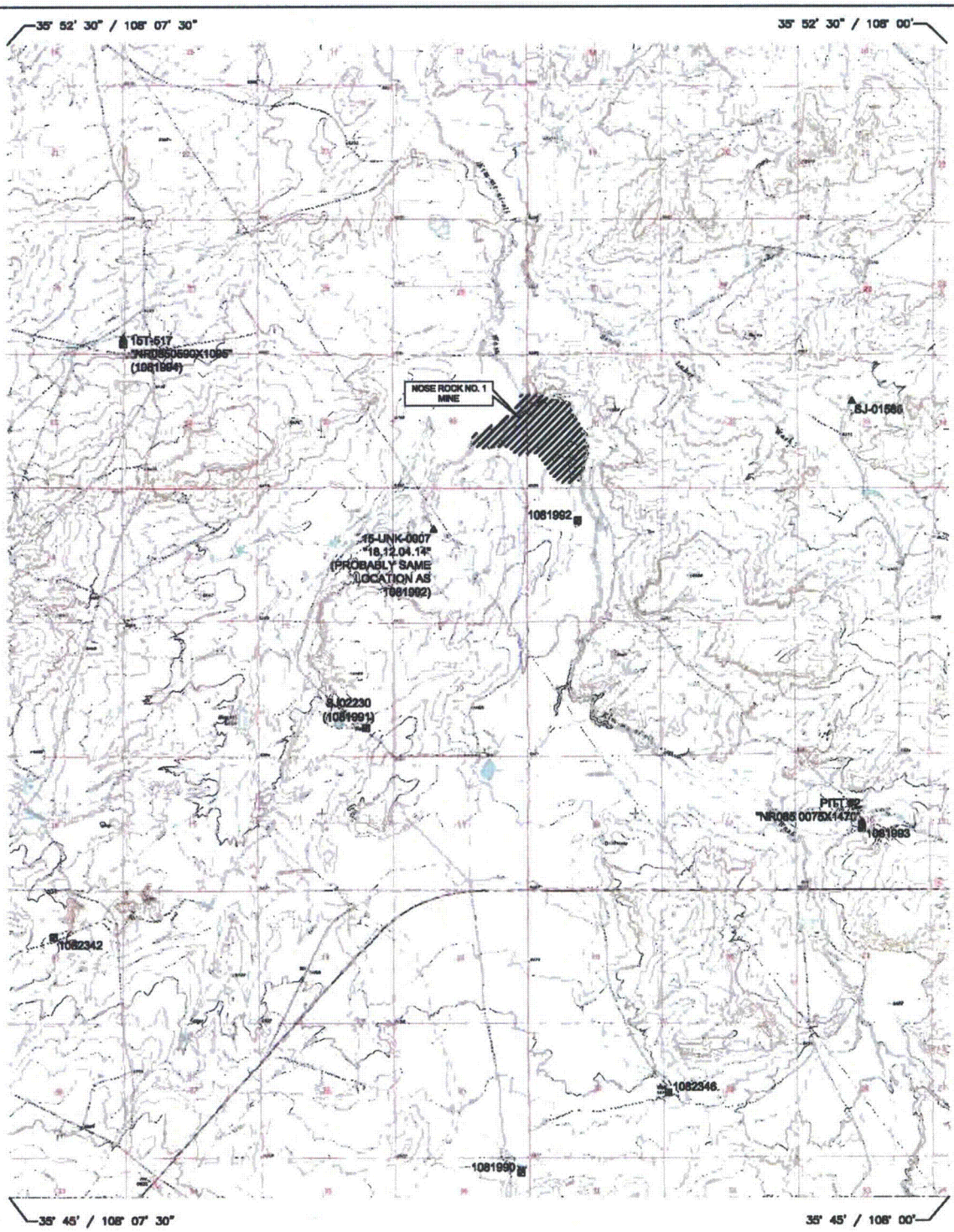
0 4000

APPROXIMATE SCALE IN FEET

ERRG Engineering/Remediation Resources Group, Inc.
4989 Pacheco Blvd., Suite 200
Martinez, California 94553
(925) 689-0760

| CLIENT: | DESIGNED BY: | TOPOGRAPHIC MAP OF CROWNPOINT AREA |
|---|---|---|
| U.S. ENVIRONMENTAL PROTECTION AGENCY | VZC 6-10-09 | |
| LOCATION: | CHECKED BY: RLM 6-10-09 | |
| CROWN POINT AREA NEW MEXICO, NAVAJO NATION | P.E./P.G.: - | |

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE NO. |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 17 |




SOURCE: USGS 7.5' QUADRANGLE OF BECENTI LAKE, NEW MEXICO–MCKINLEY CO., DATED: 1970, PHOTOREVISED: 1982

**LEGEND:**

▲ WELL LOCATION

⊠ WATER SAMPLE LOCATION (ASSUMED WELL OR SPRING LOCATION)

1081712 SAMPLE I.D.

**NOTE:**

1. MINE, WELL AND SAMPLE LOCATIONS ARE APPROXIMATE.

N

0 4000

APPROXIMATE SCALE IN FEET

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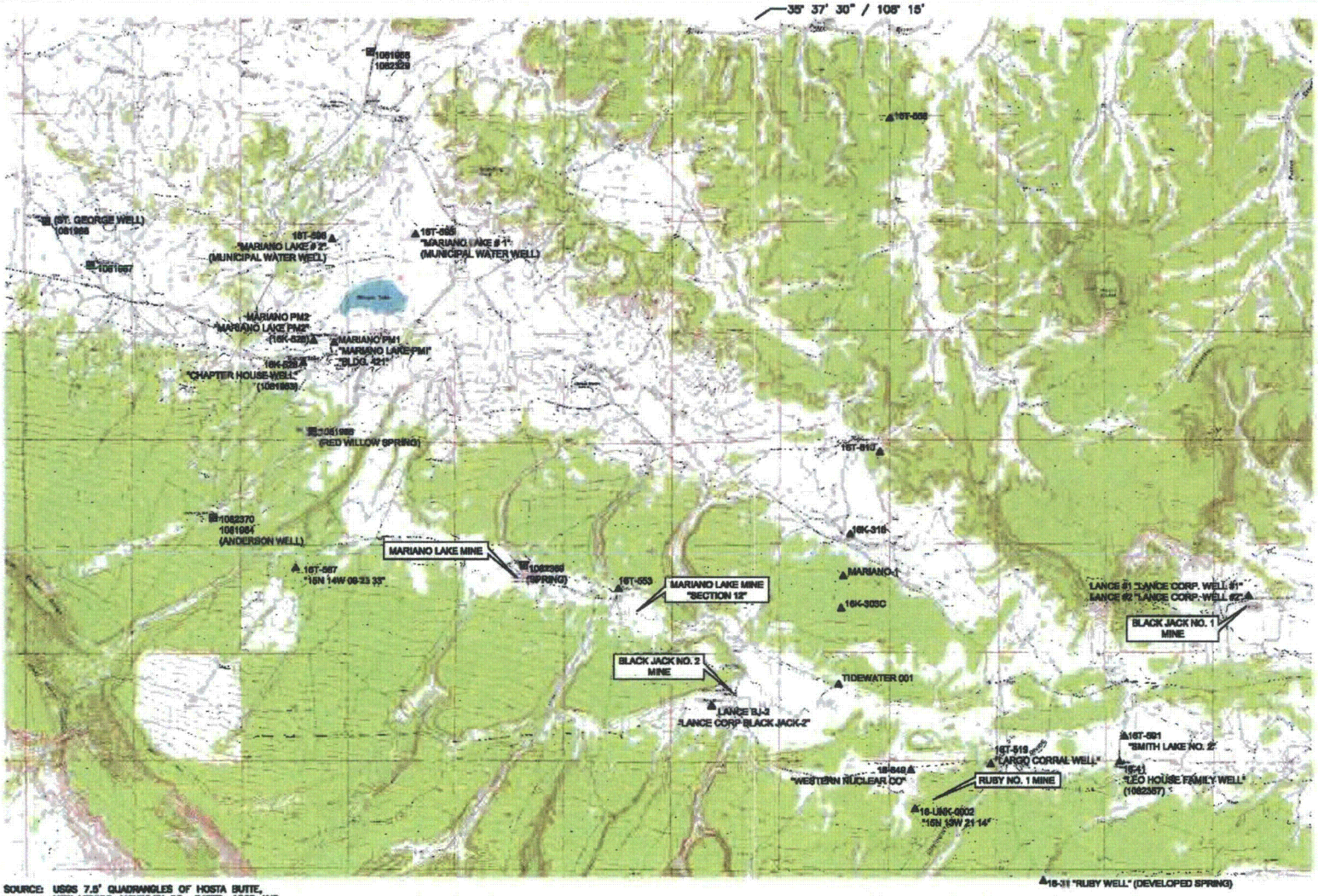
| | | | |
|---|---|---|---|
| CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY | DESIGNED BY: VZC 3-25-10 | TOPOGRAPHIC MAP FOR NOSE ROCK NO. 1 MINE IN CROWNPOINT AREA | |
| LOCATION: CROWN POINT AREA NEW MEXICO, NAVAJO NATION | CHECKED BY: RLM 3-25-10 | | |
| | P.E./P.G.: - | ERRG PROJECT NO. 28-017 | REVISION NO. 0 |
| | | SHEET 1 | OF 1 |
| | | FIGURE NO. 18 | |




**LEGEND:**

- ▲ WELL LOCATION
- ▣ WATER SAMPLE LOCATION (ASSUMED WELL OR SPRING LOCATION)
- 1082369 SAMPLE I.D.

**NOTE:**

1. MINE, WELL AND SAMPLE LOCATIONS ARE APPROXIMATE.

N

0 5000

APPROXIMATE SCALE IN FEET

SOURCE: USGS 7.5' QUADRANGLES OF HOSTA BUTTE, NEW MEXICO--MCKINLEY CO., DATED: 1963 AND MARIANO LAKE QUADRANGLE, NEW MEXICO--MCKINLEY CO., DATED: 1963, PHOTOREVISED: 1980

| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

ERRG Engineering/Remediation Resources Group, Inc.
4695 Pacheco Blvd., Suite 200
Martinez, California 94553
(925) 689-0780

CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

LOCATION: MARIANO LAKE AREA NEW MEXICO, NAVAJO NATION

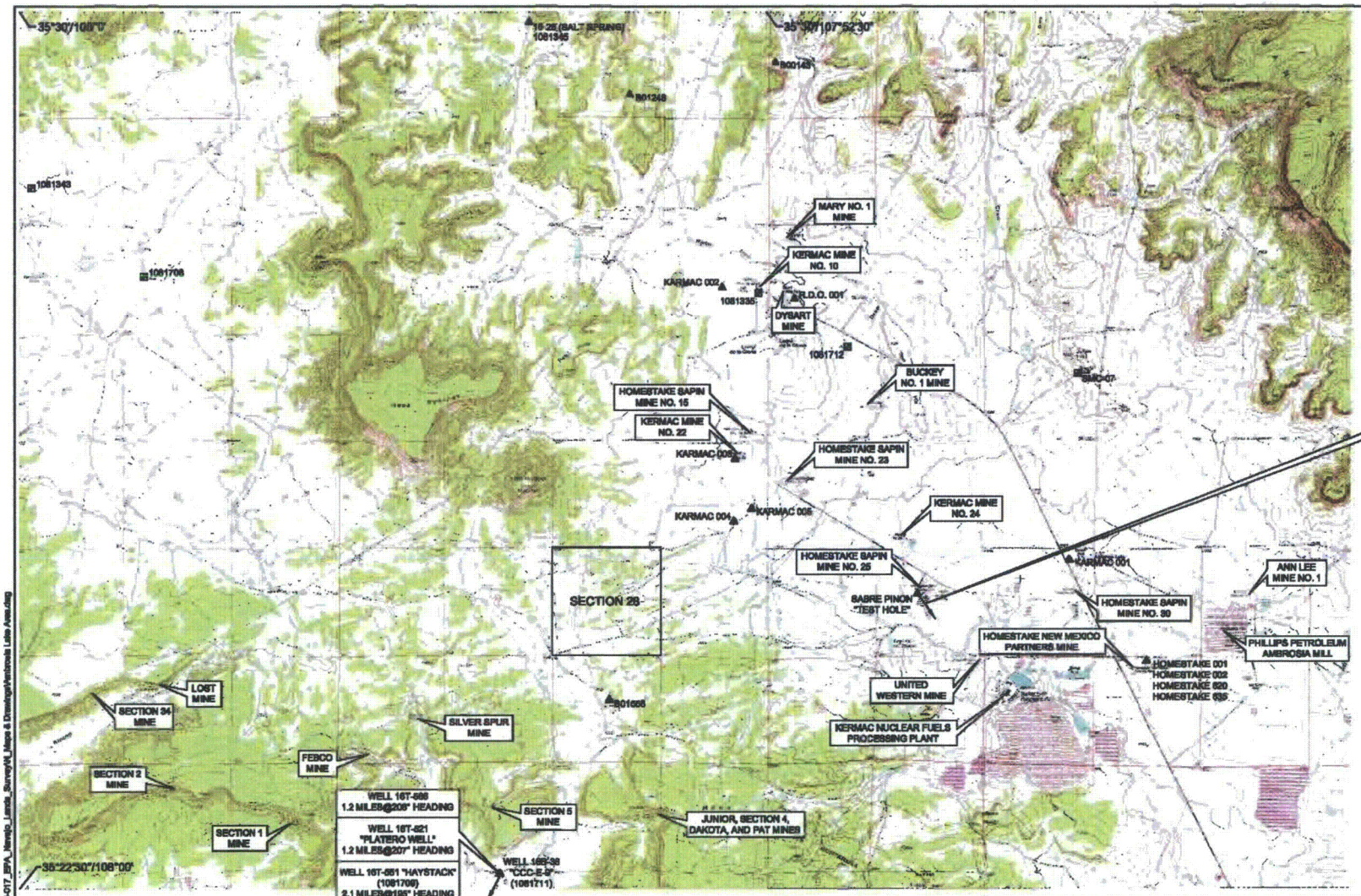
DESIGNED BY: VZC 3-25-10

CHECKED BY: RLM 3-25-10

P.E./P.G.: –

# TOPOGRAPHIC MAP OF SMITH LAKE-MARIANO LAKE AREA

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE NO. |
|---|---|---|---|---|
| 26-017 | 0 | 1 | 1 | 19 |




**LEGEND:**

- ▲ WELL LOCATION
- ■ WATER SAMPLE LOCATION (ASSUMED WELL OR SPRING LOCATION)
- 1082369 SAMPLE I.D.

**NOTE:**

1. MINE, WELL AND SAMPLE LOCATIONS ARE APPROXIMATE.

4.7 MILES@149° SMC-17
5.3 MILES@143° SMC-32 (1081739)
5.4 MILES@150° SMC-18
5.5 MILES@139° SMC-21 (RH08-0066)
6.05 MILES@141° SMC-25 (RH08-0072)
6.1 MILES@139° SMC-20 (B01115); (RH08-0055)
6.1 MILES@ 142° (RH08-0071)
6.1 MILES@143° SMC-23 (B00659); (RH08-0069)
6.15 MILES@143° SMC-24 (RH08-0074)
6.35 MILES@138° SMC-39
6.4 MILES@139° SMC-26 (B00415 O-5); (B004160-6); (B004160-7); (1081337); (1081742); (RH08-0068)
6.6 MILES@134.5° SMC-28

SOURCE: USGS 7.5' QUADRANGLES OF GOAT MOUNTAIN, NEW MEXICO DATED: 1957, PHOTOREVISED: 1980 AND AMBROSIA LAKE, NEW MEXICO, DATED: 1957 PHOTOREVISED: 1980

| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |

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

CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

LOCATION: AMBROSIA LAKE AREA NEW MEXICO, NAVAJO NATION

DESIGNED BY: VZC 3-25-10

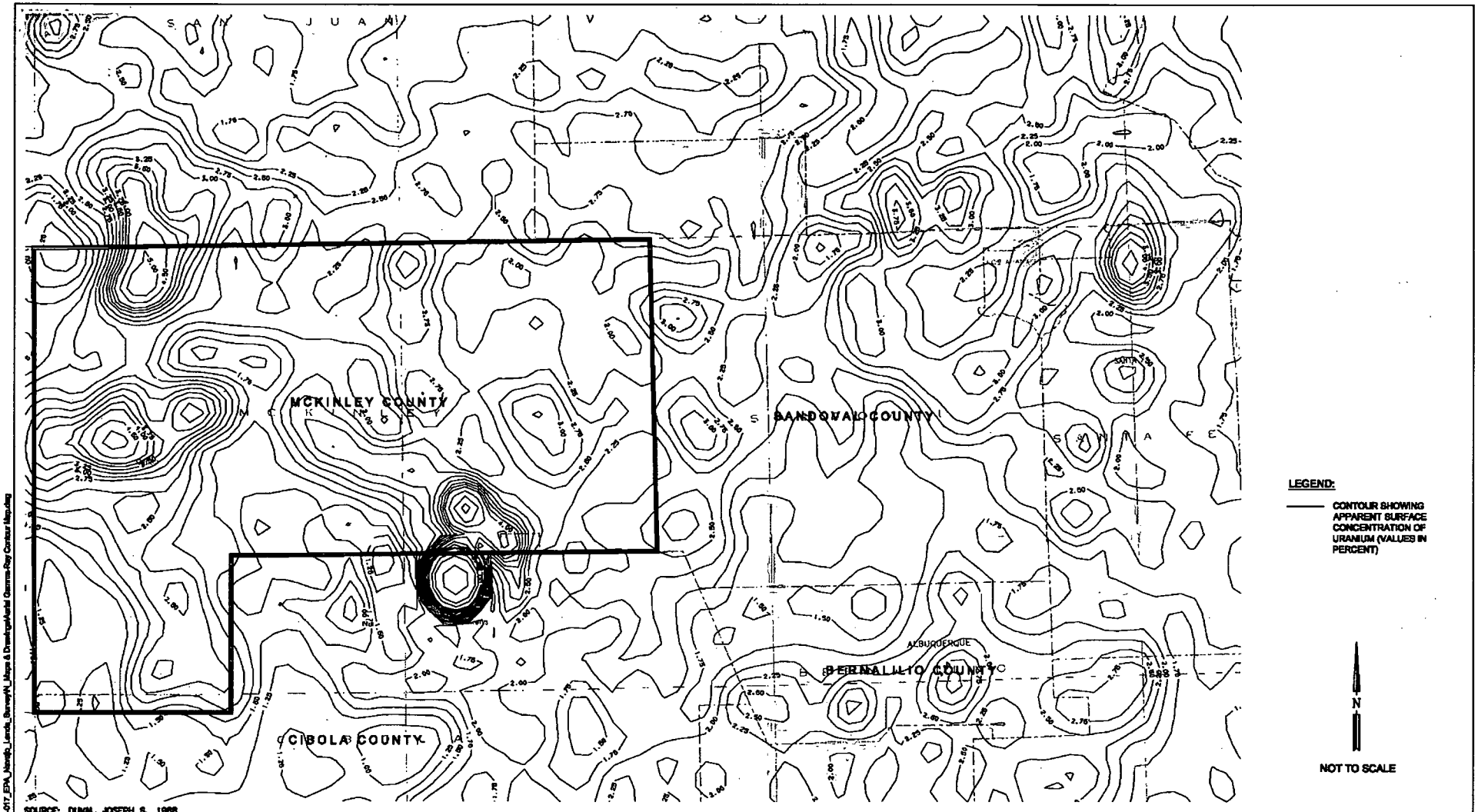
CHECKED BY: RLM 3-25-10

P.E./P.G.: –

# TOPOGRAPHIC MAP OF AMBROSIA LAKE AREA

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE NO. |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 20 |

K:\Projects\2008_Projects\28-017_EPA_Navajo_Lands_Survey\4_Maps & Drawings\Arcmods Lake Area.dwg




SOURCE: DUVAL, JOSEPH S., 1988
DEPARTMENT OF INTERIOR,
U.S. GEOLOGICAL SURVEY

| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

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

CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

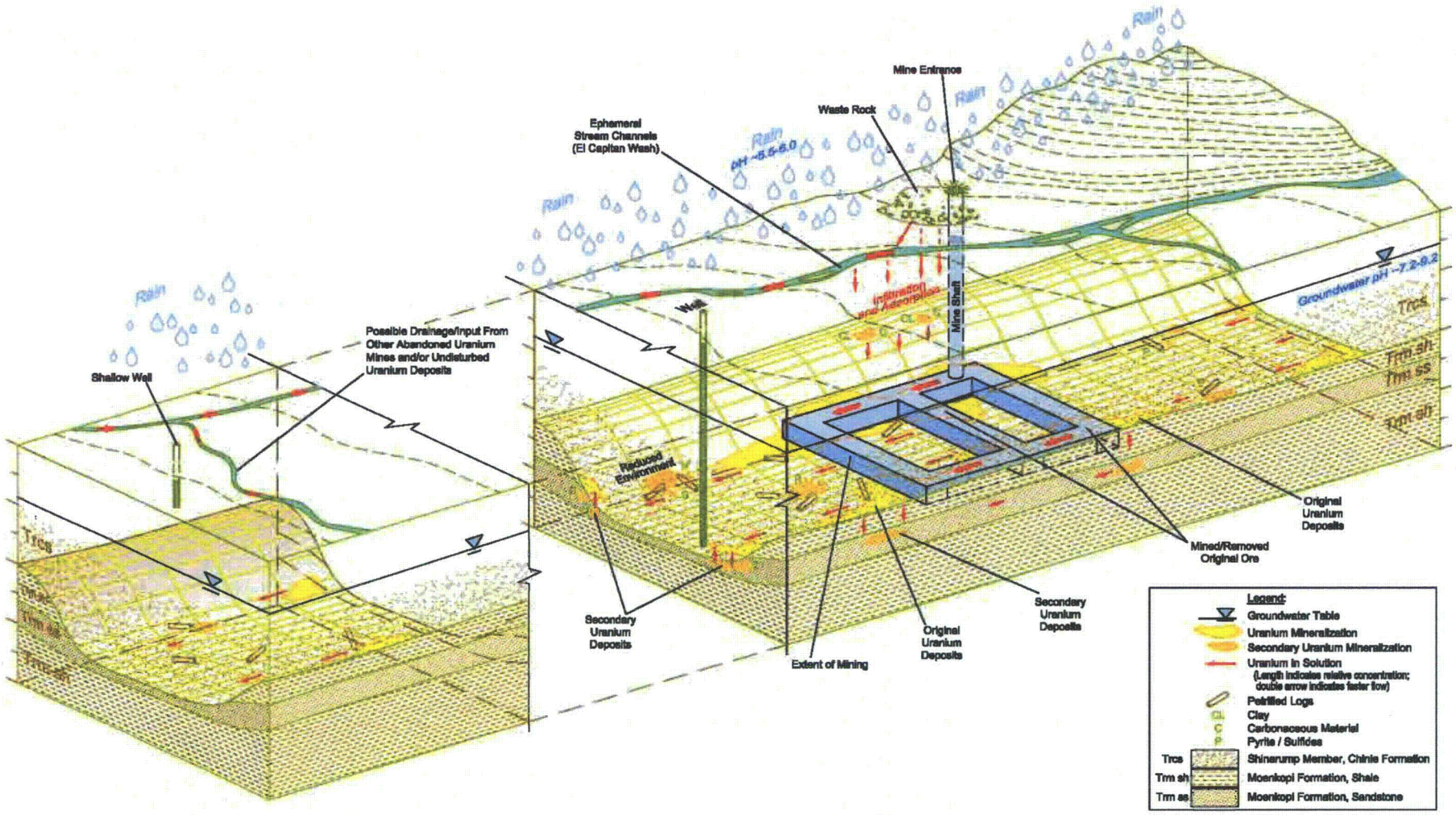
LOCATION: MCKINLEY COUNTY, NEW MEXICO

DESIGNED BY: VZC 3-25-10
CHECKED BY: RLM 3-25-10
P.E./P.G.: –

AERIAL GAMMA-RAY CONTOUR MAP OF REGIONAL SURFACE CONCENTRATIONS OF URANIUM

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE NO. |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 21 |

N:\Projects\2008_Projects\28-017_EPA_Navajo_Lands_Survey_Maps & Drawings\Aerial Gamma-Ray Contour Map.dwg




NOT TO SCALE

| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

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

CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

LOCATION: NORTH CENTRAL REGION, ARIZONA NAVAJO NATION

DESIGNED BY: RLM

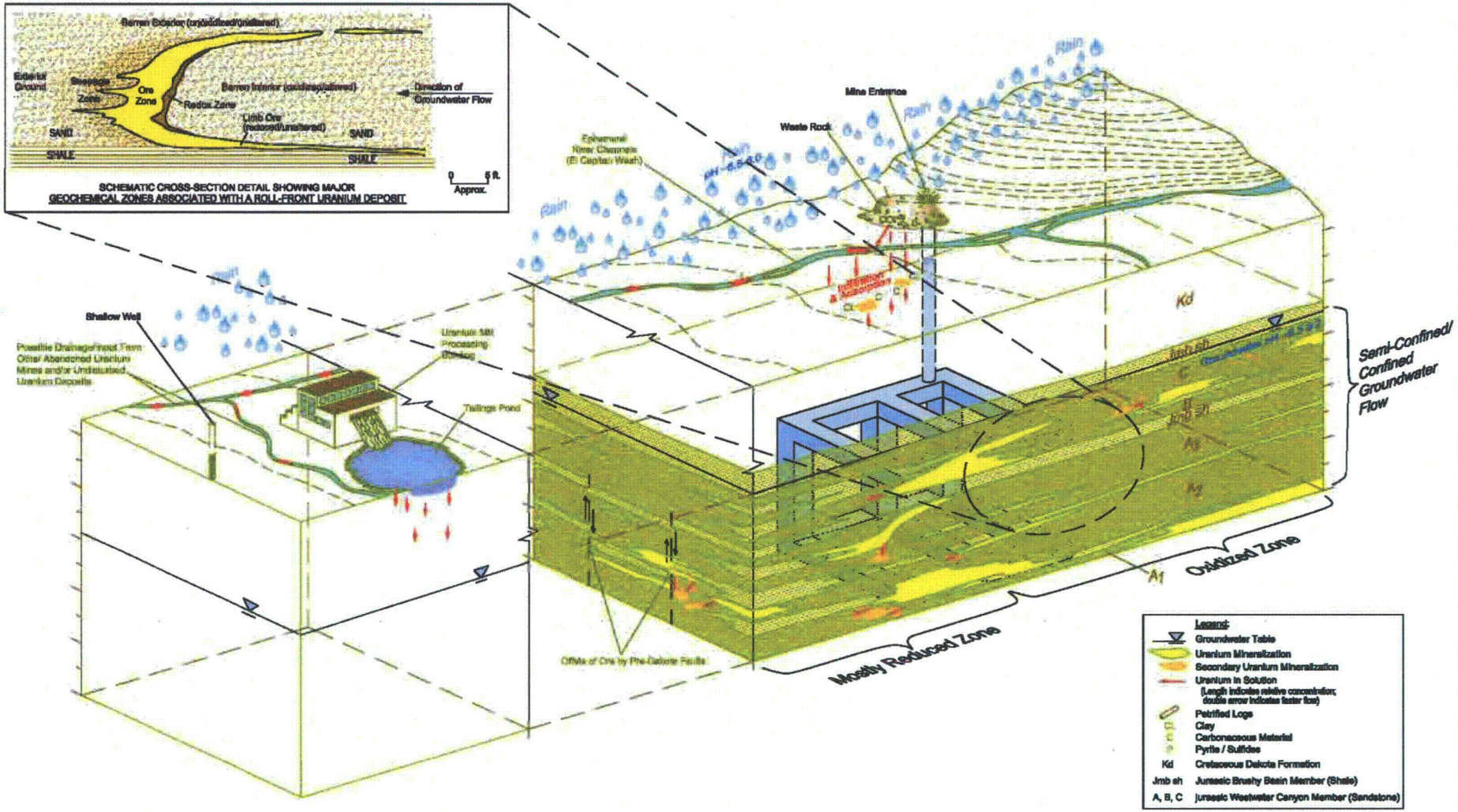
CHECKED BY: TRW

P.E./P.G.: –

GENERALIZED CROSS SECTION AND PATHWAY FOR URANIUM IN SOLUTION, MONUMENT VALLEY AREA

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 22 |

N:\2008_Projects\28-017_EPA_Navajo_Lands_Survey\Maps & Drawings\Generalized Cross Section and Pathway.dwg




| NO. | DATE | REVISIONS | APP'D | DATE |
|---|---|---|---|---|
| | | | | |

ERRG Engineering/Remediation Resources Group, Inc.
4585 Pacheco Blvd., Suite 200
Martinez, California 94553
(925) 689-0750

CLIENT: U.S. ENVIRONMENTAL PROTECTION AGENCY

LOCATION: NORTH CENTRAL REGION NAVAJO NATION

DESIGNED BY: RM
CHECKED BY: TRW
P.E./P.G.: ---

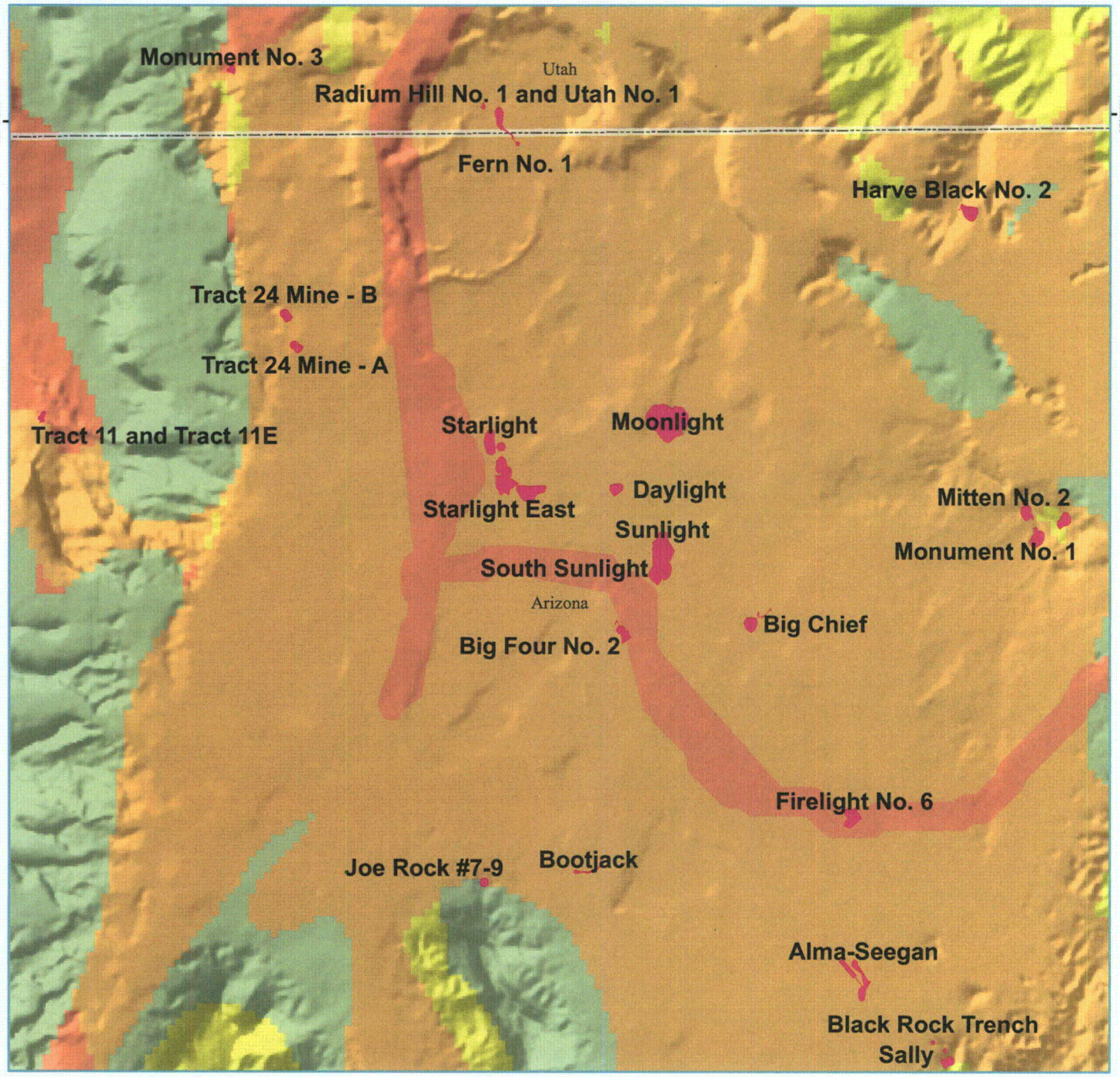
**GENERALIZED CROSS SECTION AND PATHWAY FOR URANIUM IN SOLUTION, GRANTS URANIUM REGION**

| ERRG PROJECT NO. | REVISION NO. | SHEET | OF | FIGURE |
|---|---|---|---|---|
| 28-017 | 0 | 1 | 1 | 23 |

N:\Projects\28-017 EPA\NA\Maps and Drawings\Generalized Cross Section Grants Uranium Region.dwg

# Appendix A. Geospatial Data Set Maps

# North-Central Area




North Central Region

# AQUIFER SENSITIVITY

Legend

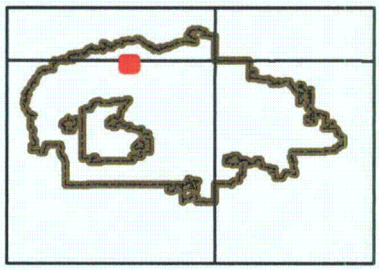
Abandoned Uranium Mines

Aquifer Sensitivity Class

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

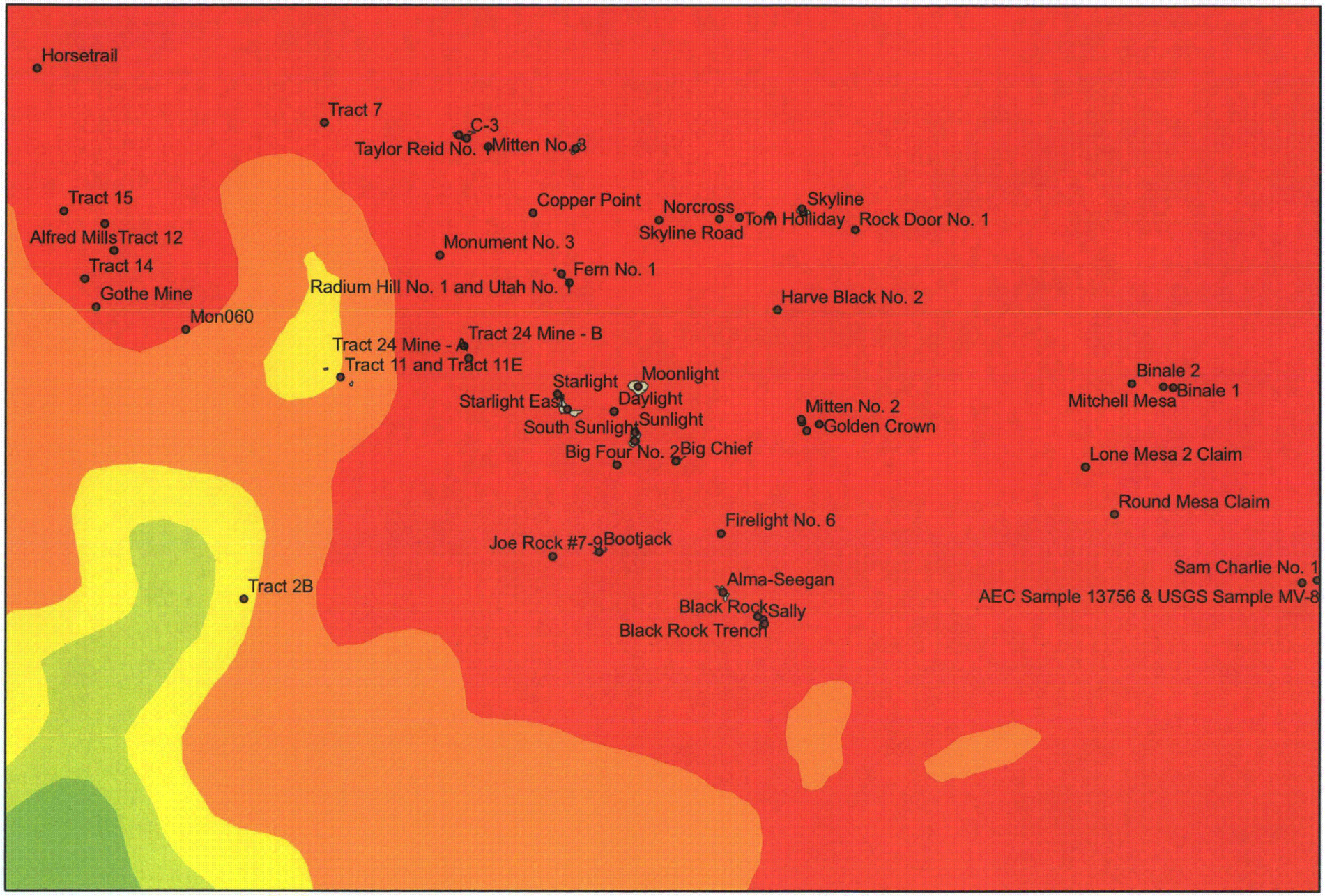
N W E S

0 2 Miles

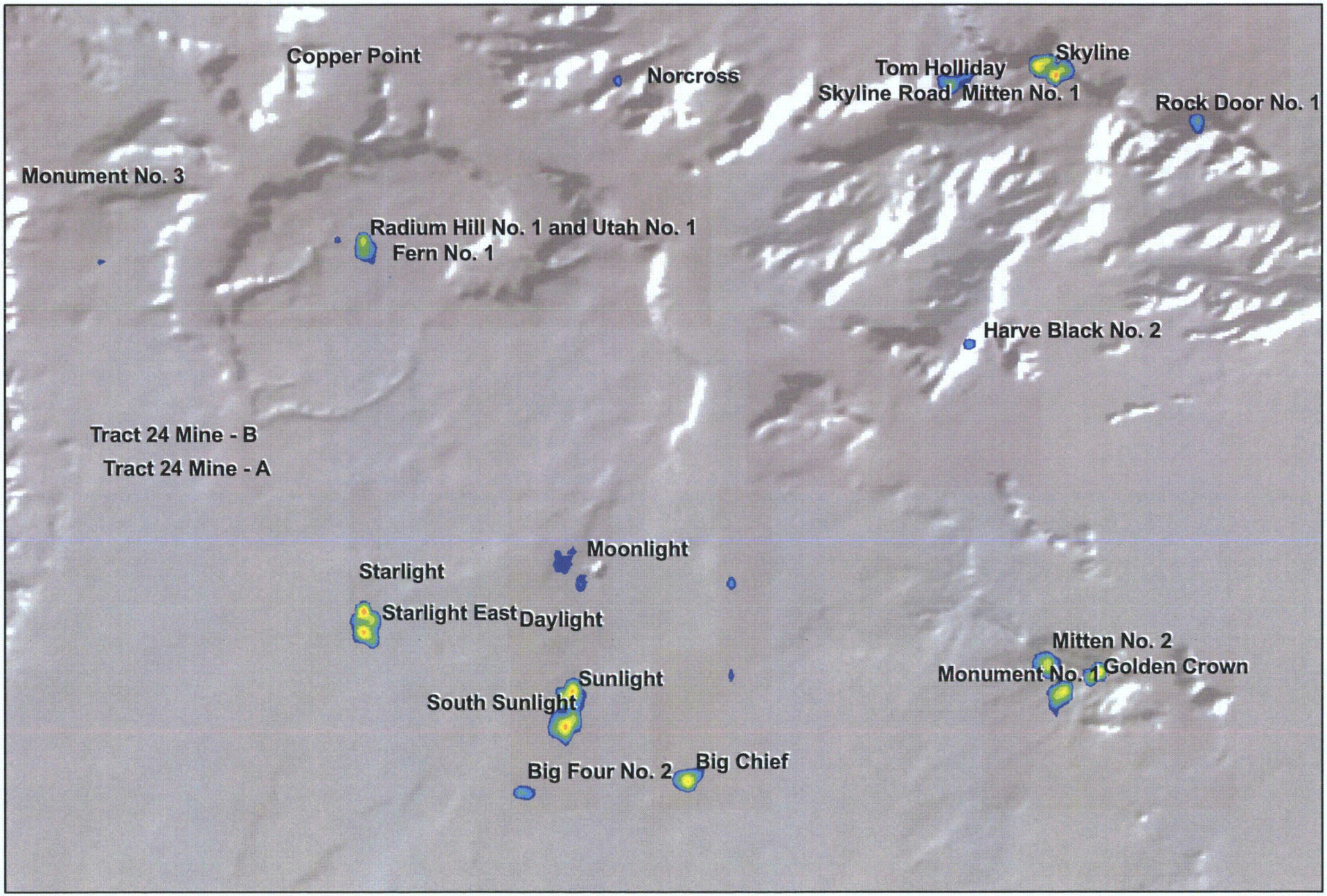


Sources

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




Average Annual Precipitation for Monument Valley Area



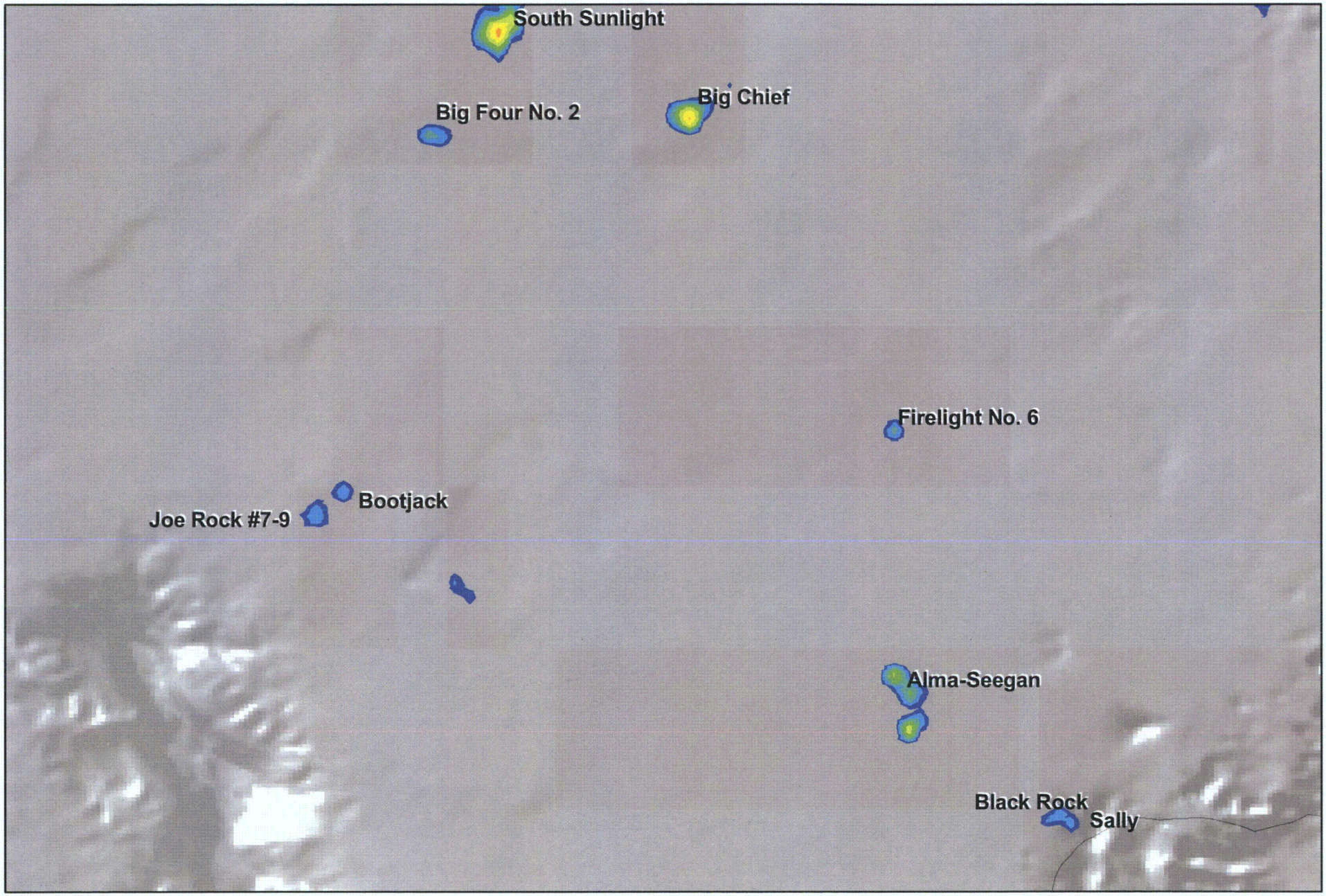

NN_Excess_Bi214_Polys

ExpoRate

- 2.4 to 3.5
- 3.5 to 5.2
- 5.2 to 7.4
- 7.4 to 10.9
- 10.9 to 16.2
- 16.2 to 23.6
- 23.6 to 34.9
- 34.9 to 52.4
- >52.5

North Central Region
Bismuth-214 Flyover Polygons

0 0.5 1 2 3 4 Miles



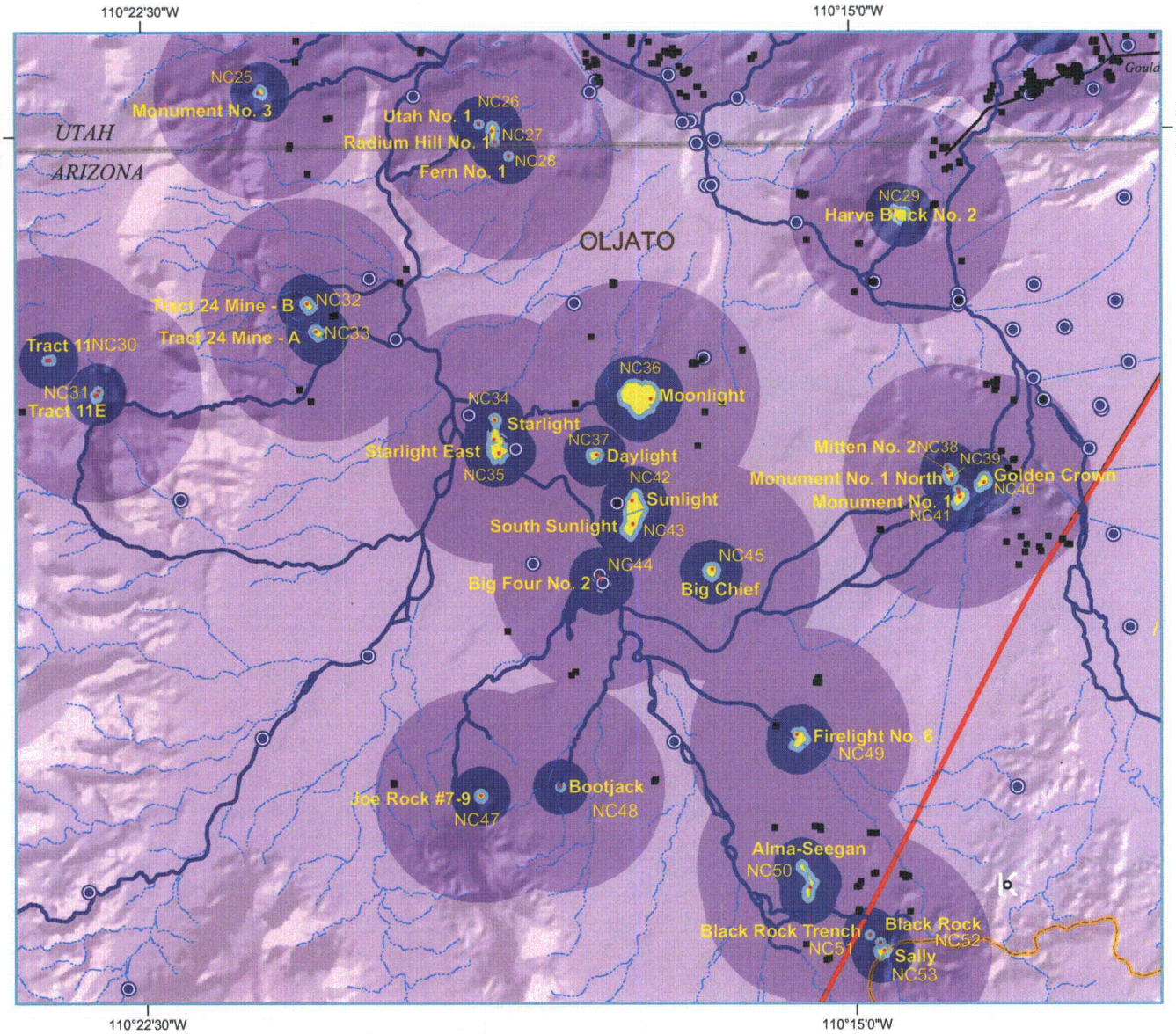

**NN_Excess_Bi214_Polys**

**ExpoRate**

- 2.4 to 3.5
- 3.5 to 5.2
- 5.2 to 7.4
- 7.4 to 10.9
- 10.9 to 16.2
- 16.2 to 23.6
- 23.6 to 34.9
- 34.9 to 52.4
- >52.5

North Central Region
Bismuth-214 Flyover Polygons

0 0.3 0.6 1.2 1.8 2.4 Miles




North Central Region

# COMBINED PATHWAYS - OLJATO

**Legend**

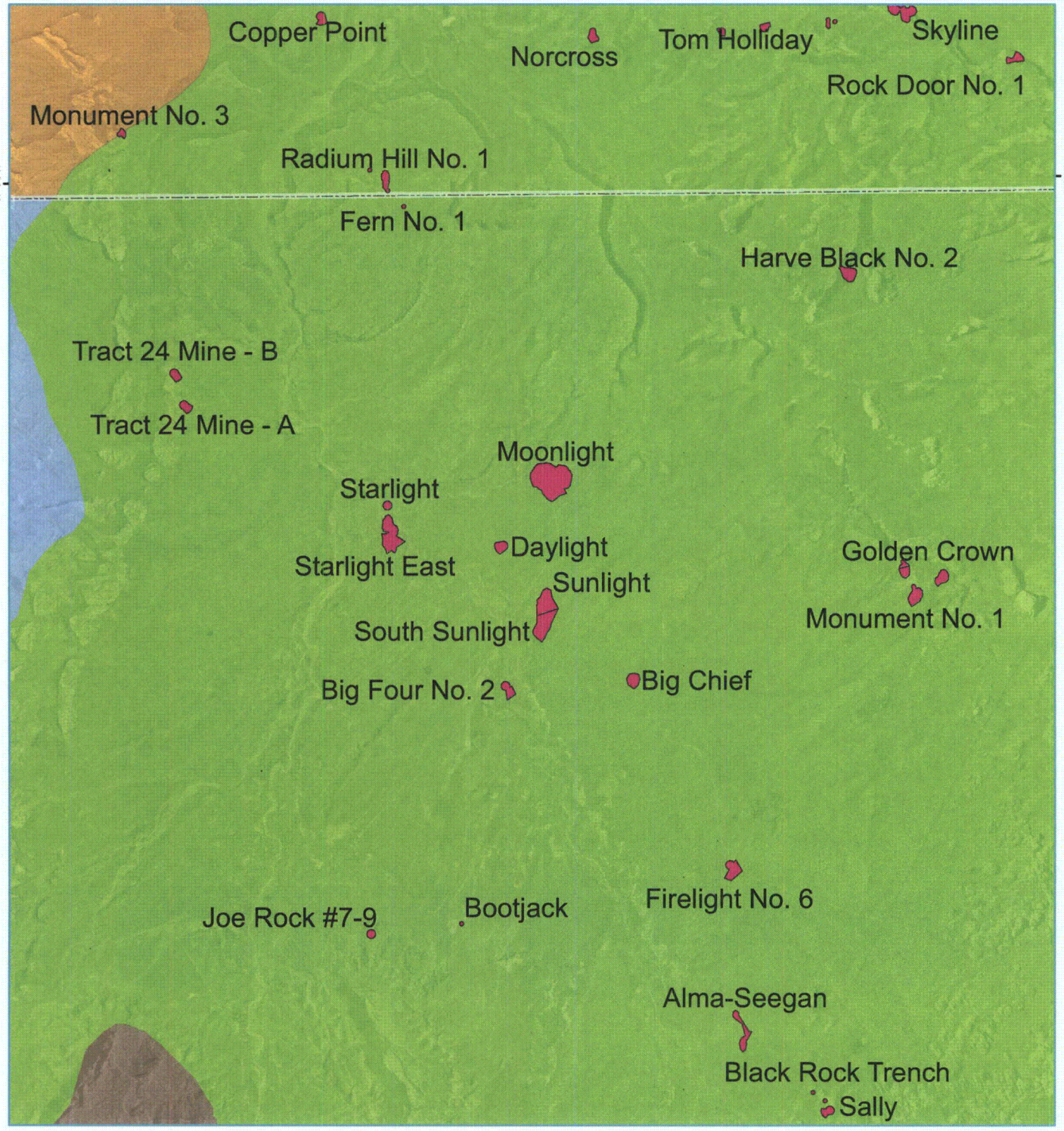
- NC10 MAP-ID
- Mine Feature
- Structure within 1 mile
- Well within 4 milles
- Downstream Water Pathway
- Intermittent Stream
- Highway
- Paved Road
- Abandoned Uranium Mine

Mine Buffers

- 200 Feet
- 1/4 Mile
- 1 Mile
- 4 Miles
- 15 Miles

N W E S

0 2 Miles




Legend

Water

HYDROLOGIC GROUP INTERGRADES, Weighted Average

A, A- High infiltration, deep soils, well drained to excessively drained sands and gravels

B+, B, B- Moderate infiltration rates, deep and moderately deep, moderately well and well drained soils with moderately coarse textures

C+, C, C- Slow infiltration rates, soils with layers impeding downward movement of water, or soils with moderately fine or fine textures

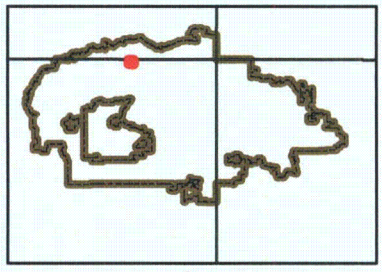
D+, D Very slow infiltration rates, soils are clayey, have a high water table, or are shallow to an impervious layer.

North Central Region

# HYDROLOGIC GROUP

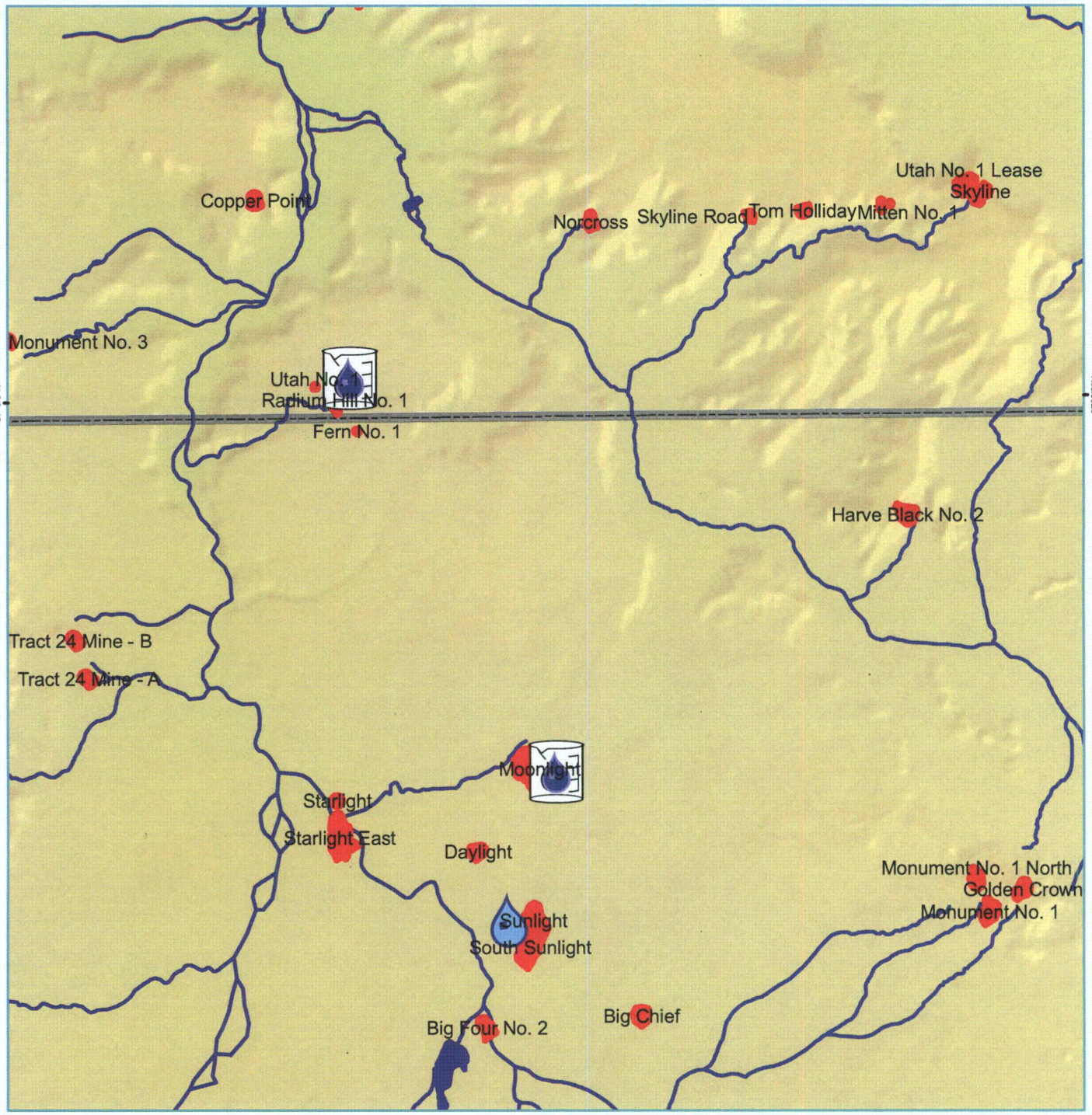
N W E S

0 2 Miles



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.




# NON-POTABLE WATER SAMPLE LOCATIONS WITH ELEVATED URANIUM

USACE Water Sample - > 20 pCi/L

USGS Water Sample - > 20 pCi/L

NURE Water Sample - > 30 parts per billion (ppb)

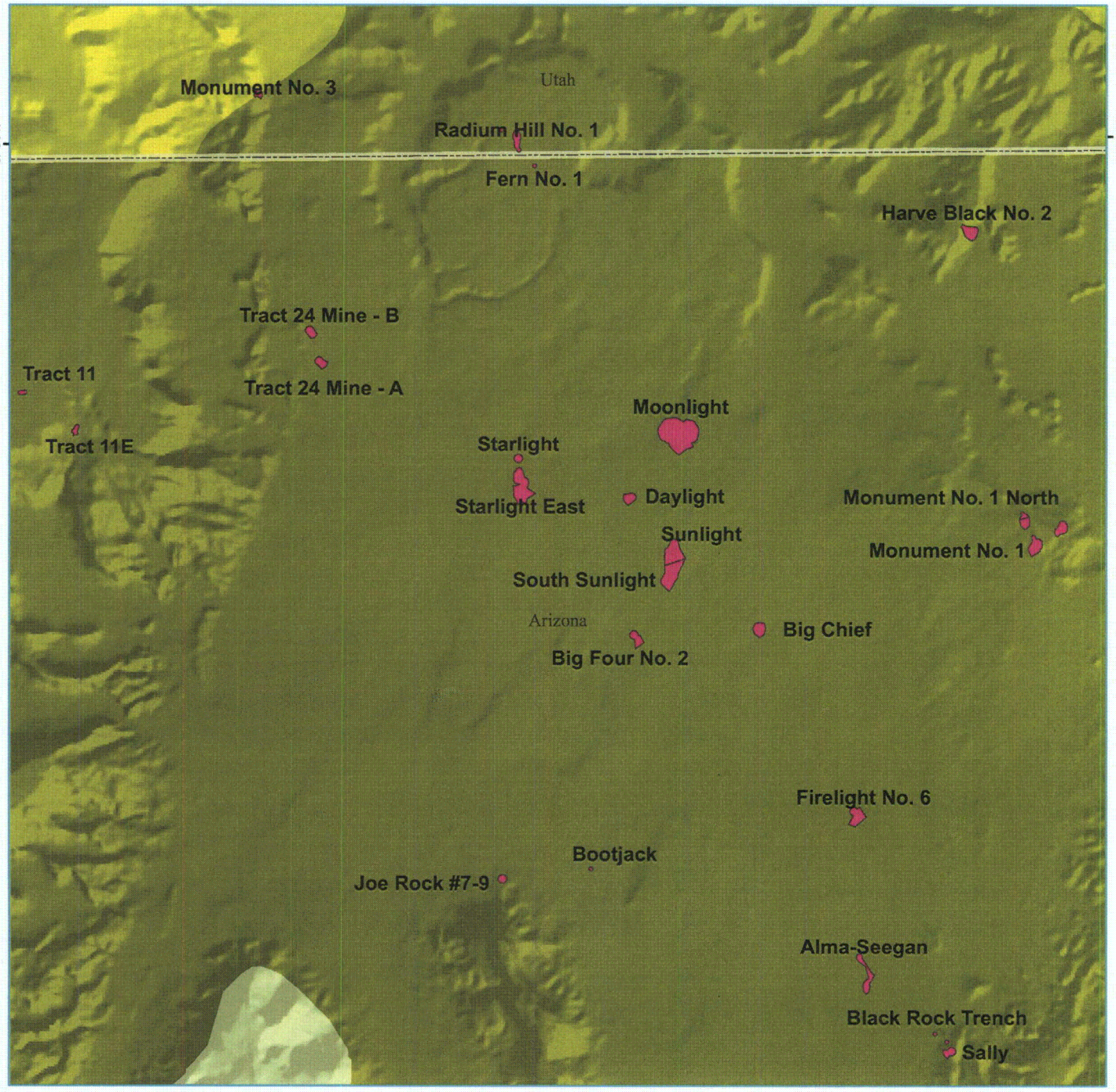
Abandoned Uranium Mine

Downstream Drainages

N W E S

0 1.5 Miles

Map Scale 1:2,000,000




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

North Central Region, Arizona

# PERMEABILITY

N W E S

0 2 Miles

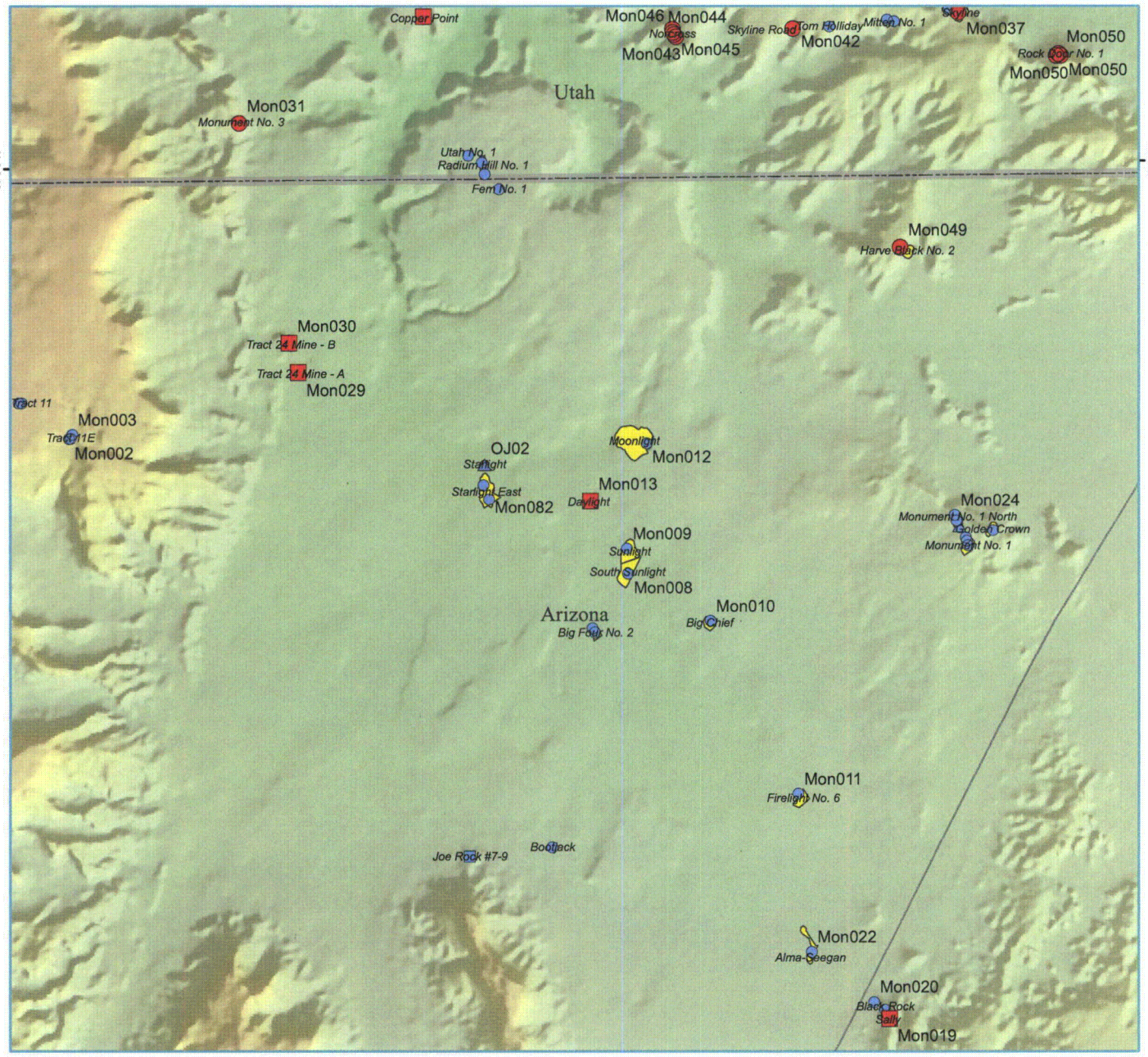
Sources

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)




NN_AUM_Pt_Features 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_Poly_Surf

**North Central Region**

# RECLAMATION STATUS AND UNMAPPED WASTE PILES

N W E S

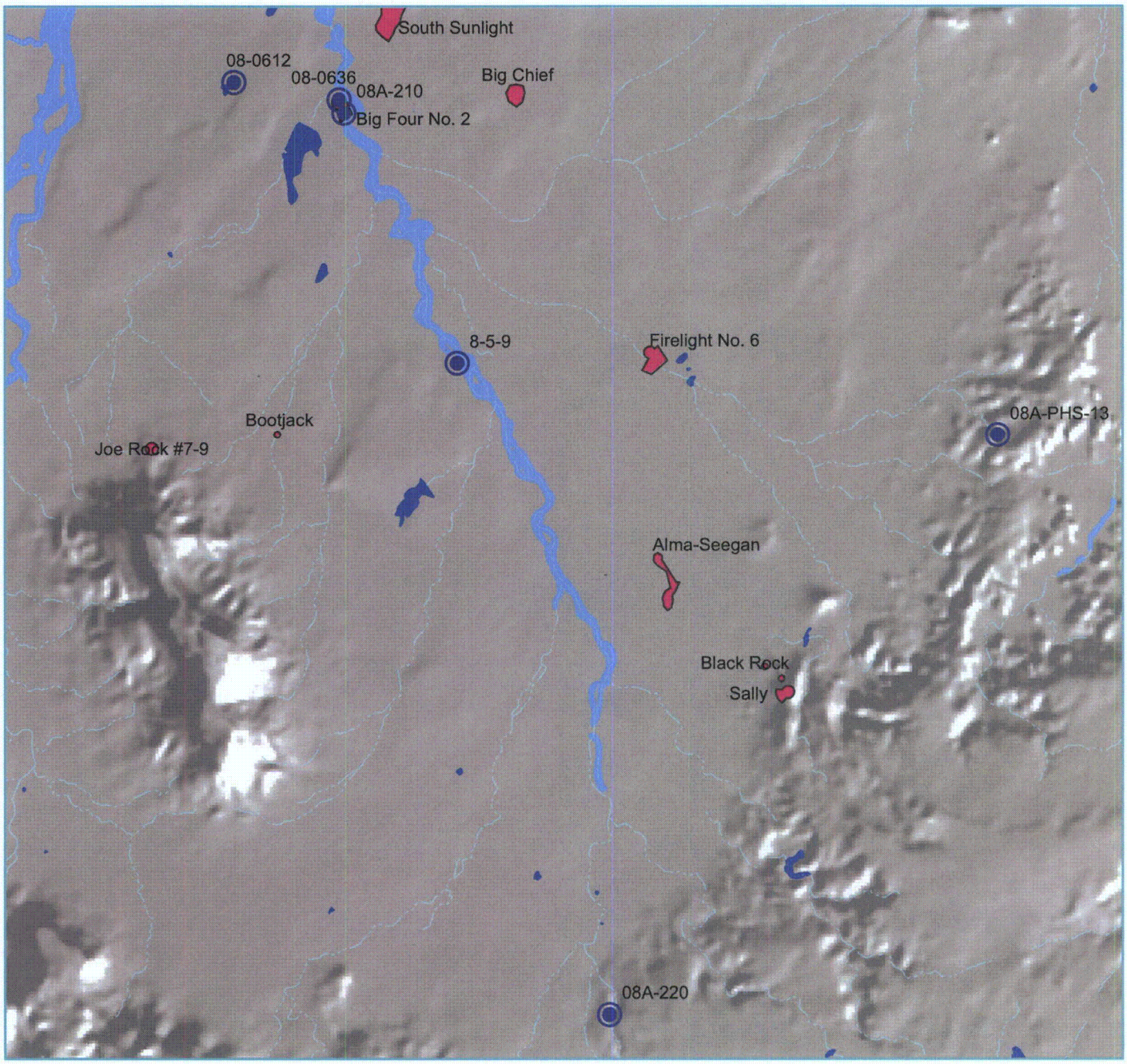
0 2 Miles

Map Scale 1:89,448

Sources

Reclamed 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




**Legend**

- Gaging Station
- Gate
- Reservoir
- Sink/Rise
- Spring/Seep
- Water Intake/Outflow
- Waterfall
- Well
- Artificial Path
- Stream/River, Intermittent
- Stream/River, Perennial
- Waterbody
- Areas: Complex Channels, Canal/Ditch, Dam/Weirs, Inundation Areas, Rapids, Streams/Rivers, and Washes

**North Central Region, Arizona**

# SURFACE WATER FEATURES

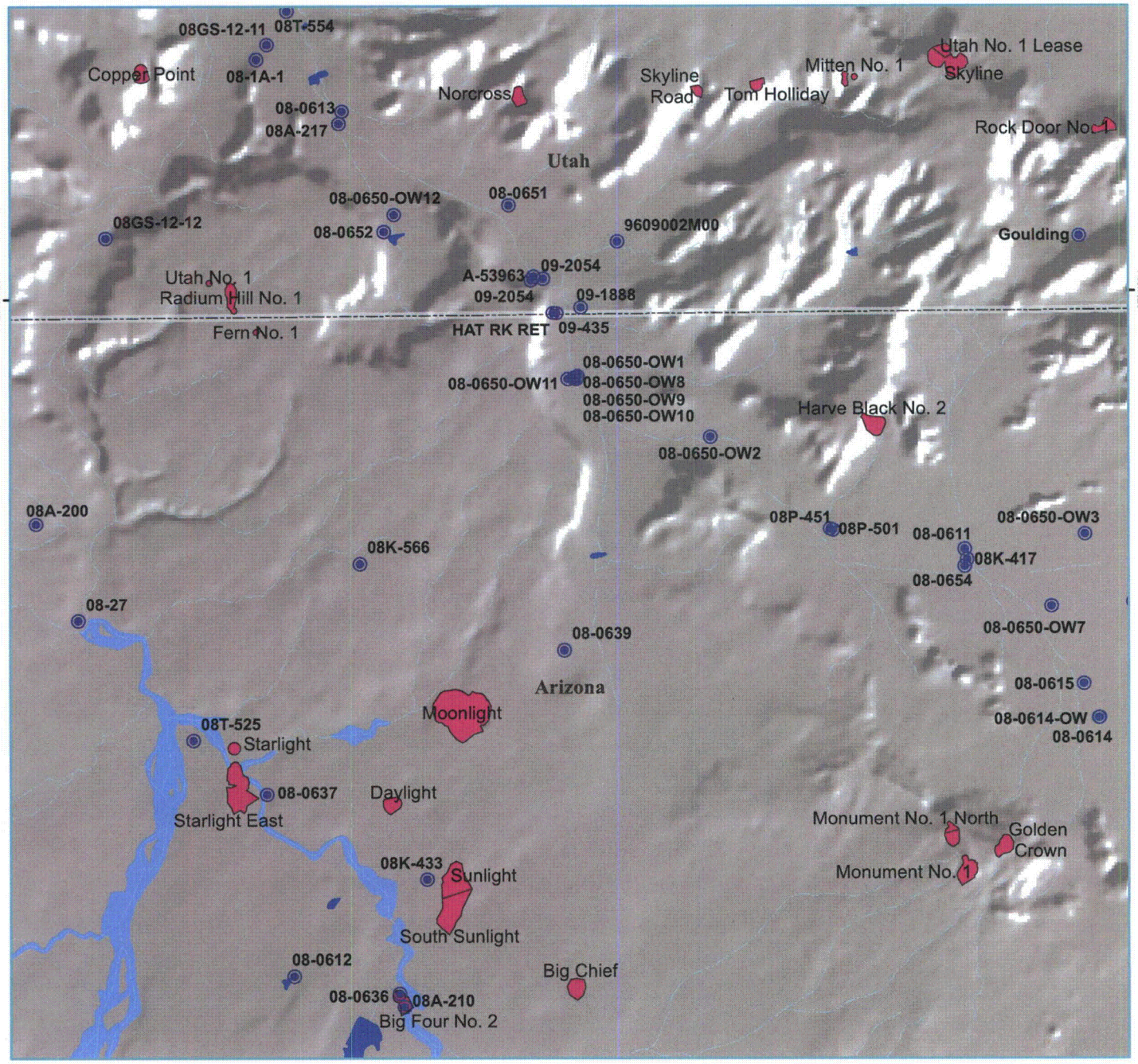
Sources

Surface water features are from the U.S. Geological Survey (USGS) National Hydrography Dataset high resolution (NHDH) 1:24,000 scale database.

Filenames:
DB/Water/NN_WaterBody_NHDH.shp
DB/Water/NN_Points_NHDH.shp
DB/Water/NN_Flowline_NHDH.shp
DB/Water/NN_Areas_NHDH.shp

N W E S

0 1 Miles




**Legend**

- Gaging Station
- Gate
- Reservoir
- Sink/Rise
- Spring/Seep
- Water Intake/Outflow
- Waterfall
- Well
- Artificial Path
- Stream/River, Intermittent
- Stream/River, Perennial
- Waterbody
- Areas: Complex Channels, Canal/Ditch, Dam/Weirs, Inundation Areas, Rapids, Streams/Rivers, and Washes

**North Central Region, Utah and Arizona**

# SURFACE WATER FEATURES

Sources

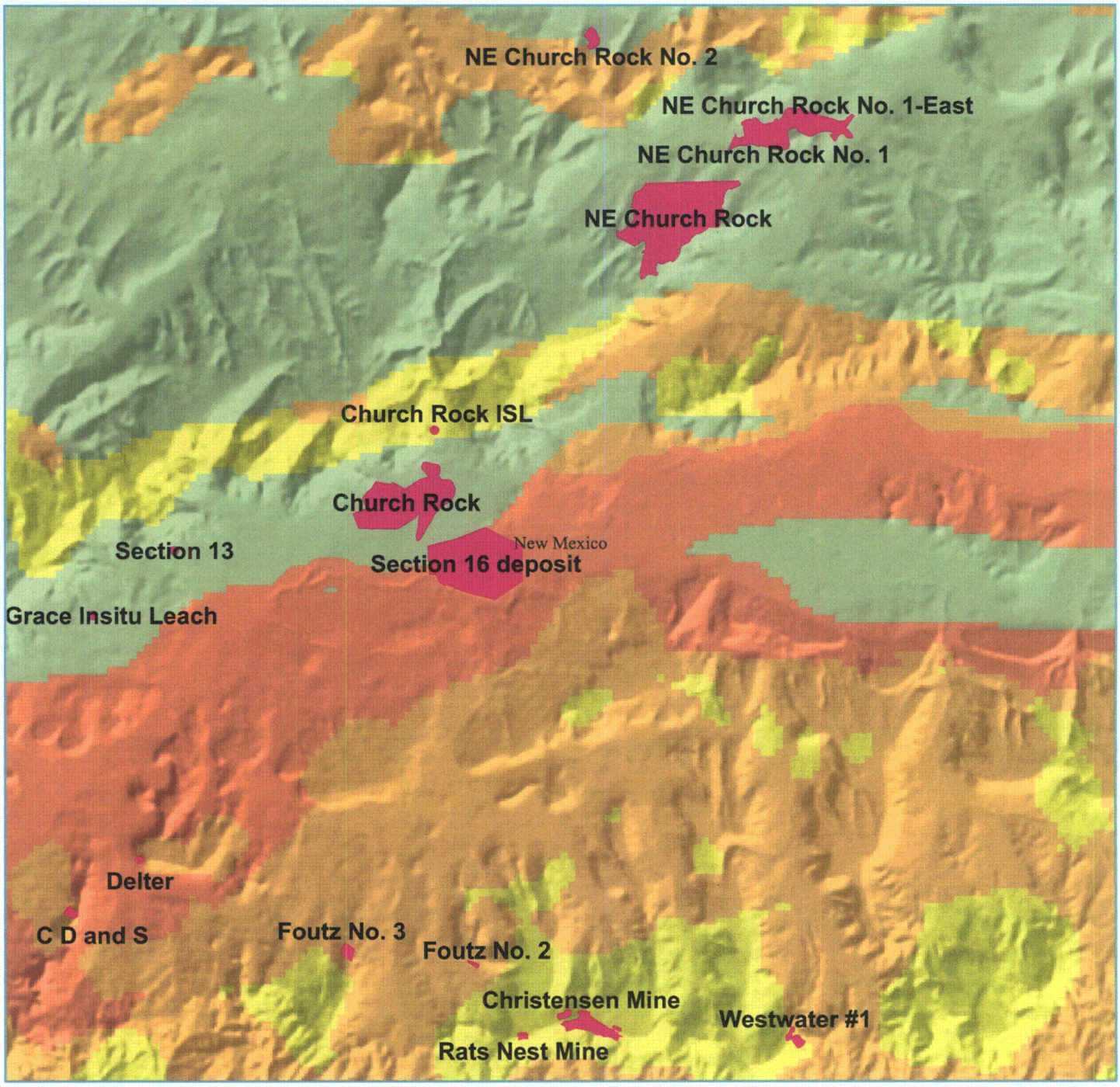
Surface water features are from the U.S. Geological Survey (USGS) National Hydrography Dataset high resolution (NHDH) 1:24,000 scale database.

Filenames:
DB/Water/NN_WaterBody_NHDH.shp
DB/Water/NN_Points_NHDH.shp
DB/Water/NN_Flowline_NHDH.shp
DB/Water/NN_Areas_NHDH.shp

N W E S

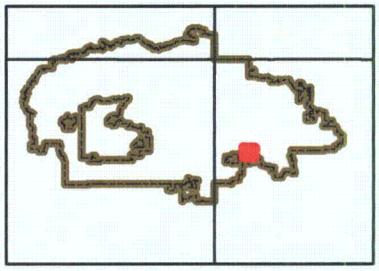
0 2 Miles

# Church Rock Area




**Eastern Region**
**Church Rock Area**

# AQUIFER SENSITIVITY



Legend

Abandoned Uranium Mines

Aquifer Sensitivity Class

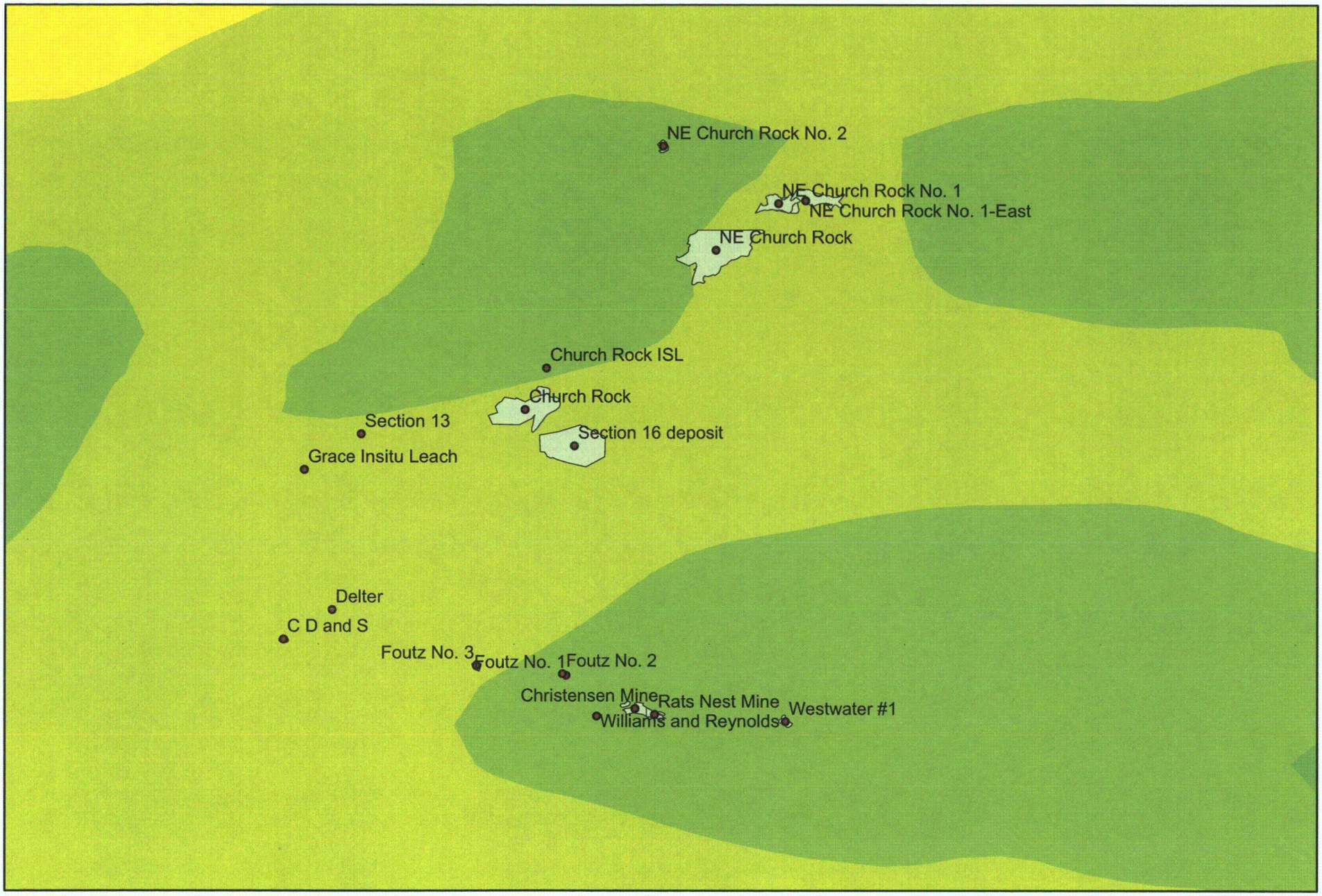
- 0 - Insignificant Potential
- 1 - Least Potential
- 2 - Intermediate Potential
- 3 - Most Potential

N W E S

0 1 Miles

Sources

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




**NN_Precipitation**

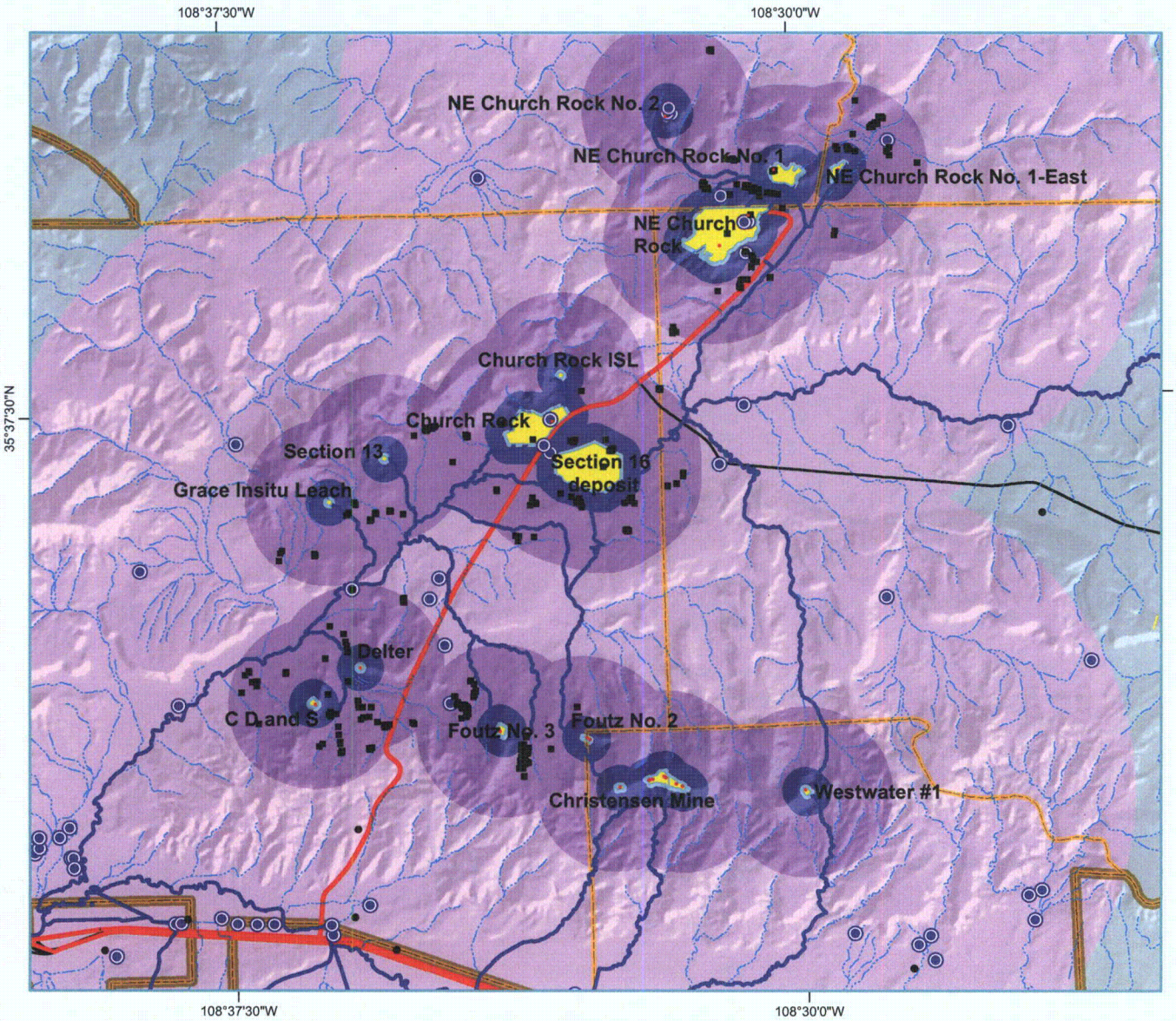
**Average Annual Precipitation (Inches)**

4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
>30

Average Annual Precipitation
Eastern Region
Church Rock Area

0 1 2 4 Miles

N W E S




**Eastern Region**
**Church Rock Area**

# COMBINED PATHWAYS

**Legend**

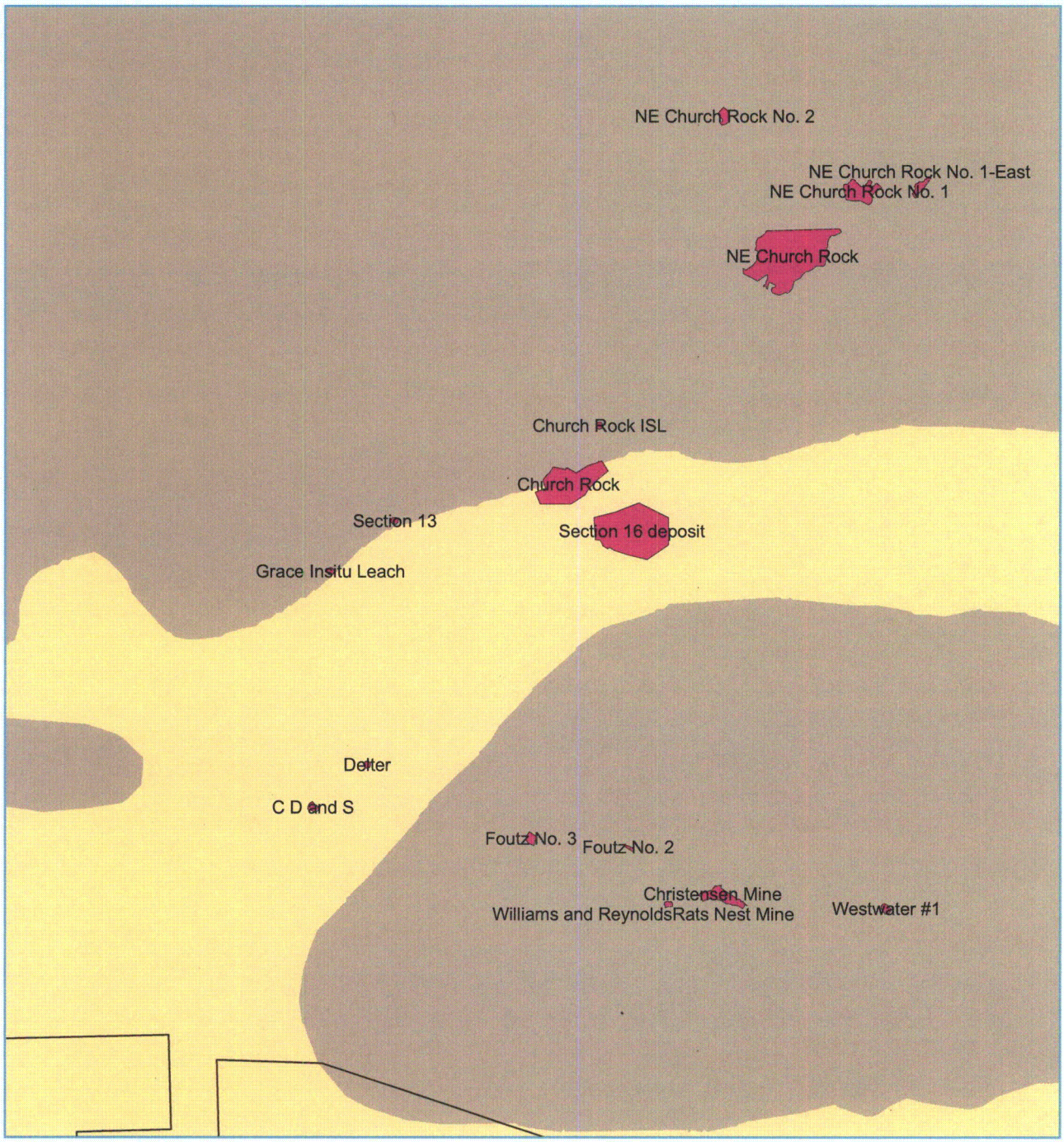
- NC10 — MAP-ID
- Mine Feature
- Structure within 1 mile
- Well within 4 milles
- Downstream Water Pathway
- Intermittent Stream
- Highway
- Paved Road
- Abandoned Uranium Mine

Mine Buffers
- 200 Feet
- 1/4 Mile
- 1 Mile
- 4 Miles
- 15 Miles

N W E S

0 1.8 Miles

Map Scale 1:80,000




Legend

Water

HYDROLOGIC GROUP INTERGRADES, Weighted Average

A, A- High infiltration, deep soils, well drained to excessively drained sands and gravels

B+, B, B- Moderate infiltration rates, deep and moderately deep, moderately well and well drained soils with moderately coarse textures

C+, C, C- Slow infiltration rates, soils with layers impeding downward movement of water, or soils with moderately fine or fine textures

D+, D Very slow infiltration rates, soils are clayey, have a high water table, or are shallow to an impervious layer.

**Eastern Region**
**Church Rock Area**

# HYDROLOGIC GROUP

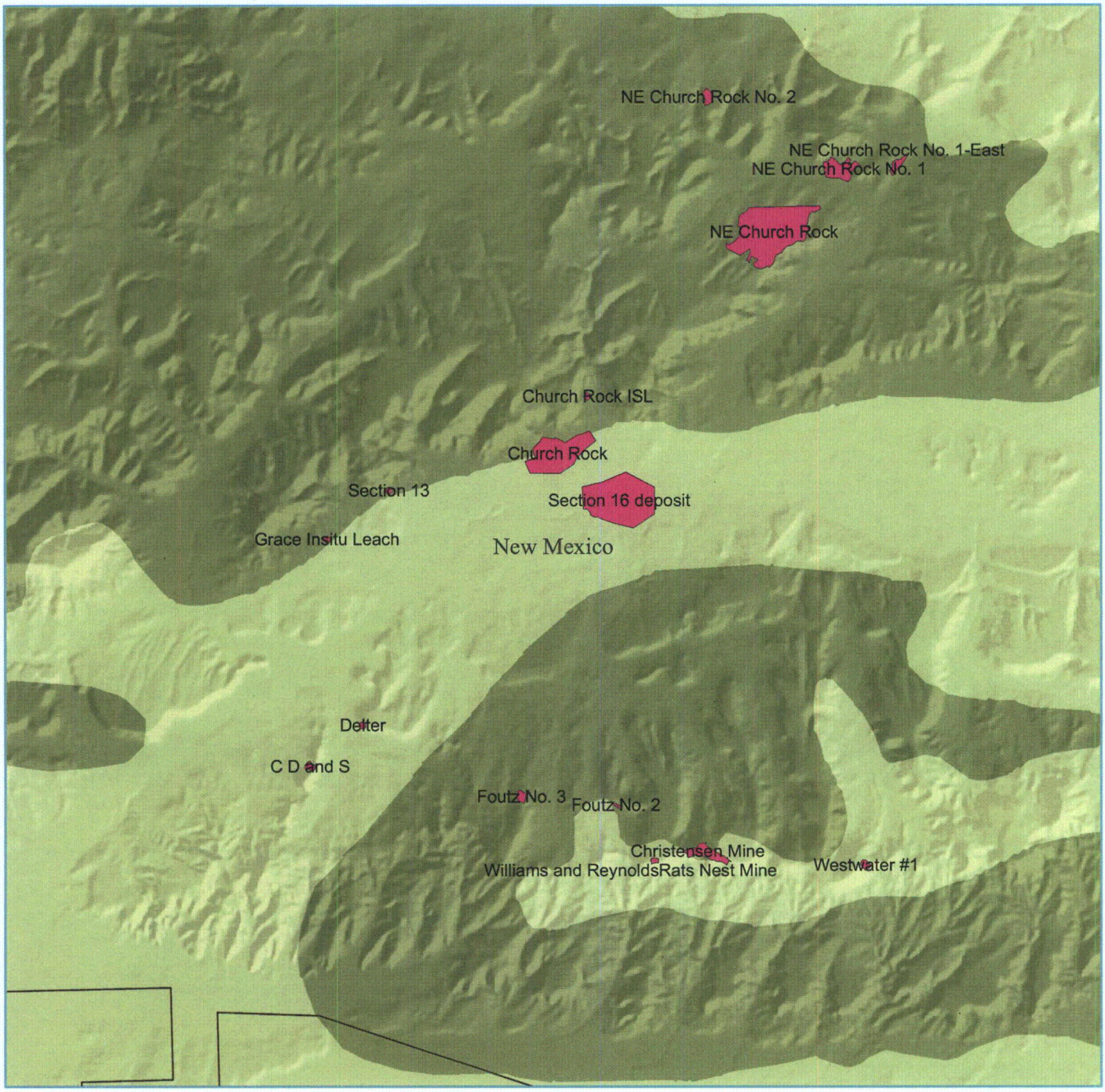
N W E S

0 0.8 Miles

Map Scale 1:94,518

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**
**Church Rock Area**

# PERMEABILITY

N W E S

0 0.8 Miles

Map Scale 1:100,637

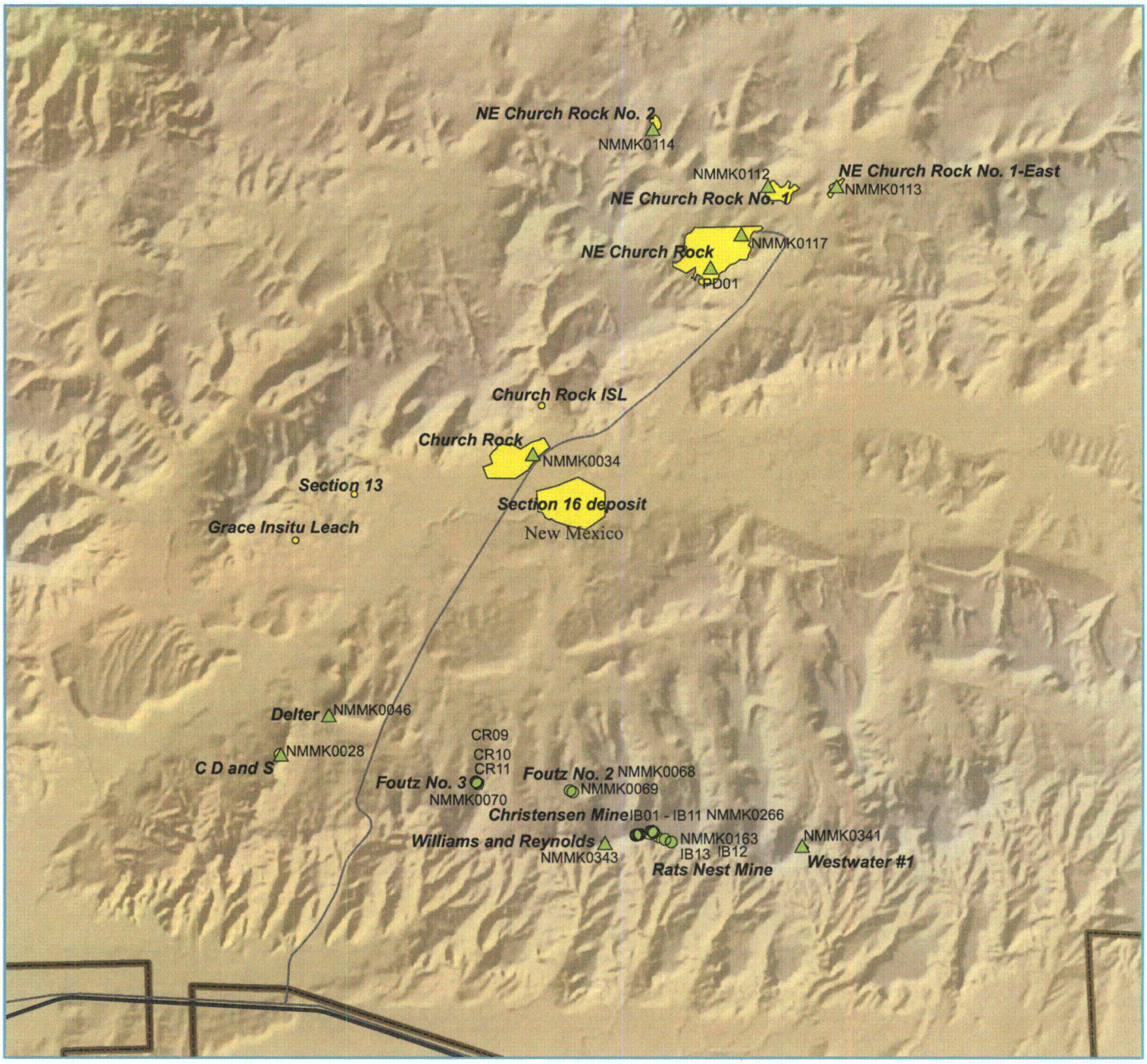
Sources

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)




Legend

AUMs

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_Poly_Surf

**Eastern Region**
**Church Rock Area**

# RECLAMATION STATUS AND UNMAPPED WASTE PILES

Sources

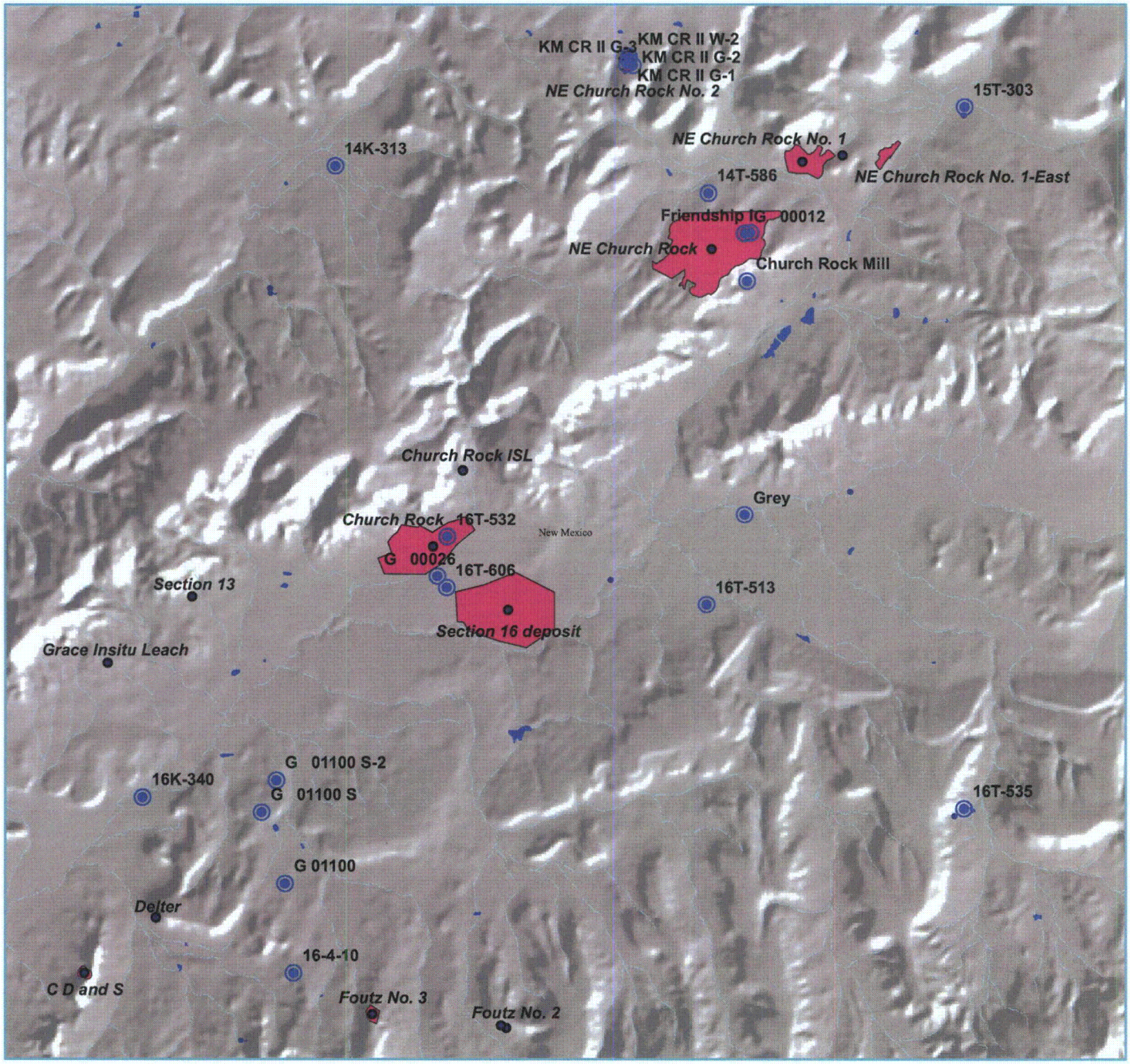
Reclamed mine feature locations and status are from the Navajo Abandoned Mine Lands Reclamation Program. The presence of waste piles was determined by NAMLRP and TerraSpectra Geomatics.

Filenames: DB/AUM/NN_AUM_Pt_Features.shp

N W E S

0 2 Miles

Map Scale 1:111,810




**Legend**

- Gaging Station
- Gate
- Reservoir
- Sink/Rise
- Spring/Seep
- Water Intake/Outflow
- Waterfall
- Well
- Artificial Path
- Stream/River, Intermittent
- Stream/River, Perennial
- Waterbody
- Areas: Complex Channels, Canal/Ditch, Dam/Weirs, Inundation Areas, Rapids, Streams/Rivers, and Washes

**Eastern Region**
**Church Rock Area**

# SURFACE WATER FEATURES

Sources

Surface water features are from the U.S. Geological Survey (USGS) National Hydrography Dataset high resolution (NHDH) 1:24,000 scale database.

Filenames:
DB/Water/NN_WaterBody_NHDH.shp
DB/Water/NN_Points_NHDH.shp
DB/Water/NN_Flowline_NHDH.shp
DB/Water/NN_Areas_NHDH.shp

N W E S

0 2 Miles