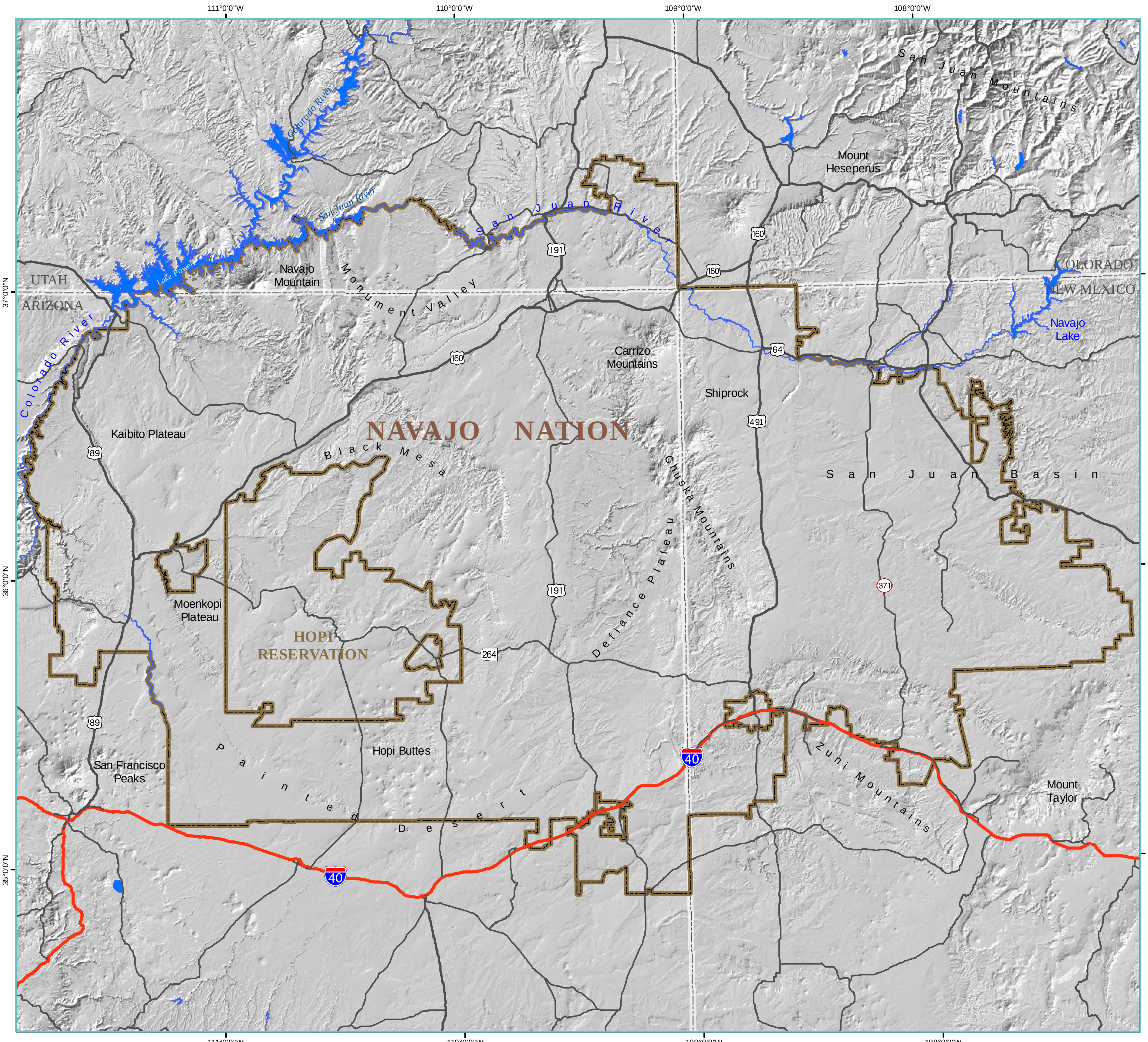


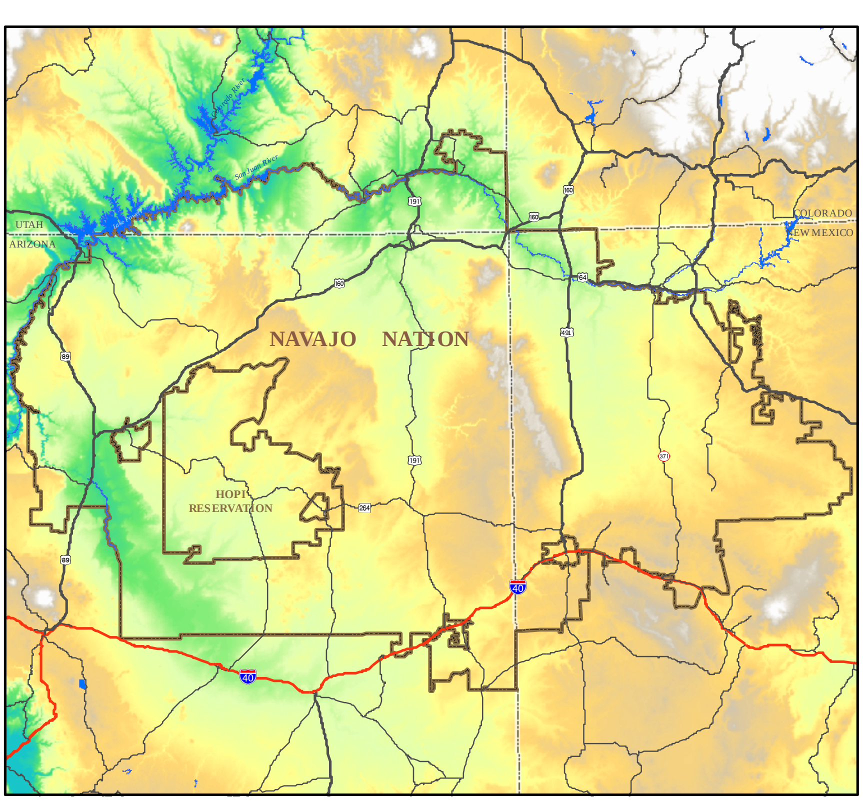
ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION SHADED RELIEF AND DIGITAL ELEVATION MODEL

N
W E
S

0 50 Miles

Map Scale 1:1,750,000



Color shaded Digital Elevation Model.

Legend

ELEVATION IN METERS

High : 3023.000000

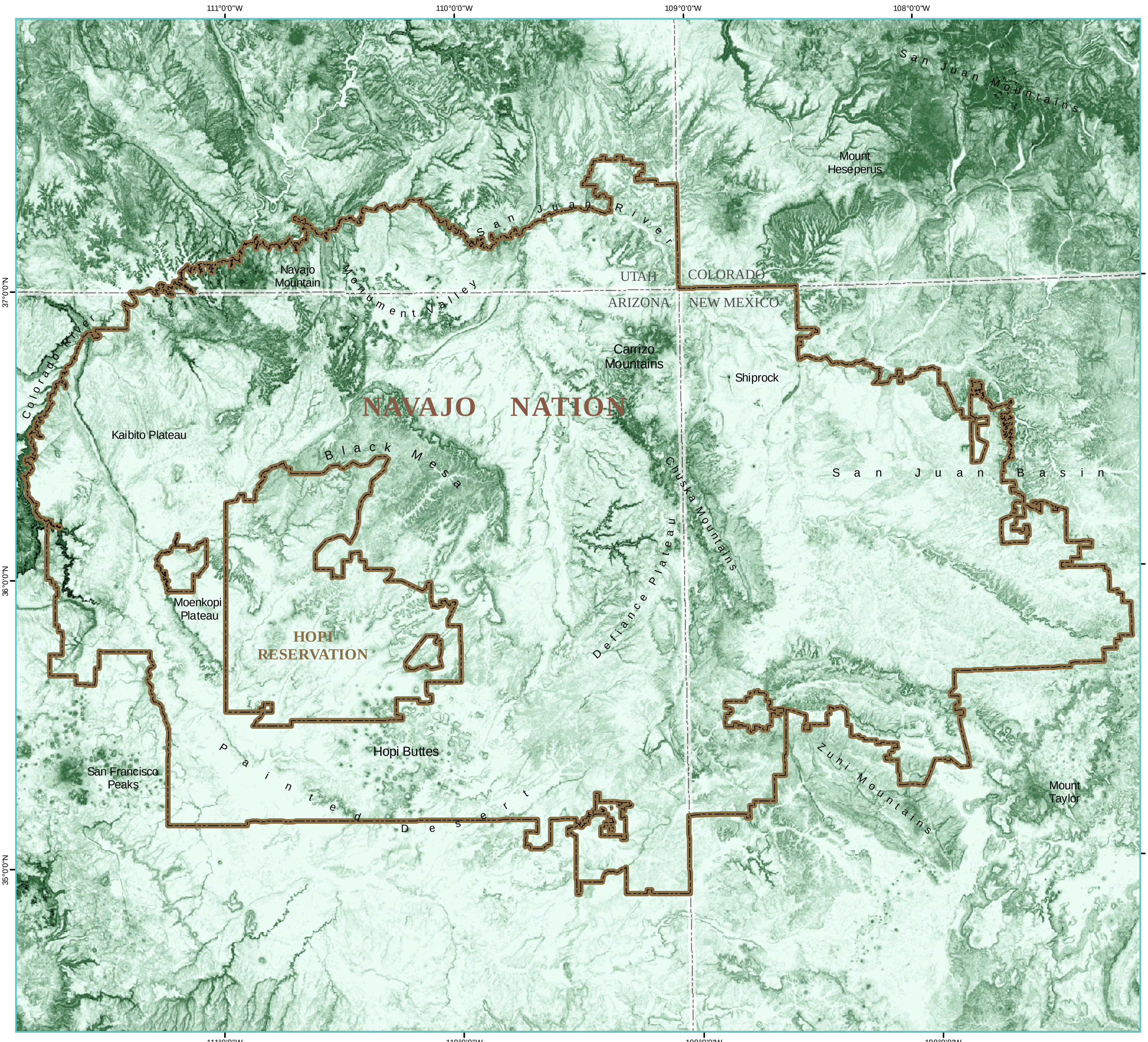
Low : 1128.000000

Source

TerraSpectra Geomatics generated the shaded relief image from U.S. Geological Survey (USGS) National Elevation Dataset (NED) 30 meter resolution Digital Elevation Model (DEM) data.
Filename: DB/Topo/NN_Shaded_Relief.img

TerraSpectra Geomatics generated the color shaded DEM from USGS NED 30-meter resolution DEM data.
Filename: DB/Topo/NN_Elevation.img

Figure 18. Navajo Nation Shaded Relief and Digital Elevation Model.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

SLOPE

N S E W

0 50 Miles

Map Scale 1:1,750,000

Photo taken in the Lukachukai Mountains at an area with steep slope resulting in erosion.

Legend

SLOPE, IN PERCENT

0 - 2	30.1 - 35.0
2.1 - 5.0	35.1 - 40.0
5.1 - 10.0	40.1 - 45.0
10.1 - 15.0	45.1 - 50.0
15.1 - 20.0	50.1 - 75.0
20.1 - 25.0	75.1 - 100.0
25.1 - 30.0	100.1 - 198.0

Source

TerraSpectra Geomatics generated the slope image from U.S. Geological Survey (USGS) National Elevation Dataset (NED) 30 meter resolution Digital Elevation Model (DEM) data.
Filename: DB/Topo/NN_Slope.img

Note: In ERDAS IMAGINE, the relationship between percentage and degree expressions of slope is as follows:

A 45 degree angle is considered a 100% slope
A 90 degree angle is considered a 200% slope

Slopes less than 45 degrees fall within the 1 - 100% range Slopes between 45 degrees and 90 degrees are expressed as 100 - 200% slopes

Figure 19. Slope (in percent) On the Navajo Nation.

PHYSIOGRAPHY

The word physiography is derived from the Greek word "*Physike*" meaning the science of nature. Physiography is the study of the earth's physical features and the processes that have shaped the landscape. A seminal classification system was developed by Nevin Fenneman in order to help understand and describe regional landscape characteristics. A map resulting from his work was compiled in 1946 for the entire United States at a scale of 1:7,000,000 and titled "Physical Divisions of the United States" (Fenneman, 1946 - S04180301). The United States was divided into eight major divisions, 25 provinces, and 86 sections representing distinctive areas having common topography, rock types and structure, as well as geologic and geomorphic history. The entire Navajo Nation is contained within the Intermontaine Plateaus division and Colorado Plateau province.

The Colorado Plateau province is further separated into physiographic sections on the basis of the distribution of canyons, rock benches, mesas, and plains. Fenneman divided the Colorado Plateau province into the following six sections: Grand Canyon, High Plateaus of Utah (rock terraces of southern Utah), Uinta Basin, Canyon Lands of Utah, Navajo section, and Datil section (Cooley et al., 1969 - S10290201). Figure 20 shows the boundaries of the sections within Fenneman's Colorado Plateau province that cover the Navajo Nation.

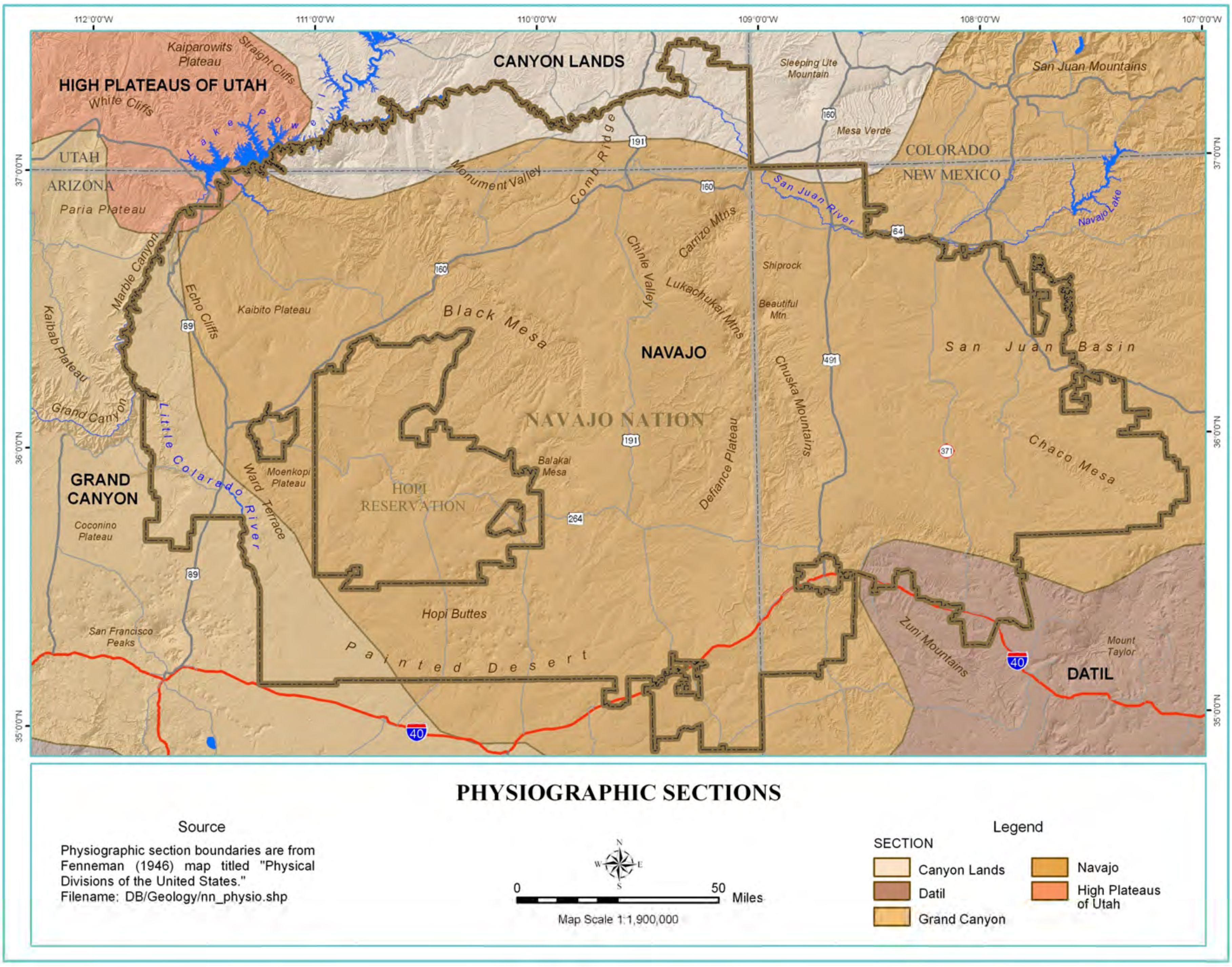


Figure 20. Physiographic Sections On the Navajo Nation.

The Defiance Plateau, Chuska, Lukachukai, and Carrizo Mountains form the area of the Defiance Uplift that splits the Navajo Nation physiographically and geologically. On the east side is the structurally low San Juan Basin, and on the west side is the structurally low Black Mesa Basin where Black Mesa is at the center. The Zuni Uplift at the location of the Zuni Mountains in New Mexico is another structural uplift at the southeastern margin of the Navajo Nation. The dramatic mesas of Monument Valley are the result of another broad uplift called the Monument Uplift.

These broad gentle upwarps are characteristic of the Colorado Plateau. The southern and eastern flanks of the Monument Upwarp in Arizona and Utah are where the Shinarump hosted uranium deposits are located, while the Defiance Uplift is the location of Morrison hosted uranium in Arizona and New Mexico.

This dataset is provided on the GIS Data DVD (DB/Geology/nn_physio.shp). Attributes include Fenneman division, province, and section codes and names.

GEOLOGY

URANIUM BEARING FORMATIONS ON THE NAVAJO NATION

The Navajo Nation occurs within the Colorado Plateau that is characterized by a relatively complete and continuous sequence of flat-lying Paleozoic and Mesozoic sediments (Figure 22) that are gently deformed by a series of folds and monoclines (Scarborough, 1981 – S09240202). These Mesozoic sediments are the dominant host of uranium and vanadium. Table 3 shows the amount of uranium production by host rock on or within one mile of the Navajo Nation.

Table 3. Uranium Production On or Within One (1) Mile of the Navajo Nation.

URANIUM BEARING HOST ROCKS	Pounds U_3O_8 Produced
Tertiary Bidahochi Formation	580
Cretaceous Dakota Sandstone	458,306
Cretaceous Toreva Formation	55,739
Jurassic Kayenta Formation	547
Jurassic Morrison Formation	98,662,464
Jurassic Navajo Sandstone	229
Jurassic Todilto Limestone	3,116,806
Triassic Chinle Formation	10,033,780
Total Navajo Nation (+ 1 Mile)	**112,328,451**

An understanding of uranium and where it is located on the Navajo Nation requires an understanding of the geology. The original sources of uranium are igneous rocks, but the ore deposits occur in sedimentary rocks. Broad, gentle upwarps are characteristic of the Colorado Plateau, and play a role in the location of uranium mines. The southern and eastern margins of the Monument Uplift in Arizona and Utah are the location of the uranium-mineralized Shinarump Member of the Upper Triassic Chinle Formation. At the center of the uplift the Chinle is eroded away. Likewise, the margins of the northern end of the Defiance Uplift and the northern flank of the Zuni Uplift are the locations of the uranium-mineralized Upper Jurassic Morrison Formation. Cameron, Arizona is the location of another outcropping of the Chinle Formation, where the uranium-mineralized Shinarump and Painted Forest Members are exposed. These rocks, being older, are exposed farther southwest from the very broad Black Mesa Basin. The uranium-mineralized upper sandstone member of the younger upper Cretaceous Toreva Formation is located near the center of the basin.

These areas characterize the southern part of the Colorado Plateau Uranium Province (Finch, 1996 - S05310701). These formations are fluvial or stream and alluvial plain deposited rocks, where more permeable channels of sand formed pathways for uranium-mineralized fluid that were surrounded by less permeable silts and clays. These ores are characterized by tabular sandstone deposits in this region. One likely source of the uranium in these deposits are thick volcanic and related sedimentary beds that overly these host formations. Volcanic arcs that were to the west and south of the province deposited thick fine-grained ash over the host formations. Uranium was later leached from the ash and perhaps precipitated by reduction in the lower host fluvial sandstones (Finch, 1996 - S05310701). However, the source and process of precipitation is still unsettled (McLemore and Chenoweth, 2003 - S08020606). The following is a discussion of the major uranium host sedimentary rocks as well as a brief discussion of the minor host rocks. Also presented are production figures for each of the formations in each of the areas of mineralization across the Navajo Nation.

<u>Triassic Chinle Formation</u>

The Chinle Formation is mineralized in the Cameron, Arizona and the Monument Valley, Arizona and Utah areas (Chenoweth and Malan, 1973 - S10280204). In the Cameron area, the uranium ore deposits are mined mostly from open pits from the fluvial sandstones of the Shinarump and Petrified Forest Members of the Chinle (Chenoweth, 1993 - S10100239). The ore deposits in the Petrified Forest Member were in sandstone lenses up to six feet thick and one mile in length that filled paleostream channels. The Shinarump deposits were similar but smaller. The Petrified Forest Member contained most of the uranium mines and produced about 1,150,000 pounds of uranium oxide; whereas the mines in the Shinarump produced about 55,700 pounds of uranium oxide. In the Bitter Springs area, mines in the Petrified Forest Member produced 718 pounds of uranium oxide.

In the Monument Valley area, uranium was only produced from the Shinarump Member of the Chinle (Gregg and Evensen, 1989- S10020208; and Chenoweth, 1991 - S03100502). In this region the Shinarump forms the many vertical walled mesas of the landscape as erosional remnants of a great fluvial system. Figure 21 shows the uneroded remnant Shinarump paleochannels in red (Young and Malan, 1964 - S06120601). Interpreted locations for eroded Shinarump paleochannels are shown in yellow. The locations of mapped AUMs are shown in black and illustrate the strong correlation with the remnant paleochannels.

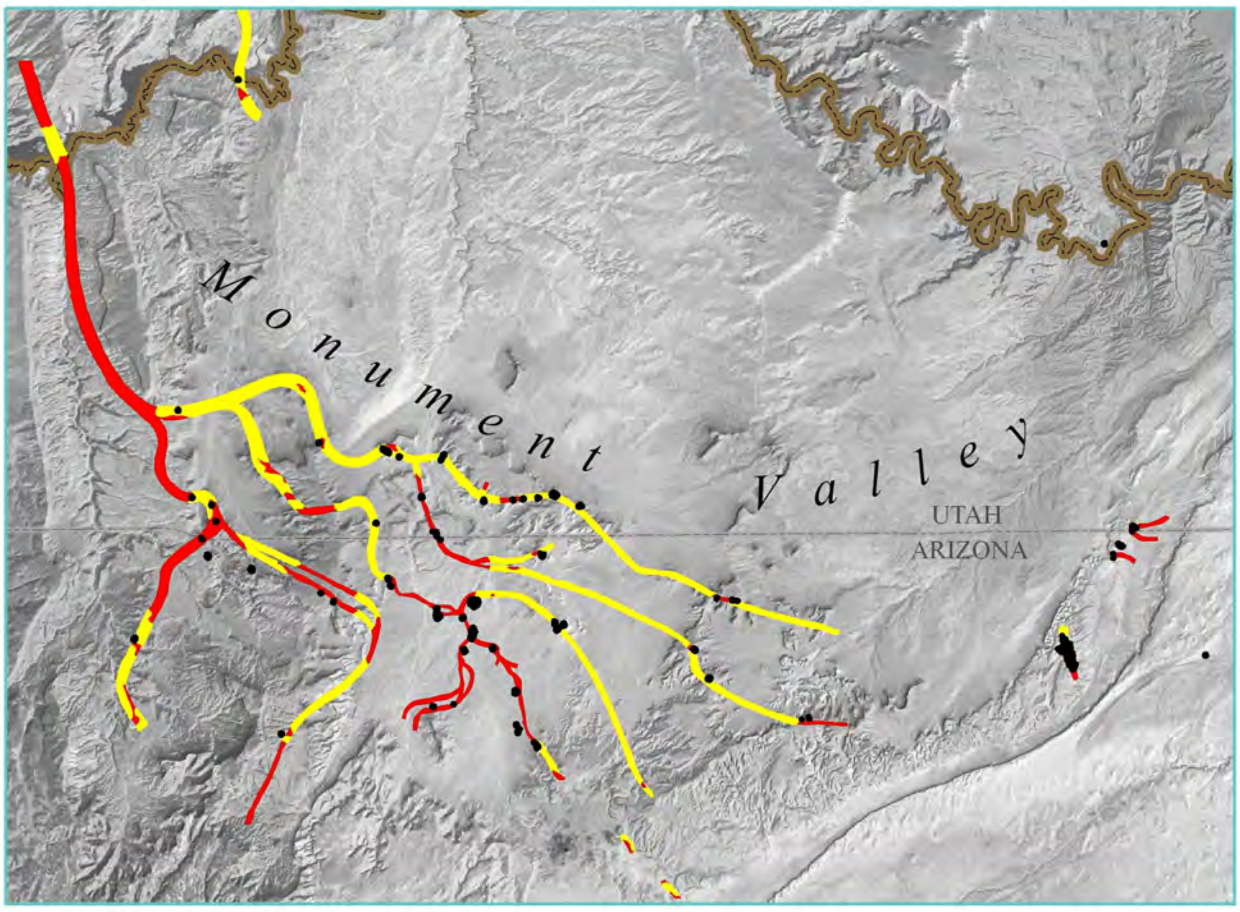
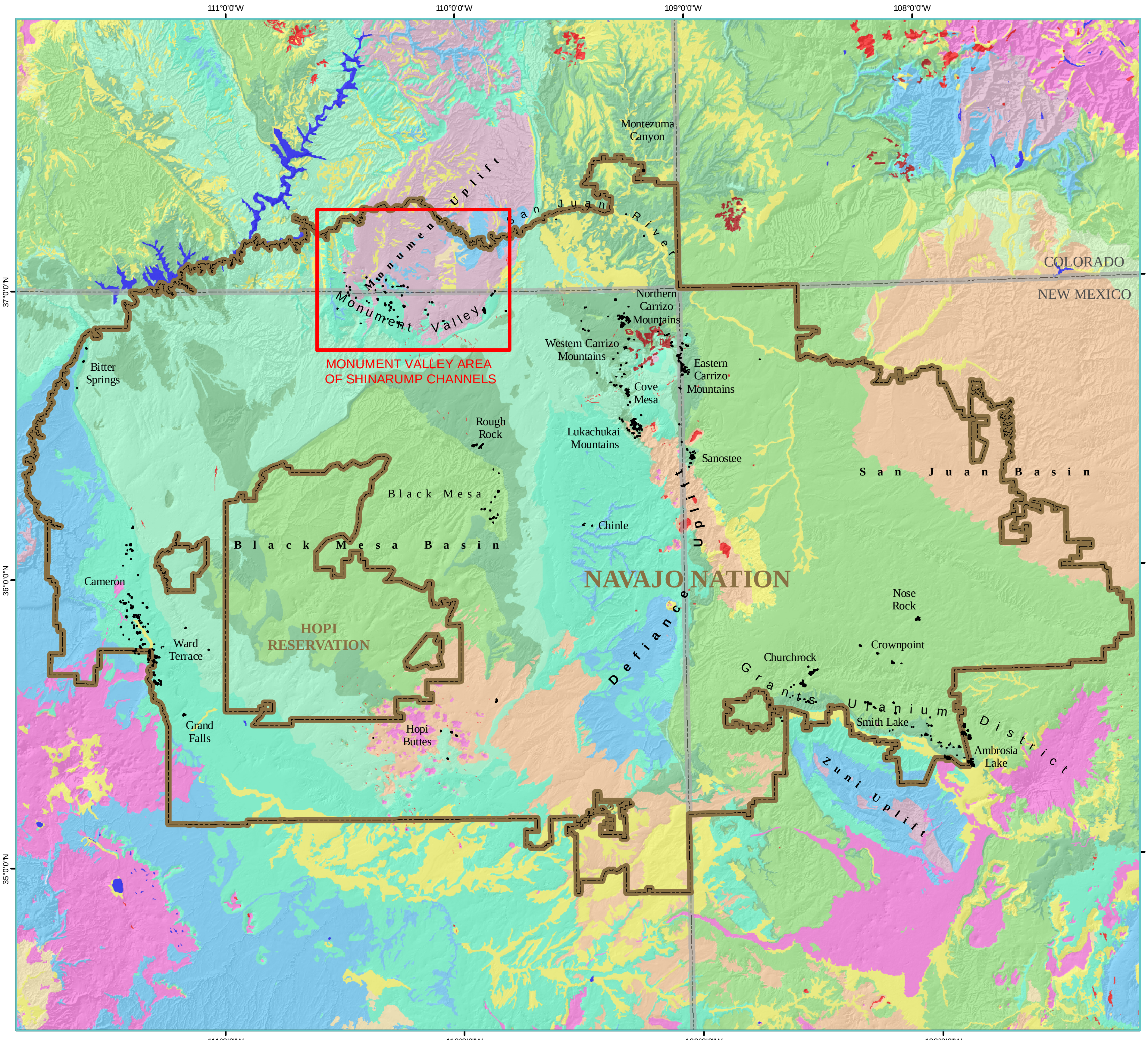


Figure 21. Shinarump Channels in the Monument Valley Area. Uranium-bearing channels of the Shinarump Member of the Triassic Chinle Formation (Young and Malan, 1964 - S06120601). Red represents the uneroded channels and yellow the estimated eroded channels. AUM locations are shown in black.

The ore deposits occurred in these channels and were up to 200 feet deep and 2,000 feet wide. The ore existed in lenses up to 8 feet thick and a few hundred feet long, with a length to width ratio up to 10 to 1. The Monument No. 2 mine, the largest producer in the region, was found in an inner scour channel that was two miles long, 700 feet wide, and 80 feet deep within an even larger Shinarump paleochannel. In the entire Monument Valley area, about 8.8 million pounds of uranium oxide were produced from the Shinarump Member.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

GEOLOGY

N W E S

0 50 Miles

Map Scale 1:1,750,000

View to the east across Red Wash from the Red Wash Point Mine site in the the Red Valley Chapter. The cliff on the left is the southern margin of King Tutt Mesa, showing an exposure of the Salt Wash Member of the Morrison Formation. On the right side across Red Wash is a full exposure of the Morrison from the Salt Wash Member in the wash wall to the Brushy Basin Member supporting the linear hill cutting across the photo in the background. Photo courtesy of TerraSpectra Geomatics.

Legend

List of Map Units

SEDIMENTARY ROCKS
- Quaternary
- Quaternary-Tertiary
- Tertiary
- Tertiary-Cretaceous
- Cretaceous
- Jurassic
- Jurassic-Triassic
- Triassic
- Paleozoic

IGNEOUS ROCKS
- Cenozoic Intrusives
- Cenozoic Volcanics
- Tertiary-Cretaceous Intrusives
- Cretaceous Volcanics

PRE-CAMBRIAN ROCKS
- Pre-Cambrian Rocks

OTHER
- Water
- Abandoned Uranium Mines

Source

The geologic map is from the RS/GIS Laboratory, College of Natural Resources, Utah State University (2004).

Filename: DB/Geology/NN_Geology.shp

Figure 22. Geologic Map of the Navajo Nation.

GEOLOGY (continued)

Jurassic Todilto Limestone

The Grants Uranium District is one of a few areas in the United States to produce uranium from limestone beds (Chenoweth, 1985 - S08020601). The Jurassic Todilto Limestone is found along the north side of Interstate 40 and below the Morrison rim to the north. It averages about 15 feet thick in this area (Hilpert, 1963 - S08250701). These limestone-hosted ore deposits were mostly mined in open pits. One Todilto Limestone deposit also occurs in the Sanostee area (Chenoweth, 1985 - S08250504).

Jurassic Navajo Sandstone

The Bluestone No. 1 mine, in the eastern part of Monument Valley, is the one known ore deposit on the Navajo Nation that is found in the Navajo Sandstone Formation (Chenoweth, 1991 - S10020202).

Jurassic Morrison Formation

The uranium-mineralized Morrison Formation is found in and around the Carrizo Mountains in Arizona and New Mexico, in the Rough Rock area west of Chinle, Arizona, and in the Sanostee area and along the northern flank of the Zuni Uplift in New Mexico. Chenoweth and Malan (1973 - S10280204) provide an overview of the Morrison Formation in northeastern Arizona, in which they report that the Morrison Formation is comprised of four members in ascending order: the Salt Wash, Recapture, Westwater Canyon, and Brushy Basin. In the Carrizo Mountain and Rough Rock areas it is the Westwater Canyon Member sandstones that are host to the uranium-vanadium ores. It ranges in thickness from 0 to 220 feet thick and is usually at least 180 feet thick where mineralized. Ore bodies are found in paleostream channels within lens shaped ore bodies that range up to 1,100 feet long, up to 400 feet wide and up to 22 feet thick. The ore bodies of the Lukachukai Mountains are the largest and contain less vanadium than other areas. On the northwest, north, and east flanks of the Carrizo Mountains ore bodies occur in clusters, while in the southern Carrizo's they are isolated deposits. In the Rough Rock area, ore bodies are few and small. In the Sanostee area the Salt Wash Member deposits are few and very small, whereas the Recapture Member is the largest producer (Chenoweth, 1985 - S08250504). The Enos Johnson 3 was the largest producing mine (134,438 pounds of uranium) in the Recapture and was the only mine outside the Grants Uranium District that produced during the post-AEC period (after 1970). The Morrison produced about 4.7 million pounds of uranium in Arizona and in the East Carrizo's and Sanostee areas of New Mexico.

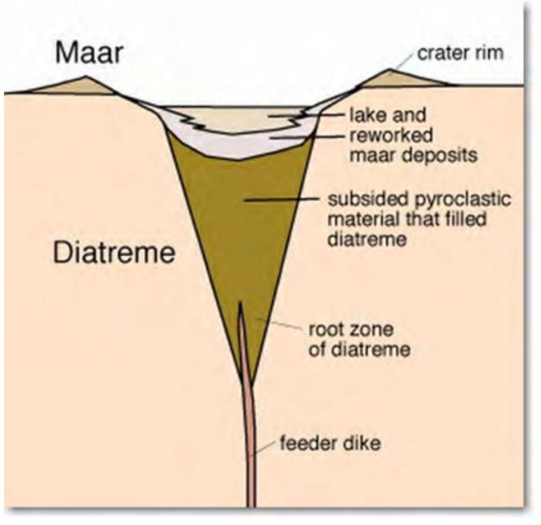
The Morrison in the Grants Uranium District dips gently northward from the Zuni Uplift into the San Juan Basin to the north, such that Morrison ore deposits are found at the surface along the rim north of Interstate 40 and at increasing depths northward (Hilpert, 1963 - S08250701). In this region, the Salt Wash Member is absent, leaving only the Recapture, Westwater Canyon, and Brushy Basin Members. Thickness ranges from 0 to 600 feet thick, averaging 450 feet. The Poison Canyon Mine, which was an economic producer, is a sandstone bed that is an intertongue of the Westwater Canyon within the Brushy Basin. The Westwater Canyon Member contains the largest number and size of ore deposits. In total, all members of the Morrison in this region produced about 94 million pounds of uranium.

Jurassic Kayenta Formation, Cretaceous Dakota Sandstone, Cretaceous Toreva Formation, and Tertiary Bidahochi Formation

Only two ore deposits (Hosteen Nez and Yellow Jeep No. 7A and 7B) are found in the Jurassic Kayenta Formation in the Ward Terrace area near Cameron, Arizona (Chenoweth, 1993 - S10100239). Several ore deposits are found in the 70 to 180 foot thick Cretaceous Dakota Sandstone in the Church Rock area. The Church Rock Mine is the most notable deposit as it is the only one to have produced from the Morrison and the Dakota (188,686 pounds of uranium).

Uranium ore deposits are found in the fluvial upper member of the Cretaceous Toreva Formation on the eastern side of Black Mesa (Chenoweth, 1990 - S10100236).

The Tertiary Bidahochi Formation is host to one productive uranium mine, the Morale Mine, found in the Hopi Buttes area of the Southern AUM Region. It is found in lake deposits of a volcanic crater (maar), likely above a buried volcanic neck (diatreme). Hopi Buttes is the largest such area in the world, containing more than 300 diatremes (Chenoweth, 1990 - S10020205)



Model of a Maar - Diatreme Volcano. Maars are low-relief volcanic craters formed by shallow phreatic explosions. The diatremes are subsurface pipes that fed the maars and were filled by volcanic material at the time of the eruption. They are now exposed because of lowering of the land surface by erosion. *From http://volcano.und.nodak.edu/vwdocs/*

GEOLOGIC MAPPING ON THE NAVAJO NATION

The geologic map (Figure 22) was produced from four state geologic maps for the Southwest Regional Gap Analysis Project. These maps were compiled at a map scale that is appropriate for regional applications. This geologic dataset is provided on the GIS Data DVD (DB/Geology/NN_Geology.shp)

In 1969, USGS published a Geological Survey Professional Paper 521-A that included a "Geologic Map of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah" at a scale of 1:125,000 (Cooley et al., 1969 - S10290201). Small portions of the map have been automated (e.g., Red Valley and Cove Chapters), but the entire map is not available in digital format. The USGS Navajo Nation Studies Program in Flagstaff, Arizona has begun a new geologic mapping project to remap the Navajo Nation. The Cameron, Arizona quadrangle is the first in a series of 30 x 60 minute quadrangles (1:100,000 scale) to be mapped, and is in a review draft stage. These maps will be made available by the USGS in GIS format.

GEOLOGY (continued)

KARST

Karst is a term used to describe a topography characterized by caves, sinkholes, and underground drainage. What distinguishes a karst landscape from other landscapes is the dominance of solution features in soluble sedimentary rocks, such as limestone and gypsum (Hill, 2003 - S06150302).

An important parameter in the evaluation of potential ground water pathways is whether an AUM site is located in an area of karst terrain. In karst formations, ground water moves rapidly through solution channels caused by dissolution of the rock materials. Therefore, hazardous substances associated with an AUM located in karst terrain would be more likely to reach the ground water (EPA, 1991 - S01230301).

Figure 23 shows areas of karst on and near the Navajo Nation. These data are from a digital version of the U.S. Geological Survey Open File Report 2004-1352, "Engineering Aspects of Karst." The open-file report is a map with accompanying explanatory text. The map shows areas containing distinctive surficial and subterranean features that have been developed by solution of carbonate and other rocks and are characterized by closed depressions, sinking streams, and cavern openings. These areas are commonly referred to as karst. Included on the map are areas of features analogous to karst, also called pseudokarst, which is karst-like terrain produced by processes other than the dissolution of rocks.

According to this regional karst dataset, there are some areas of karst carbonate rocks on the western and southernmost edges of the Western AUM Region, on the north central edge of the North Central AUM Region, and on the southern edge of the Eastern AUM Region. Volcanic pseudokarst also is present in the southernmost area of the Western AUM Region. Unconsolidated pseudokarst is shown extending north from the south central edge of the Northern AUM Region. This is the only area on the Navajo Nation that appears to have AUMs within karst or karst-like terrain.

This dataset is provided on the GIS Data DVD (DB/Geology/NN_Karst.shp). These data are intended for geographic display and analysis at the national level, and for large regional areas. The data should be displayed and analyzed at scales appropriate for 1:7,500,000-scale data. These map layers are intended to provide users with a national scale karst data coverage to use for graphic and demonstration purposes. These data are not intended for, and should not be used for, site-specific research.

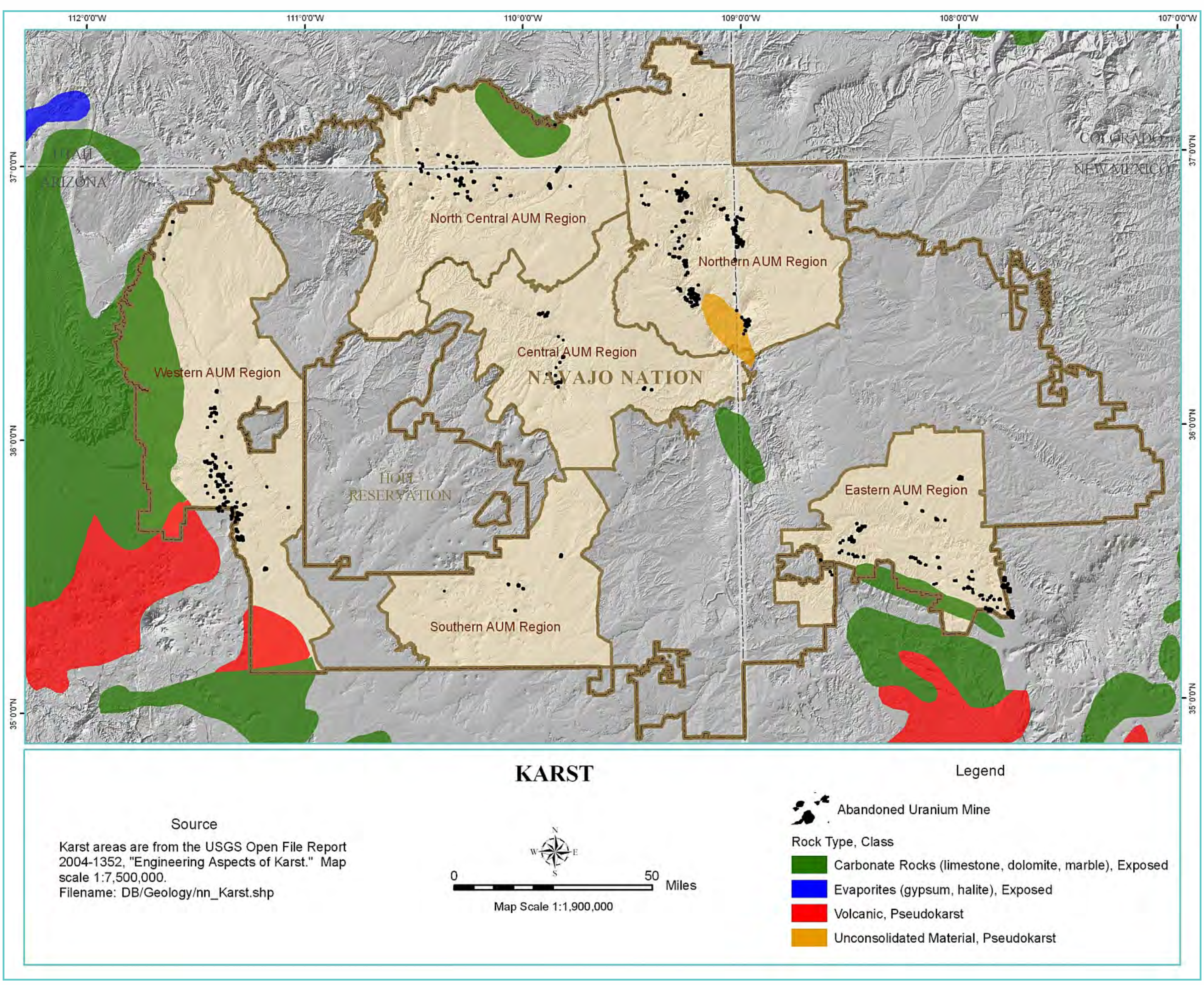


Figure 23. Karst Terrain On and Near the Navajo Nation.

GROUND WATER RESOURCES

Ground water is a potential pathway for the transport of hazardous substances. The ground water pathway is important when assessing the threat posed to drinking water and to populations relying on ground water as their source of drinking water. Evaluation of the ground water pathway requires a general understanding of the local geology and subsurface conditions. Of particular interest is descriptive information relating to the subsurface stratigraphy, permeability of the underlying strata, aquifers, and ground water use. There are two additional key considerations in the evaluation of ground water pathways: depth to aquifer and the presence of karst terrain.

COLORADO PLATEAU REGIONAL AQUIFERS

The Navajo Nation falls within the Colorado Plateau and Wyoming basin (referred to hereafter as Colorado Plateau) consolidated rock aquifer system, which covers northern Arizona, western Colorado, northwestern New Mexico, and eastern Utah (Figure 24). This area is approximately coincident with the Colorado Plateau physiographic province. The distribution of aquifers in the Colorado Plateau is controlled in part by the structural deformation and erosion that has occurred since deposition of the sediments that compose the aquifers. The principal aquifers in younger rocks are present only in basins, such as the San Juan basin. In uplifted areas, such as the Defiance Uplift, younger rocks have been eroded away, and aquifers are present in older rocks that underline more extensive parts of the Colorado Plateau area (Robson and Banta, 1995 - S06150301).

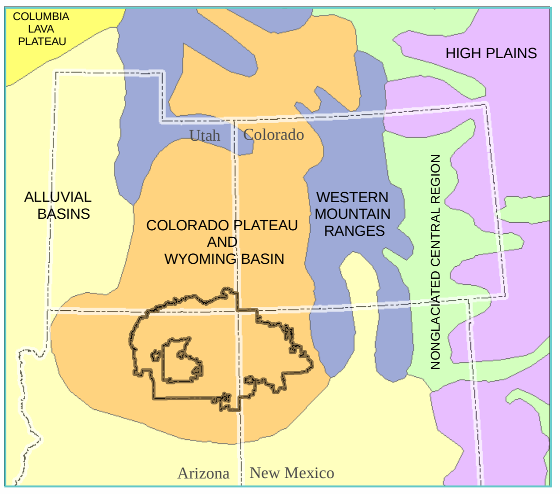


Figure 24. Ground Water Regions (from Robson and Banta, 1995 - S06150301).

For municipal water on the Navajo Nation there are several aquifers: Coconino (C), Navajo (N), Dakota (D), Morrison (M), Mesaverde, and numerous alluvial aquifers. The three primary water-bearing aquifers for the Navajo Nation are the D-, N-, and C-aquifers (Navajo Department of Water Resources [NDWR], 2000 - S12130214). Figure 25 shows the areas of aquifer recharge on the Navajo Nation and Figure 26 depicts water level contours and general direction of water movement on the Navajo Nation. These datasets are provided on the GIS Data DVD (DB/Water/NN_Aquifers.shp and NN_Water_Level_and_Direction.shp)

<u>D-Aquifer:</u> The Dakota, Cow Springs, Westwater Canyon Member of the Morrison Formation, and Entrada Sandstones form the D-multiple aquifer system. Recharge to the D-aquifer is from local precipitation and runoff from the Defiance Uplift to the east. Ground water flows to the west, and south from the areas of recharge (Figure 26). Some water is lost from the aquifer by downward leakage into the underlying aquifer. Water in the D-aquifer is of marginal to unsuitable chemical quality for domestic use (Arizona Department of Water Resources [ADWR], 2003 - S08030302).

<u>N-Aquifer:</u> The Navajo Sandstone and Wingate Sandstone are the main water-bearing units in the N-aquifer. The aquifer generally is under water-table conditions (unconfined). Precipitation falling on the exposed aquifer units is the main source of recharge for the N-aquifer. Groundwater in the N-aquifer moves southward and southeastward under Black Mesa. The flow divides under the mesa, moving westward and eastward. Water in the N-aquifer is of good quality and suitable for most uses (Cooley et al., 1969; ADWR, 2003; and NDWR, 2000).

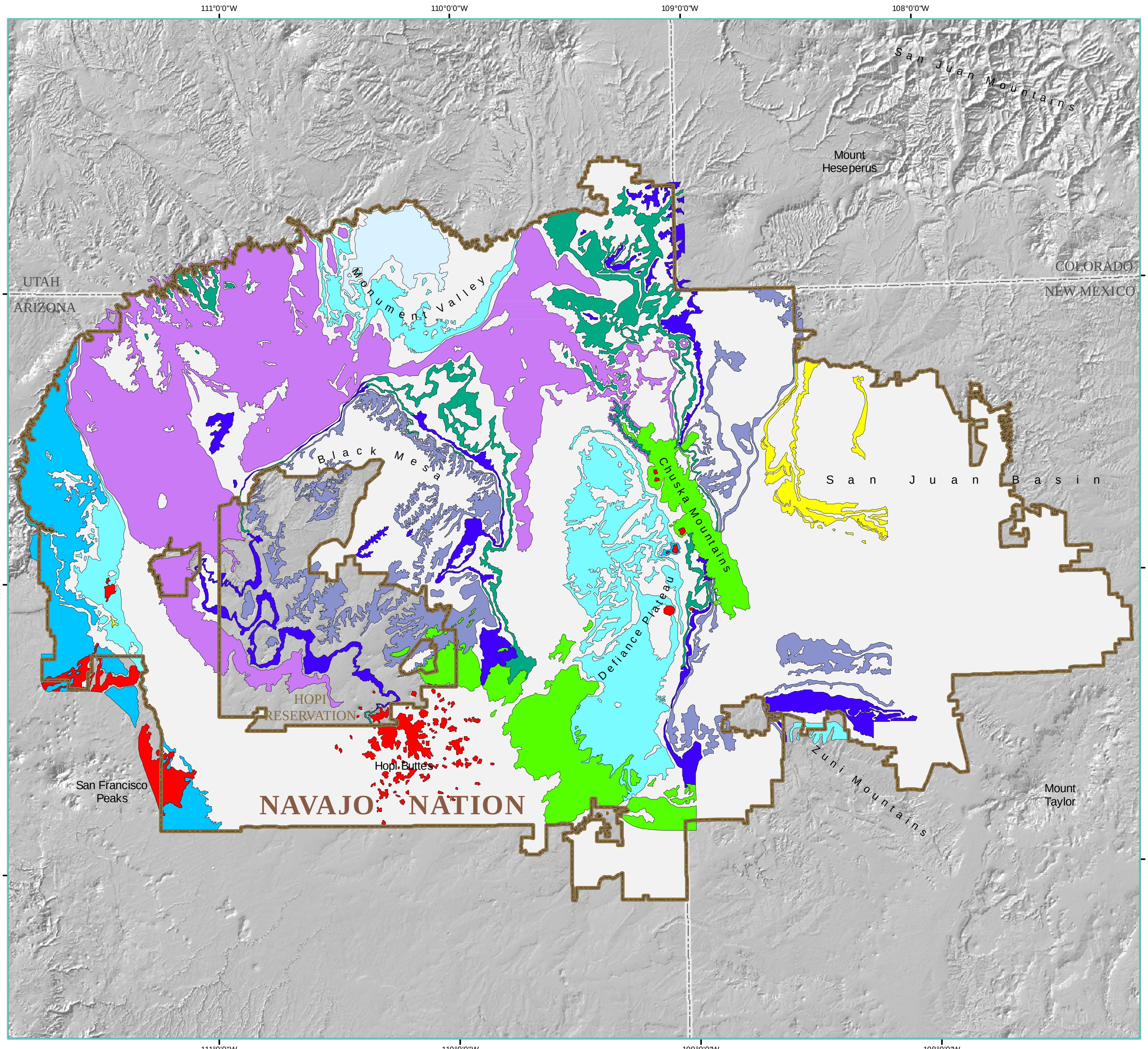
<u>C-Aquifer:</u> The Coconino Sandstone and its lateral equivalents, the De Chelly and Glorieta Sandstones, are the chief water-bearing units in the southern part of the Colorado Plateau. These units are interconnected hydraulically, and with the upper part of the Supai Formation, the Yeso Formation, and the San Andres Limestone, form the C-aquifer system (Cooley et al., 1969; NDWR, 2000). The C-aquifer is recharged by rainfall and by runoff from the Defiance Uplift. Ground water in the C-aquifer moves to the northwest from the large areas of inflow on the south and east (Cooley et al., 1969; ADWR, 2003, NDWR, 2000).

<u>Local Aquifers:</u> Water-yielding units excluded from the principal aquifers can form aquifers of local importance, but these units either are not extensive enough or are not productive enough to be considered as principal aquifers. In general, these rocks are considered to be confining units containing minor water-yielding units (Robson and Banta, 1995). Local aquifers are of importance for domestic water supplies where the three regional aquifers, the D-, N-, and C-aquifers are too deep or have unsuitable water quality (ADWR, 2003). Unconsolidated sediments and alluvial deposits, mainly of Quaternary age, have hydrologic importance (Cooley et al., 1969). The local aquifers include alluvial deposits, which occur in washes and stream channels throughout the basin and various sandstones. Water enters the alluvium as discharge from the D-, N- and C-aquifers, as streamflow infiltration, or as direct rainfall. In thicker sections the alluvium is a steady source of water, but smaller washes can go dry because of overuse or drought conditions (ADWR, 2003). The Quaternary deposits mostly are less than 30 feet thick, but are as thick as 225 feet in a few places. They form a discontinuous, rather permeable mantle. The alluvium is the chief source of water in dug wells; it is also the source of water in some springs and drilled wells. Depth to water in wells drilled in the alluvium is shallow, from a few feet to about 100 feet below the land surface (Cooley et al., 1969).

WATER SOURCES

Identifying the location of drinking water wells, the depth of the aquifer for the well, and if possible, the populations associated with a drinking water well are especially important information for contaminant pathway assessments. Depth to shallowest aquifer is an important measurement when evaluating potential contamination of ground water. An aquifer is defined by the EPA as a "saturated subsurface zone from which drinking water is drawn." The shallower a source of water, the higher the threat of contamination by hazardous substances (EPA, 1991 - S01230301).

The NDWR Water Management Branch maintains an extensive database of ground water well information, which is the primary data resource for ground water information on the Navajo Nation. For this NAUM Project, the NDWR wells dataset was augmented with data from the ADWR, New Mexico Office of the State Engineer, Utah Division of Water Rights, USACE water sample locations, USGS NHD, Geographic Names Information System, USGS Ground Water Site Investigations Database, DRGs, DOQQs, and the Church Rock Uranium Monitoring Project (CRUMP) sampled water sources. The database includes available information for: Well Identifiers (NDWR, alias names, PWSID, and USGS-ID), source of the well location, operator, type of well (artesian, mineral, observation, water or well; developed or natural spring; and unknown), use (agriculture, domestic, industry, livestock, municipal, other and unknown), well depth, and aquifer. Wells within four miles of an AUM were used as a target parameter in the HRS-derived model. Figure 27 shows the locations of water sources (symbolized by well type) within four miles of an AUM. The inset map provides an enlarged view to show better detail of the well type data and symbols. All well types were included in the analysis (only oil wells and possible oil wells were excluded). Wells outside the four mile buffers are also shown with a single point symbol. These datasets are provided on the GIS Data DVD (DB/Water/NN_Wells.shp and NN_Wells_4mi.shp).



ABANDONED URANIUM MINES AND THE NAVAJO NATION

AREAS OF AQUIFER RECHARGE ON THE NAVAJO NATION

N W E S

0 50 Miles

Map Scale 1:1,750,000

Legend

RECHARGE UNIT DESCRIPTION

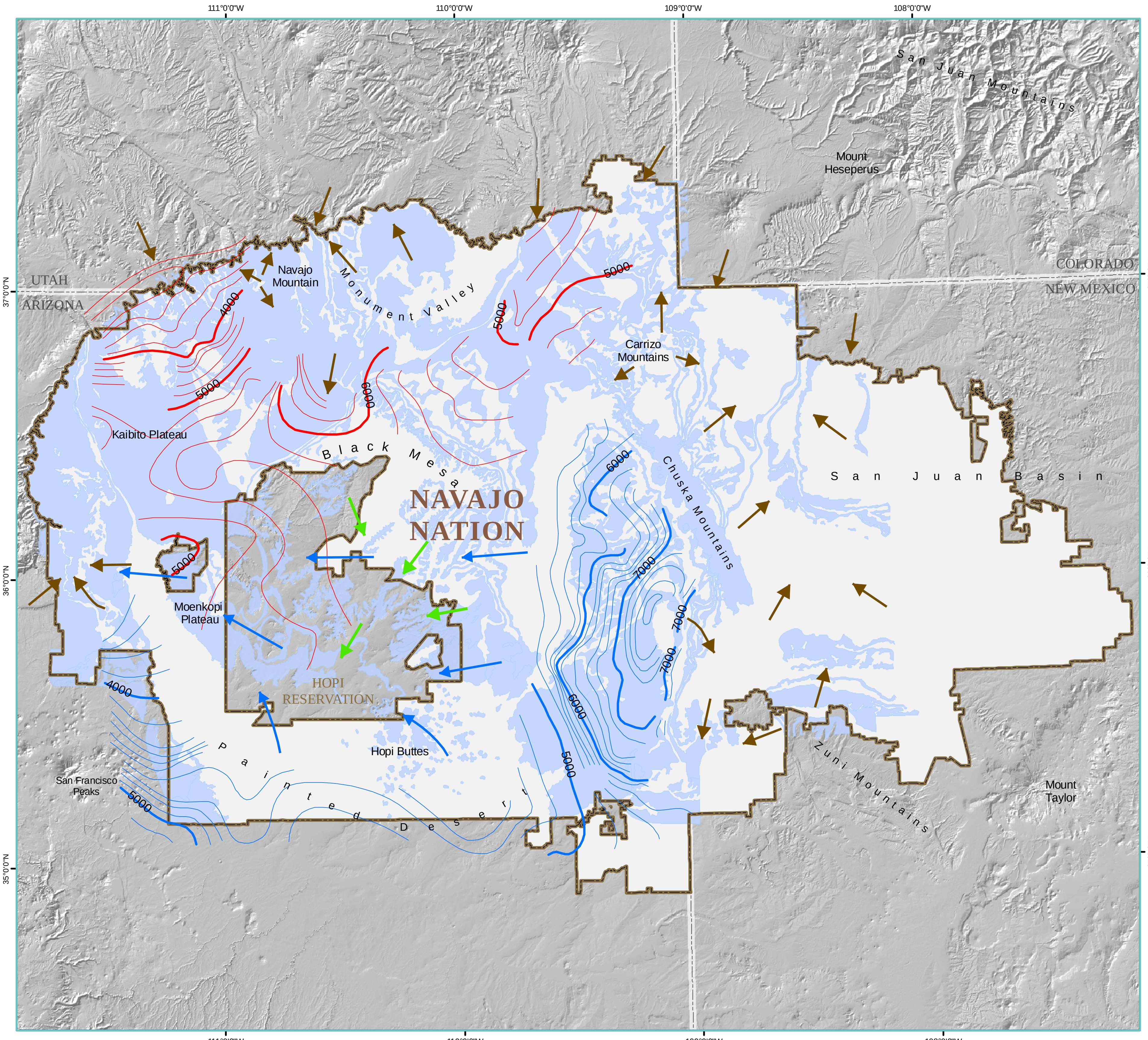
- Rocks receiving little or no recharge.
- Cedar Mesa Sandstone Member of the Cutler Formation
- Shinarump Member of the Chinle Formation, Moenkopi Formation and De Chelly Sandstone Member of the Cutler Formation in Monument Valley; Sonsela Sandstone Bed of the Petrified Foest Member and Shinarump Member of the Chinle Formation, Moenkopi Formation, and De Chelly Sandstone on the Defiance Plateau; Shinarump Member and Sonsela Sandstone Bed of the Petrified Forest Member of the Chinle Formation in the Zuni Mountains; Shinarump Member in the western part of the Navajo Nation.
- Chuska Sandstone and upper member of the Bidahochi Formation
- Rocks of the D multiple-aquifer system. Dakota Sandstone, Cow Springs Sandstone and Westwater Canyon Member of the Morrison Formation; and the Entrada Sandstone in the southern and central parts of the Navajo Nation.
- Kaibab Limestone, Toroweap Formation, and Coconino Sandstone
- Mesaverde Group. Toreva Formation and Yale Point Sandstone in Black Mesa; Gallup Sandstone and Point Lookout Sandstone in San Juan Basin.
- Salt Wash and Westwater Canyon Members of the Morrison Formation, Summerville Formation, and Bluff Sandstone in the northeastern part of the Navajo Nation; Salt Wash Member of the Morrison Formation, Summerville Formation, Bluff Sandstone, and Entrada Sandstone in the northwestern and central parts of the Navajo Nation.
- Rocks of the N multiple-aquifer system. Navajo Sandstone, sandy facies of the Kayenta Formation, and Lukachukai member of the Wingate Sandstone.
- Ojo Alamo Sandstone, Pictured Cliffs Sandstone, and Cliff House Sandstone
- Volcanic Rocks

Source

Areas of recharge and discharge of aquifers on the Navajo Nation is from Plate 5 "Map Showing Water-Level Contours, Direction of Water Movement, and Areas of Recharge and Discharge of Aquifers in the Navajo and Hopi Indian Reservations" in U.S. Geological Survey Professional Paper 521-A "Regional Hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah", by M.E. Cooley and others, 1969.

Filename: DB/Water/NN_Aquifers.shp

Figure 25. Areas of Aquifer Recharge On the Navajo Nation.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

WATER LEVEL CONTOURS, DIRECTION OF WATER MOVEMENT, AND AREAS OF RECHARGE OF AQUIFERS ON THE NAVAJO NATION

0 50 Miles

Map Scale 1:1,750,000

Source

Water level contours, direction of water movement, and areas of recharge of aquifers on the Navajo Nation are from Plate 5 "Map Showing Water-Level Contours, Direction of Water Movement, and Areas of Recharge and Discharge of Aquifers in the Navajo and Hopi Indian Reservations" in U.S. Geological Survey Professional Paper 521-A "Regional Hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah", by M.E. Cooley and others, 1969.

Filenames:
DB/Water/ NN_Water_Level_and_Direction.shp
DB/Water/NN_Aquifers.shp

Legend

WATER LEVEL CONTOURS

- 7000 — C Aquifer Water-level Contour (contour interval 100 and 200 feet)
- 4000 — N Aquifer Water-level Contour (contour interval 200 feet)

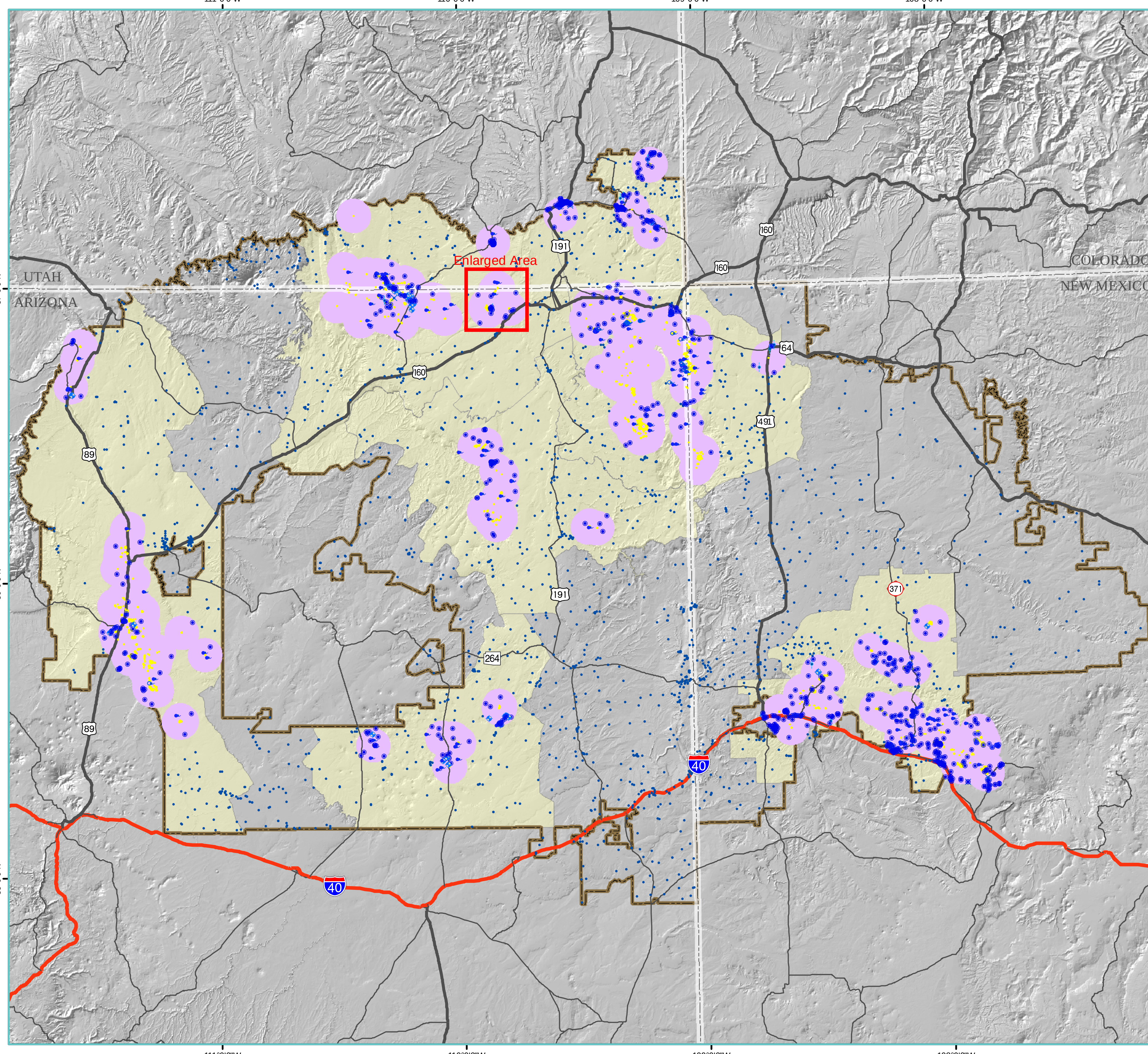
DIRECTION OF WATER MOVEMENT

- C Aquifer Direction of Ground Water Movement
- Near Surface Direction of Ground Water Movement; Near Surface Direction
- D Aquifer Direction of Ground Water Movement

RECHARGE

- Rocks Receiving Recharge
- Rocks Receiving Little or No Recharge

Figure 26. Water Level Contours, Direction of Water Movement, and Areas of Recharge of Aquifers On the Navajo Nation.

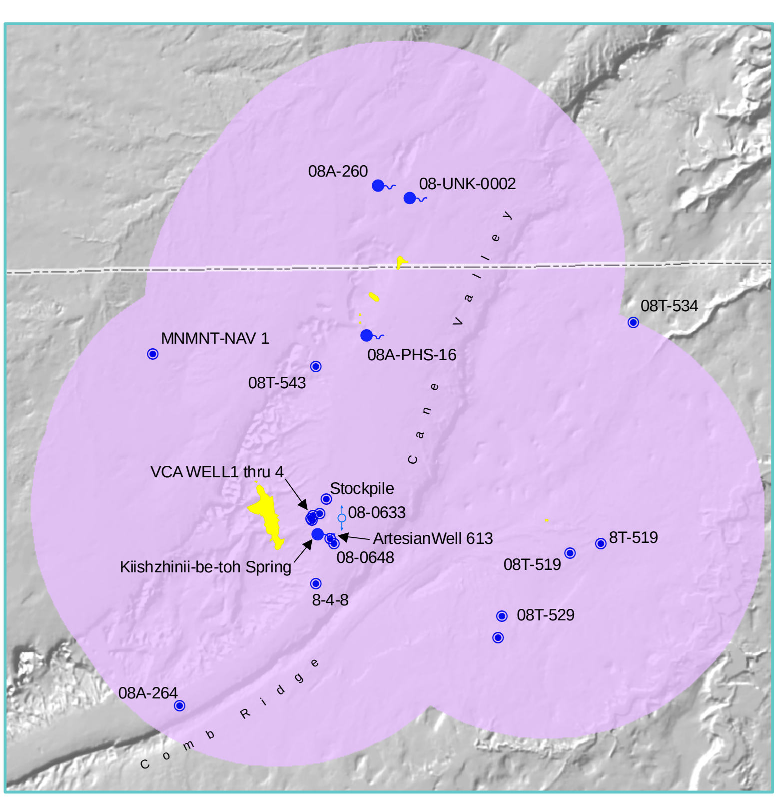


ABANDONED URANIUM MINES AND THE NAVAJO NATION

WATER SOURCES WITHIN FOUR MILES OF AN ABANDONED URANIUM MINE AND ACROSS THE NAVAJO NATION

0 50 Miles

Map Scale 1:1,750,000



Enlarged view of water sources within four miles of AUMs symbolized by "well type" in the Cane Valley, Arizona and Utah area.

Legend

TYPE OF WELL WITHIN 4 MILES OF AUM
- Artesian Well
- Developed Spring
- Natural Spring
- Unknown
- Water Well
- Well

WELLS OUTSIDE THE 4 MILE BUFFER
- All Wells

- Abandoned Uranium Mine (AUM)
- 4 Mile Buffer Around AUM

Sources

Water sources are primarily from the Navajo Department of Water Resources and augmented using data from the Arizona Department of Water Resources, New Mexico Office of the State Engineer, Utah Division of Water Rights, U.S. Army Corps of Engineers water sample locations, USGS/EPA National Hydrography Dataset, USGS Geographic Names Information System, USGS Ground Water Site Investigations Database, USGS topographic quadrangles, and USGS digital orthophotography.

Filenames: DB/Water/ NN_Wells_4mi.shp and DB/Water/NN_Wells.shp

Figure 27. Water Sources Within Four Miles of an AUM and Across the Navajo Nation.

AQUIFER SENSITIVITY

Blanchard (2002 - S01200301) cites the definition of aquifer sensitivity as “the relative ease with which a contaminant applied on or near a land surface can migrate to the aquifer of interest. Aquifer sensitivity is a function of the intrinsic characteristics of the geological materials, and the overlying unsaturated zone.” Blanchard developed a model of aquifer sensitivity for the Navajo Nation using broad physical characteristics to describe aquifer sensitivity to surface and near surface contaminants.

The factors used in the Blanchard model include geology, precipitation, soil properties, slope of the land surface, and stream courses. Each of these factors is shown to the left in Figure 28. Blanchard stated that the largest limitation to this method was inadequate information on depth to the uppermost aquifer. The following describes the inputs used in Blanchard’s (2002) assessment.

The geology was developed from Cooley et al. (1969 - S10290201). It identifies where consolidated rocks are recharged and unconsolidated deposits are at the surface and facilitate aquifer contamination (pink on the geology map in Figure 28). Geology acts as a surrogate for impact of the vadose or unsaturated zone. Yellow identifies areas that do not contribute to recharge. The eastern portion of the Eastern AUM Region was not included in the Cooley map; in order to not underestimate the contamination potential of this part of the study area, Blanchard assigned it to the “significant potential” category.

Water provides the solvent in which contaminants are transported from the land surface to the aquifers. Precipitation is the surrogate for recharge where greater precipitation results in greater potential for contaminants to infiltrate the land surface. In the precipitation map in Figure 28, pink indicates high precipitation, green indicates relatively uniform intermediate precipitation, and blue indicates the least precipitation and potential to facilitate aquifer contamination.

Several soil properties contribute to the potential to facilitate aquifer contamination, including: texture, infiltration rate, drainage, and organic content. These properties were developed from a modified version of the STATSGO, or State Soil Geographic database created by the U.S. Department of Agriculture, National Resources Conservation Service (Schwarz and Alexander, 1995 - S08030303). Blanchard further explains that finely textured soil reduces the rate at which water and contaminants move through the soil (low hydraulic conductivity). High infiltration rates indicate a soil that permits a high volume of water to enter from the land surface. Lower drainage rates indicate a higher resident time. Soil organic content affects microbial activity and sorption. Blanchard found that soils on the Navajo Nation had an organic content of less than 2 percent, indicating minimal microbial activity and sorption. With no relative difference across the Navajo Nation, organic content was not used. In the soil properties map (shown in Figure 28) blue indicates areas with the least potential, where the soil is fine-grained, has a low infiltration rate, is poorly drained, and has a high organic content. Green indicates areas with intermediate potential, and pink indicates areas with the most potential.

Land surface slope affects the ability of precipitation to infiltrate soil. Slopes less than 6 degrees (pink in the slope map in Figure 28) permit precipitation to stay in contact longer with the soil, thereby increasing infiltration of water into the land surface. Conversely, slopes of 6 to 12 degrees (intermediate slopes shown in green) and steep slopes greater than 12 degrees (blue in the slope map at left) minimize infiltration because water runs off quickly.

Blanchard developed buffered fourth-order and higher stream courses from USGS DEM’s (shown in Figure 28). Stream courses, wherever they occurred, were assigned the greatest potential to facilitate contamination because they concentrate runoff and have flat slopes. Floodplain and terrace soils are also composed of materials that facilitate contamination.

Blanchard summed the assigned numeric scores for each of the precipitation, soil properties, and slope layers and multiplied by the geology score (1 for facilitates contamination and 0 for does not facilitate contamination). A final aquifer sensitivity map was developed from these scores and is shown on Figure 29. The highest scores represent the most potential for contamination, low scores have the least potential, and intermediate scores produce intermediate potential. The insignificant category represents areas where the geology score was zero, or were not areas of recharge to bedrock aquifers, and/or were not areas of unconsolidated deposits (stream alluvial deposits).

This dataset is provided on the GIS Data DVD (DB/Water/NN_Aquifer_Sensivitiy.shp).

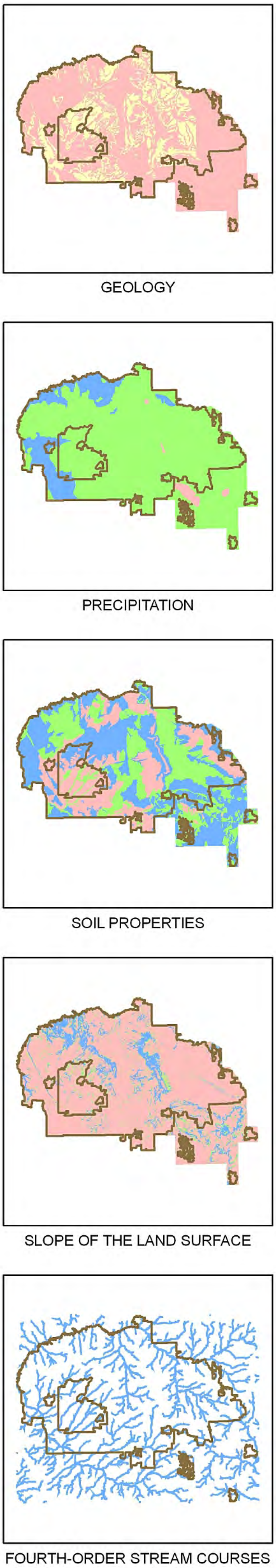
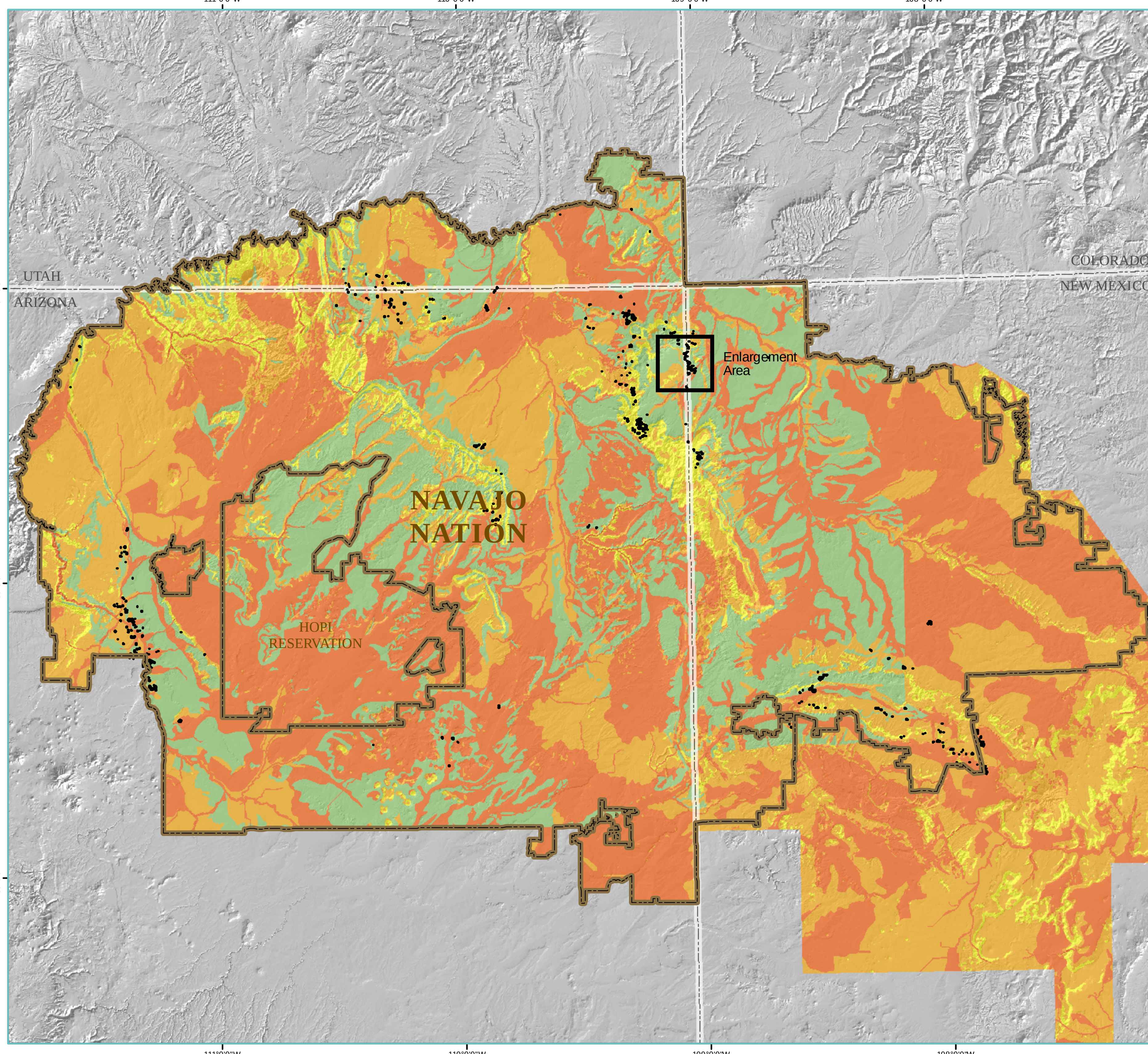


Figure 28. Inputs to Aquifer Sensitivity



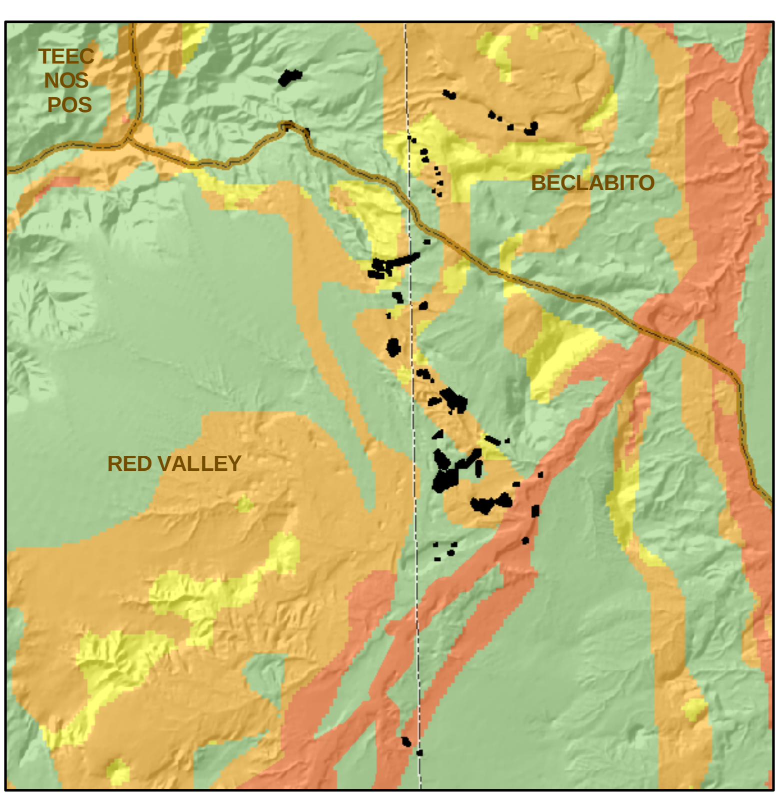
ABANDONED URANIUM MINES AND THE NAVAJO NATION

AQUIFER SENSITIVITY

N W E S

0 50 Miles

Map Scale 1:1,750,000



Enlarged view of AUMs and aquifer sensitivity in the northeast portion of the Red Valley Chapter area.

Legend

Abandoned Uranium Mines

Aquifer Sensitivity Class

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

Sources

Aquifer sensitivity was developed and provided by Paul Blanchard (2002), U. S. Geological Survey, Water Resources Division in Albuquerque, New Mexico. The data are from the Water-Resources Investigations Report 02-4051 titled "Assessments of Aquifer Sensitivity on Navajo Nation and Adjacent Lands and Ground-Water Vulnerability to Pesticide Contamination on the Navajo Indian Irrigation Project, Arizona, New Mexico, and Utah."

Aquifer sensitivity, which is shown above on a shaded relief image, refers to the potential to contaminate the ground water - ranging from "insignficant" to the "most" potential. This was determined by an investigation of the geology, precipitation, soils, slope, and stream courses of the area.

Filename: DB/Water/NN_Aquifer_Sensitivity.shp

Figure 29. Aquifer Sensitivity on the Navajo Nation.