TRANSPORTATION

Federal and state highways that provide access to the Navajo Nation include: U.S. Interstate 40 to the south, U.S. Highway 89 to the west, U.S. Highway 160 to the north, and U.S. Highway 491 to the east. A network of state highways cross the Navajo Nation and are shown in Figure 13. Highway data for the Navajo Nation was extracted from the 2002 National Transportation Atlas Database, (NTAD) and is provided on the GIS Data DVD (DB/Trans/NN_Highways.shp).

Most of the roads on the Navajo Nation are unpaved and are part of the Indian Reservation Roads (IRR) Program. IRR are public roads which provide access to and within Indian reservations, Indian trust land, and restricted Indian land. According to the 2000 BIA Road Inventory Database, the Navajo IRR system consists of 9,826 miles of public roads. Of that, the Navajo Nation maintains 1,451 miles of paved road, and 4,601 miles of gravel and dirt roads. Weather conditions often make many of those roads impassable. In the winter, snow and rain may prohibit access. Because of the prolonged drought, some of these roads have become nearly impassable due to sand dunes, rocky surfaces and deep holes (Navajo Nation, 2002 - S05240717).

The Navajo Nation's roads have been administered by the BIA Navajo Area Branch of Roads (BOR). Figure 13 shows Indian Service Routes on the Navajo Nation. These paved BIA routes are from a GIS dataset of roads obtained from the BIA in 2003. Many of the paved roads were modified by photointerpreting digital orthophotos to adjust or add road features. Figures 10 and 11 show before and after adjustments based on photo interpretation of DOQQs. These modifications were only made to paved roads in Chapters with mapped AUMs. The adjusted dataset is provided on the GIS Data DVD (DB/Trans/NN_Paved.shp).

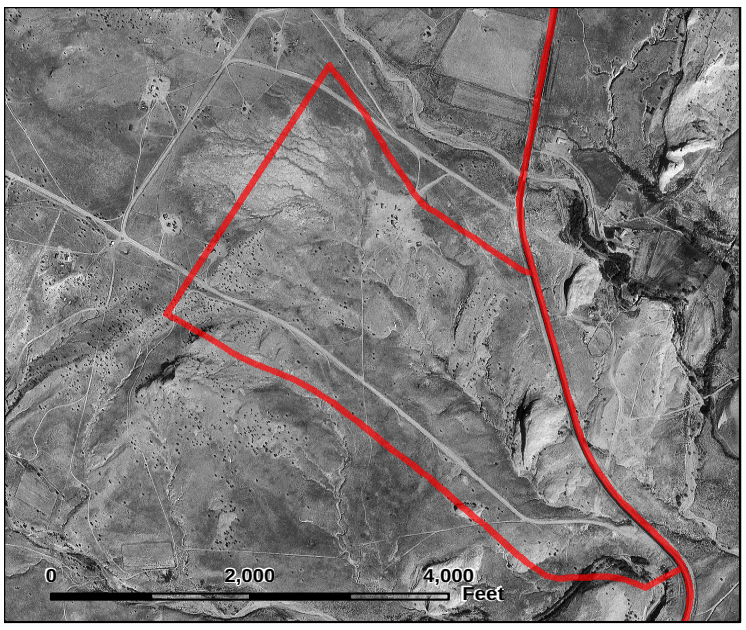


Figure 10. Example of Unadjusted BIA Roads.

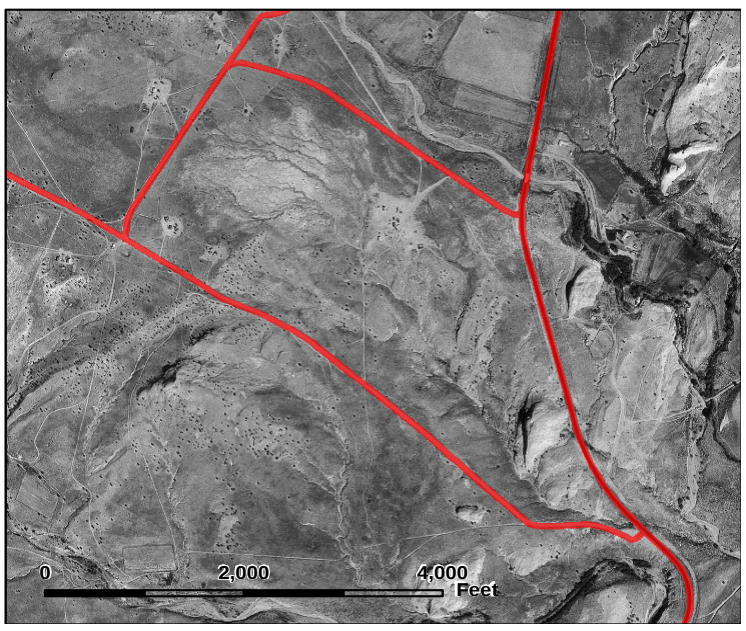


Figure 11. Example of Adjusted BIA Roads.

The Navajo Department of Transportation (NDOT) was created in 1986 by the Navajo Nation Council. NDOT is working to establish the Navajo Nation's road program, which includes development and maintenance of an IRR GIS database. BIA contracted to have aerial photography flown for the Navajo Nation in 2005, and new color orthophotography was generated. The new orthophotography, along with Global Positioning System (GPS) field measurements, will allow development of a more accurate IRR database.

The location of roads has significance to the NAUM Project. The process of locating AUMs was often assisted by following roads on the DOQQs and DRGs. This was particularly true for productive AUMs that required the ore to be hauled by truck. Haulage roads may also have significance as a potential contaminant source. In Figure 12, the Monument No. 2 AUM (outlined in black) is shown with the DOE aerial radiation survey excess Bismuth-214 results. Of note are the elevated excess Bismuth-214 contours that extend beyond the boundary of the AUM and that are coincident with the haulage road.

During the 1950's the U. S. Atomic Energy Commission (AEC) funded a program to construct and/or improve access roads to exploration and mining areas. Five projects in Arizona were on the Navajo Nation in Apache County. These roads provided better access to several uranium mining areas, especially the Lukachukai Mountains, eastern Carrizo Mountains, and the Cane Valley area of Monument Valley (Chenoweth, 1989 - S10100213).

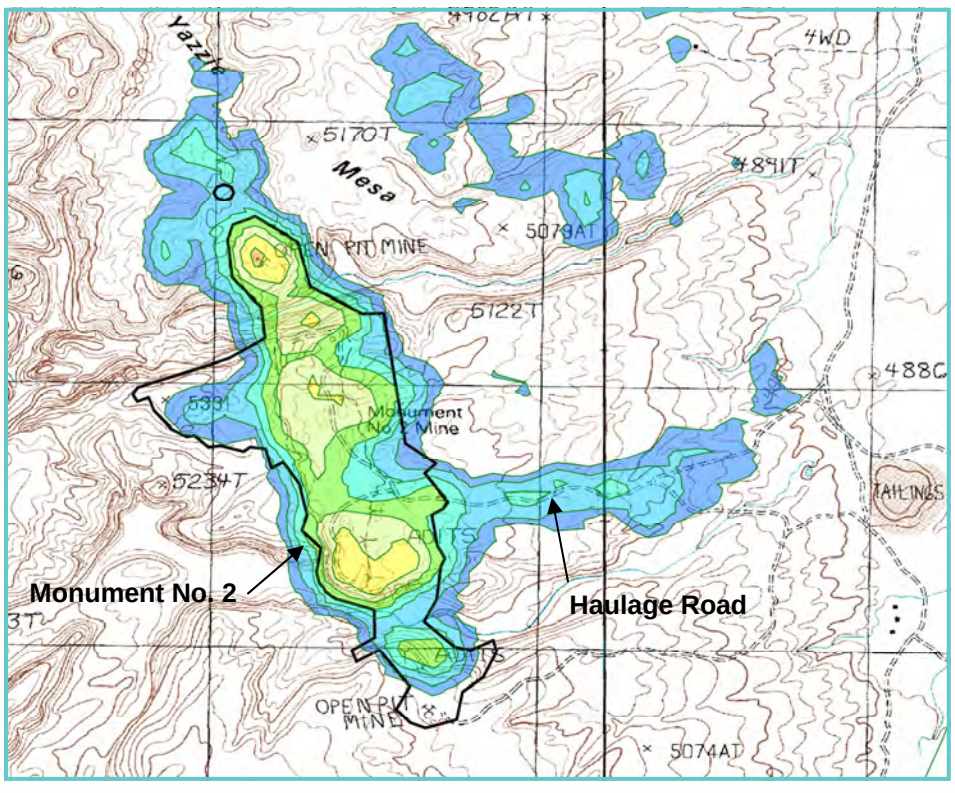


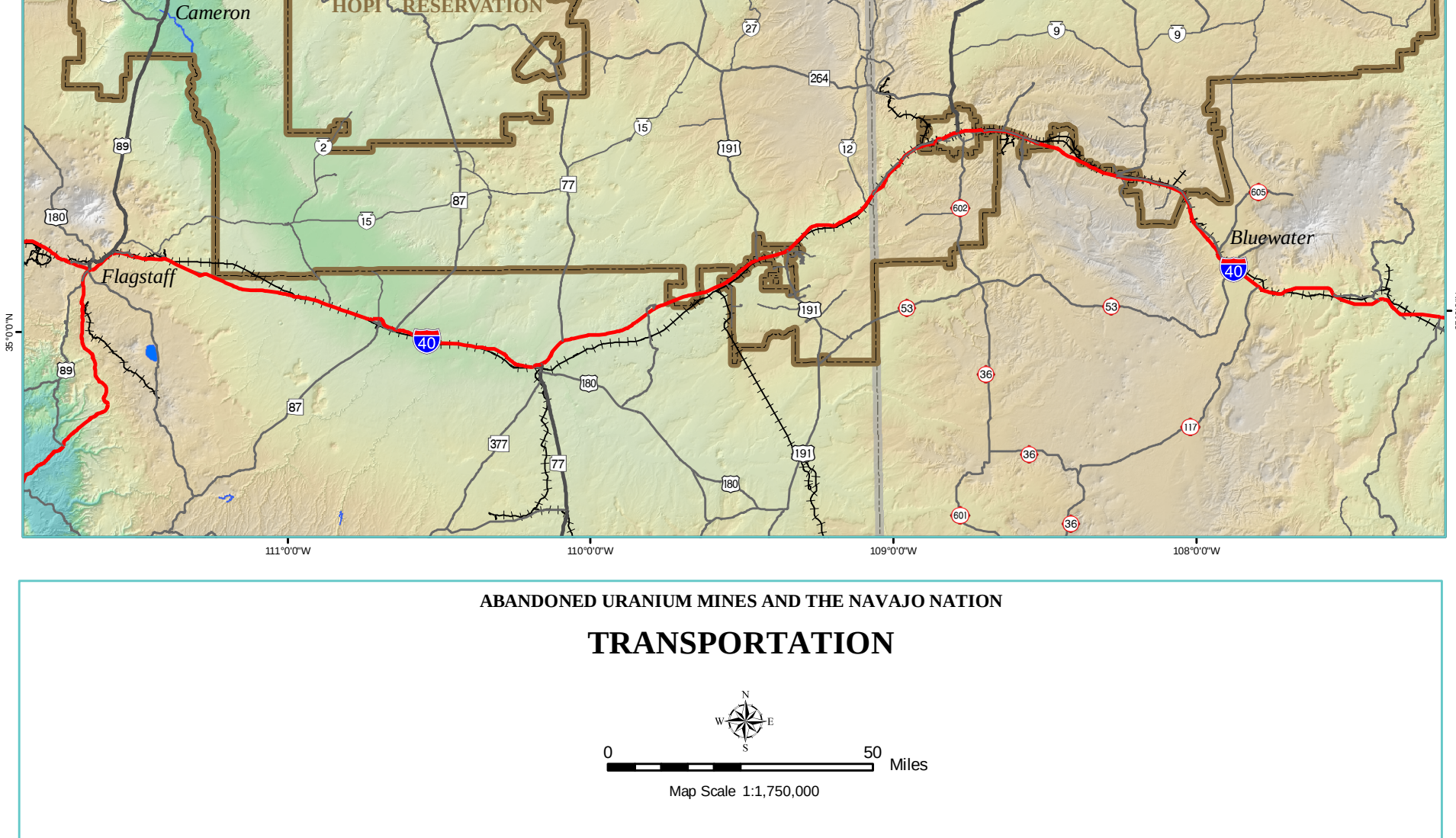
Figure 12. Elevated Excess Bismuth-214 Along Haulage Road.

Railways also played a role in the transport of uranium ore from the Navajo Nation. For example, shipments to the Bluewater ore-buying station were made from some AUMs in the Cameron area. The ore was trucked to Flagstaff and shipped by the Atkinson Topeka and Santa Fe Railway to a siding near Bluewater, where the ore was transferred to trucks for the short haul to the buying station (Chenoweth, 1993 - S10100239). These ore transfer locations may have residual radionuclides, similar to those found at the Cove and Climax Transfer Stations.

Railways that are on or near the Navajo Nation are shown on Figure 13. These data are from the Federal Railroad Administration (FRA) and the Bureau of Transportation Statistics NTAD and are provided on the GIS Data DVD (DB/Trans/NN_rail.shp).

ABANDONED URANIUM MINES AND THE NAVAJO NATION

TRANSPORTATION



0 50 Miles

Map Scale 1:1,750,000

Ore trucks, Lukachukai Mountains, Arizona. Photo courtesy of William L. Chenoweth

Legend

- Railroad

ROADS AND ROUTE SHIELDS

- U.S. Interstate Route
- U.S. Route
- Arizona State Route
- New Mexico State Route
- Utah State Route
- Indian Service Route

Sources

Highways for the Navajo Nation were extracted from the National Highway Planning Network, developed by the Federal Highway Administration (FHWA) and the Bureau of Transporation Statistics (BTS) National Transportation Atlas Database, 2002. Filename: DB/Trans/NN_Highways.shp

Paved roads are from the U.S. Bureau of Indian Affairs (BIA) and modified by adjustment or photointerpretation of DOQQs. Changes were only made for Chapters that have AUMs.
Filename: DB/Trans/NN_Paved_Roads.shp

Railroads are from the Federal Railroad Administration and BTS.
Filename: DB/Trans/NN_rail.shp

Figure 13. Paved Roads and Railroads On and Near the Navajo Nation.

CLIMATE

Temperature, precipitation, and wind conditions that characteristically prevail in a region play an important role in contaminant pathway assessments. These climate factors on the Navajo Nation are discussed in this section.

Other climate impacts are related to the drought conditions the Navajo Nation has been experiencing in recent years. Drought and temperature increases due to climate change affect the amount of vegetation growing on sand dunes. Sand dunes cover approximately one-third of the semi-arid Navajo Nation on the southern Colorado Plateau. Sand supplies here are abundant from both sandstone bedrock and dry river channels. In this area winds capable of moving sand are dominantly from the southwest (Figure 14). The risk of sand dune mobilization within this region is high given: 1) current severe drought conditions; 2) climate variability based on known historic records (such as the drought during the early 20th century); 3) the overall decrease in regional precipitation for this last century; 4) the apparent drying trend on the Navajo Nation, and; 5) the possibility of climate change. Current work indicates that reactivation of stabilized sand is occurring in many areas of the Navajo Nation where the vegetation growing on the dunes, and holding them in place, are dying. Dune mobility is a cause for concern, and is today inundating housing and causing transportation problems. It also may be contributing to a loss of rare and endangered native plants and grazing land, and lower air quality from periodic dust storms (Hiza, 2003 - S05270701). These same climatic variables may have similar effects on vegetation cover that may be stabilizing wind-blown dust from AUM debris or soil cover at AUM reclamation sites. This indicates that the air pathway may take on greater importance as desertification increases.

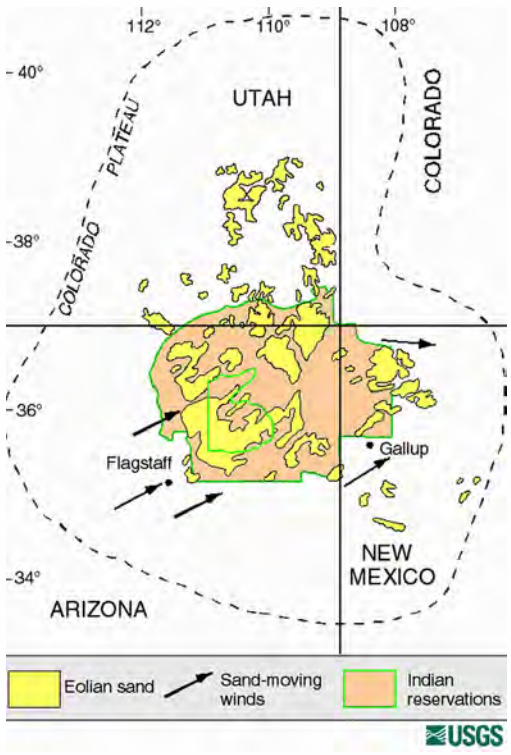


Figure 14. Location of Eolian Sand and Direction of Wind on the Navajo Nation (from Hiza, 2003 - S05270701).

PRECIPITATION

Precipitation is an important parameter to consider when evaluating potential migration pathways. Heavy precipitation provides a driving force to carry hazardous substances through the soil to the ground water, or to carry hazardous substances away from a site through runoff. Data on the intensity, duration, and frequency of storms is needed to calculate the volume of surface water run-on or run-off. If there is flooding potential, the flood characteristics (e.g. stagnant backwater or scour potential due to flow) would be useful information for assessing AUM sites. Conversely, dry conditions can enhance the wind erosion potential for certain soil types, increasing the potential for air transport.

Precipitation throughout Arizona and New Mexico is locally governed to a large extent by elevation and orographic effects and the season of the year. From November through March storm systems from the Pacific Ocean cross the state. These winter storms occur across the Navajo Nation in the higher mountains, where much of the winter precipitation falls as snow. Summer rainfall begins early in July and usually lasts until mid-September. Summer rains fall almost entirely during brief, but frequently intense thunderstorms. The general southeasterly circulation from the Gulf of Mexico brings moisture from these storms into the state. Strong surface heating, combined with orographic lifting as the air moves over higher terrain, causes air currents and condensation. Because precipitation usually is relatively intense, some local runoff and flash flooding result (Cooley et al., 1969 - S10290201).

Weather stations are sparsely and unevenly spaced throughout much of Arizona and New Mexico. Factors such as site location, density of distribution, types of equipment, and observer bias all affect the precision, accuracy, and utility of resulting climate data. The National Weather Service (NWS) operates three weather stations in Arizona (Flagstaff, Phoenix, and Tucson), and one station in New Mexico (Albuquerque). Additionally, there is a network of cooperative weather stations that regularly gather and report temperature and precipitation data. The coverage and total number of cooperative weather stations varies over the state. Arizona's tribal lands, which constitute a sizable portion of the total land area of the state, are underrepresented as are high-elevation areas in general (Sheppard et al, 1999 - S07280303).

There are many methods of interpolating climate data from monitoring stations to grid points. Some methods provide estimates of acceptable accuracy in flat terrain, but few have been able to adequately explain the extreme, complex variations in climate that occur in mountainous regions. Significant progress in this area has been achieved through the development of PRISM (Parameter-elevation Regressions on Independent Slopes Model). PRISM is an analytical model that uses point data and an underlying grid such as a digital elevation model (DEM) for a 30 year climatological average (e.g. 1971- 2000 average) to generate gridded estimates of monthly and annual precipitation and temperature (as well as other climatic parameters). PRISM is well suited to regions with mountainous terrain, because it incorporates a conceptual framework that addresses the spatial scale and pattern of orographic processes, where air masses cool as they gain elevation, resulting in precipitation. The PRISM Group at Oregon State University developed a spatially gridded average annual precipitation for the climatological period 1971-2000 that covers the Navajo Nation.

Distribution of the point measurements to a spatial grid was accomplished using the PRISM model. The PRISM Group at OSU used point estimates of precipitation from some or all of the following sources: 1) National Weather Service (NWS) Cooperative (COOP) stations, 2) Natural Resources Conservation Service (NRCS) SNOTEL, 3) United States Forest Service (USFS) and Bureau of Land Management (BLM) RAWS Stations, 4) Bureau of Reclamation (AGRIMET) stations, 5) storage gauges, 6) NRCS Snowcourse stations, 7) other State and local station networks, 8) estimated station data, 9) upper air stations, and 10) NWS/Federal Aviation Administration (FAA) Automated surface observation stations (ASOS). Grids were modeled on a monthly basis and the annual grids of precipitation were produced by averaging the monthly grids, and summing for precipitation. The gridded PRISM average annual precipitation dataset was processed into contours using ESRI's Spatial Analyst software.[1] Polygons were generated and attributed with average annual precipitation range values as shown in Figure 15. This dataset is provided on the GIS Data DVD (DB/Climate/NN_Precipitation.shp).

The largely semi-arid Navajo Nation is shown in Figure 15 by the dominance of 4-12 inches of precipitation. The orographic effect can be seen on the Chuska and Carrizo Mountains and the Defiance Plateau where precipitation rises to 12-28 inches. Black Mesa, with an intermediate elevation, shows this same effect where precipitation rises to 18 inches annually.

[1] Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.

ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION AVERAGE ANNUAL PRECIPITATION: 1971 - 2000 AND AVERAGE ANNUAL SNOWFALL

0 50 Miles

Map Scale 1:1,750,000

Aerial photo of flooding after a heavy rain storm along the intermittent Moenkopi Wash near Tuba City, Arizona. Photo courtesy the U.S. Army Corps of Engineers (photo taken October 9, 2002).

Legend

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 SNOWFALL (Inches)

- • <10.0
- •• 10.0- 39.9
- ♣ >40

Source

The average annual precipitation on the Navajo Nation for the period 1971 - 2000 is from the PRISM Group at Oregon State University (OSU). PRISM (Parameter-elevation Regressions on Independent Slopes Model) is the analytical model that uses point data and an underlying grid such as a digital elevation model (DEM) for a 30 year climatological average (e.g., 1971- 2000 average) to generate gridded estimates of monthly and annual precipitation. PRISM is well suited to regions with mountainous terrain, because it incorporates a conceptual framework that addresses the spatial scale and pattern of orographic processes. The gridded data was converted to a polygon dataset by TerraSpectra Geomatics.

Filename: DB/Climate/NN_Precipitation.shp

Figure 15. Navajo Nation Average Annual Precipitation: 1971 - 2000.

CLIMATE (continued)

The U.S. Geological Survey (USGS) Navajo Nation Studies program is compiling meteorological information on precipitation type, intensity, and timing on the Navajo Nation. The purpose of these data collection efforts is to examine trends that may contribute to drought intensity. USGS plans to conduct infiltrometer work on alluvial deposits and to use soil moisture probes to evaluate relative effects of precipitation intensities, of both simulated and actual rainfall events, on soil moisture and infiltration (USGS, 2007 - S05220702).

The Navajo Nation Department of Water Resources is developing a database with stream gauge, climate, snow survey, and precipitation data. Inquiries concerning these data can be made to the Navajo Department of Water Resources, Water Management Branch, P.O. Drawer 678, Fort Defiance, Arizona 86504.

SNOWFALL

Snow accumulation can impact the effect of melting snow on soil water recharge, and the potential for contaminant transport at an AUM site. The mean annual snowfall is related to temperature, and more directly to physiography and altitude. However, wind, exposure, and other factors can cause variation in snow accumulation. Figure 16 shows the ranges of annual snowfall recorded at cooperative weather stations in and around the Navajo Nation. These data were acquired from the Western Regional Climate Center in tabular format (Table 1) and were processed into a GIS dataset that is provided on the GIS Data DVD (DB/Climate/NN_Snow.shp).

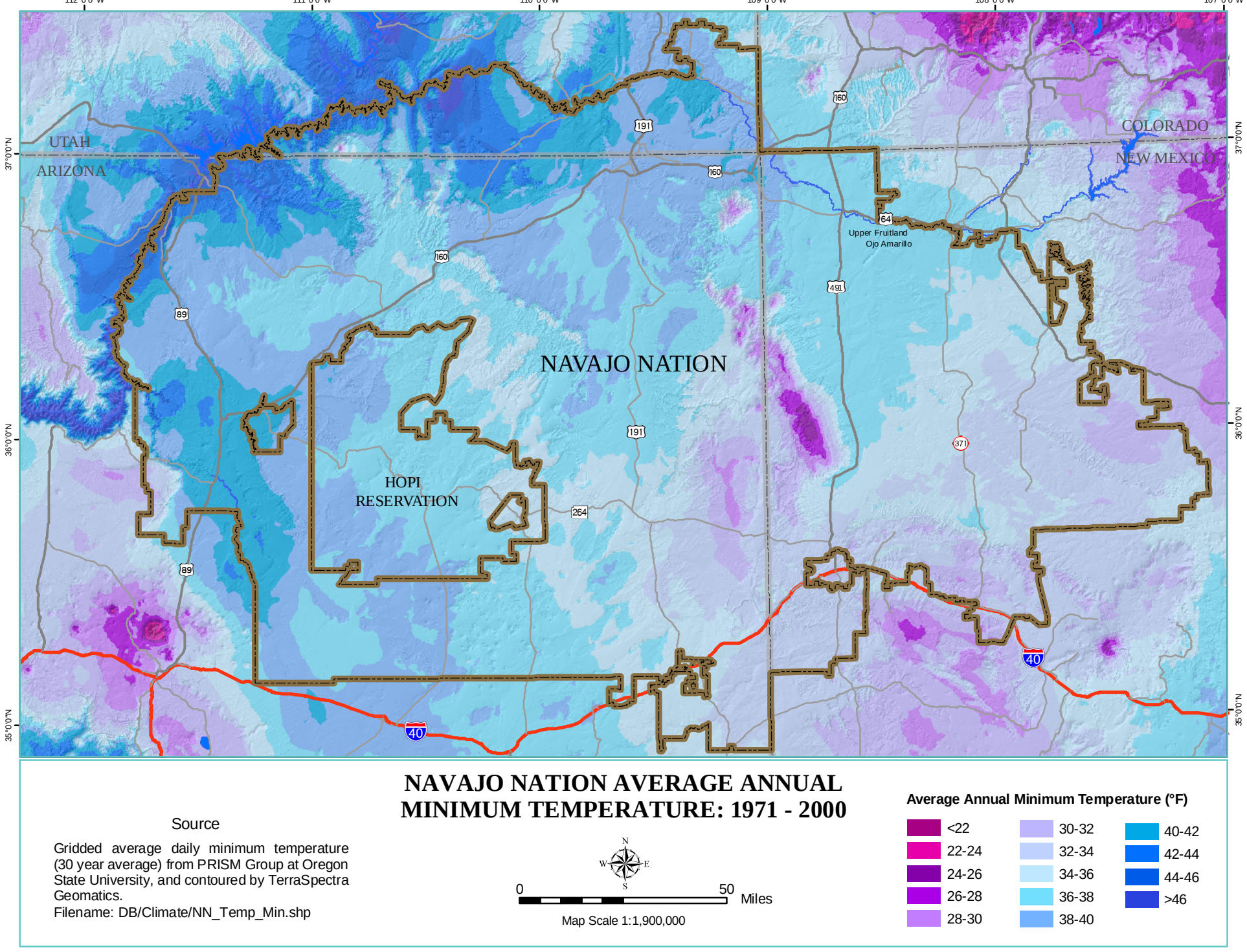
Table 1. Average Annual Snowfall On and Within 1 Mile of the Navajo Nation.

STATION ID	COOPERATIVE STATION NAME	State	Elev_ft	Start_Yr	End_Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
020750-2	BETATAKIN	AZ	7210	1948	2004	10.0	9.3	7.8	3.8	0.6	0.0	0.0	0.0	0.0	1.2	6.4	10.0	50.0
021169-2	CAMERON	AZ	4290	1948	1998	2.2	3.8	1.8	1.0	0.0	0.0	0.0	0.0	0.0	0.3	1.3	3.4	10.0
021169-2	CAMERON 1 NNE	AZ	4160	1962	1992	0.6	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.7
021248-2	CANYON DE CHELLY	AZ	5540	1970	2004	1.8	0.9	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.6	5.5
021634-2	CHINLE	AZ	5540	1908	1970	3.4	2.3	1.5	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.9	3.4	10.0
022099-2	COPPER MINE TRADING POS	AZ	6380	1948	1976	1.5	0.8	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.6	6.2
022545-2	DINNEHOTSO	AZ	5020	1950	1974	3.8	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.1	6.7
023102-W	FORT DEFIANCE	AZ	6910	1897	1949	8.7	8.2	3.7	1.4	0.8	0.0	0.0	0.0	0.0	0.1	3.4	6.6	30.0
023303-2	GANADO	AZ	6360	1948	2004	4.7	4.1	3.3	0.7	0.0	0.0	0.0	0.0	0.0	0.4	2.2	5.0	20.0
024438-2	JEDDITO	AZ	6710	1948	1955	10.0	4.7	3.6	0.2	0.2	0.0	0.0	0.0	0.0	0.1	2.4	3.8	30.0
024528-2	KAIBITO	AZ	6000	1950	1961	7.8	3.3	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.9	2.5	20.0
024578-2	KAYENTA	AZ	5680	1915	1978	4.1	2.6	1.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.1	10.0
024686-2	KLAGETOH 12 WNW	AZ	6500	1959	1993	2.7	2.5	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.4	2.3	10.0
024849-2	LEES FERRY	AZ	3140	1916	2004	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	2.1
024872-2	LEUPP	AZ	4700	1948	1981	1.7	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.2	5.1
025129-2	LUKACHUKAI	AZ	6480	1951	2003	3.9	2.7	3.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.8	3.3	20.0
025204-2	MANY FARMS SCHOOL	AZ	5320	1951	1975	0.4	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.9	4.4
025665-2	MONUMENT VALLEY	AZ	5560	1980	2004	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.7	5.1
027440-2	ST MICHAELS 6 WNW	AZ	7640	1906	1927	5.6	5.8	3.1	0.8	0.3	0.0	0.0	0.0	0.0	0.8	2.8	7.3	30.0
027488-2	SANDERS	AZ	5930	1949	2004	2.4	1.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.1	1.4	6.2
027496-2	SANDERS 11 ESE	AZ	6250	1961	1986	6.2	6.2	3.0	1.7	0.4	0.0	0.0	0.0	0.0	0.5	2.6	7.0	30.0
028468-2	TEEC NOS POS	AZ	5180	1962	2004	2.2	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.1	4.8
028792-2	TUBA CITY	AZ	4940	1900	2004	1.5	0.9	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.7	6.2
029410-2	WINDOW ROCK 4 SW	AZ	6900	1937	1999	6.3	6.1	4.7	1.4	0.1	0.0	0.0	0.0	0.0	0.5	2.5	7.8	30.0
291063-1	BLOOMFIELD 3 SE	NM	5810	1914	2004	3.7	2.2	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.6	3.4	10.0
291647-1	CHACO CANYON NATL MON	NM	6140	1922	2004	3.4	2.9	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.3	1.7	3.6	10.0
292219-1	CROWNPOINT	NM	6990	1914	1969	3.8	5.7	2.2	0.8	0.1	0.0	0.0	0.0	0.0	0.2	1.7	4.4	20.0
293142-1	FARMINGTON AG SCIENCE C	NM	5630	1978	2004	2.5	3.9	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.5	2.7	10.0
293305-1	FORT WINGATE	NM	7000	1940	1966	6.9	4.0	3.5	0.6	0.0	0.0	0.0	0.1	0.0	0.7	1.8	3.7	20.0
293340-1	FRUITLAND 2 E	NM	5150	1914	2003	3.2	2.3	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.2	1.1	2.7	10.0
293420-1	GALLUP 5 E	NM	6600	1918	1979	4.4	2.3	1.6	0.2	0.0	0.0	0.0	0.0	0.0	0.6	1.1	4.5	10.0
295290-1	LYBROOK	NM	7210	1951	2004	6.1	5.2	3.8	1.4	0.0	0.0	0.0	0.0	0.0	0.8	2.1	6.0	30.0
295685-1	MEXICAN SPRINGS	NM	6440	1944	1972	1.9	1.4	2.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.7	9.4
296098-1	NEWCOMB	NM	5570	1948	1971	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
296465-1	OTIS	NM	6880	1914	2004	6.3	5.6	4.4	1.3	0.5	0.0	0.0	0.0	0.0	0.8	2.8	5.8	30.0
296900-1	PITT RANCH	NM	6460	1948	1968	1.5	3.2	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.6	8.9
298284-1	SHIPROCK	NM	4950	1926	2004	1.4	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.0	3.7
298524-1	STAR LAKE	NM	6640	1922	2004	4.9	3.6	2.7	1.1	0.4	0.0	0.0	0.0	0.0	0.5	1.7	3.9	20.0
298830-4	THOREAU 5 ENE	NM	7100	1930	1992	8.3	5.5	5.3	1.1	0.4	0.0	0.0	0.0	0.0	1.4	3.0	8.1	30.0
298919-1	TOHATCHI 1 ESE	NM	6420	1915	1979	3.1	2.4	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.7	3.9	10.0
298921-1	TOHATCHI 6 NE	NM	5990	1914	1992	2.2	2.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	2.7	8.6
299031-2	TORREON NAVAJO MISSION	NM	6700	1961	2004	4.9	3.8	2.7	0.9	0.2	0.0	0.0	0.0	0.0	0.7	1.9	4.2	20.0
420157-7	ANETH PLANT	UT	4620	1959	2004	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.2	2.4
420788-7	BLUFF	UT	4320	1928	2004	3.1	1.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	3.0	8.2
425582-7	MEXICAN HAT	UT	4250	1948	2004	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.3	3.0
425812-7	MONUMENT VALLEY MISSION	UT	5220	1961	1989	3.6	2.5	1.5	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.6	4.2	10.0

TEMPERATURE

In climates that experience freezing temperatures, the amount of surface water run-off expected during winter months increases as percolation through frozen ground is limited. The PRISM Group at Oregon State University developed a spatially gridded average annual minimum temperature and average annual maximum temperature for the climatological period 1971-2000. The PRISM average annual temperature gridded datasets were processed to contours using ESRI's Spatial Analyst software.[1] Polygons were generated and attributed with annual temperature range values as shown in Figure 16. These datasets are provided on the GIS Data DVD (DB/Climate/NN_Temp_Max.shp and DB/Climate/NN_Temp_Min.shp).

[1] Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.



NAVAJO NATION AVERAGE ANNUAL MINIMUM TEMPERATURE: 1971 - 2000

Source

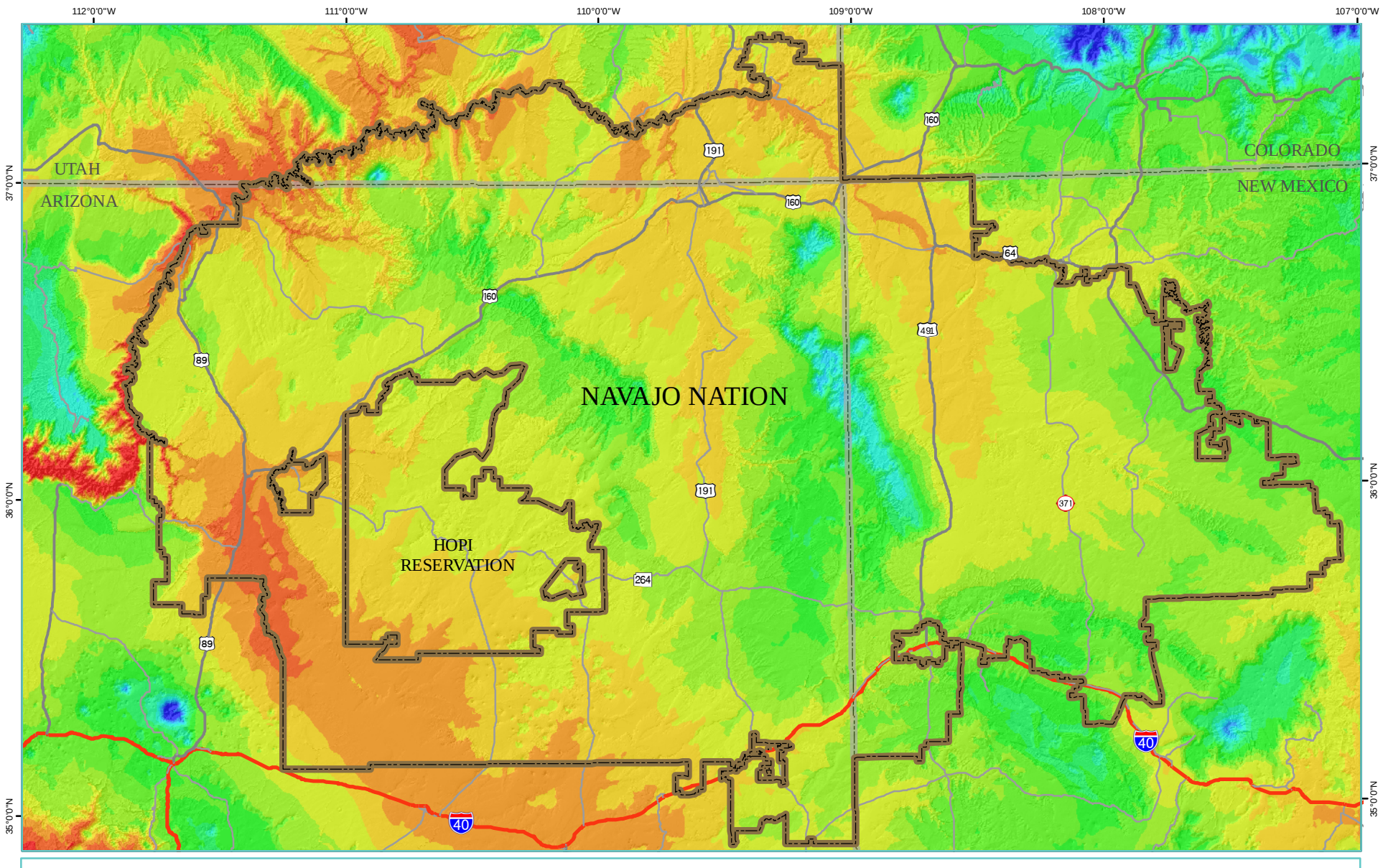
Gridded average daily minimum temperature (30 year average) from PRISM Group at Oregon State University, and contoured by TerraSpectra Geomatics.
Filename: DB/Climate/NN_Temp_Min.shp

0 50 Miles

Map Scale 1:1,900,000

Average Annual Minimum Temperature (°F)

<22	30-32	40-42
22-24	32-34	42-44
24-26	34-36	44-46
26-28	36-38	>46
28-30	38-40	



NAVAJO NATION AVERAGE ANNUAL MAXIMUM TEMPERATURE: 1971 - 2000

Source

Gridded average daily maximum temperature (30 year average) from PRISM Group at Oregon State University, and contoured by TerraSpectra Geomatics.
Filename: DB/Climate/NN_Temp_Max.shp

0 50 Miles

Map Scale 1:1,900,000

Average Annual Maximum Temperature (°F)

<48	56-58	66-68
48-50	58-60	68-70
50-52	60-62	70-72
52-54	62-64	72-74
54-56	64-66	>74

Figure 16. Navajo Nation Average Annual Minimum and Maximum Temperatures: 1971 - 2000.

CLIMATE (continued)

WIND

Wind speeds on the Navajo Nation are usually moderate, although relatively strong winds often accompany frontal activity during late winter and spring months and sometimes occur in advance of thunderstorms. Frontal winds may exceed 30 miles per hour (mph) for several hours and reach peak speeds of more than 50 mph. Spring is generally the windy season. Blowing dust and serious soil erosion of unprotected fields may be a problem during dry periods (DRI, 2003-S08020302; 2003-S08020303; 2007-S05270703).

High Resolution Wind Data

The Department of Energy's Wind Program and the National Renewable Energy Laboratory (NREL) published new wind resource maps for the states of Arizona, Colorado, New Mexico, and Utah. These resource maps show wind speed estimates at 50 meters above the ground and the depict the resource that could be used for utility-scale wind development. Future plans are to provide wind speed estimates at 30 meters, which are useful for identifying small wind turbine opportunities.

As a renewable resource, wind is classified according to wind power classes, which are based on typical wind speeds. These classes range from Class 1 (the lowest) to Class 7 (the highest). In general, at 50 meters, wind power Class 4 or higher can be useful for generating wind power with large turbines. Class 4 and above are considered good resources. Figure 17 indicates that there are areas on the Navajo Nation with wind resources consistent with utility-scale production. This dataset is presented as an indication of potential increased hazard for the air pathway, especially where AUMs are located in higher wind power class areas.

The individual state datasets (Arizona, Colorado, New Mexico, and Utah) were processed into a GIS dataset for the Navajo Nation. The Wind Resources data are provided on the GIS Data DVD (DB/Climate/NN_Wind_Power.shp).

Average Annual Wind Speeds and Average Annual Prevailing Wind Direction

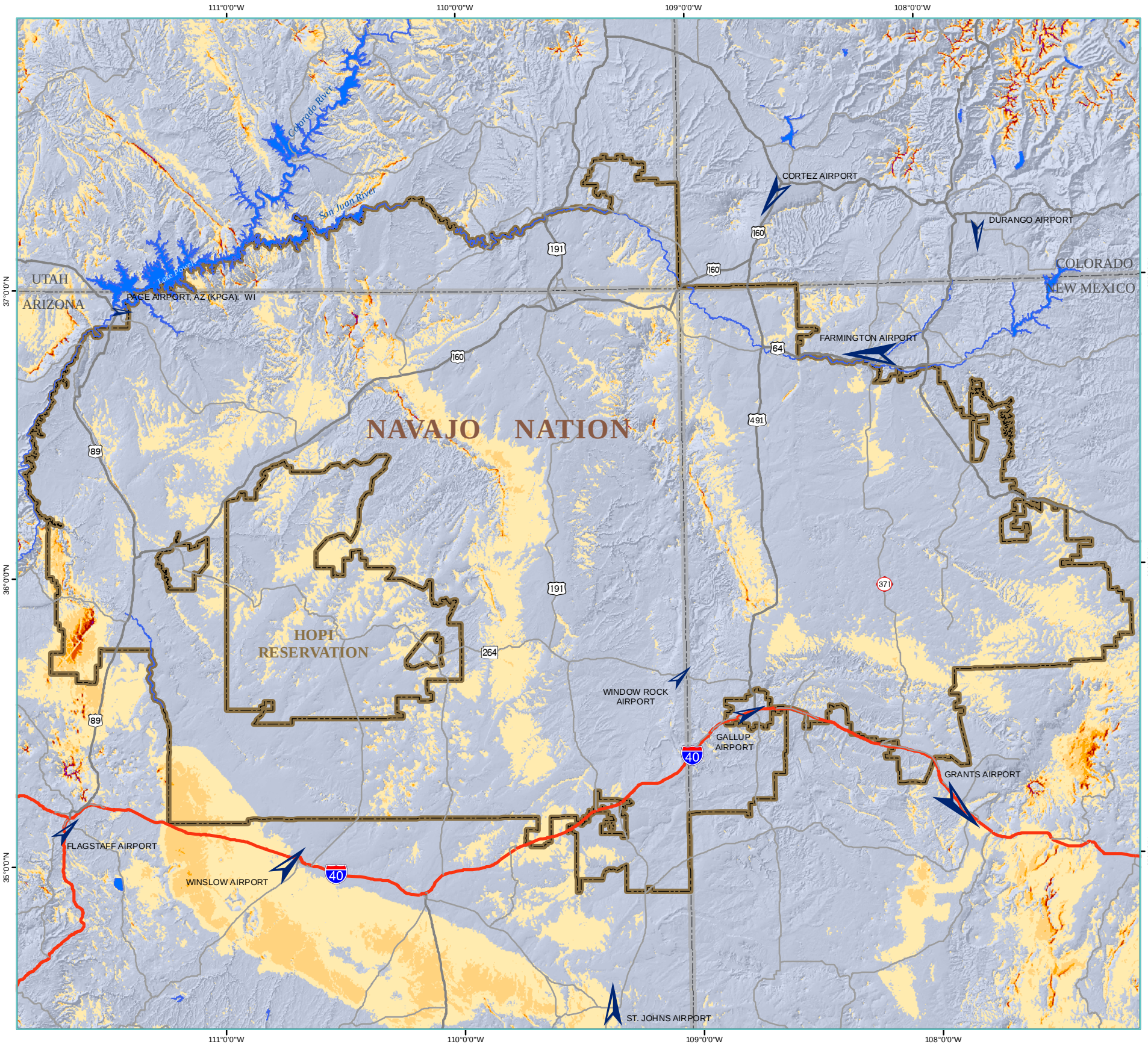
The Western Regional Climate Center (WRCC) is administered by the National Oceanic and Atmospheric Administration and provides monthly average wind speeds. These data are based on hourly observations from all reporting airports in the Western United States, and were collected from 1992-2002. Some stations began operation after 1992. All stations have at least 2 years of hourly data used for the averages. The standard anemometer height for all current stations is 10 meters.

WRCC also provides average annual wind direction. Prevailing wind direction is based on the hourly data from 1992-2002 and is defined as the direction with the highest percent of frequency. Many of these locations have very close secondary maximum which can lead to noticeable differences month to month.

Figure 17 shows the reporting locations, average annual wind speed, and prevailing wind directions for stations located on or near the Navajo Nation. The dataset that is provided on the GIS Data DVD (DB/Climate/NN_Wind.shp) was processed to include only those locations that are located on or proximal to the Navajo Nation. Average monthly wind speed is also tabulated and shown in Table 2. Attribute information in the dataset also provides average wind direction by month and average annual wind direction.

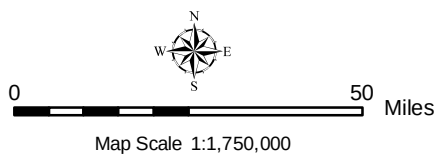
Table 2. Average Wind Speed by Month and Average Annual Wind Speed On and Near the Navajo Nation.

STATION	STATE	ELEV (M)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE ANNUAL
FLAGSTAFF AP, AZ (KFLG). WI	AZ	2137	5.9	6.5	6.2	7.5	7.3	7.1	5.4	4.3	4.7	5.1	5.7	5.9	6.0
GLENDALE-LUKE AFB, AZ (KLUF)	AZ	332	7.1	7.4	7.7	8.8	8.9	8.8	9.1	8.7	7.7	7.3	7.0	7.0	8.0
GRAND CANYON AP, AZ (KGCN).	AZ	2014	5.8	6.9	6.7	7.8	7.9	7.8	6.0	5.1	5.8	5.6	5.7	5.8	6.4
PAGE AIRPORT, AZ (KPGA). WI	AZ	1304	3.4	4.3	5.3	6.5	6.6	6.7	5.9	5.3	4.9	4.2	3.6	3.1	4.9
PHOENIX SKY HARBOR AP, AZ (K	AZ	337	4.9	5.5	6.0	6.8	6.8	6.6	6.7	6.7	5.9	5.3	4.7	4.4	5.8
PHOENIX-DEER VALLEY AP, AZ (	AZ	450	5.5	6.3	6.9	8.6	8.6	8.7	8.5	8.5	7.7	6.8	6.0	5.4	7.3
PRESCOTT AIRPORT, AZ (KPRC).	AZ	1537	6.9	7.7	8.3	9.3	9.2	9.3	8.2	7.2	7.3	7.1	6.6	6.6	7.8
SCOTTSDALE AP, AZ (KSDL). W	AZ	460	4.0	4.9	5.5	6.6	6.9	6.8	6.9	6.6	6.1	5.0	4.1	3.5	5.5
ST. JOHNS AP, AZ (KSJN). WI	AZ	1747	6.4	8.2	8.7	10.9	10.4	9.7	8.0	6.7	6.9	6.5	6.0	5.5	7.7
WINDOW ROCK AP, AZ (KRQE).	AZ	2055	4.6	5.6	6.6	8.6	8.1	7.3	5.4	4.4	4.8	4.5	4.1	4.1	5.6
WINSLOW AIRPORT, AZ (KINW).	AZ	1488	6.6	7.5	8.4	10.0	10.0	9.7	8.5	7.5	7.3	6.6	6.3	6.0	7.9
CORTEZ AP, CO (KCEZ). WIND	CO	1803	6.0	7.0	8.0	9.0	9.0	9.0	7.0	6.0	7.0	7.0	6.0	6.0	7.0
DURANGO AIRPORT, CO (KDRO).	CO	2038	5.0	6.0	7.0	8.0	8.0	7.0	6.0	6.0	6.0	6.0	5.0	5.0	6.0
MONUMENT PASS, CO (KMNH). WI	CO	3365	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
WOLF CREEK PASS, CO (KCPW).	CO	3243	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
ALBUQUERQUE-DOUBLE EAGLE II	NM	1779	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
ALBUQUERQUE INT'L AP, NM (KA	NM	1620	7.1	8.1	8.8	9.8	9.4	9.0	8.0	7.4	7.2	7.5	7.1	6.9	8.0
FARMINGTON AP, NM (KFMN). W	NM	1677	7.9	8.4	9.1	9.9	9.6	9.3	8.7	7.9	7.8	7.9	7.8	7.0	8.5
GALLUP AIRPORT, NM (KGUP).	NM	1972	5.7	6.7	7.5	9.1	8.7	8.1	6.9	5.9	5.9	5.7	5.3	4.9	6.7
GRANTS AIRPORT, NM (KGNT).	NM	1987	7.7	9.2	9.8	11.0	10.3	9.9	8.0	7.3	7.8	8.6	7.7	7.5	8.7
LOS ALAMOS AP, NM (KLAM). W	NM	2179	3.6	5.0	5.7	6.4	6.5	5.9	5.1	4.2	4.8	4.9	3.9	3.4	5.0
SANTA FE AIRPORT, NM (KSAF).	NM	1934	9.6	10.2	10.7	11.7	11.3	11.0	9.8	9.3	9.4	9.7	9.2	8.7	10.0
BRYCE CANYON AP, UT (KBCE).	UT	2312	8.4	8.9	9.1	10.6	10.0	10.1	8.5	8.5	8.7	8.4	8.2	6.9	8.8
CEDAR CITY AP, UT (KCDC).	UT	1714	7.2	7.6	8.4	9.1	9.4	9.3	8.5	8.2	7.5	6.7	6.5	6.6	7.9



ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION WIND RESOURCES



Map Scale 1:1,750,000

Dust storm near Monument Valley.
Photo taken September 30, 2004 by TerraSpectra Geomatics.

Legend

AVERAGE ANNUAL WIND SPEED (MPH) AND PREVAILING WIND DIRECTION

- 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 8.9
- 9.0 -10.0

WIND POWER CLASS	RESOURCE POTENTIAL	WIND SPEED AT 5O METERS (MPH)
1	Poor	0.0 - 12.5
2	Marginal	12.5 - 14.3
3	Fair	14.3 - 15.7
4	Good	15.7 - 16.8
5	Excellent	16.8 - 17.9
6	Outstanding	17.9 - 19.7
7	Superb	> 19.7

Source

The wind resource data is from the U.S. Department of Energy's National Renewable Energy Laboratory (NERL).
Filename: DB/Climate/NN_Wind_Power.shp

Average annual wind speed and average annual prevailing wind direction is from the Western Regional Climate Center (WRCC).
Filename: DB/Climate/NN_Wind.shp

Figure 17. Navajo Nation Wind Resources.

ELEVATION AND TOPOGRAPHY

Information about the elevation and topography of a region can provide useful insights into many natural systems, such as the climate, soil development, and vegetation. Much of the Navajo Nation is comprised of plateau-like features 4,000 - 7,000 feet above mean sea level. Rising to elevations of more than 8,000 feet are Navajo Mountain, Defiance Plateau, the Carrizo, Chuska, and Zuni Mountains, and the northern part of Black Mesa. Conversely, the deep canyons of the Colorado River (Grand, Marble, and Glen Canyons), the San Juan Canyon, and the canyon of the Little Colorado River are at elevations of less than 3,000 feet. Generally, the valleys of the Little Colorado, Chaco, and San Juan Rivers and the Chinle Wash range from 4,000 to 5,500 feet in elevation. The highest point on the Navajo Nation is Navajo Mountain in southeastern Utah, at about 10,346 feet and the lowest point is the mouth of the Little Colorado River at about 2,800 feet elevation (Cooley et al., 1969 - S10290201)

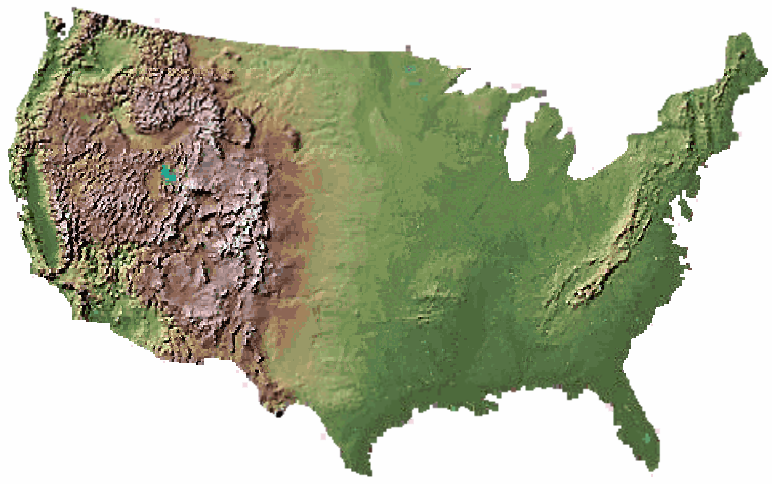
Topographic data can be used as an important parameter in evaluating the likelihood of potential hazardous material transport to ground water through infiltration or surface water through runoff. This section discusses Digital Elevation Model data and some of the useful derivative products that can be generated.

DIGITAL ELEVATION MODEL DATA

A Digital Elevation Model (DEM) is a numerical representation of the elevation of terrain. DEM data files contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The data typically is stored in a grid format, with pairs of geographic coordinates (x,y) and corresponding elevation values (z). The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems. The closer together the grid points are located, the more detailed the information will be. The details of the peaks and valleys in the terrain will be better modeled with a small grid spacing than when the grid intervals are very large. Spot elevations, other than at the specific grid point locations, are not contained in the file. As a result, summits and valley points that are not coincident with the grid are not be recorded in the file.

The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the USGS effort to provide 1:24,000-scale DEM data for the conterminous United States. NED provides data in a consistent projection (Geographic), resolution (1 arc second or approximately 30 meter), and elevation units (meters). The horizontal datum is NAD83 and the vertical datum is NAVD88.

Some areas of the Navajo Nation have more detailed 1/3 arc second (10 meter) DEM data available, but complete 10 meter coverage is not yet available for the entire Navajo Nation.



A shaded-relief representation of the conterminous United States portion of the National Elevation Dataset (NED). Elevation is portrayed as of range of colors, from dark green for low elevations to white for high elevations (USGS, 1999—S05140301)

APPLICATIONS OF DEM DATA

A DEM is often an important data layer in a GIS database because elevation data are essential for many earth science applications. Elevation data are critical to many modeling applications such as hydraulic and hydrologic studies, including drainage networks, stream-flow calculations, and watershed delineations. DEMs combined with surface and sub-surface hydrologic data are used for substance transport calculations for environmental hazard analysis. DEMs can be used to create shaded-relief, elevation contours, slope, and aspect maps. The 30 meter resolution DEM for the Navajo Nation is shown as the image in the lower left corner of Figure 18. The DEM has been color-coded to enhance the elevation differences. The DEM raster dataset is provided on the GIS Data DVD (DB/Topo/NN_Elevation.img)

Shaded-Relief Image Maps

There are many practical applications for DEMs. One useful application is to create a shaded-relief map base from DEM data. Relief shading indicates relief by a shadow effect that results in the darkening of one side of terrain features, such as hills and ridges. The darker the shading, the steeper the slope. A shaded relief map helps the user see the topography of an area. The top map on Figure 18 is a shaded relief image of the Navajo Nation that was generated using the NED DEM. Parameters used to create the image were: Solar Azimuth - 125°; Solar Elevation - 45°; Ambient Light - 0.00; DEM scale - 2.0; and Elevation units - meters. Shaded relief maps show features on the surface, such as mountains, valleys, plateaus, and canyons. Areas that are flat or have few features are smooth on the map, whereas areas with steep slopes and mountains appear to have a rough texture. The shaded relief raster dataset is provided on the GIS Data DVD (DB/Topo/NN_Shaded_Relief.img).

Slope

Slope data provides an important parameter for the ground water and surface water pathway assessments. For example, for ground water assessments, the lower the slope the higher the potential for infiltration. Conversely, for surface water pathways, the lower the slope, the lower the potential for runoff. Greater slopes generally result in lower infiltration and higher runoff.

A slope image was generated for the Navajo Nation area using the NED DEM 30-meter DEM data (Figure 19). The DEM data were processed to generate a slope image using percent for the slope value. Areas that have relatively flat terrain are shown as lighter shades of green. As the slope increases, the shades of green darken. These areas correspond with the hilly and mountainous terrain of Navajo Mountain, Black Mesa and the Chuska and Carrizo Mountains. A prominent feature is Shiprock, with very steep, almost vertical slopes on the volcanic neck. The slope raster dataset is provided on the GIS Data DVD (DB/Topo/NN_slope.img).