RECOMMENDATIONS

Results from this modified screening process will be used to assist with identifying AUM sites for possible further investigation. There are several courses of action that may be used to remediate a site, including Removal Actions and Brownfields redevelopment. If the site is eligible for CERCLA assessments, then the site proceeds through the Preliminary Assessment stage and onward. If the site is not CERCLA eligible, the Site Screen recommendation is for No Further Remedial Action, in which the site may be referred to another party. The Site Screen may also recommend a Removal Action, though not necessarily detailed characterization, of the site contamination. Site specific characterization priorities should be established based on Navajo Nation priorities, AUM screening scores, resources, and site specific factors.

ADDITIONAL POSSIBLE SCORING FACTORS

Screening assessments at mine sites commonly require evaluation of exposures from multiple sources and exposures via multiple pathways (EPA, 2000 - S02200302). The modified HRS model used for this study was developed for the purpose of performing a coarse screening based on the presence of surface water drainages and the numbers of structures and wells proximal to AUM sites. Using existing GIS datasets, or by automating readily available data for the entire Navajo Nation, it may be possible to improve the analysis to better assess priority areas for further investigation. The following provides a list of existing or available datasets that could be used to develop additional factors that consider waste characteristics, likely transport pathways, and ecological targets.

- HRS factors related to uranium mine waste characteristics:
  - AUM reclamation sites with associated unreclaimed mine debris piles
  - AUM reclamation status (reclaimed versus unreclaimed)
  - AUM production (productive versus non-productive prospects)
  - Total uranium and/or vanadium production for each mine
  - The presence of host geologic formations for uranium ore
  - Water or stream sediment samples
  - Historic uranium haul routes, buying stations, and transfer stations
- HRS factors related to pathways and likelihood of release:
  - Surface or underground AUM extraction method (e.g., open pit or underground working)
  - Extent (size) of surface and/or underground workings
  - Perched water tables or documentation of infiltrated water in AUMs
  - Precipitation
  - Aquifer sensitivity
  - Slope proximal to AUM
  - Intersections of surface water pathway buffers with downstream targets (i.e., wetlands or structures)
- HRS factors related to targets:
  - Natural springs (undeveloped)
  - Sensitive habitats
  - Agricultural fields
  - Corrals and animal pens
  - Identification of schools, hospitals, Chapter houses, and community centers
  - Cumulative effects from multiple AUMs on targets (e.g.,several AUMs within 4 miles of a single well)

Inputs for many of these parameters have been processed and are presented in Part 2 of this document “Atlas with Geospatial Data.” In order to provide spatial datasets that cover the entire Navajo Nation, many of the datasets are at regional scales (1:250,000 and smaller). While the spatial accuracies and detail of these regional datasets are not appropriate for detailed site investigations, they may provide useful information for regional assessments and site prioritizations for further study or remediation activities.

The following discussion provides several examples of how the data that has been collected could be used to augment and improve the AUM screening assessment.

NON-POTABLE WATER SAMPLES WITH URANIUM EXCEEDING MAXIMUM CONTAMINANT LEVELS

Water samples have been collected on the Navajo Nation for various programs and studies, and have in some cases included samples for for radionuclides, including uranium. Sites listed below in Tables 10, 11, and 12 have come to EPA's attention due to elevated radionuclide activity in water samples (EPA, 2000 - S02260102). As of December 8, 2003, the EPA Maximum Contaminant Level (MCL) for uranium is 30 micrograms per liter (µg/L)[1] or 20 pico-curies per liter (pCi/L)[2]. MCL is the maximum permissible level of a contaminant in water delivered to users of a public water system. Water samples from the following locations were sampled for Uranium-234, Uranium-235 and Uranium-238 and the summed total values were greater than 20 pCi/L (EPA, 2000 - S02260102). The locations of these water samples with elevated uranium levels are displayed on Figure 67 "Non-Potable Water Sample Locations with Elevated Uranium." The water sources cited were not sampled from Public Water Supply Systems (PWSS). The MCL's were used for comparison purposes only. The results for both studies were from one-time sampling events by EPA and the USGS and are not definitive with respect to attribution from mining related versus naturally occurring sources. Water sampling was conducted prior to NAMLRP reclamation activity and current conditions may differ. The Eastern AUM Region was not included in this sampling program.

Table 10. USACE Water Samples with Elevated Uranium.

REGION	USACE SAMPLE NAME	SAMPLE ID	SAMPLE DATE	SITE TYPE	TOTAL URANIUM (pCi/L)
Central	Benally Spring	KY981008CHS001	10/8/1998	Spring	47.1
Central	Burro Spring	KY981008CHS002	10/8/1998	Spring	60.1
Central	Cottonwood Spring	CH981123CHS001	11/23/1998	Spring	22.4
Central	Tank 10R-51	CH990316TCW004	3/16/1999	Wind Mill	22.3
Central	Tank 10T-533	CH981119TCW003	11/19/1998	Wind Mill	73.0
Central	Tinyehtoh Spring	KY981008CHS003	10/8/1998	Spring	39.9
Central	Waterfall Spring	CH981104BGS001	11/4/1998	Spring	61.7
Central	White Clay Spring	CH981124BGS002	11/24/1998	Spring	45.9
North Central	Baby Rock Spring 8-44	KY980901DES001	9/1/1998	Spring	36.3
North Central	Monument Pass Well	KY000112OLW014	1/12/2000	Well	40.0
North Central	Tank 8A-299	KY980902OLW001	9/2/1998	Wind Mill	171.9
Northern	9K216	RV990907SWW005	9/7/1999	Well	27.2
Northern	9T550	RV990907SWW004	9/7/1999	Well	32.3
Northern	9T586	RV990907SWW006	9/7/1999	Well	20.3
Northern	Alcove Canyon Springs	RV990330CVS010	3/30/1999	Spring	125.3
Northern	Area 1	RV990518CVS015	5/18/1999	Stream	51.3
Northern	Area 2	RV990518CVS017	5/18/1999	Stream	116.1
Northern	Area 4	RV990518CVS016	5/18/1999	Stream	148.8
Northern	Camp Mine	RV991026CVM013	10/26/1999	Mine	419.7
Northern	Cove Mesa 2	RV991020CVM012	10/20/1999	Mine	879.0
Northern	Ellison Wells	RV990517CVW004	5/17/1999	Well	34.7
Northern	P.H.S. 4-28-59	RV990329CVS005	3/29/1999	Spring	23.4
Northern	Pipe Mine	RV991019CVM010	10/19/1999	Mine	67.5
Northern	Sah Tah Spring	RV990317TNS001	3/17/1999	Spring	45.8
Northern	Slimwagon Well	RV990907SWW003	9/7/1999	Well	76.0
Northern	Thumb Rock Well	RV990519RVW005	5/19/1999	Well	30.4
Northern	Water Well 309	RV990519CVW005	5/19/1999	Well	83.7
Northern	West Thumb Rock Well	RV991201RVW013	12/1/1999	Well	32.8
Southern	Sheep Dip Spring	BI980702LGS002	7/2/1998	Spring	190.7
Southern	Tank 17T-517	BI980701LGW001	7/1/1998	Wind Mill	33.7
Western	Badger Spring	CT980729CMS004	7/29/1998	Spring	22.1
Western	Fivemile Wash Spring	CT000120CMS009	1/20/2000	Spring	28.4
Western	Lechee Spring	CT980811TCS001	8/11/1998	Spring	20.8
Western	Open Pit Mine	CT980722CAM003	7/22/1999	Mine	57.1
Western	Open Pit Mine	CT980722CAM002	7/22/1998	Mine	50.9
Western	Paddock Well	CT991130CAW007	11/30/1999	Well	46.4
Western	Tohachi Spring	CT980729CMS003	7/29/1998	Spring	84.2
Western	Tse To Baah Naali Spring	CT980729CMS005	7/29/1998	Spring	23.3

While this study is focused on elevated levels of uranium, it should also be noted that arsenic levels above the MCL were also detected in several of the water samples collected by the EPA from unregulated water sources in the Southern AUM Region, particularly in the Greasewood and Steamboat Chapters (EPA, 2000 - S02260102).

[1] EPA, 2006 (S05190701). "List of Drinking Water Contaminants and MCL's" accessed on 2/28/06 at URL http://www.epa.gov/safewater/mcl.html#mcls.

[2] EPA, 2002 (S05030601). "EPA Implementation Guidance for Radionuclides." The total uranium mass measurements for the USACE water samples were converted to activity using a conversion factor of 0.67 pCi/µg.

In 2004 the Navajo Nation Surface and Ground Water Protection Department of the NNEPA conducted a study that was titled "Sanitary Assessment of Drinking Water used by Navajo Residents not Connected to Public Water Systems (Ecosystem Management, Inc., 2004 - S05050701)." Thirteen (13) unregulated water sources were sampled for radionuclides, arsenic, pesticides, and coliform after being identified as potential sources of drinking water in the selected Chapters. Three of the samples had gross alpha results that were larger than the MCL of 15 pCi/L. The locations of these NNEPA water samples are listed below (Table 11).

Table 11. NNEPA Water Samples with Elevated Uranium.

REGION	CHAPTER	WELL NAME	GROSS ALPHA (pCi/L)
North Central	Kayenta	08T-522	25.7
Western	Coalmine Mesa	Box Spring	25.5
Western	Coalmine Mesa	Badger Tank Well	70.5

In 1991 the USGS, in cooperation with the NAMLRP, began a study to assess the chemical characteristics and hydraulic interaction of shallow ground water and mine water in AUMs in the Monument Valley and Cameron mining districts that had partially filled with water (Longsworth, 1994 - S02250302). Two AUMs in the Monument Valley mining district and six (6) AUMs in the Cameron mining district were studied. The AUMs in Monument Valley were the Moonlight and Radium Hill No. 1 mines. The Moonlight mine was an open pit that included two spoil piles and an oval shaped pit about 750 feet long by 525 feet wide and 134 feet deep. During this study about 5,000 square feet of the pit bottom was covered with as much as four feet of water. The Radium Hill No. 1 mine consisted of a drill hole approximately 2 feet in diameter and 96 feet deep, five spoil piles, and an inclined shaft. Water from these two mines contained large radionuclide activities.

Data in the Cameron area were collected from the 1) Jeepster No. 1 mine, an elliptical pit about 700 feet long by 200 feet at the widest point and ore was extracted from as deep as 60 feet below land surface; 2) Jack Daniels mine, consisted of one main pit approximately 450 feet by 250 feet and about 26 feet deep; 3) Manuel Denetsone No. 2 mine was sampled at a drill hole approximately 2 feet in diameter and 33 feet deep, and; 4) Ramco No. 20 mine at one of the smaller pits (200 feet by 400 feet and about 4 feet deep). Data were also collected from existing wells and springs. The locations of these USGS water samples with elevated uranium levels are listed below (Table 12) and are plotted on Figure 67 "Non-Potable Water Sample Locations with Elevated Uranium."

Table 12. USGS Water Samples with Elevated Uranium.

REGION	USGS SAMPLE NAME	SITE TYPE	SAMPLE DATE	DEPTH TO GROUND WATER (ft below land surface)	TOTAL URANIUM (Dissolved U^{238}, U^{234}, and U^{235} pCi/L)
Northern	Moonlight Mine (MVD-1)	Shallow well	10/15/1991	0.4	22,440
Northern	Moonlight Mine (MVD-2)	Shallow well	10/16/1991	0.2	28,530
Northern	Radium Hill No. 1 Mine	Mine drill hole	12/19/1991	86.8	450
Western	Jeepster No. 1 mine (JSW –1)	Open Pit	10/29/1991	4,225	52.8
Western	Jack Daniels Mine (JDD-1)	Shallow Well	11/01/1991	4,190	365.7
Western	Jack Daniels Mine (JDSW-1)	Open Pit	10/31/1991	4,190	25.4
Western	Manuel Denetsone No. 2 Mine	Mine drill hole	11/02/1991	4,159	418.9
Western	Ramco No. 20 NW	Open pit	11/06/1991	4,211	35.6
Western	Clay Well Spring	Spring box	11/05/1991	4,220	65.1
Western	Arizona Inspection Station Well	Well	12/19/1991	4,185	44.9

As part of the National Uranium Resources Evaluation (NURE) program (Smith, 2001 - S07250302), water samples were collected from springs, streams, and water wells by the Los Alamos Scientific Laboratory (LASL) between August and October, 1978 across the central and eastern portion of the Navajo Nation. The samples were analyzed by the LASL for elemental concentrations of uranium in water, in parts per billion, using fluorometry and delayed-neutron counting analysis techniques. Figure 67 shows the sample locations where results for concentration of uranium in water was greater than 30 parts per billion (ppb).

Review of these water sample results suggest that uranium mining may have affected the down-gradient watersheds. An area of interest is the Lukachukai mining area in the southwest portion of Cove Chapter. While the AUM scores are low, there are a series of 8 water samples that indicate elevated levels of uranium downstream from the Lukachukai AUMs, which were highly productive uranium and vanadium mines. Two of the AUMs in the Lukachukai mining area have highly elevated total uranium levels: Camp Mine (419.66 pCi/L) and Cove Mesa 2 (879.00 pCi/L). Based on notes and photos taken during water sampling field visits by the U.S. Army Corps of Engineers, both of these mines had wetland areas proximal to them.

Another area of interest is the Cove Mesa mines in the West Carrizo mining area. This is a highly productive uranium mining area with mines that score low due to their remote locations. The water sample at Alcove Canyon Spring resulted in a total uranium value of 125.34 pCi/L.

Two water sample sites have elevated radionuclide activity, but appear outside CERCLA authority:

- Thumb Rock Well - no apparent AUM nearby
- West Thumb Rock Well - no apparent AUM nearby

Water samples with elevated uranium levels should be evaluated for post-reclamation water sampling.

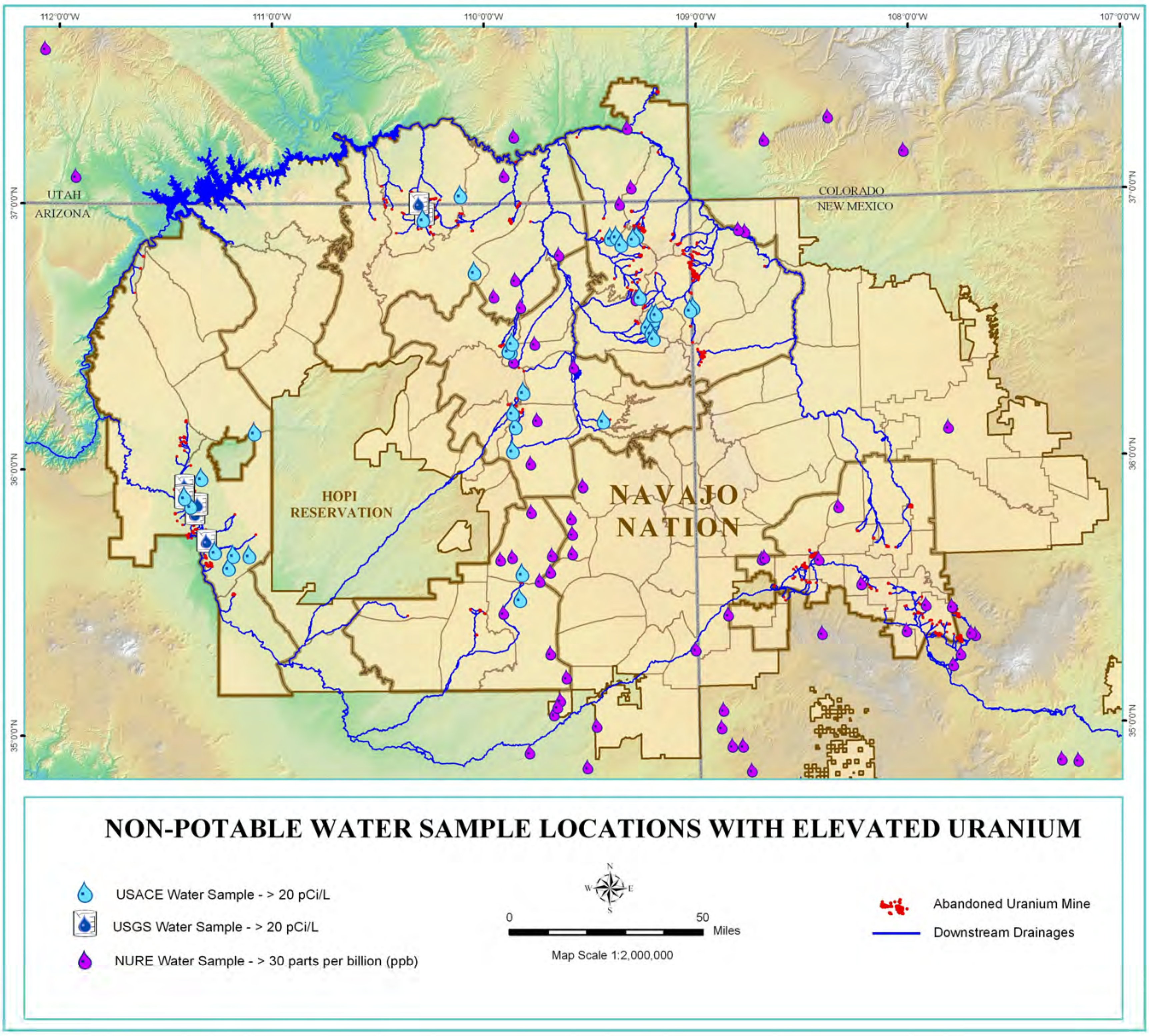

Figure 67. Water Sample Locations on the Navajo Nation with Elevated Uranium.

PERCHED OR SHALLOW WATER TABLES

Most of the mines in the North Central AUM region were extracting uranium from channel deposits in the basal Shinarump Member of the Chinle Formation. Perched water tables were present in the basal Shinarump conglomerate at many of the AUM sites. Bootjack Mine, the deepest uranium-ore deposit mined in the region was extremely wet. In 1959, ground water flowed into the workings at an average of 200 gallons per minute. This water was collected in the shaft sump and pumped to an evaporation pond on the surface (Chenoweth, 1993 - S10100222). Ground water, at the rate of 50 gallons per minute, seeped into the mine workings at the Alma-Seegan Mine (Chenoweth, 1994 - S10100230), Big Four No. 2 Mine (Chenoweth, 1994 - S10100228), Fern No. 1 Mine (Chenoweth, 1994 - S10100227) Firelight No. 6 Mine (Chenoweth, 1992 - S10100224) and Starlight Mine (Chenoweth, 1997 - S10100233). Water flowed into the mine workings at the Big Chief Mine at approximately 80 gallons per hour (Chenoweth, 1992 - S10100223). A sump and pump was required at the Moonlight Mine due to water seepage (Chenoweth, 2003 - S08250503). Perched water was encountered during mining at the Utah No. 1 Mine (School Section 36) (Chenoweth, 1991 - S03100502). Mining at the C-3 mine was in wet ground because a perched water table was encountered in the basal Shinarump (Chenoweth, 1991 - S03100502). Results from the water samples taken at the Moonlight and Radium Hill mines suggests that AUMs that partially fill with water may concentrate radionuclide activities and other dissolved constituents. Collection and analysis of additional hydrologic data would be necessary to determine shallow ground water flow characteristics and thus the implications of radionuclide mobilization near mines in the Monument Valley mining district (Longsworth, 1994 - S02250302).

MINE WATER EXTRACTION

In the Eastern AUM Region uranium was recovered from mine water. Mine water recovery is also referred to as Old Stope-Leach Projects and are described by Holen and Hatchell (1986 - S08200601) as another form of In Situ Leach (ISL) mining. Surface or recirculated mine waters, along with air to facilitate oxidation, were pumped through injection drill holes into old uranium mine stopes (an underground excavation from which ore is extracted). These water solutions were then pregnant with leached uranium, and were collected in sumps within the mine workings and pumped to the surface into open settling and holding ponds. After settling, these waters were passed to an Ion Exchange facility to remove the uranium. The extracted waters were either used for recirculation, discharged to surface waters, or were used in nearby uranium mills as process water. In some cases natural mine water flow, where underground mines were flooded below the water table, was pumped to the surface and its dissolved uranium was extracted in an Ion Exchange facility. This method of mining was used extensively at the large mines in the Ambrosia Lake area. It was also used at the Church Rock and the Mariano Lake mines where the settling and holding ponds and fences are readily visible on orthophotos. However, these pregnant solutions ponds were not mapped everywhere and have not been characterized for exposure risk. McLemore and Chenoweth (1991 - S03030608) reported that 893,787 pounds of uranium oxide were recovered from mine waters of Kerr McGee, Homestake Sapin Partners, and United Nuclear mines throughout the entire Grants Uranium District.

Table 13 lists productive AUMs that were determined to have workings below the water table or were considered wet mines that required pumping. It also shows AUMs that were not mined, but the ore deposits occur below the water table, and would likely require pumping if mined.

Table 13. AUMs With Uranium Ore Deposits Below the Water Table.

MINE NAME	PRODUCER	TONS	U3O8_LBS	START_YEAR	END_YEAR	WATER TABLE * If Mined	REGION
Crownpoint, Section 9	No					Below*	Eastern
NE Church Rock No. 2	No					Below*	Eastern
Nose Rock No. 1	No					Below*	Eastern
Section 13	No					Below*	Eastern
Section 29-Conoco	No					Below*	Eastern
Black Jack No. 2	Yes	247,613	1,129,004	1959	1970	Below	Eastern
Church Rock	Yes	292,604	883,580	1960	1982	Below	Eastern
Church Rock ISL	No					Below	Eastern
Crownpoint ISL	No					Below	Eastern
Grace Insitu Leach	Yes	9	201	1975	1975	Below	Eastern
Homestake Sapin Mine No. 23	Yes	4,811,351	17,520,976	1959	1989	Below	Eastern
Homestake Sapin Mine No. 25	Yes	3,145,969	9,960,150	1959	1983	Below	Eastern
Kermac Mine No. 22	Yes	3,851,523	13,471,257	1958	1985	Below	Eastern
Kermac Mine No. 24 and 26	Yes	2,894,860	15,365,512	1959	1983	Below	Eastern
Mariano Lake	Yes	505,489	2,265,405	1977	1982	Below	Eastern
NE Church Rock	Yes	3,498,648	9,773,362	1972	1982	Below	Eastern
NE Church Rock No. 1	Yes	836,570	2,953,673	1976	1985	Below	Eastern
NE Church Rock No. 1-East	Yes	322,602	1,234,784	1978	1983	Below	Eastern
Section 16 deposit						Below	Eastern
Alma-Seegan	Yes	6,769	25,541	1965	1966	Below	North Central
Big Chief	Yes	32,834	151,221	1959	1961	Below	North Central
Big Four No. 2	Yes	3,930	20,444	1963	1963	Below	North Central
Bootjack	Yes	36,236	331,010	1957	1966	Below	North Central
Fern No. 1	Yes	9,582	126,703	1956	1961	Below	North Central
Firelight No. 6	Yes	2,141	7,611	1959	1960	Below	North Central
Moonlight	Yes	223,237	1,177,501	1956	1966	Below	North Central
Radium Hill No. 1 and Utah No. 1	Yes	12,776	87,737	1955	1962	Below	North Central
South Sunlight	Yes	28,645	171,460	1962	1965	Below	North Central
Starlight	Yes	40,378	231,731	1958	1961	Below	North Central
Starlight East	Yes	45,990	289,378	1961	1964	Below	North Central
Sunlight	Yes	55,024	291,462	1958	1964	Below	North Central

Figure 68 shows two areas near the Bootjack Mine with above-background levels of excess Bismuth-214 (see page 91). The radiation contour area to the northeast corresponds to the location of the evaporation ponds (shown in Figure 69) where water in the mine was pumped to the surface. AUMs with underground workings that had histories of water infiltration and pumping may warrant additional examination for possible radionuclides or concentrations of other dissolved constituents.

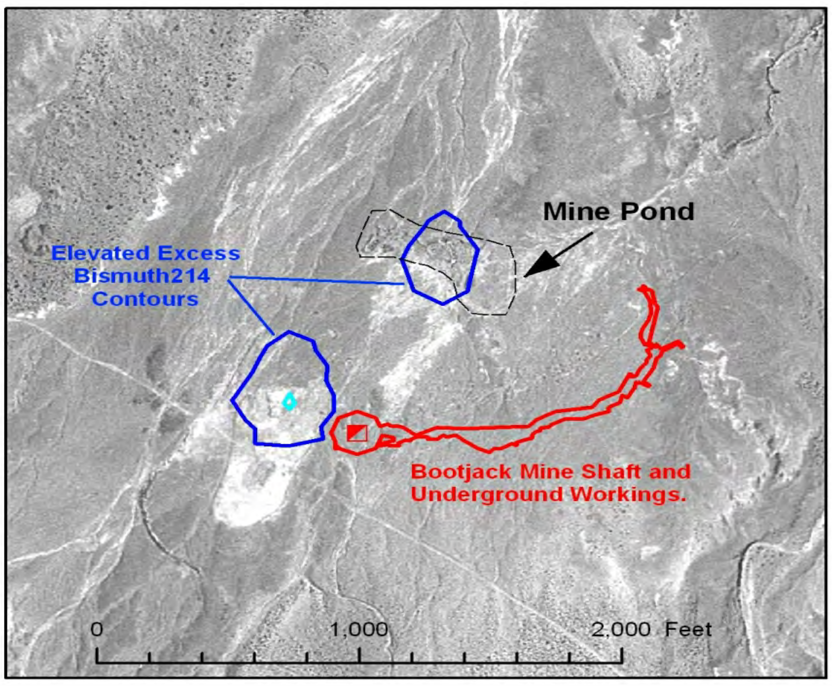

Figure 68. Bootjack Mine Surface and Underground Workings and Proximal Areas with Excess Bismuth-214.

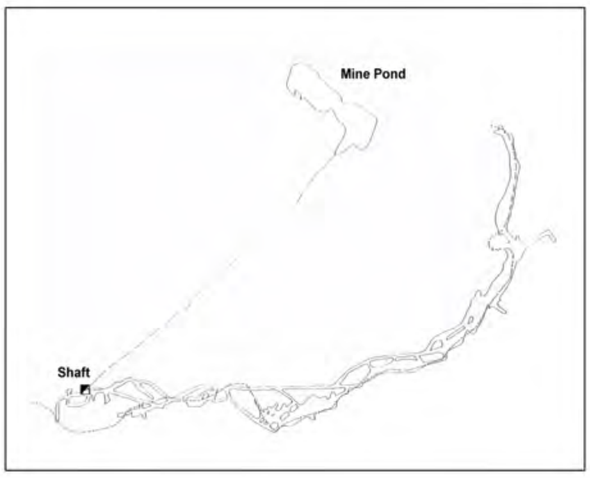

Figure 69. Plan Map of the Underground Workings and Surface Features of the Bootjack Uranium Mine (Chenoweth, 1993 - S10100222).

AUMS WITH SURFACE WATER PATHWAYS TO WATER SOURCES

Two of the AUMs in the North Central AUM region are located upstream and adjacent to major water sources - San Juan River and Lake Powell. The Whirlwind Mine is on the south bank of the San Juan River (Glen Canyon National Recreation Area) approximately 16 miles northwest of Oljato Trading Post (Chenoweth, 1991 - S03100502). The Whirlwind Mine operated from 1950 to 1966 and extracted 15,777.8 tons of ore with 69,403.5 pounds of uranium and 277,779.1 pounds of vanadium recorded. Figure 70 shows the location of the Whirlwind Mine on a natural color orthophotograph (left) generated from 2004 imagery during drought conditions. The outline of the Whirlwind Mine is shown in red and from this image it can be seen that the Whirlwind Mine is directly upstream from the San Juan River (approximately 2000 feet upstream). The USGS topographic map on the right was developed in 1987 during non-drought conditions, and shows that the Whirlwind Mine drained directly into a drainage within 400 feet of Lake Powell's shore.

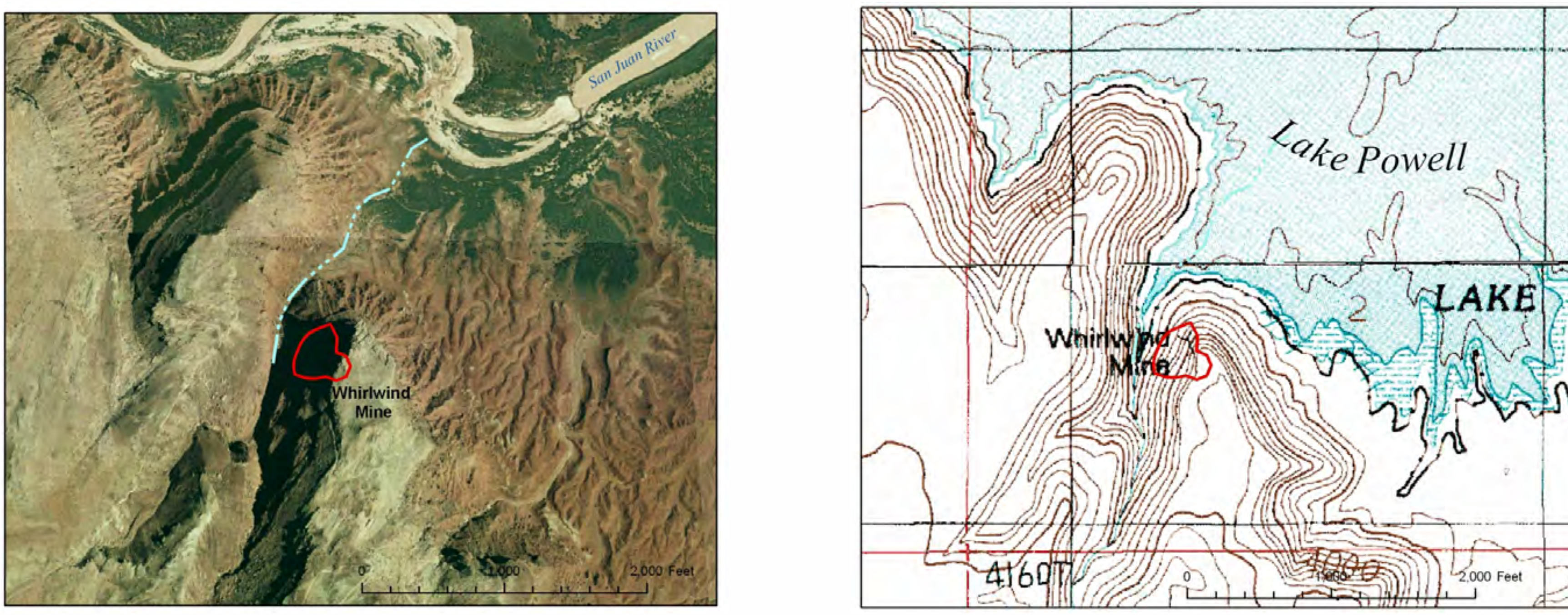

Figure 70. Whirlwind Mine on the South Bank of Lake Powell. Natural color image (left) acquired in 2004 and USGS topographic map (right) dated 1987.

Mexican Hat Stockpile (Figure 71) is an AUM-related site located in a drainage that flows directly into the San Juan River, which is located less than 1/2 mile downstream. During the late 1940's and 1950's, the Vanadium Corporation of America (VCA) and individual Navajo's mining in the vicinity of VCA's Monument No. 2 mine stockpiled their ore at this location in ore bins along the wash on both sides of the highway (Chenoweth, 2006 - S04200601). Companies mining on Oljato Mesa and on Monitor Butte also stockpiled their ores here. This was done because the small, narrow, suspension bridge across the San Juan River at Mexican Hat at that time could not support large trucks. Ores were hauled from the mines in five-ton trucks to the stockpile area and then 21-ton semi-trailer trucks were used to haul the ore to the AEC ore-buying station at Monticello, Utah or the VCA mill at Durango, Colorado (Chenoweth, 1994 - S10100221). The wagon road from Cane Valley over Comb Ridge connecting Kayenta to Shiprock road (now US Highway 160) was not improved by the Atomic Energy Commission until 1952 (Chenoweth, 1989 - S10100213). When completed, this route greatly reduced the mileage to Durango, Colorado and eliminated the Mexican Hat stockpiling.

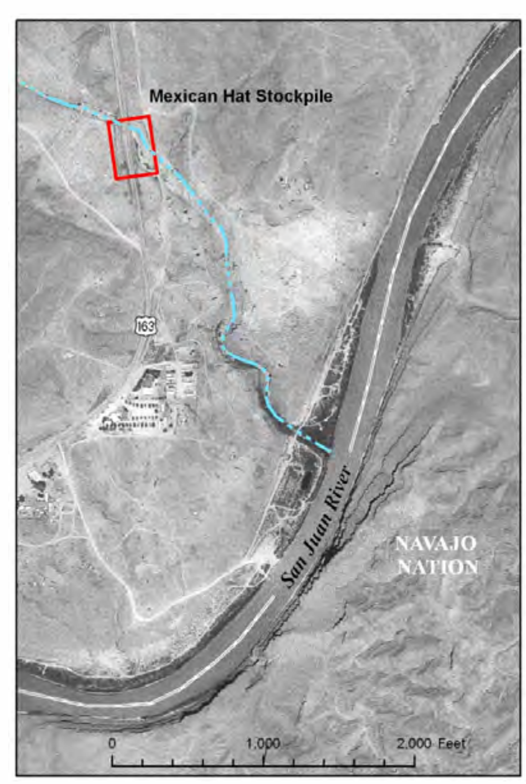

Figure 71. Mexican Hat Stockpile.

There may be other sites like the Mexican Hat Stockpile. Donald Bayles, a uranium ore hauler living in Blanding, Utah, stated in an oral history interview:

"I hauled ore from Mexican Hat which is Monument Valley One [sic] Mine. They hauled the ore up and would put the ore in a bin on the other side of the bridge. Then from there they'd have a little truck to take it across the bridge. They'd take it up on this side of Mexican Hat to a little creek. Then they'd take it on top. They had some little chutes they'd dump it in. When we'd come down and load it, we'd just open the chutes. They'd keep trucking it across the bridge there because the bridge wasn't made for too much weight."

This statement suggests there may have been another uranium ore transfer point on the south side of the bridge. Ore was loaded into a bin where it was stockpiled to load into smaller trucks to cross the bridge and dump at the Mexican Hat Stockpile (Tate, 2001 - S05310703). AUMs located upstream from water sources and/or associated riparian/wetland areas such as these sites may warrant additional study.

MINE SUBSIDENCE IN THE EASTERN AUM REGION

The Eastern AUM Region has also experienced mine subsidence, which was likely an unintended result of retreat mining underground. This can happen when a mine collapses as pillars separating stopes are extracted. Holmquist (1970 - S01140711) describes surface subsidence of 2-3 feet over thicker stopes at the Dysart No. 1 mine. The ore was 320-370 feet below the surface. At the Homestake Sapin Mine No. 15, caving above mine stopes collapsed to the surface. At the Kermac Mine No. 22 two large stopes caved to the surface creating holes 60 feet deep. The ore was at a level of 360 feet below the surface. At this mine, uranium mill tailings were run underground to prevent further caving to the surface. At the Homestake Sapin Mine No. 23, surface sand was injected via a drillhole to prevent collapse. In this area some mines were below the water table and flowed up to 1,600 gallons per minute. The environmental impact of these various mining occurrences has not been characterized.

EXPLORATION DRILLING

Navajo prospectors were the first to discover uranium mineralization in the Lukachukai Mountains (Chenoweth, 1988 - S10280203), on Black Mesa (Chenoweth, 1990 - S10100236), and in the Cameron area (Chenoweth, 1993 - S10100239). It was a Navajo sheepherder whose discovery in the Todilto Limestone triggered the boom in the Grants uranium district (Chenoweth, 1985 - S08020601). The earlier discoveries in the Carrizo Mountains and these successful prospecting efforts were followed by extensive drilling and stripping programs across the Navajo Nation by the Atomic Energy Commission (AEC) and private companies. These activities would penetrate uranium mineralization at depth or at the surface, opening additional pathways to uranium ore deposits.

Chenoweth (1990 - S10100236) describes how bulldozers were used by the AEC in the Black Mesa area of the Central AUM Region to expose uranium mineralized outcrops after ground and aerial reconnaissance revealed promising outcrops. Later these exposed outcrops and nearby areas were typically drilled to search for and define uranium ore bodies. Some were eventually mined and others left exposed. An inspection of the DOE aerial radiation surveys in this area shows strong correlation with these unexploited but radioactive outcrops.

In the Cameron area of the Western AUM Region Chenoweth (1993 - S10100239) provides an extensive description of drilling activities. He reports that from 1953 through 1962 approximately 1,005,000 feet of surface drilling occurred at about 20,000 holes that rarely exceeded 100 feet in depth. They were drilled around known mines and typically in a 500 foot grid pattern decreasing to a 50 foot grid in promising areas. Drilling was also performed at the locations of aerial radiometric anomalies.

Extensive drilling programs were conducted by the AEC in the Northern AUM Region. Exploration occurred in the eastern Carrizo Mountains (Chenoweth, 1984 - S03130303), the northern and western Carrizo Mountains (Chenoweth, 1985 - S10020203), and the Lukachukai Mountains (Chenoweth, 1988 - S10280203). It was noted that mining companies also ran some drilling programs.

In numerous locations within the North Central AUM Region there is evidence of previous uranium exploration activities. An example is the Tract 10 and Tract 11 area where there is significant surface expression of exploration drilling evident on the photos. Figure 72 shows a grid of roads used to access and lay out exploration drilling sites. Phillips Petroleum Company conducted an extensive exploration program on Tracts 10 and 11, known as the Strategic Minerals Project 68 (Chenoweth, 1991 - S03100502). This drilling included 245 holes with 40,000 feet of total linear drilling. The exploration resulted in locating an ore body at a depth of 200 feet with an average thickness of 5 feet that was reported to contain 8,300 tons of uranium. The potential impacts of these exploration activities as a migration pathway may warrant further investigation.

Malan (1964 - S04290701) prepared a map locating exploratory drilling projects of Monument Valley for Arizona and Utah. Figure 73 below shows the greater extent of exploratory drilling areas (shown in yellow) that were mapped by Malan in comparison to the extent of AUMs (shown in red).

Figure 72. Exploration Drilling in the Tracts 10 and 11 Area of the North Central AUM Region.

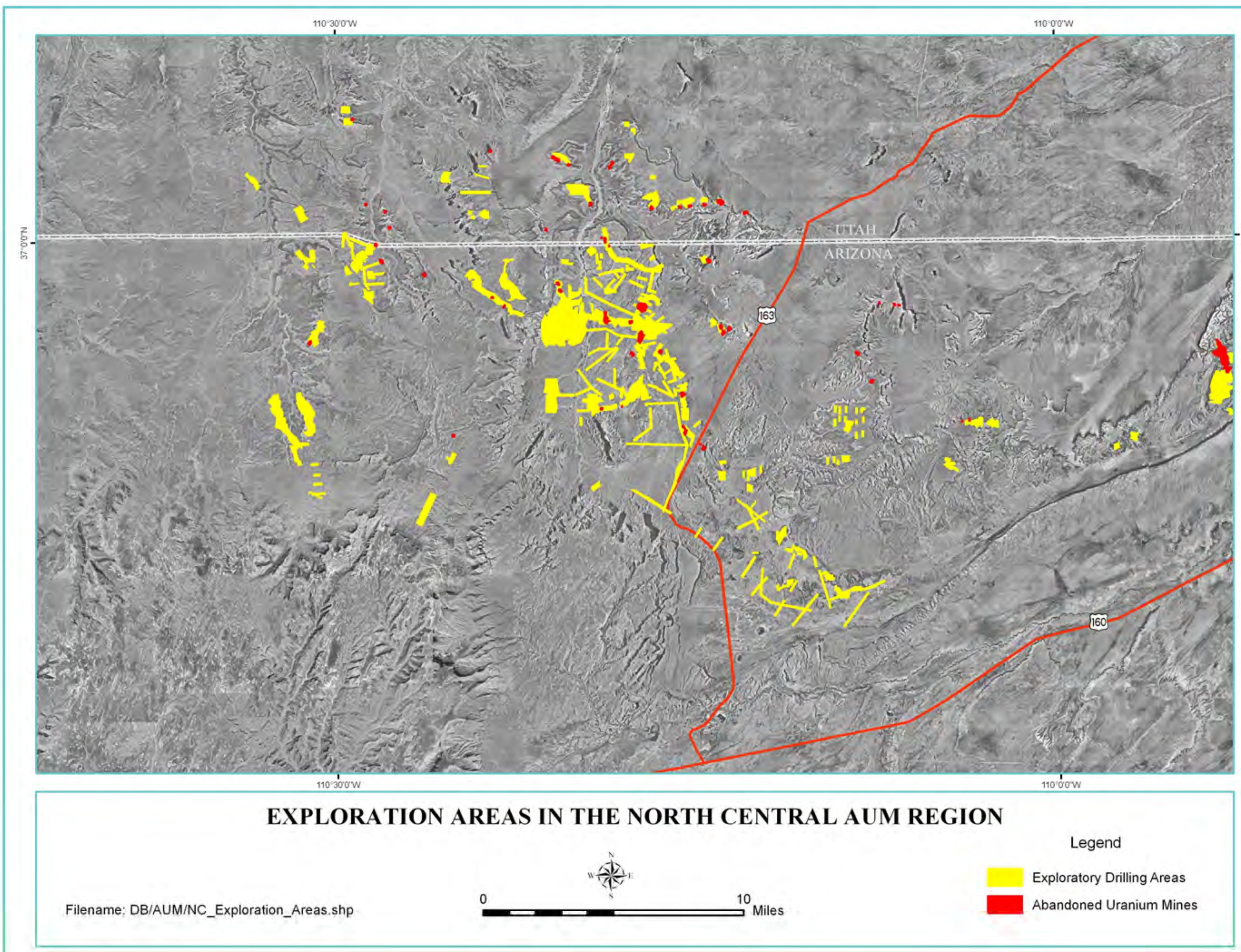

Figure 73. Exploration Areas in the North Central AUM Region.

AERIAL RADIATION SURVEY—EXCESS BISMUTH-214 AREAS

The aerial radiological surveys that were flown over portions of the Navajo Nation proved to be a useful tool for locating AUMs and AUM-related areas, like the Cove Transfer Station shown in Figure 74. See Part II, Section 2, "Aerial Radiation Survey" for more information. These types of surveys allow characterization of large areas to identify where higher spatial resolution ground-based measurements may be required. The acquisition of new high resolution aerial radiation surveys may help locate ore transfer stations, ore haulage routes, or AUMs in areas that were not flown during the 1994 - 1999 surveys, such as the Eastern AUM Region.

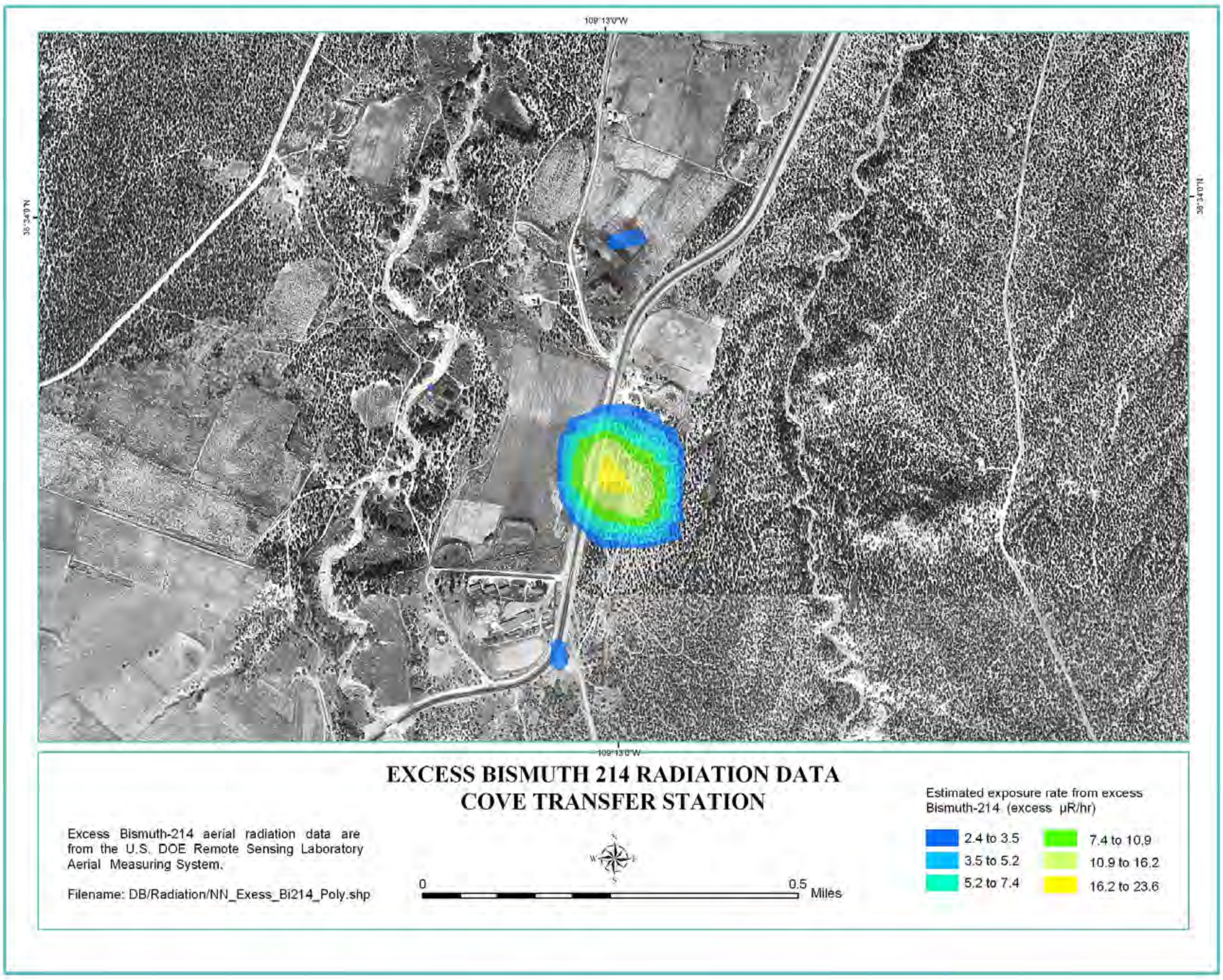

Figure 74. Cove Transfer Station. Location of this site was established by the DOE aerial gamma radiation survey.

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