

University of Nevada, Reno

Unregulated Water Source on the Navajo Nation: Assessing Risk of Unregulated Water Supplies  
and Optimal Placement of Regulated Water Supply Points

A thesis submitted in partial fulfillment of the  
Requirements for the degree of Master of Science in  
Hydrology

**By**

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**August, 2013**

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We recommend that the thesis  
prepared under our supervision by

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## Abstract

The Navajo Nation is the largest federally granted area given to Native American people in the United States, with more than 300,000 federally recognized Navajo tribal members. Approximately 58% of the people living on the Navajo Nation do not have access to public utilities, including treated drinking water (EPA 2010). Without access to drinking water sources that meet the requirements of the Federal Safe Drinking Water Act, rural residents use unregulated water sources, such as windmill driven wells designed to supply water for livestock. Approximately 30% of the population use unregulated supplies because they are not connected to the public water supply and 29% of people haul water from unregulated supplies even though they are connected to the public water supply (NNEPA 2011).

From 2008 until 2011, students from Diné College and University of Nevada, Reno sampled unregulated water supplies in 11 Chapters located within the Northern Navajo region. 10% of the stock tank wells had naturally occurring uranium and 40% had arsenic concentrations that exceeded the federal maximum contaminant level (MCL) for drinking water. Nearly 80% of these sources were also contaminated with bacteria.

Based on sampling results for arsenic and uranium, and an analysis of census data, approximately 5,000 people have a high likelihood of using contaminated unregulated sources as a drinking water supply. Although the analysis identified areas where unregulated water source use is highly likely, this has not been verified with a survey of residents. This study provides guidance for (a) educational efforts to inform residents of the potential risks associated with drinking water from unregulated sources, (b) construction of watering points by the Navajo Nation Tribal Utilities Authority and (c) setting priorities for hauling tankers of treated water periodically to chapters included in this study.

## **Acknowledgements**

This research would not have been possible without the hard work, dedication, and devotion from the faculty and students at Diné College. From the developing stages of this project, Perry H Charley from the Diné Environmental Institute has lead teams of students to collect samples and inform the general public of the hazards water sources with excess levels of heavy metals and uranium.

I would like to especially thank Mr. Charley for his expertise, passion, and commitment to this research.

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## Introduction

The Navajo Nation is the largest federally recognized tribe with a reservation, with more than 300,000 tribal members, approximately 178,000 of whom live on the reservation (Figure 1) (US Census Bureau 2010). The boundaries encompass 18 million acres in Arizona, New Mexico, and Utah (Denetdale 2011) (Figure 2). Within the reservation, the geological composition is commonly sandstones and shale deposits (AZGS 2000), which leads to an abundance of natural resources of oil, natural gas, coal, and naturally occurring uranium and arsenic (Brugge and Goble 2002, Turner 1979). Both of the latter minerals are often found dissolved in groundwater (DEI 2008-2011, NNEPA 2005, NNEPA 2011).

The Navajo Nation is a vast region with an average population density of 6.5 persons per square mile (FCC 2010). In this rural society, the Navajo Tribal Utilities Authority (NTUA) provides electrical, sewer, natural gas, and water utilities for approximately 42% of the population (EPA 2010), leaving the other 58% without these services. Those who do not have access to utilities rely on water from other sources.

Figure 1-Navajo Nation Population (US Census Bureau 2008-2011)

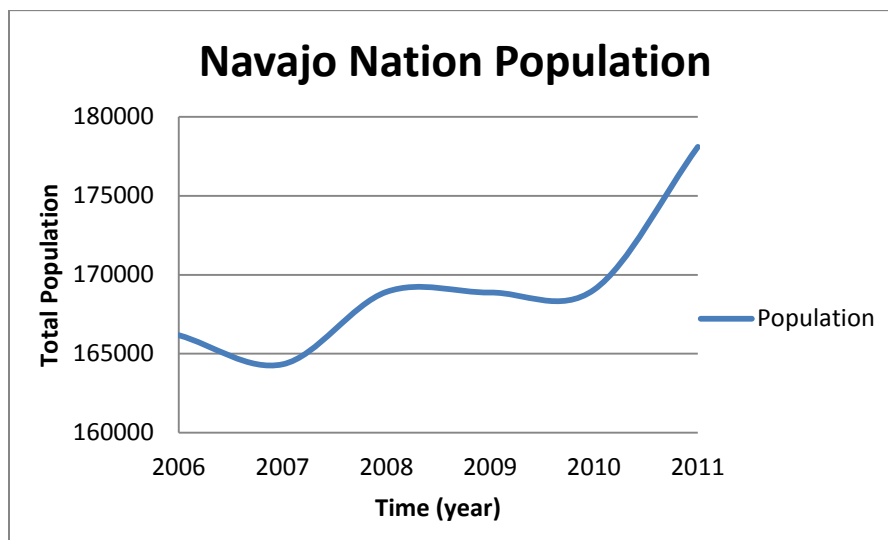
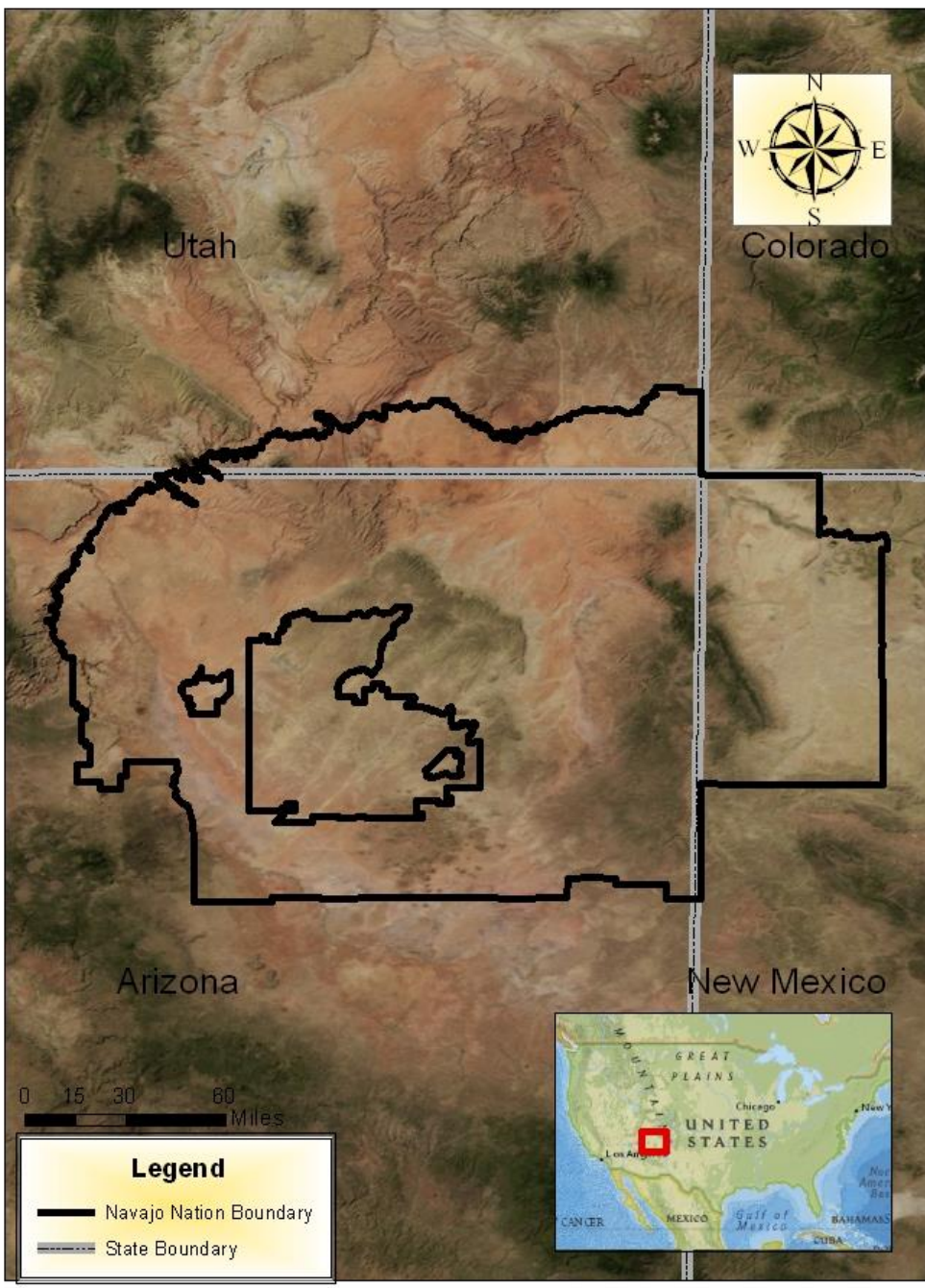


Figure 2- Navajo Nation Boundaries and Location

# The Navajo Nation



The Navajo Nation is a sovereign nation. The governmental structure of the Navajo Nation is similar to a typical state government system. The reservation is divided into regions called agencies, which are further subdivided into chapters, which are similar to counties. Each chapter has a chapter house, which is the equivalent of a county seat. The Navajo Nation has 110 chapters (Denetdale 2011). With few urban settings, the Navajo Nation is a rural society,

**Figure 3- Typical Livestock Well Construction**



with cultural values typical of a pastoral life style (Denetdale 2011).

Agriculture is a significant source of income on the Navajo Nation. Historically, Navajo agriculture included cattle and sheep production. However, water availability limited production in spite of having over 400,000 acres of open range. From the 1950s until the late 1980s, a coalition of federal agencies increased the amount of water available by installing approximately 1,000 windmill-driven wells to fill large stock tanks (Figure 3) (Turner Ruffing 1979). The wells were installed in clusters with no more than 5 miles between wells, correspondent to typical cattle grazing range (Hodder and Low 1976). These wells are not

maintained by any agency. Since installation, some have fallen into disrepair and are completely out of service.

The Navajo Tribal Utility Authority (NTUA), which is part of the tribal government, treats drinking water to meet standards specified by the Safe Drinking Water Act of 1986 and subsequent amendments (42 USC § 300g-1 1996). This includes the standards for arsenic, which has a maximum contaminant level (MCL) of 0.010 mg/L and uranium, with an MCL of 0.030 mg/L (EPA 2009). With the increase in population, high cost of installing new infrastructure, and the sparsely populated rural nature of the Navajo Nation, the NTUA has not been able to supply water to all residents. As a result rural residents rely on water from unregulated water sources (deLemos et al 2009, EPA 2005, NNEPA 2011), such as stock tank wells, in which contaminants such as arsenic and uranium may exceed federal water quality standards (NNEPA 2011, DEI 2008-2011). The most common uptake pathway of uranium and arsenic is through oral ingestion (ATSDR and CDC 2012a,b).

Epidemiological studies indicate that the Navajo have health problems that could be the result of exposure to contaminants in water from unregulated sources. Uranium (6%) and arsenic (6%) were found in samples from unregulated water supplies in concentrations that exceeded the MCL for drinking water in 10% and 38% of the groundwater supplied livestock tanks, respectively (NNEPA 2011).

The Navajo Nation Environmental Protection Agency (NNEPA) collected urine samples and found that 36% of those sampled exceeded the National Health and Nutrition Examination Survey (NHANES) national 95 percentile for uranium concentrations (0.05 µg/g) (Barney) and 3% exceeded the NHANES national 95 percentile for arsenic (18.9 µg/L) (NNEPA 2011, CDC 2013). Uranium is a carcinogen and is nephrotoxic and neurotoxic (Craft et al 2004, Zamora et al

1998). Chronic exposure to arsenic in drinking water can lead to skin lesions, skin cancer, internal organ cancers, neurological damage, hypertension, peripheral vascular diseases, cardiovascular disease, lung cancers, and diabetes mellitus (Yoshida et al 2003). The occurrence of diabetes on the Navajo Nation is approximately 6.2 times higher than in populations sampled elsewhere in the US (Hochman et al 2007). Current rates of end-stage renal disease on the Navajo Nation are 3.2 times higher than those within the American population (Hochman et al 2007).

The practice of obtaining water from unregulated water sources in barrels and transporting the water by truck to a residence for consumption is called water hauling. Studies to determine the percentage of the population that hauls water on the Navajo Nation have yielded varied results. For example, in 2005 the United States Environmental Protection Agency (EPA) reported that approximately 30% of the population hauled water (EPA 2005). A 2009 survey reported that nearly 100% of participants hauled water from at least 1 source, despite the fact that 66% of the respondents had access to NTUA water (deLemos et al 2009). A 2011 study indicated that 30% of Navajo residents were forced to haul water because of lack of available NTUA sources (NNEPA 2011). This study also found that 29% of the population hauled water in spite of availability of NTUA water (NNEPA 2011) (Table 1). Although results of these studies varied, one unifying fact from each is that hauled water is likely to be used to supplement the domestic water supply in rural parts of the reservation (EPA 2005, deLemos et al 2009, NNEPA 2011).

The Navajo Nation Division of Water Resources (NNDWR) began a program to deliver treated water to areas with a suspected heavy dependence on unregulated water sources (EPA 2012). To understand reliance on unregulated water sources on the Navajo Nation deLemos et

al (2009) created maps to communicate the potential dangers of using unregulated water sources.

**Table 1- Summary of Water Hauling Studies**

Percentage of Population Hauling Water

Study	No Other Supplies Available	Total Population Hauling Water
EPA 2005	30%	30%
deLemos et al 2009	66%	100%
NNEPA 2011	30%	59%

Although no studies have clearly linked unregulated water supplies to observed health problems, the results of water sampling, water hauling habit and urine sampling surveys suggest that unregulated supplies could be a source of exposure to contaminants through hauled water, especially in areas that have greater access to unregulated supplies than NTUA supplied water. This indicates a need to characterize the risk of consumption of unregulated water supplies, especially in areas with no other sources of drinking water, through the risk assessment process of identifying the potential hazards, assessing the magnitude of hazard, determining the extent of exposure, and finally characterizing the total risk (National Research Council 1983).

## **Purposes of Study**

This study had four purposes:

1. Organize water quality data collected from the unregulated water sources during the summer internship programs from 2008 – 2011 involving students at Diné College through the Diné Environmental Institute in Shiprock, New Mexico to determine the extent of exposure,

2. Provide information about water quality of unregulated water supplies to the local residents that reside in 11 chapters near the Four Corners area of the Navajo Nation to assess the magnitude of hazard,
3. Assess risk of exposure to uranium and arsenic through unregulated supplies, and
4. Recommend locations for treated water distribution points to reduce risk of exposure to contaminated supplies through unregulated sources.

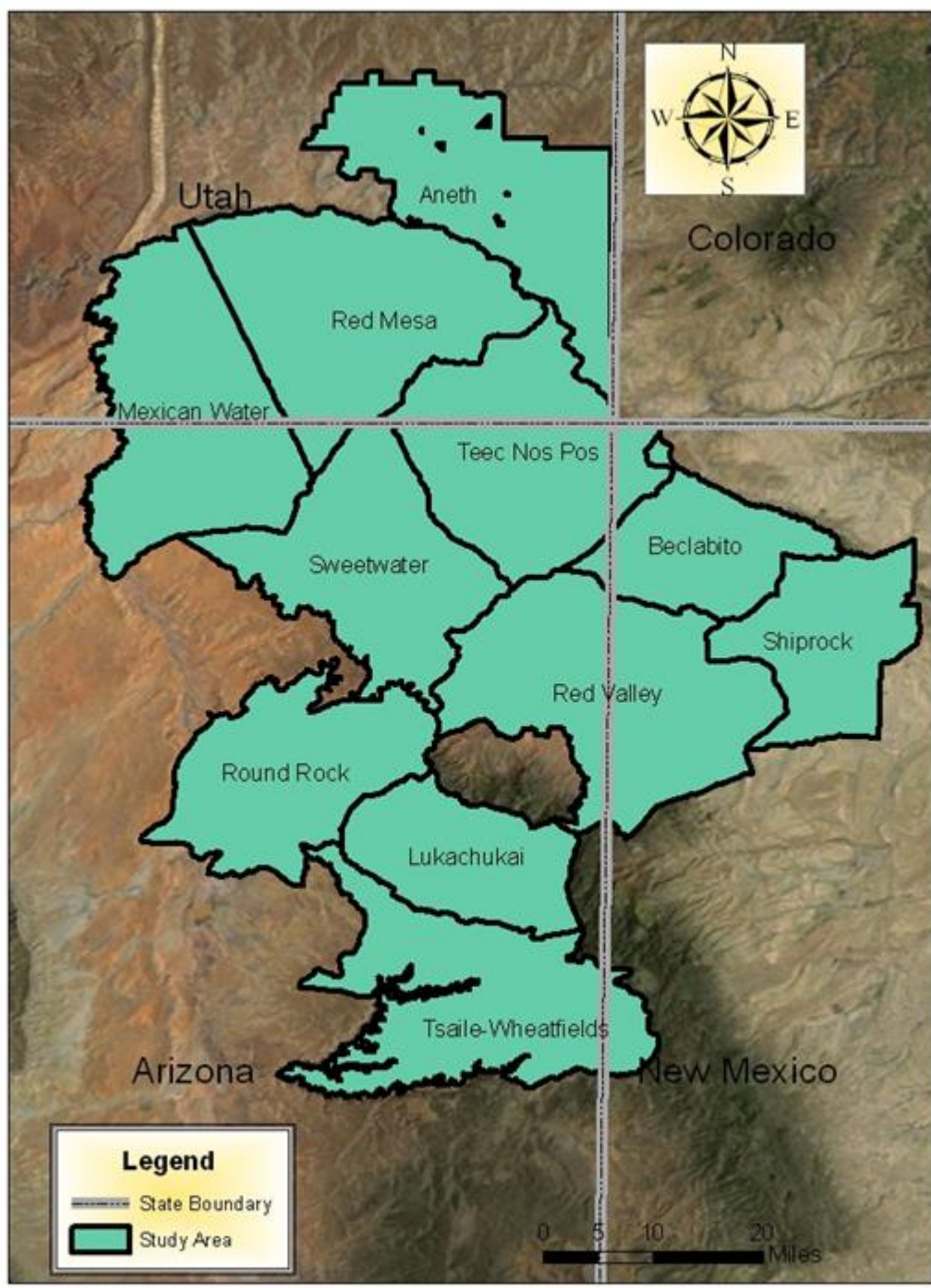
This research relied solely on a spatial analysis to identify the regions most likely to consume water from unregulated sources. Previous studies of water quality and unregulated water supply use were able to survey residents. The Navajo Nation requires review and approval by the Navajo Nation Institutional Review Board if studies include human subjects (Navajo Nation Code § 3253). My study did not have an approved human subject component, so I was unable to obtain data from surveys of rural residents about drinking water sources. Accordingly, my analyses relied on combination of surrogate measurements to identify the areas where unsafe water was most likely used as a drinking water source.

## **Methods**

### **Study Area**

The study area includes eleven Navajo Chapters: Aneth, Beclabito, Lukachukai, Mexican Water, Red Mesa, Red Valley, Round Rock, Shiprock, Sweetwater, Teec Nos Pos, and Tsaile-Wheatfields, all of which are in vicinity of the Four Corners area (Figure 4). The total area of this region is approximately 1.86 million acres, with 25,437 residents (US Census Bureau 2010). The study area had 296 stock tank wells.

Figure 4- Geographical Extent of Study Area



## Data Collection

### Data Organization

The initial step for this project was to organize the data collected from water quality surveys conducted from 2008 – 2011 by students from Diné College (Table 2). One of the most challenging aspects of this research was constructing, organizing, and reviewing the sample record. All sampling records and results were hand written paper records. When samples were collected, students were required to record well number, Chapter name, Universal Transverse Mercator northing and easting, pH, temperature in degrees Celsius, and conductivity in millisiemens per centimeter. In 2012 these data were transferred to Microsoft Excel as 261 individual records including results of laboratory analyses. These were inspected to ensure that locations were accurate and field and laboratory records were complete. I included samples in the record if the UTM coordinates matched those reported for existing wells (provided by DEI 2012) and if field measurements were complete.

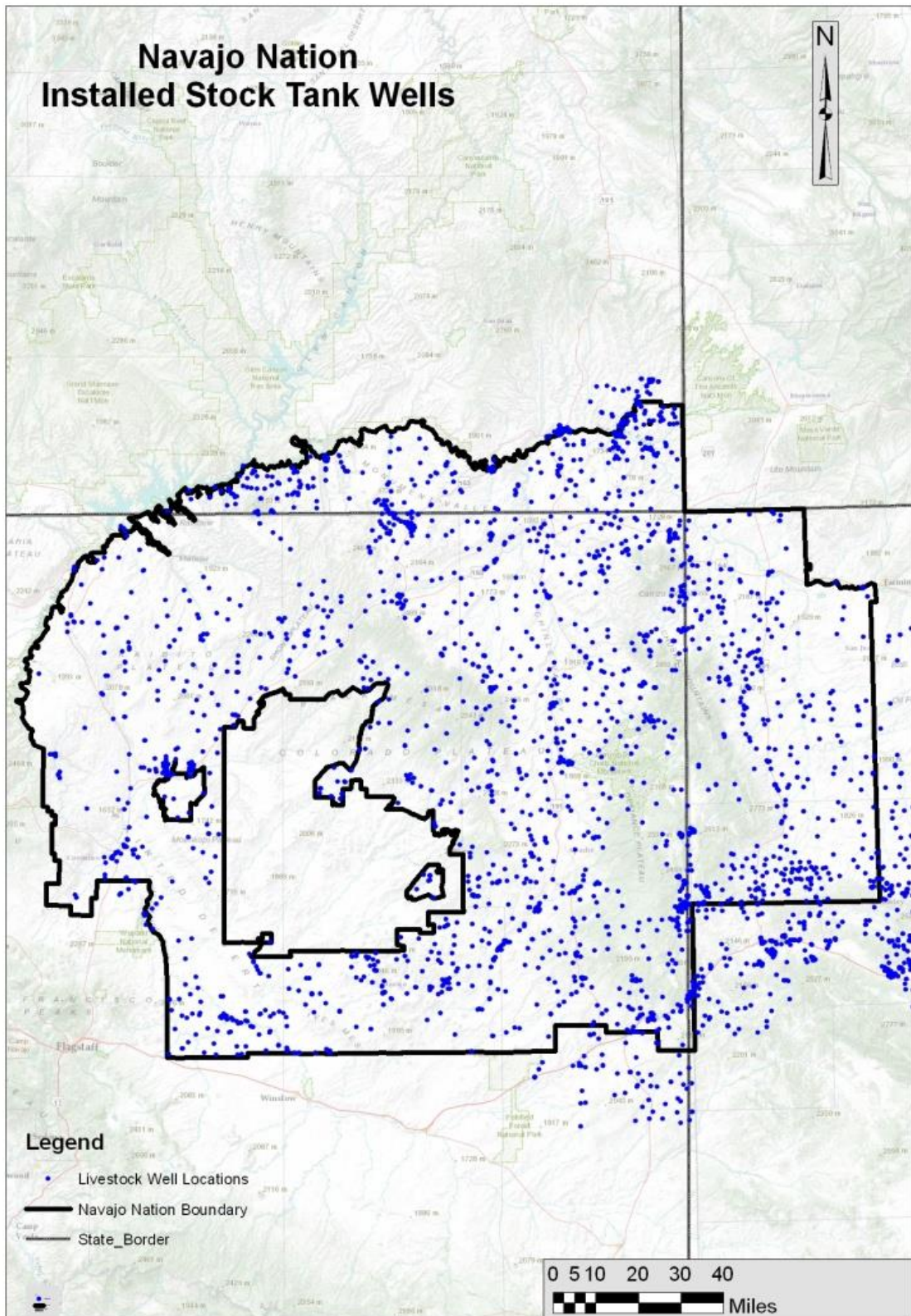
**Table 2- Summary of Collected Water Quality Samples**

Number of Samples Collected			
2008	2009	2010	2011
93	38	101	29

### Location of the Stock Tank Wells

The UTM coordinates for the stock tank wells were obtained from the Diné Environmental Institute (DEI 2012) (Figure 5).

Figure 5- Location of Stock Tank Wells on the Navajo Nation (DEI 2012)



## Water Quality

All field measurements and samples were collected using the protocols described in United States Geological Survey's *National Field Manual for the Collection of Water-Quality Data* (2003, 2004, 2005, 2006, 2008). Samples were preserved using protocols recommended by the Nevada State Health Laboratory (Nevada State Public Health Laboratory, Reno, NV), which performed analyses for uranium and arsenic using mass spectrometry for all the samples collected (EPA Standard Method 200.8) (EPA 1994). Only 101 of the 261 samples collected were analyzed for uranium and arsenic concentrations.

While in the field, water temperature, pH, and conductivity were measured using a Yellow Springs Instrument (YSI) 556 MPS (Yellow Springs Instruments, Yellow Springs, OH 2002) at each well. The YSI was calibrated daily for pH and conductivity measurements prior to use. pH was calibrated with a three point calibration curve, using pH 4.0, 7.0, and 10.0 standards (Fisher Scientific, Hampton, New Hampshire 2008-2011). Conductivity was calibrated using a single point calibration using a conductivity solution with a concentration of 1000 mS/cm. UTM coordinates were recorded using a Garmin eTrex® (Garmin International 2011) handheld global positioning system.

Test results and field measurements were transferred from paper records to Excel spreadsheets. Sample results were compared to standards specified by the Federal Safe Drinking Water Act (EPA 2009), with results exceeding standards interpreted as unsafe for human consumption.

*E.coli* and coliform enumeration was performed on 53 of the 261 samples collected at Diné College using the IDEXX Quanti-Tray® (IDEXX Laboratories Inc, Westbrook Maine) method

(40 CFR 141 § 141.21). When bacterial samples were collected, laboratory blanks and sample duplicates were included to assure that results were accurate and reliable.

### **Navajo Tribal Utilities Authority Data**

I used NTUA water distribution data system maps (NTUA 2012) to identify areas with the highest potential to use unregulated water sources. By locating the ends of service laterals, it was possible to identify regions within the study area served with treated water. While preparing this data for later use in this risk assessment, the assumption applied was that if water was delivered to a census block, all residents in the block had access to treated water.

### **Population Data**

2010 census block population data for the study area were obtained from the US Census Bureau (<http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml>). Census block level data offer the highest resolution population data. The Navajo Nation lies in three different states, with census block data most readily available by county. The population data were obtained from 13 counties in Arizona, 10 counties in New Mexico, and 7 counties in Utah (US Census Bureau AZ 2010, NM 2010, UT 2010 <http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml>). The spatial data for the census blocks were obtained through the Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) system online (US Census Bureau 2010 TIGER). The data sets were clipped to include only the census blocks within the study area. Blocks with no population within the study area were set to a null value and were excluded from analysis.

### **Model Building to Characterize Risk of Unregulated Supply Use**

The unregulated water supplies are a potential risk to the Navajo population, but I assumed the level of risk varied with several factors. These included population data, presence

or absence of treated water supplies from NTUA, availability of unregulated supplies, and the concentrations of uranium and arsenic from the water quality sampling results from Diné College and University of Nevada, Reno. I defined risk as toxicity of the contaminant (based on concentrations of arsenic and uranium normalized by the MCL) and exposure. I was unable to obtain direct information about exposure through consumption. I relied on several surrogate measurements, such as distance from unregulated water sources and population were used to create indices to characterize likely exposure.

### Estimating Risk

Two models were created to characterize regional risk. Model #1 combined population data, extrapolated water quality test results, and distance from wells. Since model #1 relied on water sampling results that included 38% of the wells within the study area, model #2 was created to consider where populations without NTUA service were located and the inverse distance between populations and the stock tank wells. Model #2 was designed with the idea that the use of any unregulated water source should be minimized (see equations 2 – 4 below), because of the potential for contamination. Because of the lack of data, biological contamination was not considered within the created risk models.

### Model #1

#### Equation 1- Likelihood of Interaction with Unregulated Water Sources Model #1

$$Risk\ Level = [NormAs] + [NormU] + PopulationScaled + RiskDistance$$

Model #1 incorporates information from the water quality survey to identify the regions where exposure to arsenic and uranium are most likely. [NormAs] and [NormU] are defined as the normalized arsenic and uranium concentration from the water quality survey (Equation 3). PopulationScaled is defined as the scaled population data (Table 3), and RiskDistance is defined as the distance from populations to unregulated water sources (Table 4).

## Model #2

### Equation 2- Likelihood of Interaction with Unregulated Water Sources Model #2

$$\text{Risk Level} = \text{Population Scaled} + \text{Risk Distance}$$

Model #2 is a conservative approach to modeling the risk from using unregulated sources. It assumes that unregulated water is unsafe for human consumption based on sampling results for arsenic, uranium or both. PopulationScaled is defined as the scaled population data (Table 3), and RiskDistance is defined as the distance from populations to unregulated water sources (Table 4).

## Water Quality Index

For model #1, I normalized sampling results for arsenic and uranium relative to the standards set in the Safe Drinking Water Act (Equation 1)

### Equation 3- Normalization of Water Quality Results

$$\text{Water Quality Index} = \frac{\text{Sample Result} \left(\frac{\text{mg}}{\text{L}}\right)}{\text{MCL} \left(\frac{\text{mg}}{\text{L}}\right)}$$

In this index, sample result is defined as the arsenic or uranium concentrations from the water quality survey and MCL is the maximum contaminant level established by the Safe Drinking Water Act (42 USC § 300g-1 1996). This approach emphasized the concentrations in unregulated sources relative to standards set to protect public health rather than absolute concentrations found in samples. The index values were then extrapolated from point data to raster format, with each grid having a resolution of 400 by 400 meters, by applying kriging, which is a geostatistical linear predictor (Cressie 1990, Venkatram 1988). This produced two raster layers with unique values for each cell, which then was applied within the two risk models.

### *Population Data*

Census block population data were scaled from one to four based on population (Table 3). The Population Scaled layer excluded the census blocks where NTUA water is provided. By using this numeric scale, population had a weight similar to the chemical concentrations and proximity to unregulated sources.

**Table 3- Population Scaling for Census Blocks Without Access to NTUA Water**

Population Data Scale	
Population	New Value
0 - 15	1
16 - 50	2
51 - 100	3
101 - 200	4

### *Distance from Unregulated Sources*

I assumed that proximity to the stock tank wells increased the likelihood of use by residents, especially in the absence of treated sources. I represented levels of likely use by applying an inverse distance buffer around the unregulated sources, creating a “bulls-eye” index. The regions closest (from 0 – 0.5 mi) to sources therefore had the highest value and regions farther (2.5 – 5.0 mi) from unregulated sources had lower values (Table 4).

The variables (Table 5) were then summed during model implementation in ArcGIS 10’s raster calculator tool. The results then were divided into quintiles to characterize different levels of toxicity and exposure (Table 8). The final characterization scheme was applied so that risk maps can be distributed and understood throughout the study area.

Table 4- Likelihood of Use Distance Ranking

Risk Distance Ranking		
Distance Range		Risk Distance Value
0	to 0.5 mi	4
0.5 mi	to 1 mi	3
1 mi	to 2.5 mi	2
2.5 mi	to 5 mi	1

Table 5- Risk Model Variables Explained

Variable	Explanation	Reference
[NormAS]	Normalized concentration of arsenic	Equation 1
[NormU]	Normalized concentration of uranium	Equation 1
Population Scaled	Population scaling for census blocks without access to NTUA water	Table 3
Risk Distance	Distance from unregulated sources	Table 4

### Identifying Watering Point Locations

I carried out an analysis to determine the optimal locations for new watering points. A watering point provides treated water for a nominal fee. I assumed that costs of construction could be minimized by minimizing the distance from existing water lines. To create this model, the distance from high risk regions identified in earlier models, distance from existing NTUA water mains, and the distance from main roads were processed using ArcGIS 10's *Euclidean distance* tool. The *Euclidean distance* tool uses the Pythagorean Theorem to determine the distance from a feature (ESRI 2013). The features that were considered included main roads and water mains, in the regions most likely to rely on unregulated water (Table 6). Main roads were considered in this model so that only locations that are easily accessible to residents would be considered. Distance from water mains were considered as a surrogate measure of cost, this assumes that the greater the distance from existing pipelines the higher the material cost to install more water infrastructure. Finally, distance from the regions defined by the previous

models was considered so that future watering points may be able to relieve the reliance on unregulated water sources. The model used to evaluate potential sites for watering points is included in equation 4. The areas with the lowest values were identified as optimal locations for future watering points to serve the most people with minimal distance from roads, water mains, and areas with high risk of using contaminated supplies. An explanation of variables can be found in table 6.

**Equation 4- Water Point Model**

$$\text{Potential Watering Point Locations} = \text{EuclRoads} + \text{EuclMain} + \text{EuclRisk}$$

**Table 6- Variable Explanation for the Watering Point Model**

Variable	Explanation
EuclRoads	Output of the Euclidean Distance tool for the Highways and State roads shapefile
EuclMain	Output of the Euclidean Distance tool for the NTUA pressure main shapefile
EuclRisk	Combined output of the regions identified as most likely to use unregulated water

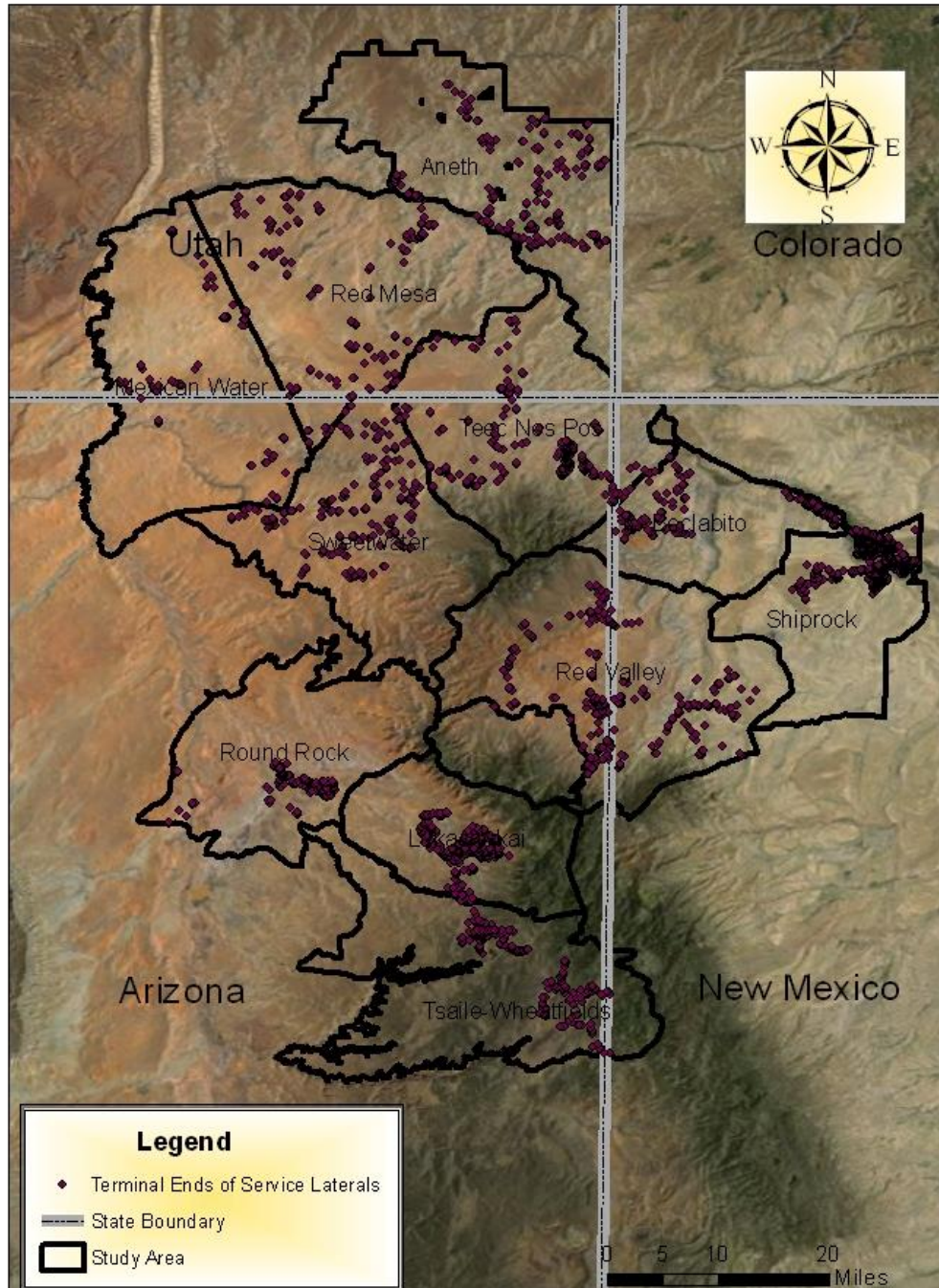
## Results

### Navajo Tribal Utilities Authority Service Locations

The locations of the terminal ends of NTUA water lines are shown in figure 6. The Mexican Water and Round Rock chapters receive the least amount of water from NTUA in comparison to the other chapters.

Figure 6- Locations Where NTUA Water is Available

### Terminal Ends of NTUA Service Laterals (2012)

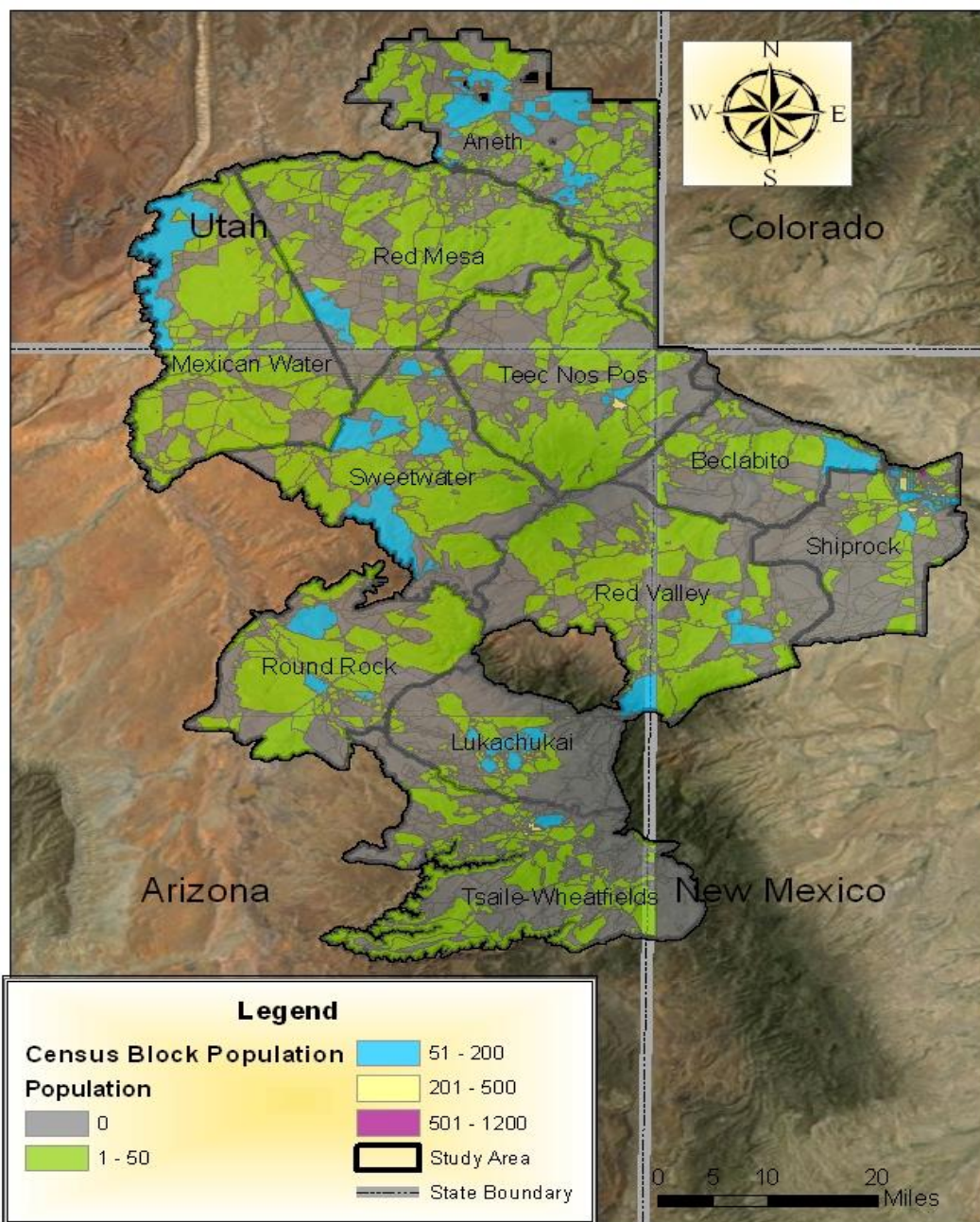


## Population within the Study Area

Within the study area, the total population as of 2010 was 25,437, with a total of 7,836 census blocks (Figure 7).

Figure 7- Population by Census Block in the Four Corners Region of the Navajo Nation

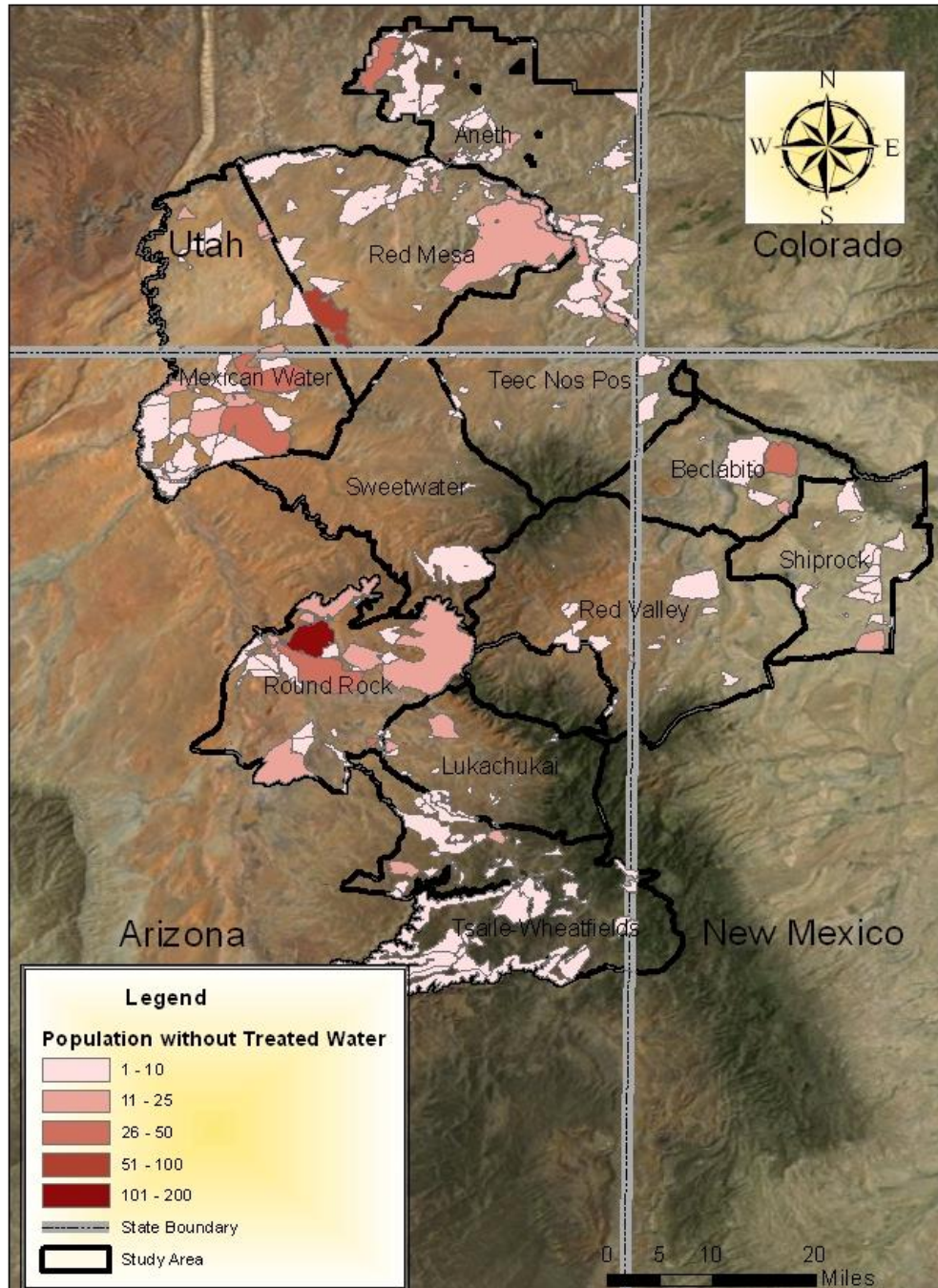
### Population by Census Block in the Northern Agency



Eighty percent (6,316) of the blocks in the study area were not populated. Within the remaining 20%, 13% (1,019 blocks) had access to treated NTUA water, leaving 573 census blocks without direct access to treated water (Figure 8). The chapters of Mexican Water, which has a population density of 1.5 persons per square mile, and Round Rock, population density of 2.6 persons per square mile, had the largest underserved population, 1117 people.

Figure 8- Census Blocks without Access to Treated Water

### Census Blocks without Access to Treated Water

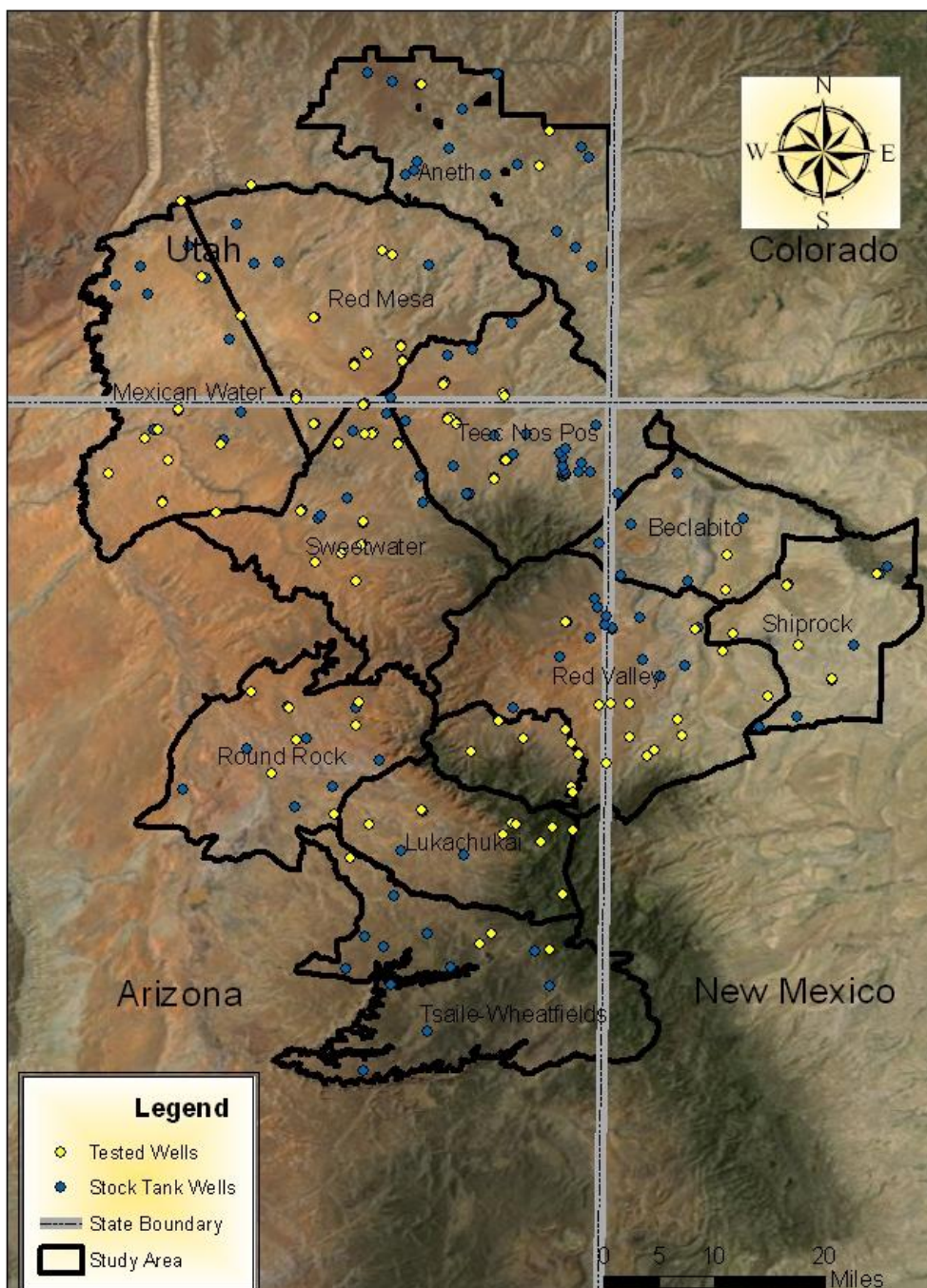


## Organization of Data

Of the 261 water quality samples taken, 101 (39%) of the samples had reliable UTM coordinates documentation and water quality sampling results. The remaining 61% of samples were not used in this study because well locations obtained during field sampling did not correspond with well locations provided from Diné Environmental Institute (2012). The locations of wells with samples used in this study are shown in figure 9.

Figure 9- Location of Sampled Stock Tank Wells

## Locations of Water Quality Sampling



## Sampling Survey Results

A summary of the water sampling results is displayed in table 7 and in figure 10. Twenty seven of 101 wells tested exceeded the MCL for arsenic, ten exceeded the MCL for uranium, and eight exceeded both standards. The range of contaminant levels varied between a maximum of 50 µg/L for arsenic (five times greater than the MCL) to below the detection limit and 760 µg/L for uranium (25 times greater than the MCL) to below the detection limit (Table 7).

Table 7- Summary of Stock Tank Sampling

Summary of Stock Tank Well Sampling							
Total Number of Wells Tested		101					
Total Number of Wells Present		265					
Percentage of Wells Tested		38.1%					
Constituent	# of Wells Measured	MCL	% of Total Wells		Standard Deviation	Range	
			Tested	Mean			
pH	83	N/A	31%	8.07	0.94	4.18	- 10
Conductivity	65	N/A	25%	0.88	0.95	0.085	- 4.89
Temperature (deg C)	60	N/A	23%	32.77	22.6	11.3	- 75.88
Arsenic (mg/L)	101	0.010	38%	0.008	0.09	ND**	- 0.050
Uranium (mg/L)	99	0.030	37%	0.02	0.085	ND**	- 0.760
<i>E.coli</i> (MPN/100 mls)	70	0	26%	81	135	0	- 960.6
Total Coliform (MPN/100 mls)	53	0	20%	67	207	0	- 1011

## Water Quality Sampling Results

		Arsenic (mg/L)	Uranium (mg/L)	<i>E.coli</i> (MPN**/100 mls)	Total Coliform (MPN**/100 mls)
1st	Quartile	0.030	0.010	1	1
2nd	Quartile	0.040	0.020	0.4	1
3rd	Quartile	0.110	0.090	133.8	12.2
4th	Quartile	0.50	0.760	960.6	1011.2
Average Concentration		0.1	0.2	81.4	66.6
MCL		0.010	0.03	0	0
% Above MCL		27%	10%	79%	60%

MPN signifies most probable number of cells

\*Note:

ND signifies not detected

Figure 10- Test Results and Estimated Concentrations for the Study Area

## Water Quality Sampling Results

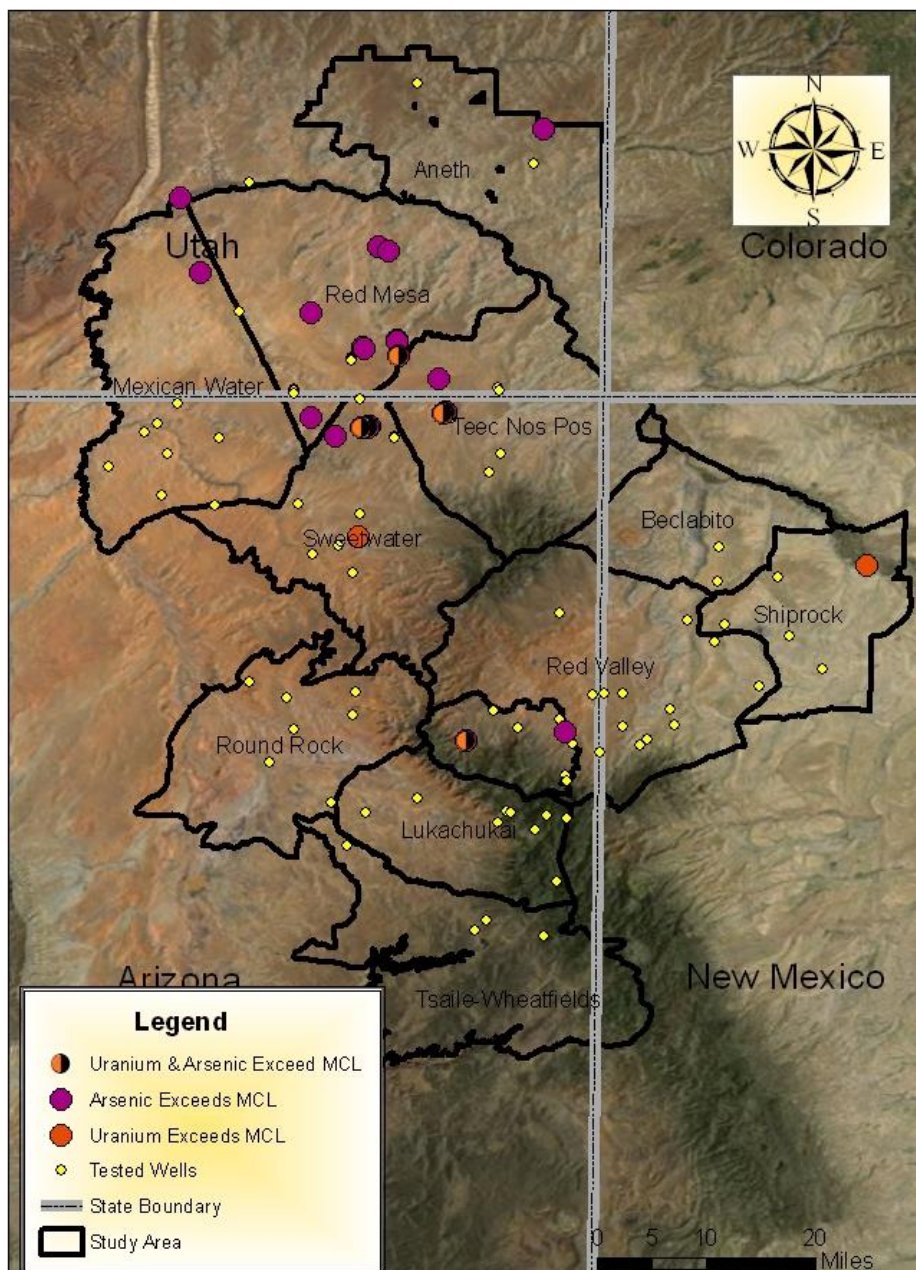


Figure 11- Extrapolated Normalized Arsenic Index Values

## Normalized Arsenic Concentrations

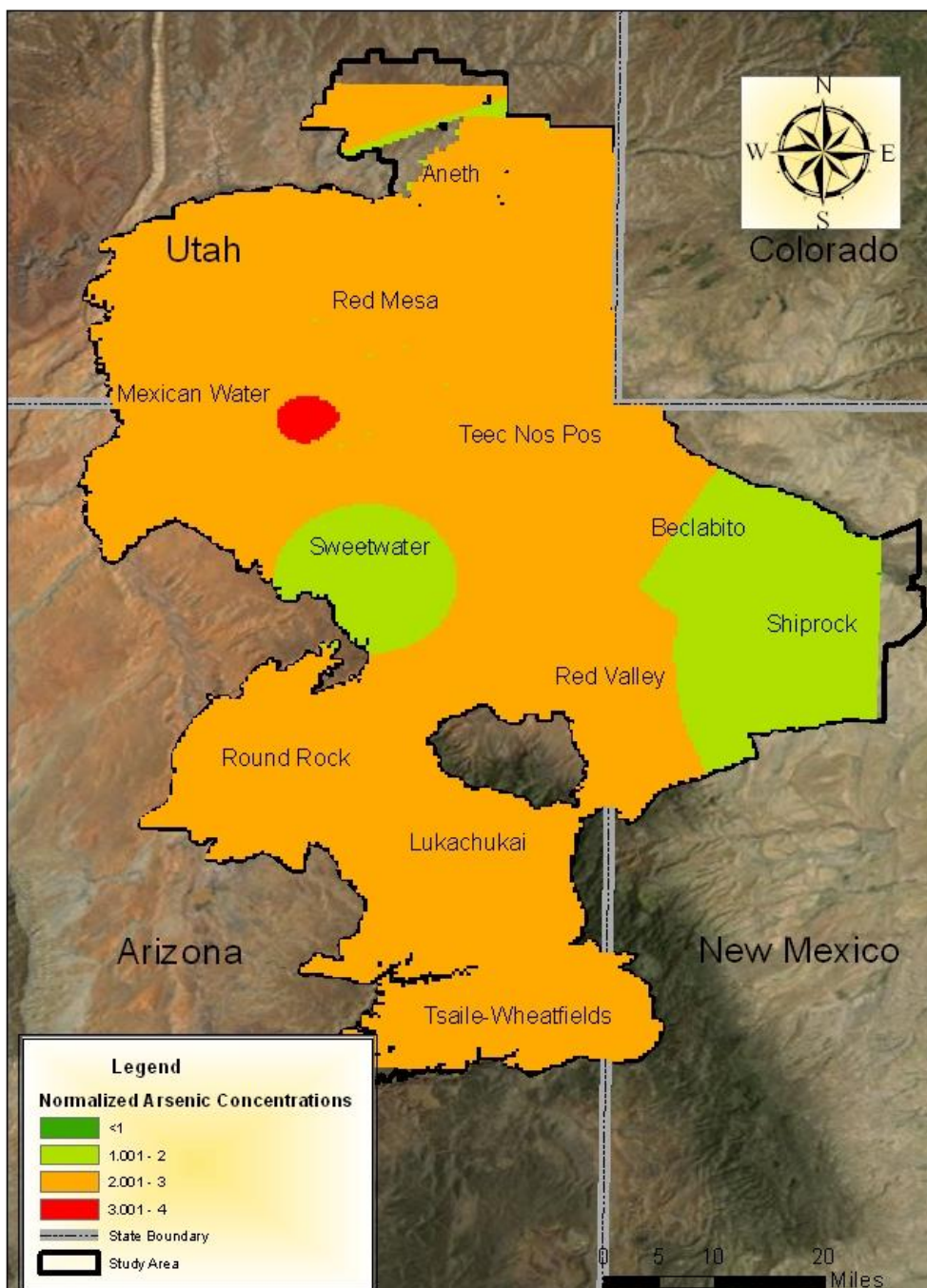
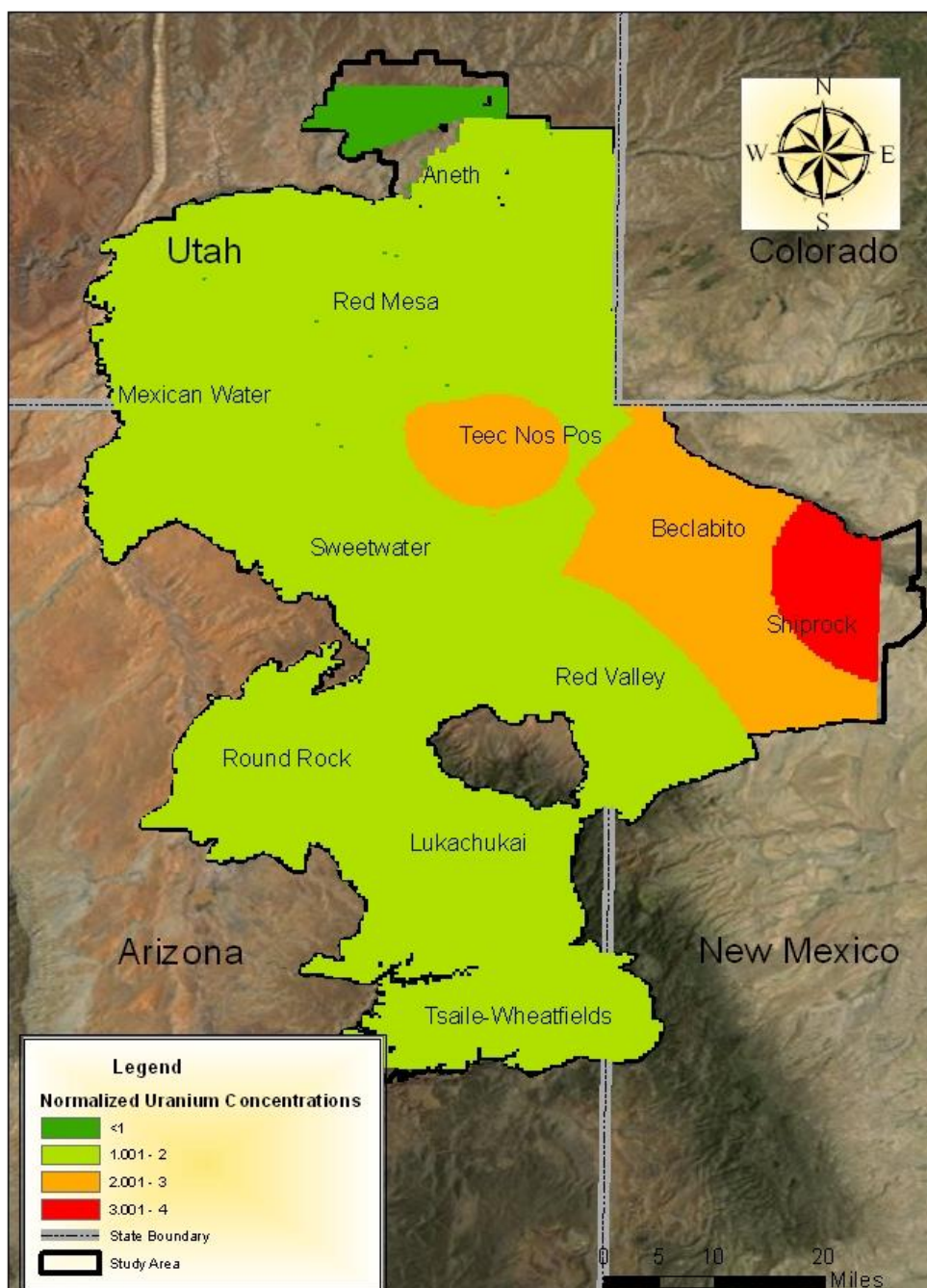


Figure 12- Extrapolated Normalized Uranium Index Values

## Normalized Uranium Concentrations



## **Index Values to Characterize Exposures**

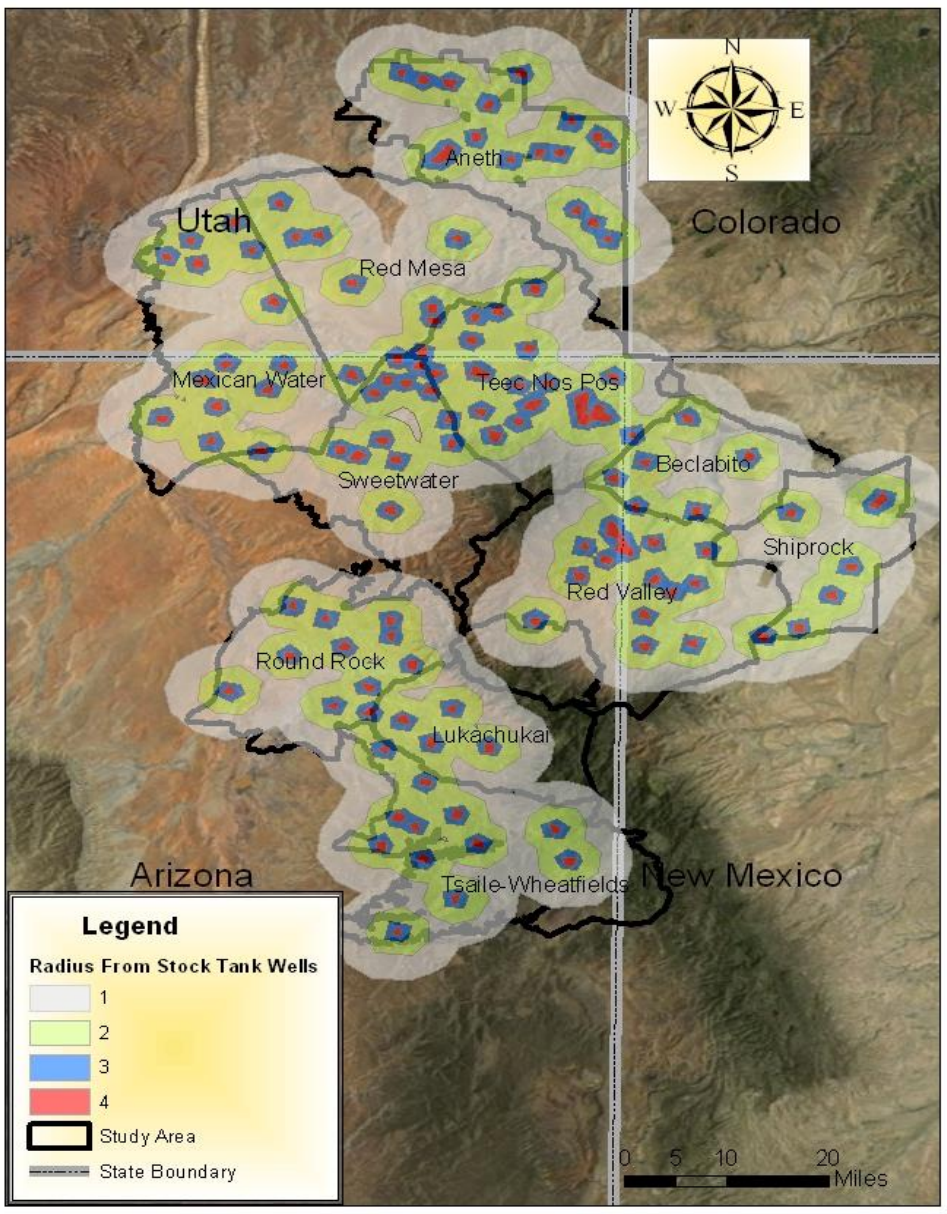
Figures 11 and 12 display mapped index values for regional concentrations of arsenic and uranium.

## **Index Values for Distances from Unregulated Supplies**

The inverse distance buffers for stock tank well locations are displayed in figure 13. The inverse distance buffer placed around each individual stock tank well has a five mile radius, and increased distances from stock tanks are assumed to be inversely related to likelihood of use (Table 4).

Figure 13- Inverse Distance Buffer of Well Locations

### Inverse Distance Buffers of Stock Tank Well Locations



The risk distance ranking of 4 is the region within a half a mile radius from the unregulated water source and a value of 1 is the between the radius of 2.5 to 5 miles away from the source.

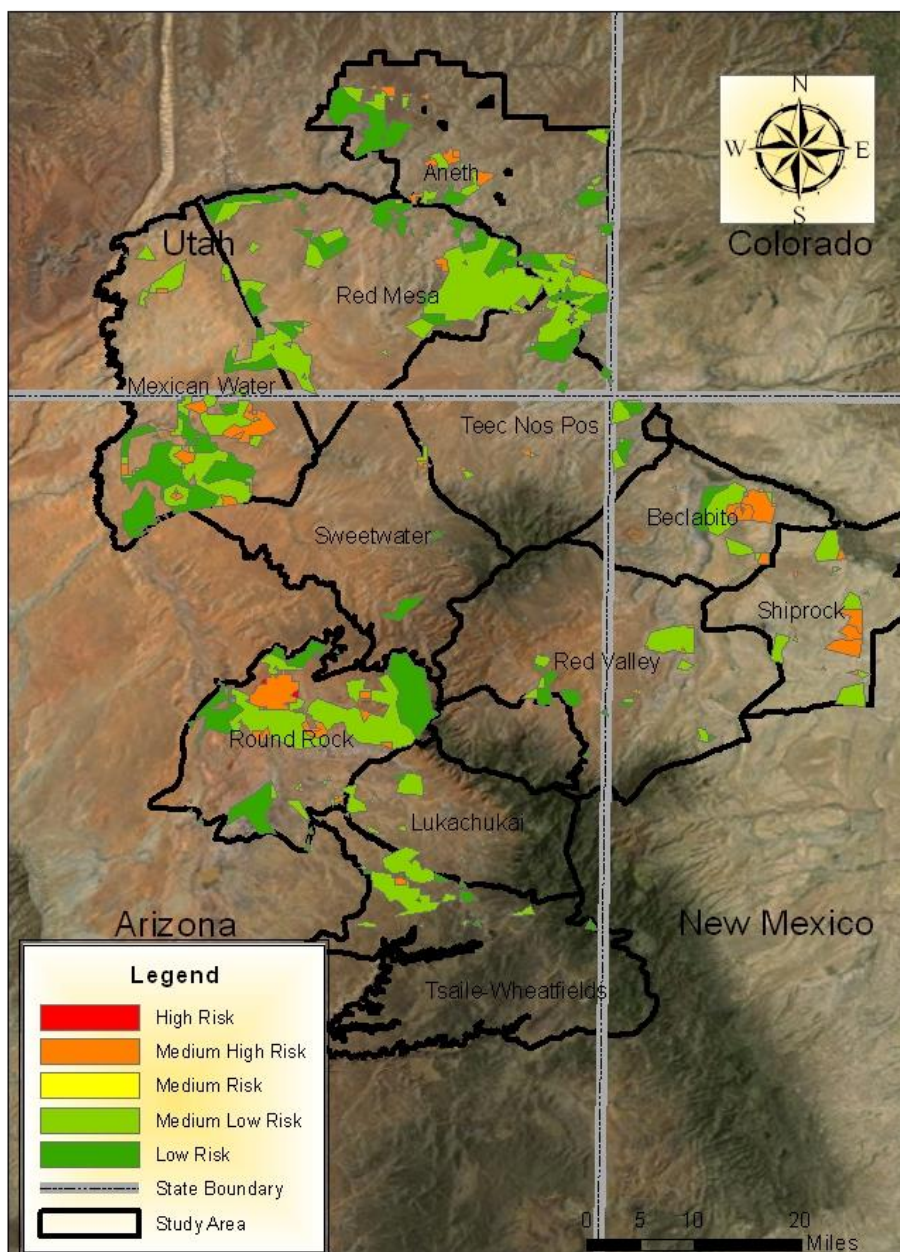
## Modeling Results

### Model #1

The results of model #1 are displayed in figure 14 and 15 and table 8. The range of values for model #1 ranged from 3.4 – 10.6, in which a score of 3.4 is considered to be the lowest risk and 10.6 is considered the highest risk region. After analysis, the range of output values were placed into quintiles, in which the population was equally divided into five groups according to the risk ranking. The quintiles were then label with a corresponding risk level so that this information can be presented to the public (Table 8). This model identified regions within the chapters of Mexican Water and Round Rock of having the highest risk of exposure to arsenic, uranium, or both in unregulated supplies.

Figure 14- Regions Most at Risk from Consuming Unregulated Water Supplies with Arsenic and Uranium

## Model #1 Results



## Model #2

The results of model #2 are displayed in table 8 and figure 15 and 16. This model also identified regions within Mexican Water and Round Rock as having the highest risk of consuming unregulated water.

Table 8- Results from Models #1 and #2

Results of Model #1			
Risk Level	Range of Values	Population	Area (acres)
Low	3.4 – 4.8	1,316	257,458
Medium Low	4.8 – 6.2	1,634	290,015
Medium	6.2 – 7.7	781	182,194
Medium High	7.7 – 9.1	954	190,017
High	9.1 – 10.6	185	6,629

Results of Model #2			
Risk Level	Range of Values	Population	Area (acres)
Low	0 - 2	2,551	432,364
Medium Low	2 - 3	1,050	77,026
Medium	3 - 4	812	20,290
Medium High	4 - 5	377	9,351
High	5 - 8	109	447

Figure 15- Results of Models 1 and 2

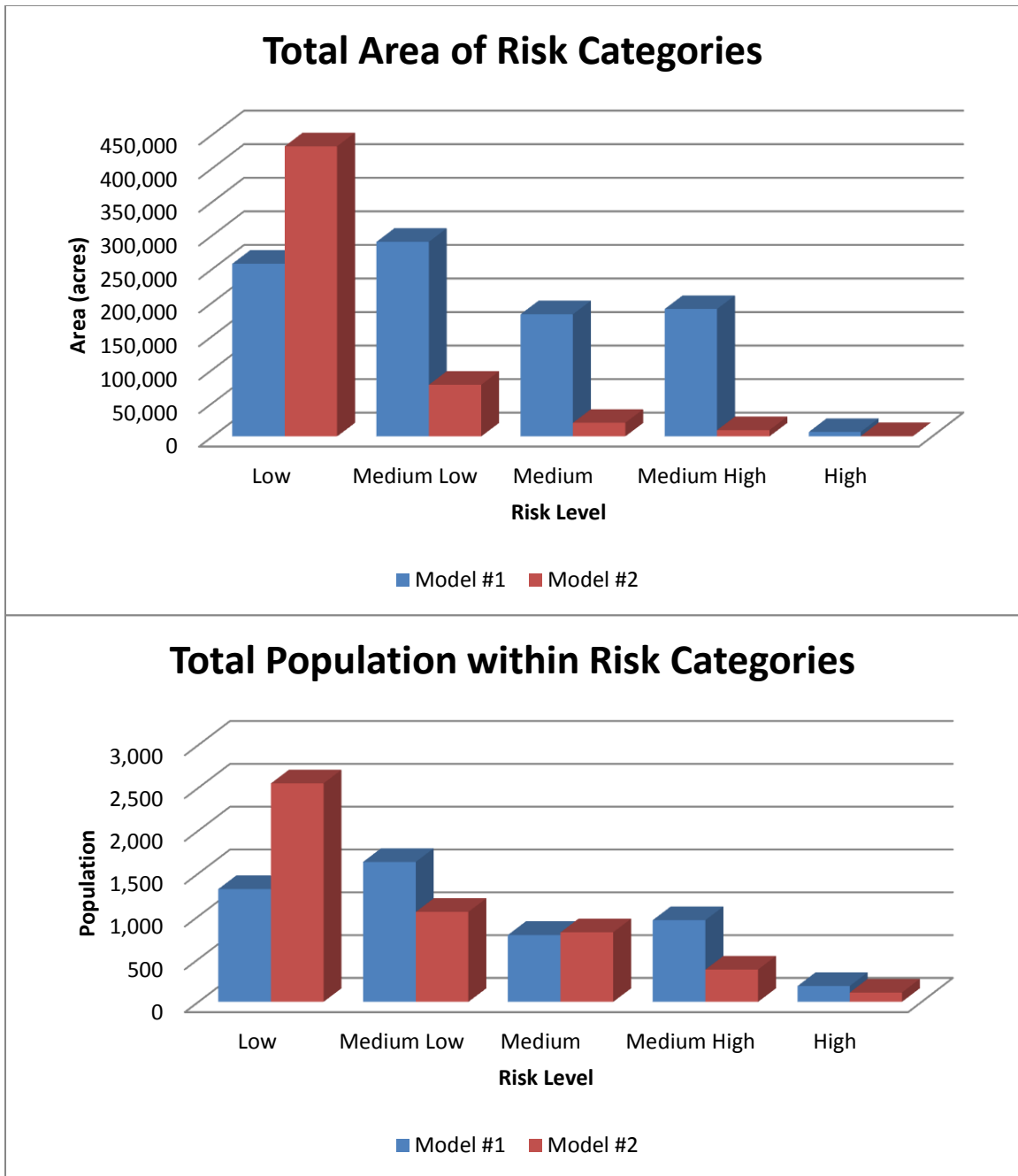
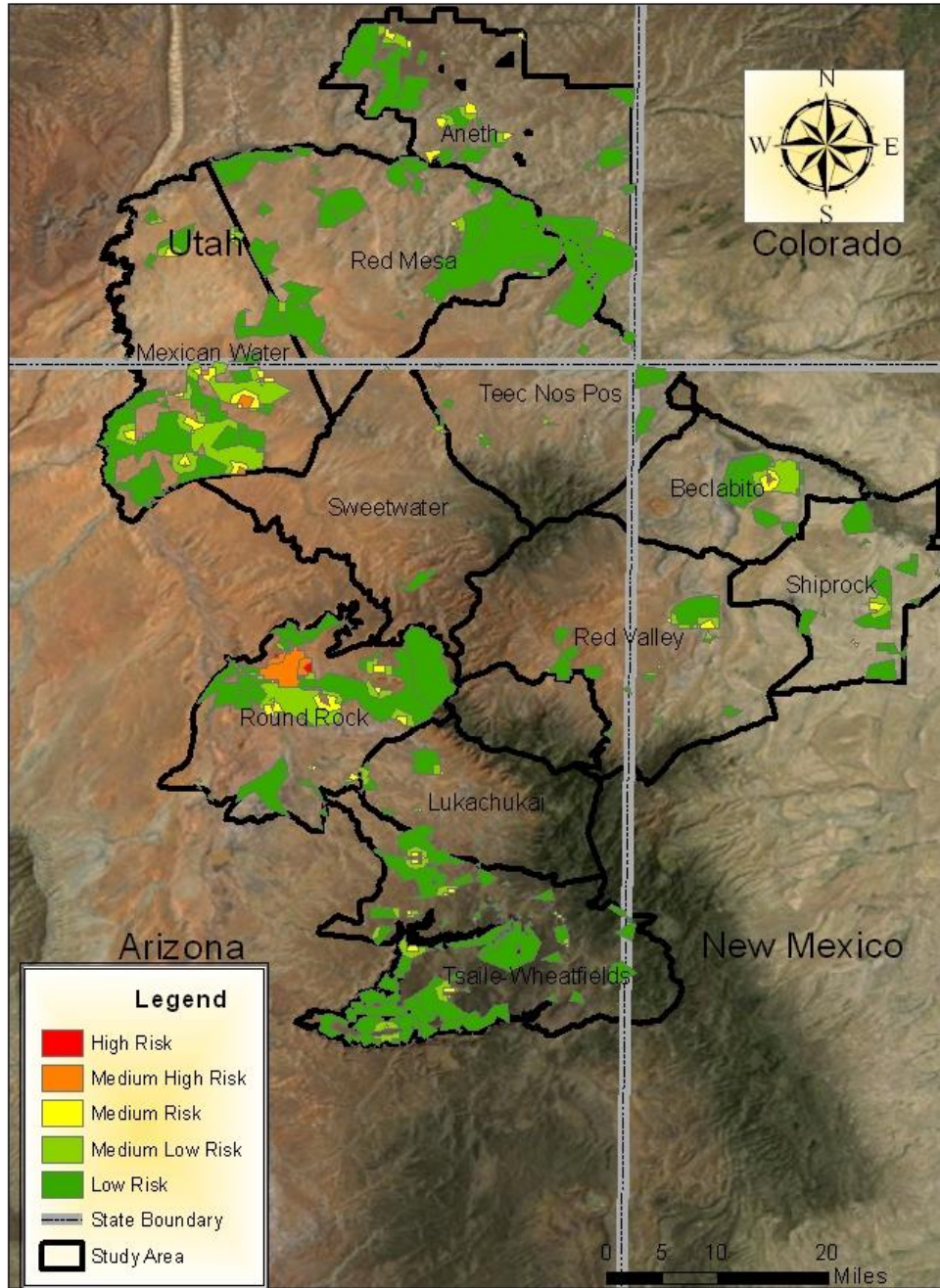


Figure 16- Regions Most at Risk of Using Unregulated Water Supplies, Model #2

### Model #2 Output

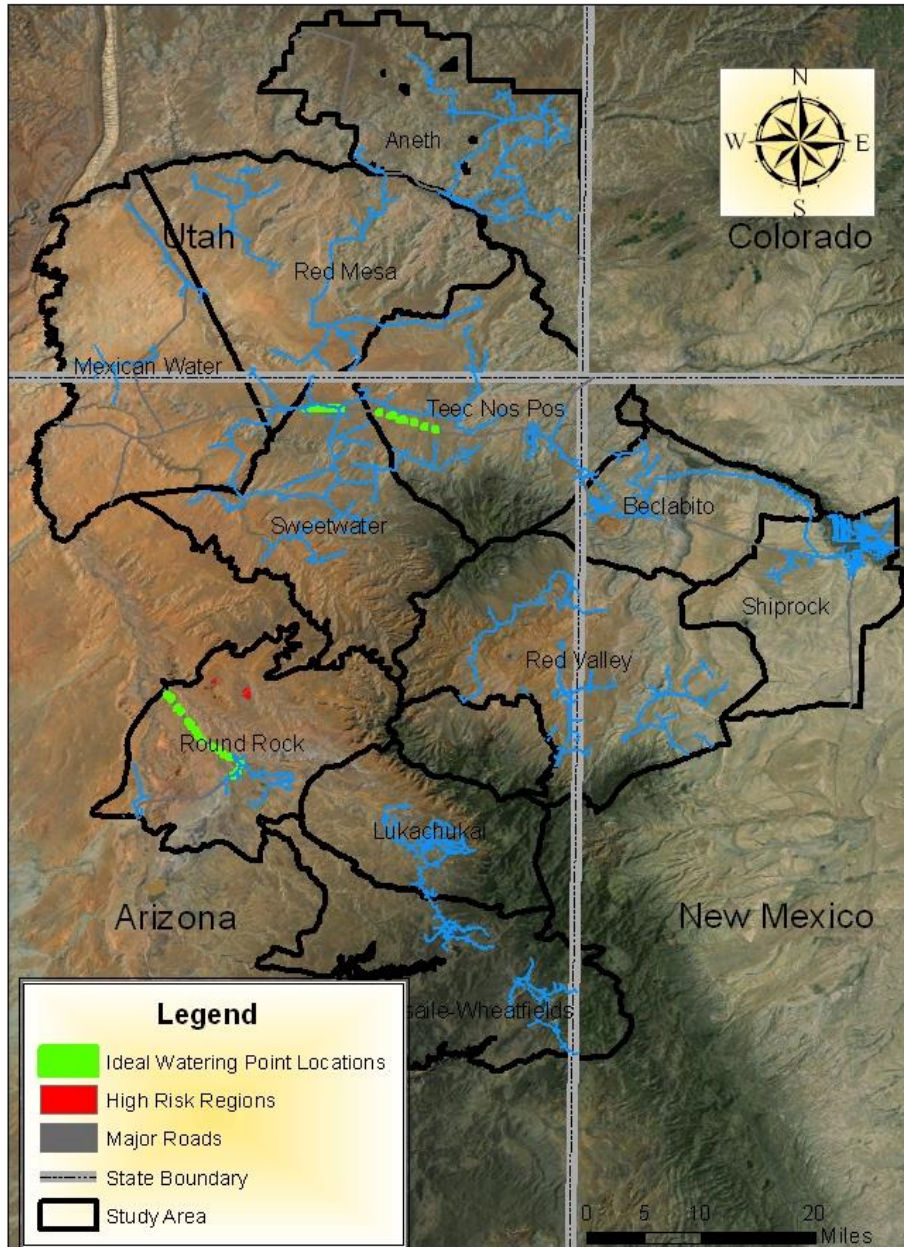


### **Identifying Watering Point Locations**

Based upon the location of the high risk regions, current NTUA distribution lines, and the location of major highways and roads, the model to identify watering point locations yielded the results displayed in figure 17. The suggested installation areas are within 100 feet from main roads within the region. In total, the watering point model identified 23 places to install a watering point.

Figure 17- Suggested Locations for Watering Point Installation

### Suggested Watering Point Locations



## Discussion

The Navajo Nation is a rural region where many residents lack access to a clean, safe drinking water source. Within the study area, approximately 5,000 people may rely on unregulated supplies that have high concentrations of arsenic and uranium (relative to established MCLs) for drinking water. Identifying the locations where people are likely to use unregulated sources has three purposes. First, the tribal government can target communities to educate residents about the dangers associated with these supplies. While educators are helping residents understand the hazards of consuming unregulated water, they can also present information about simple treatments to remove microbial contaminants. Accordingly if residents must rely on unregulated sources, they can be aware of the hazards and avoid the acute effects of microbial contamination. Secondly, these analyses can identify locations to install NTUA treated watering points, where residents can purchase treated water for a minimal fee. These have been installed in other regions of the Navajo Nation. Third, recommendations can be made to the Navajo Nation Division of Water Resources (NNDWR) for where to deliver treated water in a project that is supported by the U.S. Environmental Protection Agency. This project involves a 5,000 gallon truck to deliver treated NTUA water to those who lack access (EPA 2012). Currently, this program does not supply water within the bounds of the study area.

While modeling the risk of interaction of the unregulated water sources two models were developed that identified the same chapters as being the highest risk locations. Although both of these models identified the same regions, the overall distribution area to the different risk levels within the risk models was different. In order to determine which model is most reliable, a survey of water use habits conducted would need to be to truly understand where people obtain their water from and why.

It is important to bear in mind the assumptions used to carry out these analyses. Foremost, because public surveys are difficult to conduct on the Navajo Nation, spatial analyses were applied to model human behavior related to water consumption habits in place of a survey. It has been shown that on the Navajo Nation, even people with access to piped water use unregulated sources. Therefore assuming that no unregulated water supply use takes place because a census block receives NTUA water is unlikely to be true in all cases. It is possible that residents drink untreated water even when treated water is available. The assumption that proximity to unregulated water sources increases the likelihood of use may also be untrue. Between the literature review and the assumptions applied, the total population estimated from the models to rely on unregulated water supplies should be considered as an underestimate of the real total. Also, it is unclear exactly how and when water from these sources is used.

## **Recommendations**

I could not to interact with and survey residents about where they obtain drinking water, which means that these analyses could not be verified. To greatly improve this research, I would strongly recommend presenting this research to the Navajo Nation Human Research Review Board to gain permission to survey residents. Then results of these analyses could be verified and this approach could be applied to the rest of the Navajo Nation to identify other regions most at risk of using unregulated sources.

Next, the current watering point model on the Navajo Nation has not been studied to determine if these truly replace unregulated sources. If more watering points are to be installed, it is important to verify that people change consumption habits from unregulated sources to NTUA sources. The proportion of people who change habits could justify the use of

more funds to construct more watering points, if, in fact, they are replacing unregulated supplies.

Finally, as residents begin to rely on treated drinking water, an interesting study would be to quantify and track the relationship between uranium and arsenic levels in urine samples and general health-related issues within residents. Eliminating ingestion of water, which is the most common pathway of exposure to arsenic and uranium, may change concentrations of arsenic and uranium in urine. This additional metric may be extremely useful in demonstrating the benefits of water supply point construction and changes in sources of drinking water. This, in turn, could be useful in justifying further investment in treated water provision as a means of improving the health of rural residents on the Navajo Nation.

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