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Assessing Nitrate levels in the Private Well Water of the Albuquerque and Española Basins

By

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A Professional Project Proposal Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Water Resources

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Committee Approval

The Master of Water Resources Professional Project Report of **Meredith Porter**, entitled **Assessing Nitrate levels in the Private Well Water of the Albuquerque and Española Basins**, is approved by the committee:

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Abstract

This study analyzed the nitrate-nitrogen readings from three decades of data provided by the New Mexico Environment Department, New Mexico Tech, Bernalillo County, and the USGS. The purpose of this study was to assess the nitrate-nitrogen levels in the groundwater of the Albuquerque and Española Basin.

First the data were compared to a USGS model on nitrate-nitrogen in aquifers of the southwest United States (Which include the Albuquerque and Española Basin). Next the data were run through an interpolation model where nitrate-nitrogen levels were calculated for areas of the Albuquerque and Española Basin that had not previously been sampled. Finally, population density for the two basins was incorporated into a map with the NMPWND and with dairy locations in order to locate points of high health concern.

The different ways in which the data were analyzed showed that there were areas of both the Albuquerque and Española Basins where the nitrate-nitrogen in the groundwater is very high. The final task found ten areas that should be of high priority for testing in the future, as well as for the need to educate the water users living in those areas.

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Introduction

Many human activities are contributing to the contamination of our groundwater resources. One of the contaminant contributions humans make to groundwater is nitrogen. Once nitrogen enters the Earth's soils, bacteria in the soils convert the nitrogen into nitrate. Human and animal wastes are major contributors containing ammonia, nitrite and nitrate (for the purposes of this study we will focus on nitrate-nitrogen). All of which are decomposition products from urea and protein. The contaminant sources for nitrate-nitrogen are: dairies, agricultural activities, septic tanks, fertilizer application to turf, and industrial activities. Because there are so many anthropogenic contributors of nitrate-nitrogen to our groundwater resources, it is highly likely that wherever there are humans, there will be elevated levels of nitrate in the groundwater (Murphy, 2007)

At low levels, including ones above naturally occurring levels (the naturally occurring level of nitrate-nitrogen in the environment usually found to be 2.0mg/L or below), nitrate-nitrogen is harmless to humans (to the best of our knowledge). However, elevated nitrate-nitrogen levels in groundwater have been proven to be harmful to pregnant women and infants. The exposure to nitrate-nitrogen and nitrite-nitrogen has been reported to have adverse health effects on babies and children (methemoglobinemia, a.k.a blue baby syndrome). Due to the concern of this health effect, the U.S. Environmental Protection Agency (EPA) created a maximum contaminant level (MCL) of 10mg/L in drinking water which municipalities and large community systems have to abide by (EPA, 2007).

Nitrate-nitrogen contamination may not seem like a danger to those without children or whose children are older, but the largest amount of nitrate in groundwater is contributed via nitrogen in animal waste (humans included). This animal waste does not only contain nitrogen, but may also contain pathogens, antibiotics, and harmful chemicals as well. The possibility of groundwater containing antibiotics is higher when groundwater is close to an AFO or CAFO (Animal Feeding Operation, Concentrated Animal Feeding Operation) (Hribar, 2010; McQuillan, 2006).

Unfortunately, it is not as easy to test for the contaminants of health concern in groundwater as it is to test for nitrates. Due to the fact that nitrates, pathogens, antibiotics, and other chemicals generally come from the same source, having one's water tested for nitrates may lead to knowing whether further testing should be done for pathogens, antibiotics, or harmful chemicals.

In this study, the focus is on nitrate-nitrogen levels in private drinking water wells in the Rio Grande Aquifer System. The USGS Scientific Investigations Report 2012-5065 (from here to be referred to as the USGS model 5065) of the same area along with private well nitrate-nitrogen data that were obtained with help from the New Mexico Department of Health's Private Well Program (NMDOHPWP) will be used in this study. This specific dataset includes data that were publicly available or acquired and used with permissions from: United States Geological Survey National Water Information System

(USGS NWIS), New Mexico Bureau of Mining and Mineral Resources (NMBMMR), Bernalillo County (BC) and the New Mexico Environment Department (NMED). This dataset only includes domestic wells data and will be mentioned collectively from now on as the New Mexico private well nitrate dataset (NMPWND). Data from livestock or monitoring wells were excluded.

The NMPWND was spatially analyzed to determine where there were areas with elevated nitrate-nitrogen concentrations. These spatially analyzed layers were then used to assess areas of high vulnerability to contamination as well as which areas were of the greatest health risks. This work will help the New Mexico Department of Health (NMDOH) and the NMED focus their efforts for public health interventions.

Purpose and Scope

The purpose of this study was to characterize nitrate-nitrogen levels across the Albuquerque and Española Basin using the NMPWND (4 datasets). The USGS model 5065 data which covers the same area was assessed against the NMPWND inorder to obtain a better idea of how accurate the USGS model 5065 predictors were. Their model incorporated aspects of groundwater nitrate-nitrogen attenuation that the NMPWND did not include (see appendix II to learn more about the model and the variables used to predict nitrate-nitrogen levels in the two basins). After comparing the two datasets, only the NMPWND was used to locate areas of major health concern.

Locating these areas will help prioritize for future testing events and public health interventions by the NMDOH and NMED. These analyses together should help to show when and where nitrate-nitrogen levels should be of concern.

Background

Groundwater Use

It was estimated that in the year 2000 New Mexico had 136,800 private water wells, and in 2040 the number is estimated to be above 200,000 (Titus). That means that hundreds of thousands of people in this state are using water that is not regulated by the EPA, or any other agency (the EPA MCLs for drinking water only apply to municipalities or water systems serving 25 or more people 60 days or more per year OR 15 or more connections). Considering how many anthropogenic sources of contamination there are that can affect groundwater, even in rural areas, this leaves many people at risk for health problems related to the water they are consuming.

Fortunately, the NMED has been offering testing since the mid-1980s of groundwater quality for areas that are not regulated by any Federal, State, or other agency. They commonly have done testing of water for temperature, pH, sulfate, iron, fluoride, and nitrate. They have used different HACH kits to perform field analysis on these samples over the decades. These data do not have the same validity as water quality data collected with more stringent protocols, but it is still of high value.

While each of the contaminants tested for, at high levels, can affect a person's health, the one that is of most interest and collected with the most regularity (and will be analyzed in this study) is nitrate.

Nitrate-Nitrogen and its Common Sources

Nitrogen is a required nutrient of all living organisms (EPA, 2012). Plants use nitrate-nitrogen to grow. Unless one is in an area that has high levels of nitrate in the drinking water, most likely the majority of one's nitrate consumption is from vegetables and/or preserved meats (EPA, 2007). However, because nitrate-nitrogen is so beneficial for plant growth, for decades it has been widely used in farming, either through synthetic nitrogen fertilizers or through cattle manure. The amount of nitrates that a plant can use is limited, and much more fertilizer is generally applied to fields than is needed by the plants. The excess nitrate either leaches into the soil and eventually the aquifer below, or runs off the field and into a nearby body of surface water. In this study the focus is on nitrate in domestic well water.

Common sources of nitrate in drinking water besides land application of nitrogen fertilizers are: Animal feed lots, industrial waste, sewage, septic tanks, and atmospheric sources (EPA, 2007). There are many places on Earth where people are having to deal with nitrate contamination in their drinking water, it is certainly not a problem unique to

New Mexico or the Southwest United States (Nolan et al, 1998; Liu et al, 2005; Deans et al, 2004; Almasri and Kaluarachchi, 2004; Kanazawa, 1999).

Unfortunately, once it is in the water it can be difficult to remove and consuming too much nitrate can be unhealthy, especially for infants, pregnant women, and the elderly (EPA, 2007). Further, with respect to groundwater, nitrate-nitrogen is a contaminant that is quite mobile in aquifers. In addition to health problems that are unique to the over consumption of nitrate, another reason why nitrate in water is a concern to many is because some sources of nitrate (especially the more common ones) can contaminate water with things that are more harmful. Here are some brief descriptions of the most common sources of nitrate contamination:

Dairy

All animal waste (even human waste, which will be addressed later) contains nitrogen. A dairy can have anywhere from tens of cattle to thousands of cattle. Regardless of the size of the dairy, contributions of nitrogen are being made to the environment (which is later converted to nitrate-nitrogen by bacteria in the soil) . The larger dairies (with the thousands of cattle) can contribute more waste in a year than many large urban areas do (Hribar, 2010; Burkholder et al., 2006). The large dairies with 1000 cattle or more, are considered Concentrated Animal Feeding Operations (CAFOS), of which, there are many in New Mexico. New Mexico has hundreds of dairies with an average of 2000 cattle per dairy (NMSU). Many of these dairies are clustered in various areas of the state (Eastern New Mexico and Las Cruces especially). At this point in time, New Mexico dairies must have the quality of the groundwater under their operation tested four times a year and must send the results in to the New Mexico Environment Department (Arnold, 1999). They must also collect the waste from their cattle in lagoons and these lagoons must be lined with a synthetic lining to prevent leaching of contaminants into the groundwater to the fullest extent. This is not fool proof and from other studies done around the world, some would argue that dairies are the number one contributor of nitrate-nitrogen contamination to the environment (Arnold, 1999).

In addition to animal waste contributing nitrate to groundwater, it is possible that the same waste will also be contributing pathogens, microbes, steroids and antibiotics to groundwater (Hribar, 2010; Burkholder et al., 2006).

Other Agriculture

While some believe that the dairy industry is the largest contributor of nitrate-nitrogen to our environment, others would argue that the dairy industry is second, right after farming. Farms can cover a lot of land and apply either synthetic nitrogen fertilizers or manure directly on to the ground for their crops to use (no synthetic lining here to protect the soils) (Burkhart and Stoner, 2002).

When manure is used as fertilizer it is possible that not only nitrate, but pathogens, microbes, and pharmaceuticals, etc., will also end up in the ground water under and eventually around these fields.

Septic Tanks

Septic tanks, in New Mexico, are considered the number one source for nitrate contamination of drinking water (McQuillan, 2006). This is to say that septic tanks contribute more nitrate to the groundwater than something as big as a CAFO (Concentrated Animal Feeding Operation), rather it is that there are generally more drinking-water wells in close proximity to septic tanks than there are to a CAFO. Along those lines, septic tanks tend to pollute drinking water more as lot sizes decrease to provide space for a larger population – forcing the distance between a drinking water well and a septic tank to shorten (McQuillan, 2006; Wakida and Lerner, 2005; Arnade, 1998). Many people, especially those in rural communities, use septic tanks on their property for their waste. It is probable that at some point in time all septic tanks will leak. This means that if one has a septic tank, one is contributing (at least at some point) to nitrate-nitrogen groundwater contamination.

What can make pollution from a septic tank even worse than some of the other common nitrate sources to groundwater is that the same waste that contributes the nitrogen (which is later converted to nitrate-nitrogen) has the potential of contributing other contaminants such as pathogens, microbes, viruses, steroids, and pharmaceuticals, etc., (Godfrey et al, 2007; Strauss, 2001). These contaminants may be even more harmful than nitrate-nitrogen, and this issue will be addressed later in the study.

Urban

According to Wakida and Lerner's research, from a paper they wrote in 2005, "Leakage from sewage and water supply networks provides the highest percentage of water recharge to aquifers underlying many cities throughout the World." Improper construction and degradation, as well as natural forces such as earthquakes, can cause sewer lines to leak. There is also fertilizer application on residential lawns and gardens and golf courses.

While applying fertilizer in urban areas generally will only contribute nitrate to the groundwater, the leaking sewage pipes under a city will add not only nitrate, but pathogens, pharmaceuticals, and other chemicals as well.

Industrial

Industrial uses that contribute to nitrate in the groundwater are: plastics manufacturing and treatments; metal treatments; raw materials used in the textile industry; particleboard and plywood; household cleaning products; and the manufacturing of pharmaceuticals. Improper disposal, improper handling of materials or the use of nitrogen compounds is generally how industrial sources contribute to nitrate contamination of groundwater (Wakida and Lerner, 2005).

With the manufacturing of pharmaceuticals it would not be surprising to find pharmaceutical pollution of ground water alongside the nitrate-nitrogen contamination of the same groundwater.

Atmospheric

Atmospheric contributions of nitrate-nitrogen in groundwater come mainly from cars, industry, agriculture, and intensive livestock operations (Wakida and Lerner, 2005).

Geography, Geology, and Climate of Study Area

The Initial Study area consists of the Albuquerque Basin (or Middle Rio Grande Basin) and the Española Basin. These basins were chosen because they are within the study area of the USGS Scientific Investigations Report 2012-5065 (which includes the Rio Grande Aquifer system) and the NMPWND robustly covered large portions of these basins when testing private well water quality.

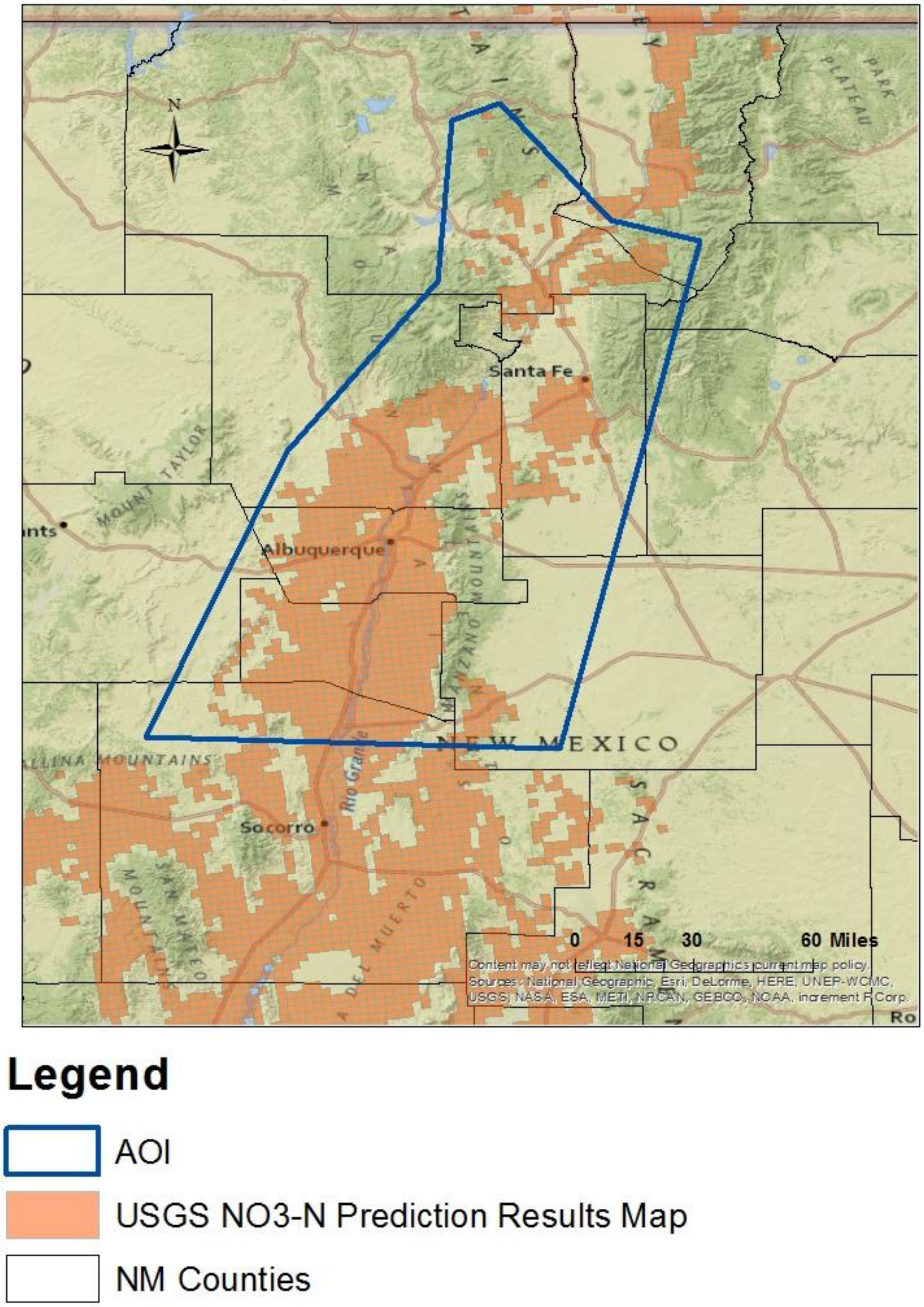
The Albuquerque Basin has been referred to as the Middle Rio Grande Basin interchangeably in the past. For this study it will be referred to as the Albuquerque Basin. The basin extends from just north of San Acacia to just north of Cochiti Lake. It is 100 miles long, and ranges in width from anywhere between 25 to 40 miles across. It encompasses parts of Bernalillo, Valencia, Sandoval, Socorro, Santa Fe, Torrance, and Cibola counties. The elevation of the basin ranges from 4,650 ft. above mean sea level (AMSL) to 11,254 ft. AMSL. The average annual temperatures for the Albuquerque Basin are 33.5° F to 78.5° F at lower elevations to between 20° F and 56.9° F at the higher elevations (on the mountain peaks). The average annual precipitation ranges from 7.6 inches/year to 23 inches/year depending on the elevation. The wettest months are July and August. The Evaporation rates through the basin range from 39.97 inches/year to 47.58 inches/year, on average. (Bartolino and Cole, 2012)

In 2010 the census bureau calculated the population of the basin to be 840,000 (the majority of the population residing within the city of Albuquerque). As of 2002, according to a map provided by the USGS, the major land uses of the Albuquerque Basin were: range land, forest, urban, barren land, and agriculture. According to New Mexico State University's Dairy Extension Program there are (as of 2011) 4 dairies in Bernalillo county with a total of 2,900 milk cows between the 4 dairies; 5 diaries in Valencia county with a combined total of 12,600 milk cows; between Socorro and Luna counties there are 8 dairies with a total of 8,600 milk cows; and between Roosevelt and Torrance counties there are 32 dairies with a combined total of 60,000 milk cows. The majority of these dairies are in the Albuquerque Basin area.

The Española Basin encompasses the Rio Grande just north of the Albuquerque Basin and extends to the Taos Plateau. It includes portions of Santa Fe, Los Alamos, and Rio Arriba counties. The basin is surrounded by mountains and the elevation ranges from 5,300 ft. to 13,101 ft. There are over 13,600 people in the Española Basin getting water from a public water system and 43,512 people using private wells for their water in the basin. The Española Basin is also home to 9,624.5 acres of cropland which appear to be mostly in the northern part of the basin around Española.

The climate of the Española Basin is also semi arid with areas like Santa Fe and Española getting little more average annual precipitation than that Albuquerque or Rio

Rancho of the Albuquerque Basin. The fact that the Española Basin is in high elevations does help decrease average temperatures slightly as well. (Daniel B. Stephens and Associates, 2003)



Map 1:Area of Interest for Study (Data Source: GCS North American 1983 (Greenwich Prime Meridian). Unit: degrees)

Literature Review

There have been many different studies done that attempt to predict nitrate groundwater concentrations in groundwater. A literature review also reflects many different approaches.

A study done in Malaysia in 2011 used indicator kriging to predict where nitrate levels were above threshold of 10mg/L (Department of Environment, or DOE, standard for Malaysia). Indicator kriging is a statistical method that uses a threshold in order to assign values to specific areas based on spatial relationships to areas with true values. Because the study was focused on where nitrate levels possibly exceed the DOE Standard this form of statistical modeling was appropriate (Jamil et al., 2011)

Another study used multivariate logistical regression to specifically compare land use types to anthropogenic compounds (including nitrate). This study was also completed for the same studies area as in the USGS Scientific Investigations Report 2012-5065. Multivariate logistic regression evaluates a response (dependent) variable to multiple explanatory (independent) variables. This evaluation is performed over and over again by the model to train its self on how the response and explanatory variables relate. It can then sufficiently predict what values should be assigned to the response variable were there was no value for it before. In this particular study they specifically wanted to find out what explanatory variables had the greatest predictive power on the level of a contaminant in certain area. They found that both Agricultural and Urban areas had high levels of nitrate. The model predicted that 25% of the time in Agricultural areas nitrate levels would exceed the maximum contaminant level (MCL) of 10mg/L, while in the Urban areas the MCL was exceeded 10% of the time. For Agriculture, it was found that type of irrigation practice, and fertilizer use were good predictors for nitrate level in an area (Paul et al, 2003)

A study done in Colorado from 1992 to 2000 A.D. used logistic regression to show the probability of detecting concentrations of nitrate and various pesticides in the groundwater. The goal was to produce a map that the Pesticide Management Program could use to identify areas of greatest need for groundwater protection. For nitrate concentrations, the threshold of 5mg/L, as 5mg/L or above was getting too close to the MCL of 10mg/L. It should also be noted that, in this study, additional USGS data was used to improve the accuracy of their maps (Rupurt, 2003).

Another USGS study, produced a map of the entire United States depicting areas of high and low aquifer vulnerability and susceptibility to nitrate contamination. They gave values to areas based on levels of nitrogen loading and various aquifer characteristics (which would cause the nitrate to infiltrate easily or not). Most likely overlay methods were used for this analysis simply by layering shapefiles of the different attributes that affected aquifer vulnerability and susceptibility to nitrate (Nolan et al., 1998)

The literature shows that there are multiple ways in which to predict nitrate-nitrogen levels in the underlying aquifers. For this particular study, in figures where a continuous value of nitrate-nitrogen is shown, the interpolation method of inverse distance weighted will be used between samples as it is already been used by the NMDOH to answer other questions. Inverse distance weighted interpolation is available in Esri's ArcMap software, a spatial data analysis tool.

Methods

The main purpose of this project was to characterize nitrate-nitrogen concentration levels in the Albuquerque and Española Basins based on the NMPWND. Then it was to determine, based on the NMPWND, the areas of concern with respect to human health. The nitrate-nitrogen levels from the NMPWND were also used in part of this study as a comparison for the USGS 5065 Model predictions which cover the same geographical area (but used many various environmental factors on a few samples to estimate the nitrate-nitrogen levels in the groundwater).

This project model was based on the NMPWND concentrations and the area covered by the predicted concentrations from the USGS model 5065 and described in Scientific Investigations Report 2012-5065 dataset 698.

The project areas of interest (AOIs) are the Albuquerque Basin and the Española Basin. These basins were chosen for the purpose of comparing the NMPWND to the USGS model 5065 and because of the ample amount of data for the two basins in the

NMPWND. The USGS model 5065 only covered the Rio Grande aquifer system in New Mexico (which the Albuquerque and Española Basins area a part of).

An initial step of this project was to transfer much of the NMPWND from hardcopy form into a spreadsheet. This step was followed by quality analysis and control of the converted data. The locational information (mostly addresses) from the spreadsheet was then geocoded so that each of the well sample records could be assigned longitude and latitude coordinates. To learn more about the process of compiling the NMPWND please reference Appendix III.

The USGS model 5065 is from a USGS Scientific Investigations report that modeled the Southwest Principle Basin-Fill Aquifers of the United State for nitrate-nitrogen and arsenic levels. The study area covered many of the Western states including New Mexico. The model used a random forest classifier algorithm to predict concentrations of nitrate-nitrogen across a model grid. The classifiers reflect natural and human related factors that affect aquifer vulnerability to contamination and relate nitrate-nitrogen concentrations to explanatory variables representing local and basin-scale measures of source, aquifer susceptibility and geochemical conditions. Several conditions were found to increase the vulnerability of basin-fill aquifers to nitrate-nitrogen contamination including: fertilizer use, livestock manure production, development of land for agriculture or urban uses, presence of desert legumes, absence of hydric soils or soils with high organic-matter content, presence of soils with high infiltration rates (sands and gravels), high rates of water-use for irrigation or public supply from groundwater or surface-water supplies, low natural recharge from precipitation, high mean air temperatures and potential evapotranspiration, and oxic geochemical conditions.

For the USGS 5065 model the grid cells were 3km and the results were classified in to ranges (Classes one through six) of nitrate-nitrogen that spanned from less than 0.5mg/L to over 10.0mg/L. A more in depth description of the model can be found in Appendix II.

Task 1:

Compare the predicted levels of nitrate-nitrogen concentrations from the USGS model 5065 with the NMPWND concentrations. This was done by comparing the basic statistics (mean, median, mode, standard deviation, and variance) of the two datasets. In addition, the NMPWND was sorted by various attributes (months, years, and ranges/classes) to investigate temporal trends of the nitrate-nitrogen concentrations.

Task 2:

Compare the location and value of NMPWND samples to the location and value of the USGS model 5065 (specifically dataset 698, which contained predictions of nitrate-nitrogen) in the same area. This was done by performing a spatial join. The spatial join connected the attribute tables in such a way that you could look up the value of each NMPWND sample overlying a particular USGS model 5065 cell, and also see what the nitrate-nitrogen range for that particular cell was. This allowed for comparing the observed levels of nitrate-nitrogen in private well groundwater from the NMPWND to what the USGS model predicted the groundwater nitrate-nitrogen level to be in the same area. The USGS model was treated as the predicted levels of nitrate-nitrogen in groundwater due to the resulting map of the USGS model 5065 representing estimations. For the NMPWND, because the values have not been manipulated they are being considered the observed levels.

Another part of task two to get a better understanding of how the two datasets compare was to create a map that showed the difference by grid cell of the USGS model 5065 class for that cell to the averaged nitrate-nitrogen class of the NMPWND samples overlaying that same cell. With the help of Zachary Stauber from the NMED, this map was completed by averaging the NMPWND samples in each grid cell and subtracting that average from the class value of the same USGS grid cell. The difference was then mapped using different colors for each value to show where the predicted levels were above, the same, or below the average class values of the NMPWND samples, and by how many classes they differed.

Task 3:

Inverse weighted distance interpolation was used to give the average of the many groupings of samples. To make the interpolation results as accurate as possible the AOI was broken up into three parts: The Española Basin, the north half of the

Albuquerque Basin, and the south half of the Albuquerque Basin. The Albuquerque Basin was split at the Isleta reservation due to the absence of water quality sampling there. To further add to the accuracy of the interpolations the angle of the interpolation results, the area from which to calculate, and the number of neighbors to use in the calculation was altered. The angle and shape of the area from which the model takes the neighbors and performs its calculations should be altered, according to Esri, if there is a directional quality to the data. Since the Rio Grande generally flows to the southwest (for the Española and Albuquerque Basins) most of the interpolations were angled in a similar manner, also making the major axis of the calculating area longer. The numbers of neighbors were also changed so that each neighbor would have more weight in the outcome. The decisions made for each of the interpolated areas are as follows:

Table 1: IDW Method

Area Interpolated	Maximum # of neighbors	Minimum # of Neighbors	Angle of Calculation Area	Length of Major Axis; Length of Minor Axis
North Albuquerque basin	4	2	20 degrees	0.28645653856; 0.20645653856
South Albuquerque basin	8	4	18 degrees	0.411635348983; 0.091635348983
Española basin	8	3	40 degrees	0.387775576967;

				0.297755769669

The results of each interpolation were depicted by the by the maximum values (from the range of values for each class that the interpolation produced) of the results for the same areas (for the minimum calculated value maps please refer to appendix VI). The maximum values should show a map with higher nitrate-nitrogen values and possibly more variation in values than the minimum values would. It should also be noted here that the USGS model was not used for this task.

Task 4:

Delineate priority areas in regards to human health. Like the previous task the USGS model 5065 will not be used in this analysis. For this task the NMPWND will be used with 2010 census projections for 2012 populations (the last year projected by the US Census for New Mexico counties). The population density by tract will then be calculated by dividing the population by the area of the tract.

The population density will be shown on the layer of counties and 2010 census tracts. Layering the NMPWND with the population density layer shows where there have been high levels of nitrate-nitrogen found in private well water coupled with where the population is the most dense. The areas that have high levels of nitrate-nitrogen and projected high population density will be circled to be shown on a map as areas of high health concern. Also, health AOIs will be drawn were there are multiple high nitrate-nitrogen readings or multiple dairies, despite the population density.

Results

Task 1: Statistics

Table 2: Albuquerque Basin Statistics for the NMPWND Samples

Min: 0.0mg/L (Class 1)	Mode: 0.0mg/L (Class 1)
Max: 112mg/L (Class 6)	Standard Deviation: 3.976
Mean: 1.8mg/L (Class 2)	Variance: 15.81
Median: 0.9mg/L (Class 2)	

Table 3: Albuquerque Basin Statistics for the USGS Model 5065 Results

Min: Class 1 (0.3mg/L)	Mode: 0.3mg/L (Class 1)
Max: Class 5 (7.5mg/L)	Standard Deviation: 0.717
Mean: 0.7mg/L (Class 2)	Variance: 0.514
Median: 0.3mg/L (Class 1)	

Table 4: Española Basin Statistics for the NMPWND Samples

Min: 0mg/L (Class 1)	Mode: 1mg/L (Class 3)
Max: 40mg/L (Class 6)	Standard Deviation: 3.3
Mean: 2.5mg/L (Class 4)	Variance: 10.9
Median: 1.6mg/L (Class 3)	

Table 5: Española Basin Statistics for the USGS Model 5065 Results

Min: Class 1 (<0.5mg/L)	Mode: 0.8mg/L (Class 2)
Max: Class 4 (2-4.9mg/L)	Standard Deviation: 0.646
Mean: 0.9mg/L (Class 2)	Variance: 0.417
Median: 0.8mg/L (Class 2)	

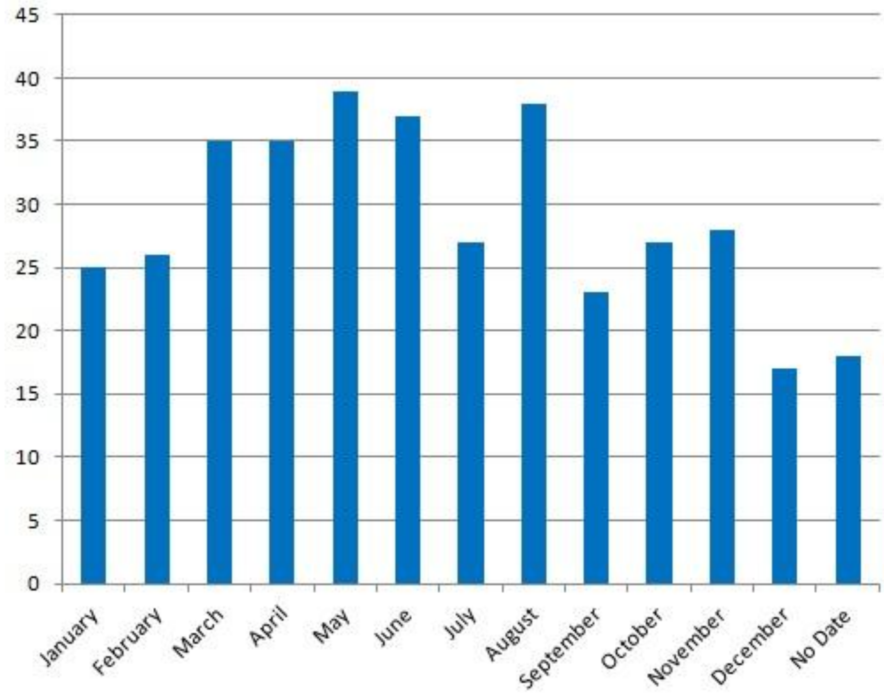


Figure 1: Number of NMPWND Samples for the Albuquerque Basin by Month

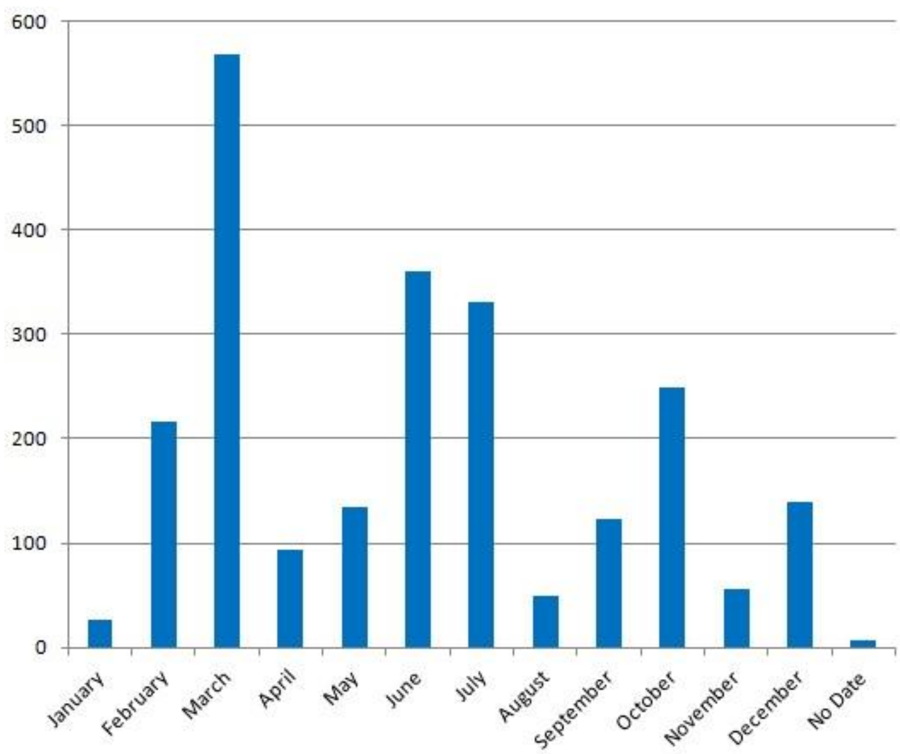


Figure 2: Number of NMPWND Samples for the Española Basin by Month

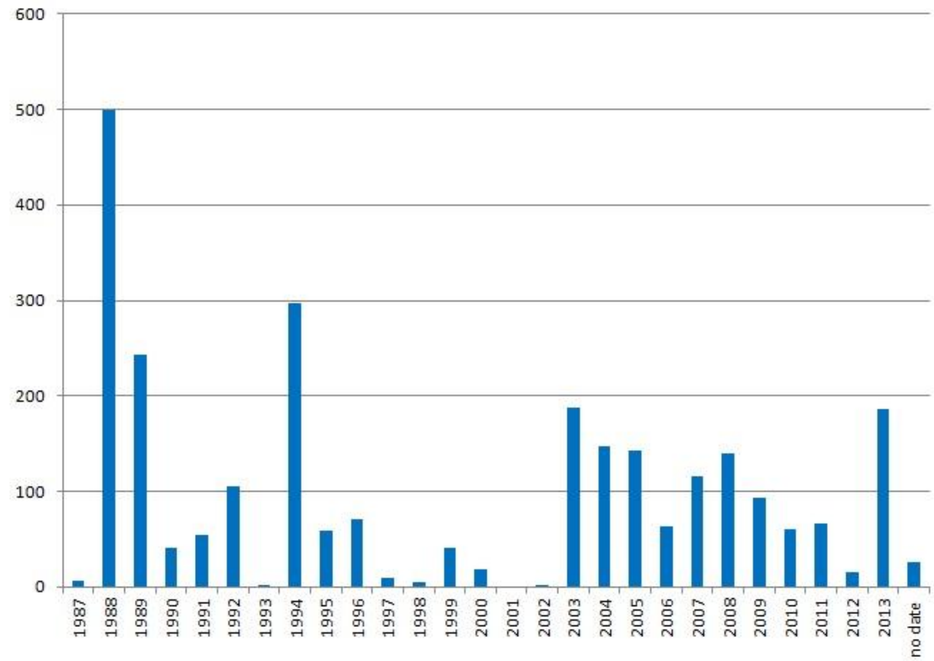


Figure 3: Number of NMPWND Samples for the Albuquerque Basin by Year

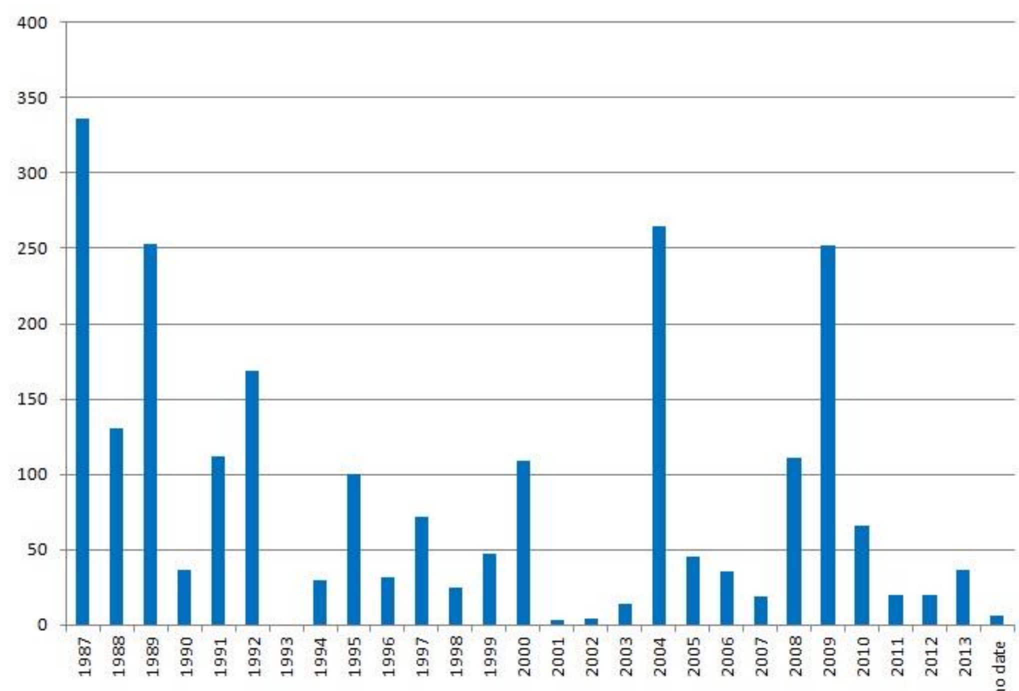


Figure 4: Number of NMPWND Samples for the Española Basin by Year

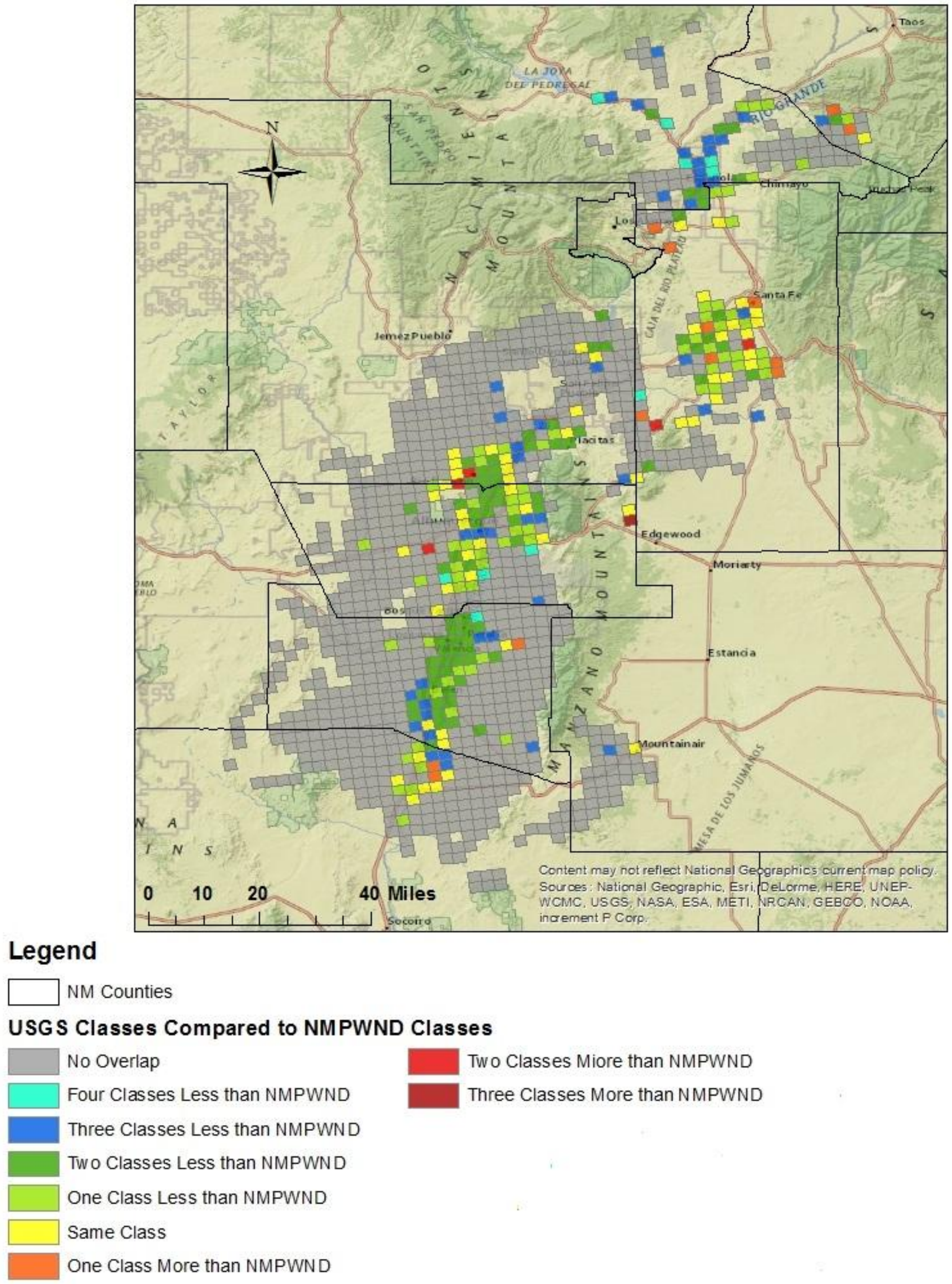
Over all, out of the 5,045 records that fell within the bounds of the two basins, 2,694 records are located in the Albuquerque Basin, while 2,351 records are located in the Española Basin. In the Albuquerque Basin samples, 25 percent of the samples had concentrations above 2.0mg/L of nitrate-nitrogen and three percent of the samples were equal to or exceeded 10 mg/L of nitrate-nitrogen. In the Española Basin, 43 percent of the samples had concentrations above 2.0 mg/L. Three percent of the samples were equal to or exceeded 10 mg/L of nitrate-nitrogen.

Task 2

Of the 2,694 samples taken in the Albuquerque Basin 2,291 of them overlap an area where the predicted level of nitrate-nitrogen is less than 0.5mg/L. Fifty percent of those observed values are higher than the predicted level of nitrate-nitrogen. There are 332 samples in the Albuquerque Basin that overlap with areas where the predicted level of nitrate-nitrogen is between 0.5 and 0.9mg/L, about 42 percent of the samples in those areas have lower levels of nitrate than the predicted range of that area, while another 42 percent of the sample points over the same range have higher observed nitrate-nitrogen readings than the predicted level they overlap. For the areas of the Albuquerque Basin where the predicted levels of nitrate-nitrogen range from 1.0-1.9mg/L, 64 sample points overlap. About one third of those points have a higher nitrate-nitrogen level than the predicted range, one third below the predicted range, and one third of the water fair samples that overlap the class 3 predicted range areas have nitrate-nitrogen readings in the same range. The same percentages apply for the areas where the predicted nitrate-nitrogen levels are between 5.0-9.9mg/L, except in this case only six samples occurred in areas where the predicted nitrate-nitrogen levels were in that range. Only one sample overlapped an area that had a predicted range of groundwater nitrate-nitrogen between 2.0-4.9mg/L. The NMPWND samples have a nitrate-nitrogen value in the same range. For the Albuquerque Basin there are no areas where the level of nitrate-nitrogen in the groundwater is predicted to be above 9.9mg/L.

For the Española Basin, 1,100 samples—of the 2,351 samples taken within the entire basin—occur in areas where the predicted nitrate-nitrogen level for groundwater is less than 0.5mg/L. Nearly 90 percent of those samples have higher levels of nitrate-nitrogen than the predicted level. For the areas that have an expected value for nitrate-nitrogen between 0.5-0.9mg/L about 60 percent of the samples have concentrations above the predicted level. For the areas where the predicted level is between 1.0-1.9mg/L 36 percent of the NMPWND, samples from those areas have nitrate-nitrogen readings higher than the predicted nitrate-nitrogen level. Finally, for the areas where the expected nitrate-nitrogen level is between 2.0-4.9mg/L the percentage of NMPWND samples whose nitrate-nitrogen reading exceeds it is only about 21 percent. For the Española Basin there were no areas where the predicted groundwater nitrate-nitrogen level is above 4.9mg/L.

Similar to comparing the NMPWND samples to the USGS model 5065 grid cells, here is the resulting map from taking the difference between the USGS model 5065 grid cells and the average NMPWND sample of the same area:



Map 2: Comparison of USGS NO3-N Data to the NMPWND by Class (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees)

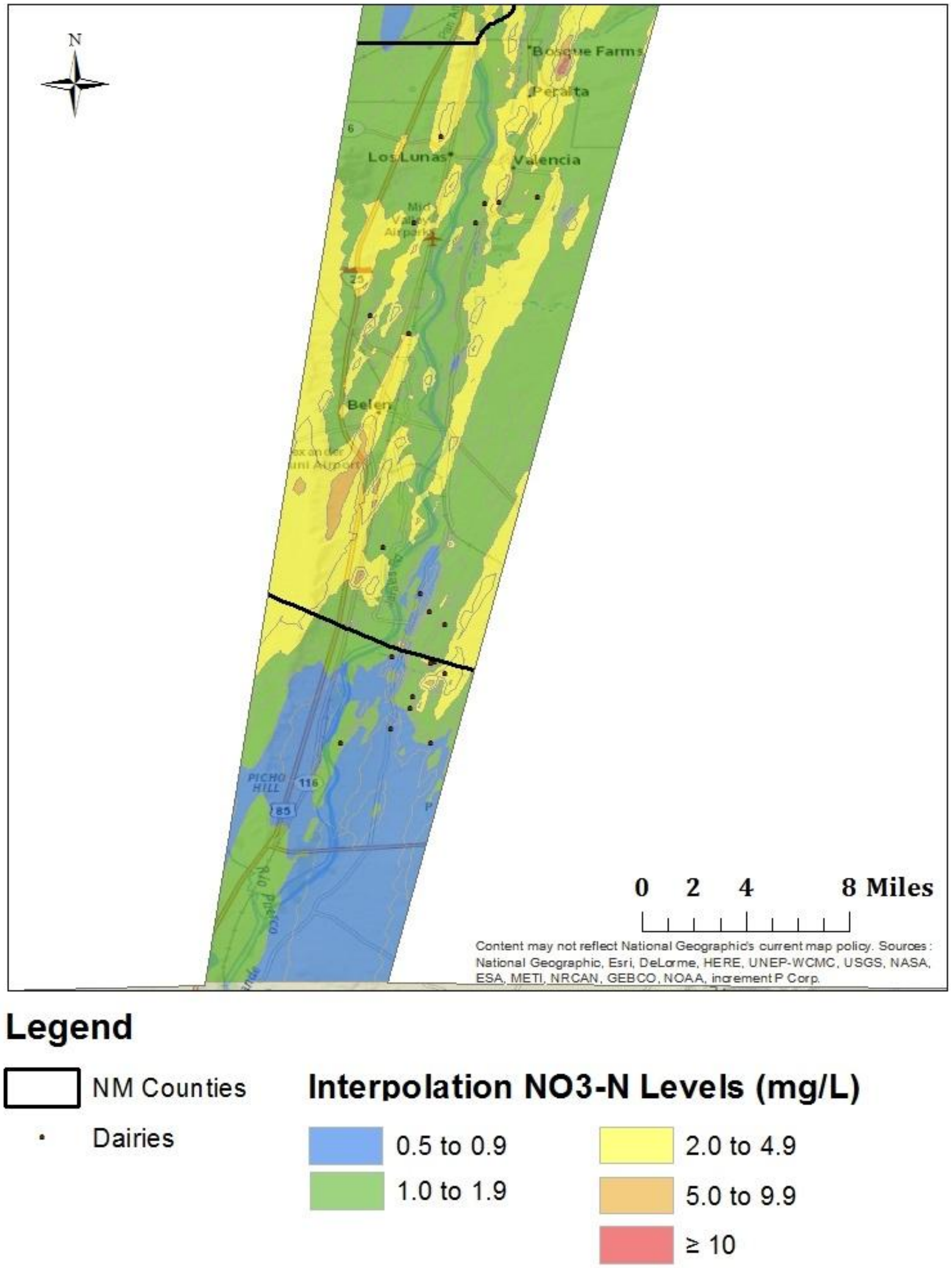
For the USGS-NMPWND difference map, in the Albuquerque Basin, only 20 percent of the USGS grid cells had overlapping NMPWND samples (178 of 887 cells). Out of the 178 cells four of them had a nitrate-nitrogen class value that was four classes less than the average NMPWND sample for that area. 26 grid cells represented a class for nitrate-nitrogen that was three classes lower than the averaged NMPWND samples in the area. 64 cells represented a nitrate-nitrogen class that was two classes lower than the averaged NMPWND samples in that area. 40 cells were one class lower than the averaged NMPWND class of that area. This means that nearly 75 percent of the USGS model 5065 grid cells in the Albuquerque Basin that had overlapping NMPWND samples had predicted a range lower than the NMPWND observed range for the same area. About 21 percent of the grid cells that had an overlap of USGS prediction and NMPWND nitrate-nitrogen observations were in the same class range. This left about four percent of the grid cells that housed both datasets with the USGS class value being higher than the averaged observed class range.

The Española Basin showed an overlap in 52 percent of the grid cells that made up the basin 98 of 203 grid cells). Roughly 69 percent of the USGS grid cells that had overlapping NMPWND samples had a lower class range than the averaged NMPWND class. 18 percent of the grid cells where the datasets overlapped shared the same nitrate-nitrogen class. Finally, only 12 percent of the USGS grid cell classes were higher than the class of the averaged NMPWND in the same area.

Task 3: IDW Interpolation

South Half of Albuquerque Basin

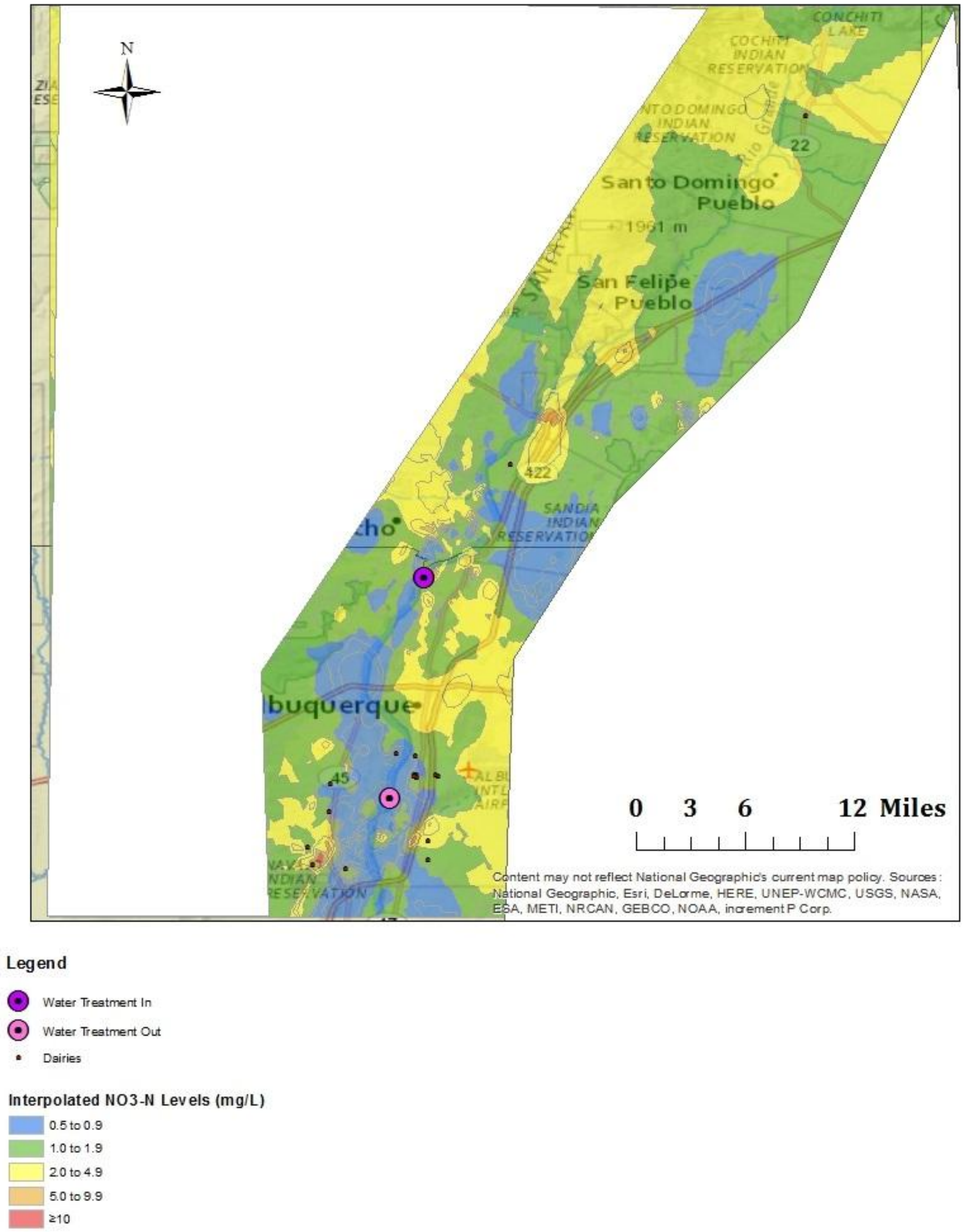
The interpolation of the south half of the Albuquerque Basin shows no areas where the nitrate-nitrogen is projected to exceed class 5 (5.0 to 9.9mg/L), regardless of whether you are looking at the map using minimum values or the map using maximum values. However the areas that are represented by class 5 (in the maximum values map, see map on the following page) are concerning because nitrate-nitrogen levels in groundwater above 2.0mg/L typically indicate anthropogenic influences and contributions of nitrogen to the environment, and class 5 represents levels very close to the maximum recommended level of nitrate-nitrogen in drinking water. Also, a reading that implies anthropogenic sources of nitrate-nitrogen in the groundwater may mean that there are other contaminants of concern in the aquifer.



Map 3: Interpolation of South Half of Albuquerque Basin Using Maximum Calculated Values (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees)

North Half of Albuquerque Basin

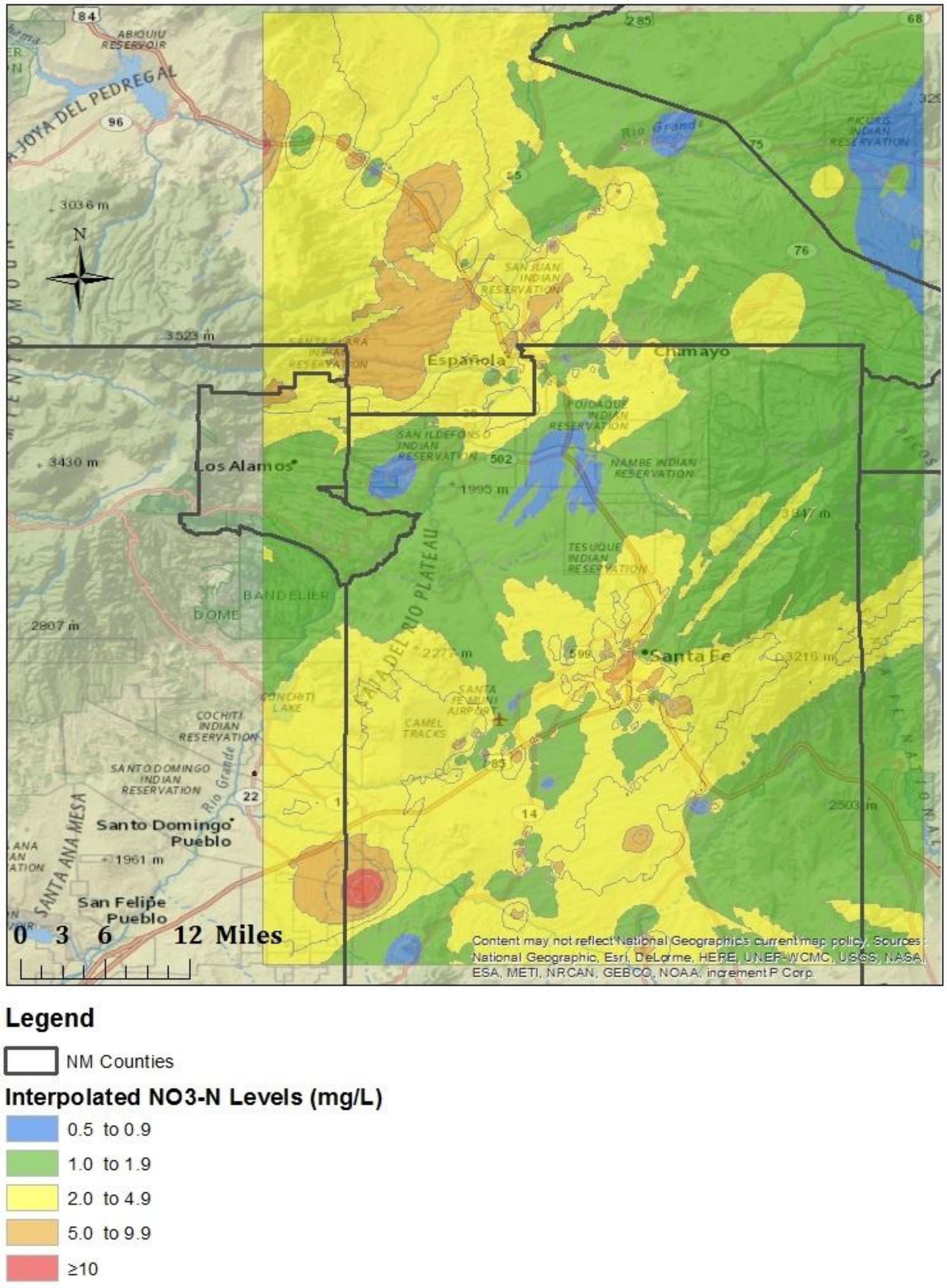
The Interpolation of the north half of the Albuquerque Basin shows no areas where the nitrate-nitrogen levels would exceed 9.9mg/L based on the interpolation's calculations. In the map displaying maximum values there is however a small area that has calculated the nitrate nitrogen levels to be between 5.0 and 9.9mg (see map on the following page).



Map 4: Interpolation of the North Half of the Albuquerque Basin Using Maximum Calculated Values. (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees

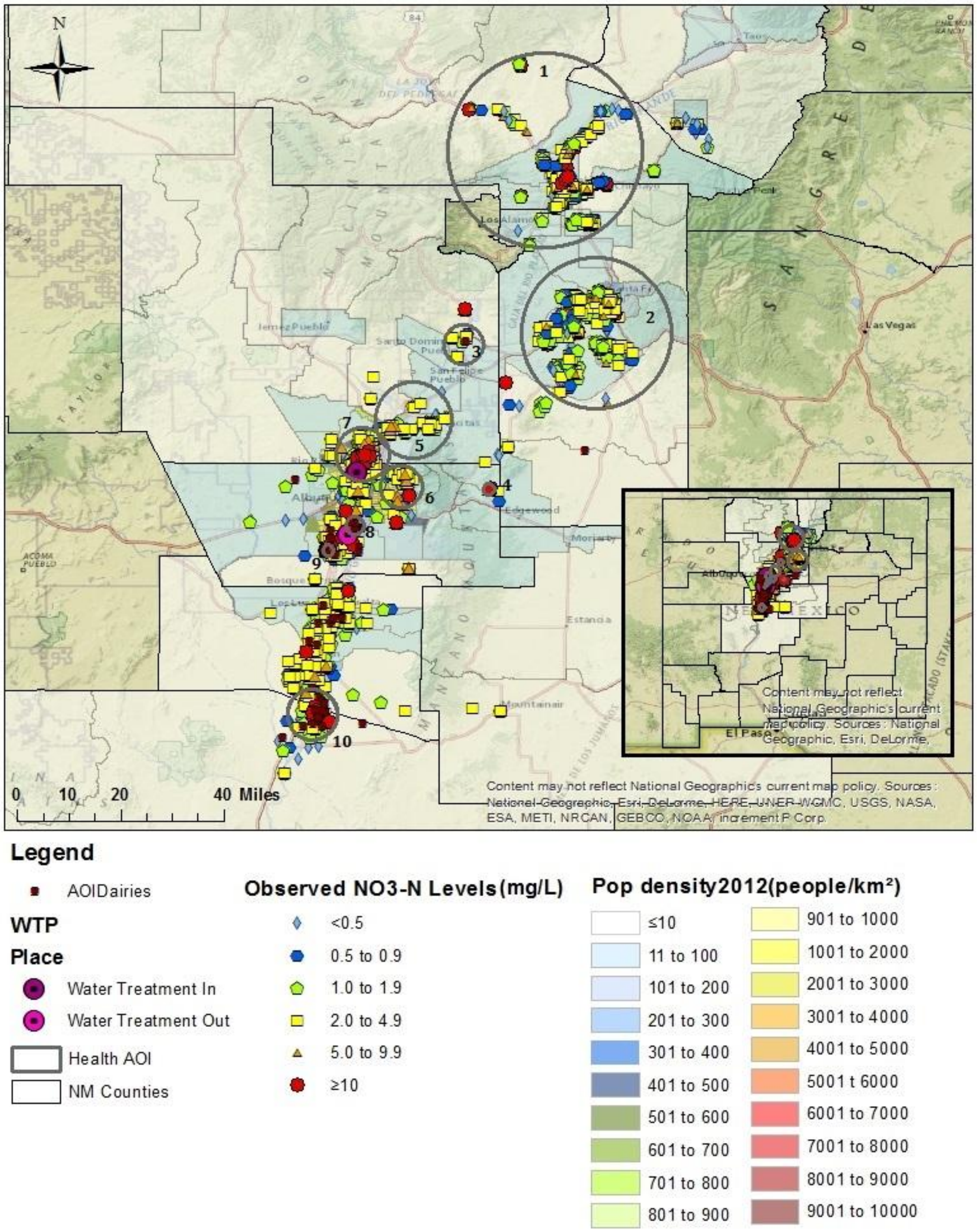
Española Basin

Both maps for the Española Basin show areas where,assuming the samples create a realistic representaion of what is happening in the aquifer, nitrate-nitrogen levels are equal to or above the maximum contaminant level of 10mg/L. However the majority of the basin appears to still be projected to a range between 1.0 and 1.9mg/L (see map on the following page).



Map 5: Interpolation of Española Basin Using Maximum Calculated Values (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Task 4: Health AOIs

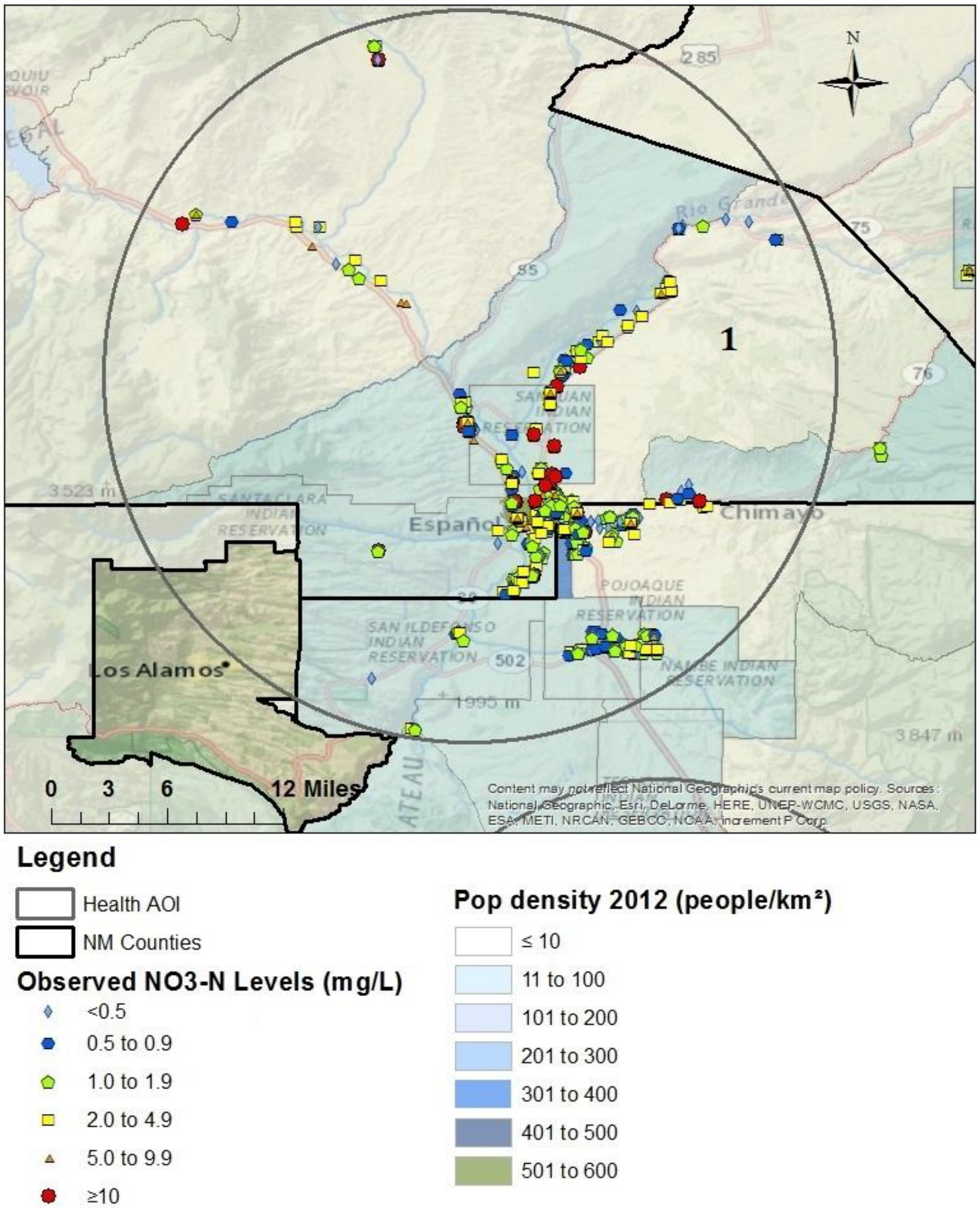


Map 6: New Mexico with Study Area and Health AOIs (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

The previous map shows all parts available and needed to locate health AOIs. The map also shows the entire state of New Mexico in order to illustrate the size of the basins (and were they are located in the state). Using the NMPWND there were a total of 10 health AOIs indentified for various reasons, with in the two basins, these areas will be described here:

Health AOI No.1: Española and the Surrounding Area

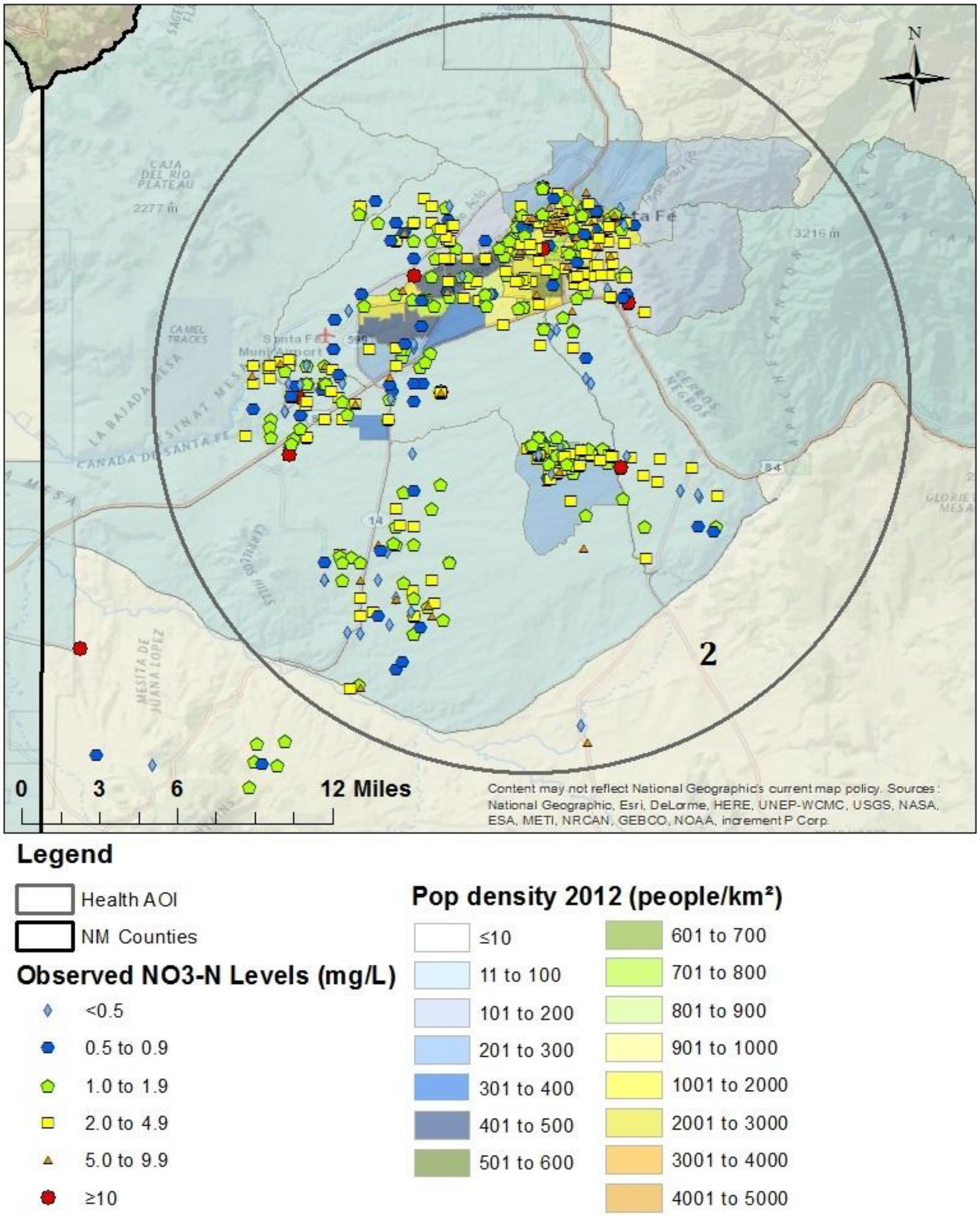
This area was chosen because of the population density and because of the number of NMPWND readings that exceeded 2mg/L (see map on the following page).



Map 7: Health AOI No.1: Española and Surrounding Areas (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.2: Santa Fe and the Surrounding Area

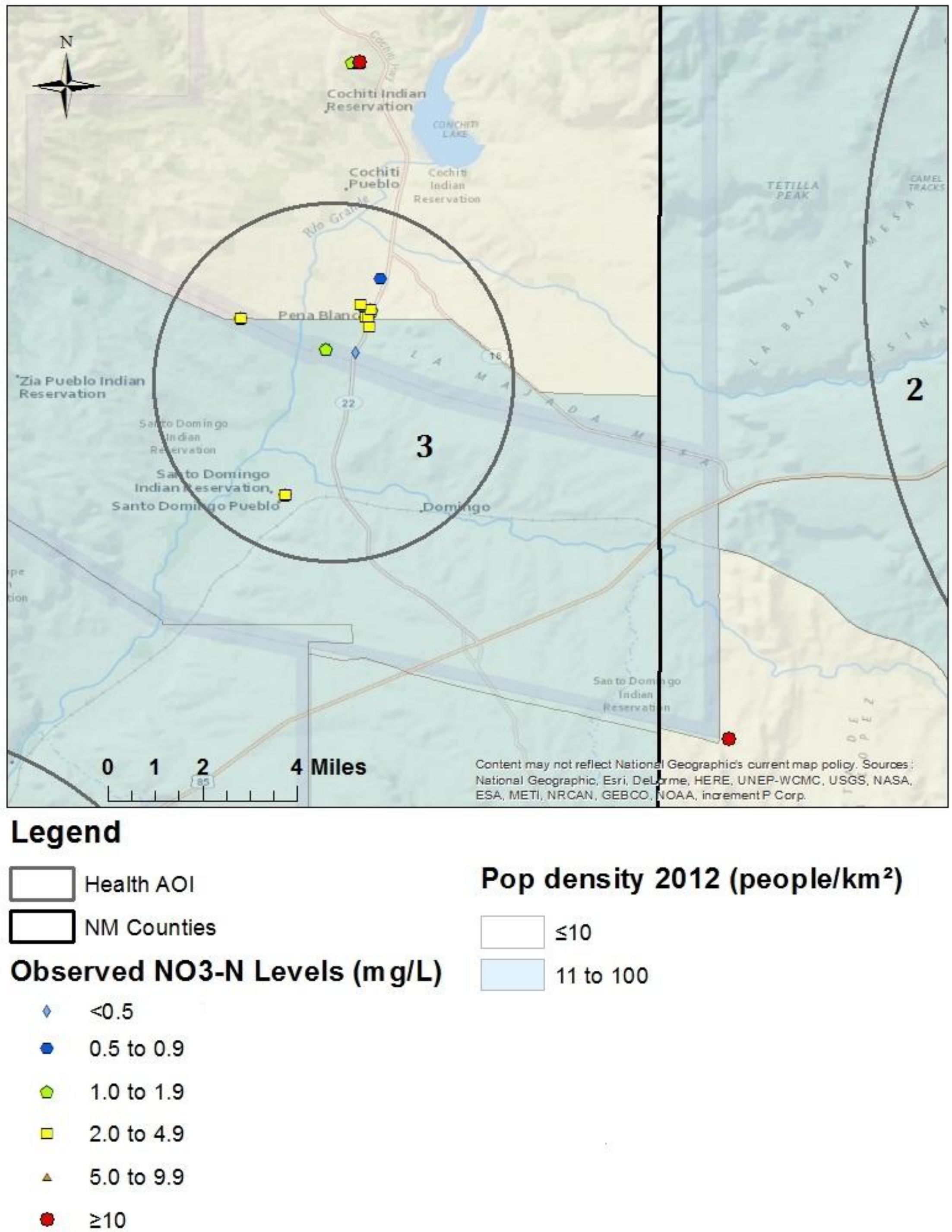
This area was also chosen for its high population density and for the many high nitrate-nitrogen readings (see map on the following page).



Map 8: Health AOI No.2: Santa Fe and Surrounding Area (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.3: West of Santa Fe

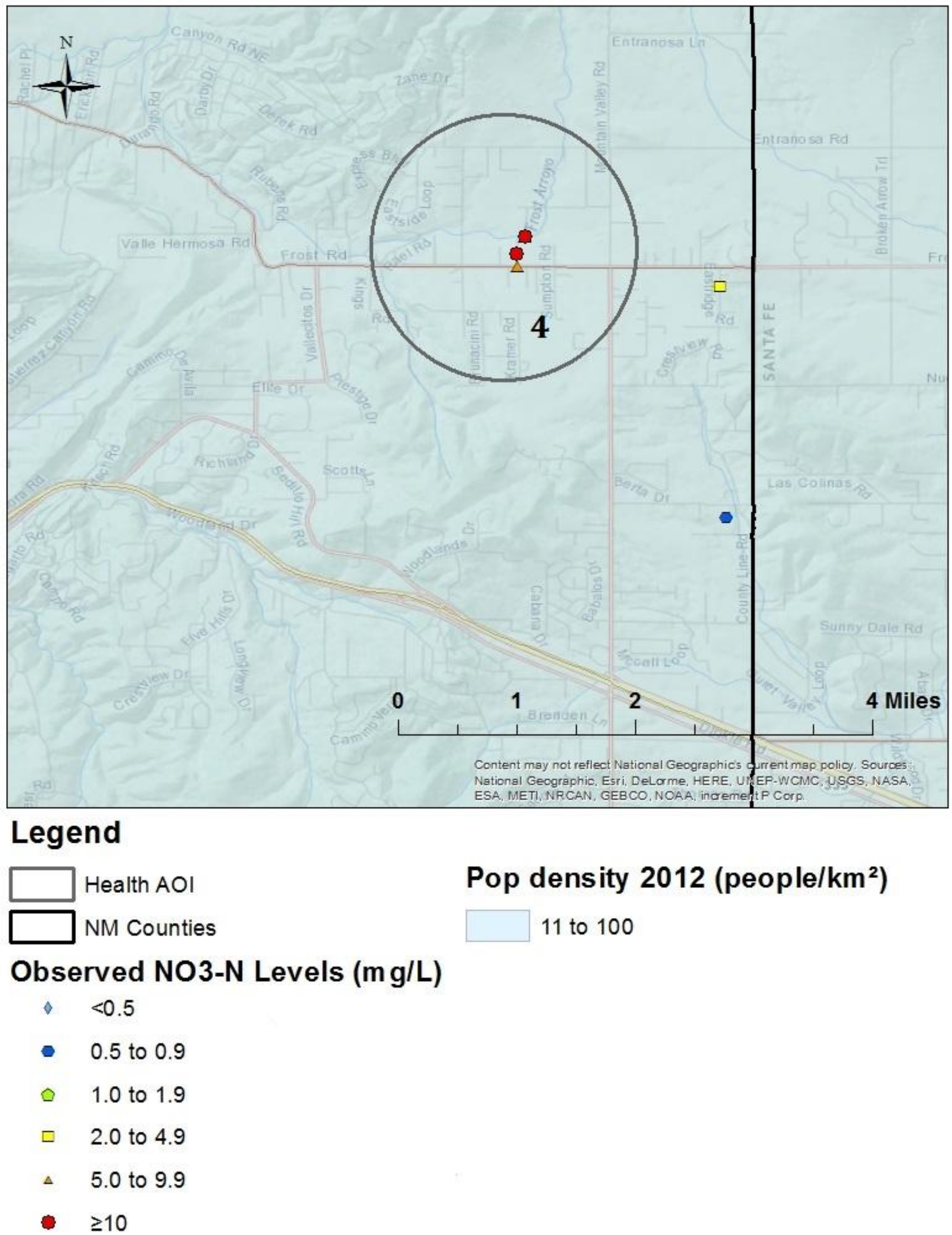
This area was identified as an area of interest for health concerns because of the number of nitrate-nitrogen readings that exceed 2.0mg/L in combination with the fact that these samples were taken near a dairy (see map on the following page).



Map 9: Health AOI No.3: West of Santa Fe (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.4: East Mountains

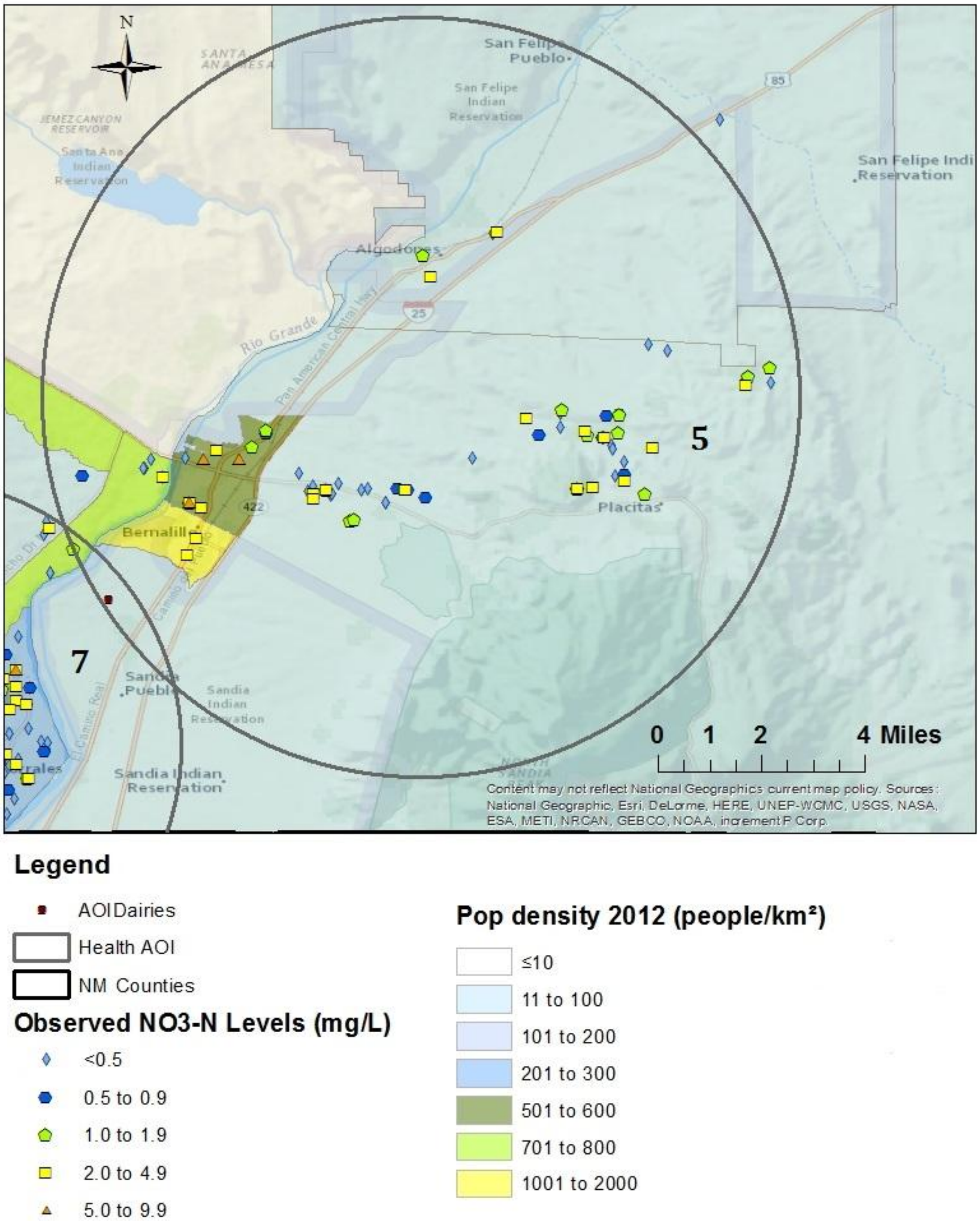
This area was chosen because of the high nitrate-nitrogen readings and the fact that they are so close together. Because of their proximity and magnitude the low population density was overlooked (see map on the following page).



Map 10: Health AOI No.4: East Mountains (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.5: Bernalillo and Surrounding Area

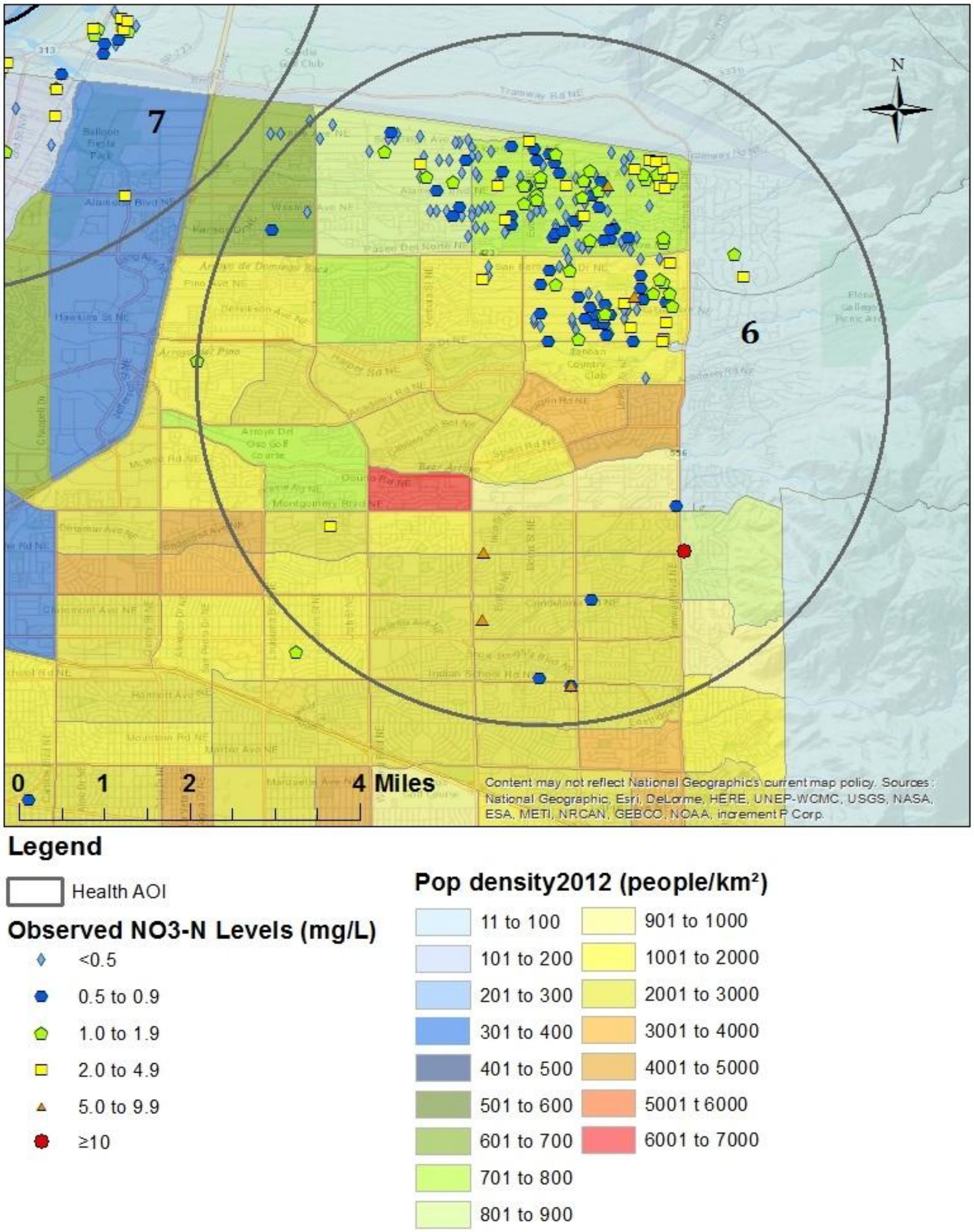
Bernalillo and the surrounding area was chosen because of the high population density and the high nitrate-nitrogen levels from the NMPWND samples. Also, there is a dairy located relatively close by (see map on the following page).



Map 11: Health AOI No.5: Bernalillo (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.6: Northeast Albuquerque

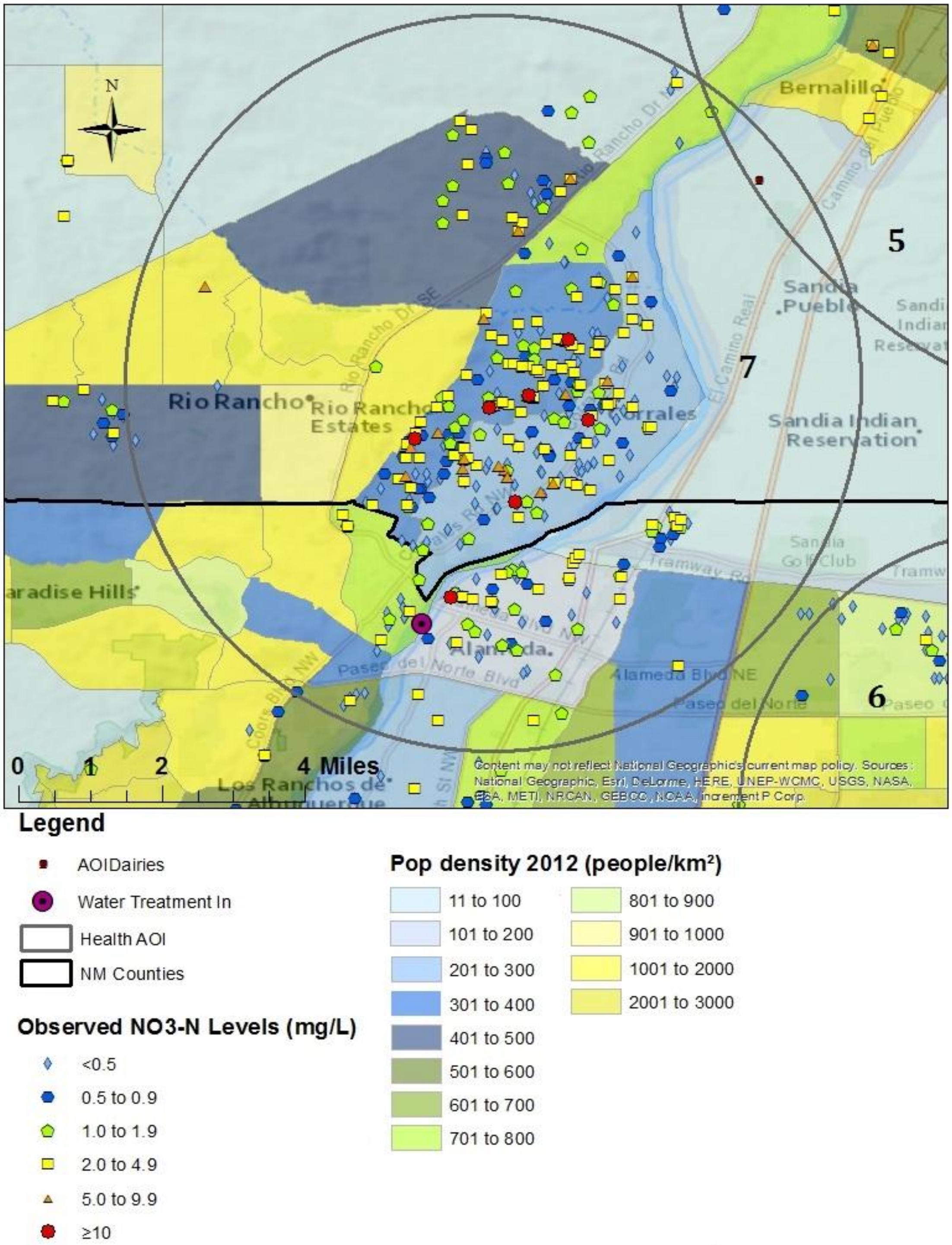
This area was chosen because the population here is very dense and because of the number of nitrate-nitrogen samples above 2.0 mg/L (see map on the following page).



Map 12: Health AOI No.6: Northeast Albuquerque (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.7: Corrales and Rio Rancho

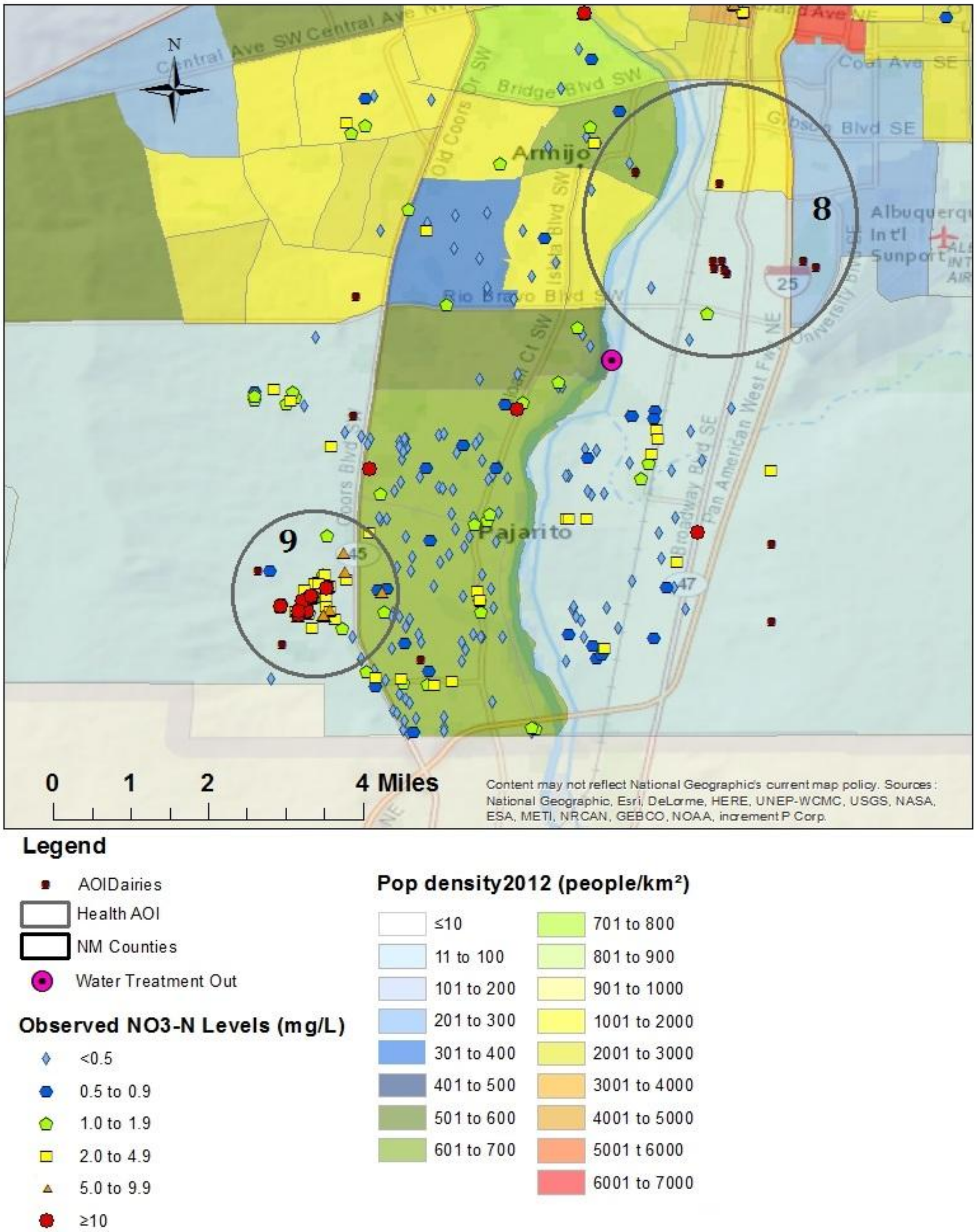
This area stood out due to the many high nitrate-nitrogen readings in such a small area. The population density of the Corrales-Rio Rancho area is also quite high (see map on the following page).



Map 13: Health AOI No.7: Corrales and Rio Rancho (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No. 8 and 9: South Valley I and II

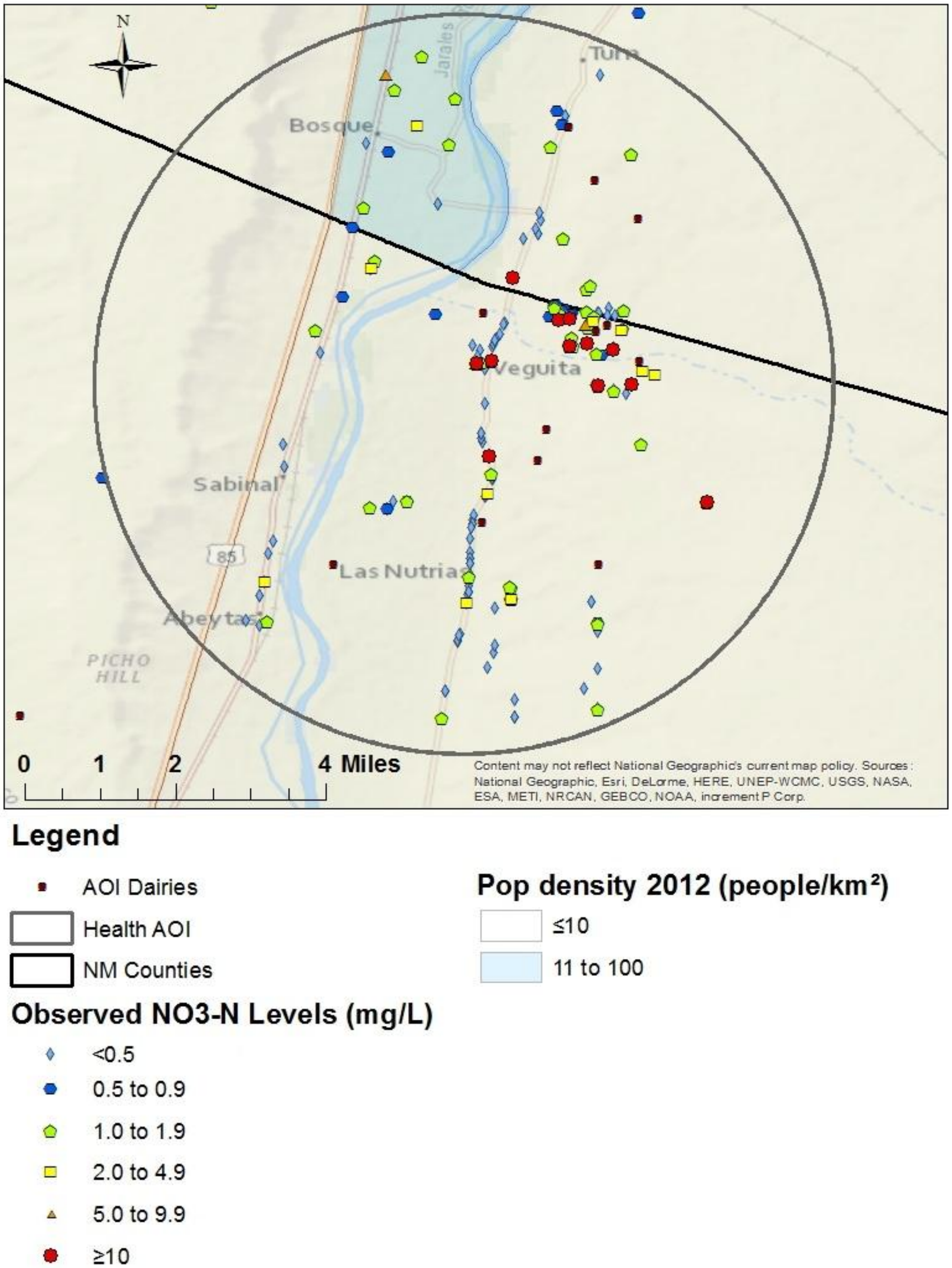
These areas were chosen because of the proximity to densely populated areas and dairies. Health AOI No.9 was also chosen due to the large number of high nitrate-nitrogen readings so close together (see map on the following page).



Map 14: Health AOIs No.8 and 9: South Valley I and II (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Health AOI No.10: Veguita and Surrounding Area

Veguita was chosen due to the many elevated nitrate-nitrogen samples and the proximity of these samples to dairies (see map on the following page).



Map 15: Health AOI No.10: Veguita (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Discussion

From calculating the statistics for both datasets and both basins it is learned that the average nitrate-nitrogen reading falls in class 2 (0.5 to 0.9mg/L) for the Albuquerque Basin for both the NMPWND and the USGS model 5065 results. For the Española Basin the average nitrate-nitrogen reading is much higher, at a range of 2.0 to 4.9mg/L, for the NMPWND. However for the USGS model 5065 average class level it is only class 2. Taking a deeper look into the NMPWND (specifically looking at classes by month by basin) it is noticeable that generally classes 3 and 4 (1.0 to 1.9mg/L and 2.0 to 4.9mg/L) are where most of the readings fall each month. This trend is especially noticeable for the Winter months and some of the Spring months (graphs can be found in Appendix IV and V). While this is what the dataset shows there are some issues, both spatially and temporally, with the data that makes it hard to say with certainty that this is a trend that that could be relied upon.

Comparing the two datasets with respect to the same geographical space showed that not only the two datasets usually differed in nitrate-nitrogen class range over the same space, but that the NMPWND samples only cover a very small portion of the each basin (this is more true for the Albuquerque Basin). For the Albuquerque Basin the majority of NMPWND samples were taken close to the Rio Grande. Although the USGS model 5065 uses fewer samples to calculate their resulting map the samples used were distributed better throughout the basins. It should also be noted that the data for the two datasets were collected over different periods of time. The NMPWND was collected over three decades (1987 to 2013), while the USGS model 5065 uses water quality samples taken from the USGS NWIS over a three year period at most (the database only go back as far as 2007, and was accessed in 2010 for this particular model). It is possible that the NMPWND and USGS model 5065 results are so different in many areas because this study did not break up the NMPWND by year when performing spatial analysis or analyzing the statistics of the dataset. In the future, to compare the observed data to predicted levels of nitrate-nitrogen in the Albuquerque and Española Basins it may be useful to compare the same years of data.

The interpolation had many samples to work with which never hurts the accuracy of an interpolation. However, not all of the surface area for each interpolation was incredibly accurate. This was easy to see when the NMPWND points were layered with the interpolation (see appendix VII). Since all of the points were used in the interpolation (even ones on the outskirts of the basins), the points that were not near other points were generally surrounded significantly by surface area that matched their class range. If only one sample is taken in an area it is faulty to assume that large areas around it would have the same value. Unfortunately this Inverse Weighted Distance interpolation calculated unknowns by using multiple points and the distance from one another, so where there is only one point for long distances it is forced to base the resulting/surrounding surface area off that one point. On the other hand, in areas where there were many samples taken in a small area the interpolated resulting surface area should be very accurate.

Overlapping the NMPWND with population density, dairy, and water treatment plant data showed that some of the areas that had clusters of high nitrate-nitrogen readings were close to dairies. Although there have been studies done proving that dairies are contributors of nitrate-nitrogen to groundwater more testing would have to be done to connect these particular samples to the dairy(ies) nearby. After all, there were also high nitrate-nitrogen readings reported where dairies were not located.

While much was accomplished in the study that could help the NMDOH and NMED (and possibly other agencies as well) there were multiple factors that could be improved upon which would in turn help the quality of the data and results of the queries.

The data was very accurate in many ways as the NMPWND was comprised of many actual nitrate-nitrogen samples (unlike the USGS model 5065 data that was a prediction based on fewer samples). Further, the many samples of the NMPWND were taken in populated areas, which when considering groundwater quality from a public health prospective is much more important than places where people do not reside. So, even though one drawback of the dataset is the lack of geographical area covered by the samples, the areas that would matter most for health concerns have been sampled relatively thoroughly. For studies outside of health concerns (or for the health concerns of future population expansion) it might still be a good idea to sample outside of populated areas on occasion. Specifically with respect to nitrate-nitrogen in groundwater this could help in determining a non-anthropogenic or naturally occurring level of nitrate-nitrogen in different areas of the state.

The next issue that needs to be addressed is a locational and temporal one of the NMPWND. With such an ample dataset, each month and most years were well represented. However, because the dataset is based on volunteer participation (which could be affected by location of testing and the quality of advertising for the testing, among other things) many of the samples are sporadic in time and position. There were not many wells tested more than once in the three decades the testing spans and there are areas where many people participated and other areas where there is quite the lack of participation. There was not much time to study this phenomena, but while looking at the data it does not always appear that the number of tests done in any one area are proportional to the population of that area. While nitrate-nitrogen may not move through the Rio Grande Aquifer System very quickly (the rate of nitrate-nitrogen attenuation could not be found for the AOI), it would be a good idea to test the same well more than once to assess the fluctuation of nitrate-nitrogen around the well. For future testing – to improve upon the accuracy of the data – it would be a good idea to test in the same areas at the same time of year and try to get either a similar number of samples for each area or a number of samples to reflect the population or population density of an area.

Because the current samples are sporadic in time and iteration it would be reaching a bit to conclude that there is a trend in the dataset when assessing nitrate-nitrogen levels by month or year. As for the geographical location of the readings, especially in areas that have been very well sampled, an area with multiple elevated levels could still be cause for concern. It should be stated however that another problem with the location of the data points is quality of the geocoding of the addresses. Many of them did not come with sufficient physical address information and thus were geolocated at the center of streets or towns. While it was considered that this would cause some of the NMPWND to be not very accurate the fact that the nitrate-nitrogen readings were of high quality outweighed the fuzzy location (which for the most part only offset the sample by a few miles). In the future it would be a better idea though to obtain more accurate physical addresses from the volunteers.

With all that said some areas of concern were able to be seen on maps and in tables especially in the Southern half of the Albuquerque Basin. Also, the maps created do show where the nitrate-nitrogen levels are that are above 2.0mg/L, and are approaching or over 10mg/L. While it might not tell you if you have a nitrate problem in your well water it might be useful in showing areas that should be tested for other contaminants that anthropogenic nitrate levels may indicate.

Conclusion

After analyzing the NMPWND from many different angles and in comparison to various other datasets, it appears that there is enough information in the NMPWND to locate areas that should be focused on and have further testing performed. The tasks performed for this study, however, do not show the exact cause of the high nitrate-nitrogen levels in the groundwater. Determining a background level for nitrate-nitrogen in different parts of New Mexico would be a good “next step” for advancing our knowledge of nitrate-nitrogen and related health issues. Also, finding out the exact cause for the elevated levels of nitrate-nitrogen in the groundwater would be a good “next step” as well. Both of those tasks could help with respect to the contaminants that are generally found with nitrate-nitrogen in these situations are various microbes and pathogens as well as pharmaceuticals. These contaminants found often with nitrate-nitrogen can be found in groundwater even where nitrate-nitrogen does not exceed the EPA’s recommended MCL. However, because these contaminates are related to anthropogenic activities they would be most likely to occur where the nitrate-nitrogen levels exceed the naturally occurring range.

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Map Sources

NO3-N Predictions (mg/L) -- USGS Scientific Investigations Report 2012-5065, dataset 698.

Observed NO3-N (mg/L) – NMPWND (NMED, USGS NWIS, NMTECH, and Bernalillo County). 1987-2013.

New Mexico Counties Layer – UNM RGIS

Dairies Layer – NMED

WTP Layer – Google Earth

Population Density Layer – US Census, 2010 (via UNM Bureau of Business and Economic Research)

Appendix I: Glossary

Terms

Geocode – Assigning x and y coordinates to an physical address
HACH Kits – A water quality testing device
Inverse Distance Weighted Interpolation (IDW) -- An interpolation technique that calculates cell values in a raster from a group of neighboring sample points that have been weighted in relation to the distance from the cell being evaluated. The points furthest away have the least impact on the cell being evaluated.
Lagoon – An area used to collect and store animal waste
Random Forest Classifier – a collection of algorithms used t**o determine outcomes for unknown areas based on preexisting data.**
Semaphore - ZP4 program – A program that contains various postal databases making it easier to find an actual address from a fragment of one.
Shapefile -- A data storage format for storing the location, shape, and attributes of geographic features.
Spatial Join -- A type of table join operation in which fields from one layer's attribute table are appended to another layer's attribute table based on the relative locations of the features in the two layers.

Acronyms

AOI – Area of Interest
AFO – Animal Feeding Operation
CAFO – Concentrated Animal Feeding Operation
EPA /USEPA – Environmental Protection Agency/United States Environmental Protection Agency
ESRI – Environmental Systems Research Institute
MCL – Maximum Contaminant Level
NMBMMR –New Mexico Bureau of Mines and Minerals Resources
NMDOHPWP – New Mexico Department of Health Private Well Program
NMED – New Mexico Environment Department
NMPWND – New Mexico Private Well Nitrate Data
USGS NWIS – United States Geological Survey National Water Information System

Appendix II: Background

Map 16: Dairy Locations in AOI (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Appendix III: Methods

New Mexico Environment Department Water Fair Data

In the early/mid-1980s the NMED started to travel around New Mexico offering to test the quality of water from domestic wells. On average, 10 locations were chosen to visit per fiscal year and people would come (sometimes from fairly far away) with samples of water from their wells. The NMED would generally test for Iron, Nitrate, Sulfate, pH, and Fluoride, as well as testing the temperature of the water. In certain areas other tests would be done (e.g. for arsenic, or uranium) depending on if there was a known problem in that area or any special funding to accommodate for the expensive testing of metals.

For almost the entire time these Water Fairs have been conducted, the test results, along with personal information, locational information, and other useful information about the well have been recorded onto hardcopy forms and stored in file boxes. During the summer of 2013 all of these hardcopy files were transferred to Excel spreadsheets with the help of five contractors.

After the data were successfully digitized, the various spreadsheet formats were standardized. Next the data were sorted in order to take out data that were not useful for the NMED or NMDOH. This meant removing entries that had no information with which to geocode, removing duplicates, and removing records with no/faulty information, as well as records where the water filtration system may have affected the quality of water for that location in the aquifer (For instance, records of reverse osmosis treated water were removed). Once the records were sorted so that all of the records were formatted the same for each category/column and all the useless records were removed. The records using Township, Range, and Section were parsed and sent to the Bureau of Land Management to be converted to latitude and Longitude coordinates, while the records that were eventually located using a physical address were cleaned and further standardized using the Semaphore - ZP4 program.

The cleaned records were then run through a composite locator which was created with multiple locators provided by Zachary Stauber of the NMED. Approximately 9,000 records were geocoded running this locator in Esri's ArcMap spatial analysis software (hereafter referred to as "ArcMap"). Another 500 records were then manually located by hand with the same composite locator. The single file address locator created by Will Athas (UNM Public Health Program), was then utilized with which another 300 records were matched. Nearly all the rest of the records were geocoded with the help of the Texas A&M online geocoding tool (geocoding most of them one by one). To improve the results of the private well water analysis, multiple private well nitrate-nitrogen concentrations were included from USGS NWIS, Bernalillo County, and NMBMMR. The USGS NWIS data were collected as part of the national monitoring program. Bernalillo County requires all new wells or well that are being transferred as part of a real estate contract be tested and reported to the county, and the NMBMMR collects private well data as a part of their Aquifer Mapping Program. These data were tabular joined. They only contain data from private wells. Non-detects were replaced with half of the stated detection limit. Finally, the files were put together and fed into ArcMap where a spatial dataset was created.

Table 6: Descriptions of Data Sources for the NMPWND.

Name of Dataset/Origin of Dataset	Description
NMED Water Fair Data	Over 30 years of nitrate readings from state water fairs. This dataset includes 3 sub datasets: NMEDWF, NMED Fairs 2006-2010, and NMED Well Fairs 2006-2012.
Bernalillo County Private Well Permit Applications	Nitrate readings collected from private well permit applications
USGS Private Well Data	Publicly available private well data found on the USGS' National Water Information System (NWIS) web interface.
NM TECH	Nitrate readings from private well samples borrowed from NM Tech's Bureau of Geology and Mineral Resources.
NMED_LANL	Private Well Samples Collected by the New Mexico Environment Department in connection with Los Alamos National Labs .

Table 7: Number of Records by Data Source for the Albuquerque Basin.

Total Number of records	**2694**
Total Number of NMED Water Fair Records (this number includes NMED_LANL records)	**2309**
Total Number of Bernalillo County records	**375**
Total Number of USGS records	**10**
Total Number of NMTECH records	**0**

Table 8: Number of Records by Data Source for the Española Basin

Total Number of Records	2351
Total Number of NMED Water Fair Records (this number includes NMED_LANL records)	2290

Total Number of Bernalillo County Records	3
Total Number of USGS Records	0
Total Number of NMTECH Records	58

USGS Model 5065

USGS model 5065 comes from the USGS Scientific Investigations report 2012-5065. It used a statistical model approach to predict aquifer vulnerability on basin-fill aquifers in the Southwest (United States) Principal Aquifer systems, which includes the Rio Grande Aquifer System in New Mexico and Colorado. A random forest classifier was built from explanatory variables that consisted, originally, of over 50 factors. The factors included source variables, geochemical variables, and susceptibility variables, all of which will be explained later on. The variables were obtained from previous USGS studies and calculated to fit the 3km grid cells that made up the study area. The original study area consisted of 6 western states (California, Utah, Nevada, Arizona, New Mexico, and Colorado) and covered roughly 190,600 square miles of basin-fill aquifer. The Albuquerque and Española Basins of the Rio Grande aquifer system make up an estimated 3,787 square miles of the study area. There were 112 samples used to train the variables in the Albuquerque Basin, and 33 water quality samples used to train the variables in the Española Basin. The model was chosen for this study to compare to the NMPWND because these many variables used to predict the spreading of nitrate-nitrogen from sampled locations within the basins.

A random forest classifier is a method of analysis that uses multiple decision trees consisting of multiple independent variables along with dependent variables (water quality samples) to teach itself what values to give to areas with no information. The water quality samples used for the USGS model 5065 were taken from the USGS NWIS database for each state that is covered in the study (presumably for the years 2007 (the first sample year in the database) to 2010 (when they accessed the database for samples). They then chose one sample to represent each grid cell, basing the sample to use on containing the most information on various groundwater contaminants. The independent or explanatory variables discussed before are defined here:

Source Variables: Human contribution of contaminants.

Aquifer Susceptibility Variables: Ways in which the water would infiltrate into the aquifer and its attenuation in the aquifer.

Geochemical variables: Chemical processes that affect the contaminants in the groundwater.

Table 9: USGS Model 5065 Variables

Variable Type	Sub Category	Examples
Source Variables	**Nitrogen loading**	nitrogen, atmospheric; nitrogen, farm fertilizer; nitrogen, unconfined manure
	Agriculture, Urban, and Biotic sources	septic/sewer ratio; basin rangeland; local population
	Geologic Sources	geology, distance to undifferentiated volcanic

		rock; geology, carbonate rocks; geology, crystalline rocks
Aquifer Susceptibility Variables	**Flow Path**	land-surface slope; land surface elevation; basin elevation .
	Soil Properties	soil, permeability; soil, clay; soil, organic material
	Water Use and Hydroclimatic	groundwater use, irrigated aricultural; recharge, basin; mean air temperature
Geochemical Variables	**Geochemistry**	groundwater, pH; groundwater, sulfate; groundwater, alkalinity

The USGS NWIS samples chosen for each grid cell interacted with various explanatory variables (depending on location) and an assessment was made on the importance of each variable. This narrowed down the variables and assigned weights to the important ones. A Goodness-of-fit evaluation was also implemented for the variables based on observed concentration class, location, statistical distribution of variables, and estimated sampling error. This created the final random forest classifier used to map a surface of predicted nitrate-nitrogen ranges.

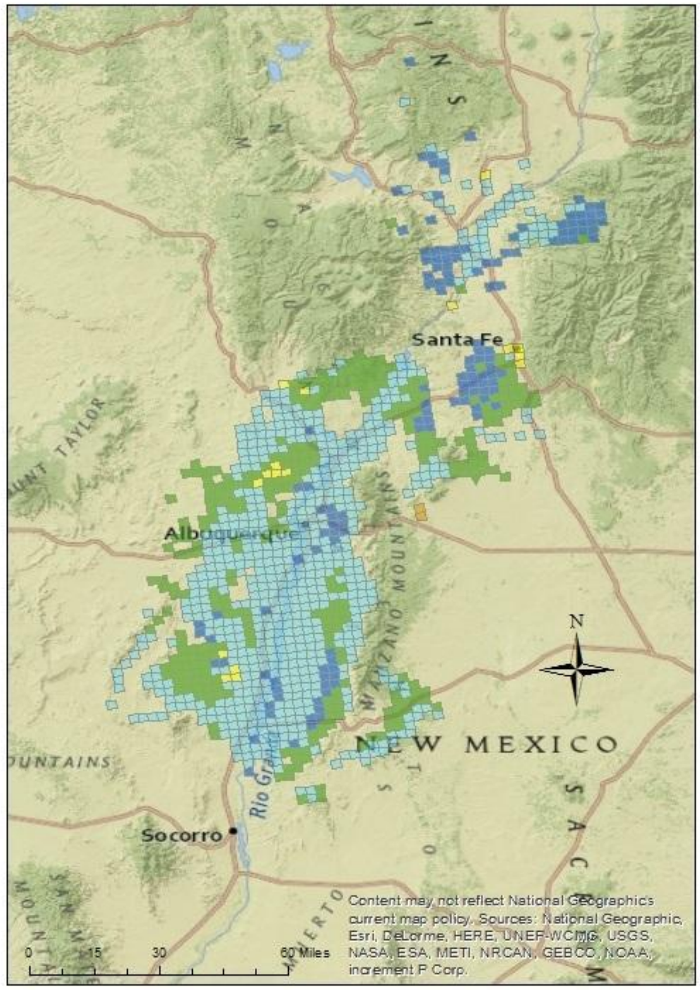
The result for the entire study area was that the random forest classifier was able to predict nitrate-nitrogen ranges, plus or minus a range, about three-fourths of the time. The rate at which the classifier was able to predict the actual nitrate-nitrogen range of an area was much less. The authors of the study contributed this to natural spatial variability (Anning et al, 2012).

Table 10: Definition of USGS Model 5065 Class Ranges, and Median Value for Each Range

Class	**Range**	**Median Value**
1	<0.5mg/L	0.3mg/L
2	0.5-0.9mg/L	0.8mg/L
3	1.0-1.9mg/L	1.5mg/L
4	2.0-4.9mg/L	3.5mg/L
5	5.0-9.9mg/L	7.5mg/L
6	≥10.0mg/L	*no value was assigned as there are no cells in the USGS data (for the AOI) that exceed class 5.

Because many factors are taken into consideration for the USGS 5065 model the results of the model, for the purpose of this study, are considered the predicted levels of nitrate-nitrogen. The NMPWND samples are considered the observed levels of nitrate-nitrogen.

Map 3: Albuquerque and Española Basins as Depicted by the USGS 5065 698 Dataset (Including NO3-N Class Ranges)



Sources: Base Map (ESRI); NO3-N Prediction Class Level layer (USGS).

NO3_N Prediction Class Level (mg/L)

NO3_N Range (mg/L)

- <0.5
- 0.5-0.9
- 1.0-1.9
- 2.0-4.9
- 5.0-9.9

Map 17: Albuquerque and Espsañola Basins as depicted by the USGS Model 5065, 698 Dataset (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Table 11: Number of Cells by Class and by Basin for the USGS Model 5065.

	Albuquerque Basin	Española Basin
Total Number of Cells	887	203
Class 1	573	57
Class 2	46	90
Class 3	255	50
Class 4	11	6
Class 5	2	0
Class 6	0	0

Appendix IV: Albuquerque Basin ,Task 1.

Table 12: Albuquerque Basin NMPWND Samples by Month, Class, and Source

Month and Dataset	Number of Records Class 1	Number of Records Class 2	Number of Records Class 3	Number of Records Class 4	Number of Records Class 5	Number of Records Class 6	Total number of Records
January	**25**	**2**	**9**	**25**	**13**	**3**	**77**
NMED	6	0	6	24	13	3	**52**
Bernalillo County	19	2	3	1	0	0	**25**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
February	**27**	**26**	**90**	**72**	**4**	**3**	**222**
NMED	11	22	86	70	4	3	**196**
Bernalillo County	16	4	4	2	0	0	**26**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
March	**61**	**78**	**156**	**52**	**4**	**0**	**351**
NMED	39	70	153	49	4	0	**315**

Bernalillo County	21	8	3	3	0	0	**35**
USGS	1	0	0	0	0	0	**1**
NM TECH	0	0	0	0	0	0	**0**
April	**66**	**17**	**21**	**26**	**28**	**26**	**184**
NMED	**37**	**10**	**20**	**23**	**28**	**26**	**144**
Bernalillo County	24	7	1	3	0	0	**35**
USGS	5	0	0	0	0	0	**5**
NM TECH	0	0	0	0	0	0	**0**
May	**77**	**208**	**54**	**20**	**5**	**4**	**368**
NMED	50	204	47	18	5	4	**328**
Bernalillo County	26	4	7	2	0	0	**39**
USGS	1	0	0	0	0	0	**1**
NM TECH	0	0	0	0	0	0	**0**
June	**59**	**28**	**25**	**38**	**9**	**1**	**160**
NMED	38	25	20	33	6	1	**75**
Bernalillo County	21	3	5	5	3	0	**37**
USGS	0	0	0	0	0	0	**0**

NM TECH	0	0	0	0	0	0	**0**
July	**67**	**48**	**55**	**32**	**3**	**2**	**207**
NMED	50	45	52	29	3	2	**154**
Bernalillo County	17	3	3	3	0	1	**27**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
August	**79**	**28**	**28**	**44**	**2**	**5**	**186**
NMED	46	27	27	42	2	3	**147**
Bernalillo County	33	1	1	2	0	1	**38**
USGS	0	0	0	0	0	1	**1**
NM TECH	0	0	0	0	0	0	**0**
September	**204**	**14**	**14**	**5**	**2**	**2**	**241**
NMED	192	8	10	4	1	2	**217**
Bernalillo County	11	6	4	1	1	0	**23**
USGS	1	0	0	0	0	0	**1**
NM TECH	0	0	0	0	0	0	**0**
October	**39**	**11**	**23**	**34**	**2**	**4**	**113**
NMED	21	8	19	32	2	4	**86**

Bernalillo County	18	3	4	2	0	0	**27**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	6	0	0	0	0	**0**
November	**133**	**27**	**65**	**92**	**27**	**11**	**351**
NMED	112	24	61	92	26	7	**322**
Bernalillo County	20	3	4	0	1	0	**28**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
December	**35**	**38**	**70**	**35**	**12**	**18**	**208**
NMED	17	38	70	35	12	18	**190**
Bernalillo County	17	0	0	0	0	0	**17**
USGS	1	0	0	0	0	0	**1**
NM TECH	0	0	0	0	0	0	**0**
No Date	**18**	**2**	**1**	**3**	**2**	**0**	**26**
NMED	0	2	1	3	2	0	**8**
Bernalillo County	18	0	0	0	0	0	**18**
USGS	0	0	0	0	0	0	**0**

NM TECH	0	0	0	0	0	**0**

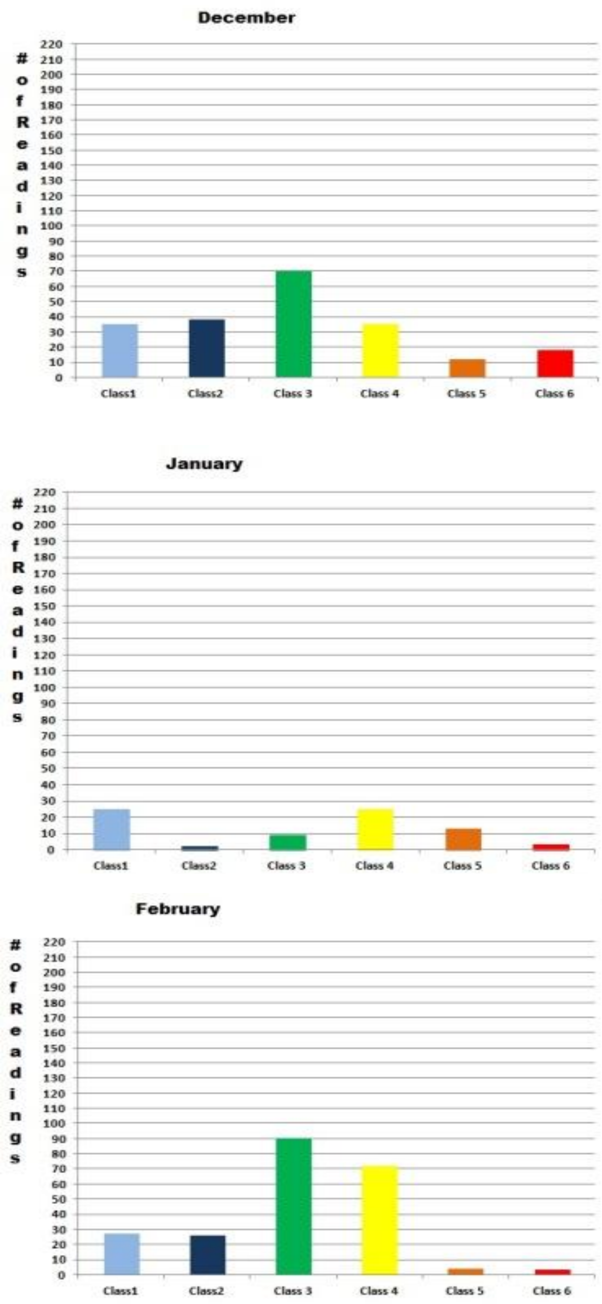


Figure 5: Albuquerque Basin Number of NMPWND Samples by Class for the Winter Months (December, January, and February)

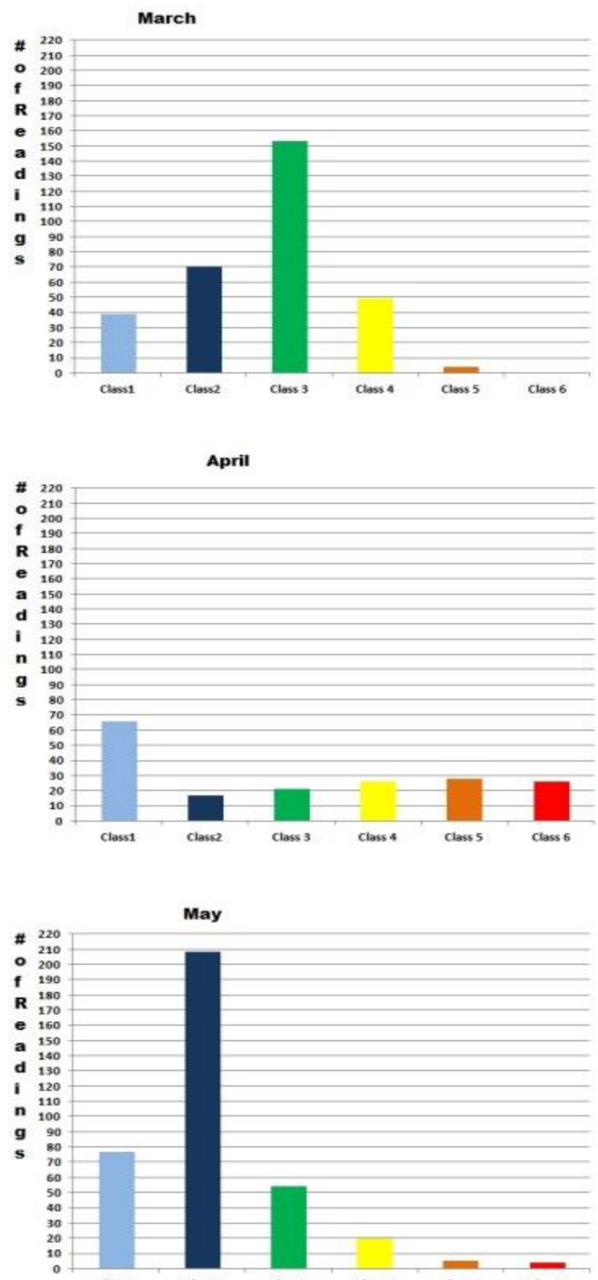


Figure 6: Albuquerque Basin Number of NMPWND Samples by Class for the Spring Months (March, April, and May)

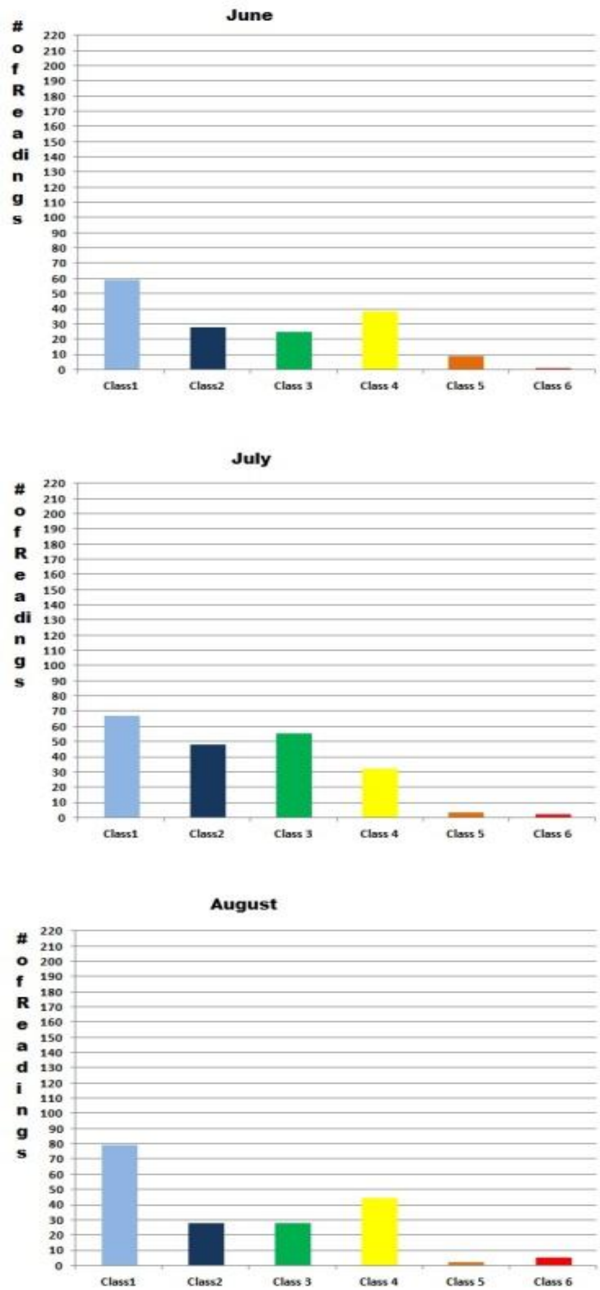
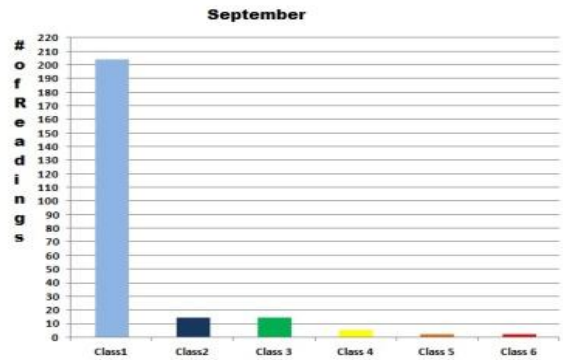
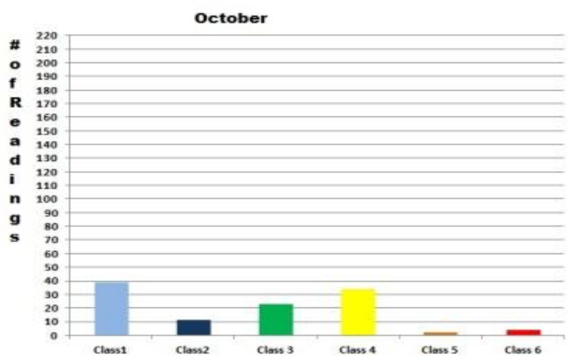


Figure 7: Albuquerque Basin Number of NMPWND Samples by Class for the Summer Months (June, July, and August)





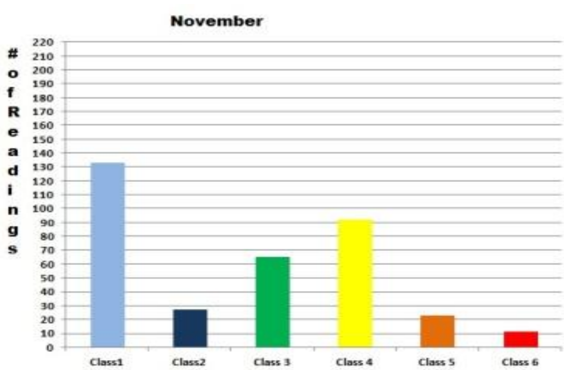


Figure 8: Albuquerque Basin Number of NMPWND Samples by Class for the Fall Months (September, October, and November)

Table 13: Albuquerque Basin NMPWND Samples by Year, Class, and Source

Year	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Total # of Records
Total 1987	**1**	**1**	**0**	**3**	**1**	**0**	**6**
Water Fair Records	1	1	0	3	1	0	**6**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1988	**34**	**206**	**91**	**95**	**45**	**28**	**499**
Water Fair Records	34	206	91	95	45	28	**499**
Bernalillo	0	0	0	0	0	0	**0**

County							
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1989	**27**	**61**	**114**	**32**	**8**	**1**	**243**
Water Fair Records	27	61	114	32	8	1	**243**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1990	**3**	**1**	**12**	**23**	**1**	**1**	**41**
Water Fair Records	3	1	12	23	1	0	**40**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	1	**1**
NM TECH	0	0	0	0	0	0	**0**

Total 1991	**1**	**21**	**19**	**10**	**3**	**0**	**54**
Water Fair Records	1	21	19	10	3	0	**54**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1992	**30**	**43**	**20**	**12**	**0**	**0**	**105**
Water Fair Records	30	43	20	12	0	0	**105**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1993	**1**	**0**	**0**	**0**	**0**	**0**	**1**
Water	0	0	0	0	0	0	**0**

Fair Records							
Bernalillo County	0	0	0	0	0	0	**0**
USGS	1	0	0	0	0	0	**1**
NM TECH	0	0	0	0	0	0	**0**
Total 1994	**195**	**17**	**50**	**23**	**4**	**8**	**297**
Water Fair Records	195	17	50	23	4	8	**297**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1995	**16**	**11**	**14**	**10**	**4**	**4**	**59**
Water Fair Records	9	11	14	10	4	4	**52**
Bernalillo	0	0	0	0	0	0	**0**

County							
USGS	7	0	0	0	0	0	**7**
NM TECH	0	0	0	0	0	0	**0**
Total 1996	**5**	**6**	**17**	**23**	**11**	**9**	**71**
Water Fair Records	5	6	17	23	11	9	**71**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1997	**2**	**0**	**1**	**5**	**1**	**1**	**10**
Water Fair Records	2	0	1	5	1	1	**10**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**

Total 1998	**1**	**1**	**1**	**2**	**0**	**0**	**5**
Water Fair Records	1	1	1	2	0	0	**5**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0		0	**0**
Total 1999	**24**	**7**	**7**	**3**	**0**	**0**	**41**
Water Fair Records	24	7	7	3	0	0	**41**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2000	**0**	**1**	**1**	**15**	**0**	**1**	**18**
Water	0	1	1	15	0	1	**18**

Fair Records							
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2001	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Water Fair Records	0	0	0	0	0	0	**0**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2002	**0**	**1**	**0**	**0**	**0**	**0**	**1**
Water Fair Records	0	0	0	0	0	0	**0**
Bernalillo	0	1	0	0	0	0	**1**

County							
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2003	**96**	**28**	**32**	**14**	**4**	**13**	**187**
Water Fair Records	95	14	32	14	4	13	**186**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	1	0					**1**
NM TECH	0	0	0	0	0	0	**0**
Total 2004	**73**	**14**	**18**	**27**	**10**	**5**	**147**
Water Fair Records	73	14	18	27	10	5	**147**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**

Total 2005	**77**	**19**	**18**	**25**	**4**	**0**	**143**
Water Fair Records	76	17	18	24	4	0	**139**
Bernalillo County	1	2	0	1	0	0	**4**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2006	**45**	**10**	**6**	**2**	**1**	**0**	**64**
Water Fair Records	0	0	1	0	0	0	**1**
Bernalillo County	45	10	5	2	1		**63**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2007	**67**	**17**	**21**	**9**	**1**	**1**	**116**
Water	2	5	9	3	0	0	**19**

Fair Records							
Bernalillo County	65	12	12	6	1	1	**97**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2008	**82**	**20**	**24**	**9**	**3**	**2**	**140**
Water Fair Records	20	5	17	1	1	1	**45**
Bernalillo County	62	15	7	8	2	1	**95**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2009	**61**	**5**	**12**	**10**	**1**	**4**	**93**
Water Fair Records	8	3	3	5	0	4	**23**
Bernalillo	53	2	9	5	1	0	**70**

County							
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2010	**20**	**6**	**7**	**26**	**0**	**1**	**60**
Water Fair Records	3	4	1	24	0	1	**33**
Bernalillo County	17	2	6	2	0	0	**27**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2011	**4**	**14**	**18**	**26**	**4**	**0**	**66**
Water Fair Records	4	14	18	26	4	0	**66**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**

Total 2012	**1**	**1**	**5**	**7**	**1**	**0**	**15**
Water Fair Records	1	1	5	7	1	0	**15**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2013	**6**	**14**	**102**	**64**	**0**	**0**	**186**
Water Fair Records	6	14	102	64	0	0	**186**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
No Date	**18**	**2**	**1**	**3**	**2**	**0**	**26**
Water Fair	5	0	0	1	2	0	**8**

Records							
Bernalillo County	13	2	1	2	0	0	**18**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**

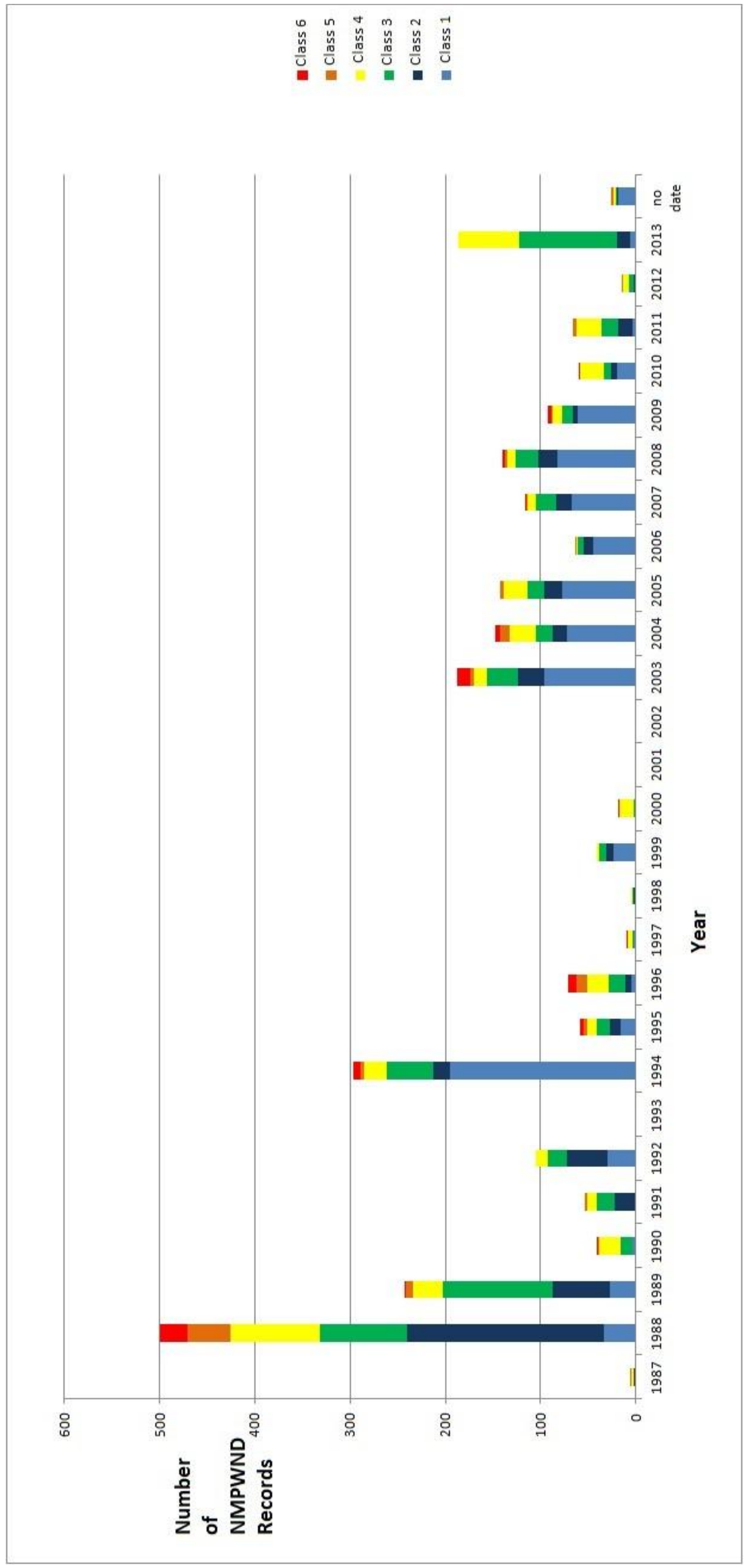


Figure 9: Albuquerque Basin Number of NMPWND Samples by Year and Class.

Appendix V: Española, Task 1

Table 14: Española Basin NMPWND Samples by Month, Class, and Source

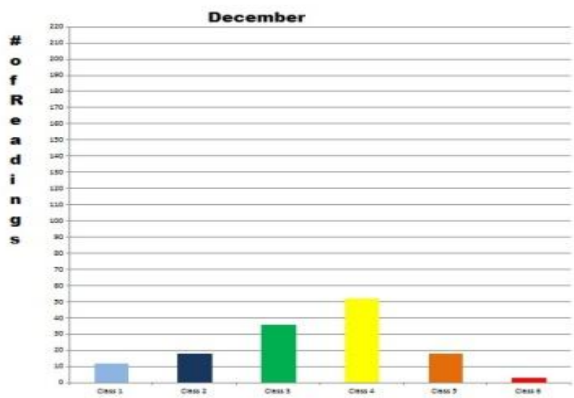
Month and Dataset	Number of Records Class 1	Number of Records Class 2	Number of Records Class 3	Number of Records Class 4	Number of Records Class 5	Number of Records Class 6	Total number of Records
January	**3**	**5**	**11**	**6**	**2**	**0**	**27**
NMED	3	5	11	6	2	0	**27**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
February	**7**	**46**	**62**	**60**	**37**	**5**	**217**
NMED	7	45	62	60	37	5	**216**
Bernalillo County	0	1	0	0	0	0	**1**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
March	**36**	**61**	**177**	**207**	**61**	**26**	**568**

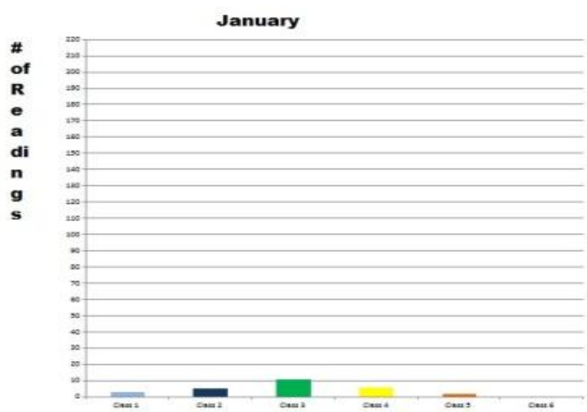
NMED	34	60	177	206	61	26	**564**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	2	1	0	1	0	0	**4**
April	**19**	**10**	**24**	**35**	**4**	**1**	**93**
NMED	13	7	23	35	4	1	**83**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	6	3	1	0	0	0	**10**
May	**22**	**15**	**35**	**34**	**26**	**2**	**134**
NMED	21	12	29	31	26	2	**121**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	1	3	6	3	0	0	**13**
June	**125**	**54**	**70**	**85**	**20**	**6**	**360**
NMED	123	53	69	81	19	6	**351**
Bernalillo County	0	0	0	0	0	0	**0**

USGS	0	0	0	0	0	0	**0**
NM TECH	2	1	1	4	1	0	**9**
July	**71**	**78**	**80**	**68**	**23**	**11**	**331**
NMED	71	78	78	68	23	10	**328**
Bernalillo County	0	0	0	0	0	1	**1**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	2	0	0	0	**2**
August	**3**	**10**	**18**	**10**	**5**	**3**	**49**
NMED	3	10	18	10	5	3	**49**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
September	**17**	**20**	**21**	**52**	**11**	**2**	**123**
NMED	17	19	18	46	9	2	**111**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	1	3	6	2	0	**12**
October	**36**	**34**	**80**	**68**	**19**	**12**	**249**

NMED	34	28	79	68	19	12	**240**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	2	6	1	0	0	0	**9**
November	**12**	**11**	**20**	**8**	**3**	**1**	**55**
NMED	11	11	20	8	3	1	**54**
Bernalillo County	1	0	0	0	0	0	**1**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
December	**12**	**18**	**36**	**52**	**18**	**3**	**139**
NMED	12	18	36	52	18	3	**139**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
No Date	**3**	**0**	**2**	**1**	**0**	**0**	**6**
NMED	3	0	2	1	0	0	**6**
Bernalillo County	0	0	0	0	0	0	**0**

USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**





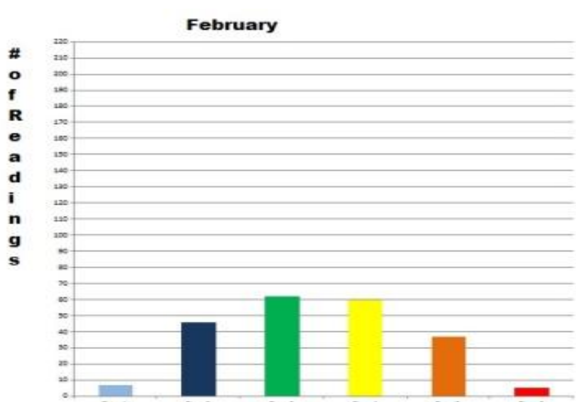


Figure 10:Española Basin Number of NMPWND Samples by Class for the WInter Months (December, January, and February)

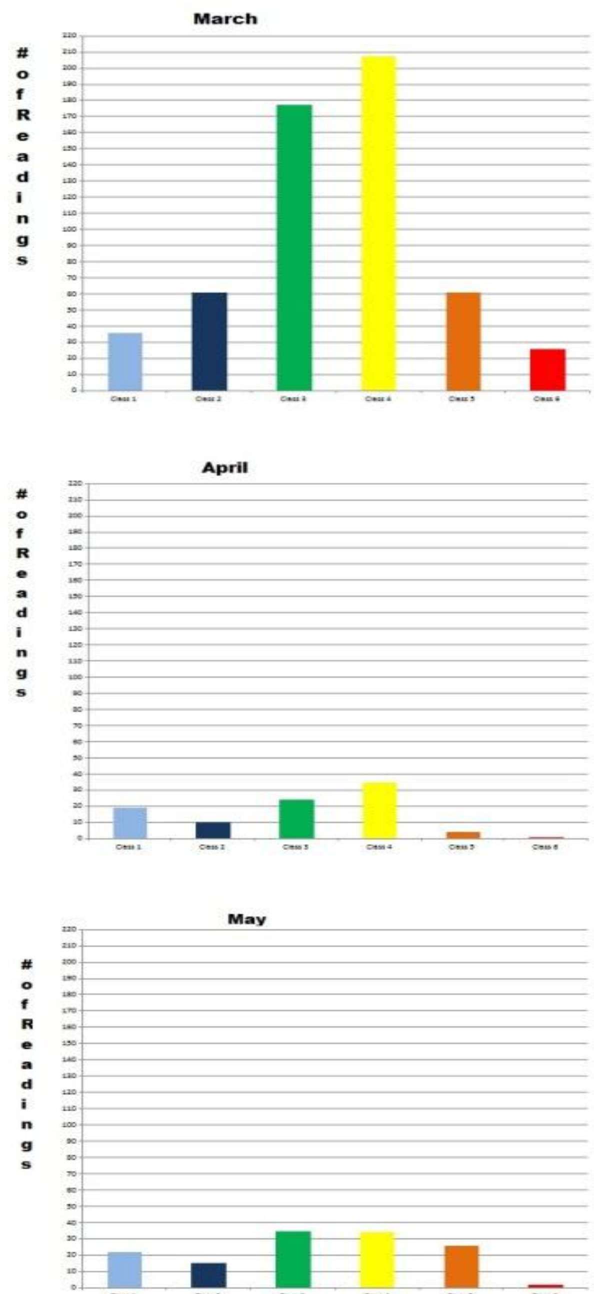


Figure 11:Española Basin Number of NMPWND Samples by Class for the Spring Months (March, April, and May)

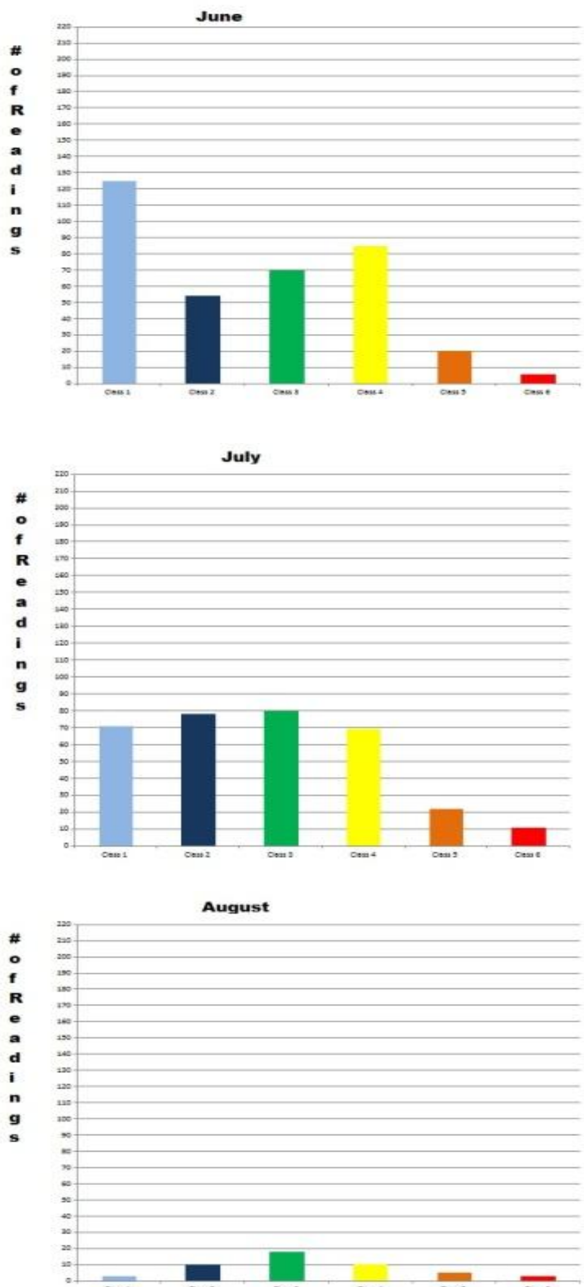


Figure 12: Española Basin Number of NMPWND Samples by Class for the Summer Months (June, July, and August)

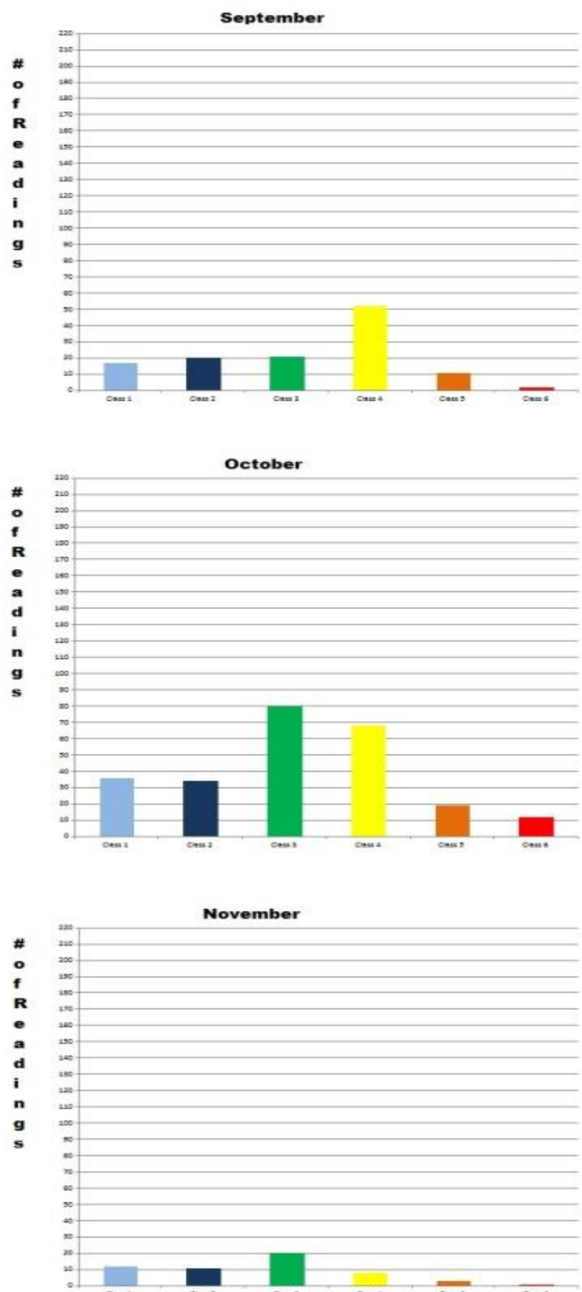


Figure 13: Española Basin Number of NMPWND Samples by Class for the Fall Months (September, October, and November)

Table 15: Española Basin NMPWND Samples by Class, Year, and Source.

Year	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Total # of Records
Total 1987	**28**	**62**	**99**	**111**	**26**	**10**	**336**
Water Fair Records	28	62	99	111	26	10	**336**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1988	**10**	**22**	**55**	**35**	**7**	**2**	**131**
Water Fair Records	10	22	55	35	7	2	**131**
Bernalillo County	0	0	0	0	0	0	**0**

USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1989	**9**	**35**	**77**	**74**	**57**	**1**	**253**
Water Fair Records	9	35	77	74	57	1	**253**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1990	**1**	**7**	**15**	**12**	**1**	**1**	**37**
Water Fair Records	1	7	15	12	1	1	**37**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total	**6**	**17**	**33**	**43**	**10**	**3**	**112**

1991							
Water Fair Records	6	17	33	43	10	3	**112**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1992	**10**	**17**	**31**	**61**	**35**	**15**	**169**
Water Fair Records	10	17	31	61	35	15	**169**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1993	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Water Fair	0	0	0	0	0	0	**0**

Records							
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1994	**1**	**5**	**9**	**14**	**1**	**0**	**30**
Water Fair Records	1	5	9	14	1	0	**30**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1995	**28**	**8**	**21**	**30**	**12**	**1**	**100**
Water Fair Records	28	8	21	30	12	1	**100**
Bernalillo County	0	0	0	0	0	0	**0**

USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1996	**2**	**5**	**12**	**11**	**2**	**0**	**32**
Water Fair Records	2	5	12	11	2	0	**32**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1997	**25**	**17**	**20**	**6**	**1**	**3**	**72**
Water Fair Records	25	17	20	6	1	3	**72**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total	**4**	**4**	**8**	**7**	**0**	**2**	**25**

1998							
Water Fair Records	4	4	8	7	0	2	**25**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 1999	**17**	**7**	**12**	**4**	**5**	**2**	**47**
Water Fair Records	17	7	12	4	5	2	**47**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2000	**4**	**11**	**21**	**47**	**18**	**8**	**109**
Water Fair	4	11	21	47	18	8	**109**

Records							
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2001	**0**	**1**	**1**	**0**	**1**	**0**	**3**
Water Fair Records	0	1	1	0	1	0	**3**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2002	**1**	**1**	**0**	**2**	**0**	**0**	**4**
Water Fair Records	1	1	0	2	0	0	**4**
Bernalillo County	0	0	0	0	0	0	**0**

USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2003	**2**	**1**	**1**	**9**	**1**	**0**	**14**
Water Fair Records	2	1	1	9	1	0	**14**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2004	**108**	**40**	**42**	**65**	**8**	**2**	**265**
Water Fair Records	108	39	39	59	6	2	**153**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	1	3	6	2	0	**12**
Total	**15**	**11**	**12**	**7**	**0**	**0**	**45**

2005							
Water Fair Records	6	3	4	2	0	0	**15**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	9	8	8	5	0	0	**30**
Total 2006	**0**	**2**	**13**	**15**	**2**	**4**	**36**
Water Fair Records	0	2	13	15	2	4	**36**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2007	**4**	**4**	**5**	**3**	**1**	**2**	**19**
Water Fair	4	4	5	3	1	1	**18**

Records							
Bernalillo County	0	0	0	0	0	1	**1**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2008	**5**	**9**	**40**	**39**	**10**	**8**	**111**
Water Fair Records	4	9	40	39	10	8	**110**
Bernalillo County	1	0	0	0	0	0	**1**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2009	**61**	**43**	**68**	**62**	**14**	**4**	**252**
Water Fair Records	61	42	68	62	14	4	**251**
Bernalillo County	0	1	0	0	0	0	**1**

USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2010	**12**	**16**	**23**	**9**	**5**	**1**	**66**
Water Fair Records	12	16	23	9	5	1	**66**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2011	**4**	**6**	**6**	**3**	**1**	**0**	**20**
Water Fair Records	0	0	3	1	0	0	**4**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	4	6	3	2	1	0	**16**
Total	**4**	**6**	**3**	**6**	**0**	**1**	**20**

2012							
Water Fair Records	4	6	3	6	0	1	**20**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
Total 2013	**2**	**5**	**7**	**11**	**10**	**2**	**37**
Water Fair Records	2	5	7	11	10	2	**37**
Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**
No Date	**3**	**0**	**2**	**1**	**0**	**0**	**6**
Water Fair Records	3	0	2	1	0	0	**6**

Bernalillo County	0	0	0	0	0	0	**0**
USGS	0	0	0	0	0	0	**0**
NM TECH	0	0	0	0	0	0	**0**

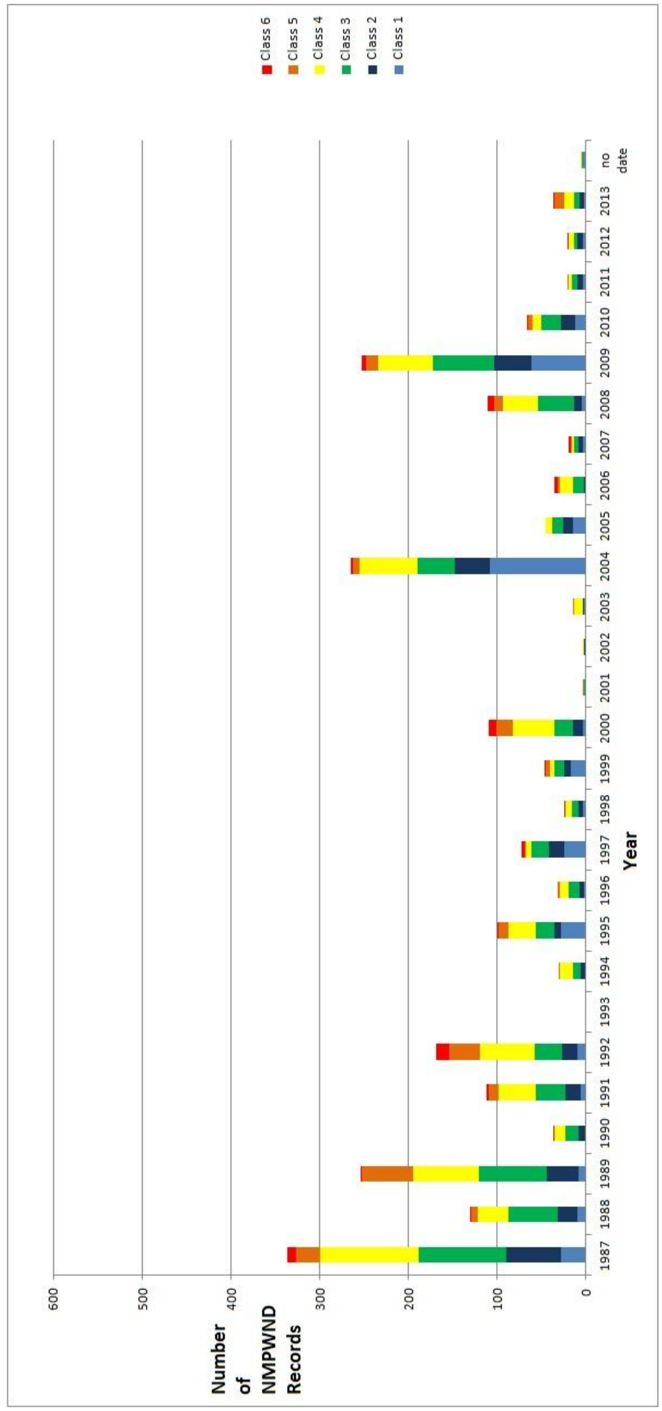
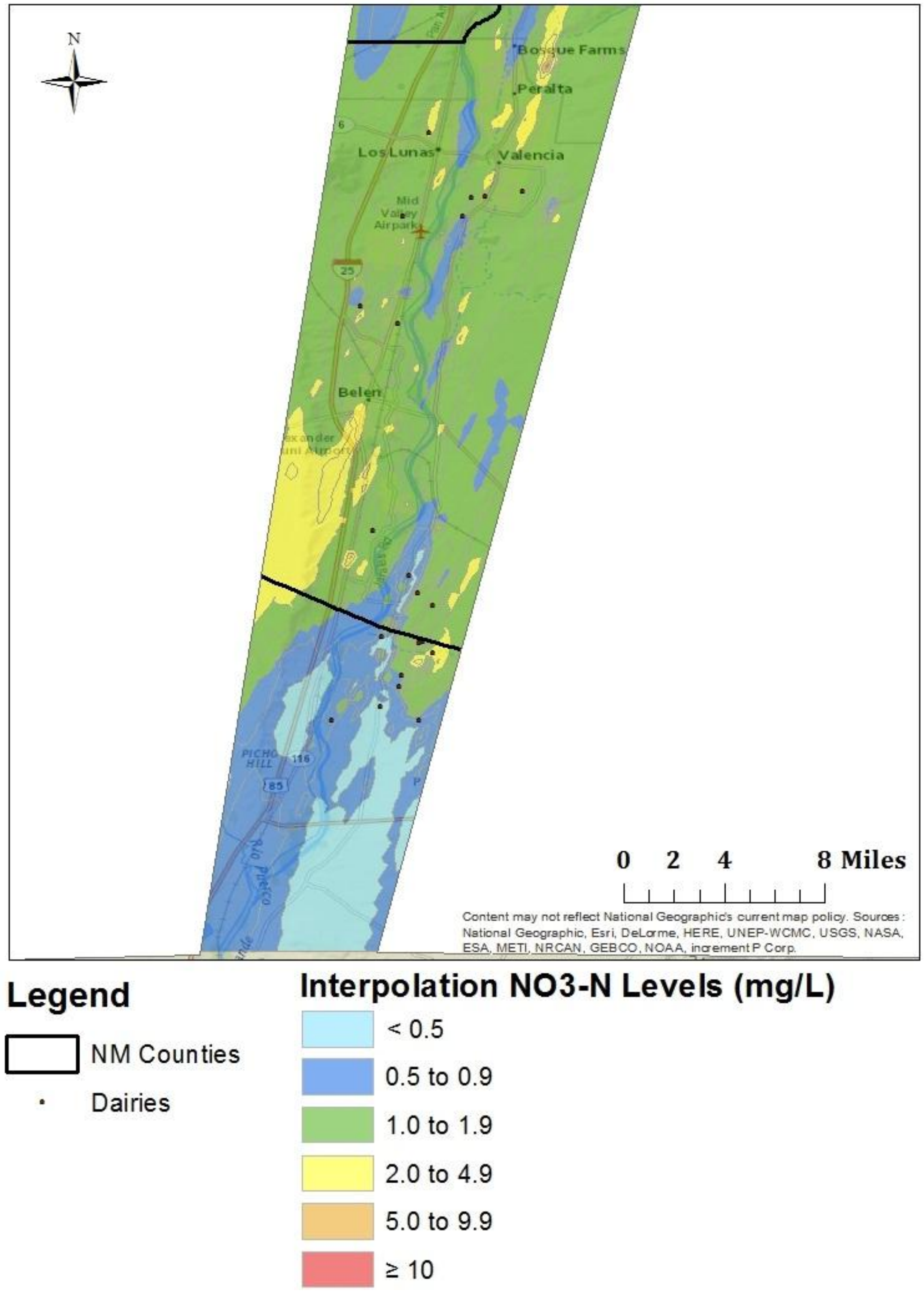
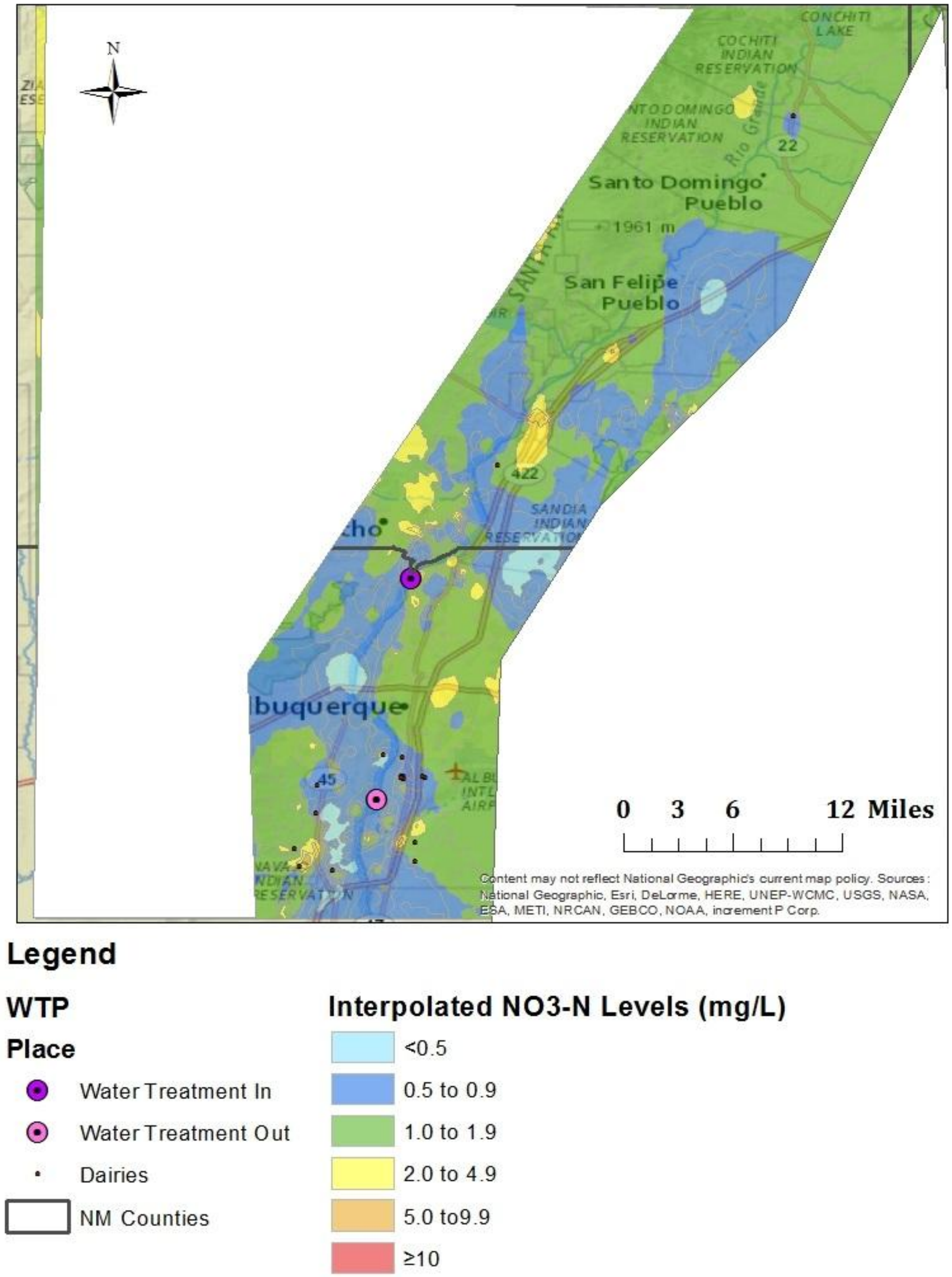


Figure 14: Española Basin Number of NMPWND Samples by Year and Class.

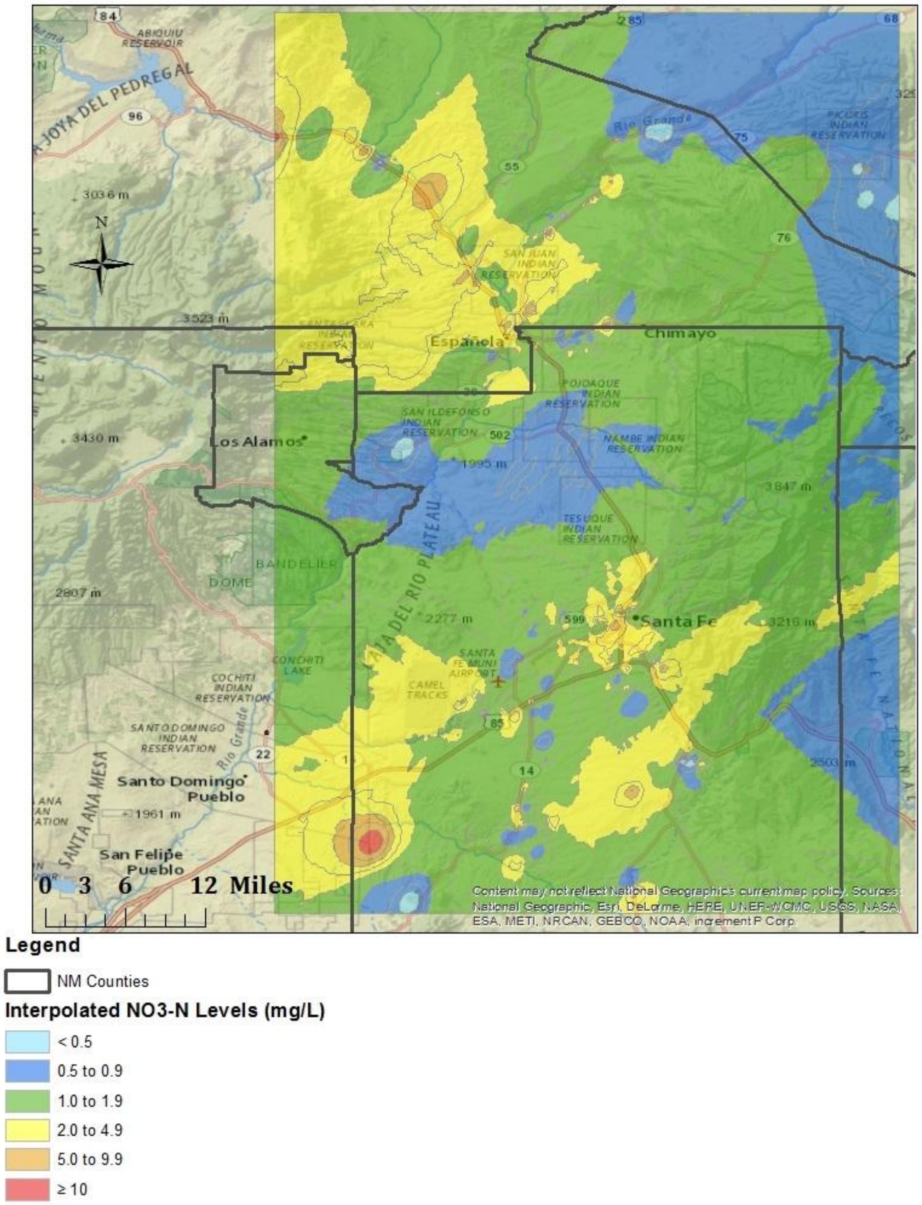
Appendix VI: Task 3



Map 18: Interpolation of South Half of Albuquerque Basin Using Minimum Calculated Values (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).



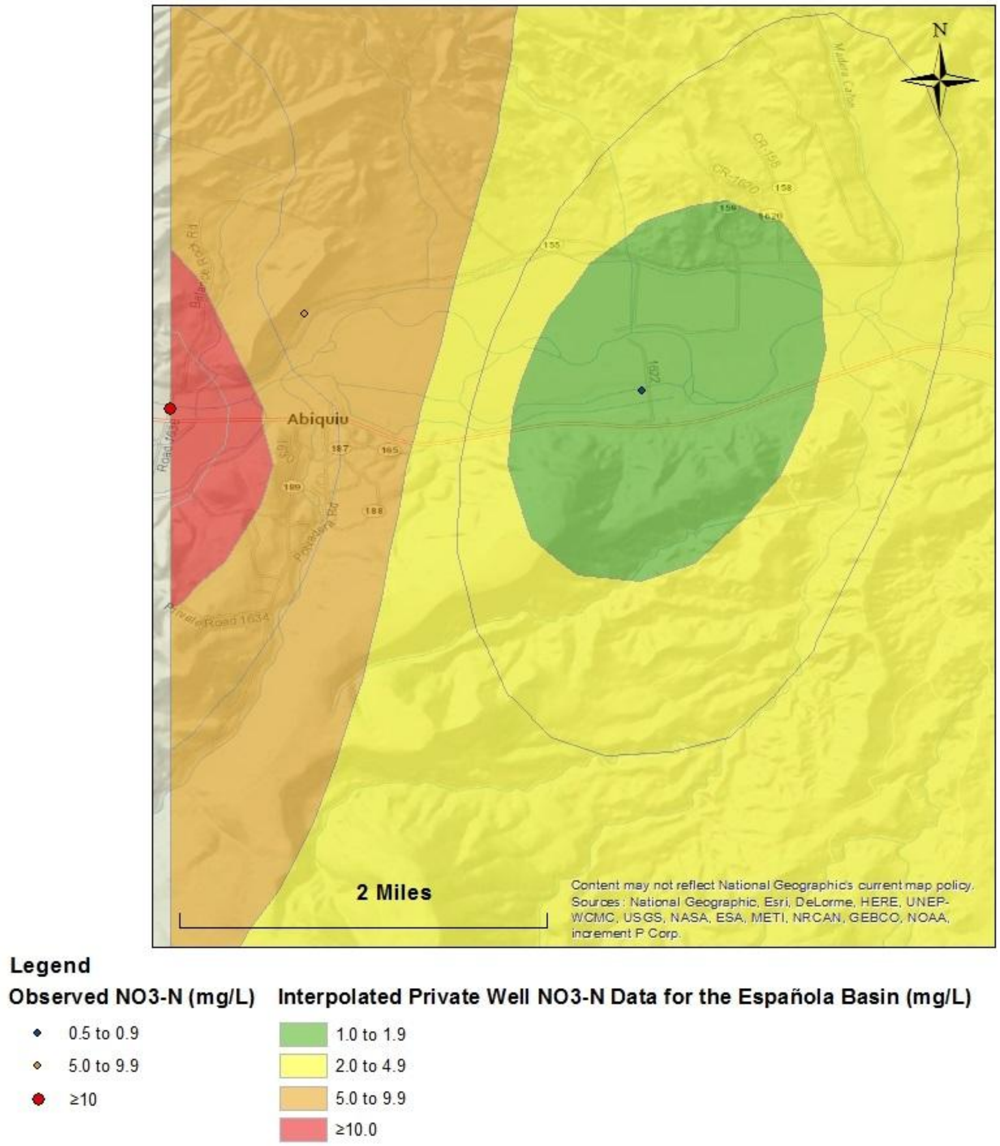
Map 19: Interpolation of North Half of Albuquerque Basin Using Minimum Calculated Values (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).



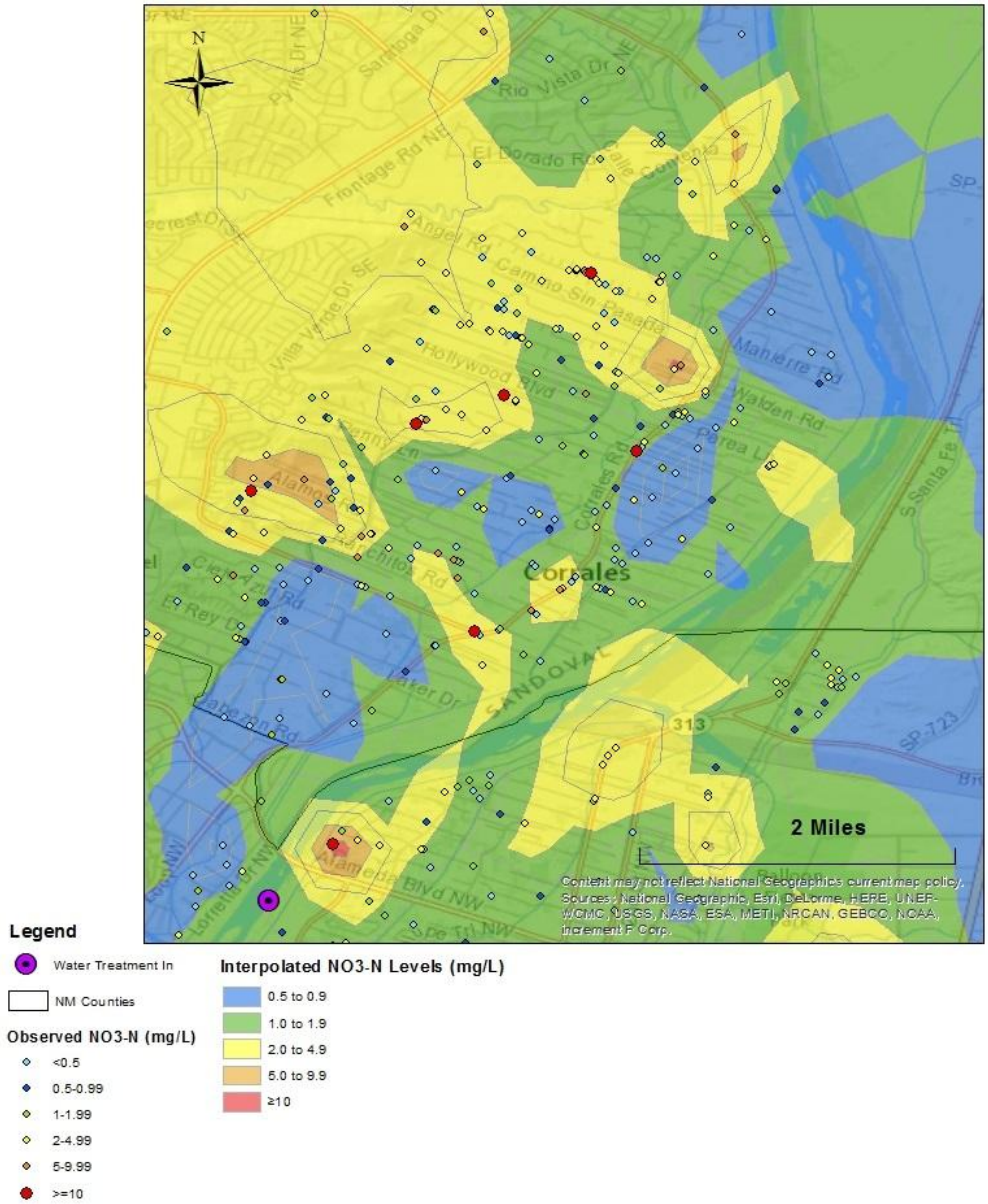
Map 20: Interpolation of Española Basin Using Minimum Calculated Values (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Assessing IDW Interpolation against the NMPWND samples

The interpolation of the three sections turned out to be more accurate in some areas than in others. The areas with the more samples taken give a more accurate interpolation result than the areas where fewer readings exist. The accuracy here refers to both the interpolation assigned value compared to the values of the points overlapping the interpolation and to the idea that an areas nitrate-nitrogen level cannot be determined based on only one (or a few sparse) reading(s). In other words, the interpolated results of areas not well sampled should not be used to predict the nitrate-nitrogen level of nearby groundwater. The following maps give examples of areas were the interpolation should not be relied upon, and where it should be more accurate.

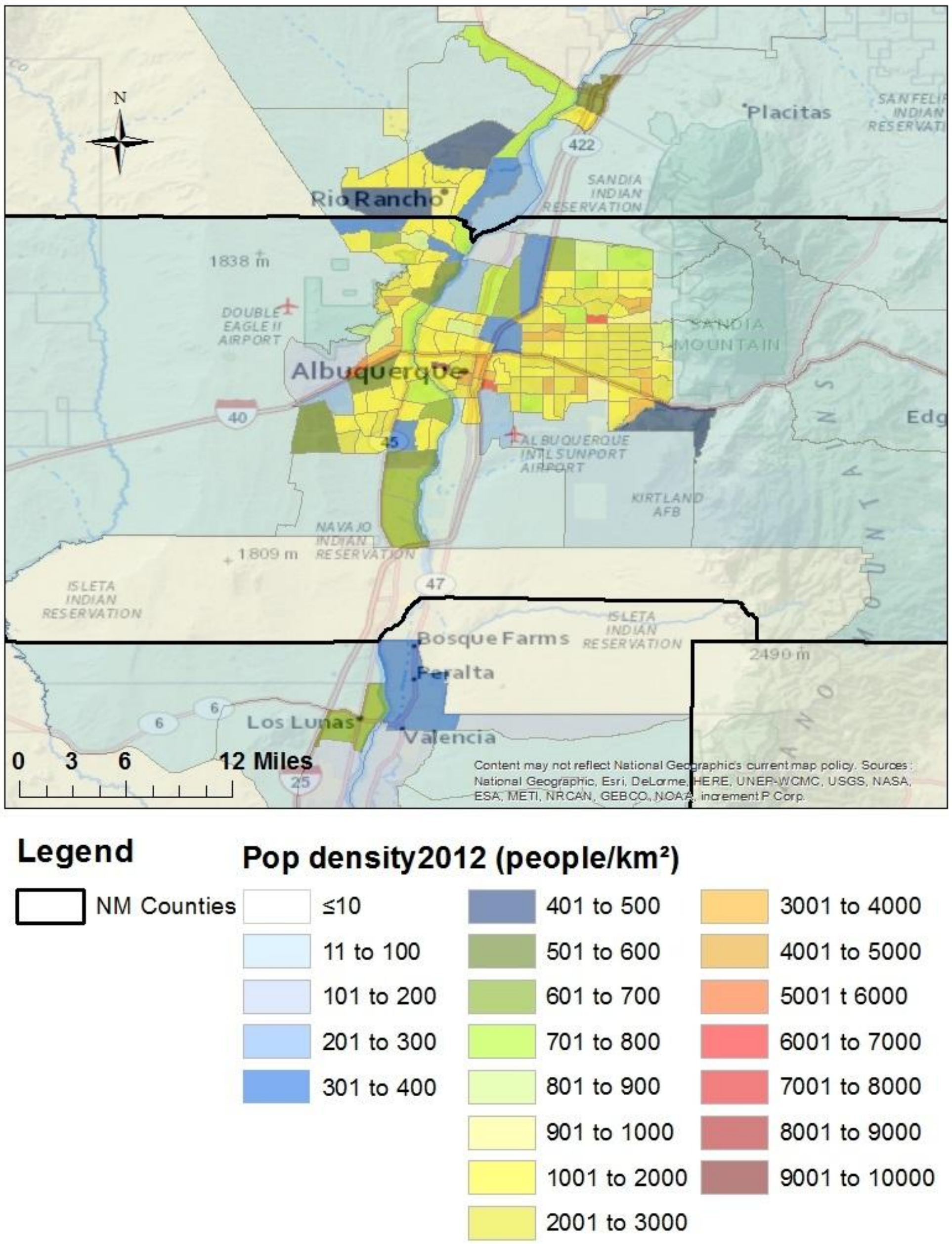


Map 21:Comparison of Interpolation to NMPWND Readings (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

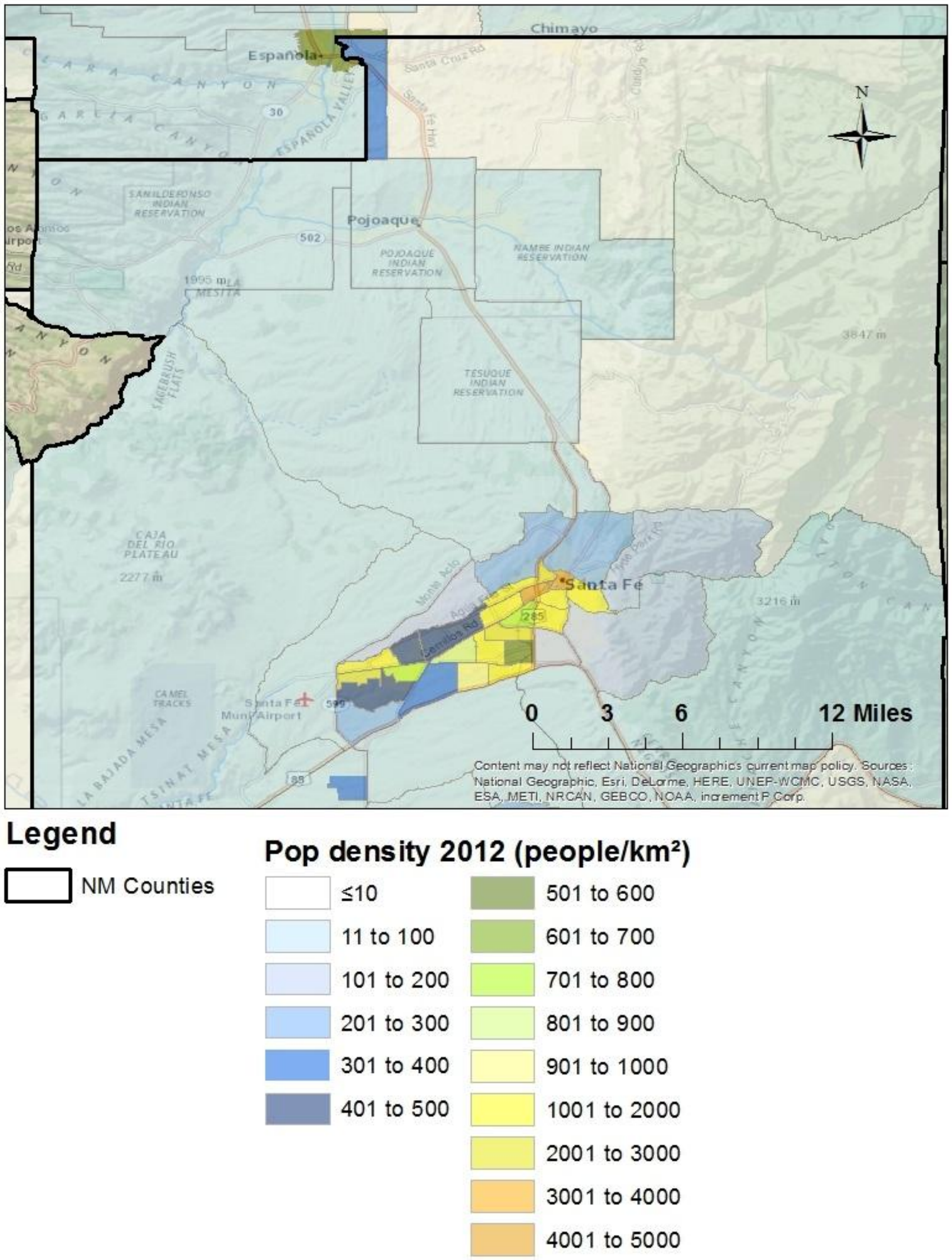


Map 22: Comparison of Interpolation to NMPWND Readings, 2nd Map (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).

Appendix VII: Task 4



Map 23: Central New Mexico with 2010 Census Tracts Showing 2012 Population Density Projections (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).



Map 24: Santa Fe and Española with 2010 Census Tracts Showing 2012 Population Density Projection (Data Source: GCS North American 1983 (Greenwich Prime Meridian); Unit: degrees).