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Groundwater contamination potential in northern Nevada from mining, associated communities, and agriculture as forecasted by two vulnerability methods

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GROUNDWATER CONTAMINATION POTENTIAL IN NORTHERN NEVADA FROM MINING, ASSOCIATED COMMUNITIES, AND AGRICULTURE AS FORECASTED BY TWO VULNERABILITY METHODS

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ABSTRACT

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by

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Two methodologies, DRASTIC and the NDEP method, were used to compare the groundwater vulnerability of mining, associated towns, and agricultural areas in northern Nevada. The DRASTIC and NDEP methods were compared to determine which method produces a more accurate depiction of vulnerability. Vulnerability maps were created using the United States Environmental Protection Agency's (USEPA) DRASTIC and Nevada Department of Environmental Protection (NDEP) methodologies. The DRASTIC map uses seven aspect layers of geologic and hydrologic information with assigned values and weights that are applied to a mathematical equation. The NDEP method uses field data collection for potential contaminant sources and well construction, well geological and hydrological information, and water quality data to create a vulnerability map. The map was created by applying values and weights to each aspect influencing the vulnerability and applied to a mathematical equation.

To compare the two methods, a correlation was performed using historic water quality data for naturally occurring and anthropogenic contaminants. The DRASTIC and

the NDEP method indicated that the vulnerability to groundwater contamination of mining areas and towns are similar with mining in regions of low to moderate and towns in regions of moderate to high. Agricultural regions were ranked differently by each method. DRASTIC indicated that agricultural areas were in regions of high vulnerability whereas the NDEP method indicated that it was in regions of very low to low vulnerability.

It can be concluded from the results that the NDEP method can forecast expected contamination with naturally occurring contaminants (e.g. arsenic, fluoride and radionuclides) better than DRASTIC. Both methods could not forecast very well expected contamination with anthropogenic nitrate. The NDEP method uses historic water quality data as a parameter which may account for the better forecasting ability. It appears that the NDEP method is sensitive to the number of contaminant sources present around a well. The NDEP method requires extensive field survey data whereas the DRASTIC method uses data that is widely available. Therefore, the cost to implement the NDEP method is much higher and time consuming compared to the DRASTIC method.

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CHAPTER 1

INTRODUCTION

The generation of large amounts of industrial waste is commonly associated with gold and silver mining, which can be potentially damaging to the environment, specifically to groundwater supplies. These mines require scrupulous operational methods to produce their prospective commodity and reduce the potential of contamination. Mining operations include a large labor force, industrial vehicles, excavation equipment, ore processing mills, and mineral extraction and refining facilities that can result in the generation of pollution. Whether it is oil from haul truck maintenance, or percolating hydrocarbons from a corroded fuel storage tank, these operational resources present a certain level of contamination risk to the groundwater in the area (Prasad, et al., 1991). The mining industry's groundwater contamination footprint can extend outside of the mine boundaries depending on the mine’s required labor force. Because most mining is carried out outside urban areas, as a mine expands its demand for labor, communities develop around the mining areas or nearby communities experience an increase in population. The increase in population requires some basic infrastructure, such as gas stations, car washes, septic tanks, dry cleaning, etc. which also can potentially impact the quality of the groundwater supply system they depend on (Toll, 2004).

Advancements in mining technologies have expanded the potential of ore mining enabling modern day mines to flourish in regions that were historically deemed uneconomical production zones (Prasad, et al., 1991; Haris & Krol, 1989; Toll, 2004). With increased mining activities the demand for mining personnel is amplified, which adds to the growth of nearby communities, altering the town's economic force (Craig & Rimstidt, 1998).

Historically, several towns have been ranching communities where mines are currently being established. This results in a shift of the economic structure for these towns. This shift often brings increased growth, and generally no change or a decrease in agriculture. However, agricultural practices of the past should be taken into consideration when evaluating contamination in mining areas. It can take many years for pesticides to leach into the groundwater after farming has been abandoned in the area (Hallberg, 1987; Nolan & Hitt, 2006).

Both mining activities and the community growth associated with it have the potential to negatively impact groundwater resources in the areas where mining is established. Gold and silver mining generates waste that can include cyanide from ore leaching, acid from ore oxidation, and volatile organic compounds from machinery fueling and maintenance (Prasad, et al., 1991). Communities associated with mining need infrastructure such as septic tanks, gas stations, dry cleaning/laundromat, car washes, hospitals, etc., which also present contamination risks to groundwater resources. With these activities associated with towns there tends to be minimal public scrutiny. Historically, potential groundwater contamination by mining activities has received much scrutiny than contamination caused by the infrastructure of mining towns. In this

research, the potential risk for groundwater contamination by gold and silver mining activities will be contrasted with that of their associated mining town's infrastructure and agricultural activities.

Nevada's gold and silver mining industry has been a significant and vital component for the state's economic, social, and political landscape since the Comstock Lode discovery of 1859 (Smith, 1943; Thorstad, 1989). Nevada produced 5.03 million ounces of gold in 2009 which represents about 66 percent of the U.S. gold production (Gold Sheet, 2010; Associated Press, 2010). This equates to roughly 5.6 percent of the overall world production (Gold Sheet, 2010). Such massive natural resource exploration efforts inevitably leave their most visible effects on mineral rich mountain passes; however, it's the less obvious impacts to the environment, such as groundwater contamination, that could ultimately prove to be the most detrimental to the development of future economic activities in the area, including mining itself.

Nevada mining has inadvertently altered historic land use in regions such as agriculture and urban development. From this large industry, towns have grown to support the labor force needed in the operation of modern mining. As these towns grow and expand, they may encroach on historic agricultural areas. This promotes a reassignment of potential groundwater contamination sources from applications of fertilizer to supporting gas stations, car washes, and dry cleaning. The existence of a dynamic environment hosting the three land activities of mining, agriculture, and towns provides further evidence to the need to compare groundwater contamination potential from these activities with an unbiased view.

It is important to recognize and understand the potential of groundwater contamination without a biased opinion so that regulations and management strategies can be developed to manage the allocation of future land use and to prevent groundwater pollution in such areas. In areas where water is a scarce resource, such as in Nevada and other arid regions, it is even more important to understand the associated risks to groundwater contamination. Activities from mining, mining towns, and agriculture may negatively impact the same aquifer and have the potential to harm multiple communities or regions. Therefore there is a need to explore the impacts to groundwater that are associated with mining activities and mining towns. This evaluation will determine the potential risk of these activities that impact groundwater quality; such determination is essential for understanding the broader implications of these related activities.

Because of concerns that these activities represent an environmental pollution risk to groundwater sources two research questions are being asked. The first question; does gold and silver mining create a greater potential of contamination compared to the contamination risk potential from associated mining communities? The second question; by comparing two index vulnerability methods, which method has a better ability to forecast groundwater vulnerability.

RESEARCH OBJECTIVES AND HYPOTHESIS

In this research, two methodologies to characterize groundwater contamination vulnerability, DRASTIC (Aller, et al., 1987) and the NDEP index method (NDEP, 2006), will be compared. In addition, the three predominant land use activities will be compared

to see which has the highest potential to contaminant groundwater. DRASTIC was developed by the United States Environmental Protection Agency (USEPA) and involves collecting easily obtainable data from various open source data warehouses. The Nevada Department of Environmental Protection (NDEP) method involves field surveying existing well/springs as well as associated potential contaminant sources to determine groundwater contamination vulnerability. Because DRASTIC uses available electronic data and does not require field surveying, it is considerably less costly and can be performed faster. Therefore, it is beneficial to investigate whether the vulnerability to groundwater contamination obtained by DRASTIC and NDEP methods are comparable. The vulnerability of groundwater resources will be characterized for mining, mining towns, and agricultural activities. With the three land uses, a comparison can be made to evaluate the activity that presents the highest vulnerability for groundwater contamination.

The region of northeastern Nevada contains a reasonable amount of the three land uses sharing similar features that influence groundwater vulnerability. These features include climate, hydrogeology, geology, and land use activity, such as potential contaminant sources and population influxes. In addition, well construction can play a role in potential contaminant transport to groundwater deserving consideration in the vulnerability assessment. Table 1 depicts several factors that may influence groundwater vulnerability to contamination.

Table 1 – NDEP Vulnerability Factors

Well Water Quality	*Hydrogeological Factors*	*Well/Spring Construction*
VOC Detection	Contaminant Source Direction	Adequate Construction
SOC Detection	Time of Travel	Seal Depth
Dioxin Detection	Aquifer Type	Casing Terminate
IOC Detection	Static Water Depth	Screen Depth
Asbestos Detection	Confining Layer	Construction Defects
Total Coliform Detection	Contaminant Mobility	Overburden Depth
E Coli Detection	Contaminant Persistence	
Radionuclide Detection	Contaminations Occurrence	
Nitrate Detection	Method to Control Contamination	

Historically, mining activities have been considered to have a significant impact on groundwater resources. Contaminant sources present in mining towns and agricultural areas may be as potentially detrimental to groundwater as mining is itself, but these activities are often perceived as less harmful. This study may reveal that groundwater in mining towns and agricultural areas have similar or greater vulnerability to contamination than groundwater located in mining areas. It is expected that both methodologies will produce similar results because hydrogeological features, which are inherent to the specific areas, play a major role in the vulnerability determination with both methods. It is also expected that groundwater located in towns are as vulnerable to contamination as groundwater located in areas where mining operations are located.

CHAPTER 2

BACKGROUND

2.1Geology

The geology of Nevada consists of mountain ranges and valleys with the ranges oriented in a north-south direction averaging sixty to eighty miles long and about ten miles wide. These ranges tend to be bounded by faults, typically normal faults on one or both sides. Nevada is also the third most seismically active state with California as first and Alaska as second (Price, 2003). This activity provides much of the geothermal activity which relates to the mineralization of metals.

Gold producing areas in the northeastern region of Nevada, particularly the Carlin Trend, have deposits of gold-silver mix produced by mineralization from geothermic activity. The gold is deposited into the regional sedimentary soil strata from rich carbon dioxide (CO_2) and Hydrogen sulfide (H_2S) water that has been heated by the geothermic activity and the resultant pressures (Zimmerman, 1991). With the up heaving from seismic activity, the deposited gold mineralization begins creating the gold deposits in this region. These deposits are typically siliceous on the western portion of the Carlin Trend and carbonate on the eastern portion. These soil strata types allow for the

necessary geochemical processes to allow the mineralization of the gold (Jones, 1989; Johnston, et al., 2008).

The hydrogeology of Nevada is comprised of approximately fifty-one percent consolidated rock and forty-nine percent of unconsolidated sediments. Nevada is typically classified as low to moderate rate of precipitation with low soil permeability. The Northeastern region of Nevada tends to have above average precipitation and moderate soil permeability (Maurer, et al., 2004). As described above, much of Nevada's groundwater is isolated from one region to the other based on these physical barriers.

The two primary types of mineral bearing ore found in northeastern Nevada are carbonate and siliceous. The carbonate ores tend to be located on the eastern face of thrust faults and the siliceous tend to be found on the western side. These mineral formations of the eastern regions are usually assemblage of carbonate, quartzite, and shale where as the western regions assemblage is of chert, perlite, sandstone, greenstone, and minor carbonate (Jones, 1989).

2.2 Gold/Silver Mining Operations

Hard rock mining, typical for precious metal mining, uses two main methods, open pit and underground bore mining. Each has its own techniques and processes to extract the gold bearing ore. Open pit mining is essentially surface mining to create a hole or pit as the mining processes continue. This technique requires the removal of some amount of soil layer that is covering the mineral rich strata. This barren soil is referred as over-burden which is removed and stock piled. Open pit mining is performed by creating ledges as the mine gains in depth for safety from falling rocks and ease of

access for mining equipment (Cobb, et al., 1988). Underground mining is a technique where a shaft or bore is placed such that it will gain access to a vein of the sought after minerals. The shaft follows the veins which can create a network of passages and levels to the mine. Careful consideration must be taken to ensure efficient removal of the ore and ensuring the integrity of the mine shaft (Cummins, et al., 1992).

Ore processing is mechanically altering the ore to a reasonable size for extracting the minerals, i.e. gold/silver. These processes can include blasting the rock from the ground, crushing, and milling the ore. Blasting techniques including charge power and placement play an important role in minimizing other processes and increasing production. By using modern techniques and geologic inspection of the strata for charge placement, the ore can be fractured to a desired size (Eloranta, 2001).

Ore processing require crushing the ore to be within certain sizes that will maximize the extraction process. For heap leaching, the ore should be within the classification of cobles and gravel to ensure an even flow over the ore and minimizing channelization (Cobb, et al., 1988). The common equipment is a cone crusher, jaw crusher, and possibly the ball mill. Each process is chosen by the individual mine based on cost and ore type (Cummins, et al., 1992). Each technique uses a different mechanism for crushing. Raw ore from the mine of non-uniform size is broken via mechanical methods to a uniform size.

Milling the ore is the next phase of ore processing. The ore is received from the crusher, usually a higher grade ore, and ground to a size classified as sand or smaller. This smaller size enables a quicker contact during leaching with the gold for a higher

extraction yield. Several methods can be used in this step that may include a ball mill or other proprietary milling machines. The technique for milling is chosen by the individual mine which is based on types of ore and cost of operation and maintenance of the equipment (Cummins, et al., 1992). Milling is simply reducing the ore from the crushing stage to a smaller size for vat leaching.

Refractory ores are ores that need additional treatment prior to the leaching process and tend to be a low grade ore. Depending on the type of ore different processes are used for treatment. Typically in the northeastern part of Nevada the ore may have sulfides present in the ore preventing the leaching action to occur (Jones, 1989). The common practices are roasting the ore, applying chemicals, or using target specific bacteria to oxidize the ore (Prasad, et, al., 1991). By oxidizing the ore, the leaching process is able to extract a significant amount more of the precious metal. Provided that precious metal prices are high, this process can increase the production output of the mine yielding a greater profit (EPA, 1994; Haris & Krol, 1989).

Biological ore oxidation utilizes bacteria that are compatible with the ore body, such as a carbonaceous or siliceous. With the biological process, the oxidation occurs under the ideal conditions for the bacteria to thrive keeping a uniform temperature and pH. Maintaining these conditions will ensure the bacteria will grow and reproduce to maintain ore oxidation. The end process will result in an ore that can be introduced to the cyanidation process without the competing compounds in the ore. The waste of the biological sludge may be placed in along with the tailings (Prasad, et al., 1991).

The chemical processes of oxidation are typically acid leaching or pressure leaching using either an alkaline or acid media also referred to as autoclaving. Chemical oxidation is predominately used for carbonaceous ores using chlorine (Haris & Krol, 1989; Prasad, et al., 1991). Initially, chlorine is added to the solution to oxidize the ore. Additional chlorine is added in a second step to form hydrochloric acid. This acid helps to remove the sulfide pyrite from the ore so that the gold is readily exposed for the cyanidation process (Prasad, et al., 1991). The alkaline process uses oxygen to oxidize the sulfides utilizing a higher pH to optimize the oxidation of the ore. This process is not used often because of concerns with toxic gases such as sulfur dioxide (Alp, et al., 2010).

A common ore processing technique used to extract gold/silver from ores is dissolution with cyanide solutions (cyanidation). Cyanidation can be performed using heap leaching or vat leaching (Prasad, et al., 1991). In heap leaching, cyanide is applied to piles of crushed ore built outdoors. In vat leaching, a cyanide solution is applied to finely crushed ore placed in tanks (i.e. vats) housed typically in a building. Depending on the ore body, the ore may have to be oxidized before cyanidation can be applied.

2.3 Gold/Silver Extraction Processes

Common extraction process for high grade gold/silver ores is Vat leaching. With vat leaching the process is normally located inside a building with several vats (e.g. tanks) loaded in series to maximize the rate of leaching. This process has a high capital cost in relation to heap leaching so only high grade ore is processed using this method (Cope, 1999). Vat leaching consists of essentially grinding the ore to a size equivalent to that of sand or smaller and adding it to a cyanide solution. This will result in a pulp that is constantly agitated to maximize the contact of the ore and the solution to optimize the

gold extraction (Prasad, et al., 1991). A continuous supply of the cyanide solution is fed into the vat as the solution loaded with the gold, referred to as pregnant solution, is siphoned off from the pulp. The solution is typically sent through activated carbon for gold adsorption and recovery, but other processes can be applied.

Heap leaching is a simple technique that has been in use for many years used to extract gold/silver from low grade ore. This system of gold extraction is implemented by simply placing milled or crushed ore on a liner with a spray system to irrigate the leaching solution, typically a cyanide solution, over the ore. The solution with the gold, the pregnant solution, is captured at one end of the liner and sent to a gold recovery process (EPA, 1994; Cobb, Dorey, et al., 1988). This is a low cost gold extraction method and used throughout Nevada for low grade ores (Haris & Krol, 1989).

Cyanidation is the primary mechanism for leaching gold from the ore in Nevada (EPA, 1994). Typically sodium-cyanide is mixed in solution and applied to the ore via several different processes. Due to the chemicals used in the leaching process and the potential for heap liner failure and spills from vat reactors, there are concerns from groundwater contamination associated with these types of operations. In general, cyanidation of gold can be expressed as

$$4Au + 8NaCN + O_2 + 2H_2O = 4NaAu(CN)_2 + 4NaOH$$

With primary reactions of

$$2Au + 4CN^- + O2 + 2H_2O = 2Au(CN)^-_2 + H_2O_2 + 2OH^-$$

As well as

$$4Au + 8CN^- + O_2 + H_2O = 4Au(CN)^-_2 + 4OH^-$$

These reactions are the typical reactions for leaching with cyanide that is commonly used in most Nevada mines. (Prasad, et al., 1991; Cobb, et al., 1988).

The pregnant solution requires additional techniques to extract the gold out of solution. The next treatment process is referred to as loading. Loading uses activated carbon to absorb the gold cyanide. This is possible because of the size of the compound, the size of the pores in the activated carbon and the high surface area of activated carbon, typically 1,050 to 1,150 square meters per gram of activated carbon (Cobb, et al., 1988). The cyanide solution, after gold cyanide has been removed is commonly referred to as barren solution and is often reprocessed to be reused in the leaching operation.

After adsorption, the gold is eluted from the activated carbon using a concentrated cyanide solution. This stripping process results in a concentrated solution of gold cyanide and carbon that can be reactivated or discarded. The concentrated solution from the carbon stripping is sent on to the last process step of gold extraction (Cobb, et al., 1988).

The last step of extracting gold is called recovery. This is where the gold is recovered from the elution solution. Two primary methods are used for gold/silver recovery, the zinc-dust or Merill-Crowe method and electrowinning. The Merrill-Crowe method uses a chemical reaction to precipitate the gold from solution. Once the particles are formed the solution is filtered. The layer of precipitate is removed from the filter and sent to be smelted. The Merrill-Crowe method can be expressed as shown in the reaction below (Cobb, et al., 1988). This reaction shown below is simplified and should be noted that impurities are collected with the gold.

$$2NaAu(CN)_2 + Zn = NaZn(CN)_4 + 2Au^0$$

Electro deposition or electrowinning process is a physical process utilizing electricity to separate the gold from the concentrated solution. An anode and cathode are placed in the solution with an applied direct current (Cobb, et al., 1988). The gold will then begin collecting on the cathode. Once the collection process is complete the cathode is striped of the gold and sent to be smelted into dorẻ bars (Cummins, et al., 1992). The simplified reaction for electrowinning is demonstrated in the following reactions. As with the Merill-Crowe method the barren solution is reprocessed.

$$4OH^- = O_2 + 2H_2O + 4e^-$$

$$2e^- + 2Au(CN)^-_2 = 2Au^0 + 4CN^-$$

Smelting is the final step of the process of extracting gold. The collected gold from either the Merill-Crowe method or electrowinning is placed into a furnace with flux and heated to a melting temperature of about 2,100 °F (Cobb, et al., 1988). Once melted slag forms at the top of the vessel, which is poured off or scraped off, the metal is poured into forms. This molded metal is referred to a dorẻ. The dorẻ bar, or other shape, is sent to a refinery for further processing and separate any other metals such as silver or copper (Cummins, et al., 1992).

2.4 Ancillary Mining Facilities

Modern gold mining operations in Nevada have become large operations that require onsite facilities for various operations. These operations can include the ore crushing and milling facilities, ore processing facilities, gold/silver adsorption and stripping facilities, mechanical repair shops for heavy equipment, administration and

employee offices, as well as maintenance buildings. In addition to this, most of these facilities require some amount of infrastructure such as roads to the mine, power lines or on site power plant, and water and sewer facilities. The larger the operation, especially open pit mining, the larger ancillary facilities or area are required (Haris & Krol, 1989).

Most modern gold mines are processing ore with mineral content fractions of an ounce per ton of ore. Based on the volume needed to extract gold form a large amount of ore, large equipment is required to minimize cost and maximize production (Gosnell, 1975). Because of their large size, heavy mining equipment are often transported in parts and assembled onsite at the mine because of load weight and size limits. These massive machines also require regular maintenance and repair, requiring facilities for these procedures (Myntti, 1979).

Energy cost for mining operation is a significant part of the overhead cost (Gentry & O' Neil, 1984). Often mines are located in remote areas with no or little infrastructure. Many mines prefer to operate with offsite power rather than operate diesel powered shovels and generation plants. However, to offset this cost, mines will often elect to build the infrastructure to their properties that will help to minimize the overhead and to help ensure a reliable power source is maintained. Without this reliable source of power mines can face hour or even days of operation delays because of short spikes or surges in power that will shutdown equipment (Jurbin, 2009).

2.5 Mining Towns and Communities

Elko, Nevada, as well as a few other mining towns, has experienced significant growth since the operation for production from the Carlin Trend gold belt was discovered

along with new mining techniques to extract the gold. Elko's population was fairly consistent reaching about 8,000 in 1980. With the new mining activities Elko's population has more than doubled in the past 30 years to 17,430 by 2009 (U.S. Census, 2010). Similar trends have been realized in Battle Mountain and Eureka due to the increased mining operations. Prior to the opening of these mines, these towns were predominately cattle ranching towns with associated agriculture (Toll, 2004; Rota & Ekburg, 1988).

The approximate current employment for northeastern Nevada, including counties of Elko, Eureka, Lander, and White Pine, in mining is approximately 6,000 employees. The approximate population for the same area is 64,000 people. This relates to about one in ten people are employed in the mining industry (U.S. Census, 2010). If we compare this number with 1980 data we see that the population for this region is approximately 31,000 people. For the same period the population employed in mining was approximately 2,200 resulting in about one in fourteen (U.S. Census, 1980). This period is significant due to the permitting and beginning operations of several large mines in this region (Haris & Krol, 1989).

Prior to the opening of several mines in the northeastern Nevada in 1980, the population involved in agriculture was approximately 1,600 people; that is, one in nineteen people. Today the number of people employed in agriculture is approximately 400 resulting in about one in one hundred seven (U.S. Census, 1980; U.S. Census, 2010). This indicates that as mining has increased, employment in agriculture has decreased even with a significant increase in the regional population. With these data it can be

assumed that the population growth increasing the sizes of the communities is related to the development and growth of the mines.

2.6 Water Use and Consumption in Mining Areas and Communities

Water is a constant issue in mining operations. In some operations, dewatering of mining shafts is needed to continue mining. Mines rely on dewatering to allow for production in underground mining that is below the water table. Dewatering also allows for steeper slopes in open pit mining maximizing the ore extraction while minimizing the overburden. Furthermore, water is needed to process the ore, to control dust in the mining site and in all extraction processes. An important aspect of some gold mines that is the use of dewater water from underground mine shafts to providing water to the ancillary facilities. Water is important for the leaching process where a large volume of water is required to extract the gold from the ore. Water is also used for other minor services such as showers and sanitary systems.

Dewatering wells can pump out in excess of 58,000 gallons per minute (GPM) depending on the water strata and the size of the mine (Chadwick, 1995). From the dewater wells the majority of the water is used for mining processes which require some treatment. For example, heap leaching recommended spray volume is 0.005 GPM per square foot of the leach pad. Depending on the mines size and permits, this can be several thousand gallons per minute of water (sodium cyanide solution) being applied to the heap pad twenty four hours per day (Cobb, et al., 1988). However, in some cases, the heap leaching need is only about ten to twenty percent of the water from dewatering wells. Excess dewatering water in many mines is discharged either to a pond for

percolation or to a nearby water body or feature, as is the case for most mines in northeastern Nevada (Chadwick, 1995).

In areas where dewatering water is not present in sufficient amounts, groundwater wells are drilled to provide water for mining operations. This water is essential in the process of extracting gold from less than 10 ounces per ton of ore with an average of about 6 ounces per ton in the northeastern region of Nevada (Heitt, 2002; Barrick, 2008; Yukon-Nevada Gold Corp., 2011). With mining extracting 250,000 tons or more per day for the Carlin Trend, this amounts to a significant amount of water required for the mining processes (International Mining, 2011).

Water consumption for towns is more than that of mines, but can be a smaller amount of actual water pumped from the aquifer. For the northeastern portion of Nevada the water consumption per capita is about 228 gallons per day (Kenny, et al., 2005). For a comparison the water consumption for the United States is about 158 gallons per day (Kenny, et al., 2005; Rockaway, et al., 2011). To put this value into an annual volume, northeastern Nevada water consumption is equivalent to about 314,000 acre feet or 490 square miles one foot deep. Mining water actual consumption by comparison is about 10% of that used by towns for northeastern Nevada (Kenny, et al., 2005).

2.7 Sources to Groundwater Contamination

Groundwater contamination can occur from point sources or non-point sources. Point sources are defined by the US EPA in section 502(14) of the clean water act as "*The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete*

fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture (USEPA, 2011)*."* Examples of potential point source contaminants include underground storage tanks, septic tanks, animal feed lots, gas stations, dry cleaning operations, etc. Non-point sources are sources originating from large areas that include urban runoff and agricultural runoff from a farming community where fertilizers and pesticides have been used.

In this research, potential sources of contamination (PCS), are any source that has the likelihood of discharging a contaminant to the environment. These sources can be grouped by associated activities such as, commercial, industrial, agriculture, automotive, etc. (US EPA, 1997). These categories have been listed from I through VI by the US EPA (US EPA, 1984). These categories have been summarized, based on the USEPA guidelines, by the Nevada Division of Environmental Protection as follows:

Category I – Sources designed to discharge substances to the environment including, subsurface percolation (septic tanks), injection wells, floor drains not connected to the sanitary sewer system, and land application.

Category II – Sources designed to store, treat, and/or dispose of substances, with potential for discharge through unplanned releases (e.g. all types of landfills and disposal sites, surface impoundments, waste piles, non-waste stockpiles, above and below ground storage tanks, containers, graveyards, and animal burial).

Category III – Sources designed to retain substances during transport or transmission including pipelines, materials transport and transfer operations.

Category IV – Sources discharging substances as a consequence of planned activities for example, agriculture practices irrigation, pesticide and fertilizer application, animal feeding operations, de-icing salts application, urban runoff, percolation of atmospheric pollutants, and surface or underground mining or mine drainage.

Category V – Sources providing conduits for inducing discharge through altered flow patterns (e.g. all types of exploration, production and monitoring wells, and construction excavation).

Category VI – Naturally occurring sources which discharge is created and/or exacerbated by human activity (e.g. natural leaching and interaction between ground and surface water).

These categories illustrate the type of potential contaminant sources that may affect groundwater for public and private drinking water use (NDEP, 2007).

Vulnerability to groundwater has been defined as "*The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer* (Carbonell, et al., 1993)." It implies a level of vulnerability can be assessed for the water sources given contaminant source located near the well/spring. With a determined level of vulnerability, decisions for treatment or permitting new wells can be addressed to help ensure the health of people reliant on the water source (Harman, et al., 2001).

Assessments to determine the vulnerability level of possible contamination can be achieved several ways. They include but not limited to; index methods, subjective hybrid methods, statistical methods, and process-based methods as outlined by the USGS (Focazio, et al., 2002). This vulnerability assessment can assist with well head protection, water resource management, and location of new wells. Each of the methodologies has strengths and weaknesses that should be realized prior to implementing of any of them (Focazio, et al., 2002). For example, the application of a statistical method would not be viable if the region is lacking significant data for a statistical analysis.

The index method is a method that uses a ranking for variables to determine an overall risk. The most common index method is DRASTIC, developed by the US EPA (Aller, et al., 1987; Liggett & Allen, 2010). This method is used often due to its relative simplicity of use, ease of data collection for evaluation, and the relatively accurate results obtained (Liggett & Allen, 2010; Babiker, et al., 2005). However, the DRASTIC model can only be used for areas greater than 100 acres limiting this method to larger regions that may not suit a small community (Aller, et al., 1987).

The hybrid method is subjective and assigns weights to different risk levels. Statistical analysis is preferred to determine a ranking of risk. The combination of these techniques provides a more accurate model that can predict a rate of possible contamination from specific categories (Focazio, et al., 2002). Because part of the method is based on a subjective modeling approach, there is an inherent issue with the accuracy of the risk ranking. It may be too conservative or too liberal for the area of study (Carbonell, et al., 1993).

Statistical methods use correlations to determine a risk ranking for a region. In this approach, existing groundwater quality data and land use are correlated to obtain vulnerability ranking. This method is suitable for determining regions of risk over large areas and for preliminary modeling for more detailed models (Focazio, et al., 2002). However, this approach does not accurately account for geochemical or other factors that may alter the actual vulnerability ranking (Carbonell, et al., 1993).

2.8 Natural and Anthropogenic Contaminants Detected in Northern Nevada Groundwater

In Northern Nevada, the most common contaminants that have been detected in groundwater are naturally occurring arsenic, fluoride and radionuclides and anthropogenic nitrate. Nitrate is often associated with septic tanks, manure spreading, and agriculture fertilizer application. Nitrate concentration is typically highest for agricultural areas with minimal or no nitrate in wilderness regions Nitrate is most commonly formed from the decay of ammonia associated with animals, such as feed lots or septic systems (Nolan & Hitt, 2006; Burow, et al., 2010). However, nitrate can be found in wilderness areas from natural occurring deposits, such as found near Lovelock, Nevada (Gale, 1912). However, natural occurrence of nitrate is very rare. Additionally, nitrate has been determined to penetrate beyond the root zone in the region of central Nevada where condition of loamy soil allows for the migration to groundwater from the decay of plants (Nettleton & Peterson, 2011).

Not all groundwater contamination comes from human activities. Because of the type of ore deposits in Nevada, many naturally occurring contaminants are detected in the northern mining region, including radionuclides, arsenic, and fluoride. Arsenic is found throughout the United States in various quantities in groundwater from naturally

occurring deposits (Welch, et al., 2000). The health effects of arsenic include discoloration of the skin, stomach pain, nausea, vomiting and has been linked to cancer (USEPA, 2010). Because of its proven health effects, the USEPA has lowered the maximum contaminant level of arsenic from 50 ppb (ug/L) to 10 ppb (ug/L) in 2006 (Walker, et al., 2005). Fluoride's drinking water standard is 4 mg/L and its concern in drinking water relates to brittle bones. Radionuclides, including uranium, alpha particles, gross beta particles, and combined radium 226/228 are regulated in drinking water because of their effects on tissues that may lead to cancer (USEPA, 2011).

2.9 Factors Influencing the Vulnerability of Groundwater Wells to Contamination

Well construction is important to minimize possible contamination to the groundwater source and maintain good water quality. Many wells that have been drilled prior to regulations can inadvertently jeopardize the groundwater quality. Some of the issues that are known to influence the water quality are open joint cases, insufficient gravel pack, as well as the depth of the sanitary seal in relation to the well screen (Exner & Spalding, 1985). This may result in nitrate contamination from nearby septic systems for regions with private wells (Verstraeten, et al., 2005). Depth of the well is also an important aspect to water quality. Shallow wells typically have a higher level of contaminants that infiltrate from the surface whereas deeper wells have minimal contaminants form surface activities (Nolan & Hitt, 2006). Additional well characteristics that should be considered for potential of contamination assessment include draw down, radius of influence, recharge rate, withdraw rate, and the hydrogeology of the aquifer (Salvato, et al., 2003; Burton, 1983).

Hard rock mining utilizes explosive to excavate the ore. Most explosive use a nitrate compound mixed with a volatile organic compound (VOC). This mixture of chemicals has potential to be introduced into the environment from explosions that have not fully detonated. This can lead to nitrates and VOCs infiltrating the groundwater (Ministry of Environment of British Columbia, 1983). However, this is unlikely but possible in the mining operations in Nevada. The infiltration would need to have large amounts of undetonated explosive left in the ground as well as a water table close to the surface.

CHAPTER 3

RESEARCH APPROACH

In this research, two index methodologies, the DRASTIC method and the NDEP method, will be used to assess the potential vulnerability to groundwater contamination in mining, associated mining towns, and agricultural areas. A geographic information system (GIS) will be used to perform the analysis. The DRASTIC method utilizes a range of regional hydrogeological aspects to forecast locations where groundwater contamination is more likely. The NDEP method utilizes land use activities, also referred to as potential contaminant sources (PCSs), local hydrogeological aspects, historic groundwater quality, and the quality of well drilling and construction to estimate the vulnerability of the groundwater to contamination. The comparison of the two methodologies will reinforce the potential of contamination to groundwater as well as the impact of the three land uses. It is expected that groundwater located in mining towns and agricultural areas are as vulnerable to contamination as groundwater located in mining areas.

The area of study is located on the Nevada State Engineer's hydrographic basin boundaries for the northeastern portion of Nevada. The area was chosen so to incorporate a region that contains enough of the three land use types and a reasonable

representation of each. Figure 1 depicts the location of the study area in relation to the State of Nevada. The hydrographic basins selected are shown in Table 2. A graphic representation of the basins involved is depicted in Figure 2.

Table 2 - Study Area Basins

Nevada State Engineer's Hydrographic Basin Boundaries

Antelope Valley	Long Valley
Big Smoky Valley	Lower Reese River Valley
Boulder Flat	Maggie Creek Area
Buffalo Valley	Marys Creek Area
Butte Valley	Marys River Area
Carico Lake Valley	Middle Reese River Valley
Clover Valley	Newark Valley
Clovers Area	North Fork Area
Crescent Valley	Pine Valley
Diamond Valley	Pumpernickel Valley
Dixie Creek-Tenmile Creek Area	Rock Creek Valley
Elko Segment	Ruby Valley
Goshute Valley	South Fork Area
Grass Valley	Starr Valley Area
Huntington Valley	Steptoe Valley
Independence Valley	Stevens Basin
Jakes Valley	Susie Creek Area
Kelley Creek Area	Upper Reese River Valley
Kobeh Valley	Whirlwind Valley
Lamoille Valley	Willow Creek Valley

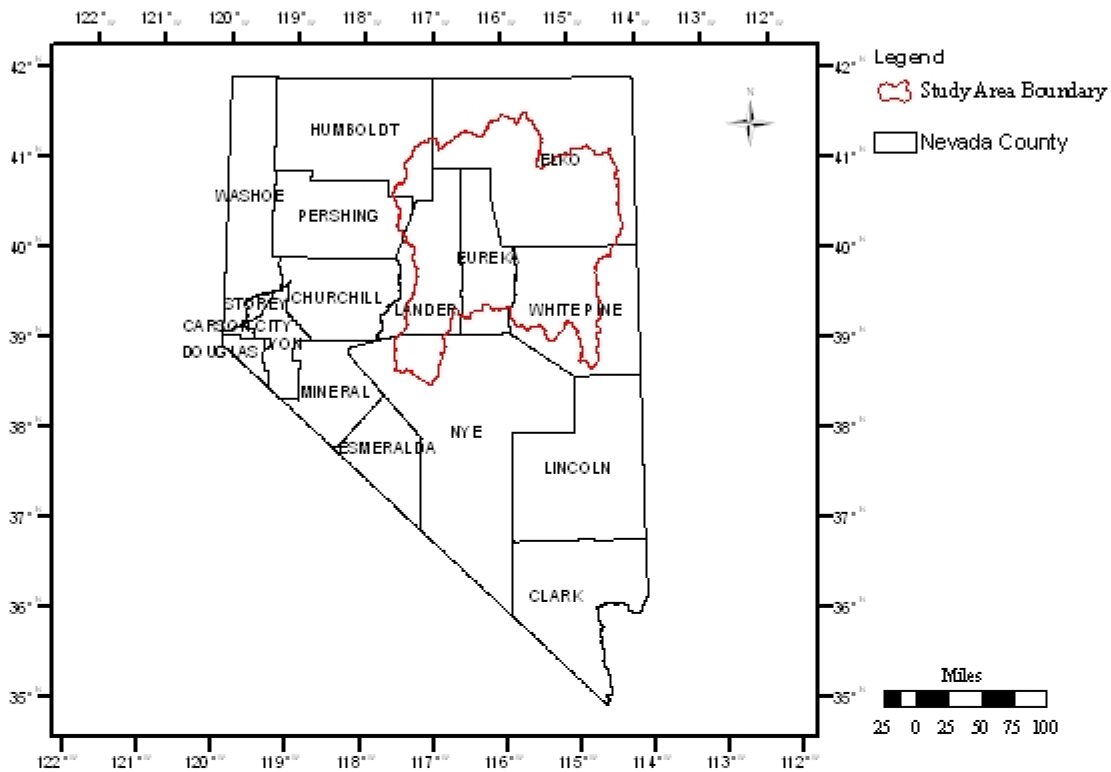


Figure 1 - Study Area: The study area is located within the northeastern portion of Nevada and it was chosen to include three different land uses (mining, towns, and agriculture).

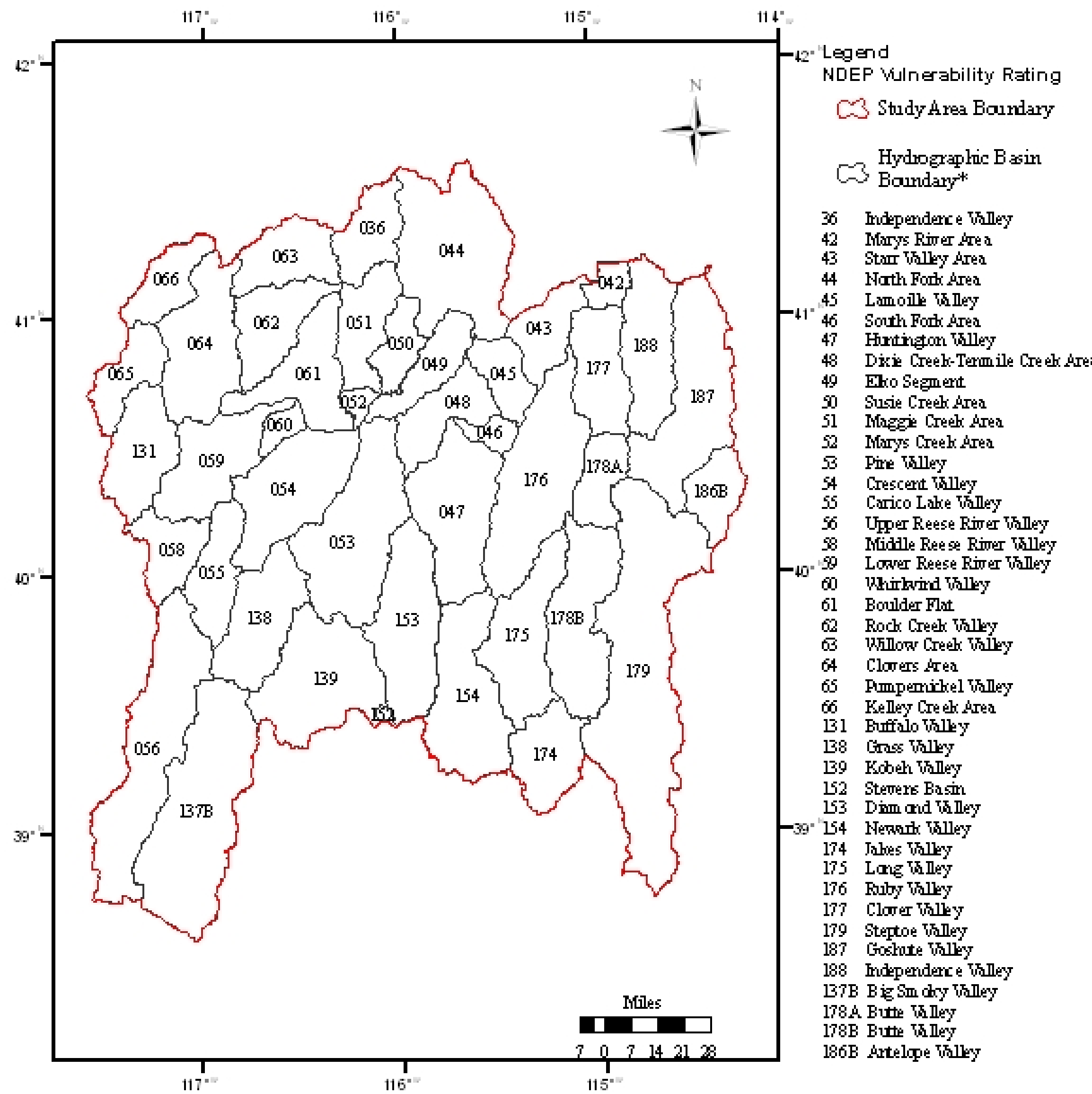


Figure 2 – Hydrographic Basin Boundaries: Hydrographic basins determined to provide the best representation of the three land uses.

DRASTIC METHOD

The DRASTIC method was developed by the USEPA (Aller, et al., 1987) and this acronym relates to the seven basin aspects used for evaluation of vulnerability: (D) depth to water, (R) net recharge, (A) aquifer media, (S) soil media, (T) topography, (I) impact of vadose zone media, and (C) conductivity (Aller, et al., 1987). Obtaining the

data needed for DRASTIC is relatively easy with today's electronic availability of data sources from various agencies. In DRASTIC, human activity can be incorporated using IMPACT, an acronym for (I) inclination of the water table, (M) measured horizontal distance from the PCS to an arbitrary point, (P) population exposed to the potential contaminant, (A) application rate of the potential contaminant (C) contaminant concentration, and (T) contaminant toxicity. These factors are applied to the DRASTIC model for a total rating of vulnerability.

Without IMPACT, the vulnerability analysis is solely based on natural or existing conditions; that is, contaminant sources are not included. The IMPACT layer is applied to the DRASTIC model as an additional eighth data set. However, the DRASTIC method does not dictate specific values for the aspect rating as well as a weight, therefore some professional judgment must be applied. For the regional basins selected, some of the data needed to incorporate IMPACT to DRASTIC are very sparse or non-existing. Therefore, IMPACT will not be considered in this research. IMPACT has met some opposition on its validation of vulnerability. This is mostly due to the lack of calibration for groundwater contaminant concentrations (Rupert M., 1997). Utilizing a statistical correlation, a rating scheme can be applied to improve the performance of the model (Rupert, 1999). For this improvement, additional data are required that may not be easily obtained. Therefore, this research will focus on DRASTIC alone, without IMPACT.

3.1 DRASTIC Data and Sources

The data sets used in this research for the DRASTIC method were obtained through several open source data warehouses (Table 3). In addition the data for mining district came from the Nevada Department of Geology and Mining, the data for populated

towns came from 2009 Tiger files, and irrigated lands came from the US Department of Agriculture for use in land use comparison.

Table 3 – Data Sources Used in DRASTIC

DRASTIC Feature	Source
Depth of Water	Static Groundwater Depths http://water.usgs.gov/lookup/getgislist
Net Recharge	Estimated National Mean Recharge http://water.usgs.gov/lookup/getgislist
Aquifer Media	Hydrogeology of Nevada http://water.usgs.gov/lookup/getgislist
Soil Media	Soils Map of Nevada http://data.geocomm.com/dem/demdownload.html
Topography	USGS NED http://seamless.usgs.gov/
Impact of Vadose Zone	Geology Map of Nevada http://tin.er.usgs.gov/geology/state/state.php?state=NV
Hydraulic Conductivity	Hydrogeology of Nevada http://water.usgs.gov/lookup/getgislist

All Data Collected on May 18, 2011

The raw data collected to apply DRASTIC to the selected basins required some alteration to produce datasets that can be correlated mathematically in GIS. The process involved: (1) Assembling information relaying each of the aspects of DRASTIC into GIS file overlays, or layers, depicting the individual aspects. Within each of the layers, a grid of cells with a cell size of 100 meters per side was created; (2) Numerically rating each cell based on its perceived threat to ground water contamination (Table 4); (3) Visually displaying the resulting ratings using GIS and colors representing a range of numerical values; (4) Overlaying or stacking each aspect layer with consideration to cell alignment and given respective weights.

The DRASTIC method uses a mathematical formula to determine the groundwater vulnerability (equation 1). This equation is a summation of weighted and

rated values for the seven layers used for the model. Each layer is individually evaluated using a mapping technique. For this research, ArcInfo version 9.3 has been utilized. After each of the layers were analyzed, they were overlaid onto one another to form numerical areas of vulnerability that can be displayed. The vulnerability ranking is typically represented with light colors for low vulnerability and dark colors for high vulnerability. Last, the raster calculator in ArcInfo was used to create a DRASTIC layer with the results of the overlaid aspect layers.

To compare the vulnerability for the different land uses, the final vulnerability layer, i.e. the DRASTIC layer, was used to create a map with the three land uses. With the land use areas plotted, the map values can be used to determine percent of vulnerability ranking.

The DRASTIC method uses two different weight values dependent on the expectation or presence of pesticide use (Table 4). Once the assemblage of the seven layers is completed, using the associated weighted value, vulnerability is computed as:

$$\text{Vulnerability} = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \quad \text{(Equation 1)}$$

Where $_R$ equals rate and $_W$ equals weight (Aller, et al., 1987; Rupert, 1999).

Table 4 - Assigned Weights for DRASTIC and Pesticide DRASTIC Features

Feature	Weight	Pesticide Weight
Depth to Water	5	5
Net Recharge	4	4
Aquifer Media	3	3
Soil Media	2	5
Topography	1	3

Feature	Weight	Pesticide Weight
Impact to the Vadose Zone Media	5	4
Hydraulic Conductivity of the Aquifer	3	2

Reproduced From Table 3 (Aller, Bennett, Lehr, & Hackett, 1987)

For the region studied in Nevada, the rating values for the individual layers are depicted below in Tables 5 to11 for aspects of the DRASTIC method suggested by the USEPA (Aller, et al., 1987).

Table 5 - Ranges and Ratings for Depth to Water

Depth to Water (feet)	
Range	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1

Reproduced From Table 4 (Aller, et al., 1987)

Table 6 - Ranges and Ratings for Net Recharge

Net Recharge (inches)	
Range	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10+	9

Reproduced From Table 5 (Aller, et al., 1987)

Table 7 - Ranges and Ratings for Aquifer Media

Aquifer Media		
Feature	Rating	Typical Rating
Massive Shale	1-3	2
Metamorphic/Igneous	2-5	3
Weathered Metamorphic/Igneous	3-5	4
Glacial Till	4-6	5
Bedded Sandstone, Limestone, and Shale Sequences	5-9	6
Massive Sandstone	4-9	6
Massive Limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst Limestone	9-10	10

Reproduced From Table 6 (Aller, et al., 1987)

Table 8 - Ranges and Ratings for Soil Media

Soil Media	
Feature	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1

Reproduced From Table 7 (Aller, et al., 1987)

Table 9 - Ranges and Ratings for Topography

Topography (Percent Slope)	
Range	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Reproduced From Table 8 (Aller, et al., 1987)

Table 10 - Ranges and Ratings for Impact of Vadose Zone Media

Impact of Vadose Zone		
Feature	Rating	Typical Rating
Confining Layer	1	1
Silt/Clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded Limestone, Sandstone, Shale	4-8	6
Sand and Gravel with significant Silt and Clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
Karst Limestone	8-10	10

Reproduced From Table 9 (Aller, et al., 1987)

Table 11 - Ranges and Ratings for Hydraulic Conductivity of the Aquifer

Hydraulic Conductivity (gpd/ft^2)	
Range	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10

Reproduced From Table 10 (Aller, et al.1987)

An evaluation of the tables above indicates that, higher vulnerability to contamination is associated with shallow groundwater table, high recharge rate aquifers, aquifers associated with limestone and gravel, steep slopes, and high hydraulic conductivity.

3.2 DRASTIC Data Reevaluation

DRASTIC requires seven layers to be used in the calculation of vulnerability. The seven layers include: depth to water, recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity. The raw data sets collected required some manipulation. Manipulation included reclassification, re-projection, re-sampling, and format conversion.

All seven data sets collected required reclassification and re-projection. Reclassification is assigning a numeric value to an aspect of the data sets, e.g., 0 to 2 percent slope receives a weight equal to 10. The data sets were projected to be in the North American Datum 1983, Universal Transverse Mercator Zone 11 projection [NAD83, UTM11]. This projection ensures that all the grids will align properly for

future calculations. This projection was chosen because it is the standard projection for Nevada. Three of the data sets, recharge, topography, and depth to water, required re-sampling to produce data sets with equal grid size. Re-classification is converting larger or smaller grid sizes to a common size, i.e. 100 m for this analysis. The topography layer was collected at 10 meter resolution cell size and converted to 100 meter cell size for easier control of the data and minimizing calculation times. The other two grid files had to be converted to 100 meter cell size, down from 300 meter for the depth to water and from 1000 meter for the water recharge data layer. Using the topography as a base, or “snap to” layer, the layers were converted to be aligned with this layer.

The data sets of aquifer media, soil media, impact of vadose zone, and hydraulic conductivity were collected in the ESRI shapefile format. A value for each aspect was assigned based on the DRASTIC rating values. Once the rating (reclassification) was established, the data layers were converted to a grid file with the same dimensions and location of cells as the topography layer. This is essential for the calculation of the vulnerability in GIS to ensure the correct values are being used. Otherwise, with runoff of cell locations, it is possible for the program to calculate adjacent cells creating erroneous values.

Values for the DRASTIC layers, for use in this assessment, have been determined using the values as outlined in the DRASTIC methodology (Tables 5 to 11), However, several data sources, including aquifer media and impact of vadose zone values, were presented with different aspects and required some interpretation. The interpreted values for the data layers are outlined in Tables A1 and A2 (Appendix A). The values from Table A2 have been developed from the Nevada Geology data provided

by the United States Geological Survey (USGS; http://www.epa.gov/nerlesd1/land-sci/nv_geospatial/pages/nvgeo_gis4_geology_md.htm#5). These values were related to the DRASTIC rating scheme as a relationship between geologic rock formation and the rock types from DRASTIC (Table 10). This method was used to provide a better representation of the vadose zone in comparison to the data offered in the soils data from the United States Department of Agriculture (USDA) NRC soil reports (http://www.nv.nrcs.usda.gov/technical/soils.html).

NDEP METHOD

The NDEP method utilizes an index method to determine groundwater vulnerability by identifying potential contaminant sources (PCS) within an influence area and incorporating hydrogeological, water quality, and well construction features to the respective groundwater sources (e.g. wells and springs). Features considered include aquifer type, confining layer depth, well construction, depth of water table, and historic water quality. In applying the NDEP method, the following steps are needed: (1) Determining the influence area (buffer zone) around the well by either hydrogeologic modeling or using a fixed radius. For this research, a fixed radius is used. The region located within the fixed radius is the influence area, within which any potential source of contamination is likely to affect the vulnerability level; (2) Assigning an initial rating of high, medium or low vulnerability based on the type of contaminant likely to be associated with specific potential contaminant sources. The general contaminant categories include inorganic compounds (IOCs), volatile organic compounds (VOCs),

synthetic organic compounds (SOC), radionuclides (RAD), and microbiological contaminants (MIC); (3) Assessing final vulnerability by taking into consideration hydrogeological, water quality, and well construction features that would warrant lowering or maintaining the initial assigned vulnerability. It includes consideration of depth of water table, presence of a confining layer, sanitary seal depth, historic water quality of the well, and other aspects.

In this research, a fixed radius or buffer of 3,000 feet was placed around the water source to evaluate the type and amount of potential sources of contamination that may impact the groundwater. This buffer zone was determined by reviewing typical aquifer transmissivity as outlined by the Nevada Division of Environmental Protection (NDEP). Nevada is predominately an alluvium aquifer with a media of unconsolidated sand and gravel mixture with areas of carbonate rock (NDEP, 2006). A fixed radius of 3,000 ft corresponds to travel times of 10 years for most groundwater aquifers in Nevada. Therefore, the NDEP method utilized this geologic feature for a simplistic hydrogeological condition to determine the radius of potential travel times of contaminants.

3.1 NDEP Method - Contaminant Source Data Gathering and Initial Ranking

Data collection involved GPS location of potential contaminant sources within the established 3,000 foot buffer zone for selected wells in the study area. The data collection campaign took place in the summer of 2010. Additional information was gathered from the Nevada Division of Water Resources and Nevada Division of Water Quality (http://water.nv.gov/) throughout the year of 2010 and the early portion of 2011. In addition, mapping data such as USGS quadrangle maps and USGS orthographic

photographs were utilized to assist with PCS locations and other pertinent features such as direction of slope and the presence of seasonal water bodies.

Potential contaminant sources were surveyed in the field using a GPS handheld device, (Trimble unit Geo Explorer 2004). These data were converted to an ESRI shapefile format compatible with the ArcInfo program and plotted as a map. The data was then used to determine location of any PCS relevant to the water sources as well as the lateral distance to the water sources.

Utilizing the NDEP category rating index (Table A3, Appendix A), an initial value of vulnerability was assigned for the potential contaminant source. These categories are defined by expected contaminant type with an associated ranking of contamination potential from low, medium, or high. The contaminant categories include inorganic compounds (IOC), volatile organic compounds (VOC), synthetic organic compounds (SOC), microbiological compounds (TBC), and radionuclide compounds (RAD). This ranking provides the initial vulnerability for the water source in relation to a single contaminant source. For example, wells/springs located in the proximity of gas stations have a high likelihood to be contaminated by VOCs, while wells located close to a feedlot have a high risk of being contaminated by microbiological compounds.

Often, within the 3,000 ft fixed radius several contaminant sources are present that make the well vulnerable to contamination, as illustrated in Figure 3.

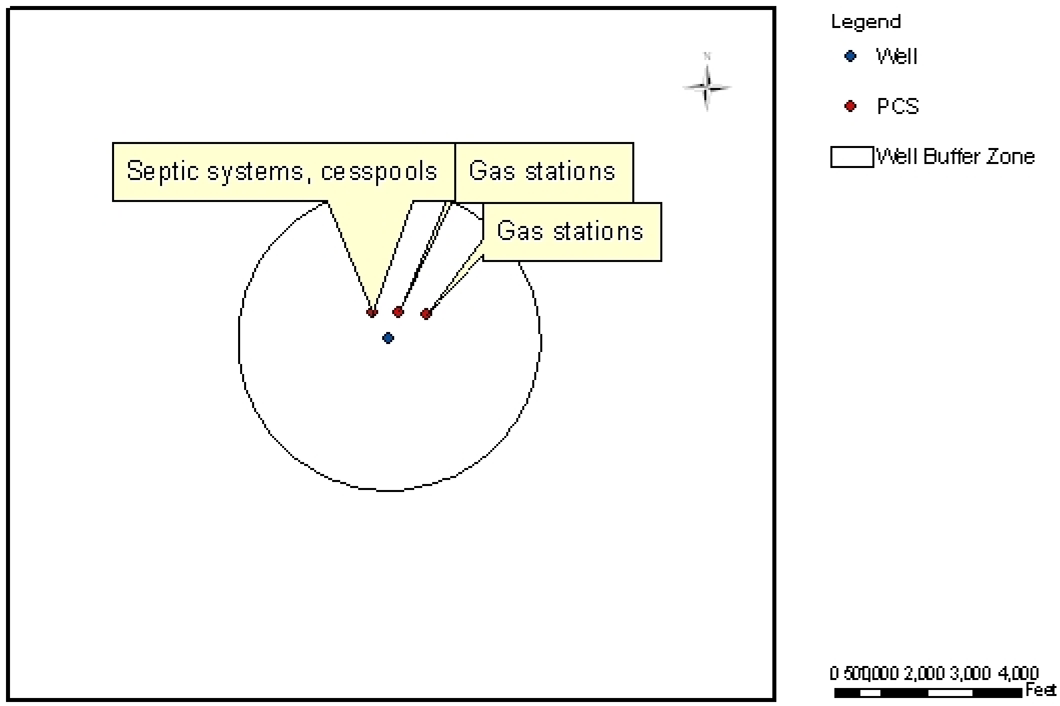


Figure 3 – Well with Multiple PCSs: This is an example of a well with multiple PCSs with different ranges of initial vulnerability ranking.

Therefore, it is necessary to devise a means by which the vulnerability of the well with respect to all contaminant sources present is computed. By using values associated to the level of vulnerability a mean ranking of initial vulnerability can be assessed for multiple PCSs within the buffer zone of the well.

In order to assign a quantitative value to the vulnerability and to account for the vulnerability to many contaminant sources, the values of 100 for low, 200 for moderate, and 300 for high have been assigned in this research. With these established values, the initial overall vulnerability of the well will be computed as follows:

$$V_{PCS\ initial} = \frac{(PCS1+PCS2+\cdots+PCSn)}{n} \qquad \text{(Equation 2)}$$

Where:

PCS_n = Initial potential contaminant source vulnerability ranking (100, 200, or 300)

n = total number of PCSs

As an example, if a well has three PCS located within the 3,000 ft buffer zone and one is rated as low, and two are rated as moderate, the assigned initial vulnerability ranking would be:

$$V_{PCS\ initial} = \frac{(100+200+200)}{3} = 166.67$$

3.2 NDEP Method – Well and PCS Data Gathering

These data were collected concurrently with the PCS data using the same methodology and GPS unit. Well information was compiled from the Nevada Division of Water Resources webpage (http://water.nv.gov/data/welllog/) that included the well driller's log. The well locations collected were used to create the 3,000 foot buffer. Once the buffer zone was created the well locations were removed from the map, for security reasons (NDRW, 2011).

Review of the well driller's log revealed the static water level, the presence or absence of a confining layer, sanitary seal depth, screen depth, and well depth. The physical inspection of the well during field visit noted casing above ground height, visible construction defects, and local features that may jeopardize the integrity of the well. These factors were weighted on significance to the possible well vulnerability using professional judgment guided by principles of contaminant transport (Section 3.5).

However, no contaminant transport modeling was performed in this research. Therefore, this process has some inherent subjectivity.

3.3 NDEP Method - Historic Water Quality Data

Historic water quality from each of the water sources was collected from NDEP via the SDWS data system. SDWS is the NDEP data storage and retrieval system that houses water quality information for each public water system in the state of Nevada. The information on SDWS contains water quality data that is submitted to NDEP annually by the well owner to assure the water meets the maximum contaminant levels (MCL) for primary and secondary water contaminants (Table A11 - Appendix A). In this research, the initial vulnerability ranking was increased based on how closely specific contaminants, found in the well, are from the MCL. For an example, a system that has reported a constituent near the current MCL as established by the USEPA's Safe Drinking Act will receive a higher ranking than a system without contaminant detection.

3.5 NDEP Modified Method - Final Vulnerability Ranking

In this research, the final ranking is based on the initial vulnerability ranking, modified by historic water quality, hydrogeologic features, and well construction. Each of the three categories contributes to the overall vulnerability of groundwater. Water quality indicates if prior contamination has occurred or the presence of naturally occurring contaminants (e.g. arsenic, radionuclides) that impact the vulnerability of the groundwater. Well construction can allow the migration of contaminants to occur if, for example, no or insufficiently deep sanitary seal is present. Hydrogeology is used to determine the ease of migration of a contaminant due to, for example, lack of a confining layer or shallow ground water depth.

The final ranking consists of modifying the initial ranking by assigning a significance factor for each of the vulnerability modifying parameters. In this research, significance factors of 5, 3, and 2, were assigned to hydrogeological, water quality, and well construction, respectively. This rating was given because hydrogeology will, often, control contaminant migration more than well construction or historic water quality.

Next, ratings are given to the different water quality parameters, well construction features, and hydrogeological factors (Table 12). The values of the ratings are subjective, but the relationship among them represents expected behavior of the parameters when evaluating contamination transport. For example, for water quality, a rating of 4 is given to wells in which the contaminant has reached the MCL, while a lower rating of 1 is given to wells where the contaminant level is < 25% of the MCL. For water quality, in addition to rating, a weight was given for the presence and absence of specific contaminants; a weight of 10 is given when the contaminant is present and a weight of zero is given when it is absent. Historic water quality values have been rated at 10 for all constituents due to drinkability, or lack of it, if the water is contaminated by any of them. If a PCS is located up gradient (upstream) of a well it will pose a greater threat than a PCS located down gradient of the well if contamination were to occur. Other hydrogeological aspects include the presence of a confining layer and contaminant mobility. Tables 12 and 13 depict the numerical significance factors, weight and rating values for the three modifying categories and features.

Table 12 – NDEP Method: Historic Water Quality Rating Values

Weight = 3	
Water Quality Constituent	***Rating***
Absent of (no)Detection	0
VOC Detect:	10
Dioxin Detect:	10
SOC Detect:	10
IOC Detection:	10
Radionuclide Detect:	10
E Coli Detect:	10
Total Coliform MCL within 2 yrs:	10
Nitrate Detect:	10

Table 13 – NDEP Method: Historic Water Quality Detection Weights

Contaminant Detections	***weights***
0-25% MCL	1
25-50% MCL	2
50-75% MCL	3
75-100% MCL	4
>100% MCL	5

Table 14 – NDEP Method: Well/Spring Construction Rating Values

Weight = 2	
Well/Spring Construction	***Rating***
Adequate Construction?:	
Yes	2
No	7
Seal Depth:	
0-25	9
25-50	7
50-75	4
>75	1
Casing > 18" Above Ground?:	

Weight = 2	
Well/Spring Construction	***Rating***
Yes	2
No	7
Screen Below Confining Layer(s)?:	
Yes	2
No	7

Table 15 – NDEP Modified: Hydrogeological Factor Rating

Weight = 5			
Hydrogeological Factors	***Rating***	***Hydrogeological Factors***	***Rating***
Contaminant Source Dir.:		**Confining Layer(s)?**	
Up Gradient	7	Yes	2
Down Gradient	2	No	7
Time of Transport:		**Is Contaminant Mobile?:**	
2 year (<1000ft)	10	Yes	7
5 year (1000-2000ft)	8	No	2
10 year (2000-3000ft)	6	**Is The Contaminant Persistent?:**	
20 year (3000-4000ft)	4	Yes	9
>20 year (>4000ft)	2	No	4
Static Water Depth (ft):		**Have Contaminations occurred?:**	
0-5ft	10	Yes	7
5-15ft	9	No	2
15-30ft	7	**Approved Method to Control Contamination?:**	
30-50ft	5	Yes	1
50-75ft	3	No	6
75-100ft	2		
>100ft	1		

Once the modifying factors and their respective weights and ratings are applied, the new vulnerability of the well, in relation to each contaminant source, can be computed using Equations 3 and 4. Equation 3 will determines a vulnerability correction

factor of the well without considering associated PCS(s). By applying Equations 2 and 3 to Equation 4, the final vulnerability of the well to contamination can be determined.

$$V_{CFwell} = \frac{SFWQ[\sum(WMCL * RWQ)] + SFhydro[\sum RHydro] + SFconst\,[\sum RConst]}{500} \qquad \text{(Equation 3)}$$

The vulnerability of the well to all contaminant sources can then be computed as:

$$V_{Final} = V_{PCS\ inital} * V_{CFwell} \qquad \text{(Equation 4)}$$

Where:

V_{CFwell} = Vulnerability correction factor for the well/spring

SF_{WQ} = Significance factor for historic water quality

W_{MCL} = Weight for water quality concentration based on MCL level

R_{WQ} = Rating of water quality constituent

SF_{hydro} = Significance factor for hydrogeologic component

R_{Hydro} = Rating of hydrogeologic features

SF_{const} = Significance factor for well construction

R_{Const} = Rating of well construction features

V_{Final} = Final Vulnerability

$V_{PCS\ inital}$ = Initial vulnerability of PCS ranking from Equation 2

The factors used to determine the initial and final ranking are similar to those used for DRASTIC and involves some subjectivity. As long as the same methodology is

applied to all the wells, the subjectivity of the values should have limited impact to the overall vulnerability to the well (Focazio, et al., 2002). The division of 500 was used in equation 3 to produce a distribution whereas the majority of vulnerability resides within moderate low to moderate high. Other values were analyzed including 300 and 1,000. These values produced a distribution that was either almost entirely in the very low to moderate or high to very high. Therefore value of 500 has been determined to be the most suitable. Table 16 displays the vulnerability levels associated with values assigned to the different ranking values.

Table 16 – NDEP Modified Method Vulnerability Ranking Values

NDEP Modified Method Ranking Index	
NDEP Value	Vulnerability
<=50	Very Low
51-100	Low
101-150	Moderate Low
151-200	Moderate
201-250	Moderate High
251-300	High
>300	Very High

<u>3.6 DRASTIC and NDEP Method Comparison and Correlation</u>

The DRASTIC and NDEP methods were correlated with several detected contaminants in wells of Northern Nevada. It was expected that no strong correlation exists between the vulnerability rankings and naturally occurring contaminants because their presence is independent of contaminant transport. Strong correlation is expected between anthropogenic contaminants (i.e. nitrate) and the determined vulnerability. For mining, a low correlation is expected because mining areas have low number of septic

tanks. A high correlation is expected for agriculture and towns because a large number of septic tanks and agricultural activities are present.

The correlation was based on the frequency of contamination for arsenic, fluoride, and radionuclide, and nitrate (Kalinski, et al., 1994). The contaminants were plotted as frequency versus vulnerability with the entire data sets. Nitrate was plotted in the same fashion, except that the data sets were separated into the three land uses. From the plots, a correlation can be established. The NDEP method requires a transformation from points to a raster (grid) for comparison to the DRASTIC method. Two methods were tested to convert the NDEP method points to an area map, Kriging and triangulation. Once the raster had been prepared the correlation of contaminants were plotted for both the DRASTIC and the NDEP methods. The correlation coefficients of both DRASTIC and NDEP were compared to determine which method correlates best to the water quality data and the expected outcome.

CHAPTER 4

RESULTS

The vulnerability results for the two methodologies studied have been presented in a percent occurrence format. The DRASTIC method was analyzed by the raster cell value that occur within each of the defined land use areas to find the percent vulnerability for each ranking. This represents the natural condition of vulnerability based on geologic and hydrogeologic conditions. The NDEP modified method was analyzed based on PCSs, well construction data, hydrogeologic features, water quality, and land use. The wells were analyzed for vulnerability by determining the frequency of occurrence per ranking level associated with the three land uses. The wells, which in GIS constitute (points), were transformed into a raster (grid) via triangulated irregular network (TIN) for a direct comparison with DRASTIC. Kriging and Inverse Distance Weighted methods were considered but found to be inadequate based on an analysis of the data and the variogram. The Inverse Distance Weighted method results eliminated all data of the very low, low, high and very high ranges. The resulting vulnerability map when the data was removed provided a vulnerability map that shows little distinction of the land uses. The Kriging method was not used because of the high variability of the resulting variogram.

4.1 DRASTIC Method

Each of the seven elements required to make up the DRASTIC vulnerability map were analyzed and plotted in ArcMap. The numeric rating values from the DRASTIC tables were color coded for visual reference. Figures 4 to 10 depict the resulting layers used for this analysis. The figures have been placed in order of the acronym DRASTIC. In the Figures, the greater the numeric values the greater the vulnerability aspect.

When the DRASTIC equation (Eqn. 1) is applied to the study area, a groundwater vulnerability map is obtained from the seven data input layers (Figure 11). The layer cell addition resulted in a rating of 47 to 187; these values were then categorized into a vulnerability rating of 1 through 7, with 1 and 7 representing the lowest and the highest vulnerability respectfully. In the vulnerability map, light colors represent areas of low vulnerability and dark colors represent areas of high vulnerability.

Analysis of the DRASTIC aspects of the studied area revealed that the mountainous region is comprised of carbonate and other rocks, has seasonal (non-primary) aquifers, and recharge of 2 inches per year or greater (Figures 4, 5, and 6). The valleys are comprised of sand and gravel, primary aquifers, and recharge of less than 2 inches per year. The mountainous regions also are comprised of loam soils and carbonate rock in the vadose zone (Figures 7 and 9). The valleys are comprised of slopes less than 2% whereas the mountainous regions have slopes 12% and greater (Figure 8). Hydraulic conductivity is less than 100 gallons per day per square foot for the mountainous regions and over 300 gallons per day per square foot for the valleys (Figure 10).

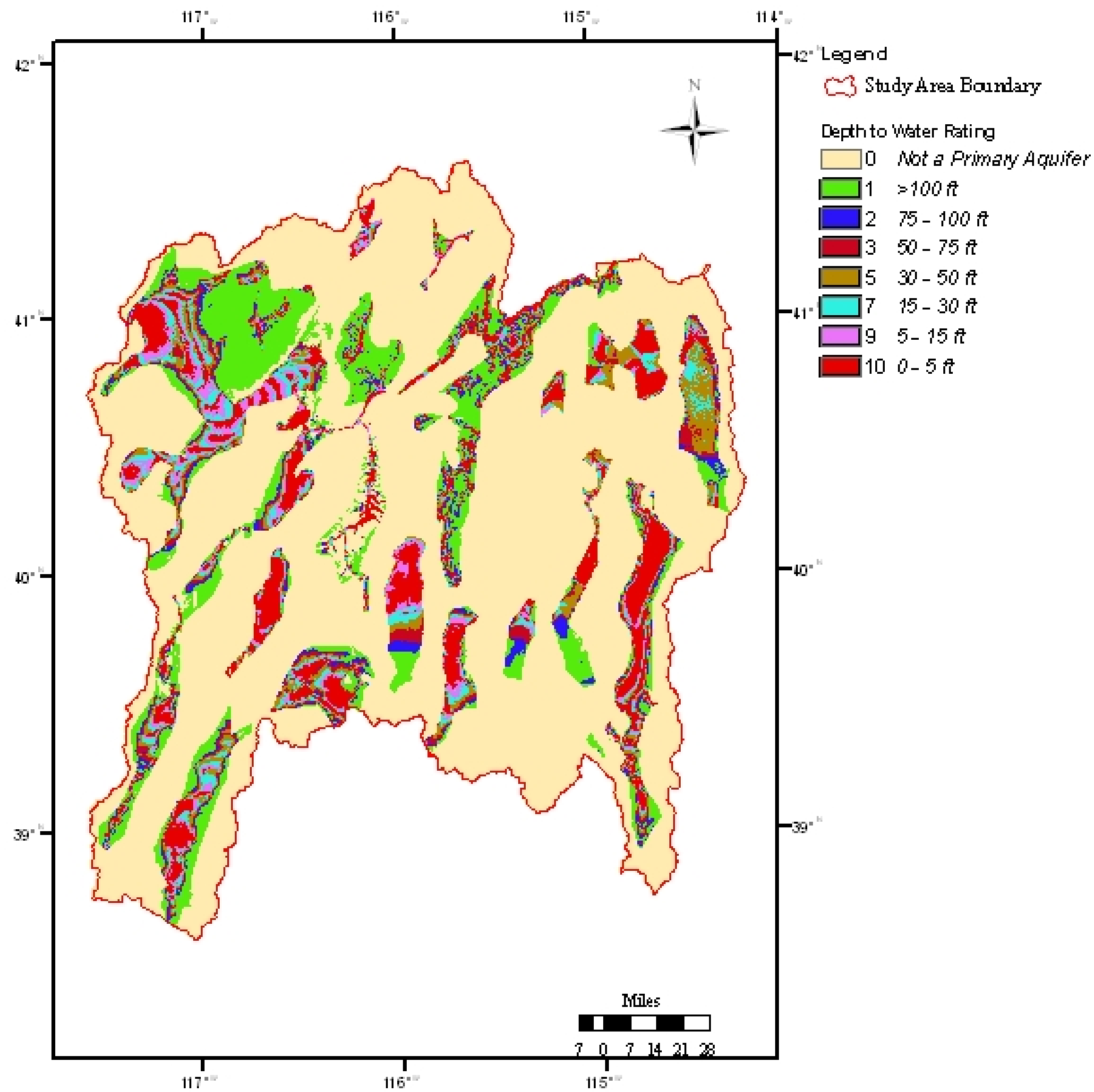


Figure 4 – DRASTIC- Depth to Water Ratings: Areas of 0 indicate the areas of non-primary aquifers of seasonal aquifers. The values from 1 through 10 represent the depth of the aquifer measured in feet from the ground level.

Depth to water layer in the region was assumed to correspond to the depth of the static water table. The areas with 0 values are areas with no data, meaning that these regions are not primary aquifers or are aquifers without any associated data for verification.

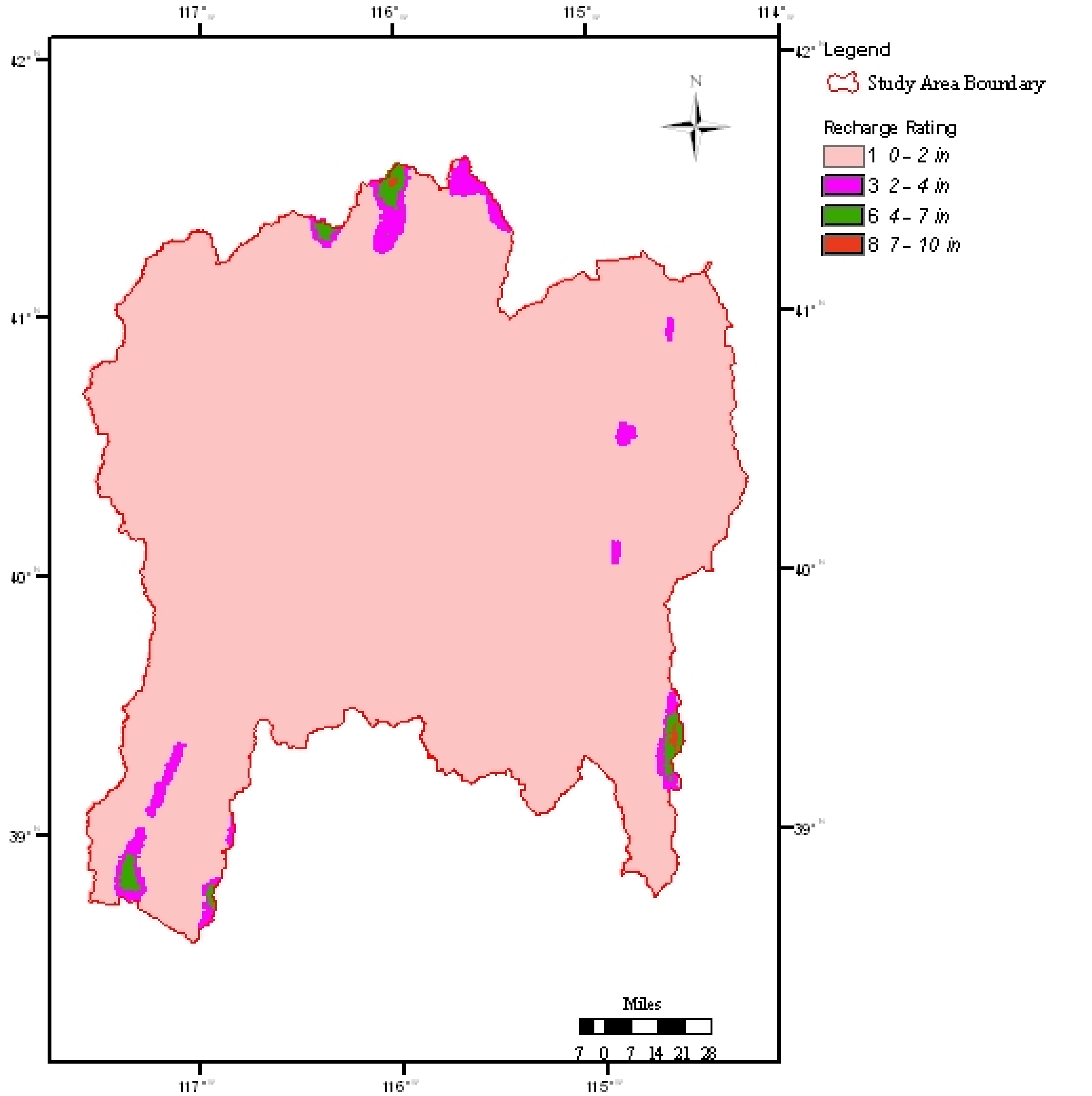


Figure 5 – DRASTIC Recharge Ratings: Showing that most areas included in the study have recharge rates < 2 inches/year, except in north, southwest, and east where recharges are 2 to 10 inches for the north and the southeastern, 2 to 7 inches for the southwestern, and 2 to 4 inches for the eastern areas.

Recharge values for the study area are predominantly 2 inches or less for the entire study area with the exception of four small regions located in the north, east, southeast, and southwest where the recharge has been determined to be greater than 2

inches per year. Recharge is based on natural rainfall and not on artificial recharge such as irrigation.

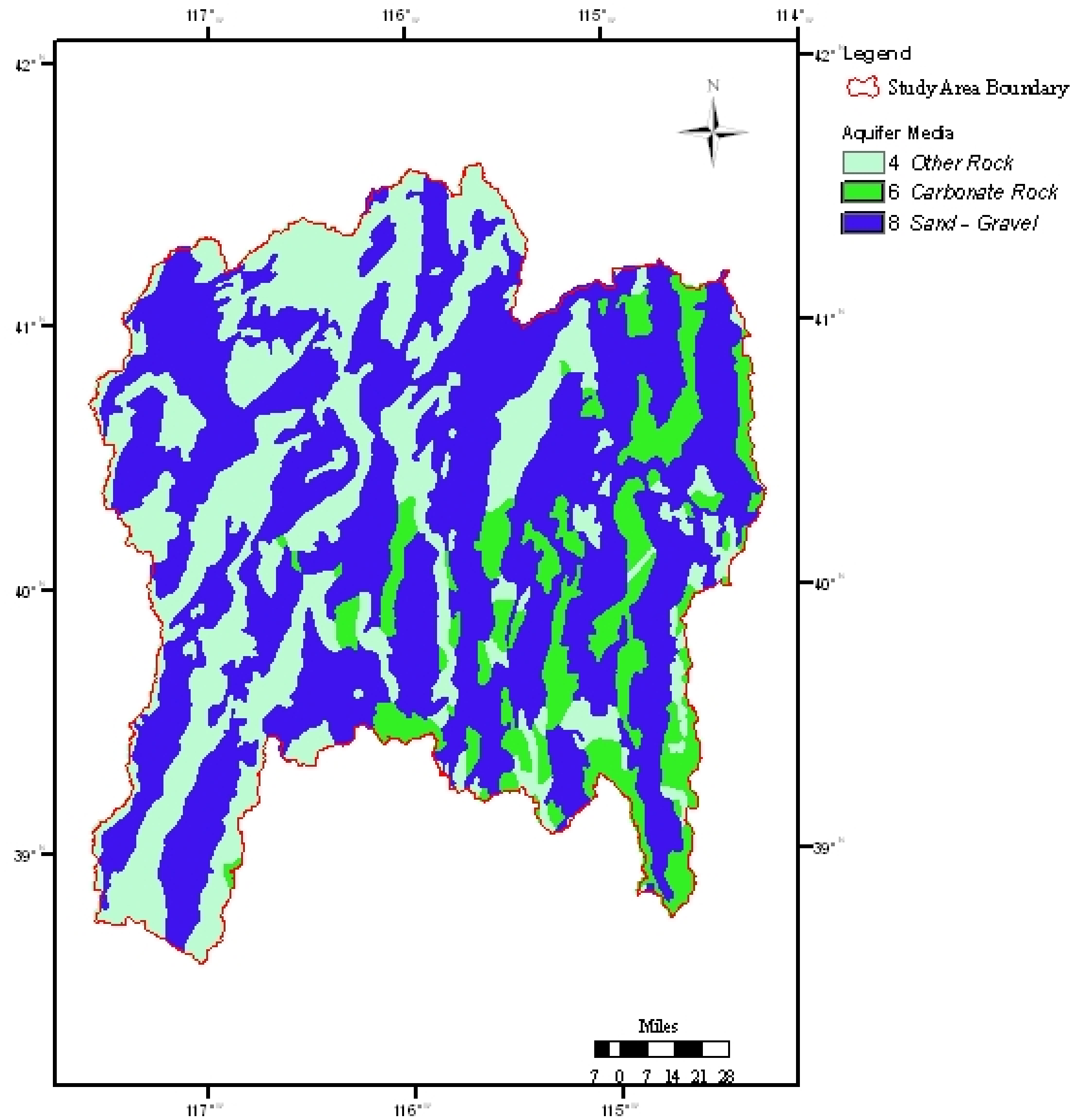


Figure 6 – Aquifer Media Ratings: Other rock and carbonate rock are predominately located in the mountain ranges and sand gravel mixture is located in the valleys. This can be seen with the overlap of the topography (not displayed).

When the aquifer media map is compared with the topography map, the regions of sand and gravel are within the valleys and carbonate rock and other rock are in the

mountain ranges. Sand and gravel have a greater infiltration rate than rock formations giving it a higher value than carbonate rock, which has moderate infiltration rate.

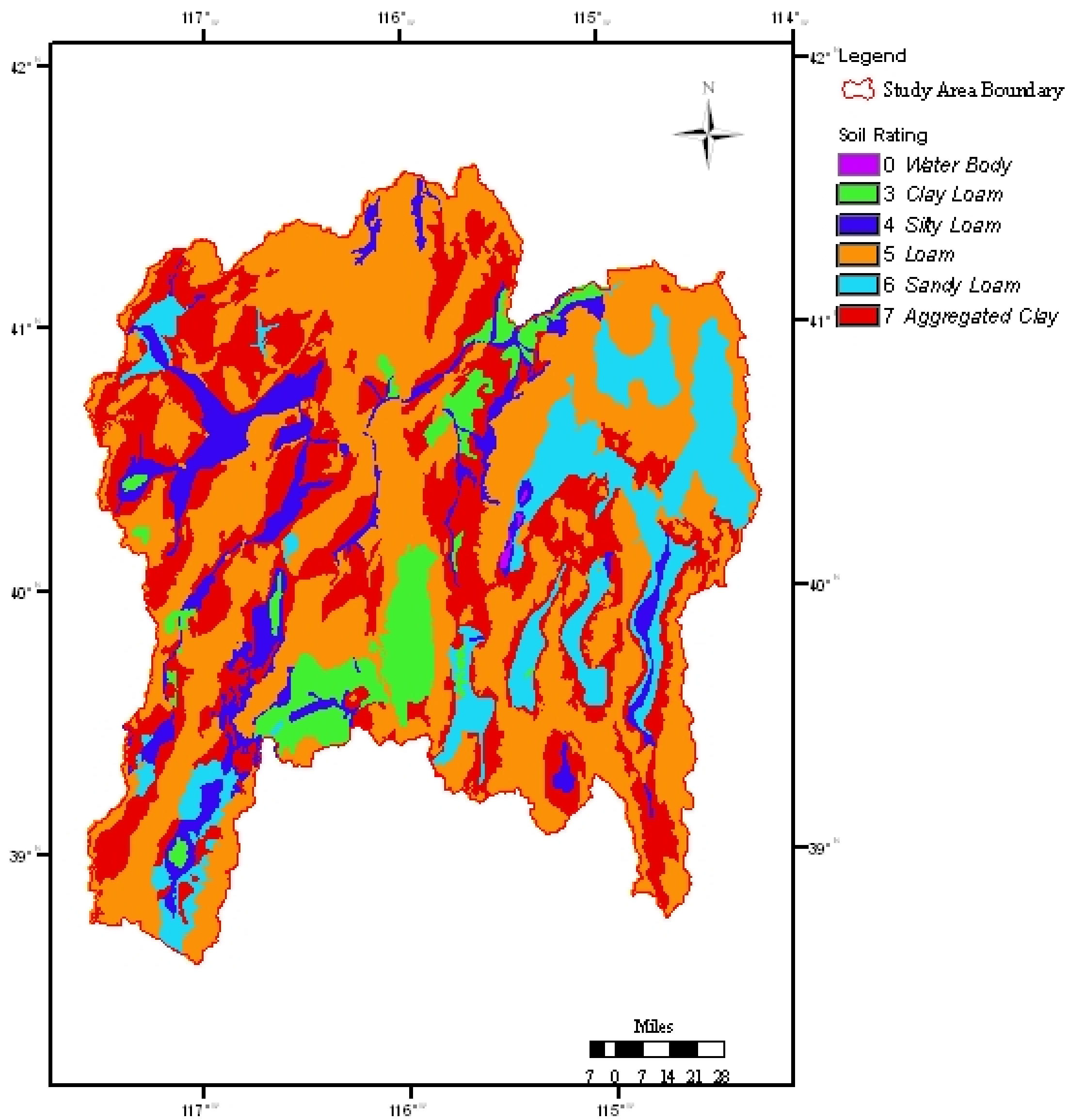


Figure 7 – Soil Media Ratings: Sandy loam and loam are the predominant soils types on the eastern portion of the study area and silty loam and aggregated clay is the predominant soil type to the west with clay loam in the south.

Soil media ratings were based on the ease of infiltration with a high value for high infiltration and low runoff rates as well as low values for low infiltration rates and high

runoff. The lower values indicate a higher runoff rate. Sandy loam is found mostly in the valley regions and loam soils are found in the mountain ranges.

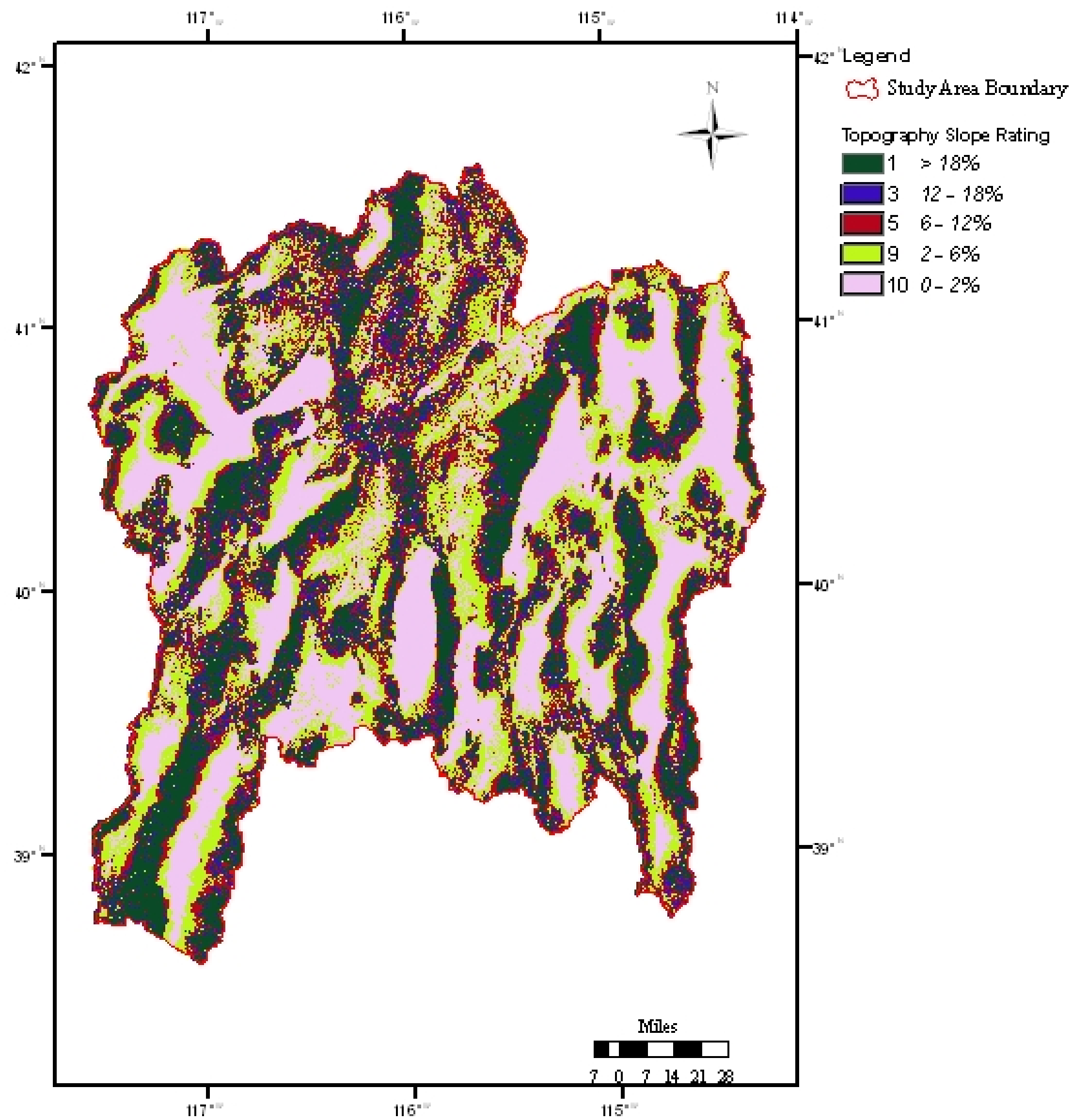


Figure 8 – Topography Slope Ratings: Areas with slopes greater than 18% indicate the predominant mountain ranges. Slopes less than 2% indicate the valleys.

The percent slope of the topography was calculated from the change in elevation as ft/ft and transformed to a percentage. The mountain ranges have a high slope percentage with a low rating value and the valleys have a low slope percentage with a

high rating value. This means, the higher the rating value the lower the runoff velocity which would allow for greater infiltration to occur.

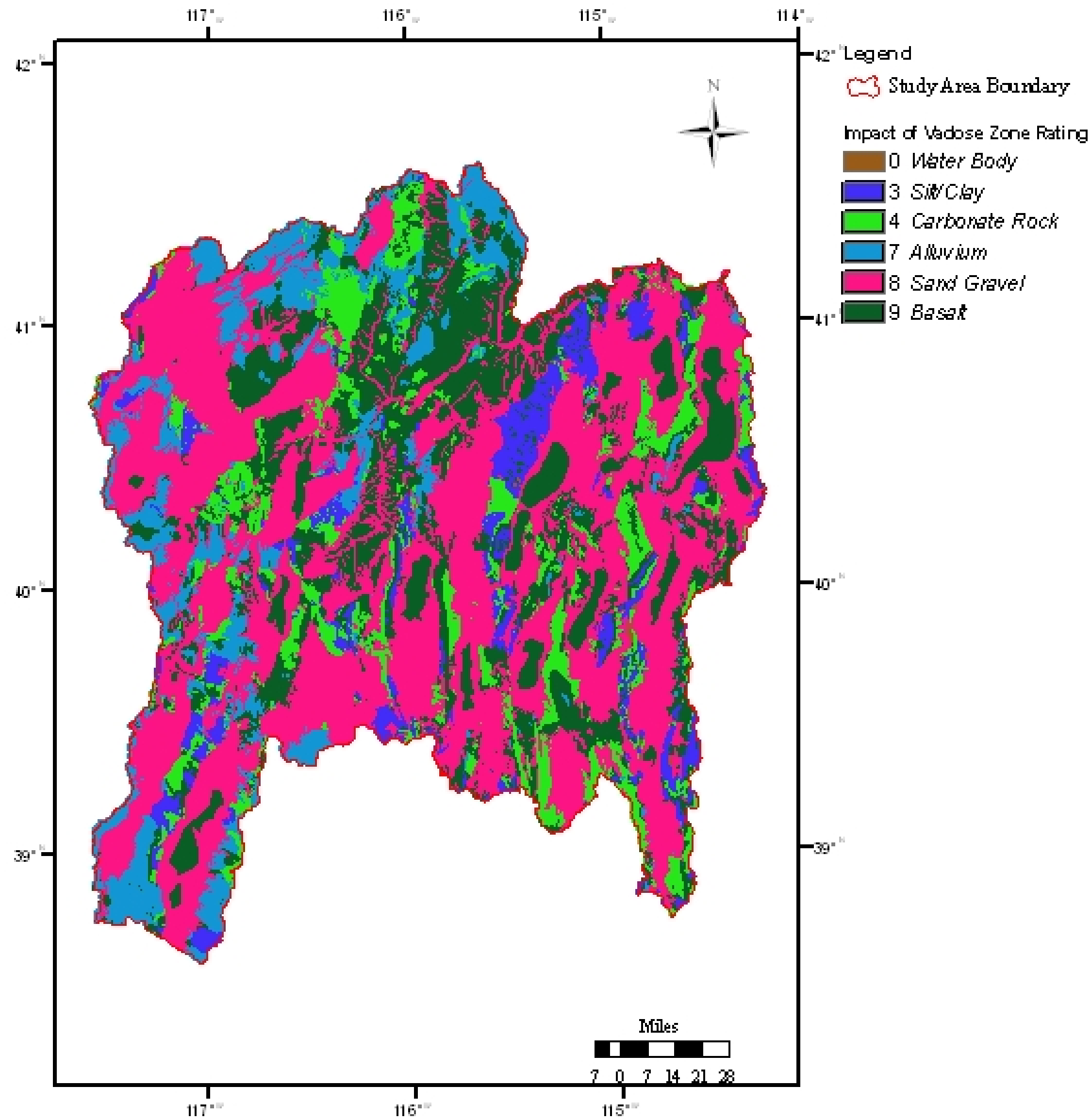


Figure 9 – Impact of Vadose Zone Ratings: Sand and gravel mixtures are shown to be predominantly in the valleys and silt/clay and alluvium tend to be in the mountain ranges.

The rating values of the vadose zone indicate that greater values result in a greater infiltration rate through the strata. Sand and gravel as well as basalts have high infiltration where as other strata types have lower infiltration rates. If contamination

were to occur, the higher rating values would allow the transport of the contaminants at a faster rate than with a low rating value.

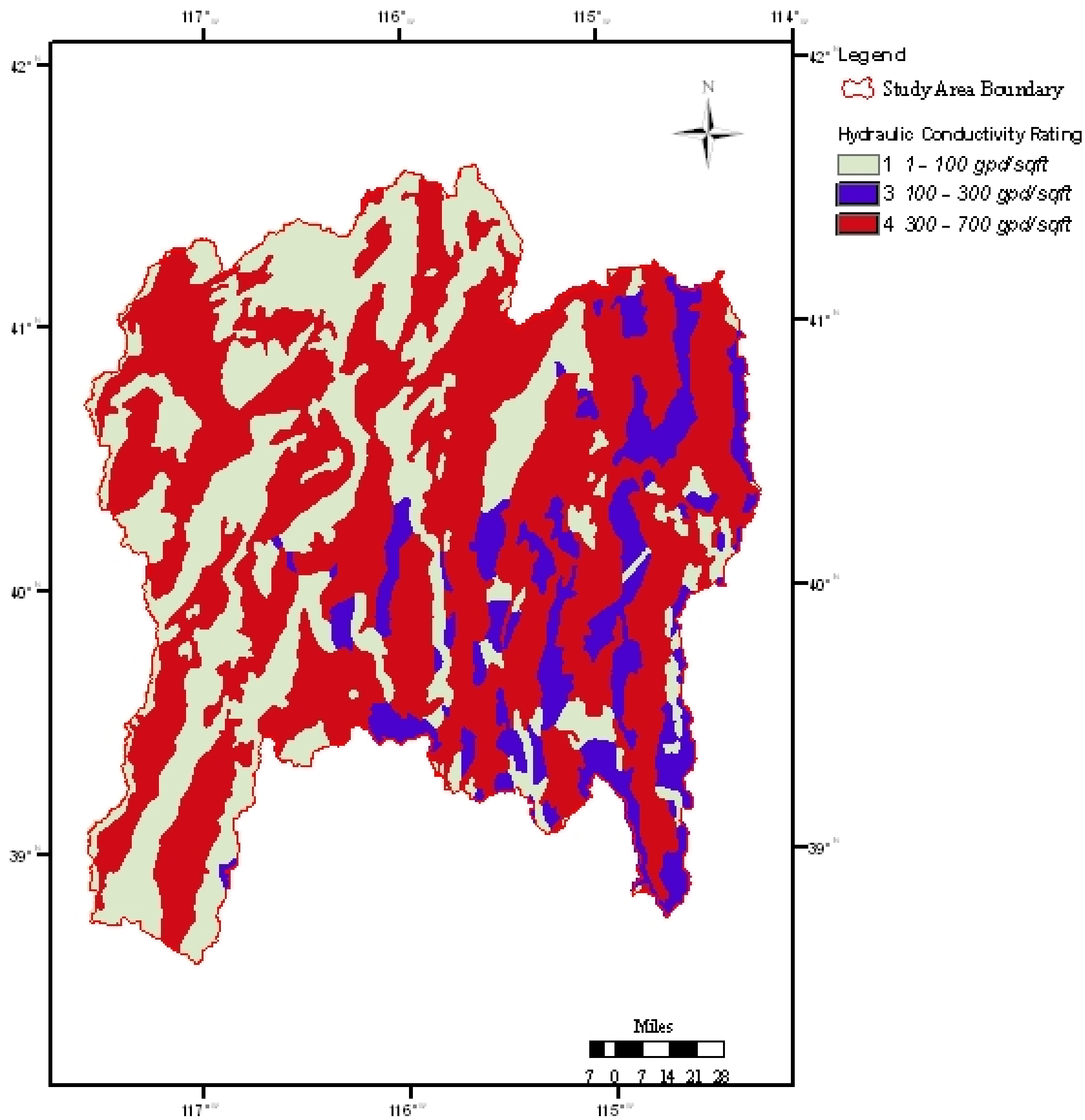


Figure 10 – Hydraulic Conductivity Ratings: Hydraulic conductivity of 300 to 700 gpd/sqft is located within the valleys and the hydraulic conductivity of less than 100 gpd/sqft is located in the mountain ranges.

Hydraulic conductivity rating values indicate that, when compared to the topography map, higher conductivity occurs in the valley floors than it does in the

mountainous regions. The higher the rating value the faster a contaminant can travel through the media than through a region with a low rating.

The previously described aspect layers were assembled and Equation 1 was applied to determine the vulnerability for the study area. The calculated values were from a low of 46 to a high of 187. From these values a vulnerability rating can be applied using Table 17. Values found in the range of 0 to 79 were assigned a new value of 1 (-this is referred to as reclassification-); calculated values in the range of 80 to 99 were reclassified with a value of 2 and so on, up the value of 7 which represents extreme vulnerability to contamination.

Table 17 – DRASTIC Method – Rating Index Values

DRASTIC Rating Index		
Rating	DRASTIC Value	Vulnerability
1	<79	Very Low
2	80-99	Low
3	100-119	Moderate Low
4	120-139	Moderate
5	140-159	Moderate High
6	160-179	High
7	180-199	Very High

From the reclassified values a map can be assembled using a visual code to depict the different values. Figure 11 displays the results of the vulnerability calculation with associated colors for the vulnerability ratings. Comparing with the individual layer maps, in general, the vulnerability areas appear to be high in the valley floors and low in the mountain ranges. Values of very low and low vulnerability are predominantly in the mountain ranges where topography, soil media, aquifer media, and impact of vadose have

low to moderate ratings are found in the mountain ranges whereas high rating are found in the valleys.

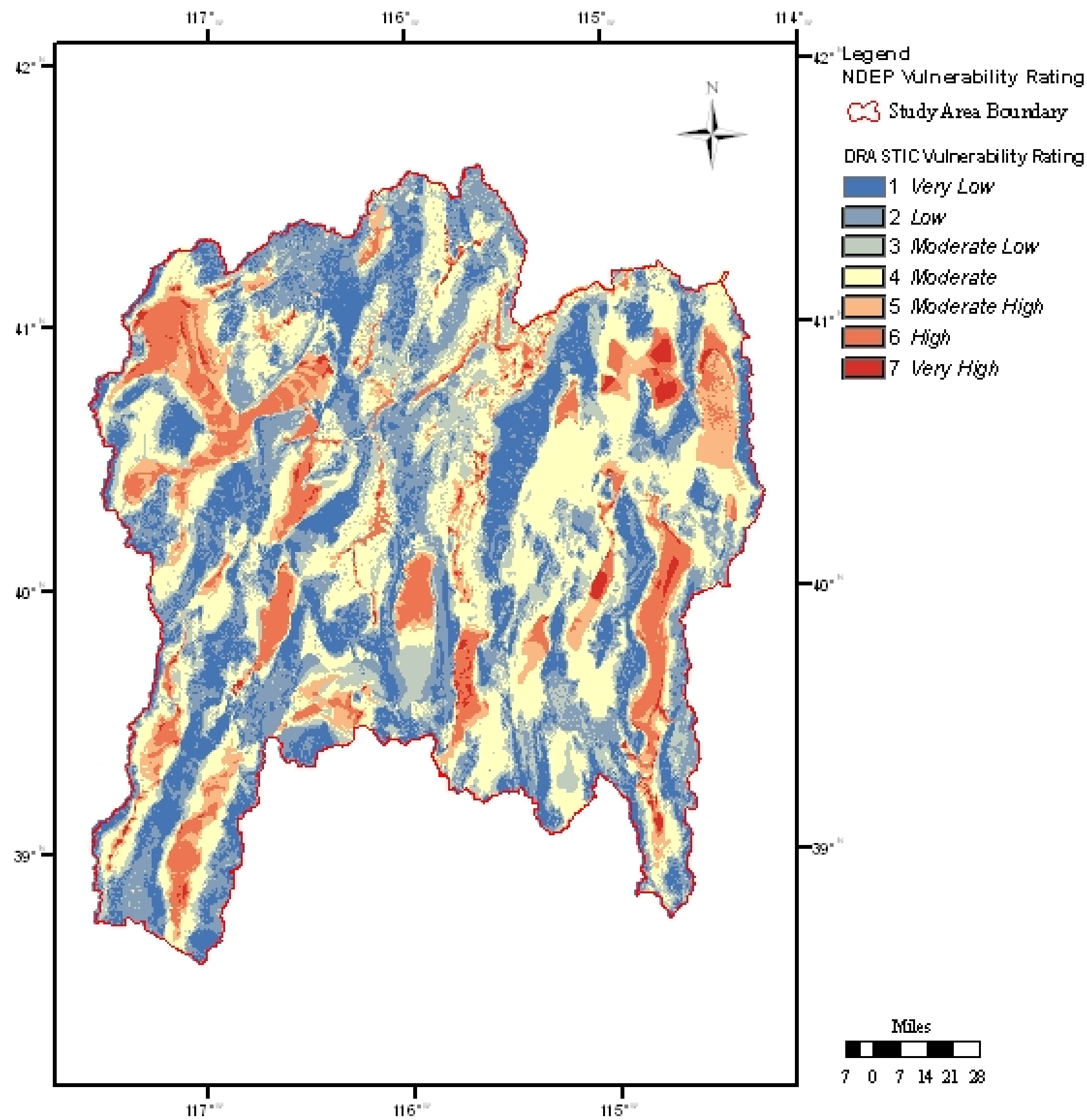


Figure 11 – DRASTIC - Vulnerability Ratings: When compared with the topography, high vulnerability is predominantly located in the valleys and low vulnerability is located in the mountain ranges.

4.2 DRASTIC Method Sensitivity Analysis

Several studies have addressed the reliability of DRASTIC and the subjectivity of the rating obtained (Barbash & Resek, 1996; Koterba, et al., 1993; Rupert M., 1997; USEPA, 1993). One of the criticisms of DRASTIC is that some variables used in the mapping may not be needed for determining vulnerability. In this research, sensitivity analysis was performed for the DRASTIC map obtained. Two types of sensitivity analyses have been employed: (a) the map removal sensitivity analysis and (b) the single parameter sensitivity analysis (Lodwick, et al., 1990; Napolitano & Fabbri, 1996). The map removal sensitivity analysis uses a method of removing one or more layers of a map to determine the significance of the removed layer(s) (Lodwick, et al., 1990). The single parameter sensitivity analysis determines a "theoretical" weight for each of the seven layers which are compared with the "effective" (actual) weight that was used in the vulnerability parameters (Napolitano & Fabbri, 1996).

The map removal sensitivity analysis involved removing one layer at a time to determine the effects of that layer on the initially calculated vulnerability. The removal was performed in order of the acronym of DRASTIC and is displayed in Table 18. Each letter indicates the layer removed for the analysis. By comparing the means of the initial vulnerability map, an evaluation can be performed about the significance of the layers. A comparison of the mean values reveal that the layers of (D) depth to water, (R) recharge, and (C) hydraulic conductivity have low impact on the vulnerability map built. This was determined by comparing the values of mean (107.10, 108.64, and 107.10) with the mean of the initial vulnerability map of 112.96. The vadose zone layer was found to be the most significant for the map, based on 112.96-83.47=29.49, producing the greatest value.

Aquifer media, topography, and soil media are the next most significant layers, while the least significant layers are found to be depth to water, recharge, and hydraulic conductivity.

Table 18 – DRASTIC Method Map Removal Sensitivity Analysis Results

Layer	Weight	std	Mean	Sensitivity	min	max
D	5	30.57	107.10	5.86	44.00	179.00
R	4	32.77	108.64	4.32	42.00	183.00
A	3	28.59	93.48	19.48	34.00	163.00
S	5	31.64	85.87	27.09	21.00	152.00
T	3	24.00	94.23	18.73	43.00	157.00
I	4	28.67	83.47	**29.49**	36.00	151.00
C	2	30.57	107.10	5.86	44.00	179.00
ASTI Vuln.	N/A	22.83	84.69	28.27	40.00	125.00
Vuln.	N/A	32.47	112.96	N/A	46.00	187.00

The DRASTIC vulnerability map was recalculated by removing the three less significant data sets of depth to water, recharge, and hydraulic conductivity. With the removal of the three least significant layer, a smaller range of values, a smaller standard deviation and a smaller mean were found (ASTI Vuln.). When compared to the vulnerability map results (Vuln.) the sensitivity value is 28.27 confirming the four layers are the most significant. Additionally, the range decreased resulting in a decrease of degrees of vulnerability for the map. A reclassification would be needed to reestablish the proper degrees of vulnerability. A figure has been plotted (Figure 12) with just the four significant layers for a visual reference.

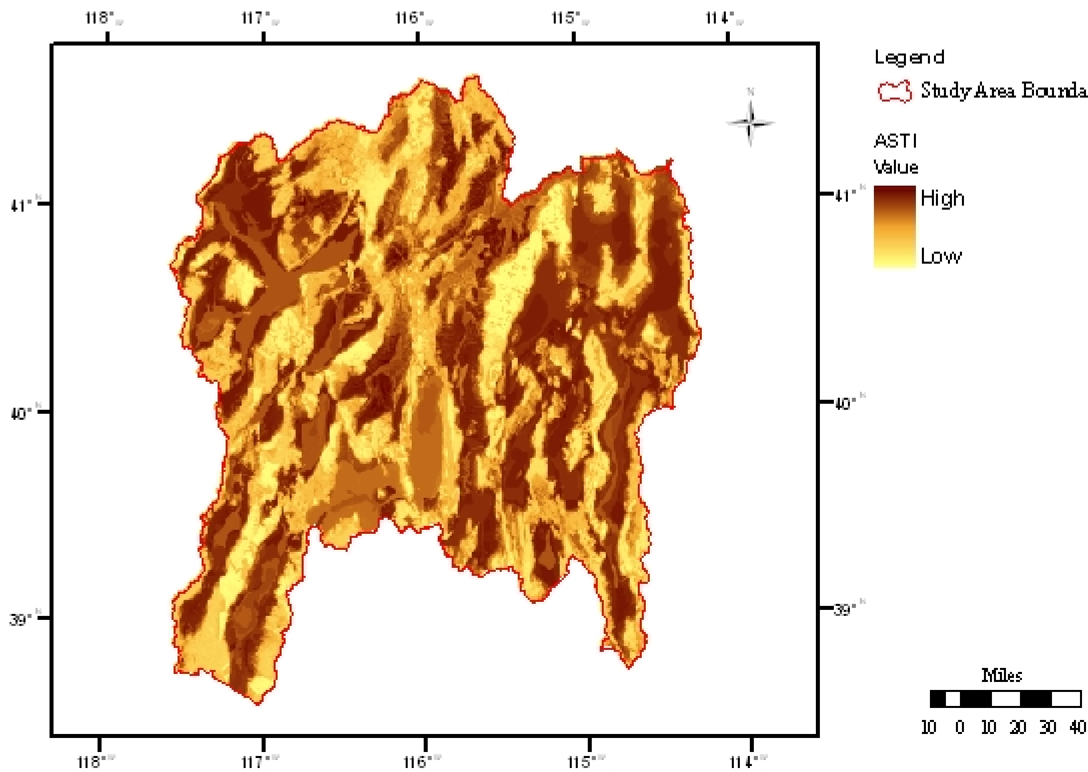


Figure 12 –ASTI - Vulnerability Ratings: When depth to water, recharge, and hydraulic conductivity are removed, the resultant map indicates similar regions of vulnerability.

The single parameter sensitivity method uses equation 5 to determine the theoretical weight for comparison to the effective weight used in the vulnerability map computation.

$$W_{pi} = \frac{P_{Ri} P_{Wi}}{Vuln_i} 100 \qquad \text{(Equation 5)}$$

Where

W_{pi} = Theoretical Weight (Avg. %Weight)

P_{Ri} = Layer Rating Value (e.g. 1 – 10)

P_{Wi} = Layer effective Weight (weight used in the model of 1 – 5)

$Vuln_i$ = Calculated Vulnerability result for DRASTIC

By applying the equation in the raster calculation feature of ArcInfo, statistical elements can be determined. Table 19 is a summary of these results for each of the seven layers indicated by the representative letter on the left column. Comparing average percent weight (Avg. %Weight) and effective percent weight (%Weight) a determination can be made about the effectiveness of the layers. The layers of depth to water, recharge, and hydraulic conductivity are less significant than aquifer media, soil media, topography, and impact of vadose zone. Impact of vadose zone is the most effective layer for this model indicated by 25.10-15.38=9.72 resulting in the largest value. The next most effective layer is aquifer media with a result of 5.04 followed by topography and soil media.

Table 19 – DRASTIC Method Single Parameter Sensitivity Analysis Results

Layer	Weight	%Weight	Avg. %Weight	std	Mean	min	max
D	5	19.23	6.81	9.36	5.06	0.00	46.30
R	4	15.38	3.68	2.73	4.23	2.14	35.56
A	3	11.54	16.58	3.76	17.59	7.10	37.50
S	5	19.23	23.07	7.78	25.77	0.00	54.35
T	3	11.54	15.94	7.28	15.35	1.88	40.00
I	4	15.38	**25.10**	6.96	26.93	0.00	50.00
C	2	7.69	4.99	2.01	5.06	1.18	12.50

Both sensitivity analysis methods indicated that impact of vadose zone, soil media, aquifer media, and topography are the most significant layers. Depth to water, recharge, and hydraulic conductivity have been found to be less significant based on the two sensitivity analyses. These results also explain why in the region, the areas of high

vulnerability are located in the valleys while the areas of low vulnerability are located in the mountain ranges.

The importance of grid size on the results of DRASTIC was evaluated by recalculating the vulnerability rankings with a 500 meter cell size instead of the 100 meter previously used. The 100 meter cell size was selected to allow for a comparison with the NDEP method, where contaminant sources within a 1000 ft radius are considered. When a 500 meter cell grid size was used, the values of vulnerability obtained were very similar to those found when a 100 meter grid was established. Therefore, the use of 100 meter cell size is adequate for this map. The difference appears to be that the 100 meter cell size has a slightly better standard deviation than the 500 meter cell size map.

Table 20 – DRASTIC Cell Size Comparison

	Mean	STD	Min	Max
100 meter	112.69	32.47	46	187
500 meter	117.03	38.42	46	187

4.3 DRASTIC Method Land Use Comparison

A comparison between the three land uses has been prepared using a percent occurrence based in the defined regions. This was accomplished by tallying the values of the 7 levels of vulnerability to determine the percent of values that occur within each of the defined regions. The results are shown in Table 21 and in the accompanying graph (Figure 16). The graph has been displayed with the three land uses side by side per value of vulnerability.

Figures 13 to 15 show the vulnerability map reproduced from Figure 11. According to the DRASTIC vulnerability map and from visual reference, a generalization can be made that mining is located in regions with low vulnerability and irrigated lands and towns are located in areas of high vulnerability. Additional analysis, using actual contamination data will be needed to determine if the visual generalization is valid.

Table 21 summarizes the results of percent occurrence for each of the seven layers of vulnerability as well as each of the three land uses. As expected from the visual generalization, mining is predominately located in regions of very low (36.46%) and low (32.99%) vulnerability. In addition, towns and agriculture are located in regions of moderate to high vulnerability.

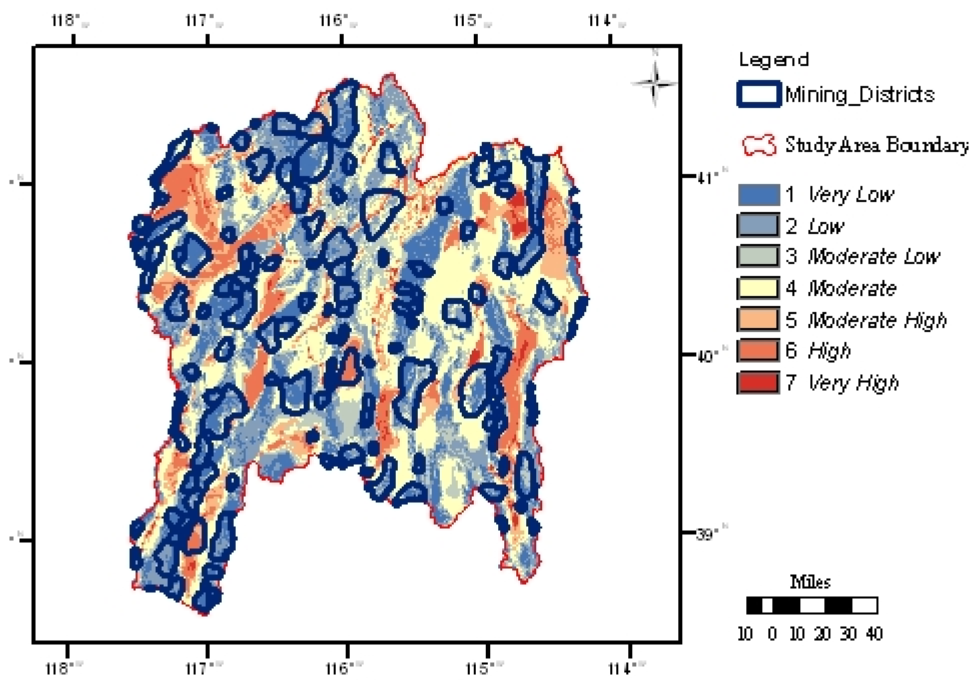


Figure 13 – DRASTIC Vulnerability MAP with Mining Activities

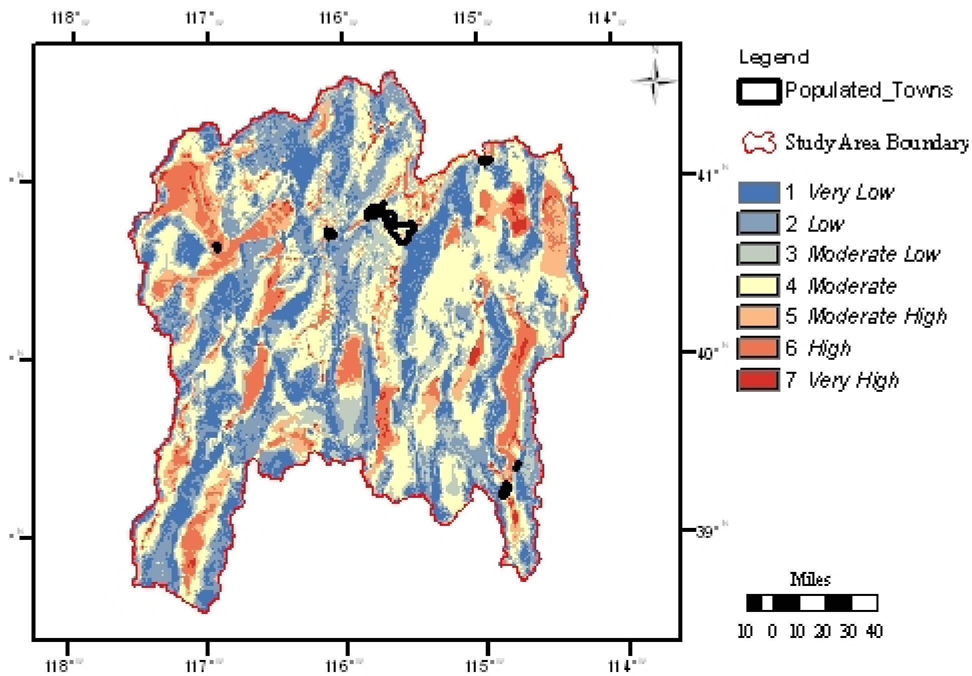


Figure 14 – DRASTIC Vulnerability MAP with Towns

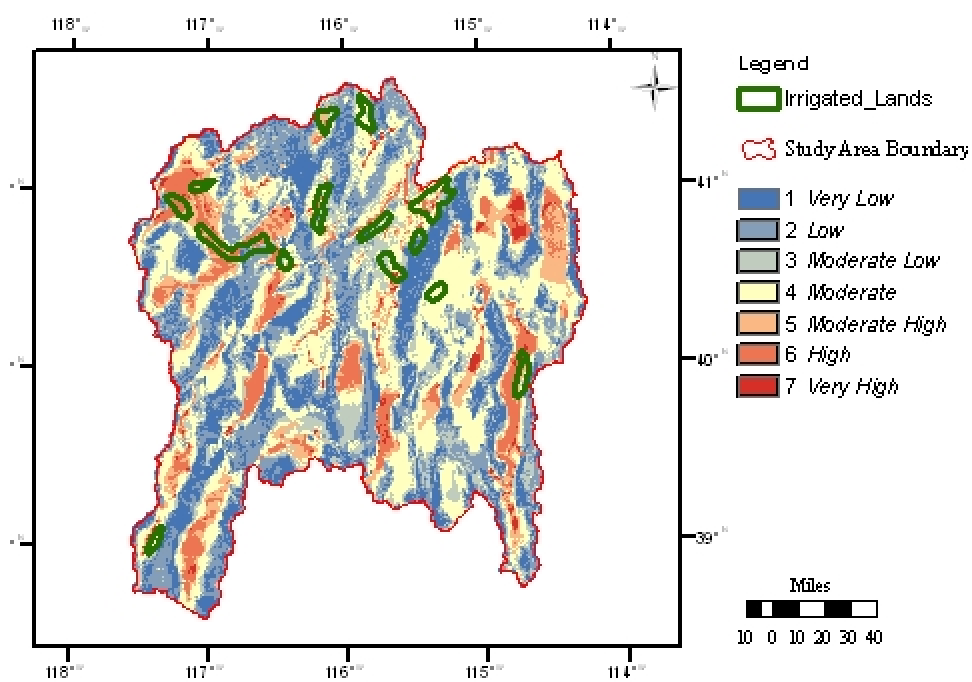


Figure 15 – DRASTIC Vulnerability with Agricultural Activities

Figure 13 through 15 depict the vulnerability results from DRASTIC with the three land uses, one for each map. The regions of the three land uses indicate their locations in relation to the vulnerability. Mining tends to be located in regions with less vulnerability, agriculture tends to be in regions with high vulnerability, and towns tend to be located in a range moderate low to high vulnerability levels.

Table 21 – DRASTIC Method – Results Percent Per-rating

DRASTIC Percent Vulnerability				
Ranking	Rating	Mining	Towns	Agriculture
1	Very Low	**36.46**	0.35	3.52
2	Low	**32.99**	1.05	7.98
3	Moderate Low	**17.21**	12.67	13.66
4	Moderate	10.40	**34.98**	**25.73**
5	Moderate High	2.06	**31.11**	**16.26**
6	High	0.78	**17.64**	**26.22**
7	Very High	0.10	2.20	6.63

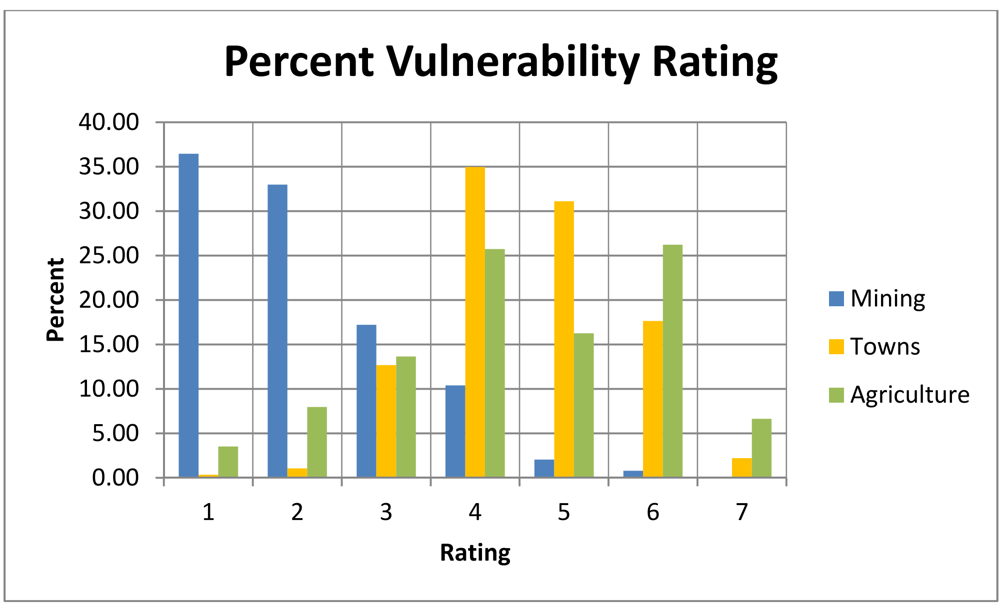


Figure 16 – DRASTIC - Percent vs. Rating Vulnerability Graph: Land use is displayed in percent occurrence for each of the three defined regions

The results indicate that, in the region studied, mining is located predominantly in regions of very low to moderate vulnerability. This finding is coincidental in this region because the natural deposits of precious metals are typically located in mountain regions in Nevada. In contrast, agriculture is located in regions of moderate to high vulnerability. This can be realized based on the shallow slope and the shallow depth to ground water, which are favorable conditions for agricultural activities. Similarly, towns are located mostly in the moderate to high regions of natural vulnerability most likely due to the location of the dominating industry (e.g. mining and agriculture) and accessibility to water.

It was hypothesized in this study that activities in towns may be as potentially detrimental to groundwater as mining. The vulnerability map for the studied region indicates that activities in towns are potentially more detrimental to groundwater quality due to the location and geologic and/or hydrogeologic conditions. This implies that if a contaminant were to be released at a town, the ground water could be contaminated more readily than if a similar contamination were to occur at a mining site. This is almost entirely due to the differences in location of the land use areas and should be considered coincidental or a special case in Nevada. Therefore, DRASTIC results indicate that the potential for groundwater contamination in Northern Nevada is higher for mining towns than for mining itself.

Agriculture has the highest vulnerability indicating that any contaminant released in agricultural areas may likely contaminate the groundwater easier than if a similar

contaminant were released in towns or mining areas. As with the towns, geologic conditions that favor agriculture are in regions of high vulnerability.

4.4 Arsenic and Nitrate contamination correlation with vulnerability and land use

Naturally occurring and anthropogenic contaminants have been detected in groundwater wells of northern Nevada. Naturally occurring contaminants detected in the area include arsenic, fluoride, and radionuclides. Nitrate, an anthropogenic contaminant has also been detected.

While arsenic, fluoride, and radionuclides in Nevada are naturally occurring, nitrate is generally associated with the use of septic tanks, manure spreading, and the use of fertilizers in agricultural activities. A correlation was performed between the detection of naturally occurring and anthropogenic compounds detected in wells of the study area with the vulnerability ranking established by DRASTIC and land use types. It is expected that a low correlation will be found for naturally occurring compounds because their transport is independent on the aspects considered in DRASTIC. Nitrate, on the other hand, being an anthropogenic contaminant should have a strong correlation with vulnerability for the three land uses because the contaminant is commonly associated with specific potential contaminant sources. It is expected that that mining areas have a lower vulnerability to nitrate contamination than towns and agricultural areas.

The correlation between DRASTIC and the detected contaminants was tested by plotting occurrence frequency versus the level of vulnerability (Table 22). The frequency was computed by dividing the number of wells with contaminant detections per total

number of wells located in the defined level of vulnerability (equation 6) (Kalinski, et al., 1994).

$$\text{Frequency} = \frac{Number\ of\ Wells\ with\ Detects}{Total\ Number\ of\ wells} \qquad \text{(Equation 6)}$$

Table 22 – Correlation of Arsenic with Vulnerability

Vuln Rating	Wells w/ As	Total Wells	Frequency
1	6	6	1.00
2	3	6	0.50
3	9	10	0.90
4	16	23	0.70
5	16	19	0.84
6	17	19	0.89
7	6	6	1.00

Figure 17 shows the frequency of arsenic detections versus vulnerability rating for 110 wells located in the studied region. When all the data were plotted, a very weak correlation (R^2=0.0986) was found. However, when the low vulnerability ranking was removed, a very strong correlation was observed (R^2=0.9689). The rationale of removing the low vulnerability data is that there are few or no areas in the region where the potential for groundwater contamination with naturally occurring contaminants is low; this is the case because these compounds occur extensively in the entire region.

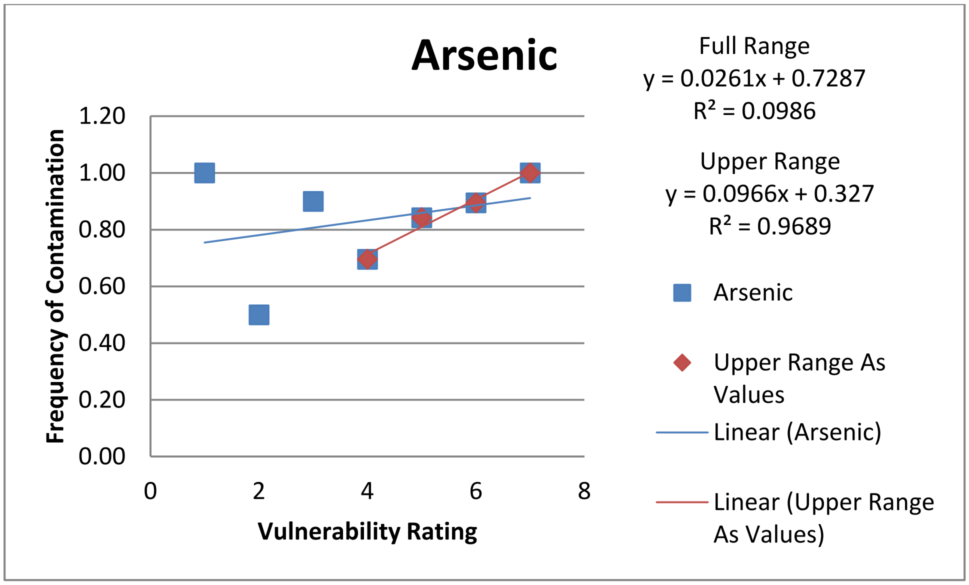


Figure 17 – Arsenic detection correlation with vulnerability ranking using DRASTIC.

A similar correlation to that performed for arsenic was also carried out for fluoride and radionuclide detections. Similar to that observed for arsenic strong correlation was also found for fluoride when the low vulnerability data was removed (Tables 22 and 23, Figures 17 and 18). The correlation for radionuclides is not as strong as that observed for arsenic and fluoride.

Table 23 – Correlation of Fluoride with Vulnerability

Vuln Value	Wells w/ F	Total Wells	Freq.
1	5	6	0.83
2	3	6	0.50
3	8	10	0.80
4	22	23	0.96
5	14	19	0.74
6	15	19	0.79
7	4	6	0.67

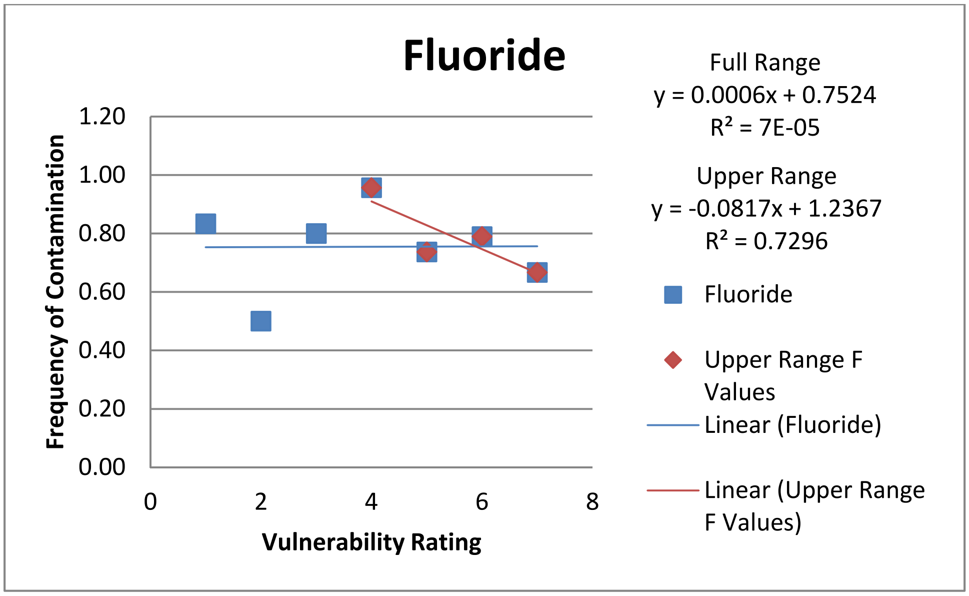


Figure 18 – Fluoride detection correlation with vulnerability ranking using DRASTIC.

Table 24 – Correlation of Radionuclide with Vulnerability

Vuln Value	Wells w/ RAD	Total Wells	Freq.
1	6	6	1.00
2	3	6	0.50
3	6	10	0.60
4	18	23	0.78
5	13	19	0.68
6	16	19	0.84
7	5	6	0.83

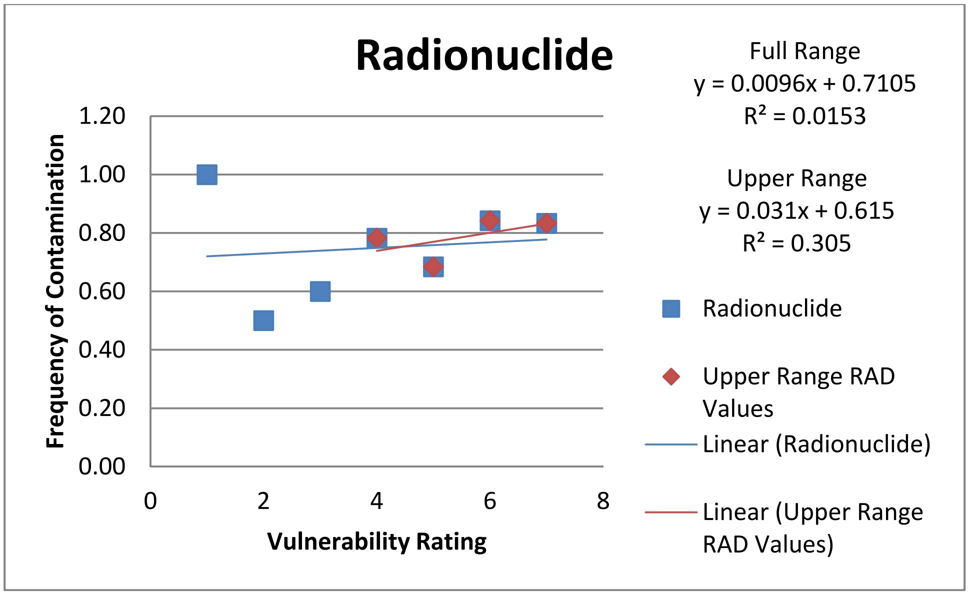


Figure 19 – Radionuclide correlation with vulnerability ranking using DRASTIC.

The very low correlation coefficient (0.0153) found for radionuclides, indicating weak overall correlation between radionuclide occurrence and the various vulnerability levels. When the low vulnerability data is removed, a slightly higher correlation coefficient (0.305) is found. However, this correlation coefficient is much smaller than for those found for arsenic and fluoride. This result is unexpected; one expects the same trend for radionuclides, fluoride, and arsenic. This discrepancy cannot be explained using the current data available.

Nitrate contamination is typically associated with sources such as animal feed lots, septic tanks, cesspools, etc. In many mining towns septic tanks are used widely and one would expect a correlation of nitrate with this land use. In addition, because of their remoteness, mining operations themselves make use of septic tanks to accomplish sanitation goals on the site, but the number of septic tanks present in towns is much higher. Likewise, one would expect some correlation of nitrate occurrence with

agriculture due to increased use of manure spreading and fertilizer on fields. However, from all three activities, mining is expected to be the one with less likelihood to promote contamination by nitrate because the number of septic tanks and other nitrate-generating activities are less prevalent in this land use than in agriculture and towns.

Figure 20 shows a very low correlation between nitrate detections in the entire region and the vulnerability established by DRASTIC.

Table 25 – Correlation of Nitrate with Vulnerability for the three land uses

	Mining			Agriculture			Towns			Total
Vuln Value	Nitrate Detect	Total Wells	Freq.	Nitrate Detect	Total Wells	Freq.	Nitrate Detect	Total Wells	Freq.	Freq.
1	0	2	0.00	5	5	1.00	0	0	0.00	0.83
2	0	3	0.00	2	3	0.67	2	2	1.00	0.67
3	2	3	0.67	7	7	1.00	0	0	0.00	0.90
4	2	8	0.25	13	18	0.72	4	7	0.57	0.83
5	2	8	0.25	2	3	0.67	13	13	1.00	0.89
6	0	0	0.00	1	1	1.00	15	20	0.75	0.74
7	0	0	0.00	1	3	0.33	1	4	0.25	0.33

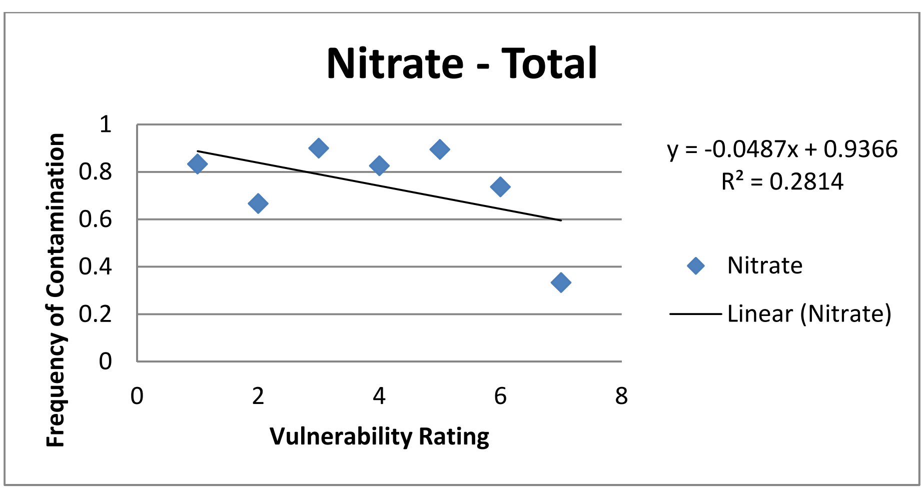


Figure 20 – Correlation between nitrate and vulnerability as established by DRASTIC.

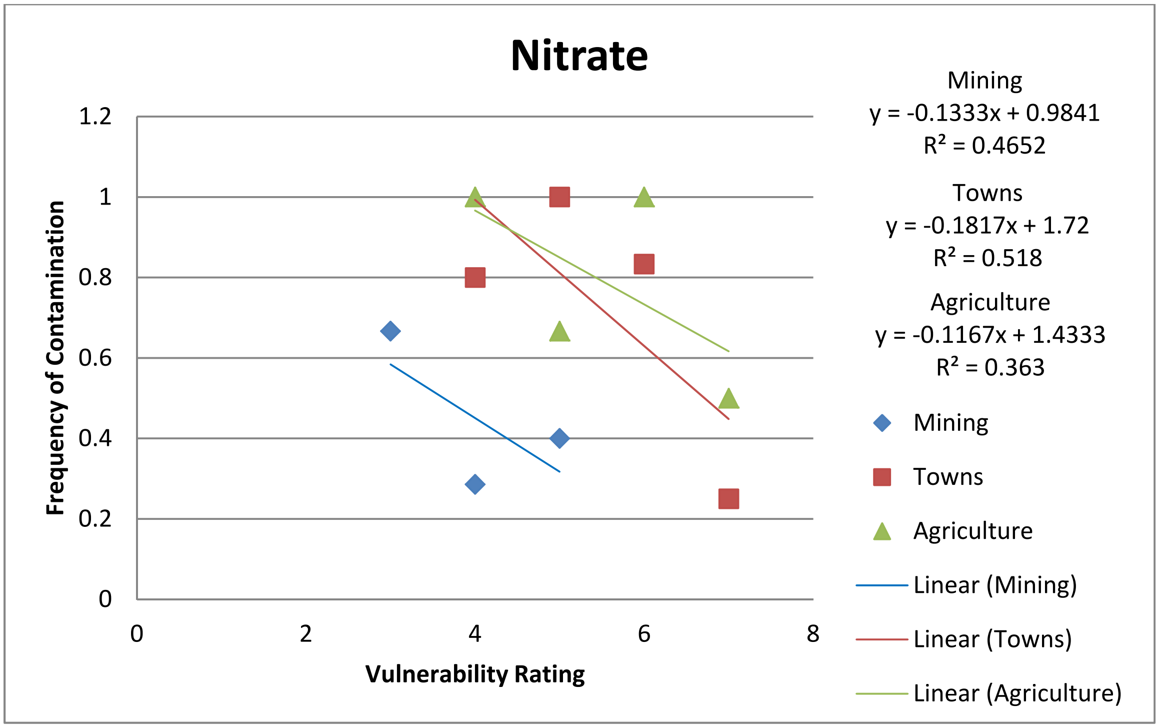


Figure 21 – Correlation of Nitrate with DRASTIC vulnerability for the three land uses.

A correlation between detections of nitrate and vulnerability are displayed for the three land use in Figure 21. Low correlation coefficients of 0.4652, 0.518, and 0.363 are found for mining, towns, and agriculture, respectively. The number of wells with nitrate detection in the entire region, including mining areas, is very high. Therefore, the results indicate that the vulnerability map provided by DRASTIC does not forecast adequately the vulnerability to nitrate contamination. The correlation coefficient was found to be higher for towns than for mining, as expected. However, a lower correlation was found for agriculture. The higher correlation coefficient found for mining and the high number of wells with positive detects could be the result of past agricultural activities where mining activities are now taking place. Several mining operations have established their

ancillary facilities in the foot hills, encroaching on historic agriculture. For these plots, the low vulnerability data was removed for agriculture and towns as well as the high vulnerability data was removed for mining.

4.5 NDEP Modified Method

The NDEP modified method uses characteristic of individual wells to determine a numeric value that is related to a level of vulnerability. Vulnerability was established in seven levels as very low, low, moderate low, moderate, moderate high, high, or very high. The results were based on the calculation of 110 wells and springs, hereon referred as wells, located in the three land uses, agriculture, mines, and mining towns within the same study area as used in the DRASTIC model. Figure 22 depicts the approximate well locations with the assigned vulnerability rating for a visual reference of occurrence.

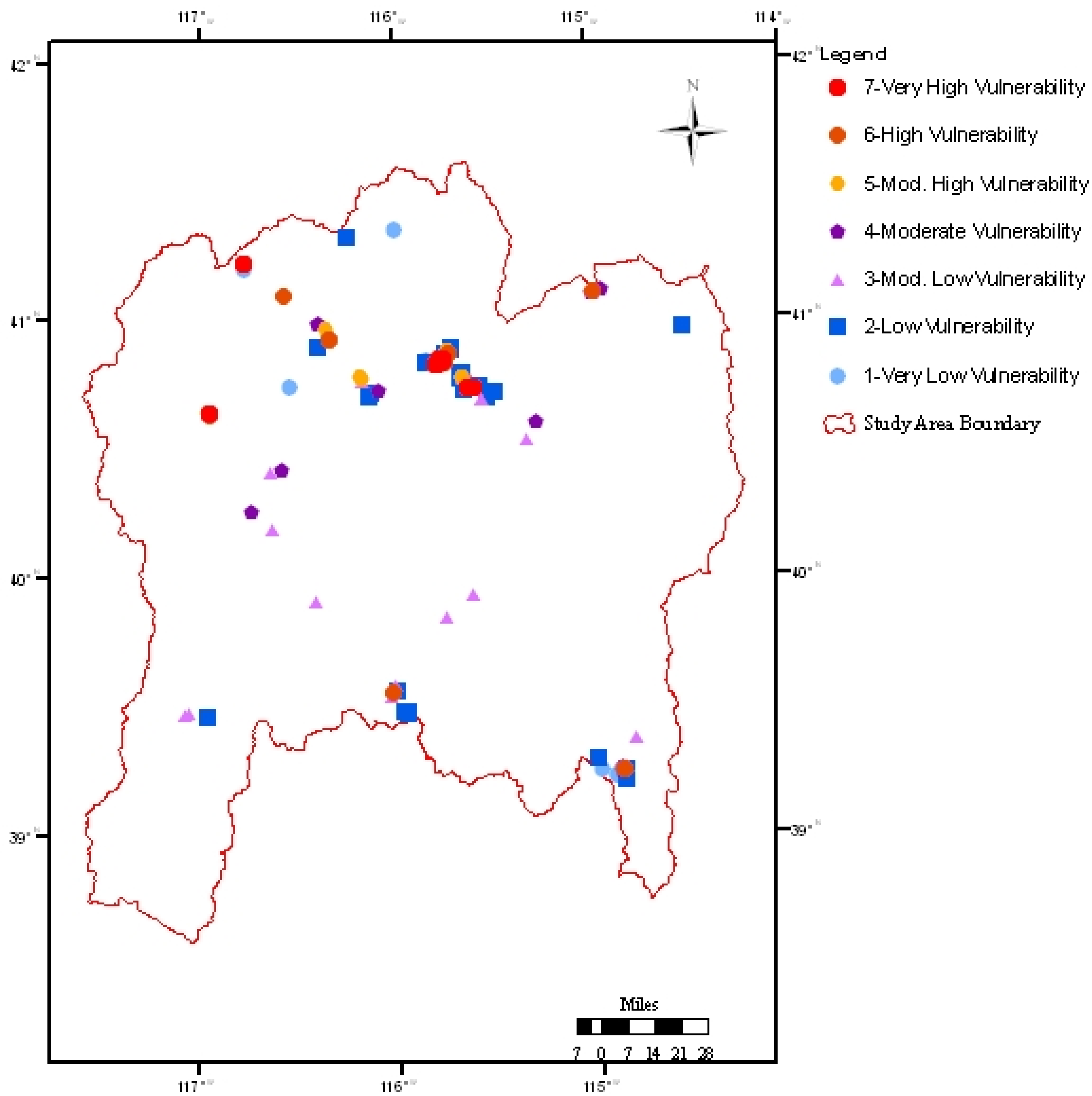


Figure 22 – NDEP Modified Method approximate well locations: Wells with different shading indicate different levels of final vulnerability.

A comparison between the three land uses has been prepared using a percent occurrence based on the land use from the well locations. This was accomplished by tallying the values of the 7 levels of vulnerability to determine the percent of values that occur within each of the defined regions. The results are shown in Table 26 and accompanying graph (Figure 23). The graph has been displayed with the three land uses side by side per value of vulnerability.

Table 26 – NDEP Modified Method – Results Percent Per-rating

NDEP Modified Method Percent Vulnerable				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	20.83	8.16	**8.70**
2	Low	8.33	20.41	**50.00**
3	Moderate Low	**25.00**	6.12	**17.39**
4	Moderate	**12.50**	**16.33**	6.52
5	Moderate High	**16.67**	**10.20**	6.52
6	High	12.50	**22.45**	4.35
7	Very High	4.17	16.33	6.52

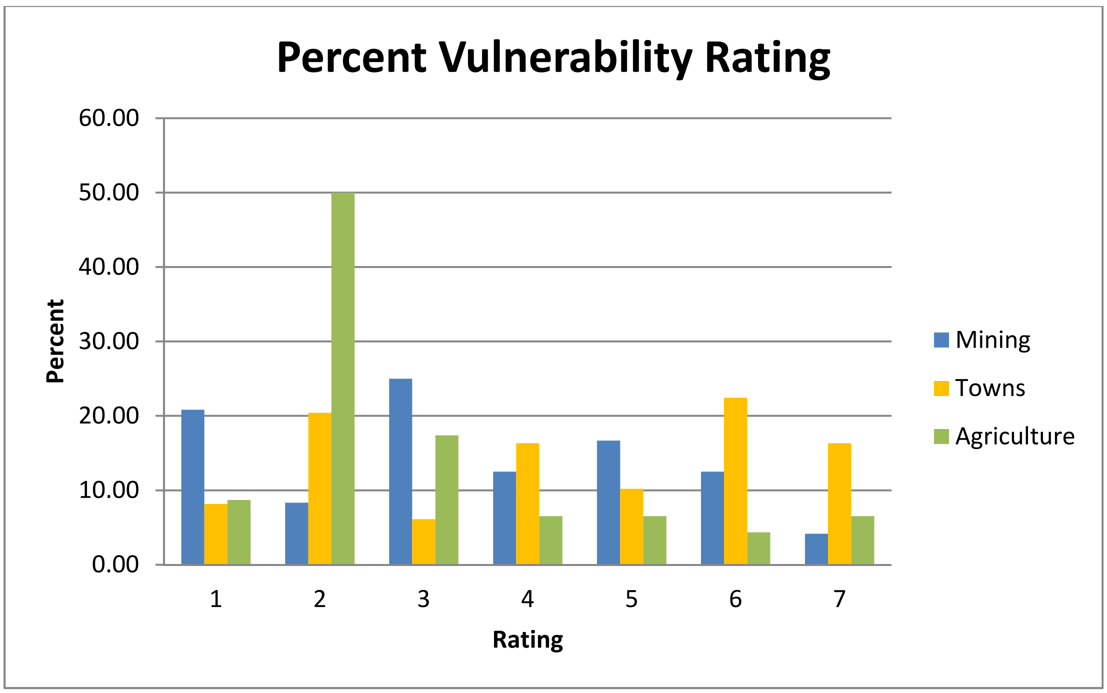


Figure 23 – NDEP Modified Method - Percent vs. Rating Vulnerability Graph: Land use is displayed in percent occurrence for each of the three defined regions of land uses.

The results indicate that mining falls into a range of very low to moderately low vulnerability; agriculture is predominantly moderate to low vulnerability and towns are in

moderate to high vulnerability areas. From examining the data of the wells associated with agriculture, few of the wells have significant number of PCSs located within the buffer zone. These wells also have a small number of contaminant detections resulting in predominantly low vulnerability ranking. Towns are located in areas that have many to no PCSs associated with the wells. The water quality of towns tends to have more contaminants detected than other wells. Mining results in a range of values of vulnerability with most occurring from very low to moderate. From reviewing the data, the majority of the wells are located away from mining activities with few PCSs. The water quality of mines tends to have greater number of naturally occurring contaminant detections.

DRASTIC AND NDEP MODIFIED METHOD COMPARISON

The DRASTIC vulnerability map indicates that most mining areas are located in low vulnerability regions with towns and agriculture located areas of moderate to high vulnerability. When comparing the percent area vulnerability forecasted by DRASTIC and the NDEP method, mining and towns are rated similarly by both methods. However, while DRASTIC rates agricultural areas as being of moderate to high vulnerability, the NDEP method rate agricultural areas as having moderate to low vulnerability. Because both methods contain inherent subjectivities, one cannot determine which one is more accurate unless they are compared with actual contaminant detection data.

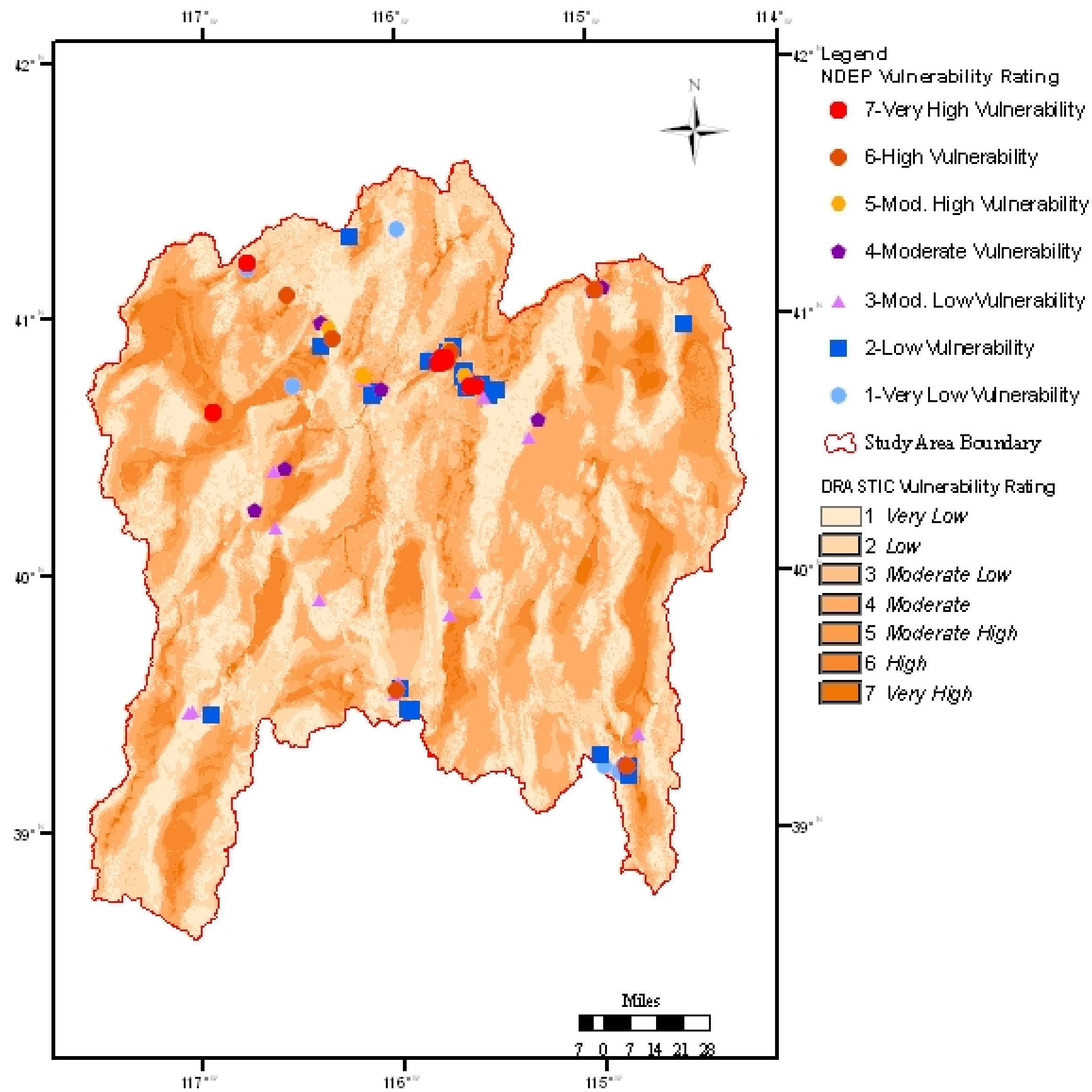


Figure 24 – DRASTIC and NDEP Vulnerability Comparison Map

Figure 24 depicts both methods within the same map for a visual comparison of the vulnerability levels. The background is the vulnerability results of DRASTIC and the symbols are the different results from the NDEP modified method. With the visual comparison as well as the percent occurrence results, one can see that a different means of comparison is needed.

To compare the two methodologies, the NDEP point map was transformed from points into a raster (grid). Having two raster images allows for direct comparison of the land use boundaries. Initially, Kriging was considered as a potential technique to convert the point data to a map. The point Kriging method, contained within ArcMap, did not generate a satisfactory map. With the assistance from Dr. A.K. Singh (UNLV Math department), area Kriging, using a proprietary software, was experimented with. However, the variogram obtained (Appendix B, Figure B1) was very poor indicating that the use of Kriging was not appropriate. In addition the Inverse Distance Weighted method in ArcMap was also analyzed. The results indicated a range of values from the moderate low to moderate high range. The values for very low, low, high, and very high were omitted from the results. This produced very little distinction between the land uses rendering any analysis difficult to interpret. The transformation of the NDEP points to a raster was then performed via triangulated irregular network (TIN) methodology contained within the ArcMap software.

The well contaminant detection data, previously used with DRASTIC (Section 4.4) was then used to compare DRASTIC and the NDEP modified method. The goal is to determine which map best predicts the actual occurrence of contamination.

Table 27 – DRASTIC and NDEP Modified Method Comparison - Arsenic

	NDEP			DRASTIC		
Vuln Value	Wells w/ As	Total Wells	Freq.	Wells w/ As	Total Wells	Freq.
1	1	2	0.50	6	6	1.00
2	22	27	0.81	3	6	0.50
3	10	15	0.67	9	10	0.90
4	5	9	0.56	16	23	0.70
5	7	7	1.00	16	19	0.84

	NDEP			DRASTIC		
Vuln Value	Wells w/ As	Total Wells	Freq.	Wells w/ As	Total Wells	Freq.
6	12	12	1.00	17	19	0.89
7	12	12	1.00	6	6	1.00

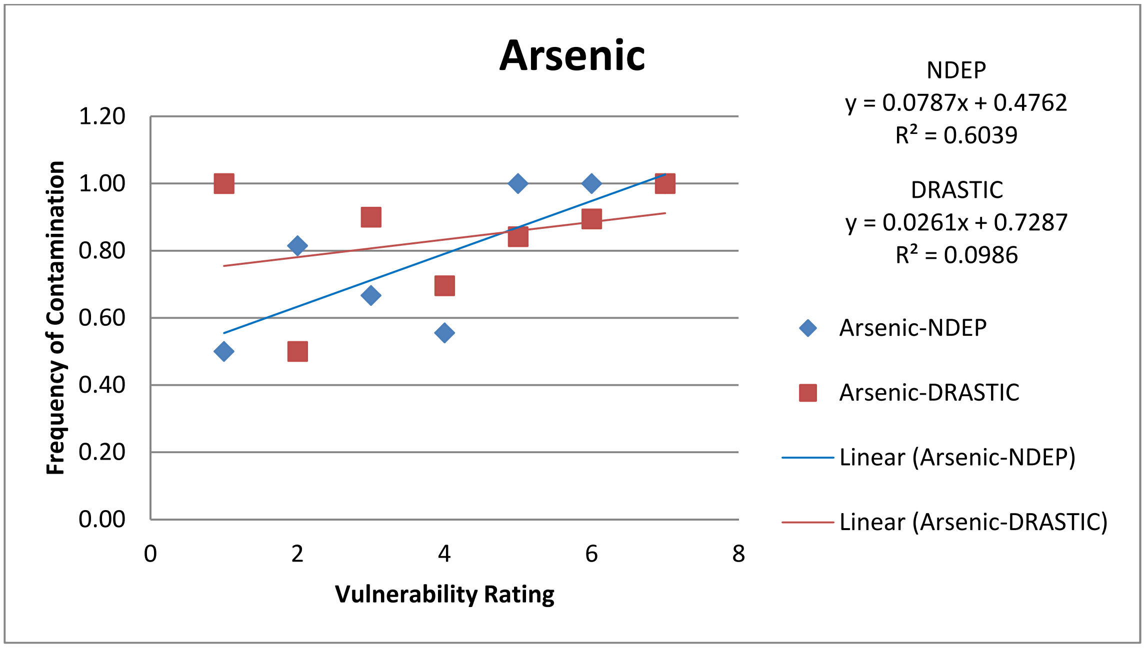


Figure 25 – NDEP versus DRASTIC comparison arsenic contaminant.

Figure 25 shows the comparison between the NDEP and DRASTIC methods to forecast arsenic detection in 84 wells. NDEP has a better correlation (0.6039) than DRASTIC (0.0986) for arsenic contamination. For fluoride, the NDEP method forecasts the data better than the DRASTIC method as well. The same is observed for radionuclides (Figure 27). Because the NDEP method takes into consideration historic contaminant detection in its vulnerability ranking, it accounts for naturally occurring contaminants. That is not the case with DRASTIC. Therefore, an advantage of the

NDEP method is its capacity to include naturally occurring contaminants in the vulnerability ranking.

Table 28 – DRASTIC and NDEP Modified Method Comparison - Fluoride

	NDEP			DRASTIC		
Vuln Value	Wells w/ F	Total Wells	Freq.	Wells w/ F	Total Wells	Freq.
1	1	2	0.50	5	6	0.83
2	21	27	0.78	3	6	0.50
3	12	15	0.80	8	10	0.80
4	8	9	0.89	22	23	0.96
5	5	7	0.71	14	19	0.74
6	11	12	0.92	15	19	0.79
7	12	12	1.00	4	6	0.67

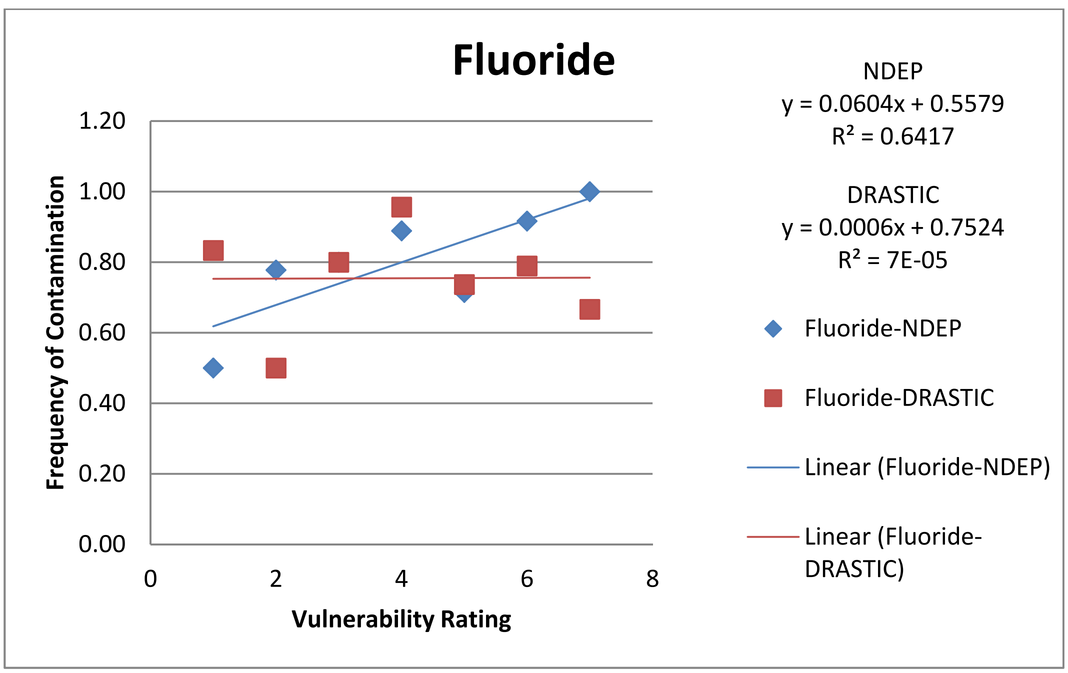


Figure 26 – NDEP versus DRASTIC correlation for fluoride detection: NDEP has a better correlation (0.6417) than DRASTIC (0.00007) for fluoride contamination.

Table 29 – DRASTIC and NDEP Modified Method Comparison - Radionuclide

	NDEP			DRASTIC		
Vuln Value	Wells w/ RAD	Total Wells	Freq.	Wells w/ RAD	Total Wells	Freq.
1	0	2	0.00	6	6	1.00
2	20	27	0.74	3	6	0.50
3	10	15	0.67	6	10	0.60
4	6	9	0.67	18	23	0.78
5	3	7	0.43	13	19	0.68
6	11	12	0.92	16	19	0.84
7	10	12	0.83	5	6	0.83

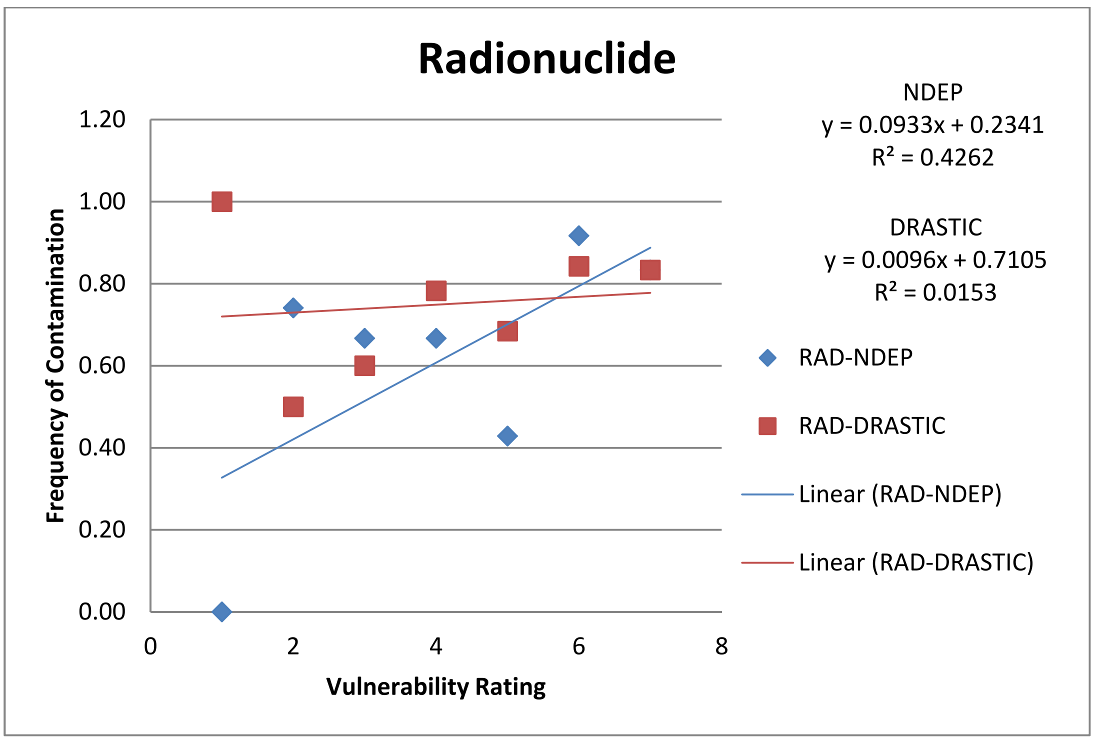


Figure 27 – NDEP versus DRASTIC correlation for radionuclide contamination: NDEP has a better correlation (0.4262) than DRASTIC (0.0153) for radionuclide contamination

Table 30 – DRASTIC and NDEP Modified Method Comparison - Nitrate

	NDEP			DRASTIC		
Vuln Value	Wells w/ Nitrate	Total Wells	Freq.	Wells w/ Nitrate	Total Wells	Freq.
1	2	2	1.00	5	6	0.83
2	27	27	1.00	4	6	0.67
3	12	15	0.80	9	10	0.90
4	7	9	0.78	19	23	0.83
5	4	7	0.57	17	19	0.89
6	9	12	0.75	14	19	0.74
7	12	12	1.00	2	6	0.33

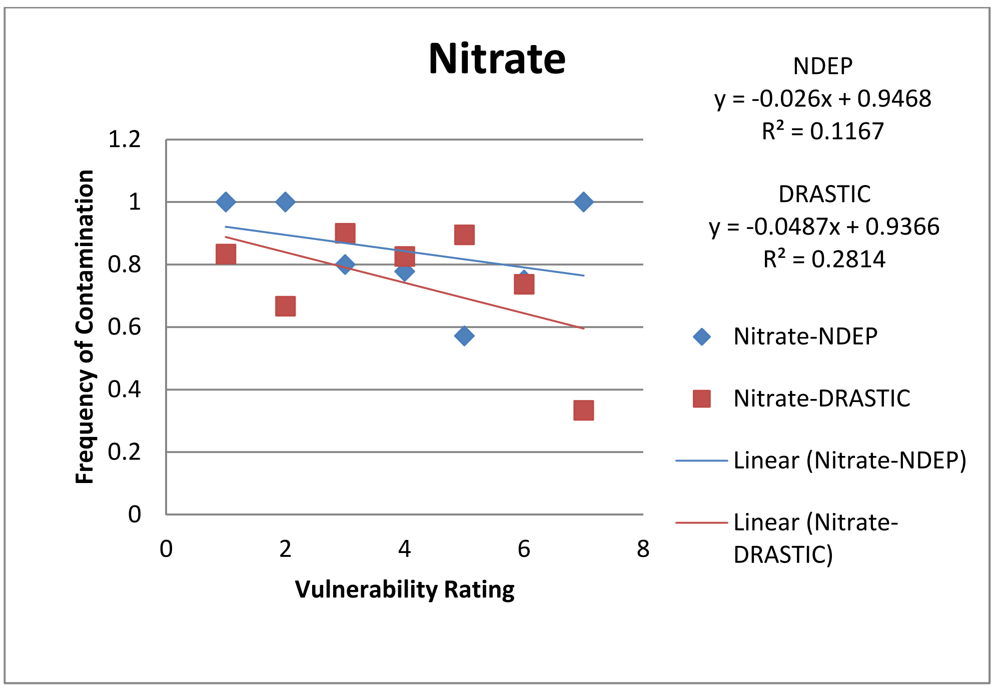


Figure 28 – NDEP versus DRASTIC correlation for nitrate contamination.

Figure 28 shows the correlation between nitrate detection for the DRASTIC and the NDEP method. Both methods have a poor correlation with nitrate detection. A reason for the weak correlation with DRASTIC is the presence of many nitrate detections

in the area of low and very low vulnerability for the agricultural land use. For the NDEP method, the sparse number of potential contaminant sources within the established 3,000 foot radius results in a low vulnerability as compared to wells with a larger number of potential contaminant sources. The area studied has a few small towns associated with it, but the region is predominantly rural. Therefore, many wells have only a few potential contaminant sources associated with it. It seems there is an inherent bias in the NDEP method related to the number of potential contaminant sources associated with the wells under evaluation. Although not investigated in this thesis, it would be interesting to examine this hypothesis in an urban area where a large number of potential contaminant sources are associated with specific wells.

LIMITATIONS OF DRASTIC AND NDEP METHOD

There exist several advantages and disadvantages when comparing DRASTIC with the NDEP index methods.

Table 31 – DRASTIC and NDEP Limitations Comparison

DRASTIC	NDEP
Less time consuming; minimal labor required	Uses water quality data
Able to determine vulnerability for large regions	Accounts for potential sources of contamination
Able to suggest location of future wells	Expensive and time consuming (Labor intensive)
Does not account for water quality	Only assesses area within a buffer zone
Does not account for PCSs	Vulnerability is determined after well is dug

The major ones are shown in Table 31. In addition, there are several limitations when using either method, including: accuracy of data, missing data, general data quality. Specific limitations of the methodology include:

1) DRASTIC vulnerability mapping is reliant on the accuracy of the data available. Because the data set is collected from different sources, information on specific aspect layer may be more complete on others. For example, in the case of depth to water, a large portion of the study area did not have data associated with it. Therefore, in the model the absence of data corresponds to a value of zero, but it is not necessarily the case.
2) DRASTIC does not account for historic contamination because it does not use water quality as a parameter.
3) IMPACT, the eight component of DRASTIC, may account for PCSs but appears that IMPACT can only account for one PCS at a time creating a cumbersome vulnerability map when dealing with a multitude of PCS types.
4) In the specific case of this study, the entire data sets used for the DRASTIC vulnerability map may not be needed from the results of the sensitivity analysis. Therefore, recharge, depth to water, and hydraulic conductivity could be omitted with similar results. However, the accuracy of the remaining four data sets would be more important to insure that areas of low vulnerability are not misrepresented and vice versa.

The NDEP index method also has limitations:

1) NDEP vulnerability mapping is reliant on the accuracy of the well driller's log and the surveying of PCS within the buffer zone. Older driller's logs may omit crucial information such as confining layers or identifying water barring strata above the well screen placement.

2) New wells that do not have historic water quality associated with it will be reported as no detections. Therefore, the vulnerability is underrated.

3) Like DRASTIC, the NDEP method does not directly account for naturally occurring contaminants. Arsenic, as an example, is found to be common in the study area. With no recorded detection this well could be listed at a lower vulnerability rating than the actual rating.

4) The NDEP method seems to be limited by the number of PCSs present, giving lower rating to areas with smaller number of PCSs. 5) The NDEP modified method uses a predefined value for a PCS that is 100, 200, or 300 based on the level of initial potential to contaminate. Equations 3 and 4 were based on these values. If different values are to be assigned for the initial rating, the values of the equations will need to be reassigned as well.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Conclusion

The two main objectives in this research are: (1) to compare the three land use of mining, towns, and agriculture based on the groundwater vulnerability assessments using the DRASTIC method; and (2) compare the DRASTIC method and the NDEP modified method as tools to evaluate ground water vulnerability in northern Nevada. The first objective used a percent occurrence for the three defined land uses utilizing a DRASTIC map prepared in accordance of the USEPA guidelines. The second objective used a triangulated irregular network (TIN) to reevaluate the well to a raster and determined a percent occurrence for the same land use areas. Additional data were used to further compare the methods with actual historic water quality data. The methods were tested to forecast detection of naturally occurring and anthropogenic contaminants.

The first objective was accomplished by applying the outline of the methodology for DRASTIC and plotting the land use regions on a raster map (grid). The DRASTIC method was prepared by using the seven parameters with a determined numeric value for each unique feature of the parameters. Using a simple calculation with weighted values, a determination of vulnerability was created. Using defined areas for the three land uses,

a determination of how many cells of each value occur within the three land uses was computed. This was converted to a percent occurrence for comparison for each of the seven levels of vulnerability.

The second objective was accomplished by utilizing the NDEP modified method and applying a numeric rating for different aspects for the wells. The numeric values were converted (reclassified) into values 1 through 7 for very low to very high respectfully. The well values were categorized into the three land uses to determine a percent occurrence for the seven levels of vulnerability. To be compared with DRASTIC, the point data of the wells had to be transformed into a raster image utilized triangulation.

The main conclusions of this research are as follows:

1) In general, the DRASTIC vulnerability map created for northern Nevada indicates that areas of high ground water contamination vulnerability are located in the valleys while the mountainous regions have low vulnerability to contamination. That is, mining areas are associated with very low to moderate vulnerability and agricultural areas and towns are located in areas of moderate to high vulnerability. Therefore, according to DRASTIC, in northern Nevada, mining towns and agricultural areas are more susceptible to groundwater contamination than mining areas.

2) A sensitivity analysis of the parameters involved in DRASTIC, using two methods revealed that the vadose zone, aquifer media, soil media and topographic slope are the most significant parameters controlling vulnerability. The

parameters with least significance are depth to water, recharge, and hydraulic conductivity.

3) A correlation between naturally occurring and anthropogenic contaminants and the vulnerability ranking from DRASTIC revealed that a very poor correlation exists for arsenic, fluoride, and radionuclides, which are naturally occurring. This was expected since DRASTIC does not account for naturally occurring contamination. Naturally occurring contaminants are widely detected in wells in northern Nevada and are expected to occur randomly. Therefore, all areas in northern Nevada have high potential for the detection of naturally occurring contaminants. When the low vulnerability data were removed from the dataset, a very high correlation was found for arsenic and fluoride. Radionuclides did not correlate well.

4) Correlation of DRASTIC ranking with nitrate was very weak (R^2=0.281). Correlation of nitrate detections with specific land uses were stronger (R^2=0.465 for mining; R^2=0.518 for towns; and R^2=0.363 for agriculture). However, the correlation coefficients are not sufficiently high to strongly support the supposed correlation. However, the number of nitrate detections in the entire region is very high. Therefore, DRASTIC cannot forecast nitrate contamination well for this region. It is likely that nitrate contamination currently detected in mining areas is the result of historic use of the land for agriculture, before mining was established. Several mining operations have located their ancillary facility foot hills near or on historic agricultural areas. DRASTIC does not account for this fact.

5) A comparison of the vulnerability ranking provided by DRASTIC and by the NDEP method revealed that mining and towns are rated similarly by both methods as having low to moderate and moderate to low vulnerability, respectively. However, DRASTIC rated agricultural areas as moderate to high vulnerability while the NDEP method rates it as moderate to low vulnerability. Both methods are subjective and one cannot ascertain their accuracy unless they are compared with actual contamination data.

6) Correlation of actual contaminant data with DRASTIC and NDEP vulnerability forecasts revealed that the NDEP method provides a better correlation between naturally occurring contaminants (i.e. arsenic, fluoride, and radionuclides) than DRASTIC. This is the case because the NDEP method uses historic contaminant detections as one of its variables. Correlation between nitrate detections and both NDEP and DRASTIC methods is poor (R^2=0.117 for NDEP and R^2=0.2814 for DRASTIC). For DRASTIC the reason maybe that many detections of nitrate are found in areas forecasted as having low vulnerability. The sparse number of contaminant sources in rural areas as compared to towns, may have contributed to this low vulnerability rating.

7) In general, it seems that the NDEP method can better forecast contamination compared to DRASTIC. However, the NDEP method requires extensive data collection and therefore it is more costly and time consuming than DRASTIC.

5.2 Recommendations for Future Research

Both methods, DRASTIC and NDEP generate usable data for communities or planners to deal with issues of potential contamination of groundwater. Neither one

depicts the full impact of the groundwater vulnerability. However, the NDEP method forecast the presences of naturally occurring contaminants better than DRASTIC.

Suggested future research in this area includes:

1) The impact of the number of potential contaminant sources on the vulnerability forecast by the NDEP method. This could be accomplished by applying the method to an urban area where potential contaminant sources can be added step-wise.
2) Applying DRASTIC to other areas of Nevada where the topographic component (i.e. valleys and mountains) is not as significant as in northern Nevada. Recommended Counties would be Clark and Washoe which have long valley ranges, where most of the population is located.
3) The correlation between nitrate and both vulnerability determination methods was poor, possibly because nitrate is associated with many different sources. It would be worthwhile to investigate other contaminants such as volatile organic compounds (VOC) and synthetic organic compounds (SOC) correlation with DRASTIC and the NDEP method. These contaminants are specific to certain sources.

APPENDIX A

Table A1 - Ratings for Revised Aquifer Media Features

Aquifer Media	
Feature	**Rating**
Unconsolidated Sand and Gravel	8
Carbonate-rock	6
Other Rock	4

Table A2 - Ratings for Impact of Vadose Zone Media Features

Impact of Vadose Zone		
Feature ID	**Feature Name**	**Rating**
WBDY	Water body	0
bx	Breccia	3
Cc	Carbonate rocks & minor quartzite	3
Cpm	Prospect mountain quartzite	3
CPq	Foliated metaquartzite	3
DCm	Calcite marble & dolomite marble	3
Jgr	Granite	3
Kgr	Granite	3
Oe	Eureka quartzite	3
Oem	Metaquartzite	3
Dd	Sevy, Simonson, & Nevada formations	4
Dgd	Guilmette & Devils Gate formations	4
Dm	Graphitic marble	4
DOm	Dolomite marble	4
DPm	Metamorphic rocks	4
DSlm	Lone mountain dolomite	4
Knc	Newark canyon formation	4
m	Migmatite	4
Mzgn	Gneiss	4
Oa	Aura formation	4
OCm	Calcite marble	4
Op	Pogonip group	4
PMl	Limestone, shale, chert, orthoquartzite, & quartz	4

Impact of Vadose Zone		
Feature ID	Feature Name	Rating
Pp	Pequop formation	4
Ppc	Park City group	4
PPcd	Carbonate & detrital rocks	4
Ps	Schist	4
Tgr	Alaskitic granite	4
Tw	Welded tuff, tuffaceous sedimentary rocks, vitric	4
DOd	Dolomitic rocks	7
DSrm	Roberts mountains formation	7
Jd	Diorite	7
JTRs	Nonmarine sedimentary rocks	7
Ma	Argillite of Lee canyon	7
Mbn	Banner & Nelson formations	7
Ms	Sedimentary clastic & limy rocks	7
Mtp	Tripon pass limestone	7
Mw	Webb formation	7
Pmc	McCoy creek group	7
Ppcg	Grandeur formation	7
PPPcs	Carlin sequence	7
PPPhr	Havallah & reservation hill formations	7
Qg	Glacial morains 7 rock glasiers	7
Ta2	Phenoandesitic and phenolatitic flows	7
Ta3	Pyroxene & hornblende phenoandesite & phenodacite	7
Tg3	Gravel	7
Tls	Landslide deposits	7
Tpr	Porphyritic phenorhyolitic & phenodacitic flows &	7
Tr2	Phenorhyolitic & phenodacitic tuff, flows, & domes	7
Tr3	Phenorhyolitic & phenodacitic flows & domes	7
TRPs	Sedimentary and volcanic rocks	7
TRs	Marine sedimentary rocks	7
Tt1	Phenorhyolitic to phenodacitic ignimbrite	7
Tt3	Pyroxene phenodacite ignimbrite	7
Tts	Ignimbrite, tuff, and sedimentary rocks	7
Ttsl	Tuff, sedimentary rocks, and lava	7
Qa	Alluvium	8
QThs	Hot-spring travertine and sinter	8
QTls	Landslide deposits and colluvium	8
Tbi	Big island formation	8
Tbx	Breccia	8
Dl	Limestone	9
DOs	Mdst.,Sh.,chert,Slts.,Gray Qzt.	9
DOsl	Limestone	9
DSd	Dolomitic limestone & dolomite	9
Dt	Platy siltstone, limestone, & shale	9
Dw	Woodruff formation	9
Jf	Frenchie creek rhyolite	9
Mc	Chainman shale	9
MDg	Grossman formation	9

Impact of Vadose Zone		
Feature ID	Feature Name	Rating
MDjp	Joana limestone & pilot shale, undivided	9
OCs	Shale, phyllite, & limestone	9
Pbl	Unnamed bioclastic limestone	9
Pem	Edna mountain formation	9
Pgp	Gerster & phosphoria formations	9
Phm	Sandstone & siltstone of Horse mountain	9
PPe	Ely limestone	9
Pph	Phosphoria formation	9
PPmc	Mitchell creek formation	9
PPMdc	Diamond peak & Chainman formations, undivided	9
PPMdp	Diamond peak formation	9
PPMpd	Unnamed bioclastic limestone	9
PPMs	Schoonover formation	9
PPPl	Limestone and dolomite	9
PPPs	Strathearn formation	9
PPPu	Undivided limy rocks	9
PPq	Quilici formation	9
PPvd	Van Duzer limestone	9
Qls	Landslide deposits and colluvium	9
Qp	Pluvial lake deposits	9
QTa	Older alluvium	9
QTs	Sedimentary rocks	9
SOd	Predominantly dolomitic rocks	9
SOh	Hanson creek formation	9
Ta1	Andesitic to latitic flows and pyroclastic rocks	9
Tb	basalt flows	9
Tb2	Basalt, basaltic tuff, & tuff breccia	9
Tb3	Basalt	9
Tbc	basaltic cinder, tuff, and lava cones	9
Tc	Conglomerate	9
Tgd	Granodiorite, quartz monzonite	9
Tjr	Jarbidge rhyolite	9
Tl	Latitic rocks	9
Tr1	Rhyolitic to dacitic flows and domes	9
TRPc	Marine conglomerate	9
Ts1	Sedimentary rocks	9
Ts2	Tuffaceous & clastic sedimentary rocks	9
Ts3	Sedimentary and volcanic rocks	9
Ts3	Sedimentary and volcanic rocks	9

Table A3 – NDEP Vulnerability Rating Table

Potential Contaminant Source Initial Risk Ranking

#	Potential Source	Category	Risk Rank	#	Potential Source	Category	Risk Rank
	Agricultural				*Medical/Educational*		
1	Animal burial areas	C, D	H	28	Educational institutions	B, C	M
2	Animal feedlots	B, C, D	H to M	29	Medical institutions	D, E	L
3	Chemical application	C, B	H	30	Research laboratories	A to E	H
4	Chemical mixing & storage	A, B, C	H		*Storage*		
	Irrigated fields	A, B	M	31	Aboveground storage tanks	A, B	H
5	Irrigation ditches	B, C	H	32	Underground storage tanks	A	H
6	Manure spreading & pits	A, C, D	M	33	Public storage	A, B, C	L
7	Unsealed irrigation wells	A, B, C, D	H	34	Radioactive material storage	E	L
	Industrial				*Municipal Waste*		
8	Chemical manufacturing	A, B, C	H	35	Dumps and landfills	A to E	H
9	Electroplaters & fabrication	C	H	36	Municipal incinerators	B, C, D	M
10	Electrical manufacturing	C	H	37	Recycling/reduction facilities	A to E	H
11	Machine & metalworking	A	H	38	Scrap & junkyards	A, C	H
12	Manufacturing sites	A, B, C	H	39	Wastewater treatment plants	A, B, C, D	H
13	Petroleum distribution	A	H	40	Sewer transfer stations	A, B, C, D	H
	Commercial				*Miscellaneous*		
14	Dry Cleaners	A	H	41	Airports	A	H
15	Furniture & wood stripping	A, C	H	42	Asphalt plants	A	H
16	Jewelry & metal plating	C	H	43	Boat yards	A	H
17	Laundromats	-	L	44	Cemeteries	D	M
18	Paint shops	A	H	45	Construction areas	A	M
19	Photography & printing	C	H	46	Dry wells	A	H
	Automotive			47	Fuel storage systems	A	H
20	Auto repair shops	A, C	H	48	Golf courses & parks	B, C	H
21	Car washes	A, C, D	M	49	Mining	A, C, E	H
22	Gas stations	A, C	H	50	Pipelines	A	H
23	Road deicing & storage	C	M	51	Railroad tracks & yards	A, B, C, D	H
24	Road maintenance depots	A, C	H	52	Surface water	D	H
	Residential			53	Stormwater drains & basins	A to E	H
25	Household hazardous waste	A, B, C	M	54	Unplugged abandoned wells	A, B, C, D	H
26	Private wells	A, B, C, D	M to H	55	Operating well	A, B, C, D	H to L
27	Septic systems & cesspools	B, C, D	H to M	56	Other	A, B, C, D	H to L

Contaminant Category Codes (A - VOC, B - SOC, C - IOC, D - Microbial, and E - Radionuclides).
Risk Ranking Codes (L - Low, M - Moderate, and H - High) Potential Contamination Vulnerability.
Table has been reproduced from the NDEP Source Water Protection Report (NDEP, 2007).

Table A4 – DRASTIC Vulnerability Rating Table without Depth to Water

Minus Depth to Water				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	38.47	0.49	4.10
2	Low	33.66	2.07	9.52
3	Moderate Low	18.17	47.18	49.95
4	Moderate	9.70	50.26	36.43
5	Moderate High	0.00	0.00	0.00
6	High	0.00	0.00	0.00
7	Very High	0.00	0.00	0.00

Table A5 – NDEP Vulnerability Rating Table without Recharge

Minus Recharge				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	52.19	0.66	6.06
2	Low	24.68	2.34	9.40
3	Moderate Low	14.46	24.61	17.94
4	Moderate	6.57	41.58	22.84
5	Moderate High	1.56	20.15	22.04
6	High	0.54	10.50	21.40
7	Very High	0.00	0.16	0.32

Table A6 – NDEP Vulnerability Rating Table without Aquifer Media

Minus Aquifer Media				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	67.28	2.85	11.77
2	Low	22.30	24.70	21.05
3	Moderate Low	8.25	41.61	23.14
4	Moderate	1.58	20.15	21.68
5	Moderate High	0.59	10.52	22.03
6	High	0.00	0.17	0.33
7	Very High	0.00	0.00	0.00

Table A7 – NDEP Vulnerability Rating Table without Soil Media

Minus Soil Media				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	79.7	2.83	14.57
2	Low	15.54	25.26	19.24
3	Moderate Low	2.84	44.36	22.92
4	Moderate	1.25	14.75	15.49
5	Moderate High	0.67	12.8	27.78
6	High	0	0	0

Table A8 – NDEP Vulnerability Rating Table without Topography

Minus Topography				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	64.03	1.19	11.88
2	Low	24.70	27.42	20.72
3	Moderate Low	9.41	46.24	25.78
4	Moderate	1.61	20.45	31.34
5	Moderate High	0.25	4.70	10.28
6	High	0.00	0.00	0.00

Table A9 – NDEP Vulnerability Rating Table without Impact of Vadose

Minus Impact of Vadose				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	82.29	10.16	21.41
2	Low	13.33	36.96	24.71
3	Moderate Low	2.81	31.98	15.42
4	Moderate	1.41	18.13	30.20
5	Moderate High	0.16	2.77	8.26
6	High	0.00	0.00	0.00

Table A10 – NDEP Vulnerability Rating Table without Hydraulic Conductivity

Minus Hydraulic Conductivity				
Ranking	**Rating**	**Mining**	**Towns**	**Agriculture**
1	Very Low	43.91	0.67	4.20
2	Low	33.94	3.77	12.61
3	Moderate Low	14.35	31.12	21.28
4	Moderate	5.88	38.18	19.35
5	Moderate High	1.46	17.11	21.84
6	High	0.46	9.15	20.72

Table A11 – Water Quality Maximum Contaminant Levels

Contaminant	MCL (mg/L)
Microorganisms	
Cryptosporidium	0
Giardia lamblia	0
Heterotrophic plate count	0
Legionella	0
Total Coliforms	0
Turbidity	0
Viruses (enteric)	0
Disinfection Byproducts	
Bromate	0.01
Chlorite	1
Haloacetic acids (HAA5)	0.06
Total Trihalomethanes (TTHMs)	0.08
Disinfectants	
Chloramines (as Cl2)	MRDL=4.01
Chlorine (as Cl2)	MRDL=4.01
Chlorine dioxide (as ClO2)	MRDL=0.81
Inorganic Chemicals	
Antimony	0.006
Arsenic	0.01
Asbestos	7 MFL
Barium	2
Beryllium	0.004
Cadmium	0.005
Chromium (total)	0.1
Copper	1.3
Cyanide (as free cyanide)	0.2
Fluoride	4
Lead	0.015

Contaminant	MCL (mg/L)
Mercury (inorganic)	0.002
Nitrate (measured as Nitrogen)	10
Nitrite (measured as Nitrogen)	1
Selenium	0.05
Thallium	0.002
Organic Chemicals	
Acrylamide	0
Alachlor	0.002
Atrazine	0.003
Benzene	0.005
Benzo(a)pyrene (PAHs)	0.0002
Carbofuran	0.04
Carbon tetrachloride	0.005
Chlordane	0.002
Chlorobenzene	0.1
2,4-D	0.07
Dalapon	0.2
1,2-Dibromo-3-chloropropane (DBCP)	0.0002
o-Dichlorobenzene	0.6
p-Dichlorobenzene	0.075
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
cis-1,2-Dichloroethylene	0.07
trans-1,2-Dichloroethylene	0.1
Dichloromethane	0.005
1,2-Dichloropropane	0.005
Di(2-ethylhexyl) adipate	0.4
Di(2-ethylhexyl) phthalate	0.006
Dinoseb	0.007
Dioxin (2,3,7,8-TCDD)	0.00000003
Diquat	0.02
Endothall	0.1
Endrin	0.002
Epichlorohydrin	0
Ethylbenzene	0.7
Ethylene dibromide	0.00005
Glyphosate	0.7
Heptachlor	0.0004
Heptachlor epoxide	0.0002
Hexachlorobenzene	0.001
Hexachlorocyclopentadiene	0.05
Lindane	0.0002
Methoxychlor	0.04
Oxamyl (Vydate)	0.2
Polychlorinated biphenyls (PCBs)	0.0005
Pentachlorophenol	0.001
Picloram	0.5
Simazine	0.004
Styrene	0.1
Tetrachloroethylene	0.005
Toluene	1
Toxaphene	0.003
2,4,5-TP (Silvex)	0.05

Contaminant	MCL (mg/L)
1,2,4-Trichlorobenzene	0.07
1,1,1-Trichloroethane	0.2
1,1,2-Trichloroethane	0.005
Trichloroethylene	0.005
Vinyl chloride	0.002
Xylenes (total)	10
Radionuclides	
Alpha particles	15 pCi/L
Beta particles and photon emitters	4 millirems/yr
Radium 226 and Radium 228 (combined)	5 pCi/L
Uranium	30 ug/L

APPENDIX B

Table B1 Part A – NDEP Modified Method Data Values

ID	LANDUSE	Int Vuln	Int V	VOC	W VOC	SOC	W SOC	IOC	W IOC	RAD	W RAD	TR	Ecoli	WQ W
Source 1	Agriculture	Low	100	0	1	0	1	10	5	10	5	0	0	3
Source 2	Agriculture	Low	100	0	1	0	1	10	5	10	5	0	0	3
Source 3	Agriculture	Low	100	0	1	0	1	10	5	10	5	0	0	3
Source 4	Town	High	300	0	1	0	1	10	3	10	2	0	0	3
Source 5	Town	High	300	0	1	0	1	10	5	10	5	0	0	3
Source 6	Town	High	300	0	1	0	1	10	5	10	1	0	0	3
Source 9	Town	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 10	Town	Low	100	0	1	0	1	10	4	0	3	0	0	3
Source 11	Agriculture	Low	100	10	1	10	4	10	1	10	2	0	0	3
Source 12	Agriculture	Low	100	10	1	0	1	10	5	10	3	0	0	3
Source 13	Agriculture	High	300	10	1	10	1	10	4	10	4	0	0	3
Source 14	Agriculture	High	300	0	1	10	1	10	5	10	4	0	0	3
Source 15	Agriculture	Low	100	10	1	0	1	10	3	10	4	0	0	3
Source 16	Agriculture	Low	100	10	5	10	5	10	2	10	1	0	0	3
Source 17	Agriculture	Low	100	0	1	0	1	10	2	10	1	0	0	3
Source 18	Agriculture	Low	100	0	1	0	1	10	2	0	1	0	0	3
Source 19	Agriculture	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 20	Town	Low	100	0	1	0	1	10	3	10	1	0	0	3
Source 21	Town	High	300	0	1	0	1	10	3	10	1	0	0	3
Source 22	Town	High	300	0	1	0	1	10	5	10	1	0	0	3
Source 23	Town	High	300	0	1	0	1	10	1	10	1	0	0	3
Source 24	Town	Low	100	0	1	0	1	10	1	10	1	0	0	3
Source 25	Town	High	300	0	1	0	1	10	1	10	1	0	0	3
Source 26	Town	High	300	0	1	0	1	10	1	10	1	0	0	3
Source 27	Town	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 28	Town	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 29	Agriculture	Low	100	10	5	0	1	10	5	10	4	0	0	3
Source 30	Agriculture	High	300	0	1	0	1	10	1	0	1	0	0	3
Source 31	Agriculture	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 32	Agriculture	Low	100	0	1	0	1	10	2	0	1	0	0	3
Source 33	Agriculture	Low	100	0	1	0	1	10	4	0	1	0	0	3
Source 34	Agriculture	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 35	Agriculture	Low	100	0	1	0	1	10	4	0	1	0	0	3
Source 36	Agriculture	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 37	Agriculture	Low	100	0	1	0	1	10	4	10	2	0	0	3

ID	LANDUSE	Int Vuln	Int V	VOC	W VOC	SOC	W SOC	IOC	W IOC	RAD	W RAD	TR	Ecoli	WQ W
Source 42	Agriculture	High	250	0	1	0	1	10	1	0	1	0	0	3
Source 43	Agriculture	High	250	0	1	0	1	10	1	0	1	0	0	3
Source 44	Agriculture	Low	100	0	1	0	1	10	1	10	2	0	0	3
Source 45	Town	High	300	0	1	0	1	10	4	10	2	0	0	3
Source 46	Town	High	300	0	1	0	1	10	2	10	1	0	0	3
Source 47	Town	High	300	0	1	0	1	10	1	10	1	0	0	3
Source 48	Town	High	300	0	1	0	1	10	1	10	1	0	0	3
Source 49	Agriculture	Low	100	10	5	0	1	10	1	10	1	0	0	3
Source 50	Agriculture	High	300	10	1	0	1	10	4	10	2	0	0	3
Source 51	Agriculture	High	300	10	5	0	1	10	3	10	2	0	0	3
Source 53	Agriculture	Low	100	0	1	0	1	10	1	10	1	0	0	3
Source 54	Agriculture	Low	100	10	1	0	1	10	3	10	2	0	0	3
Source 55	Agriculture	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 56	Town	High	300	0	1	10	2	10	4	10	2	0	0	3
Source 57	Town	High	300	0	1	10	1	10	4	10	2	0	0	3
Source 58	Town	High	300	0	1	10	1	10	4	10	2	0	0	3
Source 59	Town	High	300	0	1	0	1	10	4	0	2	0	0	3
Source 60	Town	High	300	0	1	10	1	10	5	10	2	0	0	3
Source 61	Town	High	300	0	1	10	2	10	4	10	4	0	0	3
Source 62	Town	High	300	0	1	10	1	10	3	10	5	0	0	3
Source 63	Town	High	300	10	5	10	2	10	5	10	5	0	0	3
Source 64	Town	High	300	10	5	10	2	10	4	10	5	0	0	3
Source 65	Town	High	300	10	5	10	5	10	4	10	5	0	0	3
Source 66	Town	High	300	0	1	10	4	10	4	10	5	0	0	3
Source 67	Town	Low	100	10	1	0	1	10	5	10	5	0	0	3
Source 68	Town	High	300	0	1	10	4	10	2	10	5	0	0	3
Source 70	Town	Moderate	200	10	1	10	2	10	3	10	5	0	0	3
Source 71	Town	High	300	0	1	10	5	10	5	10	5	0	0	3
Source 75	Town	High	300	0	1	0	1	10	5	10	3	0	0	3
Source 76	Town	Low	100	10	1	0	1	10	4	10	1	0	0	3
Source 77	Town	High	300	0	1	0	1	10	1	0	1	0	0	3
Source 78	Town	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 79	Agriculture	Low	100	0	1	0	1	10	1	10	2	0	0	3
Source 80	Mining	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 81	Mining	High	300	10	1	10	1	10	5	0	1	0	0	3
Source 82	Mining	High	300	10	1	0	1	10	5	10	2	0	0	3
Source 83	Mining	High	300	0	1	10	2	10	5	10	1	0	0	3
Source 84	Agriculture	Low	100	10	5	0	1	10	4	10	3	0	0	3
Source 85	Agriculture	Low	100	0	1	0	1	10	3	10	3	0	0	3
Source 86	Agriculture	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 87	Mining	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 88	Mining	Moderate	200	0	1	0	1	10	1	0	1	0	0	3
Source 89	Agriculture	Low	100	0	1	0	1	10	1	0	1	0	0	3

ID	LANDUSE	Int Vuln	Int V	VOC	W VOC	SOC	W SOC	IOC	W IOC	RAD	W RAD	TR	Ecoli	WQ W
Source 90	Town	Low	100	0	1	0	1	10	3	10	5	0	0	3
Source 91	Town	Low	100	0	1	0	1	10	2	10	5	0	0	3
Source 92	Mining	Low	100	0	1	0	1	10	2	10	3	0	0	3
Source 93	Mining	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 94	Mining	High	300	0	1	0	1	10	1	0	1	0	0	3
Source 95	Mining	Moderate	200	10	1	0	1	10	2	10	3	0	0	3
Source 96	Mining	Low	100	0	1	0	1	10	1	0	1	0	0	3
Source 97	Mining	Low	100	0	1	0	1	10	3	0	1	0	0	3
Source 98	Mining	High	300	10	5	10	1	10	3	0	1	0	0	3
Source 99	Agriculture	Moderate	200	10	5	0	1	10	5	0	1	0	0	3
Source 100	Mining	High	260	0	1	0	1	10	1	0	1	0	0	3
Source 101	Agriculture	Moderate	200	0	1	0	1	10	2	0	1	0	0	3
Source 102	Mining	Low	100	0	1	10	3	10	5	0	1	0	0	3
Source 103	Town	Moderate	200	0	1	0	1	10	1	0	1	0	0	3
Source 104	Town	Moderate	200	0	1	0	1	10	1	0	1	0	0	3
Source 105	Agriculture	High	250	0	1	0	1	10	4	10	2	0	0	3
Source 106	Town	Moderate	200	0	1	0	1	10	4	10	2	0	0	3
Source 107	Town	Moderate	200	0	1	0	1	10	1	0	1	0	0	3
Source 108	Mining	High	267	0	1	0	1	10	1	0	1	0	0	3
Source 109	Agriculture	Low	100	0	1	10	5	10	5	10	3	0	0	3
Source 110	Agriculture	High	300	0	1	10	1	10	5	10	3	0	0	3
Source 111	Mining	High	300	0	1	0	1	10	5	0	1	0	0	3
Source 112	Mining	High	300	0	1	0	1	10	5	0	1	0	0	3
Source 113	Mining	High	300	0	1	0	1	10	1	0	1	0	0	3
Source 114	Mining	High	300	10	1	0	1	10	5	10	1	0	0	3
Source 115	Mining	High	300	0	1	0	1	10	5	0	1	0	0	3
Source 116	Agriculture	Moderate	200	10	1	0	1	10	1	10	1	0	0	3
Source 117	Agriculture	High	300	0	1	0	1	10	5	10	1	0	0	3
Source 118	Agriculture	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 119	Agriculture	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 120	Agriculture	Low	100	0	1	0	1	10	5	10	2	0	0	3
Source 121	Mining	Moderate	225	0	1	0	1	10	2	10	2	0	0	3
Source 122	Mining	High	300	0	1	0	1	10	1	0	1	0	0	3
Source 123	Mining	High	300	0	1	0	1	10	1	0	1	0	0	3

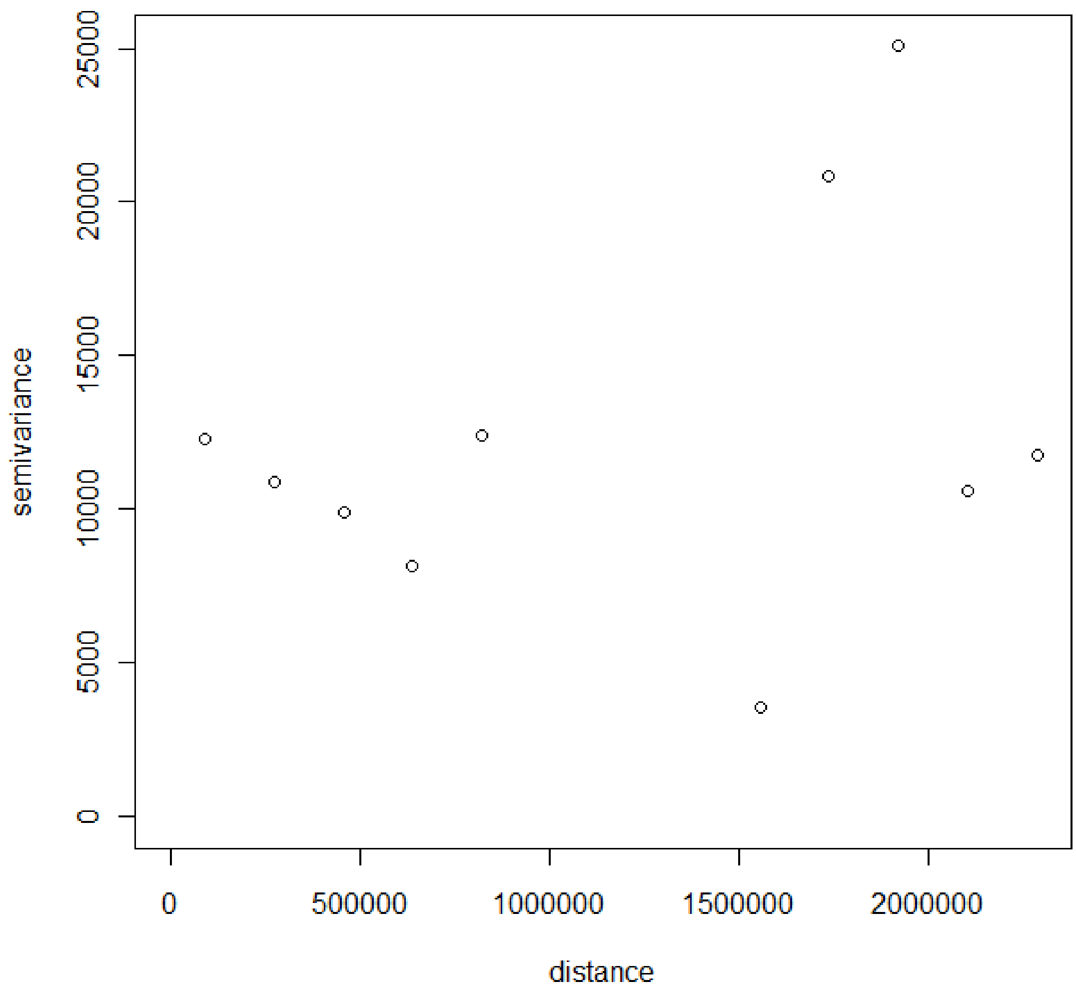
Table B1 Part B – NDEP Modified Method Data Values

ID	Const	Seal Dpth	Case Ht	Screen	Const W	UPGRAD	TOT	DTW	CONF LAY	Mobile	Persist	Contm	APP Meth	Hydro W	Vunl Calc	Total
Source 1	2	9	7	7	2	0	0	10	7	7	4	7	1	5	530	106
Source 2	2	9	7	7	2	0	0	10	7	7	4	7	1	5	530	106
Source 3	2	4	7	2	2	0	0	1	2	7	4	7	1	5	440	88
Source 4	2	4	2	2	2	7	6	9	2	7	4	7	1	5	385	231
Source 5	2	4	7	7	2	7	6	9	7	7	4	7	1	5	580	348
Source 6	2	1	7	7	2	7	6	9	7	7	4	7	1	5	454	272.4
Source 9	2	9	7	7	2	0	0	10	7	7	4	7	1	5	440	88
Source 10	2	1	7	2	2	0	0	1	2	7	4	7	1	5	254	50.8
Source 11	2	4	7	2	2	0	0	2	2	7	4	7	1	5	385	77
Source 12	2	4	7	7	2	0	0	2	7	7	4	7	1	5	450	90
Source 13	2	4	7	2	2	7	6	7	2	7	4	7	1	5	535	321
Source 14	2	4	7	2	2	7	6	7	2	7	4	7	1	5	535	321
Source 15	2	4	7	7	2	0	0	3	7	7	4	7	1	5	425	85
Source 16	2	4	7	2	2	0	0	1	2	7	4	7	1	5	530	106
Source 17	2	4	7	2	2	0	0	5	2	7	4	7	1	5	250	50
Source 18	2	1	7	2	2	0	0	2	2	7	4	7	1	5	199	39.8
Source 19	2	1	7	7	2	0	0	1	7	7	4	7	1	5	199	39.8
Source 20	2	1	2	7	2	0	0	2	7	7	4	7	1	5	284	56.8
Source 21	2	9	7	7	2	7	6	2	7	7	4	7	1	5	375	225
Source 22	2	9	7	7	2	7	6	3	7	7	4	7	1	5	440	264
Source 23	2	7	7	7	2	7	6	1	7	7	4	7	1	5	306	183.6
Source 24	2	1	7	2	2	7	6	5	2	7	4	7	1	5	279	55.8
Source 25	2	1	2	7	2	7	6	1	7	7	4	7	1	5	284	170.4
Source 26	2	1	2	2	2	7	6	1	2	7	4	7	1	5	249	149.4
Source 27	2	1	2	7	2	0	0	3	7	7	4	7	1	5	199	39.8
Source 28	2	1	2	7	2	0	0	1	7	7	4	7	1	5	189	37.8
Source 29	2	1	2	7	2	0	0	1	7	7	4	7	1	5	579	115.8
Source 30	2	4	2	7	2	7	6	3	7	7	4	7	1	5	270	162
Source 31	2	9	7	7	2	0	0	10	7	7	4	7	1	5	440	88
Source 32	2	9	7	7	2	0	0	10	7	7	4	7	1	5	290	58
Source 33	2	9	7	7	2	0	0	10	7	7	4	7	1	5	350	70
Source 34	2	9	7	7	2	0	0	10	7	7	4	7	1	5	260	52
Source 35	2	9	7	7	2	0	0	10	7	7	4	7	1	5	350	70
Source 36	2	4	2	2	2	0	0	1	2	7	4	7	1	5	340	68
Source 37	2	4	2	2	2	0	0	1	2	7	4	7	1	5	310	62
Source 42	2	4	2	7	2	3	4	9	7	7	4	7	1	5	270	135
Source 43	2	4	2	7	2	0	0	7	7	7	4	7	1	5	225	112.5
Source 44	2	7	7	7	2	0	0	9	7	7	4	7	1	5	311	62.2
Source 45	2	4	2	2	2	7	6	10	2	7	4	7	1	5	420	252

ID	Const	Seal Dpth	Case Ht	Screen	Const W	UPGRAD	TOT	DTW	CONF LAY	Mobile	Persist	Contm	APP Meth	Hydro W	Vunl Calc	Total
Source 46	2	1	7	2	2	7	6	2	2	7	4	7	1	5	294	176.4
Source 47	2	4	2	2	2	7	6	9	2	7	4	7	1	5	295	177
Source 48	2	9	2	7	2	3	6	7	7	7	4	7	1	5	310	186
Source 49	2	9	7	7	2	3	6	10	7	7	4	7	1	5	485	97
Source 50	2	4	7	2	2	3	6	1	2	7	4	7	1	5	395	237
Source 51	2	1	7	7	2	3	6	1	7	7	4	7	1	5	514	308.4
Source 53	2	1	7	7	2	3	6	1	7	7	4	7	1	5	274	54.8
Source 54	2	4	7	7	2	0	0	3	7	7	4	7	1	5	365	73
Source 55	2	1	7	7	2	0	0	3	7	7	4	7	1	5	389	77.8
Source 56	2	1	7	2	2	7	6	7	2	7	4	7	1	5	469	281.4
Source 57	2	1	7	2	2	7	6	7	2	7	4	7	1	5	439	263.4
Source 58	2	4	7	2	2	7	6	7	2	7	4	7	1	5	445	267
Source 59	2	1	7	2	2	7	6	1	2	7	4	7	1	5	319	191.4
Source 60	2	1	7	7	2	7	6	5	7	7	4	7	1	5	494	296.4
Source 61	2	4	7	7	2	7	6	7	7	7	4	7	1	5	570	342
Source 62	2	4	7	2	2	7	6	5	2	7	4	7	1	5	495	297
Source 63	2	7	7	2	2	7	6	7	2	7	4	7	1	5	751	450.6
Source 64	2	1	7	7	2	7	6	9	7	7	4	7	1	5	754	452.4
Source 65	2	4	7	2	2	7	6	5	2	7	4	7	1	5	795	477
Source 66	2	4	7	7	2	7	6	3	7	7	4	7	1	5	640	384
Source 67	2	9	7	7	2	7	6	1	7	7	4	7	1	5	580	116
Source 68	2	9	7	2	2	7	6	1	2	7	4	7	1	5	545	327
Source 70	2	9	7	2	2	7	6	2	2	7	4	7	1	5	550	220
Source 71	2	9	7	2	2	7	6	1	2	7	4	7	1	5	665	399
Source 75	2	4	7	2	2	7	6	7	2	7	4	7	1	5	475	285
Source 76	2	1	7	7	2	7	6	7	7	7	4	7	1	5	444	88.8
Source 77	2	1	7	7	2	7	6	5	7	7	4	7	1	5	284	170.4
Source 78	2	1	7	7	2	7	6	5	7	7	4	7	1	5	284	56.8
Source 79	2	9	7	7	2	7	6	1	7	7	4	7	1	5	340	68
Source 80	2	1	7	7	2	3	6	1	7	7	4	7	1	5	244	48.8
Source 81	2	1	7	7	2	7	10	1	7	7	4	7	1	5	464	278.4
Source 82	2	1	2	7	2	7	10	1	7	7	4	7	1	5	484	290.4
Source 83	2	4	2	7	2	3	6	1	7	7	4	7	1	5	450	270
Source 84	2	4	7	2	2	0	0	1	2	7	4	7	1	5	500	100
Source 85	2	4	2	2	2	0	0	1	2	7	4	7	1	5	310	62
Source 86	2	1	2	7	2	0	0	1	7	7	4	7	1	5	189	37.8
Source 87	2	4	2	2	2	0	0	5	2	7	4	7	1	5	180	36
Source 88	2	4	7	7	2	3	10	1	7	7	4	7	1	5	270	108
Source 89	2	4	7	7	2	7	6	1	7	7	4	7	1	5	270	54
Source 90	2	4	7	7	2	3	10	5	7	7	4	7	1	5	500	100
Source 91	2	4	7	7	2	3	10	5	7	7	4	7	1	5	470	94
Source 92	2	4	2	7	2	0	0	1	7	7	4	7	1	5	315	63

ID	Const	Seal Dpth	Case Ht	Screen	Const W	UPGRAD	TOT	DTW	CONF LAY	Mobile	Persist	Contm	APP Meth	Hydro W	Vunl Calc	Total
Source 93	2	4	2	7	2	0	0	1	7	7	4	7	1	5	195	39
Source 94	2	4	2	7	2	3	6	1	7	7	4	7	1	5	240	144
Source 95	2	4	2	7	2	3	6	1	7	7	4	7	1	5	390	156
Source 96	2	1	2	7	2	0	0	1	7	7	4	7	1	5	189	37.8
Source 97	2	4	2	2	2	0	0	1	2	7	4	7	1	5	220	44
Source 98	2	1	2	7	2	7	10	1	7	7	4	7	1	5	514	308.4
Source 99	2	4	2	7	2	3	10	5	7	7	4	7	1	5	550	220
Source 100	2	4	2	7	2	3	6	1	7	7	4	7	1	5	240	124.8
Source 101	2	9	7	7	2	7	10	7	7	7	4	7	1	5	360	144
Source 102	2	9	7	7	2	0	0	1	7	7	4	7	1	5	425	85
Source 103	2	4	7	2	2	0	0	1	2	7	4	7	1	5	170	68
Source 104	2	1	2	2	2	0	0	1	2	7	4	7	1	5	154	61.6
Source 105	2	4	2	2	2	7	8	1	2	7	4	7	1	5	385	192.5
Source 106	2	1	7	7	2	3	10	7	7	7	4	7	1	5	444	177.6
Source 107	2	1	7	7	2	3	6	7	7	7	4	7	1	5	274	109.6
Source 108	2	4	2	2	2	3	10	1	2	7	4	7	1	5	225	120.15
Source 109	2	1	2	7	2	0	0	1	7	7	4	7	1	5	549	109.8
Source 110	2	4	2	7	2	3	8	1	7	7	4	7	1	5	490	294
Source 111	2	4	2	7	2	3	6	1	7	7	4	7	1	5	360	216
Source 112	2	4	2	7	2	3	6	1	7	7	4	7	1	5	360	216
Source 113	2	1	2	7	2	3	6	1	7	7	4	7	1	5	234	140.4
Source 114	2	4	2	7	2	0	0	5	7	7	4	7	1	5	395	237
Source 115	2	1	7	7	2	7	10	1	7	7	4	7	1	5	404	242.4
Source 116	2	9	7	7	2	7	10	7	7	7	4	7	1	5	390	156
Source 117	2	4	7	2	2	7	10	1	2	7	4	7	1	5	405	243
Source 118	2	4	7	7	2	0	0	10	7	7	4	7	1	5	430	86
Source 119	2	4	7	7	2	0	0	7	7	7	4	7	1	5	415	83
Source 120	2	4	7	7	2	0	0	3	7	7	4	7	1	5	395	79
Source 121	2	4	2	7	2	0	0	2	7	7	4	7	1	5	290	130.5
Source 122	2	1	2	7	2	7	8	1	7	7	4	7	1	5	264	158.4
Source 123	2	1	2	7	2	7	6	1	7	7	4	7	1	5	254	152.4

Figure B1 – NDEP Variogram



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