RISK MAPPING OF GROUNDWATER SALINIZATION USING THE DRASTIC METHOD IN THE RINCON VALLEY

BY

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ABSTRACT

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Dr. Christopher P. Brown, Chair

Farmers in the Rincon Valley are using saline groundwater to irrigate crops due to declining levels of surface water from the Elephant Butte Reservoir. Using saline water can affect crop yield. A lot of farmers in the Rincon Valley are transitioning traditional crops from the valley such as peppers, cotton, and wheat to pecan orchards. There are a lot of problems that should be evaluated when transitioning to pecan orchards. Pecan orchards are a costly investment and require a lot of water. The water that pecan orchards require is of high quality due to pecans being sensitive to saline water. One of the major problems that need to be evaluated is the inability for pecan orchards to be rotated. This causes salts to be left behind in the soil making the soil highly saline throughout the years.

In this study, the groundwater vulnerability to pollution was evaluated for The Rincon Valley, Southern New Mexico using GIS DRASTIC model. The DRASTIC Method is a time and cost-effective approach in showing areas of greatest potential for ground water contamination based on hydrogeologic and anthropogenic factors.   investment for many farmers and are especially sensitive to salinity in reduced yields and even tree mortality. Based upon available data, seven thematic maps were generated and combined using the Weighted Sum tool to create a DRASTIC Index map. All data were acquired from public sources. Most raw data were vector shapefiles, with three raster images which were collected for land cover, topography, and crop data for the study area. Most data that was then converted to raster shapefiles.

The DRASTIC Index map showed most of the study area had a high risk of ground water contamination potential. This is due to the parameters with the highest weights had high ratings. Although the DRASTIC method usually gives satisfactory results in the evaluation of groundwater intrinsic vulnerability to contamination, it is important to add additional data to strengthen my results (Al-Rawabdeh et al., 2014) . In this research, Total Dissolved Solids (TDS) data and crop data were added. TDS data and Crop data were important to understand the spatial variability of salinization in the Rincon Valley.

Keywords: DRASTIC, Geographic Information Systems (GIS), Groundwater, Salinization, Rincon Valley, Pecan Orchards

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CHAPTER 1

INTRODUCTION

Background

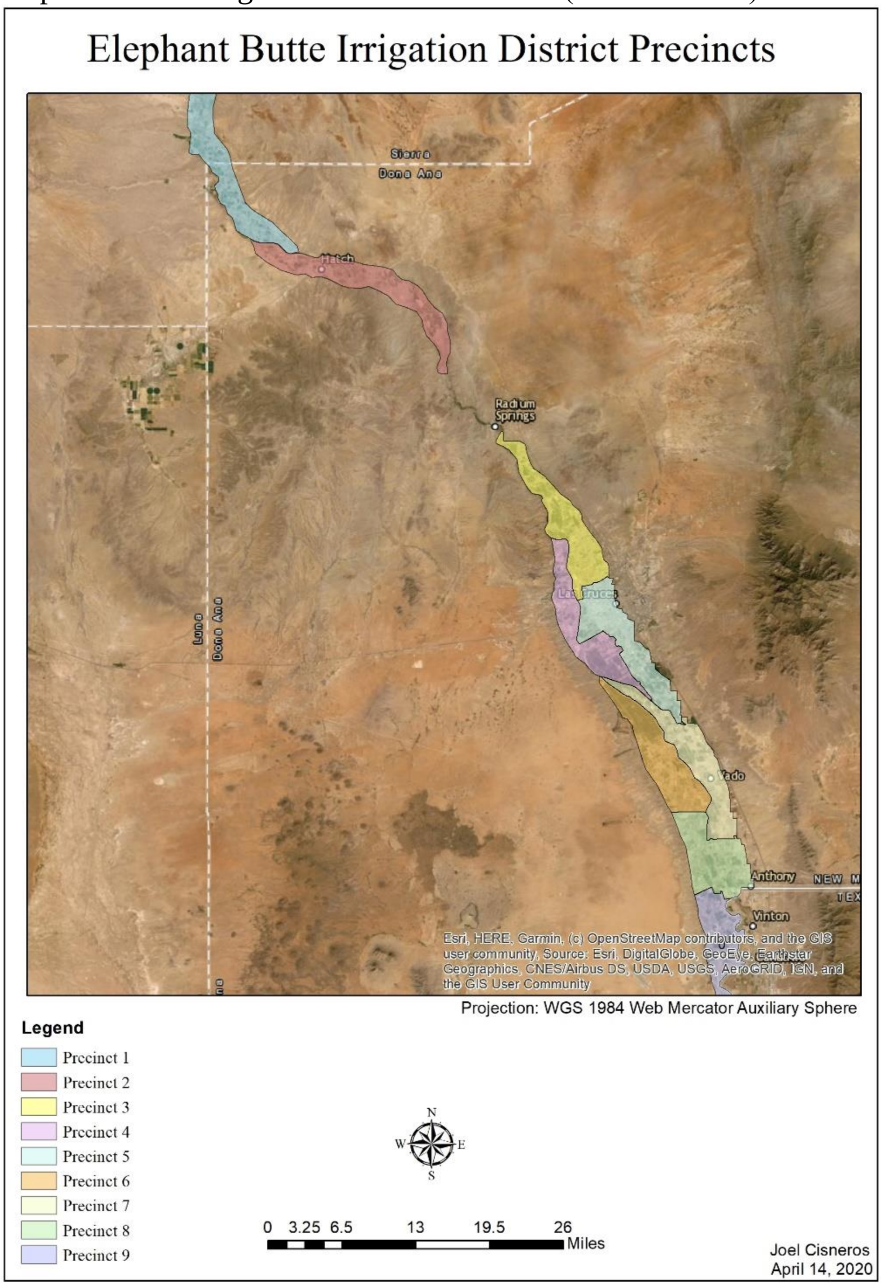
New Mexico has always been connected to water because of the importance of agriculture in the state. Agriculture and food processing in New Mexico accounted for $10.6 billion (roughly 12.3%) of New Mexico's $86.5 billion gross state product (GSP) in 2012 (Diemer, Crawford, and Patrick n.d.). Although New Mexico benefits greatly from agriculture, there is a problem that will become more prevalent in the future. The problem is how water is being managed in the agricultural sector. It is estimated that for the whole year of 2010 irrigated agriculture accounted for roughly 79 percent of total withdrawals from the state's rivers and aquifers (Longworth et al. 2013). The water used for agriculture is also involved with a lot of controversy about who is entitled to what and how much. New Mexico and Texas have been in a legal battle about how the shared water should be developed and managed. Legal problems in combination with the prolonged drought that New Mexico has been enduring will generate significant challenges for water suppliers in the years to come.

Climate change will play a significant role in the future of New Mexico and its neighboring states. New Mexico is getting hotter and drier. From 2001-2010 the average temperatures were the hottest recorded in 110 years. According to the National Climate Assessment, during the ten years temperature were nearly 2 degrees Fahrenheit higher than historical averages (Hoerling et al. 2013). David DuBois, New Mexico climatologist, said this

August (2019) was the second hottest on record, out of 120 years New Mexico State University has been gathering that information. It's not a new phenomenon. He explained that temperatures have been increasing since the 1970s (Romero, 2019). Rain patterns are also changing to a higher percentage of winter precipitation falling as rain instead of snow (Gutzler 2005). This means less alpine snowpack which affects surface water coming from Colorado to fill reservoirs. One of those reservoirs is Elephant Butte Lake, a surface water reservoir managed by Elephant Butte Irrigation District (EBID). EBID serves about 8,000 farmers in the Rincon and Mesilla valleys in southern New Mexico. The district starts from a small town named Arrey in the North and reaches South to the border town of Sunland Park. There are nine precincts in the district with Precinct One being in the North and the Precinct Nine in the South (see Figure 1.1).

Due to the average temperature increases and climate variability, the Elephant Butte irrigation district is having a hard time allocating and storing water for the 2019 irrigation season. The increasing temperatures will increase the atmospheric evaporative demand for water thereby increasing evapotranspiration thus increasing water demand (Garfin et al. 2019). Evapotranspiration will also make droughts worse due to increasing water loss in soil and plants. Dr. Phil King, water resources specialist for the District, noted that total usable project storage currently sits at just 118,563 acre feet at the 2019 December Elephant Butte Irrigation District Board of Directors meeting (Ray 2018). King mentioned that the Elephant Butte reservoir is at 5% storage and are anticipating only a 4-8 inch final allotment (Ray 2018). For the 2019 irrigation season, the irrigation district set the allotment at 10 inches in May but, this was later changed to 14 inches in a special session of the Elephant Butte Irrigation District's Board of Director's meeting on Friday June 21st.

Figure 1. 1 Elephant Butte Irrigation District Precincts ("EBID" 2019)



Due to less surface water being available, farmers are having a hard time growing crops such as the well-known green chile that gives the region its identity. For example, we have farmers such as Maria Martinez who sells her family's produce at Las Cruces farmers market. In an interview with New Mexico In Depth Maria mention that it was a struggle to grow this year due to insufficient water (Romero 2019). Ms. Martinez's case if just an example of challenges many farmers face.

Due to less surface water, a lot of farmers in the Rincon Valley have resorted to using groundwater. Using groundwater is a finite solution with a range of problematic impacts. For example in an interview with Las Cruces Sun news, a farmer named Dickie Ogaz explains how he relies on surface water from EBID to wash away salts accumulated from groundwater (Soular 2015). The article also mentions how farmers prefer surface water to ground water due to better quality.

Also, surface water helps with pushing crop-harming salts down into the soil, past the plants' growth zone (Soular 2015). When using groundwater, it raises the cost of production and exposes crops to higher levels of salinity (Miyamoto 2006). According to Hargrove, there are three reasons why salt loads are increasing in the Rio Grande (Hargrove et al. 2013). The first reason is the increasing annual temperatures southward which lead to higher evaporation and evapotranspiration rates in the irrigated fields. Secondly, the high geothermal gradient of the Rio Grande Rift may enhance upwelling of highly mineralized ground water from deeper parts of basins. Lastly, the dissolution of salt-rich sedimentary rocks in the central and southern parts of the Rio Grande Valley plays a role.

As surface water becomes less available due to climate change and climate variability, it is essential to evaluate the potential problem that exists when using groundwater to irrigate crops (Crane, Roncoli, and Hoogenboom 2011; Hoerling et al. 2013; Maslin 2014). One of the essential steps to evaluate this problem is first to determine where salinization can occur. According to Aller, different types of groundwater vulnerability assessments models have been created (Aller et al.1987). A vulnerability assessment is a process by which information relevant to characterizing groundwater vulnerability is assembled to produce a map that distinguishes areas of greater groundwater vulnerability from areas of lesser groundwater vulnerability (Harter and Walker 2001).

There are various ways to map groundwater vulnerability these methods are grouped into three categories which are; index-and-overlay methods, process-based computer simulations, and statistical analyses. Processed based involves numerical modeling and is useful at the local level but not the regional level. Statistical analysis involves correlating actual water quality data to spatial variables and requires a large amount of site-specific data. Lastly index-and-overlay method involves obtaining and combining maps of the parameters that affect the transport of contaminants from the surface to groundwater, then assigning an index value to those parameters; the results are a spatially oriented vulnerability index (Harter and Walker 2001).

The DRASTIC Method is an index-based methodology used to determine the potential of groundwater contamination of surface pollutants based on seven characteristics. The word DRASTIC is an acronym for the seven parameters. Which is depth of water table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C). With these seven characteristics, it is possible to estimate the possibility of pollution or contamination at the ground level to reach an aquifer (Mondal et al. 2017).

Research Objective

Irrigation and farming practices have explicitly spatial dimensions, hence modeling tools like DRASTIC that are implemented in a geographic information system tool like ArcGIS yield outcomes that inform my research questions. The objective of this research is to explore the utility of the DRASTIC model to map spatial variability of risk for salinization due to higher use of ground water in the Rincon Valley.

The DRASTIC Model was built to be a standardized system for water managers and city planners to be used in the United States. Although the model was intended for use in the United States it is continued to be used in studies all over the world (Walker, Brown, and Fernald 2015).

This model was chosen due to its cost-effective approach in showing areas of greatest potential for ground water based on hydrogeologic and anthropogenic factors.

Like mentioned before DRASTIC is an acronym for the seven parameters. Each parameter of the model is analyzed to create individual maps in ArcGIS and are overlaid to create a final index map. The DRASTIC index map is created by overlaying each of the seven parameter maps together by using an ArcGIS tool named Weighted Sum tool. The Weighted Sum tool provides the ability to weight and combine multiple inputs to create an integrated analysis.

Once the Drastic index map is complete, total dissolved solids (TDS) data and crop data from the National Agricultural Statistics Service (NASS) will be overlaid as well. Crop data is important in understanding the spatial variation of salinization. With the help of the DRASTIC Model and its axillary data a risk surface will be made that will help farmers and water managers. The risk surface will help in various ways, most importantly it will greatly help pecan growers in the Rincon Valley.

In the Rincon Valley, a lot of farmers are transitioning to the cash crop pecans. Doña Ana is responsible for 70 percent of New Mexico's industry acreage ("The Pecan Industry Today" 2019). The transition to pecan orchards needs to be evaluated. Agricultural censuses show a steady growth pecan production area ("2017 Census of Agriculture").

Pecan orchards rely on large amounts of surface and ground water. The Elephant Butte Irrigation District (EBID) throughout the past years has had a hard time in supplying surface water to pecan farmers. Last year the Elephant Butte Reservoir was at 3 percent capacity, and data show this will be a continued trend (Paskus 2018). As surface water supplies becomes marginal and unreliable, ground water has become the main water source for many pecan farmers.

Richard Heerema, an Extension Pecan Specialist, said in an interview with the Southwest Farm Press that the water problem for pecan farmers is twofold. "When we don't have adequate water in the reservoir, growers rely on groundwater," he says "That's a fine backup strategy but it comes with a drawback: water quality isn't as good, and salt content is higher". "When the aquifer is stressed, we end up with saline water — which makes the problem worse." Plants, including pecan trees, require more water when available water is salty. Groundwater also costs more to pump than river water. Growers face two significant issues with moisture, Heerema says. "With insufficient water, they suffer yield and quality losses. That hasn't been the main problem unless they had no access to water." The bigger issue has been salt accumulation in the soils. "Pecans are sensitive to salt. Pistachios, for example, can handle about three times as much salt as pecans without any symptoms on the leaf." Mitigating salt content requires water, Heerema says. "We have to physically remove salt from the soil through leaching. Soil type and water quality are also factors" (Smith 2015). As stated by Richard Heerema in the interview many growers are facing significant issues with moisture.

One of the major issues that needs to be evaluated today is salt accumulation. Salt accumulation hurts pecan orchards in yield and quality losses (Miyamoto 2006). Evidence show temperatures will continue to rise thus systematically reducing the amount of surface water available in reservoirs (Garfin et al. 2014). With the use of the DRASTIC method farmers and water managers can take a more analytical approach in understanding the area that is managed and farmed on. The study area for this study will the lower half of the Rincon Valley.

CHAPTER 2

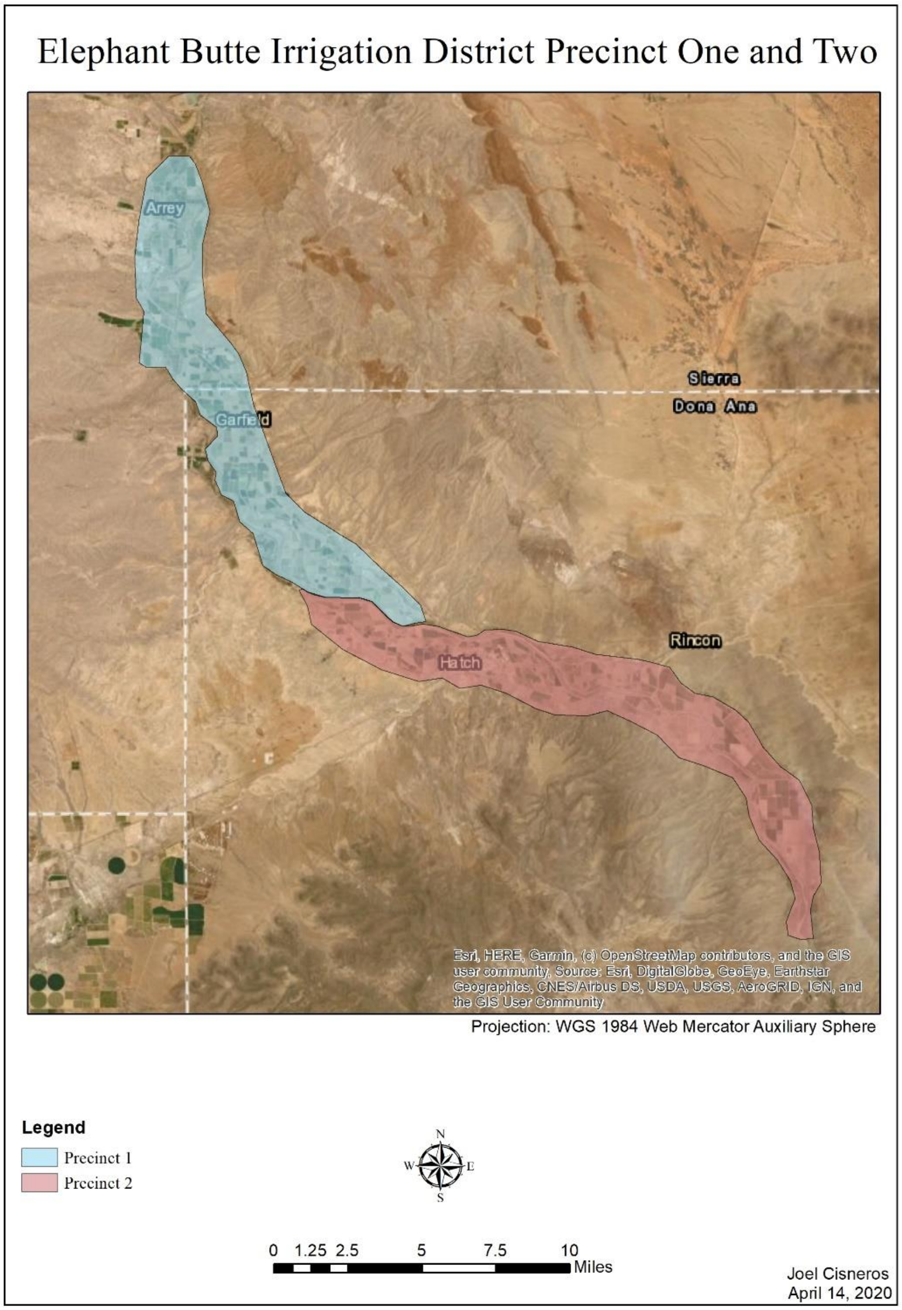
LITERATURE REVIEW

The Rincon Valley

The Rincon Valley is defined as the Rio Grande erosional valley (Rio Grande flood plain) from Caballo Dam on the north to Selden Canyon on the south (Anderholm, 2002). The valley is roughly about 38 miles long and relatively flat. The Rio Grande River traverses through most of the valley and is the lowest point in the flood plain. There are several geographic features throughout in the Rincon Valley. The Caballo Mountains and Tonuco Mountain are located on the east side of the valley. There is also the Sierra de las Uvas, a mountainous area located in the southwest side of the valley (Anderholm, 2002).

The Rincon Valley is home to multiple agricultural towns which are: Arrey, Derry, Garfield, Salem, Hatch, and lastly Rincon. Throughout the years there have been multiple crops that are grown in the Rincon valley. The main crops according to Anderholm are alfalfa, peppers, onions, wheat, cotton, and pecans (Anderholm 2002). The valley agriculture depends upon surface water from Elephant Butte Reservoir, supplemented with ground water from hundreds of wells (King et al., 1971). See Figure 2-1 for EBID precincts. Shifts in which crop is grown most in the valley have occurred. In 1970’s the main crop grown was lettuce. That has changed in present day because of the high-quality water needed for lettuce to flourish today; the crop with the most acres harvested as of 2018 is hay.

Figure 2. 1 EBID Precinct One and Two ("EBID" 2019)



The most popular crop has been the world-famous green chile known for its taste and luster. In Hatch, NM there is a festival called the Hatch Chile Festival created to celebrate Hatch being the Chile Capital of the World ("Village of Hatch,"). Although green chile has been essential in the Rincon Valley, there is another crop that has been gaining attraction from farmers, this crop being pecans (see Table 2-1). According to the Agricultural censuses, pecan orchard area been increasing steadily since 2002 ("USDA NASS" 2019). Chile and pecans are not the only things that grow in the Rincon Valley. Other crops include onions, cotton, corn, and alfalfa. The agricultural sector in the valley is crucial to the people that live there. Irrigated agriculture is by far the foremost form of industry and source of income and tax revenue in the Rincon Valley (Fuchs, Carroll, and King 2018). Although the region benefits from agriculture production, some problems will hinder production, these problems being water shortage, water salinity, and water rights issues.

Table 2. 1 New Mexico Commodities by Acres Harvested ("USDA NASS" 2019)

Commodity	Years	Acres Harvested
Cotton	2018	62,800
	1998	67,600
	1963	190,000
Wheat	2018	105,000
	1998	265,000
	1968	305,000
Hay	2018	250,000
	1998	360,000
	1968	264,000
Peppers	2018	7,900
	2000	19,000
Pecans	2017	44,434
	2012	36,630
	2007	35,746
	2002	33,123

Water Rights Issues in the Rincon Valley

There is an institutional context of water rights that will greatly impact the future water supply in the Rincon Valley. The Rio Grande River provides water to New Mexico and Texas; lately there have been a series of legal disputes. Texas submitted a dispute before the US Supreme Court claiming that New Mexico is using water in excess of its apportionment under the 1938 Rio Grande Compact (Wheat 2015). If the Supreme Court rules in favor of Texas, it is likely that limitations on ground-water pumping will be imposed. This adds another issue to a complex problem in the Rincon Valley.

Climate Change in the Rincon Valley

The Southwest is known for being one of the hottest and driest regions in the United States. Climate change is posing new challenges to an already arid area. The Southwest is expected to get warmer and drier, especially in the southern half (Garfin et al., 2014). The region has heated up markedly in recent decades. The decade 2001-2010 was the warmest in the 110 year of instrumental records, with temperatures almost 2 degrees higher than historical averages (Hoerling et al., 2013). Increased temperatures and changes to the hydrologic cycle will significantly affect the region's agriculture sector. Warmer temperatures will affect the lives of 56 million people in the region (Theobald, Travis, & Gordon, n.d.). Severe drought will put a strain on water sources, which are already over-utilized in many areas in the region.

Drought will also force increasing competition among water users. A warmer, drier climate is projected to accelerate current trends of massive transfers of irrigation water to urban areas (Jackson et al., 2013). These factors will affect local agriculturally dependent economies such as small towns in the Rincon Valley. Droughts and extreme water affect the market value of fruits and vegetables because of sales depending highly on appearance.

Agriculture in the Southwest region faces uncertainty and change because of all these factors and more. Farmers are renowned for adapting to yearly changes in the weather, but climate change in the Southwest could happen faster and more extensively than farmers' ability to adapt. The significant factor that contributes to water shortage is climate change. Winter snowpack in the southwest region is crucial because it is a natural reservoir. Over the past 50 years, there has been less late-winter precipitation falling as snow. Some projections note this will be a continued trend, and this will result in further reduction of late winter and spring snowpack (G. Garfin et al. 2014). These results pose increased risks to water supplies not only in the Rincon valley but too many more regions.

Salinity in the Rincon Valley

The Rio Grande is the main drainage through the Rincon Valley (Anderholm 2002b). Discharge in the in Rio Grande has large variation due to the Caballo Reservoir releasing irrigation water based on demand. Typically, no water is released from mid-October until March. A complex system of canals moves the irrigation water to individual fields in the Rincon Valley. It is important to evaluate the relationship between surface water and ground water when it comes to salinity. The quality of surface water used for irrigation affects ground-water quality and the quality of ground water affects surface-water quality because of interaction between the surface and groundwater systems (Anderholm, 2002). This is because surface water infiltrates and recharges the groundwater system, and ground water discharges to the drains and the Rio Grande (Anderholm, 2002).

There is a lot of research that has been conducted to determine why the salt loads are increasing in the Rio Grande River. Although it has been investigated for about 75 years, no conclusive answer has been reached (Hogan et al. 2007). Although there is no conclusive answer there are three reasons that are agreed upon from various researchers. The three agreed reasons are: (1) the increasing annual temperatures southward which lead to higher evaporation and evapotranspiration rates in the irrigated fields (Phillips et al., 2003), (2) the high geothermal gradient of the Rio Grande Rift, which may enhance upwelling of highly mineralized groundwater from deeper parts of basins (Moore et al., 2008) (Witcher et al. 2004), and (3) the dissolution of salt-rich sedimentary rocks in the central and southern parts of the Rio Grande Valley (Hogan et al. 2007).

Salinization possess a major challenge to agricultural towns in the Rincon Valley. River salinization results in great economic damage through direct reduction of crop productivity and long term damage to agricultural soils (Hogan et al. 2007). Although today the problems that are caused by salinization are minimal, it is important to keep evaluating this problem in the valley. To evaluate this problem, you first have to asses which locations are prone to salinization and what counter measures can be implemented to mediate salinization. A modified DRASTIC Model is a fast and cost-effective way of evaluating surfaces through hydrogeologic parameters.

DRASTIC Method

The purpose of the DRASTIC Method is to estimate the ground-water pollution potential of any hydrogeologic setting by systematically evaluating existing data anywhere in the United States (Aller et al., 1987). The DRASTIC Method was prepared to assist planners, managers and administrators in the task of evaluating the relative vulnerability of groundwater. The DRASTIC Method was also developed for it to be readily displayed on maps. This is done with the implementation of a system which produces a numerical rating for evaluation.

The DRASTIC Method contains three significant parts: weights, ranges and ratings. Each DRASTIC parameter will have a set weight from 1 to 5 describing its importance in the model with respect to the other parameters. The most significant factors have weights of 5; the least significant, a weight of 1. The weights were determined by using a Delphi (consensus) approach. The Delphi consensus method is a structured survey that gathers expert opinions of correct answers, to obtain hydrogeological factors and their ratings and weights, provides the system with expert backing and structure (Aller et al. 1987).

Within each DRASTIC parameter there is a scaled rating system from 1 to 10 (see tables 2. 2 to 2. 8) that is ruled by variations throughout the parameter. Once the parameter's rating and weight are set, the DRASTIC index formula can be used, as noted below (see Table 2. 2 for description and weights).

$$\mathrm{DRASTIC}_i = Dr \times Dw + Rr \times Rw + Ar \times Aw + Sr \times Sw + Tr \times Tw + Ir \times Iw + Cr \times Cw$$

Where: r = the rating for the parameter and w = the assigned weight for the parameter.

Table 2. 2 Description and Weights of DRASTIC Parameters (Aller et al. 1987)

DRASTIC Parameters	**Weight**	**Description**
(D) Depth to Water	5	The depth from the ground surface to the water table in unconfined aquifer and to the bottom of the confining layer in confined aquifer.
(R) Net Recharge	4	The total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer.
(A) Aquifer Media	3	Consolidated or unconsolidated rock which serves as an aquifer (such as sand, gravel, and limestone.
(S) Soil Media	2	The uppermost portion of the vadose zone characterized by significant biological activity.
(T) Topography	1	The slope and slope variability of the land surface.
(I) Impact of the Vadose Zone	5	The zone above the water table which is unsaturated or discontinuously saturated.
(C) Hydraulic Connectivity	3	The ability of the aquifer materials to transmit water

Once the DRASTIC index formula has been computed, I can create a risk surface which identifies areas which are more susceptible to groundwater contamination relative to one another. The numerical value of the DRASTIC index can be considered as an indicator to determine the areas that are more likely to be susceptible to groundwater contamination. A higher DRASTIC index shows greater groundwater contamination vulnerability.

DRASTIC Parameters

In the following sections, I will describe every individual hydrogeological parameter and follow the description with the ranges, ratings, and weights in a table. The description will have information pertaining to the area of the Rincon valley. The following table (Table 2-1) shows the weights of every parameter as noted by the original Model by (Aller et al., 1987)

Table 2. 3 Relative Assigned Weights of DRASTIC MODEL Parameters (Aller et al 1987).

PARAMETER	WEIGHT
DEPTH TO WATER	5
NET RECHARGE	4
AQUIFER MEDIA	3
SOIL MEDIA	2
TOPOGRAPHY	1
IMPACT OF VADOSE ZONE	5
HYDRAULIC CONDUCTIVITY	3

D - Depth-to-Water in the Rincon Valley

Depth to water is vital in the DRASTIC Method, as it determines the depth of material through which a contaminant must travel before reaching the aquifer (Aller et al. 1987). The depth to water is also vital because shallow depth provides the maximum opportunity for oxidation by atmospheric oxygen (Aller et al. 1987).

In all the hydrogeologic reports in the Rincon Valley Conover (1954) provides a good description of the depth to water in the Doña Ana which the Rincon Valley resides. According to Conover (1956), the depth to water in upland areas in Doña Ana County ranges from less than 25 feet to more than 400 feet. Areas with of the greatest depth to water are in the relatively flat plains away from the mountain fronts, such as the La Mesa surface (Conover, 1954).

Table 2. 4 Range, Rating, and Weight for Depth to Water (Aller et al 1987).

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
WEIGHT 5	

R - Net Recharge in the Rincon Valley

A primary source of groundwater is most typically precipitation. Rainwater infiltrates through the surface of the ground and percolates to the water table. Net recharge represents the amount of water per unit of land, which penetrates the ground surface and reaches the water table (Aller et al. 1987). Recharge pays a vital role in transporting the contaminants to the groundwater table.

Precipitation in the Rio Grande valley is not enough to satisfy the soil moisture capacity for recharging groundwater. Most recharge occurs principally by the infiltration of surface run-off into rills and arroyo channels during summer storms. Prevalent storm runoff is redirected from the valley by dams to the Rio Grande River (Anderholm 2002).

Discharge in the Rio Grande has significant variation because releases from the Caballo reservoir generally control it. Typically, little or no water is released from mid-October until March. During this time discharge at the streamflow gauge on the Rio Grande below Caballo Dam is generally less than 10 ft^3s^{-1}. Discharge in the Rio Grande increases downstream because of groundwater discharge to the river and inflow from drains. The highest releases in the Rio Grande generally are in June, July, and August (Anderholm, 2002).

Recharge to the flood-plain alluvium is from irrigation, seepage from the Rio Grande and canals, precipitation, and surface and subsurface inflow from tributary arroyos. For many years, the balance between recharge and discharge was about equal. According to Fuchs, Carroll and

King (2018) aquifer recharge is highly dependent of surface water allotments from EBID. If water shortages to the EBID remain as they have, ground water depletion is surely unavoidable (Fuchs, Carroll, and King 2018). The water table in the Rincon Valley may decline as much as 10 feet during years of very little surface-water delivery and much groundwater extraction (Wilson et al. 1981).

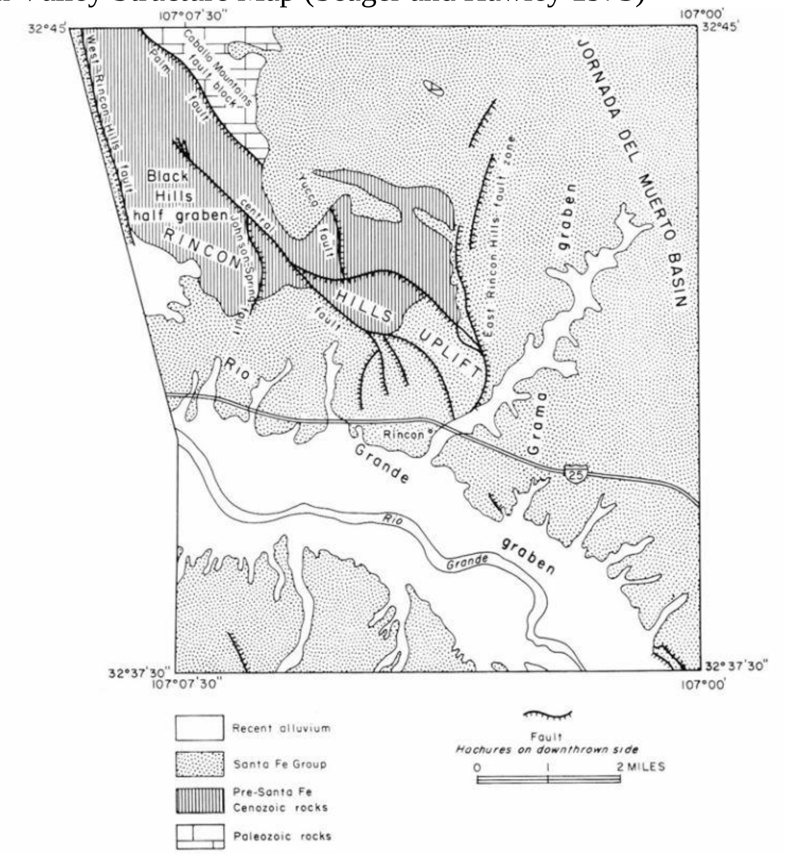
Table 2. 5 Range, Rating, and Weight for Net Recharge (Aller et al 1987).

NET RECHARGE (INCHES)	
RANGE	RATING
0-2	1
2-4	3
4-7	6
7-10	8
10+	9
WEIGHT 4	

A - Aquifer Media in the Rincon Valley

Aquifer media refers to the consolidated or unconsolidated medium which serves as an aquifer (e.g., sand and gravel or limestone). The larger grain size and the more fractures within the aquifer, the higher the permeability and the lower the attenuation capacity for the aquifer media (Aller et al. 1987). Aquifers in the Rincon Valley area are the flood-plain alluvium, the narrow strips of alluvial fill in the tributary arroyos, and sand and gravel alluvial-fan deposits in the Santa Fe Group (Wilson et al., 1981). The flood-plain alluvium in the Rincon Valley forms a long and narrow continuous aquifer no more than 2 miles wide and about 60 to 80 feet deep.

Figure 2. 2 Rincon Valley Structure Map (Seager and Hawley 1973)



Most of the Rincon Valley is underlain by the fine-grained facies of the Santa Fe Group. The Quaternary valley fill, according to King and others, is about 80 ft thick and consists of gravel, sand, silt, and clay-sized sediment (King et al., 1971). In the table below are the original ranges, rating and weight of aquifer media.

Table 2. 6 Ranges, Rating, and Weights for Aquifer Media (Aller et al 1987).

AQUIFER MEDIA		
RANGE	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	6
BASALT	2-10	9
KARST LIMESTONE	9-10	10
WEIGHT 3		

S - Soil Media in the Rincon Valley

Soil media refers to that uppermost portion of the vadose zone characterized by significant biological activity (Aller et al. 1987). The soil has a considerable impact on the amount of recharge which can infiltrate into the ground and hence on the ability of a contaminant to move vertically into the vadose zone. Some practical factors determine the potential pollution of soil comprising the type of clay, the grain size, and shrink potential of clay (Gheisari n.d.).

The National Cooperative Soil Survey produces soil data and information. It is operated by the USDA Natural Resources Conservation Service (NRCS) and provides access to the most abundant natural resource information system in the world, according to NRCS ("Web Soil Survey - Home" 2019). In Table 2.7 below is the original range, rating, and weight of soil media.

Table 2. 7 Range, Rating, and Weight for Soil Media (Aller et al. 1987).

SOIL MEDIA

RANGE	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 NON-AGGREGATED CLAY	1
WEIGHT 2	

T - Topography in the Rincon Valley

Topography refers to the slope and slope variability of the land surface. Topography helps control the likelihood that a pollutant will run off or remain on the surface in one area long enough to infiltrate (Aller et al. 1987). The Rincon Valley is a valley that has relativity smooth alluvial floors ranging in width from a few hundred feet to a maximum of about 5 miles. The altitude of the Rincon Valley ranges from about 4,140 feet above sea level at Caballo Dam to 3,974 ft at Leasburg Dam, a slope of about 4.5 ft to the mile (Conover, 1954).

The Rincon Valley is bordered by steep bluffs, about 50 to 100 feet high, of loosely cemented sand, silt, clay, and gravel. From the bluffs, gently inclined plains extend back to the mountain. The Caballo Mountains parallel the Rincon Valley a few miles to the east and separate it from the *Jornada Del Muerto*. West of the Rincon Valley, the plains extend nearly to the Mimbres Mountains. At the southern end, we have Selden Canyon, which eroded into the igneous rocks that form the Serra de las Uvas (Conover, 1954). In table 2.8 below is the original range, rating, and weight as by (Aller et al. 1987) of Topography.

Table 2. 8 Range, Rating, and Weight for Topography (Aller et al. 1987).

TOPOGRAPHY

(PERCENT SLOPE)

RANGE	RATING
0-2	10
2-6	9

6-12	3
12-18	3
18+	1
WEIGHT 1	

I - Impact of the Vadose Zone in the Rincon Valley

The vadose zone is defined as that zone above the water table which is unsaturated or discontinuously saturated (Aller et al. 1987). Vertical movement of water in the vadose zone is essential for pollution transport (Gheisari n.d.). Vertical ground-water movement in the Rincon Valley generally comes from ground-water recharge to the Quaternary valley fill deposits.

Recharge comes from infiltration of precipitation, water from the Rio Grande, and irrigation water, and inflow of ground water from adjacent areas. In the shallow part of the Quaternary valley-fill Deposits, the interaction of the Rio Grande River and irrigation wells have created many localized flow systems (Anderholm, 2002).

Table 2. 9 Ranges and Ratings for Impact of the Vadose Zone Media (Aller et al. 1987).

IMPACT OF THE VADOSE ZONE MEDIA

RANGE	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
WEIGHT 5		

C - Hydraulic Conductivity in the Rincon Valley

Hydraulic conductivity refers to the ability for the aquifer material to transmit water, which, in turn, controls the rate at which groundwater will flow under a given hydraulic gradient (Aller et al. 1987). A high groundwater flow rate represents high contaminant advection. Wilson and others (1981) estimated groundwater movement using 15 specific capacities in the Rincon Valley. These 15 wells were perforated in the flood-plain alluvium.

Static and pumping water levels were measured. Estimated specific capacities were calculated based on a measured pumping level in the well and a static water level determined from the measured static water level in the nearby well. The specific capacities calculated for wells in the Rincon Valley range from 17 to 79 gallons per minute per foot of drawdown and average 50 gallons per minute per foot of drawdown (Wilson et al., 1981).

Conover estimated that transmissivities from specific capacities of wells in the flood-plain alluvium in the Rincon Valley range from about 2,700 to 14,800 ft^2 per day and average about 9,200 ft^2 per day and an average saturated thickness of 55 ft for the flood-plain alluvium. Transmissibility (or transmissivity) is a property closely related to hydraulic conductivity that describes the capacity of a specific water-bearing unit of a given thickness, such as an aquifer, to transmit water. Transmissibility is most simply defined as the effective hydraulic conductivity of an aquifer or other water-bearing unit multiplied by the thickness of that unit (Dielman 2005). The average hydraulic conductivity of the alluvium aquifer is estimated to be about 170 ft per day (Wilson et al., 1981).

Table 2. 10 Ranges and Ratings for Hydraulic Conductivity (Aller et al. 1987).

HYDRAULIC CONDUCTIVITY (GPD/FT^2)	
RANGE	RATING
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10
WEIGHT 3	

The DRASTIC Method and the Rincon Valley

The DRASTIC Method is a time and cost-effective approach in showing areas of greatest potential for ground water contamination based on hydrogeologic and anthropogenic factors. The DRASTIC Method can help shine a light on areas in the Rincon Valley that need closer monitoring and attention. The DRASTIC Method can be particularly helpful to pecan producers. Pecan orchards is one of the fastest growing products in the Rincon Valley. Pecans are a costly investment for many farmers and are especially sensitive to salinity in reduced yields and even tree mortality.

Crop data will be important in understanding the spatial variation of salinization. The U.S. Department of Agriculture National Agricultural Statistics Survey (NASS) collects and publishes crop growth status and soil moisture conditions in major U.S. agricultural regions (Colliander et al. 2019). In the Rincon Valley, a lot of farmers are transitioning to the cash crop pecans. Doña Ana County is responsible for 70 percent of New Mexico's industry pecan acreage ("The Pecan Industry Today" 2019). The transition to pecan orchards needs to be evaluated. Agricultural censuses show a steady growth in area of pecan production ("USDA NASS" 2019) Pecan orchards rely on large amounts of surface water as EBID is unable to allocate the much-needed surface water for these thirsty crops. Saline groundwater is used extensively as an alternative mean for irrigation. Saline water hinders pecan orchards greatly because of their low resistance to salt and the inability to rotate crops (Miyamoto 2006).

It is very costly to move a mature tree; it is not economically feasible because of high fuel and labor costs (Heerema and White 2008). Other popular crops in the Rincon Valley such as alfalfa or green chile can be rotated and moved or switched with higher salt resistant plants. Unfortunately, pecan orchards cannot be rotated every year, which leaves salt leaching as one of the best tools for mitigating salinity problems of pecan orchards (Miyamoto, 2006). Leaching is the process of applying more water to the field than can be held by the soil in the crop rootzone such that the excess water drains below the root system, carrying salts with it. The more water that is applied in excess of the crop water requirement, the less salinity there is left in the rootzone even though more salt has been added to the field (Grattan 2002). Unfortunately, salt leaching requires a lot of water. To leach a highly saline soil, you may need to apply as much as 48 acre inches of water per acre? (Provin & Pitt,). The only reservoir that can provide that water to farmers comes from the Elephant Butte Irrigation District (EBID).

As a result of recent snow droughts and higher temperatures, EBID cannot provide the large quantities of water needed in the Rincon Valley for salt leaching. Snowpack reservoirs such as the ones that supply water to the district have been declining since the mid-twentieth century. Recent declines are driven by rising temperatures which reduce snow water equivalent, even when there are increases in precipitation (Mote et al., 2005).

Another factor that will be a challenge for pecan farmers in the Rincon Valley is the water rights issue. Doña Ana shares borders and Rio Grande water with Mexico and Texas, and it is a region of highly contentious water issues. In 2013, in the latest of a series of legal disputes, the state of Texas submitted a complaint before the US Supreme Court claiming that New Mexico is using water in excess under the 1938 Rio Grande Compact (Wheat 2015).

As stated previously, it is important to evaluate the growth of pecan orchards in the Rincon Valley. With that growth comes the use of more saline ground water to compensate for the loss of surface water. The utility of DRASTIC Method will be explored to map spatial variability of risk for salinization due to higher use of ground water in the Rincon Valley.

CHAPTER 3

DATA AND METHODS

All data were acquired from public sources. Most raw data were vector shapefiles, with three raster images which were collected for land cover, topography, and crop data for the study area. Most data that was then converted to raster shapefiles. All data manipulation was performed in ArcGIS 10.7 for Desktop, Spatial Analyst, Microsoft Excel, and JMP 14 (SW) a statistical program. List of the unprocessed data for the project are found in the table below (Table 3.1).

Selection of Study Area

The selected study area is Precinct Two in the Elephant Butte Irrigation District; there are a total of nine precincts in the district. Precinct Two is the lower half of the Rincon Valley; this area was chosen because of ease of travel, familiarity, and data availability (see Figure 2.1). It was also selected because of two technical articles from New Mexico Water Resources Research Institute (WRRI). The two articles are Technical Completion Report No. 332 *Creation of a Digital Hydrogeologic Framework Model of the Mesilla Basin and Southern Jornada Del Muerto Basin* (Hawley and Kennedy 2004) and Technical Completion Report No. 367 *Use of the DRASTIC Model to Evaluate Groundwater Pollution Sensitivity from On-site Wastewater Systems in the Mesilla Basin.* Methodology from Technical Completion Report No. 367 (Walker, Brown, and Fernald 2015) was used for some of the DRASTIC parameters. Data used were from Technical Completion Report No. 332 (Hawley and Kennedy 2004).

Table 3. 1 List of Unprocessed Data.

Dataset	Source	Scale	Year
Boundaries			
EBID Precinct two	Elephant Butte Irrigation District (EBID)	N/A	2019
Doña Ana County	rgis.unm.edu/rgis6/ (RGIS)	N/A	2000
Roads	datagateway.nrcs.usda.gov/GDGOrder.aspx (USDA)	N/A	2015
Well Data			
Study area well data	https://groundwaterwatch.usgs.gov/default.asp	N/A	2000-2018
TDS	maps.nmt.edu/ (NMBGMR)	N/A	2006
Land Use/Land Cover Data			
National Land Cover Dataset	datagateway.nrcs.usda.gov/GDGOrder.aspx (USDA)	30 Meter	2011
Cropland Data	datagateway.nrcs.usda.gov/GDGOrder.aspx (USDA)	30 Meter	2008
Surface Geology			
State Geologic Map	maps.nmt.edu/ (NMBGMR)	1:500,000	N/A
Plate R1	John W. Hawley and John F. Kennedy	1:100,000	2004
SSURGO Soil Coverage Data			
New Mexico Soils	datagateway.nrcs.usda.gov/GDGOrder.aspx (USDA)	1:24,000	2008
Digital Elevation Model			
Study Area DEM	datagateway.nrcs.usda.gov/GDGOrder.aspx (USDA)	30 Meter	N/A

Choosing a Pollution Sensitivity Model

There are several different types of groundwater vulnerability assessment models**.** Numerous approaches have been used or proposed for assessing ground water vulnerability. They range from sophisticated models of the physical, chemical, and biological processes occurring in the vadose zone and ground water regime, to models that weigh critical factors affecting vulnerability through either statistical methods or expert judgment (National Research Council (U.S.) 1993). Finding ways to model the complexities of the environment while keeping the model as concise and manageable as possible is a challenge researchers face; the *DRASTIC* model performs well enough to support much work by many researchers (Walker, Brown, and Fernald 2015).

Although the DRASTIC model might be popular it does come with some disadvantages. The major problem that has been brought up by researchers is the subjectivity of the rating determinations and scales it employs. Since factors are chosen instead of calculated it makes the model more qualitative than quantitative (Walker, Brown, and Fernald 2015). Although the DRASTIC model comes with some disadvantages the advantages outweigh them. The most important advantage of the DRASTIC model is that it was designed to be a management tool that is cost effective, simple to use, and uses existing data (Aller et al., 1987). For these reasons this model was used for this study.

Methods

DRASTIC Model

As was introduced previously, the DRASTIC model is a pollution sensitivity mapping model that focuses on seven hydrogeology factors (parameters) that rule pollution transmittance to groundwater (Aller et al., 1987). The parameters form the acronym naming the system: Depth to Water (D), Net Recharge (R), Aquifer Media (A), Soil Media (S), Topography (T), Impact of the Vadose Zone (I), and Hydraulic Conductivity (C). The model is designed with a ranking system for each parameter that determines the pollution potential. Once each parameter map is completed, they are overlaid to produce the final index map. The following sections describe how the original model was manipulated based on hydrogeologic data available for the Rincon Valley. The methodology and some data were used from *Technical Completion Report No. 367 Use of the DRASTIC Model to Evaluate Groundwater Pollution Sensitivity from On-site Wastewater Systems in the Mesilla Basin* (Walker, Brown, and Fernald 2015).

Depth to Water Parameter (D)

The Depth to Water parameter map was created from well data from the USGS Active Groundwater Level Network. I chose to obtain the data from here because the well data were already averaged from all historic water marks. It also showed the highest noted water mark that each well measured. High watermark measurements yield a water-table surface nearest to the ground surface, which increases the sensitivity to a 'worst-case scenario.' This also removes variability in the surface over time, which negates some of the pumping draw-down that may have occurred and gives the surface a null date (Walker, Brown, and Fernald 2015). For this reason, the highest watermark was chosen instead of the average water level. There was a total of 16 wells in EBID Precinct Two; each was extracted and imported to ArcMap for data manipulation. The depth to water surface was created by interpolating using the highest watermark depth to water level. The interpolation was created with the kriging tool from Spatial Analyst; results are noted below in the panel of maps (see Figure 3.1).

Net Recharge Parameter (R)

Originally this parameter map was going to be built by using precipitation data but proved to be much more demanding in time and data. The methods for this parameter maps were borrowed from (Walker, Brown, and Fernald 2015). The Net Recharge parameter map was built by reclassifying a 2011, 1:24,000 scale, USGS National Land Cover Dataset classification model (Fry et al. 2011) using the Net Recharge parameters determined by Creel and others (1998) and Kennedy (1999) for how much surface water per unit of area is available for each land-cover type (Walker, Brown, and Fernald 2015). The USDA landcover dataset was reclassified with the Reclassify Tool using table 3.2 for net recharge ratings based from Creel and others (1998) and Kennedy (1999). The results of this analysis are detailed below in panel of maps (see Figure 3.1).

Table 3. 2 Net Recharge Ratings, for 2011 USDA National Land Cover Codes (Walker, Brown, and Fernald 2015)

NLCD Code[1]	NLCD Classification[1]	Rating[2]
11	Open Water	9
81/82	Pasture/Hay/Cultivated Crops	9
90/95	Woody Wetlands/Emergent Herbaceous	8
42	Evergreen Forest	6
21/22/23/24	Developed Land (All Densities)	1
31	Barren Land (Rock/Clay/Sand)	1
52/71	Shrub/Scrub/Grassland/Herbaceous	1

[1] As per Fry (2011)
[2] As per Walker et al (2015)

Aquifer Media (A)

The Aquifer Media Parameter map was created by using a geology map from Technical Completion Report No. 332 *Creation of a Digital Hydrogeologic Framework Model of the Mesilla Basin and Southern Jornada Del Muerto Basin* (Hawley and Kennedy 2004). The geology map that was used was Plate R1 Hydrogeology of the Rincon Valley and Adjacent Parts of the Southern Palomas and Jornada Basins, South-Central New Mexico (Hawley and Kennedy 2004). The map was imported to ArcMap and then georeferenced to the study area. The geology map has hydrostratigraphic units (HSUs), which are the specific types of geological media that form a distinct hydrologic unit with respect to groundwater flow. They are comparable to the mappable, hydrogeological settings of *DRASTIC*. Lithofacies (LFAs) are distinct strata of sedimentary media combined into groups based on color, grain size, texture, distribution, composition, structure, or post-depositional alteration (Walker, Brown, and Fernald 2015). The study area is very simple when it comes to the hydrostratigraphic units (Hawley and Kennedy 2004).

The study area was comprised of only one type of HSUs which was RA. The RA HSU was digitized and created into a polygon; added to the polygon was the rating assigned by (Walker, Brown, and Fernald 2015). The polygon was converted into raster format and then reclassified to display the rating. The reasons Walkers' rating was used is due to this project using the same type of data and the same methodology. Also, Steve Walker conducted telephone interviews with ground water specialists when selecting the ratings. The results of this analysis are shown below in the panel of maps (see Figure 3.2).

Soil Media Parameter (S)

The Soil Media parameter map was build using soil data from the web soil survey. The Web soil survey has the option to add a region of interest (ROI), so I added the ROI of my study area (Precinct Two). Once the ROI was imported, I downloaded the SSURGO data that pertained to the study area. The SSURGO soil series provided many different soil types beyond the nine that Aller and others (1987) had originally described for *DRASTIC* (Walker, Brown, and Fernald 2015). With expert advice (personal interview by S. Walker and C. Monger on June 26, 2012), Walker designed a table using the original soil types and rating as a base, and a table of expanded ratings for each soil type. Soil horizon ratings were combined into a single rating for each series using a formula for vertical hydraulic conductivity perpendicular to layering (Fetter 2001).

The downloaded data were then added to ArcMap and then classified. Once in ArcMap, I used the Table to Excel tool to export the soil data to Excel and then to JMP (14) to add the rating for the soil entries. Once, the table was populated with all the ranges for the various types of soils, the soil table was imported back to ArcMap. The table was then joined back to the soil polygon using the join function. The soil polygon was then converted into raster format using the Polygon to Raster tool. The results of this analysis are shown in the panel of maps (see Figure 3.2).

Topography Parameter (T)

The Topography parameter was built from a USGS, National Elevation Dataset (NED) digital elevation model (DEM). Two DEMs were needed to cover all the study area, since there where only two DEMs they were both merged together using the Mosaic tool. Once the DEMs were merged the Slope tool was used to calculate a slope percent. The shape file was then reclassified using the reclassify tool and the Table 3.3 which is shown below. The results of this analysis are shown below in the map panel (see Figure 3.3).

Table 3. 3 *DRASTIC* Topography Component - Range, Rating, and Weight (Aller et al. 1987)

Range [percent slope]	Rating	Weight
0 to 2	10	1
2 to 6	9	1
6 to 12	5	1
12 to 18	3	1
18+	1	1

Impact of Vadose Zone Parameter (I)

The Impact of the Vadose Zone parameter was built from the same Aquifer Media parameter shapefile. This is due to the RA HSU having data pertaining to the Vadose Zone. The simplicity of the Rincon valley made this an easy parameter to make. The rating and the weight were chosen based on the (Walker, Brown, and Fernald 2015) table which is displayed below. Table 3-3 lists the geomorphology, maximum depths, and vadose zones based on properties found in (Hawley and Kennedy 2004). The vadose range was adjusted with expert advice (personal interview by S. Walker with J.W. Hawley on July 17, 2012) for each hydrogeology type based on its known formation, components, and porosity (Walker, Brown, and Fernald 2015). The results of this analysis are shown below in the map panel (see Figure 3.3).

Table 3. 4 Surface Hydrogeology Rating System for Vadose Zone (Walker, Brown, and Fernald 2015)

Hydrogeology[1]	Geomorphology Zone[1]	Vadose Zone[1]	Vadose Range[2]	Impact of Vadose Zone Rating[3]
RA	Rio Grande Valley	Mostly Saturated	Sand/Gravel	9
TA	Rio Grande Valley	Entirely Vadose	Sand/Gravel	9
USF2	Santa Fe Group	Partly Vadose	Sand/Gravel	9
USLM	Santa Fe Group	Entirely Vadose	Sand/Gravel	9

[1] Hawley and King (2004)
[2] Aller et al (1987)
[3] As per J.W. Hawley, interviewed by S. Walker on July 17, 2012.

Hydraulic Conductivity Parameter (C)

The Hydraulic Conductivity Parameter was also built from the same Aquifer Media parameter, since hydraulic conductivity is an attribute of the hydrogeologic media. Polygons created for the Aquifer Media component were classified with both hydrostratigraphic units (HSUs) and lithofacies assemblages (LFAs). Walker, Brown and Fernald (2015) created a table using LFAs reclassified with *DRASTIC* Hydraulic Conductivity ratings (Aller et al. 1987), entries from Hawley and Kennedy (2004), and expert advice (personal interview by S. Walker with J.W. Hawley on December 15, 2012) (Walker, Brown and Fernald 2015).The ratings and weights were chosen based on Walker, Brown and Fernald (2015) Table 3.5 which is displayed below. The results of this analysis are shown below in the map panel (see Figure 3.4).

Table 3. 5 Hydrogeology Rating System for Hydraulic Conductivity (Walker, Brown, and Fernald 2015)

LFA Values[1]	Hydraulic Conductivity[1]	K (feet per day)[1]	K (gallons per day per square foot)[2]	Hydraulic Conductivity Rating[4]
1/a1	High	65	486.2338	4
1,2	High-High Moderate	56.92	425.7912	4
1,2,3/ 1,3/ 2,1	High Moderate	48.83	365.27379	4
2/ a	Hight-Moderate	40.75	304.83119	4

[1] As per Hawley and Kennedy (2004).
[2] Conversion rate 1 foot per day x 7.48052 gallons per cubic foot (Fetter 2001).
[3] As per Aller et al. (1987).

Figure 3. 1 Depth to Water and Net Recharge Parameter Maps

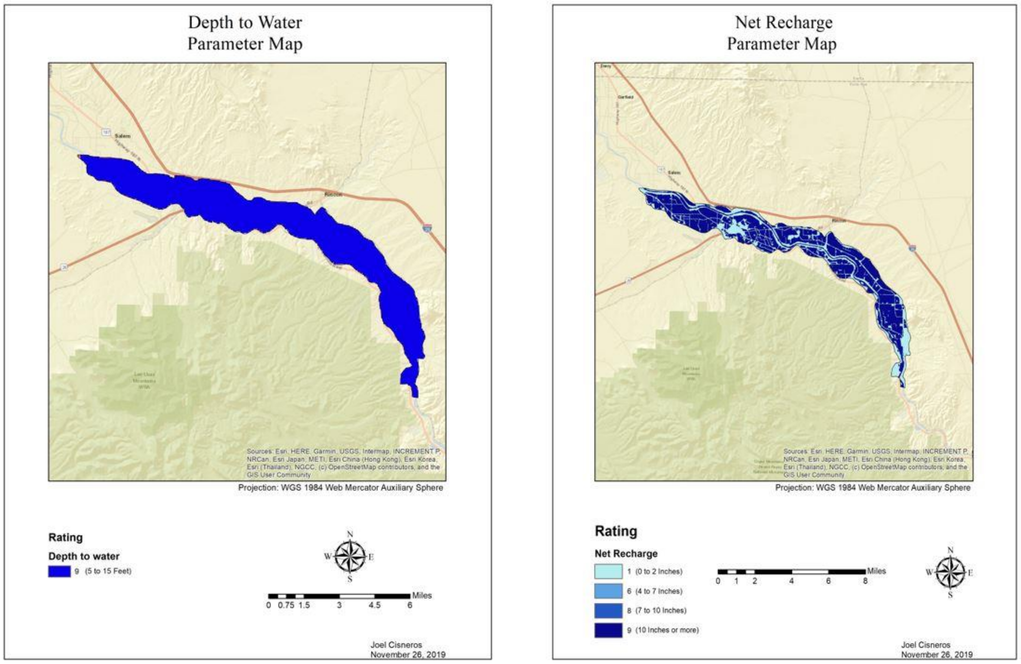


Figure 3. 2 Aquifer and Soil Media Parameter Maps

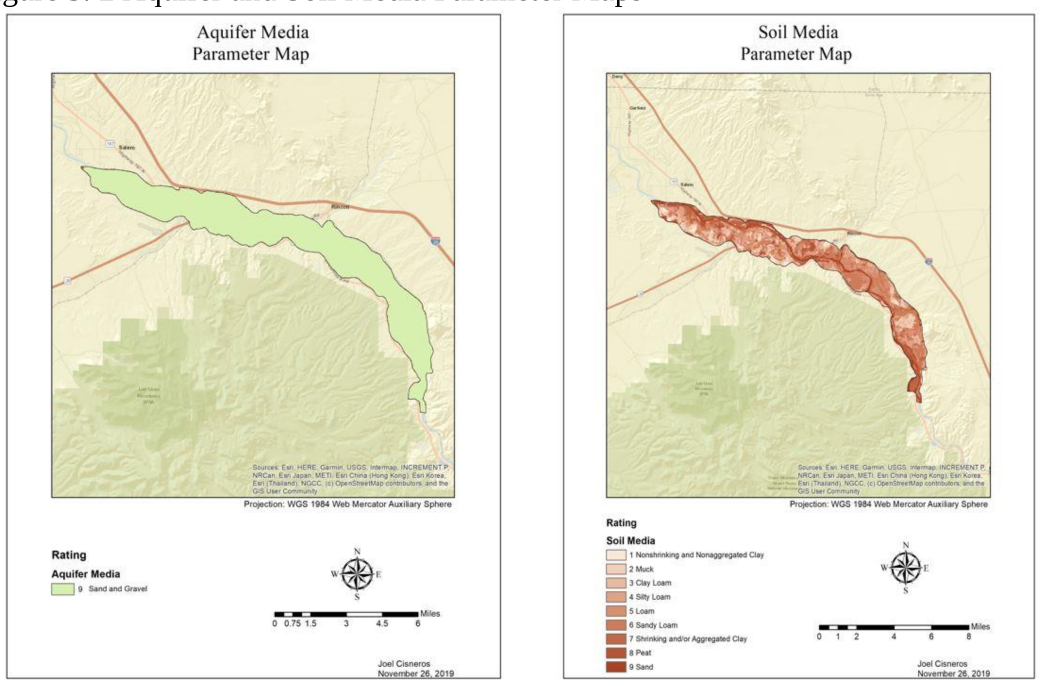


Figure 3. 3 Topography and Impact of Vadose Zone Parameter Map

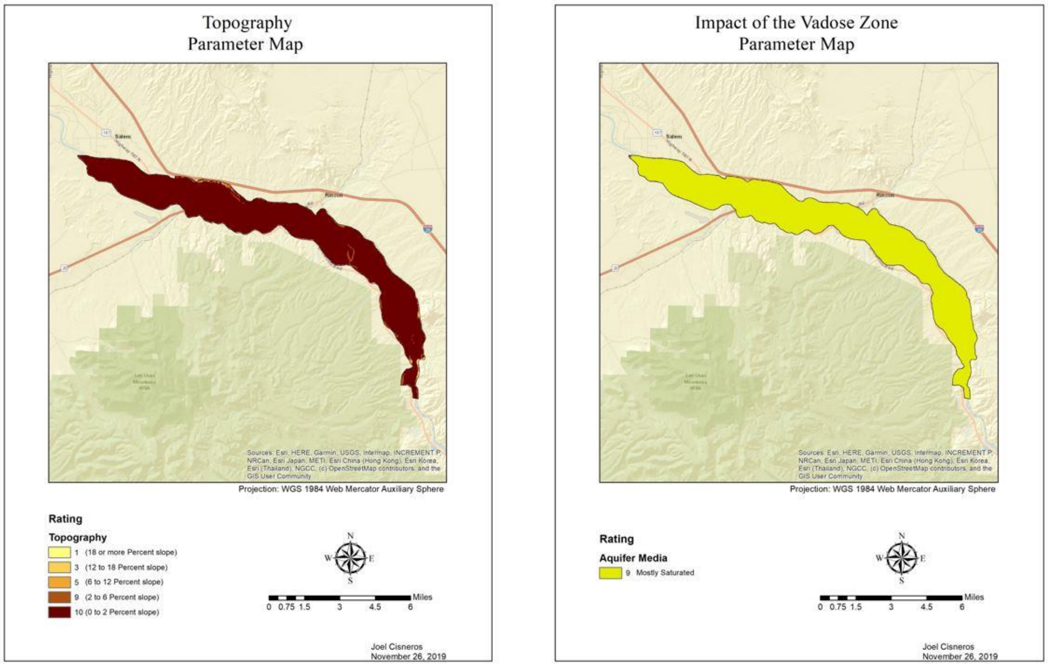
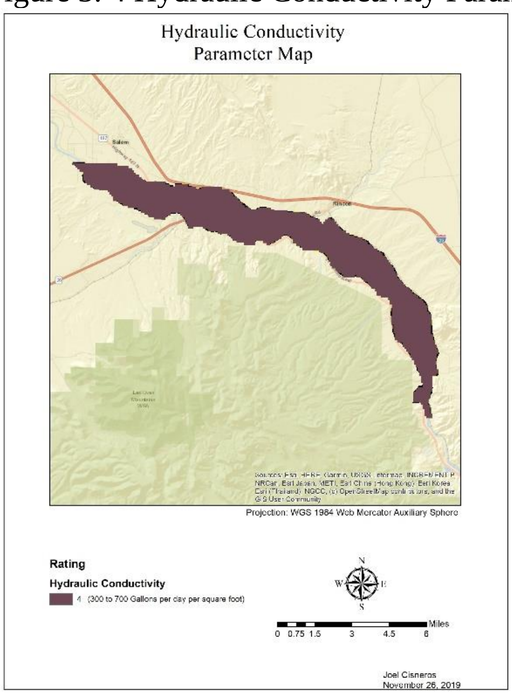


Figure 3. 4 Hydraulic Conductivity Parameter Map



DRASTIC Sensitivity Index

To create the DRASTIC index map, all the seven parameter index map layers were overlaid using the Geoprocessing tool, with Weighted Sum Overlay falling under the Spatial Analyst extension in the Arc toolbox. The Weighted Sum tool only accepts raster files. Each parameter map needed to be converted into a raster data layer; this was done by using the Polygon to Raster tool. Once converted, some parameter shapefiles needed to be reclassified using the Reclassify tool. They were reclassified to represent their appointed rating. For example, the Net Recharge tiff was based on a USGS National Land Cover, NLCD Codes which represent classification such as open water or evergreen forest were reclassified to their appointed DRASTIC rating. Once this was completed the Weighted sum could then overlay several rasters and multiply each by their given weight and sum them together. The output of the Weighted Sum tool is the final DRASTIC Index map. How this tools works is detailed below in Figure 3.2.

Figure 3. 5 Illustration of Weighted Sum (“ESRI” 2019)

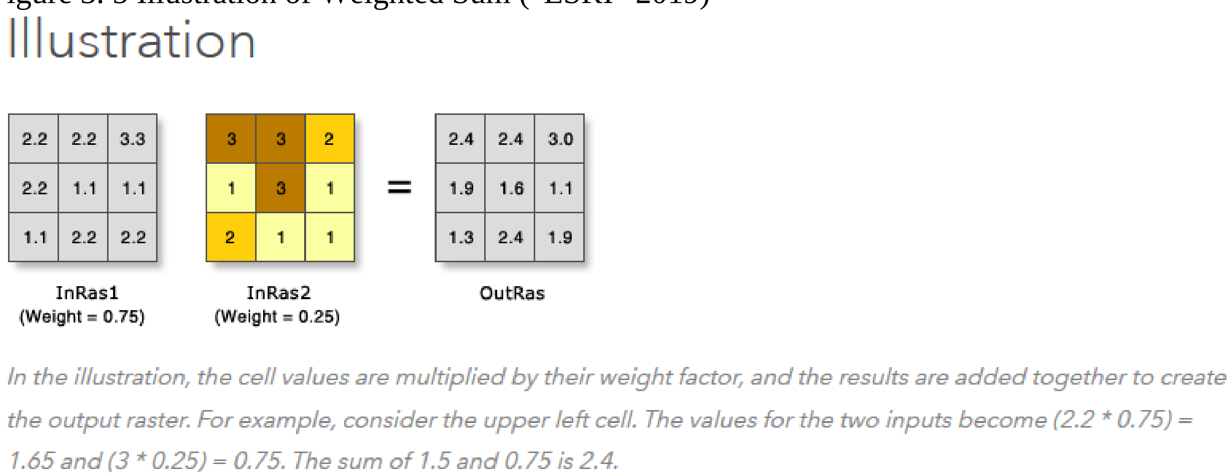
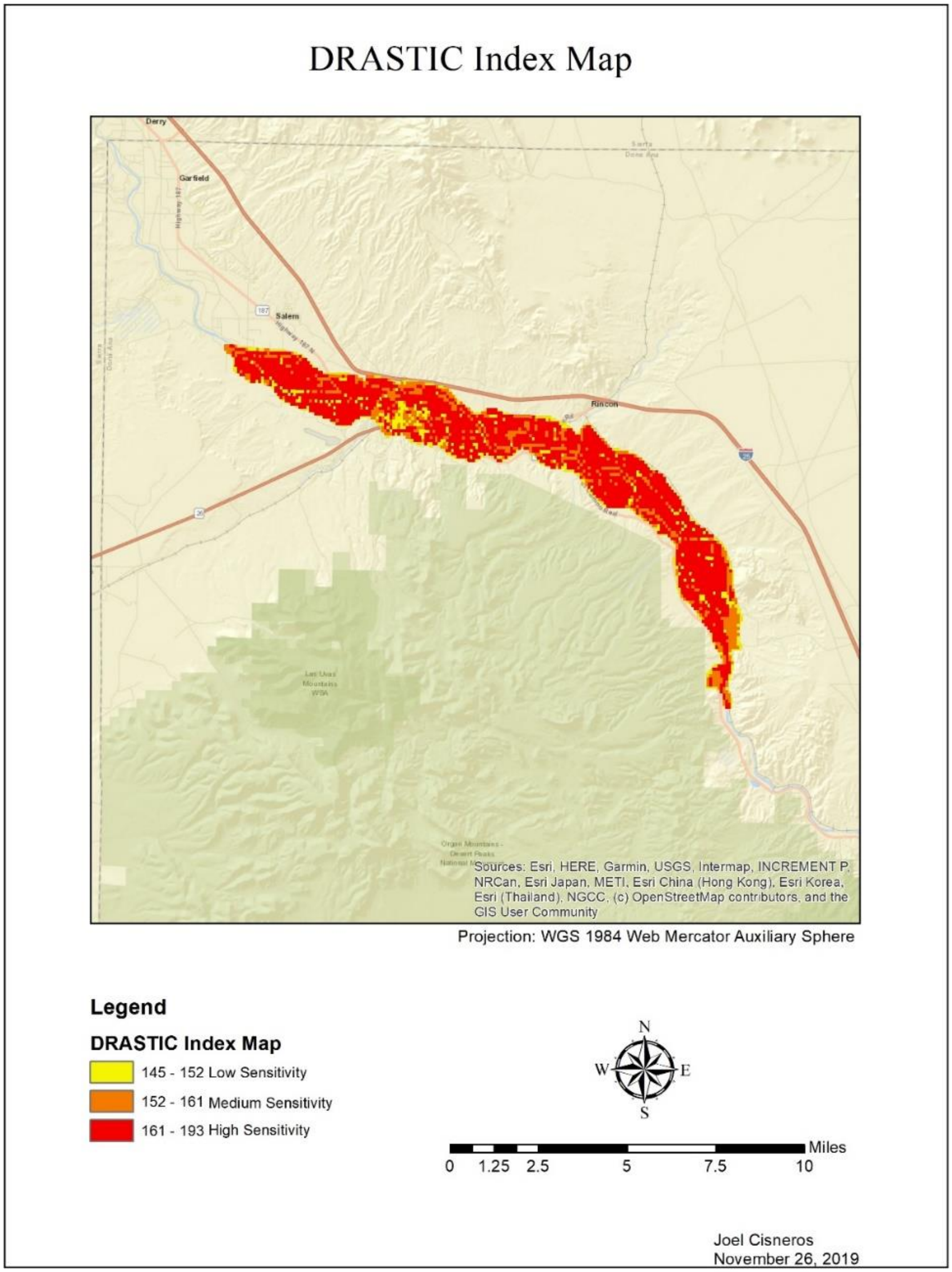


Figure 3. 6 DRASTIC Index Parameter Map



Crop Data and Total Dissolved Solids Data

Crop data produced by the U.S. Department of Agriculture National Agricultural Statistics Survey (NASS) was used to locate pecan orchards. NASS crop data is a great asset due to its temporal resolution. Crop data date to 2008 and a new dataset is released every year. The NASS crop data has a total of 33 different types of crop classifications, among these classifications was pecans. The total percentage of pecan acreage in the study area was 21.72%. The most significant concentration of pecan orchards was next to the small town of Rincon. This data was acquired from the USDA Geospatial Data Gateway. Along with the NASS crop data, total dissolved solids data (TDS) were obtained from New Mexico Bureau of Geology and Mineral Resources (NMBGMR). Crop data was imported to ArcMap and categorized to display the crop types. The TDS data were reclassified using the Reclassify tool from spatial analyst to show two levels of permissible limits of irrigation water based on Fipps classification of permissible limits of irrigation water see Figure 3.12. The results of this analysis are detailed below in Figure 3.5 and 3.6.

Table 3. 6 Permissible limits for classes of irrigation water based on (Fipps)

Classes of Water	**Gravimetric ppm**
Class 1 Excellent	175
Class 2 Good	175-525
Class 3 Permissible	525-1,400
Class 4 Doubtful	1,400-2,100
Class 5 Unsuitable	2,100

Figure 3. 7 2018 NASS Crop Distribution

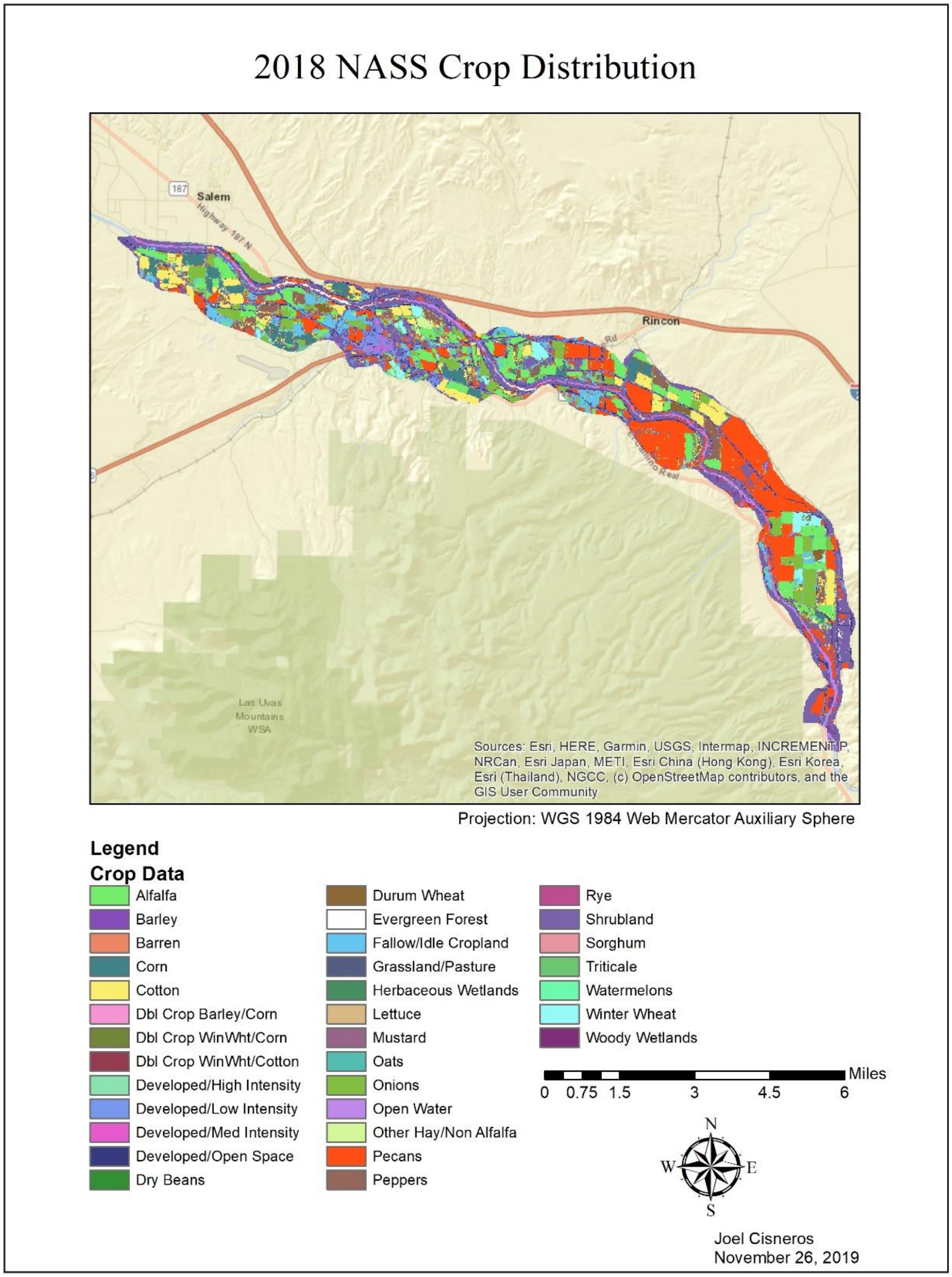
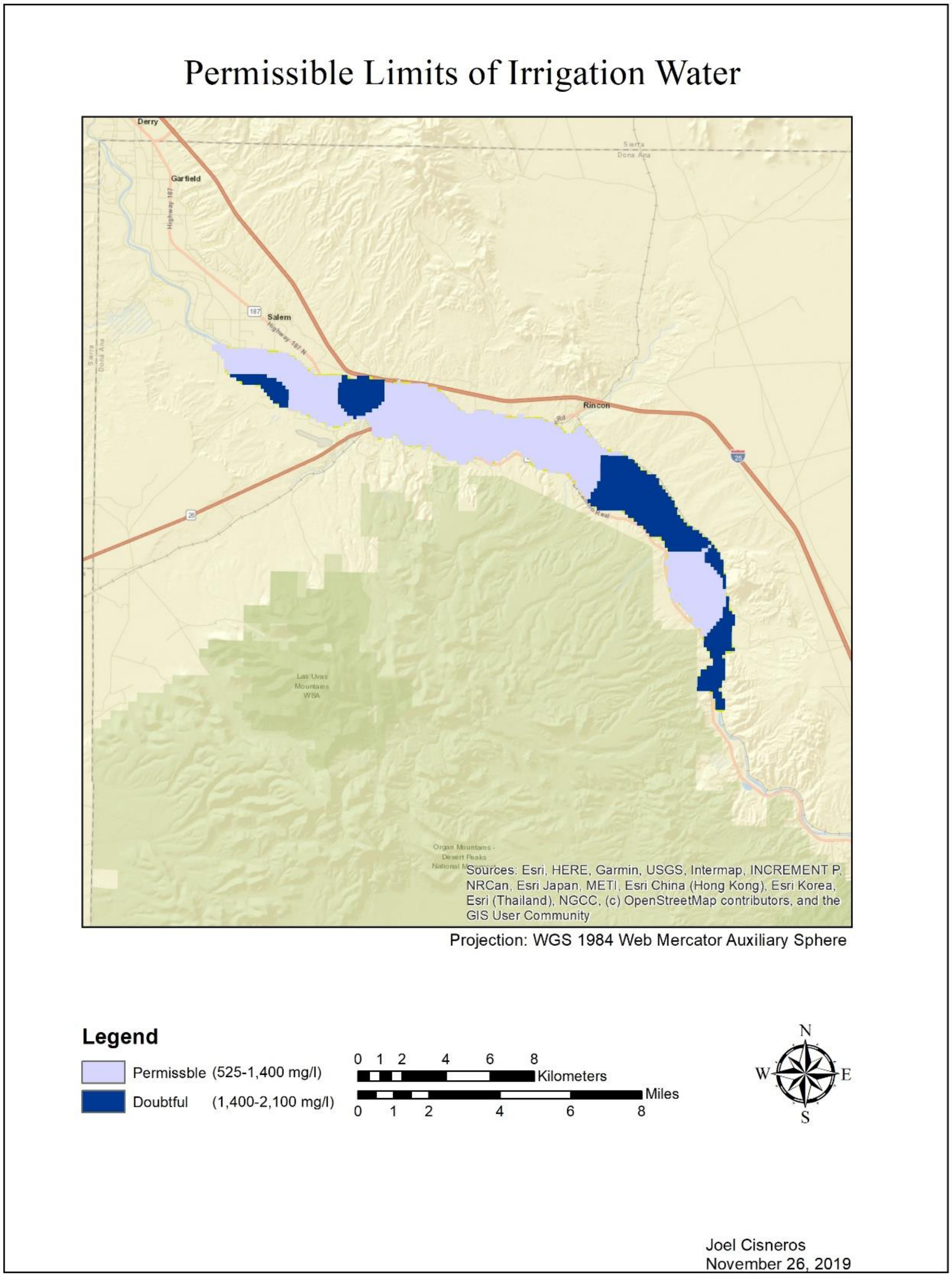


Figure 3. 8 Permissible Limits of Irrigation Water



CHAPTER 4

Results and Discussion

This chapter reports the results of the DRASTIC model and discusses the limitations and strength of the model as well.

DRASTIC Method

All seven required layers for DRASTIC vulnerability evaluation were created using ArcGIS; each layer was reclassified and rated using the rating scales based on a standard DRASTIC rating system from Aller and others (1987). Among the DRASTIC parameters, the Depth to Water is one of significant importance due to its weight of 5. The Depth to Water parameter was interpolated with the Kriging tool from spatial analyst. The surface of the Depth to Water was only one rating, which is 9; due to the depth to water being only 5 to 15 feet.

The Net Recharge parameter was based on a USGS National Land Cover Dataset classification model. Most of the study area had a high rating surface; this is due to the lower Rincon Valley land use being primarily agricultural (See Figure 3.1). The Soil Media parameter map has various rating surfaces. This is due to the study area having vast differences of soils (see Figure 3.1). The Topography surface is mainly a high rating due to the valley floor of the study being flat (see Figure 3.1). The three remaining parameter maps, which are Aquifer Media, Impact of Vadose Zone, and Hydraulic Conductivity were all built using the same shapefile.

The three parameters were built from a map from the Technical Report 332 *Creation of a Digital Hydrogeologic Framework Model of the Mesilla Basin and Southern Jornada Del*

Muerto Basin (Hawley and Kennedy 2004). The map *Plate R1 Hydrogeology of the Rincon Valley and Adjacent Parts of the Southern Palomas and Jornada Basins, South-Central New Mexico* (Hawley and Kennedy 2004) was georeferenced to the study area and the RA HSU geology polygon was extracted by manually digitizing it.

Once the polygon was created, information pertaining to the RA HSU was added along with tabular data from (Walker, Brown, and Fernald 2015). The Tabular data added was the rating for the Aquifer Media, Impact to the Vadose Zone, and Hydraulic Conductivity (see Table 3.4 and Table 3.5). For each of these three parameter maps, they only had one single rating surface due to being based on RA HSU. Once all maps were created, the Weighed Sum Tool was used to obtain the final map called the DRASTIC index.

DRASTIC Index

The DRASTIC index was found to be between 145 and 193. The numerical value of the DRASTIC index can be considered as an indicator to determine the areas that are more likely to be susceptible to groundwater salinity. A higher DRASTIC index shows greater groundwater contamination vulnerability. The DRASTIC index was classified into 3 classes using Jenks natural breaks. The three classes where low, medium, and high sensitivity.

The DRASTIC Index map showed most of the study area had a high risk of ground water contamination potential (See Figure 3.3). This is due to the parameters with the highest weights had high ratings. For example, the Depth to Water map (Figure 3.1) had a surface rating of 9 for the whole study area. This was also true for aquifer media and vadose zone. The net recharge parameter map mostly had a high rating. This is due to the land cover in the Rincon Valley primarily being agriculture. Agriculture areas according to previous research with *DRASTIC* by Creel and others (1998) and Kennedy (1999) have a higher level of recharge increasing sensitivity. Also, most of the maps were single value maps due to the lack of variability of geology and depth to water in the study area. Like mentioned before, geology maps from Technical Report No. 332 showed only one geology class which was RA (Hawley and Kennedy 2004).

TDS and Crop Data Results

Although the DRASTIC method usually gives satisfactory results in the evaluation of groundwater intrinsic vulnerability to contamination, it is important to add additional data to strengthen results (Al-Rawabdeh et al., 2014). In this research, groundwater TDS data and crop data were added. TDS data is very important due to farmers relying more on groundwater. The TDS data was reclassified to display permissible limits of irrigation water based on (Fipps). According to the map (Figure 3. 5) 68.82 percent was permissible, and 33.18 percent was doubtful. Fibbs notes that leaching is needed if permissible water is used; doubtful water limits need good drainage (Table 3. 6).

When Combining the DRASTIC Index, TDS, and Crop Data, you get a sense of the utility of the model. In this study, a couple of areas of interest were found that require further analysis.

These areas of interest are large pecan orchards with doubtful limits of groundwater. Doubtful limits are classes of total dissolved solids (TDS) based on the classification from (Fipps). From the DRASTIC Index map, we know that most of the study area has a high risk of contamination potential. Therefore, the crop and groundwater TDS data are vital when pointing out areas that need to be further evaluated. Pecan orchards are tied heavenly to this study due to the inability of rotation, sensitivity to saline water, amount of water required, and heavy transitioning from conventional crops to pecan orchards.

In Figure 4.1, there is a large pecan orchard in the Southern part of the study area. This area will require extensive research for mitigation strategies. The DRASTIC Model was originally built as a preliminary tool to locate sensitive areas for more comprehensive studies (Walker, Brown, and Fernald 2015). The research that I have conducted has shown that there is a lot of utility from the DRASTIC Method in the Rincon Valley.

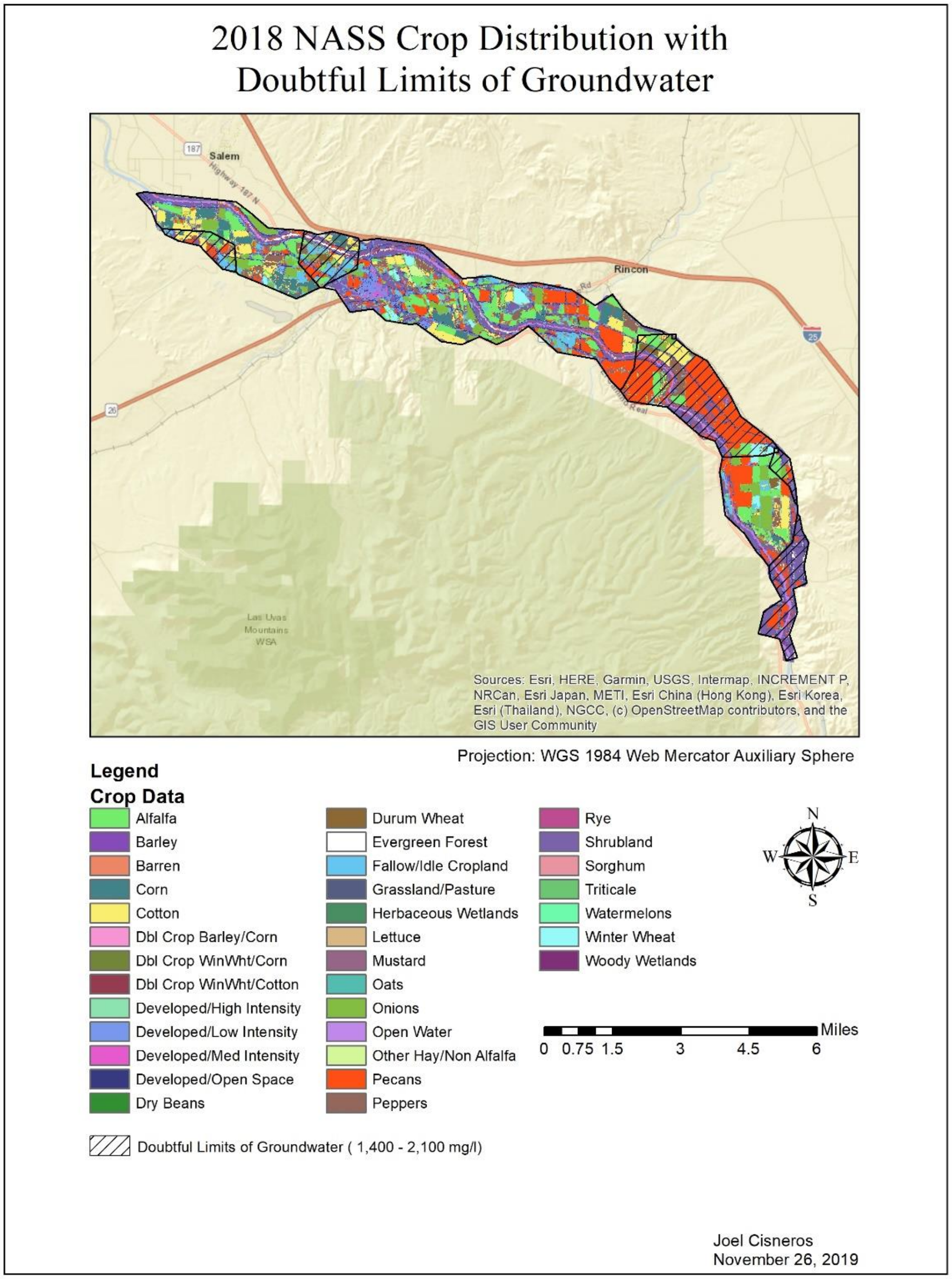
Pecan orchards of interest can be further evaluated. According to Miyamoto, growers are not convinced that salts are affecting yields, partly because symptoms of salt-affected trees are challenging to differentiate from those under other types of stress, such as water stress (Miyamoto 2006). With the data from this study farmers and water managers can take a better approach when dealing with pecan orchards.

Limitations and Strengths

There are a few limitations that limit the use of the DRASTIC model. One of the main concerns is the subjectivity of the rating determinations and scale they employ. Since factors are chosen instead of calculated it makes the model more qualitative than quantitative (Walker, Brown, and Fernald 2015). Researchers also have doubts over the inclusion and exclusion of parameters, researchers such as (Al-Rawabdeh et al. 2014) and (Singh et al., 2015). Another disadvantage that DRASTIC users note is that accuracy testing is tough (Walker, Brown, and Fernald 2015).

Although the model does have a few limitations, it remains one of the most popular models used to this day (Kumar et al. 2015). Its popularity stems from its low cost and rapid implementation of the model (Jang et al. 2017). Other strengths are the Delphi consensus method which is a structured survey that gathers expert opinions of correct answers, to obtain hydrogeological factors and their ratings and weights, provides the system with expert backing and structure (Aller et al. 1987).

Figure 4. 1 2018 NASS Crop Distribution with Doubtful Limits of Groundwater



CHAPTER 5

Summary

As temperatures rise in the United States Southwest region, causing surface water shortages due to less snowpack (Garfin et al. 2014). The water used for agriculture is involved with controversy about who is entitled to what and how much. New Mexico and Texas have been in a legal battle about how the shared water should be developed and managed. Legal problems, in combination with prolonged drought will generate significant challenges for water suppliers in the years to come. Farmers in the Rincon Valley are resorting to using saline groundwater for irrigation. It may be a short temporary solution, but it comes with a lot of problems. The crop that is causing the most concern is pecan orchards. This is due to the inability of rotation, sensitivity to saline water, amount of water needed, and heavy transitioning from conventional crops to pecan orchards.

In this study, the purpose was to explore the utility of the DRASTIC Model to map spatial variability of risk for salinization due to the higher use of groundwater in the Rincon Valley. In my research, I run the DRASTIC Model on the ArcGIS platform. The seven parameters of the Model are analyzed to create individual maps in the ArcGIS and to were overlaid to create a final index map.

The results of the model showed that most of the Rincon Valley have a high risk of contamination potential. The DRASTIC Model and its auxiliary data; which are Total dissolved solids (TDS) and crop data showed areas of interest. These areas of interest are large pecan orchards with doubtful limits of groundwater. These areas will require extensive research for mitigation strategies. It is essential to note the DRASTIC Model was originally built as a preliminary tool to locate sensitive areas for more extensive studies (Walker, Brown, and Fernald 2015).

The DRASTIC Method has a few limitations, but it still one of the most popular models used to this day (Kumar et al. 2015). Its popularity stems from its low cost and rapid implementation of the Model (Jang et al. 2017). The DRASTIC method can be implemented in other areas quickly as well. It is crucial to evaluate the relationship between pecan orchards and salinity. Information can guide our farmers and water managers to mitigation efforts and inform relevant agencies of the potential risk to groundwater contamination.

One of the agencies that can benefit from this research is the Pecan Extension from New Mexico State University. The Pecan Extension can use the model in other areas South of the Rincon Valley. Due to its rapid implementation the Pecan Extension can use the model to find pecan orchards with high risk of contamination. There are large pecan orchards in southern Doña Ana that need to be evaluated.

Future Research

The DRASTIC Method is known for its ability to be modified; this is one of the reasons for its popularity. The model is modified by adding additional data and parameters. One example of this is the addition of remote sensing data to the model. Singh and others (2015) added another parameter that accounts for anthropologic factors when determining contamination potential

(Singh et al. 2015). For this study, using remote sensed data to evaluate the moisture status of pecan orchards can greatly improve this research (Othman et al. 2014). With remote-sensing techniques one can detect and scale up leaf-level physiological responses to large areas without harming leaves or plants (Ormeci, Sertel, and Sarikaya 2009; Othman et al. 2014). One of the hardest challenges for pecan growers is determining if yields are diminishing due to water stress or salinity stress (Miyamoto 2006). With the addition of remote sensing this could potentially help farmers in determining what is diminishing yields.

This research can also be used to make a profitably surface when buying or investing in pecan orchards. Pecan orchards are rapidly growing in Doña Ana County and farmers are looking to start growing or buying pecan orchards. Pecan orchards are a costly investment and with the help of this research farmers can determine which orchards will require the less investment. Thus, becoming a negotiation tool when buying or selling pecan orchards. Like mentioned above the ability to add additional data to the DRASTIC Method is vital. Water pump and water right data can be added to this profitably surface. Pecans require a lot of good quality water and is important when determining in investing or buying. There are many other ways that this researched can be furthered it is just a matter of creativity.

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