A COMPARATIVE STUDY OF TWO NON-TRADITIONAL WATER SUPPLIES IN SOUTHERN NEW MEXICO TO ADDRESS WATER SCARCITY AND DISASTER VULNERABILITY

BY

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ABSTRACT

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The purpose of this thesis is to discuss the most suitable approach for ensuring water sustainability in southern New Mexico using non-traditional water resources projects. Mainly, the focus of this report is to use a multi-criteria decision making (MCDM) analysis to present and compare the drawbacks and benefits of the development of a produced water reuse system or a new brackish groundwater desalination facility. The criteria for this project are split into four categories: system performance, economic, social, and environmental. All of these categories have subcategories of their own. Evidence from a variety of sources is discussed and values for each subcategory are compiled for analysis. The results of the MCDM analysis are ranked in this way from most to least favored: Desalination, PW Project 1 (generating clean brine quality), PW Project 3 (generating drinking water quality), and Project 2 (generating irrigation quality). The

goal is to share this data with stakeholders and partners involved with these case studies to ensure clarity of details of effects within these communities and to make decisions about where to invest to ensure water sustainability.

Keywords: multi-criteria decision making analysis, produced water, brackish water, desalination, water reuse, water resources, water sustainability

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CHAPTER 1: INTRODUCTION

1.1 Introduction & Objectives

Water scarcity is an increasingly urgent problem in the southwest United States and a serious threat to the prosperity of future generations. The appropriate consideration of all water resources in an area is therefore critical to fully address water scarcity. In southern New Mexico, on the west side of the Permian Basin, the continuous operation of hydraulic fracturing (HF) by the oil & gas industry requires water and displaces it. Reuse of the displaced water, called produced water (PW), presents a reliable opportunity to reduce the water usage of HF. Furthermore, fit-for-purpose treatment of PW, which the oil & gas industry disposes of at a rate of about 115.1 million gallons per day (MGD) (New Mexico Environment Department, 2020a), could turn some of this wastewater into a usable and valuable water resource. While this volume is already greater than the demand for HF, the volume of PW created in this area is expected to increase over time (Scanlon et al., 2020). By minimally treating the water for its intended use in industrial, municipal, and agricultural industries, energy and money may be saved while keeping treated PW, a useable water source, within the water budget. This possibility will be explored in Case Study 1.

Another reliable water resource opportunity is found below the freshwater table of southern New Mexico where brackish groundwater aquifers exist. The desalination of these deep brackish water aquifers with appropriate technology will be explored in Case Study 2. This process may extend the lifetime of precious freshwater aquifers that are currently being pumped faster than their natural recharge rate and reduce saltwater intrusion. These two case studies of non-traditional water resources will be evaluated using the same criteria which will then be compared in a multi-criteria decision making (MCDM) analysis.

In this paper, desalination of brackish water for potable use and PW reuse for non-potable purposes will be evaluated using the criteria in Table 1. For this analysis, all of the criteria are weighted evenly. Weights may be easily changed with stakeholder input in the future.

Table 1: MCDM Criteria

Category of criteria: System Performance, Economics, Social, Environmental

List of Criteria for MCDM Analysis	
Product water quality	Capital plus operation and maintenance
Source (feed) water quality	Effect on water rates
Longevity of source	Public acceptance
Effect on water resources	Disaster mitigation
System maintenance & operation complexity	Effect on local ecology
Return on investment	Energy consumption/GHG emissions
Employment	Disposal (hazardous waste & safety)

Case Study 1: Produced Water Reuse involves Eddy and Lea counties in southeastern New Mexico (Figure 1). These counties struggle with competition for their freshwater supply, which is causing it to rapidly decline. Therefore, the pressure to find new solutions to better manage water resources is growing. Both counties are part of the Permian Basin, making them part of the highest oil-producing counties in the U.S. Important information about the counties are found in Table 2. The surface water source for Eddy County, the Pecos River, is responsible for supplying flow to Texas through an interstate agreement that originated in 1948. There are no surface water sources in Lea County. Rainfall is limited. Currently, about 50% of PW generated is reused for secondary oil recovery due to a recent shift in PW recycling within the oil & gas industry (Sabie et al., 2022). Top water uses in these counties include irrigated agriculture, public water supply, and mining (Figure 2).

Table 2: Information about Lea and Eddy Counties, location of Case Study 1. Source: (Sabie et al., 2022)

	Lea County	**Eddy County**
Geographical Size (mi^2)	4,400	4,200
Population (as of April 2022)	71,000	58,500
Groundwater Sources	Ogallala	Roswell Basin, Pecos River Alluvial Aquifer
Surface Water Sources	-	Pecos River
Average annual rainfall (inches)	14.9	13.2

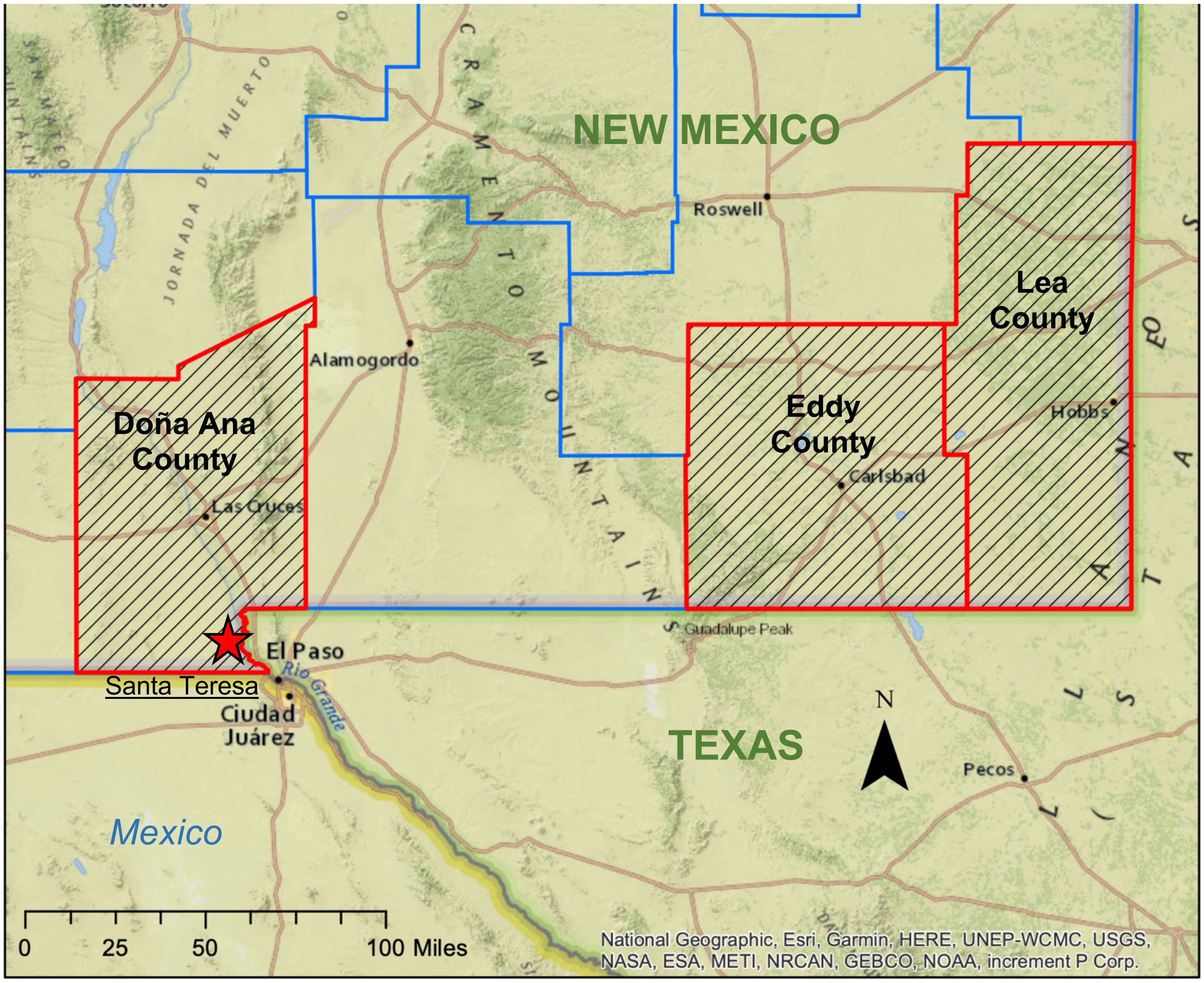


Figure 1: Map of Case Study 1 location (Lea and Eddy Counties in New Mexico, which border Texas and are part of the Permian Basin) and Case Study 2 location (Santa Teresa, within Doña Ana County, NM). Santa Teresa is indicated by the star.

For Case Study 2: Desalination of Brackish Groundwater, the Santa Teresa area has been proposed as a potential location for a new desalination plant to serve southern NM (Figure 1). Santa Teresa, as well as the city of El Paso which it borders, has been growing in industry and population, which has put pressure on local water resources. According to a Triple Bottom Line analysis by Stratus Consulting, the current water supplies of El Paso Water Utilities will be more than 53 MGD (60,000 acre-feet per year) shy from estimated demand by 2050. This projected demand in 2050 is about 170 MGD (190,000 acre-feet per year) (Raucher & Raucher, 2011). The Santa Teresa Industrial Park area specifically is expected to need an additional 1.90 MDG (1,317 gpm) to meet the maximum daily demand by 2034 (Fowlie & Tuite, 2014).

Part of the analysis at hand addresses the need for disaster mitigation. Rather than viewing natural disasters such as the ongoing drought in southern NM as accidental geophysical features of a specific place, researchers view disasters as conditions of inequality and subordination in society (Haenn et al., 2016). Disaster effects are deeply embedded in the history, ideology, and political economy of a certain region. Social systems generate conditions for people separated by class, race, gender, or age at different levels of risk from the same event or process. The prospective hazard mitigation caused by natural disasters, in this case drought, is examined in the social impacts of these case studies.

1.2 Review on Multi-Criteria Decision Making (MCDM) Analysis

A multi-criteria decision making (MCDM) analysis is a method of comparing alternative engineered systems for ranking based on a set of specific criteria. MCDM analyses allow criteria of different scales and importance to be compared with either quantitative or qualitative measurement. The criteria for the MCDM proposed in this report can be found in Table 1. Each of these criteria will be assigned a measurement per system based on scientific evaluation and the goal will be to maximize or minimize it. The evidence will be presented in the respective sections of this paper. Criteria will be assigned a weight to alter their relative importance. The Visual Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) software was used to create a completed table with subsequent values found in the "Results" section of this report (Chapter 5). Based on this table, the best alternative may be selected. The theoretical background and practical framework have been developed in Munasinghe-Arachchige et al., (2020).

The criteria in Table 1 were selected based on the goals of stakeholders and sustainability targets. Some were sourced from other published MCDM analyses evaluating water systems. Many of these criteria are related. Source and product water quality are important in determining appropriate treatment technology, which informs energy and cost requirements. The longevity of the source, or how long the source may contribute water for its proposed purpose(s), is a measure of sustainability. The system maintenance & operation complexity relate to the feasibility of successful performance over time. Economic considerations are often quantified with criteria such as return on investment, employment, and capital plus operation and maintenance costs.

The effect on water rates is considered to determine a potential economic burden on the local community. It is vital to acknowledge the public acceptance of each water resource and its application because social impacts can have a huge effect on the success of engineering projects. Sustainability goals often focus on environmental consequences; the most important of these consequences may be the effect on local ecology, energy consumption (e.g., greenhouse gas emissions), and the achievability of appropriate disposal of waste products such as solid waste and brine.

The case studies involved in this MCDM analysis can operate harmoniously; one does not need to be pursued instead of the other in southern NM. However, it is helpful to compare these systems against each other to holistically understand the effects on the people, politics, and environment of this region and how compromises may be made to meet certain goals. These two case studies are being compared against each other because they provide context for the reader. Furthermore, this comparison may help future decisionmakers who are faced with these options in the same region.

It is important to note that this is a high system level MCDM analysis, meaning some unit process details needed to fully evaluate the system performance are not considered. Because these case studies are still in the early stages of design, there is a lack of information regarding the system components and infrastructure sizing. For example, exact treatment trains, storage needs, and pipeline lengths and diameters are not known. Only once these systems are fully designed can they be compared holistically. This MCDM analysis can be modified as new information emerges.

CHAPTER 2: METHODOLOGY

Both of the case studies within this report apply data and resources appropriate to the intended project to assess its impact and performance with the criteria listed in Table 1. Case Study 1 involving PW reuse demand and feasibility used data from a variety of sources including state, federal, and academic research institutes. Water use by category data originate from the New Mexico Office of the State Engineer 5-year water use by category reports from 1975-2015 (Magnuson et al., 2019). The United States Department of Agriculture's Cropland Data Layer dataset for 2008 through 2020 informed change in crop type over time, which affects irrigation demand (USDA-NASS, 2021). The New Mexico Water Resources Dynamic Statewide Water Budget tool provided data about water budget trends. This data uses a mass balance approach for water accounting on a monthly timestep from 1975 through 2018. Demand for water application as a dust suppressant on unpaved roads in Lea and Eddy counties was estimated using a combination of road centerline data from the New Mexico 911 Program and the 2010 U.S. Census Bureau (Sabie et al., 2022). Public perception was determined based on comments received by the New Mexico Environment Department (NMED) after the passing of the Produced Water Act-NM House Bill 546. A summary document produced by NMED was used and an inspection of the raw database was performed to provide additional insight. Personal interviews of various stakeholders were also conducted and analyzed to begin to understand local perspectives.

Case Study 2, which involves desalination of brackish groundwater, references a preliminary assessment of the Santa Teresa region and the proposed facility (King et al., 2019).

Similar facilities in the region of Santa Teresa also acted as resources to determine certain operation and maintenance impacts. The final Environmental Impact Statement (EIS) reports from the Alamogordo Regional Water Supply Project and the City of El Paso Brackish Water Desalination Plant (now named the Kay Bailey Hutchison (KBH) Desalination Plant) were used to inform the potential impacts of a new desalination plant and supporting facilities in the southern New Mexico region. These are both desalination treatment facilities built within the last 15 years. The location in Santa Teresa is about 90 miles southwest of the Alamogordo desalination facility and about 25 miles west of the KBH Desalination Plant. Although the El Paso facility is closer, the Alamogordo facility is more recent and has a similar treatment size. It is assumed that a new facility would utilize similar technology to that which exists within these facilities.

These data are used to inform a measurement applied to each criteria selected for the MCDM analysis. The results for this analysis are compiled into Chapter 5 of this document where the alternatives are compared and discussed.

CHAPTER 3: CASE STUDY 1 – PRODUCED WATER

3.1 System Performance

3.1.1 Product water quality

The requirement of treated PW quality may vary greatly based on the intended end use. Municipal water is the second largest water user in both Eddy and Lea counties, however, this would probably be one of the least likely uses for treated PW because of the concern over potential exposure to residual contaminants (Figure 2). Furthermore, there may be ample end users eager to use this resource for operations that do not require potable water quality. Instead, indirectly using treated PW for municipal water demand by injecting it into local groundwater aquifers will offset their withdrawal for use at the treatment facility. Agricultural end users include potentially all local farmland. The water may be used to irrigate crops or provide water for livestock to drink and bathe. Cooling towers at power plants may also use this water.

Other than reuse within the energy sector for further HF, the focus of this case study is on four potential PW end uses: agricultural irrigation, road dust control, industrial cooling towers, and surface water in-stream flow augmentation. Agricultural irrigation was selected as a potential end use to investigate in this study because it is the largest water use in the region and is also complicated by high intra-annual variation in demand (Figure 2; Appendix B). The application of water for dust suppression on many unpaved roads, specifically within oil & gas field operations, is favorable because of its low-quality, annually-stable water requirement. Steam turbine cooling tower technology may also be able to use water at a lower quality requirement and at a fairly steady rate year-round. The Pecos River is a local surface water resource that may greatly benefit from supplement flows offered by treated PW. The volume of demand for these end uses will be evaluated in Section 3.1.5 “System maintenance & operation complexity.” The resulting impact of the PW quality can be found in the “Social Justice” section of the model performed in Section 3.2.1 “Return on investment” (Figures 12, 13, and 14). This model explores the outputs of three different end use PW quality scenarios: irrigation, clean brine, and drinking. Beyond the end uses evaluated here, environmental remediation (especially for mining), aquifer recharge, carbon sequestration, and more could be viable end uses for treated PW. However, they should all fit into these three water quality categories.

3.1.2 Source (feed) water quality

Typically, PW is saline with high concentrations of total dissolved solids (TDS). Sodium (Na^{+}), calcium (Ca^{2+}) , chloride (Cl^{-}), magnesium (Mg^{2+}), and sulfate (SO_4^{2-}) ions are chemicals that contribute to TDS in PW (Rodriguez et al., 2020). Raw PW has the potential to contain numerous free, dispersed, or emulsified organic constituents, many of them toxic or hazardous. Heavy metals, dissolved gases, biopolymers, microbes, humic substances, naturally-occurring radioactive material (NORM), and more may be present (Scanlon et al., 2020). Injected chemicals from oil & gas operations, as well as naturally-occurring chemicals, are found in PW. Typically, less than 15% of PW in New Mexico is “flowback” water, or the fluid mixture that has returned to the surface after being injected into the formation for the purpose of hydraulic fracturing (Thomson & Chermak, 2021). Furthermore, flowback water ends after HF operation and then only formation water is displaced. Raw PW constituents that are removed throughout the treatment process end up needing to be disposed, which is discussed in Section 3.4.3 Disposal (hazardous waste & safety).

The lack of information about the quality of raw PW has been a hindrance to the adoption of PW reuse. This is because without complete knowledge of the constituents in the raw water, it is impossible to know if they are removed and what risks this may pose to human and environmental health. However, recent studies have emerged that attempt a complete analysis of PW in the Permian Basin (Chaudhary et al., 2019; Hu et al., 2022; Jiang et al., 2022). Even low concentrations of certain constituents may be toxic and the analytical tools capable of determining the presence of organics at low concentrations are limited. One current study attempts to address this challenge by proposing a multi-tiered analytical approach with the goal of utilizing sensitive, accurate, robust, and cost-effective evaluation methods (Jiang et al., 2021). Current water quality regulations may not be sufficient for assessing feasibility of PW reuse because they may not include some of the currently “unknown” constituents found in the raw water (Scanlon et al., 2020). It is important to note that, while a comprehensive evaluation of PW constituents is outside the scope of this report, without the feasibility of such comprehensive evaluation, a complete risk assessment is impossible. However, progress has been made locally to address this issue. For Lea and Eddy counties, geospatial data about the quality distribution (e.g., total dissolved solids) of raw PW from the Petroleum Recovery Research Center has been analyzed by within the New Mexico Water Resources Research Institute (NMWRRI) (Chaudhary et al., 2019). A sample of these spatial distributions of raw PW quality in Lea and Eddy counties can be found in Appendix A.

Ultimately, the quality of raw PW will not impact feasibility as much as the quality of the treated product water (effluent), however, the raw water quality will impact the cost of treatment. This means that the treatment technology utilized and its cost is important to feasibility. Although high-quality product water will be desired, it is important to consider what "high-quality" means for the intended end uses. For example, the natural salinity of raw PW is an asset when it comes to road dust suppression; therefore, it is necessary to find a treatment technology that will result in effluent water considered to be "clean brine." This may reduce the costs and energy needed to produce a usable end product compared to technology like reverse osmosis which will produce water of an unnecessarily high quality for the intended purposes explored in this case study, compared to the quality of drinking water where quality standards are stringent.

3.1.3 Longevity of source

The source of PW will last as long as oil & gas operations continue to run in southern New Mexico. Current PW quantities are expected to increase due to continued oil & gas operations and technological advancements (Scanlon et al., 2020). Thomson & Chermak, (2021) found that the volume of PW increased by almost 40% and the number of oilfield wells doubled between 2015 and 2019 in NM, despite a drop in the PW-to-oil ratio. The Permian Basin in southern NM is considered dependable in volume because of its reliable geography, meaning groundwater pumping yields will be high, the potential for land subsidence is low, and there is excellent opportunity for co- or post-development Administrative Site Review (Hawley, 2016). However, the longevity of PW reuse is dependent on steadfast collaboration with oil & gas operators, end users, regulators, and the public. PW is traditionally disposed of through salt water disposal (SWD) wells. The drawbacks of this disposal method are the potential for increased seismicity, contamination of overlying aquifers, and water scarcity from removing this resource from the hydrologic cycle (Scanlon et al., 2020). As long as these drawbacks remain relevant, PW reuse may be economically and environmentally suitable for a long time.

3.1.4 Effect on water resources

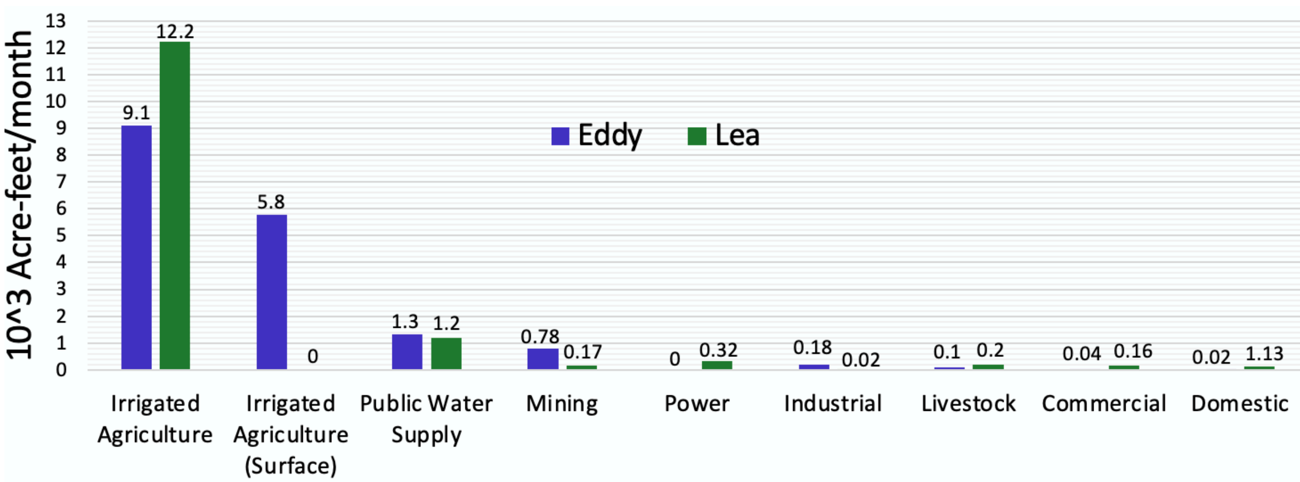


Figure 2: Graph of annual surface and groundwater withdrawals in Lea and Eddy Counties using data published every five years between 2010-2015. Source: (Peterson et al., 2019)

PW reuse may have a positive effect on water resources. This is because treating this resource for beneficial uses outside of oil & gas operations may retain large volumes of water in the hydrologic cycle instead of removing it with subsurface disposal (Scanlon et al., 2020). Based on the New Mexico Water Resources Dynamic Statewide Water Budget tool, 17,340 acre-ft/month (21,390,000 m^3/month) or 208,080 acre-ft/year (256,660,000 m^3/year) of water are withdrawn from surface and groundwater sources in Eddy County (Figure 2) (Peterson et al., 2019). In Lea County, this value is 14,400 acre-ft/month (17,800,000 m^3/month) or 172,800 acre-ft/year (213,100,000 m^3/year) (Figure 2). Based on the demand for treated PW calculated in

Section 3.1.5, the total demand for PW outside of the oil & gas industry is variable based on time and space. Reuse within the oil & gas industry is the first and best opportunity for treated PW because of the low cost for treatment, transportation, and relative low risk. After sufficiently meeting this demand within industry, there may not be enough PW to meet the full demand of treated PW outside of the industry. However, any amount that may be contributed to this demand will be beneficial for offsetting freshwater use.

3.1.5 System maintenance & operation complexity

The potential demand and the location of the demand for treated PW impact the feasibility of potential reuse outside of the oil & gas industry. This is because transportation costs and methods are often referred to as one of the biggest expenses and hindrances to successful performance by scientific literature and industry meetings alike. Although transportation practicality is considered vital to the success of PW reuse, little information exists describing the distances PW is transported (Sabie et al., 2022). Delineation of demand will also quantify the potential positive impact on water resources (see Section 3.1.4 Effect on water resources).

A large potential demand for treated PW is irrigated agriculture. Irrigated agriculture accounted for approximately 76 percent of the total withdrawals in New Mexico in 2015 (Magneson et al., 2019). In Eddy and Lea counties, the total withdrawals for irrigated agriculture in 2015 were approximately 203,353,000 m^3 (164,861 acre feet) and 144,769,000 m^3 (117,366 acre feet), respectively (Sabie et al., 2022). The types of crops grown and their spatial distribution over time can provide additional insight into the potential for reusing treated PW

(Appendix B). Irrigated agricultural water demand in Eddy and Lea counties varies by crop composition throughout the growing season (Figure 3) (Sabie et al. 2022).

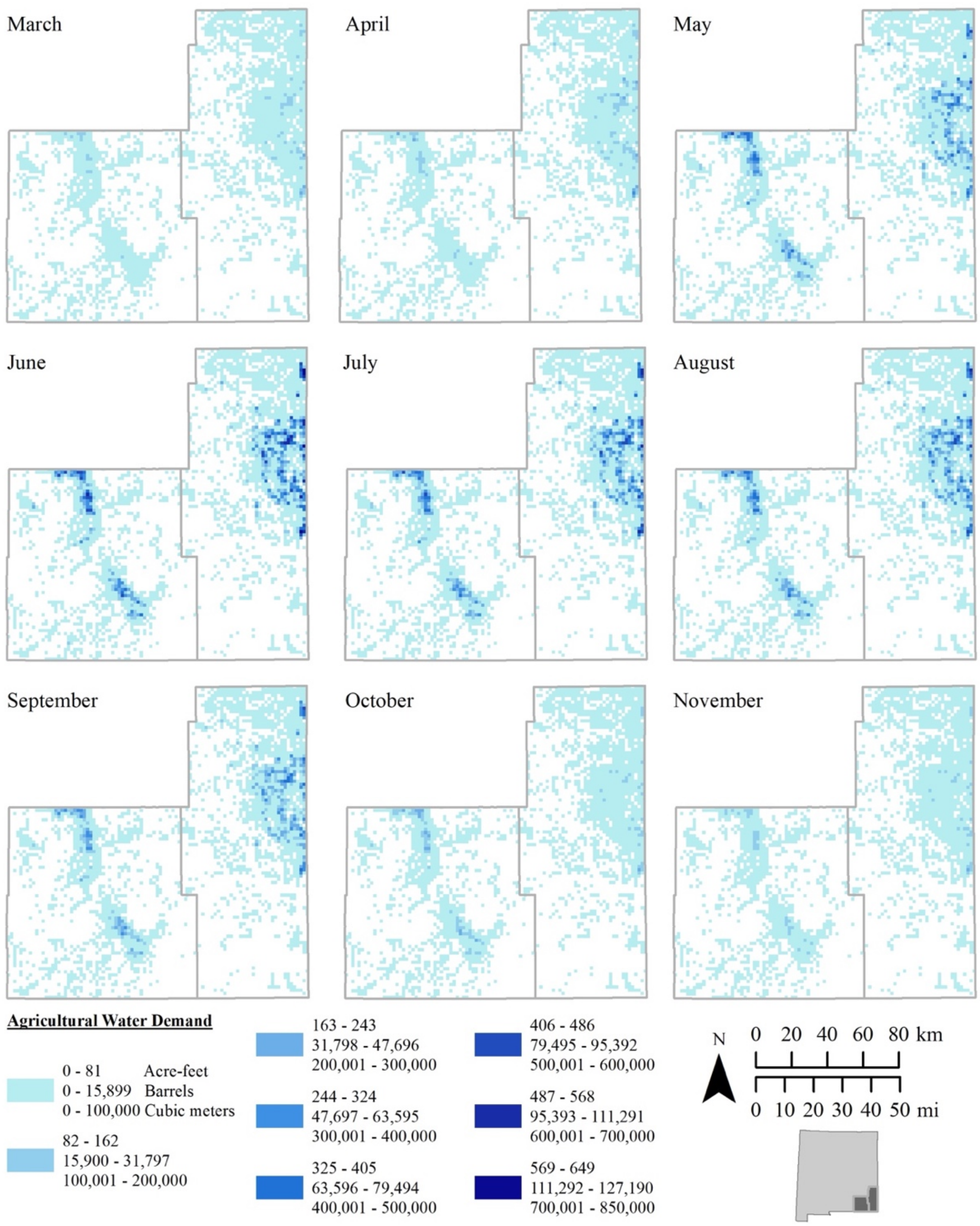


Figure 3: Agricultural water demand in Lea and Eddy Counties from March to November. Source: (Sabie et al., 2022)

Heavy traffic is a consequence of the prosperous oil & gas industry in Lea and Eddy counties. This has necessitated lots of roads which have been left unpaved. Public works managers are interested in treated PW as a dust suppressant on these natural roads (Figure 4). The water is used to moisten and compact the top layer of the road to control the lift of dust into the air. Because water is scarce and must be transported long distances in this rural area, it is expensive to move and obtain freshwater. The labor force in this region for trucking and other services is limited due to the competition from the oil & gas operations. Local authorities acknowledge that PW, even in its minimally-treated saline form, is an asset for dust suppressant applications. This water may hold the top layer of dirt better under heavy traffic and for a longer amount of time because of its salinity. Consequently, application of the water may be less

Figure 4: Water being sprayed on road to suppress dust in Las Cruces, New Mexico. Source: Author photo

frequent. Because PW may not cost as much as freshwater, may require shorter distances of transportation, and may be able to be delivered by operators of oil companies, this water source could have economic and logistical benefits (J. Burns, personal communication, May 10, 2021). All of these benefits may free up funds for municipalities to invest in other water projects.

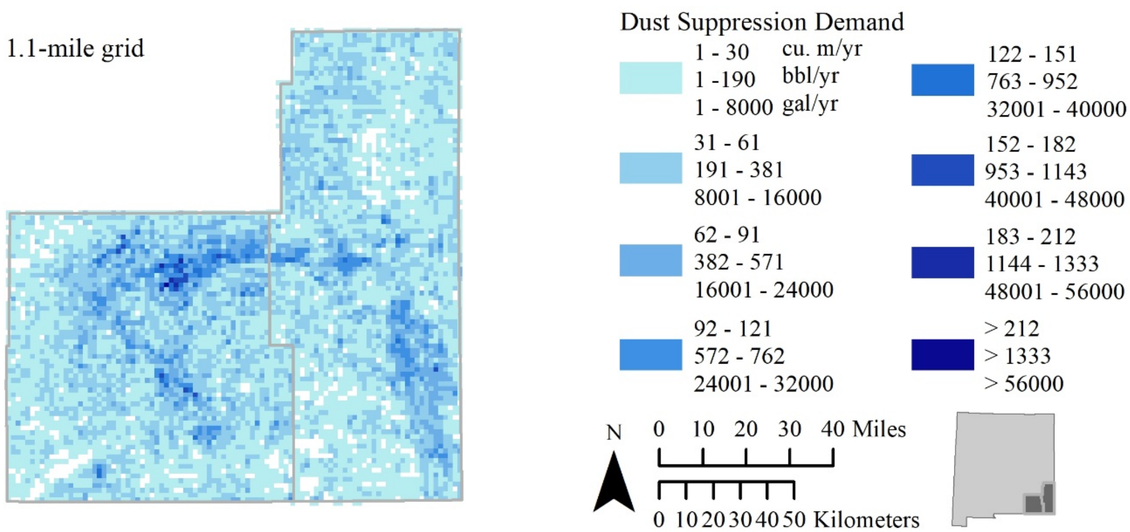


Figure 5: Estimated water demand for dust suppression based on the length of unpaved roads within each grid cell. Source: (Sabie et al., 2022)

Sabie et al., (2022) calculated the total length of unpaved roads using GIS. It was assumed that each segment would be treated one time per year on 15-foot-wide roads to estimate the volume of treated PW demand for dust suppression. A conservative dust suppression application rate for water of 2 mm per unit area from Yonkofski et al (2018) was used, resulting in an estimated 3,388 gallons/mile (7.969 m^3/km) treated PW demand for dust control (Figure 5).

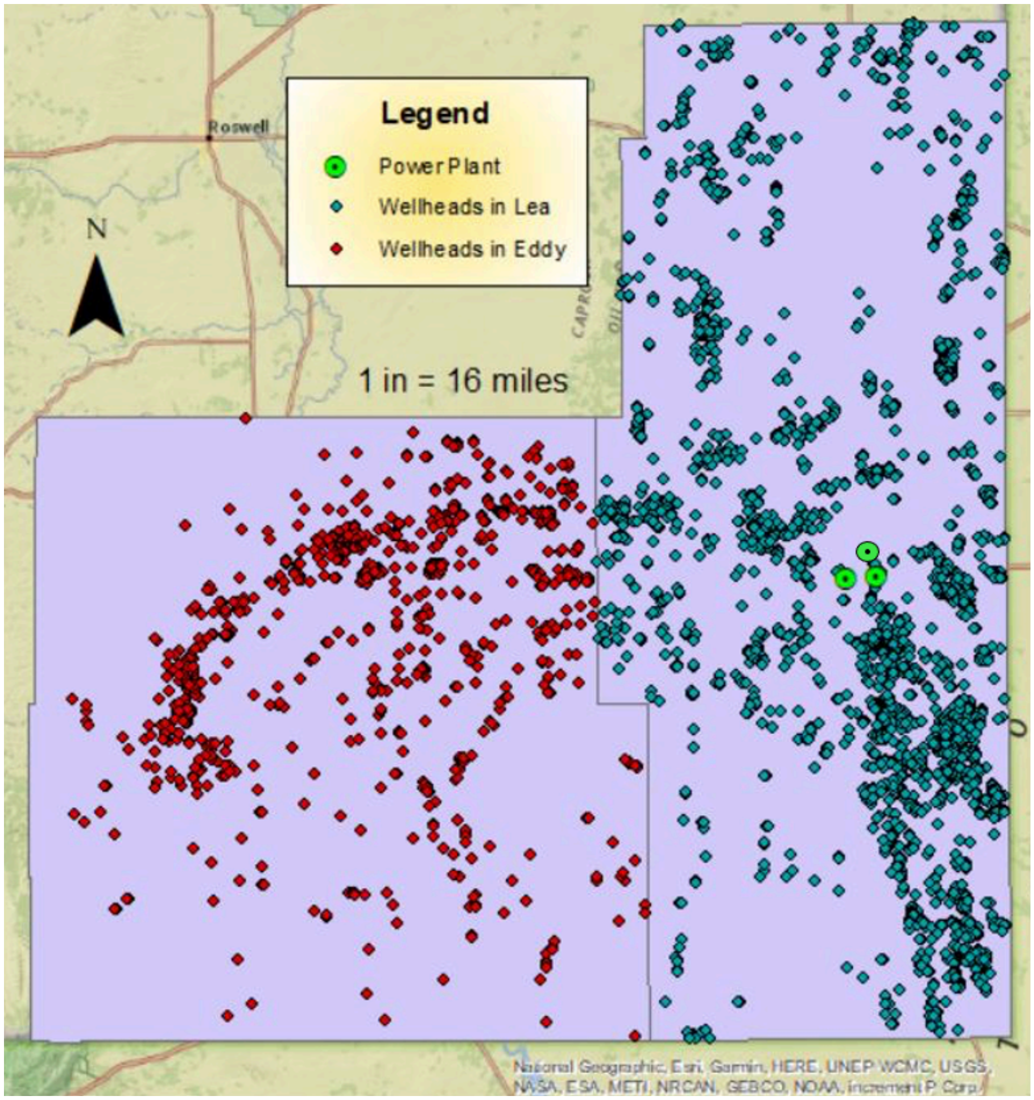


Figure: 6: Map with locations of oilfield wellheads and two power plants in Lea and Eddy County, NM

There are three thermal-electric power plants with steam turbine cooling technology that currently operate in Lea County, and these represent another potential end use for treated PW (Figure 6). It was found that 4,472 acre-feet/year (3.43 MGD), or 373 acre-ft/month assuming consistency, of fresh groundwater is consumed by these power plants (Magnuson et al., 2019). All power plants are in Hobbs, NM within 5 kilometers of each other and are powered by natural gas. Two are operated by Southwestern Public Service Co. and the other, called the Hobbs Generating Station, is operated by Lea Power Partners, LLC. They draw groundwater from wells for the steam turbine operations. The others are called the Cunningham Steam Turbine Power Plant, which has a capacity of 519 Megawatt electrical (MWe) and the Maddox Gas Plant, which has a capacity of 213 MWe. The Hobbs Generating Station has a capacity of 682 MWe and utilizes combined cycle technology, which uses ninety percent less water than comparable generating stations (Harris, 2008). Of the four units at Cunningham, two include steam turbines, while only one of two units at Maddox utilizes steam turbine technology (U.S. Energy Information Administration, 2021). There are no thermal-electric power plants with cooling towers in Eddy County.

In addition to the Roswell Basin and the High Plains Aquifer, Lea and Eddy counties are heavily reliant on the Pecos River Basin which has come under extreme political pressure (Figure 7). The water from this basin is used locally for the irrigation of agriculture, industry operations such as potash mining and oil & gas, and domestic uses. As pictured in Figure 7, the Pecos River Basin extends into west central Texas. Historically, ample planning and management are needed to maintain water availability. The Pecos River Compact requires New Mexico to deliver a minimum amount of flow through the Pecos River into Texas. Typically, the existing shortfall to this water requirement is 10,000 to 50,000 acre-feet/year (AFY) (Natural Resource Consulting Engineers, 2004). In 2022, this number is 161,000 acre-feet according to

Pecos River Bureau Chief Frank Scott. Consequently, the Supreme Court ordered New Mexico to provide an additional 10,000 acre feet annually to Texas. The state spent more than $100 million in buying water rights and drilling different wells to make sure it could make the extra 10,000 acre-foot delivery on average, every year to Texas on the Pecos.

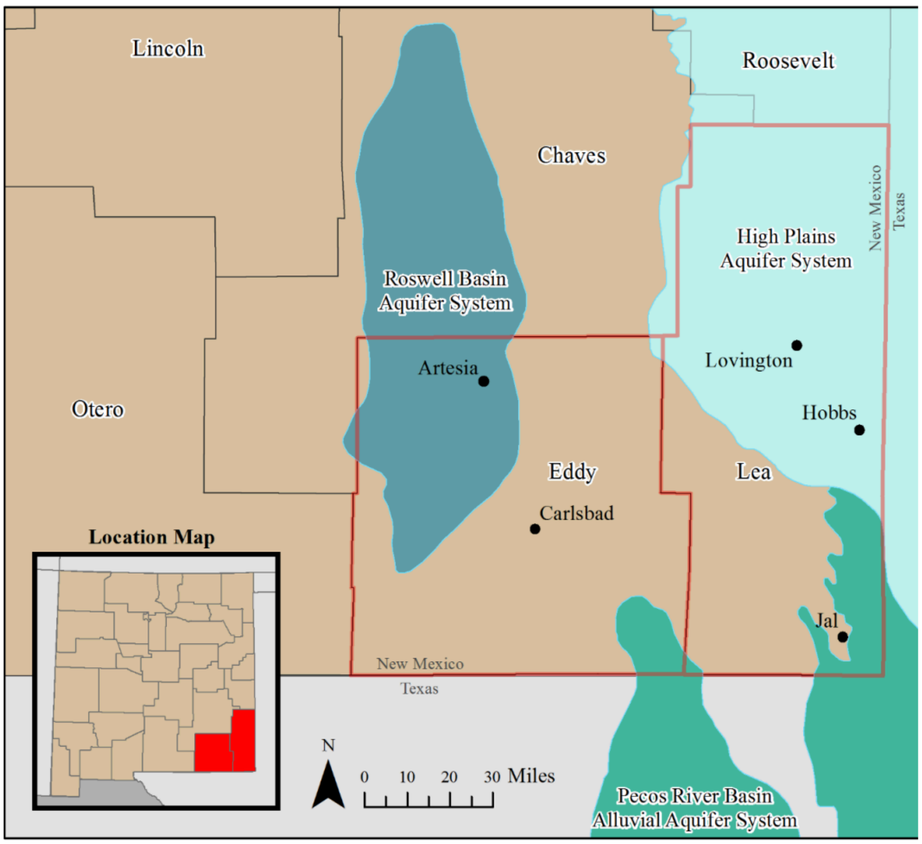


Figure 7: Water resources of Lea and Eddy counties. Source: (Sabie & Fernanld, 2016)

If treated PW could be used to meet the Pecos River Compact requirements, the pumping of groundwater above Carlsbad to meet Compact obligations could be reduced or stopped and local groundwater could be used for other uses such as irrigation. In 2002, a NM House Bill (HB 388) was passed providing tax credits to investments in PW reuse with the idea that the treatment and discharge of PW into the Pecos River Basin would help NM meet the Pecos River Compact obligations. No entities ever took advantage of the relatively substantial ($1,000/acre-foot) tax credit before the bill expired in 2006. The bill required that discharges be in compliance with the New Mexico Water Quality Act, New Mexico Water Quality Control Commission regulations, and the Federal Clean Water Act. Supplementation of the Pecos River Basin could benefit the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA). The most beneficial point of discharge may be before the Brantley Reservoir where augmentation could be accepted year-round with acceptable dilution factors (F. Scott, personal communication, March 11, 2022).

Based on the economies of scale rule, the greater the volume of raw PW flowing into a centralized treatment facility, the lower the costs per barrel of treated PW. In this case study, existing pipelines from oilfield wellheads to SWD wells could be taken advantage of as one system to consolidate the raw PW. It is anticipated that the water will need to be consolidated even more to reach a flow where it would be worth building a treatment facility. The more SWD wells connected to a single facility, the more economic it could be. However, the cost for transportation and collection pipelines also needs to be considered. Therefore, the location of SWD wells was used to find ideal treatment facility locations (Figure 15).

Based on water demand analysis, the total water demand for the top potential end users of treated PW varies based on spatial and temporal variation in both Lea and Eddy counties. About 115.1 MGD (10,750 acre-feet/month) of PW was created through oil & gas operations in NM in 2018 (New Mexico Environment Department, 2020a). Sabie et al., (2022) estimated the annual supply of treated PW to be 22,855,016 m^3 (18,536 acft) in Eddy County and 22,605,859 m^3 (18,334 acft) in Lea County. This is an estimate; the actual values could change based on changes in source water quality, treatment recovery rate, and volumes used for within-industry use. Although the total demand may not be satisfied with treated PW alone, it will help decrease the reliance on fresh groundwater supply.

In addition to these end uses, there are other areas that could benefit from treated PW. Environmental restoration, especially for mining operations, and augmenting river flows are significant needs for arid lands like southern NM. It is typically required of companies that extract natural resources on public lands to remediate a site before the agency releases its bond and responsibility for the site (Sabie et al., 2022). Reestablishing a specific vegetation community requires a water source. Treated PW might also be used for restoring important riparian areas along major rivers and arroyos.

3.2 Economic Impacts

3.2.1 Return on investment

Because there are many different end uses involved in this case study of PW reuse, there are many different economic consequences. Results cannot be produced without specifications; therefore, many assumptions were made to provide data on the economic return of a few different treatment and reuse scenarios. This section utilized the "Produced Water-Economic, Socio, Environmental Simulation Model" decision-making tool or "PW-ESESim" created by Sandia National Laboratory (Tidwell et al., 2022). This model is developed for use within Powersim Studio. With this model, the user is able to select specific township locations within Lea and Eddy counties, the target industry, treatment capacity, and effluent water quality. The model uses these selections along with data from the economic assessment program called IMPLAN to estimate the benefits associated with economics, public health, and social justice.

The model allows the user to define three potential reuse projects (i.e., generating irrigation quality, generating clean brine quality, and generating drinking quality). The three project locations for this study are shown in Figure 8. The location of Project 1 was chosen because it has a high density of active oil wells. The location of Project 2 was chosen based on its proximity to the optimized hot spot found in Eddy County shown in Figure 15. This map was created using the "Optimized Hot Spot Tool" in ArcGIS which finds clusters of point data (in this case, the locations of SWD wells) that are near each other in a statistically significant way. The location of Project 3 was chosen based on its proximity to the optimized hot spot found in Lea County shown in Figure 15.

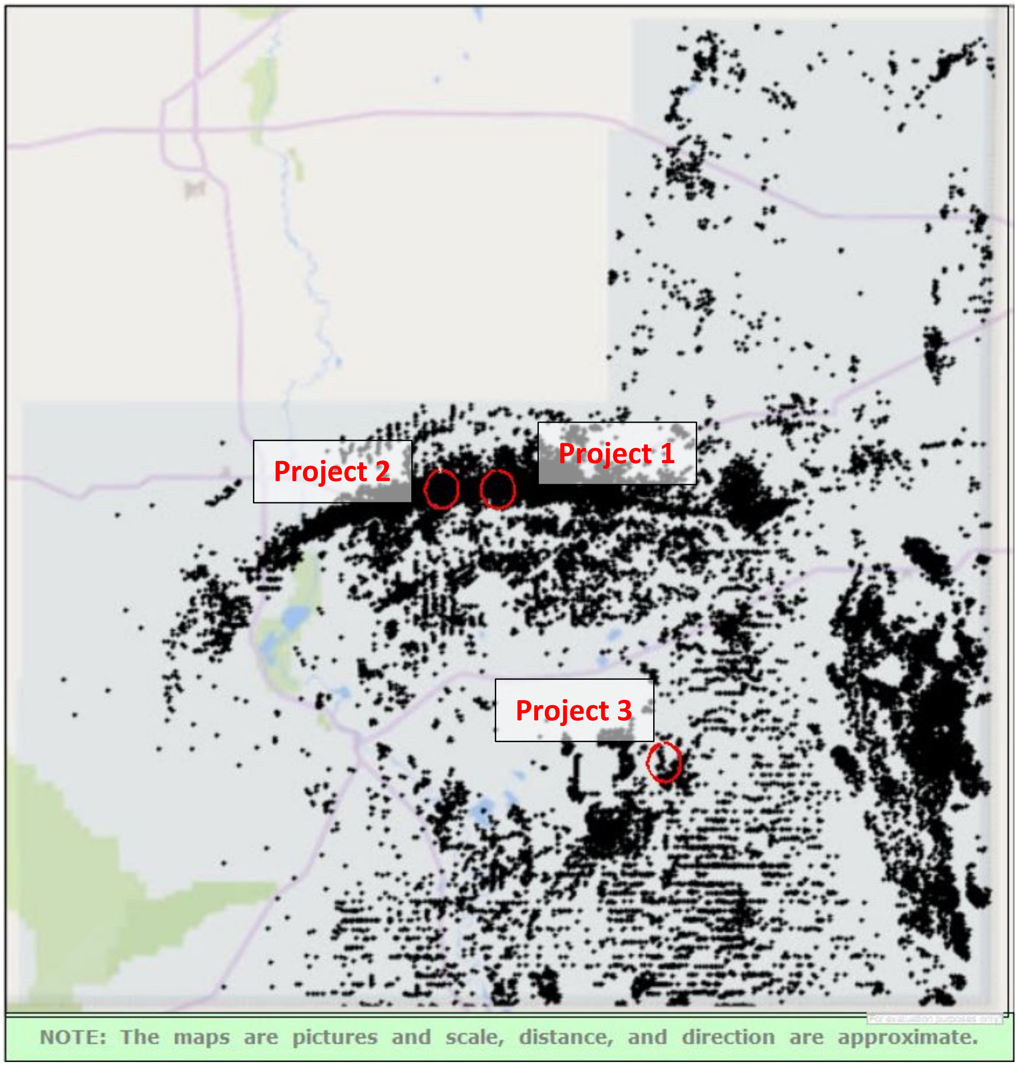
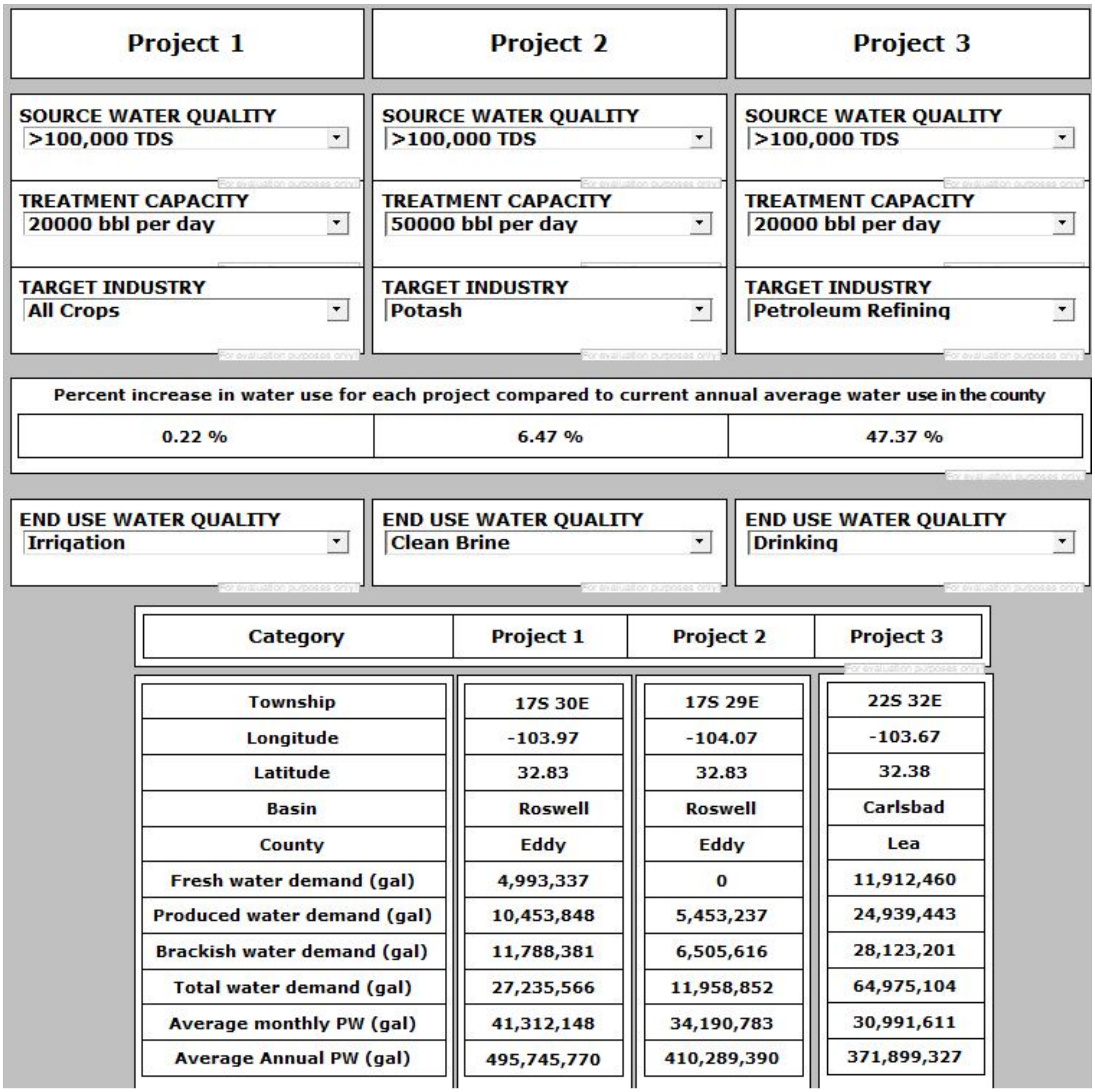


Figure 8: Locations of Project 1, 2, and 3, selected in the Map Interface of the PW-ESESim model. Lea and Eddy counties are shaded slightly blue. The black dots represent active oil wells.

The results from this model are based on the three projects being completely independent of each other; in other words, there is no sharing of treatment facilities or pipelines. Figure 9 is the “Project Setup” page, which shows all the inputs used in the model. All the parameters except the target industries were default settings and automatically selected by the model based on the selected geographic locations. The target industries were chosen because they require a different end use water quality. The project timeline runs from the year 2021 to 2050.



	Project 1	Project 2	Project 3
SOURCE WATER QUALITY	>100,000 TDS	>100,000 TDS	>100,000 TDS
TREATMENT CAPACITY	20000 bbl per day	50000 bbl per day	20000 bbl per day
TARGET INDUSTRY	All Crops	Potash	Petroleum Refining

Percent increase in water use for each project compared to current annual average water use in the county

0.22 %	6.47 %	47.37 %

	Project 1	Project 2	Project 3
END USE WATER QUALITY	Irrigation	Clean Brine	Drinking

Category	Project 1	Project 2	Project 3
Township	17S 30E	17S 29E	22S 32E
Longitude	-103.97	-104.07	-103.67
Latitude	32.83	32.83	32.38
Basin	Roswell	Roswell	Carlsbad
County	Eddy	Eddy	Lea
Fresh water demand (gal)	4,993,337	0	11,912,460
Produced water demand (gal)	10,453,848	5,453,237	24,939,443
Brackish water demand (gal)	11,788,381	6,505,616	28,123,201
Total water demand (gal)	27,235,566	11,958,852	64,975,104
Average monthly PW (gal)	41,312,148	34,190,783	30,991,611
Average Annual PW (gal)	495,745,770	410,289,390	371,899,327

Figure 9: Project setup within the PW-ESESim model. These are the inputs to the model.

	Incoming Water Quality	Water Quantity	Industry	Water Quality
Project 1	>100,000 TDS	20000 bbl per day	All Crops	Irrigation
Project 2	>100,000 TDS	50000 bbl per day	Potash	Clean Brine
Project 3	>100,000 TDS	20000 bbl per day	Petroleum R	Drinking

COST TO DISPOSE PRODUCED WATER $1 $2 $3 $4 $5 $6 $7 $8 $9 $10 per bbl

$0.75 per bbl

iDST Treatment Costs (plant and O&M), Pipeline costs

	Project 1	Project 2	Project 3
Total Energy Demand (kWh/yr)	541,200	541,200	9,575,800
Flow Rate (BBL/yr)	5,845,714	14,657,143	5,845,714
Water Recovery (%)	50 %	90 %	30 %
Total Treated Water per Year (BBL/yr)	2,630,571	11,872,286	1,578,343
FIXED COSTS			
Capital Cost ($) (1)	15,022,300	9,422,300	16,466,300
Pipeline Costs ($) (2)	475,200	633,600	475,200
Trucking Costs ($) (3)	$8,156,013	$7,991,629	$8,174,729
VARIABLE COSTS			
Capital Payment ($/yr) (4)	1,755,500	1,068,000	1,929,500
Pipeline payments ($/yr) (5)	38,131	50,842	38,131
O&M Costs ($/yr) (6)	1,038,600	626,900	1,063,700
SUMMARY			
Total plant and pipeline costs ($) (7) (4 + 5 + 6)	2,832,231	1,745,742	3,031,331
Treatment Cost with Contingency ($/yr) (8)	6,027,662	6,620,448	3,888,642
Normalized Treatment Cost ($/BBL)	2.26	0.55	2.43
Cost Savings non-disposal of PW ($/yr) (9)	1,972,929	8,904,214	1,183,757
Total cost with savings ($) (10) (8 - 9)	4,054,734	-2,283,766	2,704,885

Figure 10: Treatment costs results for each Project within the PW-ESESim model.

The results from the PW-ESESim model suggest that PW reuse has the potential to provide a large return on investment. Figure 10 shows that treated PW for a beneficial reuse can have a lower cost per barrel compared to a disposal cost of $0.75/barrel under these

Economic Baseline

Category	Project 1	Project 2	Project 3
County	Eddy	Eddy	Lea
Employment	42,370	42,370	42,931
Labor Income	3,010,262,068	3,010,262,068	2,886,413,442
Value Added	7,593,747,168	7,593,747,168	5,988,885,718
Output	13,255,494,024	13,255,494,024	11,371,733,109

Each project is independent: no sharing of treatment plant or pipelines.

Percent increase in water available for each project after buidling a treatment plant, with the characteristics show above, compared to the current annual average water use in the county for the chosen industry

0.22 %	6.47 %	47.37 %

Economic Impact

Category	Project 1	Project 2	Project 3
County	Eddy	Eddy	Lea
Employment	42,375	42,411	44,364
Labor Income	3,010,393,727	3,013,974,851	3,042,392,305
Value Added	7,593,941,801	3,013,974,851	6,667,396,052
Output	13,255,783,063	13,268,927,917	13,151,780,867
Tax Change	-1,380	120,976	5,711,743

Economic Change

Category	Project 1	Project 2	Project 3
County	Eddy	Eddy	Lea
Employment	5	41	1,433
Labor Income	131,659	3,712,783	155,978,862
Value Added	194,633	7,350,400	678,510,335
Output	289,039	13,433,894	1,780,047,758
Tax Change	-1,380	120,976	5,711,743

Financial analysis - one treatment plant per project, one new industry of the average size per project

Project	Industry	NPV	Payback period (years)
1	All Crops	$5,619,543	0.79 yr
2	Potash	$38,987,893	0.05 yr
3	Petroleum Refining	$163,109,665	0.02 yr

Cash flow diagrams - one treatment plant per project, one new industry of the average size per project

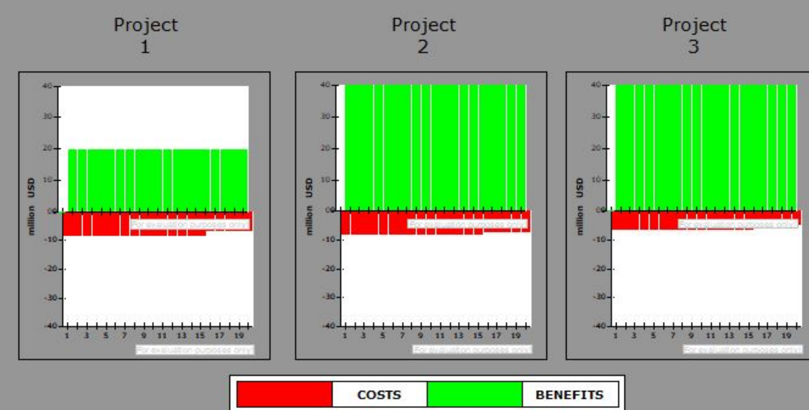


Figure 11: IMPLAN results in PW-ESESim model.

Figure 12: Social Justice Summary results for Project 1 in PW-ESESim model.

circumstances. Furthermore, the cost of treatment is reduced after accounting for savings accrued from not using traditional disposal technology. The financial analysis results show that all three projects have fast payback periods; all are within one year (Figure 11). This means that the economic benefits will outweigh the investments quickly. The Net Present Value (NPV) amounts show the value today, including economic costs and benefits, if the project were to run for twenty years. The largest NPV is for Project 3, petroleum refining, even though this project had the highest cost per barrel in Figure 10. This shows that there are many economic values to consider when planning treatment for PW and economic benefits can change when looking at long-term versus short-term investments.

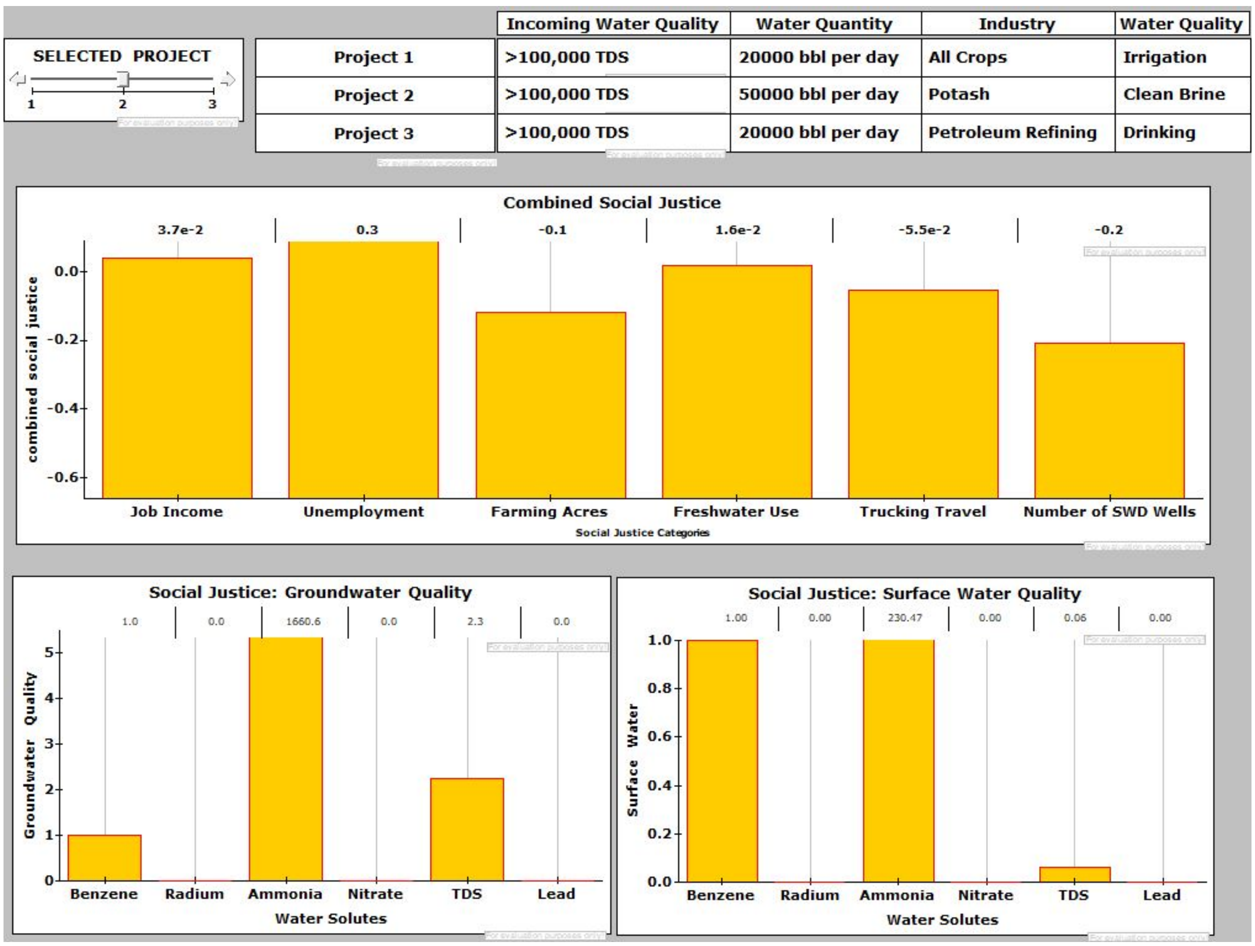


Figure 13: Social Justice Summary results for Project 2 in PW-ESESim model.

Figure 14: Social Justice Summary results for Project 3 in PW-ESESim model.

3.2.2 Employment

Not only would PW reuse introduce new employment to build, operate, and maintain the infrastructure necessary to produce a viable output for end users, but also it would provide security for the water-dependent jobs that already exist in the area. The incentives for potential end users are profound as they struggle with their dependency on depleting freshwater aquifers. Without a source of water for irrigation, the future of the local agricultural industry is at risk.

The effects of these projects on job income and unemployment are found in Figures 12, 13, and 14. Based on these results, all of the projects have a positive effect on job income. The "combined social justice" graph is calculated based on the relative change from the baseline values. The baseline values are based on the most recent data available and represent the current state of the system. For example, for unemployment the result is calculated with:

$$\begin{aligned} &Value\ on\ y-axis \\ &\quad = (unemployment\ new - unemployment\ baseline)\ /\ unemployment\ baseline \end{aligned}$$

However, the formula is manipulated so that the preferred impacts will result in a positive value. Therefore, any value on the social justice graphs that is positive is considered a benefit. Because of this, it is determined that overall employment rates will be positively impacted only in Projects 2 and 3. Under "Economic Change" in Figure 11, the growth in jobs and labor income is enumerated. Project 3 has the potential to create the most jobs based on this output.

3.2.3 Capital plus operation & maintenance

Effective and suitable treatment technologies are necessary to the success of PW reuse, however, these technologies can be expensive and energy-intensive. The source water quality and product water quality goal will determine the type of treatment train required for successful operation. These treatments may include pretreatment only (for operations such as hydraulic fracturing), pretreatment and partial desalination (for operations such as thermal-electric cooling towers), or pretreatment, desalination, and blending (for operations such as surface/groundwater discharge). However, water quality parameters (e.g. TDS) may be too high for the economic feasibility of certain treatment technology such as reverse osmosis (Scanlon et al., 2020).

Because raw PW quality is dynamic, the appropriate treatment technology will need to be effective for a variety of water qualities.

The treated PW demand explored in Section 3.1.5 is also pertinent to economic feasibility. Based on the economies of scale rule, the more raw PW flowing into a centralized treatment facility, the lower the costs per barrel of treated PW. PW supply for end uses such as crop irrigation may be too little to justify considering the size of demand. In this project, the location of SWD wells has been used to find ideal treatment facility locations (Figure 15).

Figure 15 shows the best locations for treatment facilities based on the proximity of SWD wells to each other. Using the "Optimized Hot Spot Analysis" tool, a raster layer of optimal hot spots was created based on the SWD wells as the input data. This tool automatically aggregates the input data, identifies a scale of analysis, and corrects for errors. The scale of analysis determines an appropriate, useful distance from each data point based on the information provided and the aggregation of input data automatically calculates the average and median nearest neighboring distances of all points (ESRI, 2020). Based on this knowledge, it is clear that this GIS tool only uses the proximity of the input dataset—in this case, the SWD well locations. Another analysis taking into consideration the quality and quantity of PW at each SWD well may provide an even more accurate assessment of optimal centralized treatment facility locations. Figure 15 shows that the best locations for a treatment facility would be along Route 82 east of Artesia in Eddy County and the area east of Carlsbad in Lea County. The exact number of treatment facilities to be constructed to minimize cost will need to be determined based on the costs of transportation and treatment operation/construction costs.

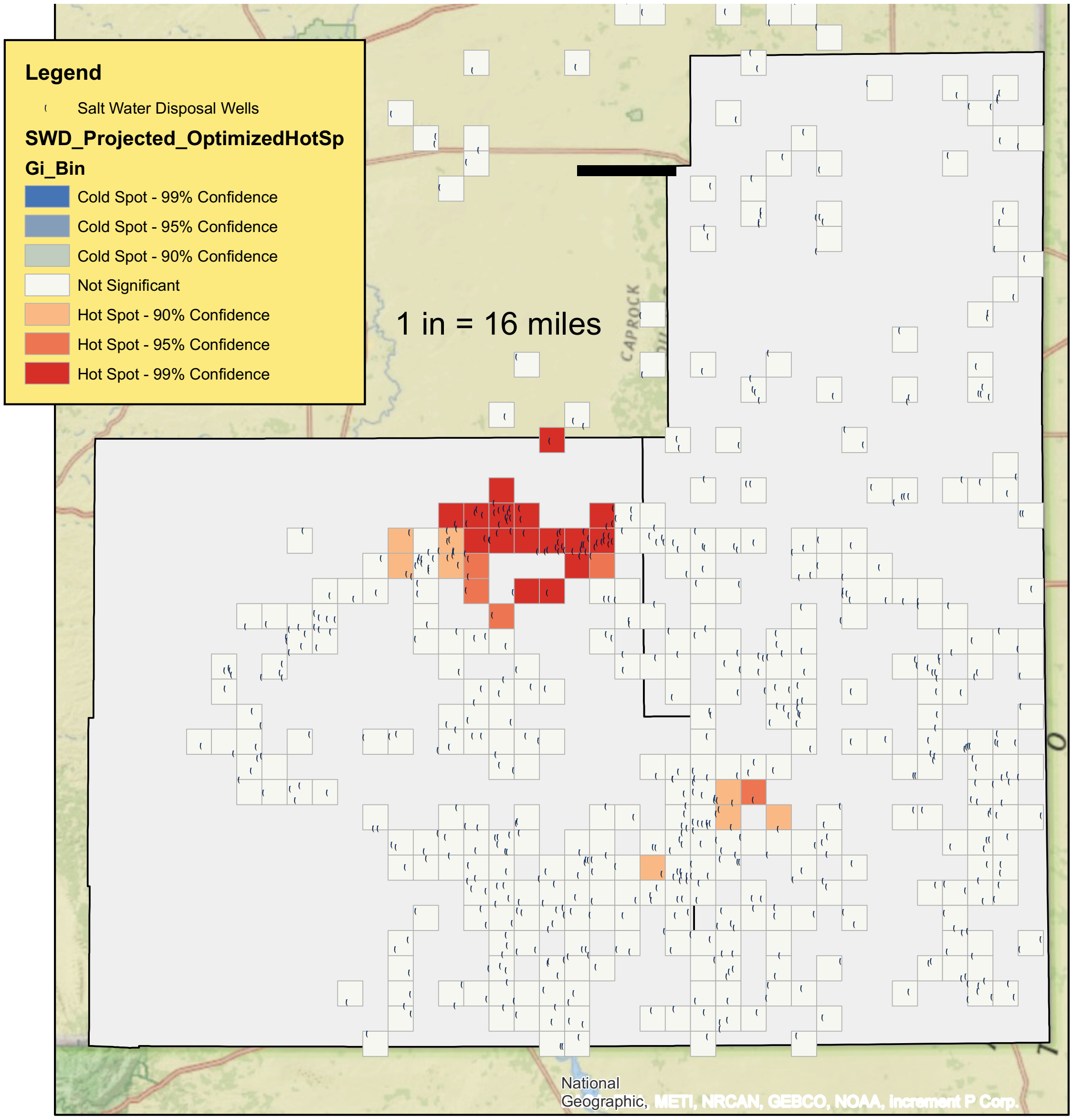


Figure 15: Map of optimized hot spot locations, or locations best suited for a treatment facility based on raw PW consolidation at SWD wells, in Lea and Eddy Counties.

3.2.4 Effect on water rates

End users may benefit economically by using treated PW rather than potable freshwater. Because freshwater supply is limited and the demand is high in southern NM, its cost is high. Even though there may be some scenarios where the cost to treat the PW for beneficial reuse may be more expensive than traditional disposal, the benefits may outweigh the cost in the long-term once the capital investment on the treatment facility and other infrastructure is paid off. This is what is shown with the NPV in Figure 11. There may be some scenarios where the cost to treat the PW for beneficial reuse is more affordable than the costs to use freshwater (such as in Project 2). In this case, the water rates of residential users in this area may be positively affected as, even though there is no scenario in this case study where the PW is treated for public water supply, more treated PW used means less freshwater used, and that may result in prolonged freshwater availability for potable uses.

3.3 Social Impacts

3.3.1 Public perception

The analysis of public perception, or the widespread human social response to the proposed project, will help professionals know if and in what way the local population supports or opposes their initiatives. Public support is vital to raise capital, recruit and retain talent, and maintain long-term viability of the project, among other valuable benefits (Rassenfoss, 2019). Any unintended consequences of the safety and socioeconomic status of the local population must also be considered and minimized. It is mandated in the New Mexico Produced Water Act (HB 546) to protect the people, environment, and economic activities of those that use water sources (*Fluid Oil & Gas Waste Act*, 2019).

How PW reuse legislation, as well as oil & gas operations in general, is presented and politicized in the media may be important in the formation of public perception. A local researcher found that 80% of oil & gas articles in Lea and Eddy counties contained topics with negative connotations, such as economic dependence and environmental degradation, in an evaluation of public perceptions through newspaper articles. Only 20% contained topics with positive perceptions, such as large profits and environmental stewardship (Caballero, 2021). Many of the top themes were contradictory, which may indicate that people in this region have different interpretations of the same information.

The New Mexico Environment Department (NMED) sought an initial sense of the public perception of PW reuse in New Mexico in the fall of 2019. They asked the public for comments and ideas about the reuse of PW outside of the oil & gas industry. Although the meetings were physically held in Albuquerque, Santa Fe, Carlsbad, Farmington, and Las Cruces, the NMED also accepted input electronically on their website and through direct mail from anyone, anywhere. The results from this procedure were highly varied. Most comments expressed a general concern of unknown compounds surrounding the use of PW outside of the oil & gas industry, how to regulate them, and how this could affect human health and the environment. Among the statements of concern, 30% expressed unease about the disclosure of proprietary information and the integrity of research, while 24% worried about exposure to toxicity. Appropriate standards and regulations for these operations was another popular topic of concern. Those who supported the project wanted to use this opportunity to adopt stricter regulations in the oil & gas industry, as well as dramatically limit or abolish the use of freshwater in their operations (New Mexico Environment Department, 2020b).

A retired Texan professor and research engineer, among other stakeholders, advised that the public perception of projects like this is not fixed. Based on their methods, the best way to improve public perception is through creating a partnership with the community. Public education and outreach is vital, our stakeholders noted, including communication with local leaders, key community members, and county or town officials. Media may be used as an outlet to reach the wider population. Because many have an emotional reaction to PW reuse before a logical one, judgements may need to be overcome to reach “belief” in science or data. The stakeholders suggested that simply talking about what issues may exist and educating them about the project may result in a substantial increase in local acceptance. Further, education is a matter of painting a story, using the experts to support the message, and targeting the voting population.

Conveying the expected drawbacks or risks of the project may be just as beneficial as communicating the benefits; this is how trust is created.

Another aspect of PW reuse that should be elucidated to gain public acceptance is the problem to which this method offers a solution. The immensity of the water scarcity problem, how deeply it affects American agriculture among other industries, and how severe those consequences would be are important to understanding why seemingly unusual measures such as PW reuse may be necessary. Additionally, PW reuse is a unique resolution. While other methods of water conservation or resources to manipulate may exist, the disposal of so much PW in southern New Mexico is a great untapped resource.

While PW reuse in southern New Mexico has already been introduced to the public in a number of settings, progressing and sustaining public education and outreach has been proposed based on the above recommendations. Web-based communications will be used for the public to easily access research and reports such as health and safety data, meeting minutes, press releases, and presentations. Educational programs and public meetings will continue to be held to support community understanding of the project. Complete disclosure of all of the chemicals in New Mexico produced waters and discussion about their impacts is expected to be part of the community outreach program to address some of the concerns revealed in the initial public input meetings. The relative risk of treated PW compared to other sources will be explored, as well as the overall costs and benefits of this project. Questions and concerned may be addressed at in-person meetings or free webinars with the help of technical experts, doctors, public health professionals, and others. A community partnership built on trust and understanding is hoped to be created with these methods.

3.3.2 Disaster mitigation

Drought is considered a natural disaster. However, natural disasters are more than an environmental process or event that humans have no control over; disasters overwhelm the capacity of a certain vulnerable area to resist or recover. Therefore, an area's vulnerability to disaster can be observed as the societal factors that create or exacerbate risk and impact of a natural disaster. The interplay of economics with social and political power in the production and distribution of resources determines how adapted a society is to a certain area over time. The relationship between society's knowledge of vulnerability to a disaster and their action to mitigate this vulnerability is a huge part of effective disaster mitigation and response (Haenn et al., 2016). In other words, unsafe conditions may exist for a long time before the trigger event, or the natural disaster, that brings about hazards.

In Lea and Eddy counties, underlying social conditions may exist that exacerbate current or future severe drought conditions. The "Pressure" or "Crunch" model created by Wisner et al. 2004 explains this phenomena (Figure 16) (Wisner et al., 2004). Certain weakened, unequal, or underdeveloped aspects of a society, called root causes and dynamic pressures, can exacerbate the social and environmental impacts of a natural disaster. These pressures are resolved with the "Release" model (Figure 17). Vulnerability is not equal throughout a region. Root causes are static underlying historical causes of vulnerability and typically stem from how power is distributed throughout different social groups. These root causes manifest into evolving dynamic pressures that lead to unsafe conditions for those most vulnerable to disaster.

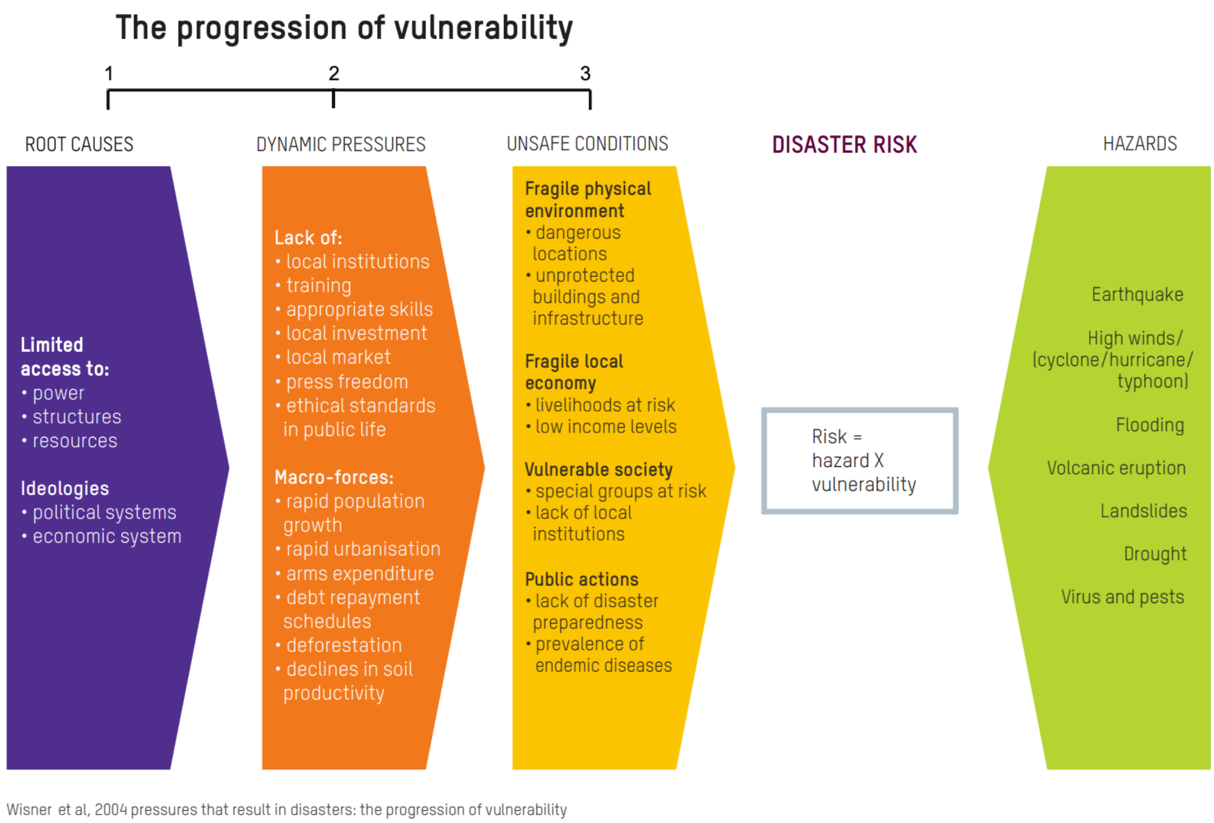


Figure 16: The Pressure Model, originated from Wisner et al. 2004. Source: Oxfam

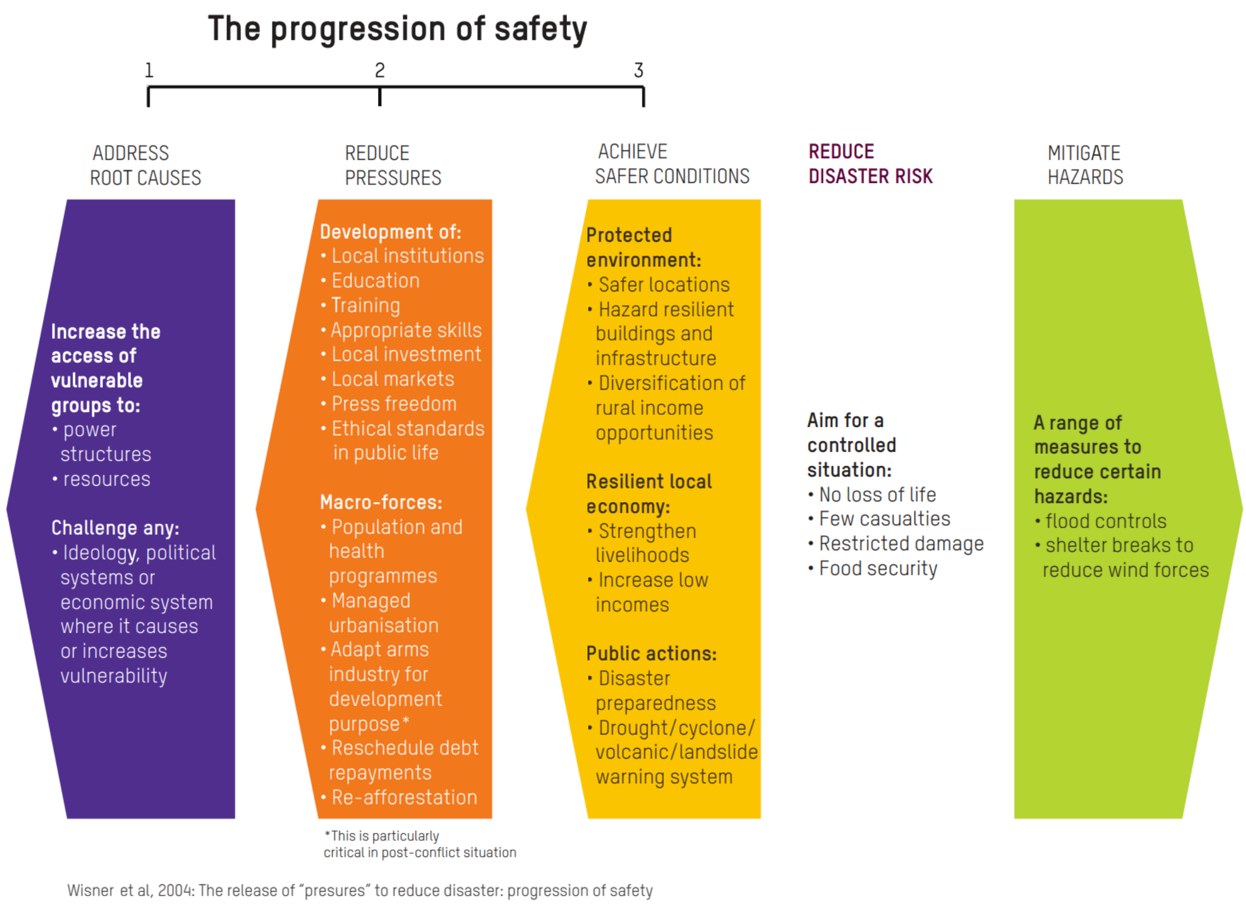


Figure 17: The Release Model by Wisner et al. 2004. Source: Oxfam

As a whole, investing in water resources projects for better local water management enhances social equity; but, as researchers, it is important to evaluate any negative effects of PW reuse on the local community. If certain PW reuse systems were to hinder those with already low incomes, for example, this would need to be addressed. However, PW reuse has the potential to increase the progression of safety and resilience during drought due to the reallocation of water resources. End users with lower incomes such as those in the agriculture business would benefit from treated PW because they would be able to water the crops they invested in. Based on an interview with a potential end user in the agricultural sector, great support for PW reuse prevails locally.

Investment in agriculture may have a direct positive impact on food security in the area. According to one agriculturalist in Lea County, historical over-appropriation of water has caused problems for industries in southern New Mexico. Water legislation has notoriously promised more water than it could provide. One large aquifer called the Ogallala reaches from North Dakota to Lea County. When this aquifer “goes dry,” he warned, food prices all around America will be affected. He commented that the treated PW needs to reach a level of safety, just enough where no residual components could harm cattle or people, blended with what little freshwater there is left if necessary, to keep agriculture viable in the United States. He exemplifies the local advocacy for PW that exists, especially from potential end users like him.

Chemical recovery is an additional incentive with positive social impacts. Although the economic benefits do not yet exist to invest in the technology that could recover certain valuable chemicals from PW, there is a chance this could be pursued in the future. Lithium and arsenic, for example, may be concentrated and sold (Miranda et al., 2022). Chemical recovery in PW could have large societal benefits versus traditional mining methods of these chemicals. Salt could be recovered from PW to put on roads for de-icing in places with severe cold weather, which has the potential to reduce vehicular casualties. Public support is built by explaining these possibilities, using the experts to support the message, and targeting the voting population.

3.4 Environmental Impacts

3.4.1 Effect on local ecology

Conventionally, PW is disposed of through deep well injection at SWD wells. Disposal by injection is linked to aquifer contamination and increased seismicity over time (Weingarten et al., 2015). Reuse of PW would concentrate the volume requiring SWD well injection. The first and best opportunity for PW reuse is for hydraulic fracturing. Only minimal treatment may be necessary to reach usable "clean brine" for this purpose (Scanlon, 2020). It is best because it would be overall cheaper, less risky, and less energy intensive. With more intensive treatment, water for thermal-electric power plant cooling tower steam turbines, dust suppression and road maintenance, irrigation for crops, and surface or groundwater discharge are other end use opportunities for PW recycling. The unintended consequences and risks involved with each beneficial use will need to be analyzed due to the potential for contamination. Figures 12, 13, and 14 show the result of some PW reuse projects on the environment.

3.4.2 Energy consumption/GHG emissions

The more intensive the treatment required to reach a product water for a certain end use, the more energy is used. Consumption of this energy almost always necessitates emissions of greenhouse gases (GHG). Energy is consumed through infrastructure construction, material and chemical product use and delivery, and maintenance of these systems. Even with the help of renewable technology such as solar or wind, the burning of fossil fuels is unavoidable at some point in the processes of utilizing this technology. In addition to the treatment technology used, transportation in the form of pipes, pumps, and/or trucking of PW and related wastes to and from a treatment facility would add to the amount of emissions released. Figure 10 shows the total annual energy demand of each PW reuse project evaluated in the PW-ESESim model.

3.4.3 Disposal (hazardous waste & safety)

Raw PW may naturally contain oil/grease droplets, suspended solids, transition metals, naturally-occurring radioactive material (NORM), organic compounds, BTEX chemicals, polycyclic aromatic hydrocarbons (PAHs), biopolymers, humic substances, microbes, and more (Scanlon et al., 2020). Even with effective treatment technology, these constituents would be concentrated in the waste stream of certain treatment technologies. These concentrates or wastes loaded with contaminants could be solid or liquid. Appropriate and effective management of this waste is vital to minimize the environmental consequences of PW reuse.

3.5 Discussion & Conclusion

Table 3 shows the evaluation of criteria for all of the PW reuse projects in the case study based on the investigations illuminated in the case study. Where specific quantitative values could not be determined, a categorical value was assigned based on the following scale: exceptionally negative, moderately negative, neutral/mixed, moderately positive, and exceptionally positive. These variables are all weighted equally, however, this can be modified in the future should new information about stakeholder priorities arise.

Table 3: Evaluation criteria for PW reuse (all projects).

Criteria	Ranking/Value		
	Project 1 (irrigation quality)	Project 2 (clean brine quality)	Project 3 (drinking quality)
Product water quality	Moderately negative		
Source (feed) water quality	Exceptionally negative		
Longevity of source	Moderately positive		
Effect on water resources	Exceptionally positive		
System maintenance & operation complexity	Moderately negative		
Return on investment	Moderately positive	Exceptionally positive	Exceptionally positive
Employment	Neutral/mixed	Moderately positive	Exceptionally positive
Capital plus operation & maintenance	$2.26/bbl or $62.80/thousand gallons	$0.55/bbl or $15.00/thousand gallons	$2.43/bbl or $67.50/thousand gallons
Effect on water rates	Neutral/mixed	Moderately positive	Neutral/mixed
Public acceptance	Exceptionally negative		

Disaster mitigation	Exceptionally positive		
Effect on local ecology	Neutral/mixed		
Energy consumption/GHG emissions	Moderately negative	Moderately negative	Exceptionally negative
Disposal (hazardous waste & safety)	Moderately negative		

The value for "Product water quality" was determined because of the results found in Figures 12, 13, and 14. Although the treatment may be very effective, there is chance of risks of releasing contaminants and "unknown" chemicals of concerns to the environment. Potential routes of exposure and impacts on public health and environment will need to be evaluated for different beneficial reuse scenarios. "Source water quality" was assigned a ranking of exceptionally negative because this is one of the biggest hurdles to adoption of beneficial reuse of PW. This has consequences in social, economic, and environment aspects. One of the reasons for this is because of the uncertainty; the application of extremely accurate, precise, and sensitive analytical techniques may help overcome this difficulty. To be able to fully comprehend the source and product water qualities is vital for the success of PW reuse.

The "Longevity of source" value is based on the fact that the reliability of the resource is not quantifiable because it is dependent on an industry, however, the oil & gas industry has historically been very persistent. The "Effect on water resources" value is based on the idea that the PW volumes will help offset freshwater use in a meaningful way. "System maintenance and operation complexity" is based on the complicated transportation and collection infrastructure that needs to exist for these PW reuse projects to be successful. However, this may be simplified if it is possible to use some existing infrastructure, such as the pipelines already in place from wellheads to SWD wells.

The economic section criteria are valued per project based on results from the model, which can be found in Figures 11, 12, 13, and 14. “Effect on water rates” is based on the “Capital plus operation and maintenance” value, as the most practical uses are those where the water rate is not significantly higher than business as usual.

The “Public perception” ranking is based on the perceptions that already exist as well as the potential of change in these views that may come about based on recommendations from stakeholders. The “Effect on local ecology” is mixed because of the potential for both better water resource allocation and contamination. Drinking water quality requires much more energy than the other PW reuse projects because of the treatment technology needed, which is factored into the “Energy consumption/GHG emissions” rankings. Although the technology is established, the “Disposal (hazardous waste & safety)” ranking is based on the unknowns involved with concentrate disposal.

CHAPTER 4: CASE STUDY 2 – DESALINATION OF BRACKISH GROUNDWATER

4.1 System Performance

4.1.1 Product water quality

The intended end use for the desalination technology used to treat the brackish groundwater in Santa Teresa is municipal and industrial uses. This means that the water will need to be treated to the high quality standards of potable water. It is likely that the desalination technology used to treat this water will be reverse osmosis (RO); because of RO technology's high removal efficiency of salts and other organic and inorganic contaminants, saline water such as brackish groundwater can be converted to usable, drinkable freshwater (Biesheuvel et al., 2020). The finished water, which is the permeate from the RO membranes after it has been blended to reintroduce an appropriate amount of salts and minerals, is capable of compliance with federal and state drinking water standards (Landreth & Sansone, 2004). The published report containing the preliminary design of the desalination facility in Santa Teresa compares RO and electrodialysis reversal (EDR), where ions are pulled across selective membranes with electrodes. Groundwater from a local well was treated with RO and produced a stable high quality permeate in a pilot-scale test (King et al., 2019). The removal of selected constituents can be found in Table 4.

Table 4: Permeate water quality of pilot-scale RO test with brackish groundwater from Santa Teresa area. Source: (King et al., 2019)

Constitute	Unit	Feed	Permeate	Removal
pH	pH unit	7.65	5.85	

Electrical conductivity	µmhos/cm	2360	36.8	98.4%
TOC	mg/L	6.34	0.25	96.1%
Turbidity	NTU	0.25	0.04	83.3%
Total hardness (as $CaCO_3$)	mg/L	234	2.75	98.8%
Chloride	mg/L	333	9.96	97.0%
Sulfate	mg/L	393	0.5	99.9%
Nitrate	mg/L	6.98	0.82	88.2%
Bromide	mg/L	4.69	0.19	95.9%
Ammonium	mg/L	1.28	0.17	86.7%
Silicon dioxide	mg/L	40.2	0.7	98.3%
Calcium	mg/L	72.95	1.02	98.6%
Magnesium	mg/L	12.71	0.05	99.6%
Potassium	mg/L	8.85	0.2	97.7%
Sodium	mg/L	262	5.0	98.1%
Arsenic	mg/L	0.0534	0.005	90.6%
Boron	mg/L	0.469	0.287	38.7%

4.1.2 Source (feed) water quality

The aquifer being considered as the source for the desalination facility at this location is the Mesilla Basin. Slightly to moderately brackish groundwater (TDS <5,000 mg/L) is found below the unconfined shallow flood-plain alluvium of this area. Based on preliminary testing, the feed water for this project would be found primarily in the upper and middle parts of the Santa Fe Group within the Mesilla Basin aquifer in terms of depth. The upper part is the most productive water bearing section, but is unsaturated in the south and western parts of the Mesilla Basin. The middle part is generally saturated throughout.

Source water quality data taken from the preliminary design report can be found in Table 5. It was found that the most abundant cation is sodium and the most abundant anion is chloride. Based on the water quality data, pretreatment chemicals and methods, anti-scalant chemicals, and other relevant system design characteristics are determined (King et al., 2019).

Table 5: Groundwater quality of three selected wells in the Mesilla Basin and the regulatory levels. Source: (King et al., 2019)

	Units	Wells AVG	Primary (MCL)	Secondary (MCL)
Sodium	mg/L	677	-	500
Arsenic	mg/L	0.015	0.01	-
Chloride	mg/L	643	250	250
TDS	mg/L	2,100	-	500
Alkalinity	mg/L	146	-	-

4.1.3 Longevity of source

One of the main reasons why this water resource is seen as valuable is its resistance to drought and seasonal change. Because it is a deep water reserve from outside of the hydrologic cycle, it is a predictable, steadfast resource (Raucher & Raucher, 2011). This brackish aquifer supply in southern New Mexico and western Texas is large, but it is not infinite. It is estimated that there is about 60 to 65 million acre-feet of brackish water that will be usable over the lifetime of the Mesilla Basin aquifer (Hawley, 2016). The Mesilla Basin is recharged by the Rio Grande, but primarily recharged by underflow from local sources that are predominantly brackish. Exactly how well this aquifer is recharged is unknown. There is potential space to store artificial recharge for future recovery from other water resources. The aquifer source for the KBH Plant is the Hueco Bolson Aquifer. One of the main purposes of establishing the KBH

Plant was to prolong the usability of the Hueco Bolson Aquifer, which also consists of invaluable freshwater.

The Mesilla Basin aquifer is spread over New Mexico and Texas in the United States and Mexico. The three different powers at play present policy obstacles for the future. These three regions all appropriate and govern water differently. The only water-related treaties between any of these entities, even between New Mexico and Texas, only applies to surface water. These are called the International Boundary and Water Commission Treaties (IBWC, 2019). Therefore, there are no rules regarding where or how much to pump from this transboundary aquifer. This could produce longevity problems as the demand for the Mesilla Basin continues to grow by different regions over time. It could turn into a race to capture this precious resource, resulting in increasingly deep well drilling. Sustainable management of groundwater resources, especially those shared across borders, seems to have low priority for these governments, which could lead to unstable consequences. Fortunately, cooperation through research programs such as the Transboundary Aquifer Assessment Program (TAAP) established in 2006 could promote support for sustainable management of shared natural resources without formal treaties or agreements. (King et al., 2019).

4.1.4 Effect on water resources

Overpumping has occurred from freshwater being withdrawn from the aquifers faster than its natural recharge rate. However, the nearby KBH Plant slows the intrusion of brackish water into freshwater wells by intercepting brackish groundwater flows that could intrude on freshwater sources and reducing the withdrawals of fresh groundwater (Landreth & Sansone, 2004). With the desalination plant in operation, the idea is to proportionately reduce the amount of freshwater pumped from other wells; therefore, the total amount of water drawn from the Mesilla Basin in the case of Santa Teresa should plateau. There may be a slight change in aquifer drawdown from feed and blend wells. Hydrologic modeling is needed to be performed on proposed feed and blend wells to determine the effect of pumping.

Based on data from the NM Office of State Engineer, an average of 3,710 acre-feet/month is withdrawn from fresh groundwater for public water supply in Doña Ana County, NM (Magnuson et al., 2019). The desalination plant could offset part of this water demand; a 5 MGD desalination plant would produce about 460 acre-feet/month. Less heavily treated water would be better to use for end uses like irrigated agriculture and livestock where the standard of potable water is not needed. Therefore, this entire flow may be used towards municipal drinking water and industries that require drinking water quality.

If the RO concentrate is to be disposed through deep-well injection, connections between the injection zone and other aquifers should first be analyzed to determine if contamination will occur. Should contamination occur, this may affect the usability of freshwater within the water table. It is standard for the deep-well injection of concentrate to be double-walled with concrete and steel up to a certain depth to prevent leakage into the freshwater table. After that, a single-walled barrier continues until the well reaches an impermeable layer that prevents the upflow of concentrate. Local test hole studies will come before permitting and full implementation of this disposal method. For example, the Texas UIC regulations specify the SWD well construction requirements followed by the KBH Plant (Landreth & Sansone, 2004). Maintaining geochemical compatibility in concentrate with naturally-occurring water is another consideration. The benefits due to reduced use of freshwater sources may be substantial.

4.1.5 System maintenance & operation complexity

The treatment process at the KBH Plant includes pretreatment, RO treatment, and post-treatment of finished water. The pretreatment used at this facility is a sand strainer to remove sand particles and an injection of a chemical antiscalant (sulfuric acid and phosphoric/phosphonic acids) to deter fouling. The water then travels through a filter that removes particles larger than 5 micrometers to prevent damage to the RO membranes. A similar system is proposed in the preliminary Santa Teresa design, although hydrochloric acid is used as the antiscalant chemical to avoid precipitation of $CaSO_4$ (King et al., 2019). Post-treatment involves mixing of blend water with permeate; the adjustment of pH with caustic soda, a sodium hydroxide solution; disinfection with sodium hypochlorite; and the inhibition of corrosion with sodium hexametaphosphate.

It is proposed that 25% of the feed water will bypass treatment to be blended with RO permeate to maintain pH and TDS levels. The proposed water recovery rate is 81.3% for the RO system and 85% for the alternative EDR system (King et al., 2019). Therefore, more than 80% of the original feed water flow will be generated as product water with either treatment method. Pressure, flow, and TDS concentration must be monitored during operation. Routine system cleaning is needed to remove fouling of membranes. Permeate is used to prevent fouling when there are membranes not in use (Landreth & Sansone, 2004).

Regular monitoring and reporting of the deep-well injection operations are needed to maintain the permit necessary for this disposal infrastructure. Monitoring of the flow and pressure along the concentrate pipeline is also needed at the control center, where an alarm would sound if a leak is detected. Locations where the pipe can be accessed for maintenance (pigging stations) exist at the plant and SWD well injection site at the KBH Plant (Landreth & Sansone, 2004).

Operation and maintenance includes the storage of chemicals. Two 15-day supply 6,000 gallon tanks of the chemical antiscalants are maintained at the KBH Plant, as well as two temperature-controlled 10,000 gallon tanks of 50% solution sodium hydroxide and 12.5% solution sodium hypochlorite. The corrosion inhibitor is stored in a 6,000 gallon tank. Acids, bases, enzymes, biocides, oxidants, chelating agents, and detergents may also be needed to periodically clean any fouling from membranes. The storage of permeate is needed for flushing if there are any membranes not needed in operation to prevent fouling (Landreth & Sansone, 2004). Operators will need the correct permits to work with these chemicals.

The exact number of feed and blend wells necessary to meet the proposed treatment capacity of the blend will need to be drilled. According to the KBH Plant EIS, their depths would be approximately 900 to 925 feet, their diameter 26 inches with a 16-inch diameter lining, and backfilled with gravel (Landreth & Sansone, 2004).

4.2 Economic Impacts

4.2.1 Return on investment

The projected life span of the KBH Plant and its pipelines is 50 years. For the Santa Teresa facility, a life span of 30 years is assumed. Resource recovery operations could help offset the cost of operating the facility; while uranium deposits have been reported in some west Texas locations, it is not anticipated to cultivate commercial quantities at the proposed site in Santa Teresa.

The economic value in tapping into deep brackish aquifers may be most easily illustrated by comparison to alternatives. The last resort and most expensive alternative per unit is the importation of water (Raucher & Raucher, 2011). It has been shown that for many methods without appropriate promotion of reduced water use, conserving water is expensive compared to the value of water saved (Ward et al., 2007). Additionally, water conservation measures in agriculture can result in increased water use (Ward & Pulido-Velazquez, 2008). The recycling of municipal water supply is not as advantageous as desalination because this supply is already cyclical in nature and not much water is actually consumed in the process. Studies show that urban water recycling have little effect on addressing water scarcity problems (Richter et al., 2013). Thus, desalination may produce the intended effects to address water scarcity without the expense of importation.

4.2.2 Employment

For the construction of the KBH Plant and its SWD wells, 25 full-time employees were hired. For operation and maintenance, 16 full-time workers are employed at the KBH Plant. It is difficult to determine the staffing needs of the proposed Santa Teresa facility because each desalination plant will have its own conditions that influence personnel requirements. Even though the intended end use for the brackish groundwater facility is municipal drinking water, use of desalinated water lowers the demand for fresh groundwater. Therefore, employment within agricultural communities may be sustained as they may continue use of their groundwater sources for crop irrigation (Raucher & Raucher, 2011).

4.2.3 Capital plus operation & maintenance

It was predicted that the capital cost of the KBH Plant would be $26.5 million for the desalination facility itself, $13.5 million for the deep-well injection disposal and its pipeline, and $32 million for remaining costs such as the drilling of new blend wells and pipelines for a total of $72 million of public investment (Landreth & Sansone, 2004). However, the total capital project cost ended up being about $90 million, with a disposal cost of $19 million. The KBH Plant is a much bigger facility than the one proposed in Santa Teresa, however, with a design capacity of 27.5 MGD compared 5 MDG (Texas Water Development Board, 2014).

The capital and operation cost per year of the treatment system for the proposed Santa Teresa facility was calculated in the preliminary design report based on off-the-shelf material and advisement from the superintendent of the KBH Plant. According to this report, the approximate estimations for the costs involved with a 5 MGD system is presented by treatment type in Table 6.

Table 6: Cost estimations for 5 MGD desalination facility in Santa Teresa, NM. Source: (King et al., 2019)

Treatment Type		Cost Estimation
Reverse Osmosis	Capital	$7.4 million
	Annual operation & maintenance	$3.7 million
	Unit treatment	$2.30/thousand gallons
Electrodialysis	Capital	$10.3 million
	Annual operation & maintenance	$3.8 million
	Unit treatment	$2.50/thousand gallons

However, these values do not include the construction, installation, piping, pumping, or disposal costs (King et al., 2019). Because the EDR system is projected to be more expensive, the RO system is likely to be favored.

4.2.4 Effect on water rates

Any change in water rates for residential and industrial end users will be most impactful for those experiencing poverty. The demographic index of the southern New Mexico and western Texas region is shown in Figure 18. In this case, "Demographic Index" is a measurement of socioeconomics using a combination of percent low-income and percent minority. These are the two demographic factors that were explicitly named in Executive Order 12898 on Environmental Justice. The two numbers are averaged together for each Census block group. The formula is as follows: Demographic Index = (% people of color + % low-income) / 2 (US Environmental Protection Agency, 2022). A census of the population served by the intended brackish water desalination plant is recommended to determine demographic index and the impact of potentially higher water rates on this population on a finer spatial scale. Current water rates for customers of El Paso Water Utilities and the Camino Real Regional Utility Authority (CRRUA), which serves Santa Teresa, can be found in Appendix C. For the El Paso Water Utility ratepayers, a 19 percent increase was projected in 2004 to cover water infrastructure costs like the KBH Plant. According to this facility's EIS, water rates in this area were expected to increase whether the desalination plant was built or not; use of alternate sources would have become necessary at some point, which can be even more expensive (Landreth & Sansone, 2004). Therefore, any water rate increase may not be a direct result of the desalination facility because this option should actually be saving ratepayers' money in the long run. Nevertheless, a rate increase is expected which may result in a larger portion of the area struggling to pay their utility bills, which has been reported with the addition of a desalination facility in other case studies (Richter et al., 2013).

In a model produced by Moore and Negri where a 10% reduction in water supply was simulated, the effect on the national market price would rise for three major crops grown with Bureau of Reclamation water (Moore & Negri, 1992). Thus, enhancing rural economic development in the Mesilla Basin region, which the desalination facility has the potential to do indirectly, may have positive economic results nationally.

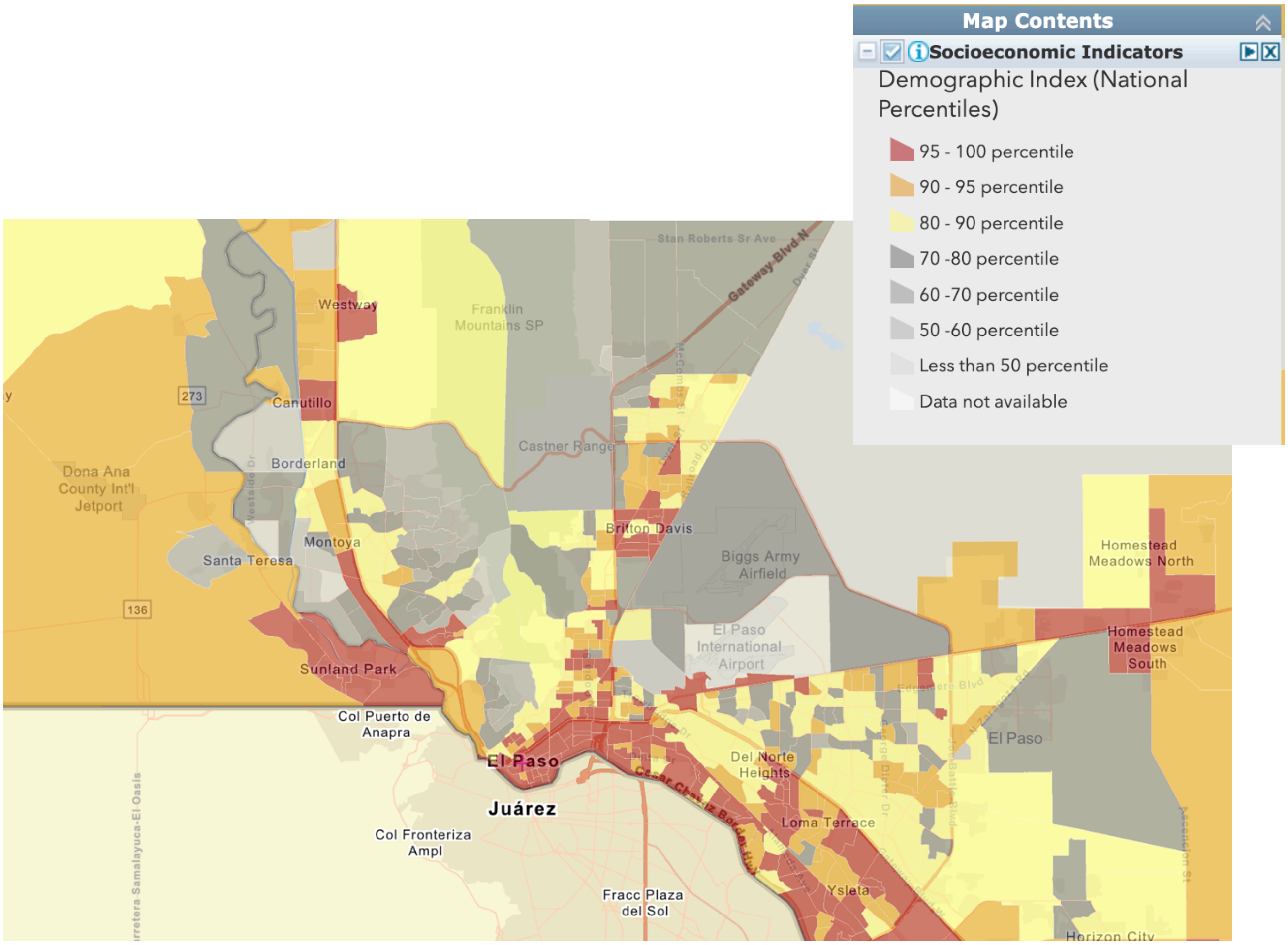


Figure 18: Demographic index by Census block in the southern New Mexico and western Texas regions. Source: EPA Environmental Justice Screening and Mapping Tool (Version 2.0)

4.3 Social Impacts

4.3.1 Public perception

It is important to have the public, especially local communities, involved and informed at every step in the design and building process to promote support, acceptance, and understanding of the desalination project. Allowing a period of public input on documents that detail the project's scope and influence is an important part of this. In promotion of involvement and sharing information, the public had an opportunity to comment on the KBH Plant's Draft EIS. Notices in the local newspaper and public service announcements were published to advertise the invitation for public comment. Several public meetings were held for local organizations and individuals interested in providing written or oral comments (Landreth & Sansone, 2004).

The KBH Plant includes a Learning Center for ongoing public involvement at the facility itself. This space is used for exhibits about the importance of water in a desert environment, convention areas, and other public education.

While concerns about the aesthetics and impact on traffic patterns were raised for the KBH Plant, they should not be a concern in a less populated area like Santa Teresa. The water supply could drive growth that may have aesthetic and traffic pattern impacts, but the desalination plant itself is not expected to have severe impacts in this area. No impact on identified cultural resources is expected. Some Native American groups raised concerns about the deep-well injection site of the KBH Plant, and contact to the appropriate tribes and tribal governments was initiated (Landreth & Sansone, 2004).

4.3.2 Disaster mitigation

A proactive approach to diversify the water supply in the Santa Teresa region of New Mexico with a brackish groundwater desalination facility may help mitigate the varied effects of natural disasters such as drought. The maintenance of a reliable water supply is necessary in the face of disaster for a naturally arid, salty region such as southern NM. Over-appropriation of local water resources has exacerbated the state of the natural geophysical characteristics. The issue of water scarcity is complex and the future is uncertain, which makes evaluating disaster vulnerability essential for the health of the populations that live here.

Even though the intended end use for this desalinated water is for municipal and industrial water supply, use of desalinated water lowers the demand for fresh groundwater and the consequences affect all sectors. Furthermore, the cyclical nature of municipal water uses ensures that this water is not necessary consumed, as it returns to the environment (Richter et al., 2013). By introducing a new source of water, groundwater is not only conserved, but supplemented.

The agriculture industry is of significant importance because it is one of the largest water users in arid regions like southern NM and the economic value of water used here is low compared to other sectors. However, this sector is important to protecting food security for everyone, including those most vulnerable, even though up to two-thirds of the food produced in rural regions go to feed those in cities (Ward et al., 2018). This means that rural water usage is actually an indirect usage of urban populations who rely on these sources for sustenance (Blackhurst et al., 2010). According to Ward et al. (2018), these rural residents on both sides of the international border “live in at-risk and disadvantaged communities that lack access to safe and reliable water-services. Furthermore, these communities are vulnerable and ill-prepared to cope with growing risks of severe drought and climate change” (Ward et al., 2018). The valuable Mesilla Basin aquifer is resistant to drought and seasonal change because it is a deep water reserve from outside of the hydrologic cycle. This makes it less vulnerable to natural disaster and very important to disaster mitigation (Raucher & Raucher, 2011). Furthermore, water conservation in irrigation can actually lead to increased water use, rendering this strategy counterproductive (Ward & Pulido-Velazquez, 2008). What needs to be considered with the implementation of desalination in this area is that consumption of the Mesilla Basin may come quickly without proper cooperation and management between New Mexico, Texas, and Mexico (Ward et al., 2018).

4.4 Environmental Impacts

4.4.1 Effect on local ecology

The construction of the desalination facility itself may have a minimal impact on the local ecology. This impact depends on the location of the plant and its supporting infrastructure. The KBH Plant disturbed about 227 acres of land. Any disturbance of arroyo vegetation should be avoided to prevent soil erosion and other effects. It is recommended to spray soil with water during construction operations to reduce dust pollution. Adverse environmental impacts may need to be monitored by law for the right to use the proposed plot of land. The land for the KBH Plant was permitted for use by the Fort Bliss Army Base, leading them to implement stringent environmental compliance monitoring that may be valuable to model in future endeavors such as the Santa Teresa facility (Landreth & Sansone, 2004).

Ground disturbance from the construction of the desalination facility and concentrate disposal risks loss of vegetation and habitats for wildlife. There is also a risk of groundwater contamination from the concentrate disposal wells. A comprehensive list of sensitive species in the Santa Teresa area (endangered and threatened) will need to be compiled and evaluated as to whether the region of influence may disturb these plants and animals. However, this area is the heart of the Chihuahua desert, where there is a relatively low density of wildlife. Desert shrubland exists in this region today and vegetation has already been disturbed (P. King, personal communication, August 14, 2020). Any chemical storage tanks include a 110 or 150% volume secondary containment structure to prevent spilling from leaks or tank failures (Landreth & Sansone, 2004).

4.4.2 Energy consumption/GHG emissions

Construction of the facility itself, as well as construction of the supporting facilities such as the brackish and blend wells, pipelines, and disposal sites, would increase power consumption for a finite period of time, according to data from the KBH Plant. This 18-month construction period may slightly increase air pollution emissions (Landreth & Sansone, 2004).

Operational air emissions are considered minor and will not require permitting. The bulk of air emissions will result from energy use. The KBH Plant includes sustainability measures such as energy-efficient motors, energy recovery turbines, energy-efficient glass, and waterless urinals. An estimation of 4.5 megawatts (or megavolt-amperes) is the peak electrical demand of the KBH Plant's water wells and pipeline pumps. This does not include the SWD wells, which would be utilized for disposal of the concentrate (Landreth & Sansone, 2004). This would require hook up to either the El Paso Electric Company, solar panels, or gas/diesel generators. Because the electrical access to Santa Teresa is lower than that to El Paso, the increase in power consumption from the plant will need to be analyzed precisely to ensure that service can be provided in this area. Photovoltaic panels (solar) is an option that is being considered to power the facility, however this would require space for a solar farm. Whether the pumping and deep well injection of concentrate would be passive or pressurized will be addressed in test wells. Should the pumping be passive, these power requirements would be negligible to the power requirements for the facility.

4.4.3 Disposal (hazardous waste & safety)

The concentrated brine removed from the feed water in the desalination process, called concentrate, is disposed of through an underground pipeline to a 2,000-ft deep well injection site at the KBH Plant. The pipeline material of HDPE or PVC is preferred to prevent corrosion, reduce cost, and ensure ease of installation. Depth of the pipeline and thickness of the walls must be determined based on the maximum pressure the pipes could experience from military vehicles to prevent breakage. Other hazardous materials transported to and from the facility for other parts of the water treatment process slightly increase the risk of a spill. Hazardous chemical cargo routes are both via truck and the Union Pacific railroad (Union Pacific, n.d.). Otherwise, these chemicals will be stored and used onsite. No special hazardous waste storage or permits are expected (Landreth & Sansone, 2004).

Should there be a leak or break in the pipeline that travels from the desalination treatment facility to the SWD, contamination of the soil and shallow aquifer may result. Pressure monitors may be installed along concentrate pipes to detect a leak or break. Regular monitoring must be in place to obtain the permit for this type of structure as well as an alarm when a leak is detected. Emergency action plans may be set in place should a leak or equipment failure occur. If the location of the SWD is near a geothermal resource, the usability of this resource in the future may be impacted because of the relatively cool temperature of the concentrate. Deep-well injection has been linked to increased seismicity in some areas, although this risk is reportedly low in this area (Landreth & Sansone, 2004).

Alternative methods of concentrate disposal include solar gradient ponds to reach zero liquid discharge and secondary treatment with volume-reduction technologies such as a membrane concentrator. Appropriate concentrate disposal methods need to be evaluated for the new, smaller facility in Santa Teresa. In addition, used flushing permeate, antiscalants, and antifouling chemicals would be disposed of through a sanitary sewer rather than in the concentrate disposal.

It is predicted that petroleum, oil, lubricants, paints, and solvents would be located on site during construction of the desalination facility, similar to those found at any construction site of an industrial facility. Effective procedures have been established for the storage and use of chemicals needed for water treatment as these are standard for all conventional treatment facilities. Sulfuric acid, an antiscalant (phosphoric/phosphonic acids; no occupational exposure values), sodium hydroxide, a disinfectant (sodium hypochlorite), and a corrosion inhibitor (sodium hexametaphosphate) are the chemicals used at the KBH Plant. These chemicals are not unique to desalination facilities and are commonly found in water treatment plants across the U.S. (Raucher & Raucher, 2011).

4.5 Discussion & Conclusions

Table 7 shows the evaluation of criteria based on the investigations illuminated in the case study. Where specific quantitative values could not be determined, a categorical value was assigned based on the following scale: exceptionally negative, moderately negative, neutral/mixed, moderately positive, and exceptionally positive. These variables are all weighted equally, however, this can be modified in the future should new information about stakeholder priorities arise.

Table 7: Evaluation criteria for desalination case study.

Criteria	Ranking/Value
Product water quality	Moderately positive
Source (feed) water quality	Moderately negative
Longevity of source	Moderately positive
Effect on water resources	Exceptionally positive
System maintenance & operation complexity	Neutral/mixed
Return on investment	Moderately positive
Employment	Moderately positive
Capital plus operation and maintenance	$0.082/bbl or $2.30/thousand gallons
Effect on water rates	Neutral/mixed
Public acceptance	Neutral/mixed
Disaster mitigation	Exceptionally positive
Effect on local ecology	Neutral/mixed
Energy consumption/GHG emissions	Moderately negative
Disposal (hazardous waste & safety)	Moderately negative

The value for “Product water quality” was determined because of the high quality results found in Table 6. Because this water will be directly consumed, the product quality standards are high. “Source water quality” was assigned a ranking of moderately negative because of the constituents found in the source water that do not meet regulation (Table 7). However, these are chemicals that may be effectively removed with RO treatment technology (Table 4).

The “Longevity of source” value is based on the fact that the source is very reliable but essentially finite. The “Effect on water resources” value is based on the idea that the benefits due to reduced use of freshwater sources and increased use of water outside of the hydrologic cycle may be substantial on water resources. “System maintenance and operation complexity” is based on the fact that the collection and distribution will be standard, but the treatment technology itself is fairly complicated compared to traditional water treatment technology. Experienced personnel may be required for operation.

“Effect on water rates” is based on the fact that rates may increase for ratepayers, despite that this is ultimately unavoidable no matter the water resources investments made locally and that the money could come back to more impoverished regions by enhancing rural economic development.

The “Public perception” ranking comes from the relatively uncontroversial source of this water and the potential for acceptance through public outreach and involvement. The “Effect on local ecology” is mixed because of the potential for both better water resource allocation and contamination. Drinking water quality requires a lot of energy relative to traditional water treatment, which is factored into the “Energy consumption/GHG emissions” rankings. Although the technology is established, the “Disposal (hazardous waste & safety)” ranking is based on the unknowns involved with concentrate disposal.

CHAPTER 5: MULTI-CRITERIA DECISION MAKING (MCDM) ANALYSIS RESULTS & DISCUSSION

5.1 Results

In the Visual PROMETHEE software, the 5-point qualitative evaluation system is represented as very bad, bad, average, good, and very good. The values are translated into these categories (from exceptionally negative, moderately negative, neutral/mixed, moderately positive, and exceptionally positive) for the qualitative criteria. The completed PROMETHEE model is found in Appendix D. Figure 19 shows the overall preference ranking output by the PROMETHEE software.

The results show that desalination is the most preferred non-traditional water resource project to be pursued in southern NM, followed by Project 2 (clean brine quality) in the PW case study, Project 3 (drinking quality), and Project 1 (irrigation quality). However, the criteria were all weighted evenly for this run of the model. Some criteria more easily cause a change in ranking based on the weight, especially those in the Economics section. The “Visual Stability Intervals” task within the PROMETHEE software shows this sensitivity by displaying how the Phi multicriteria net flow scores change with the weight (Figures 20 and 21). For these criteria, assigning weights beyond the stable range would change the preference ranking. All of the other criteria not shown in these Figures were completely stable regardless of the weight.

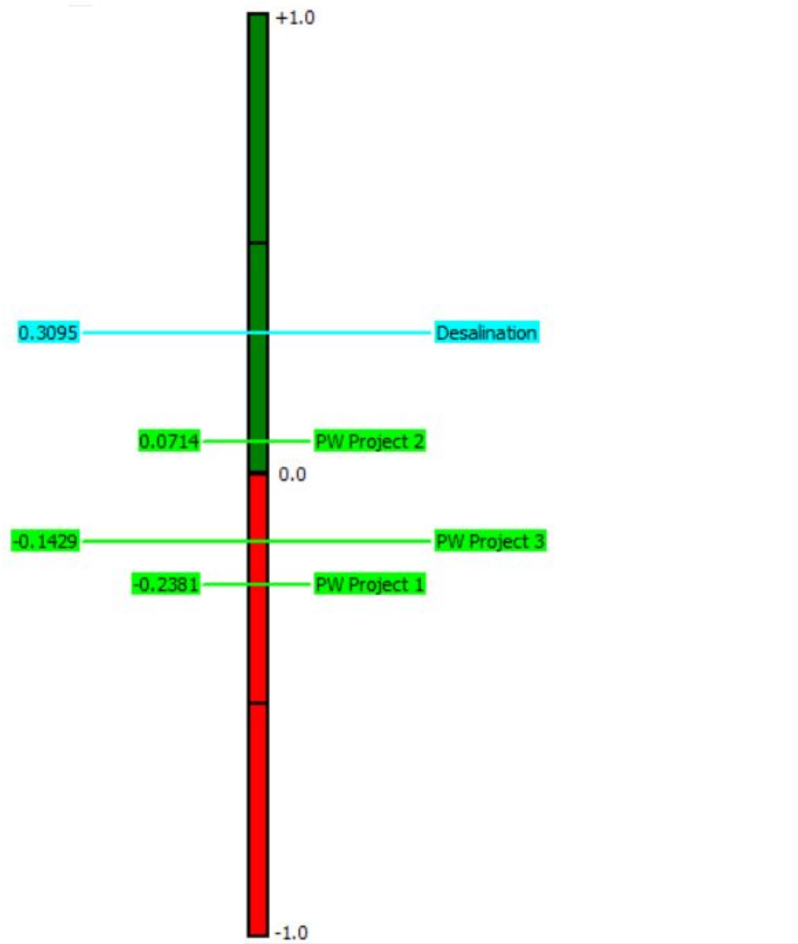


Figure 19: Ranking of projects by PROMETHEE software.

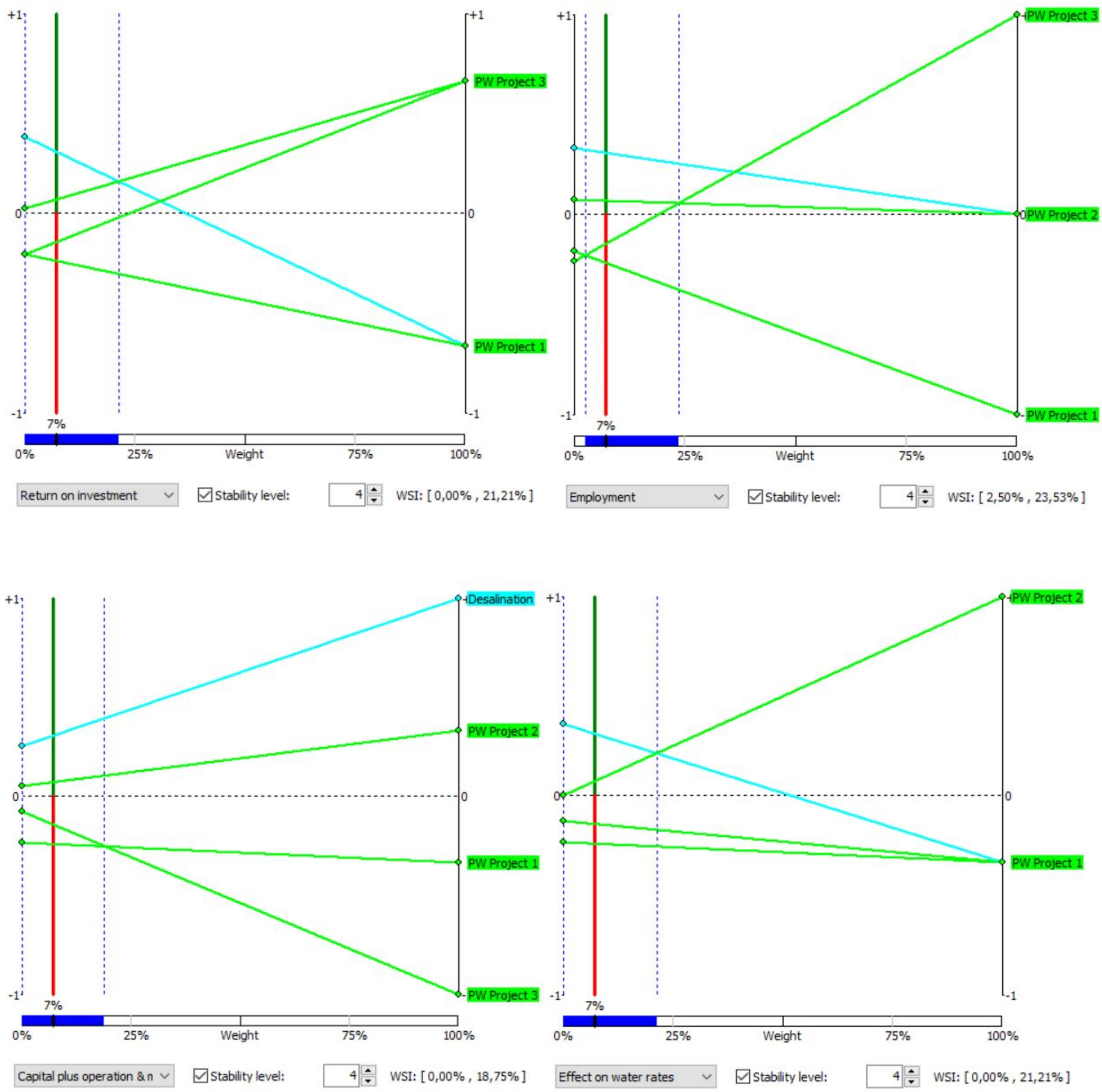


Figure 20: Visual Stability Intervals for Economic criteria.

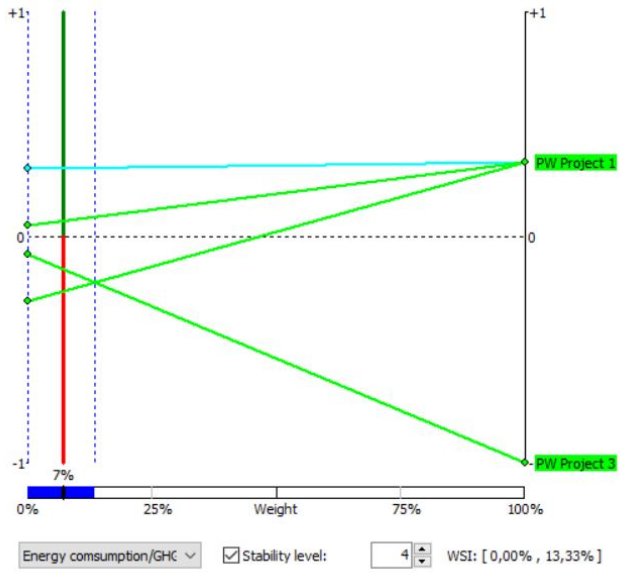


Figure 21: Visual Stability Interval for Environmental criteria.

5.2 Discussion & Conclusions

To address the increasing water scarcity in the southwest United States, the recycling of wastewater from HF operations is being proposed as an innovation to meet demand in Lea and Eddy counties, New Mexico. This type of water, called produced water, will be minimally treated for its intended purpose rather than treated to drinking water standards, to reduce energy requirements and expenses. In addition to PW reuse, desalination of deep groundwater aquifers in Santa Teresa, NM has also been proposed. Both of these opportunities are explored as case studies in this paper.

Some major conclusions about the PW case study were established. The risk of releasing contaminants and “unknown” chemicals of concerns to the environment, despite the possibility of very effective treatment, is a cause of major concern. Different beneficial reuse scenarios may have different potential routes of exposure and impacts on public health and environment. The quality of the raw PW is one of the biggest hurdles to adoption of beneficial reuse, mainly because of the uncertainty involved. This has consequences in social, economic, and environment aspects. The application of extremely accurate, precise, and sensitive analytical techniques may help overcome this difficulty. The success of PW reuse may hinge on the ability to fully comprehend the source and product water qualities.

Furthermore, the dependability of the PW resource is not quantifiable because it is dependent on an industry, which is intrinsically unpredictable. However, Appendix E shows the steadiness of the industry with volume of oil and gas sold over time. PW volumes will help offset freshwater use in a meaningful way for the time it is viable. The complicated transportation and collection infrastructure that needs to exist for these PW reuse projects to be successful is a major task to be designed and implemented. The pipelines already in place from wellheads to SWD wells may be extremely helpful in simplifying this process. Therefore, a new analysis taking into consideration the quality and quantity of the PW consolidated at each SWD well may provide valuable information about optimal locations and operation conditions of treatment facilities. It is clear that PW reuse has the potential to be economically sound. The most practical uses are those where the water rate is not significantly higher than business as usual.

Perceptions that already exist of PW reuse are overwhelmingly negative, however there is a potential of change in these views that may come about based on recommendations from stakeholders. There is potential for both better water resource allocation and contamination. Although more intensive treatment may open up new beneficial reuse opportunities, this requires much more energy than the other PW reuse projects. Overall, there are unknowns involved with this case study, but if overcome, could lead to a successful, beneficial source of usable water for southern NM.

The desalination case study was investigated just as thoroughly. Because this water may be directly consumed as a supplemental municipal potable supply, the product quality standards are high. There are constituents found in the source water that do not meet regulation, but the treatment technologies available are capable of producing an appropriate effluent (Table 4 and 5).

The brackish groundwater source is very reliable, but fixed in volume. The benefits due to reduced use of freshwater sources and increased use of water outside of the hydrologic cycle may be substantial on water resources. The collection and distribution will be standard and much of this infrastructure is already established. However, the treatment technology itself is fairly complicated compared to traditional water treatment technology, which could be a challenge for operators.

Charges may increase for ratepayers. This is ultimately unavoidable no matter the water resources investments made locally. Enhancing rural economic development could ensure a return of funds to more impoverished regions. By investing in a solar farm to power the desalination facility, both the environmental and social impacts could be positively influenced.

This water resource is relatively uncontroversial source and the potential for acceptance through public outreach and involvement is high. There is again a potential for both better water resource allocation and contamination. Because of the nature of the source water, drinking water quality requires a lot of energy relative to traditional water treatment. The success of this option is dependent on the economic arrangement and established technology.

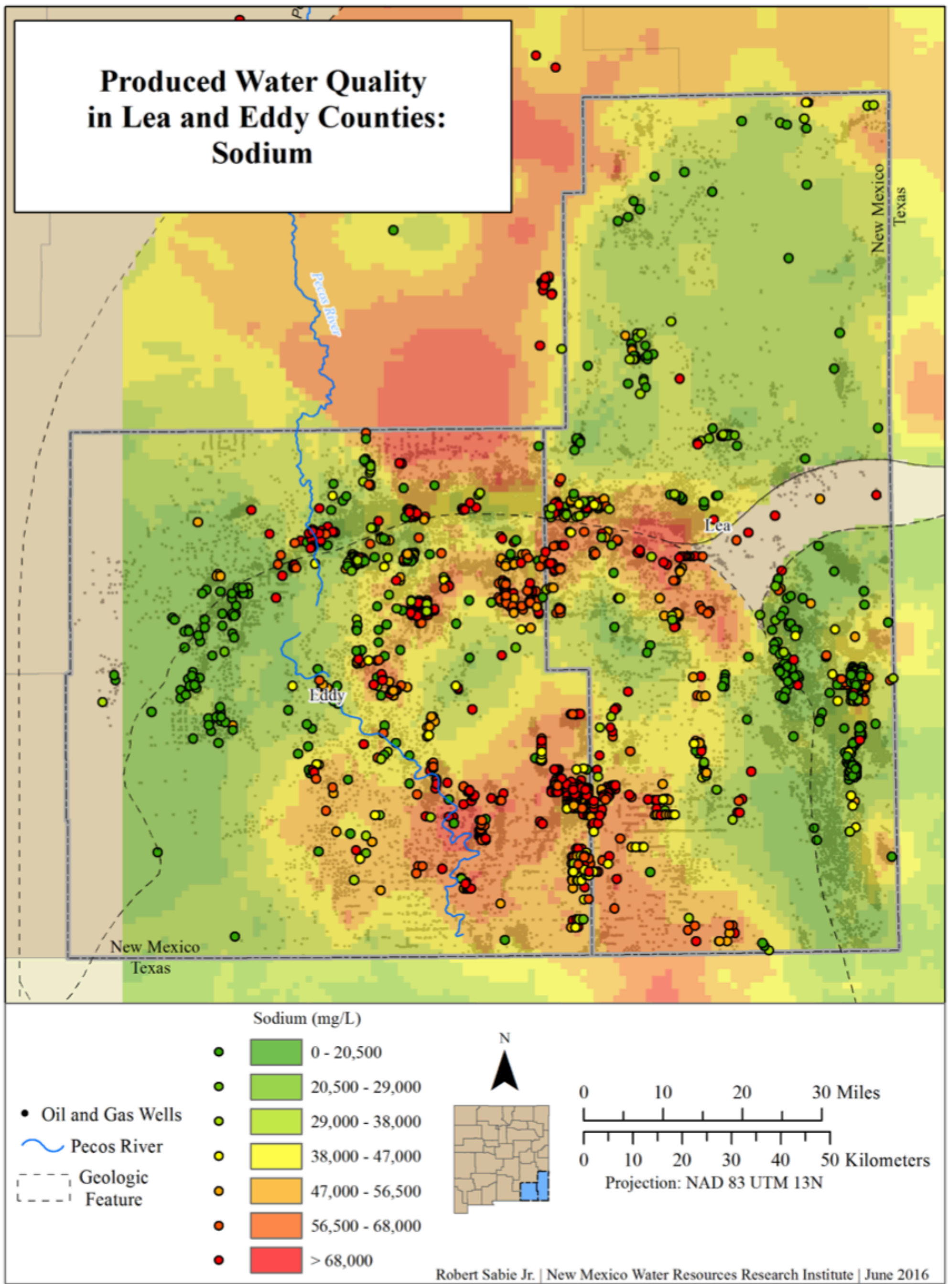
This analysis considers social, economic, and environmental aspects of these projects, as well as the feasibility of system performance. The criteria selected have been evaluated per project and the results are run in an MCDM analysis software called PROMTHEE. The results show that desalination is the most preferred non-traditional water resource project to be pursued in southern NM, followed by Project 2 in the PW case study, which treats the water to a clean brine standard. Project 3, drinking water quality PW, and then Project 1, irrigation quality PW, came in last.

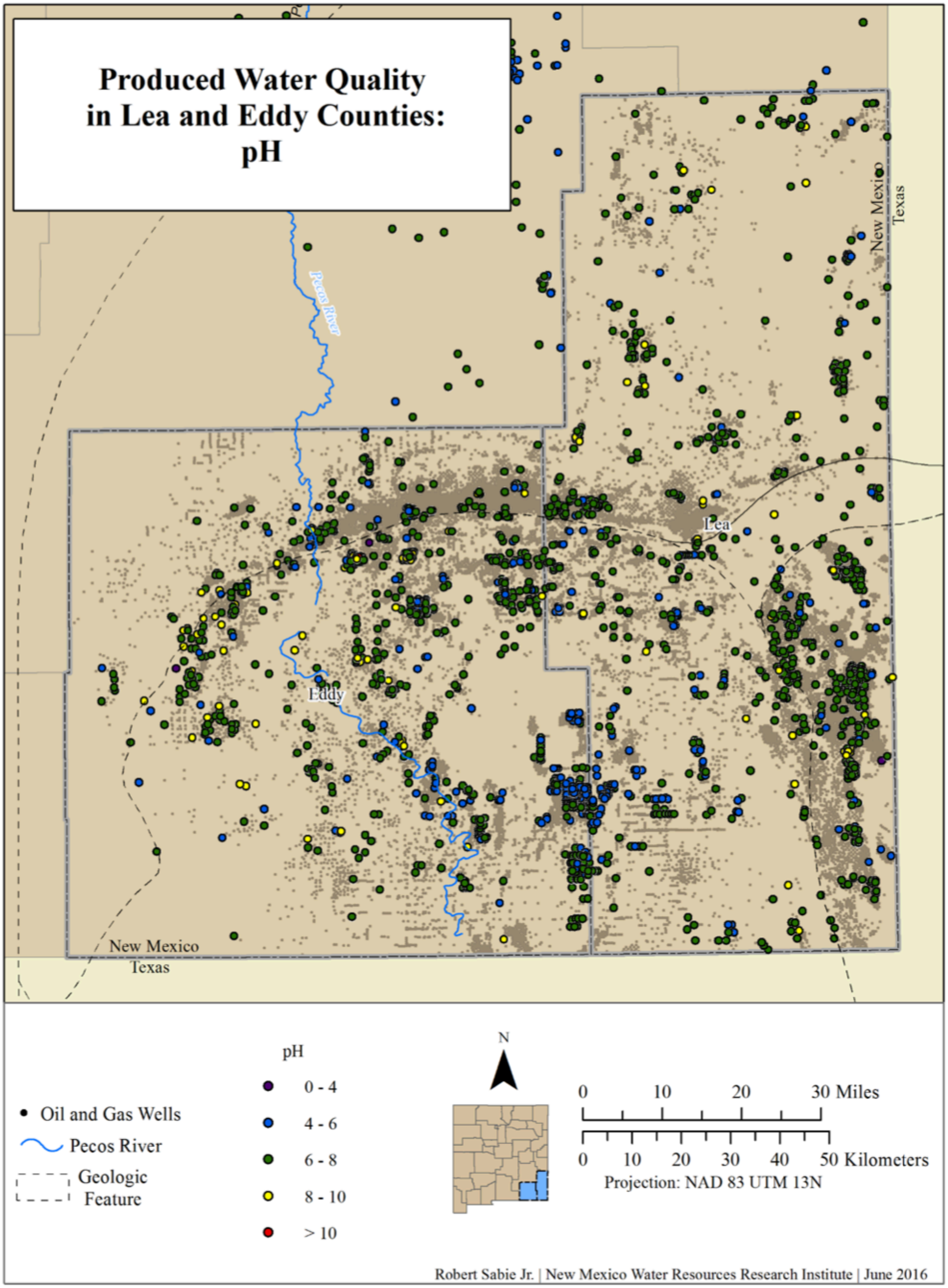
This MCDM analysis is sensitive to a couple factors. The weight of certain criteria affects the ranking output. Namely, the subcategories “Return on investment,” “Employment,” “Capital plus operation and maintenance,” “Effect on water rates,” and “Energy consumption/GHG emissions” were sensitive to weighting. The overall ranking of the projects would be susceptible to change should the weight of these subcategories change. Additionally, some interpretation is required to assign a value to each criteria based on the given evidence. There are instances where a different qualitative value could be argued based on the same collected information. As more concrete design systems and relevant data become available, better qualitive values or exact quantitative measures may replace the preliminary value assigned to these case studies.

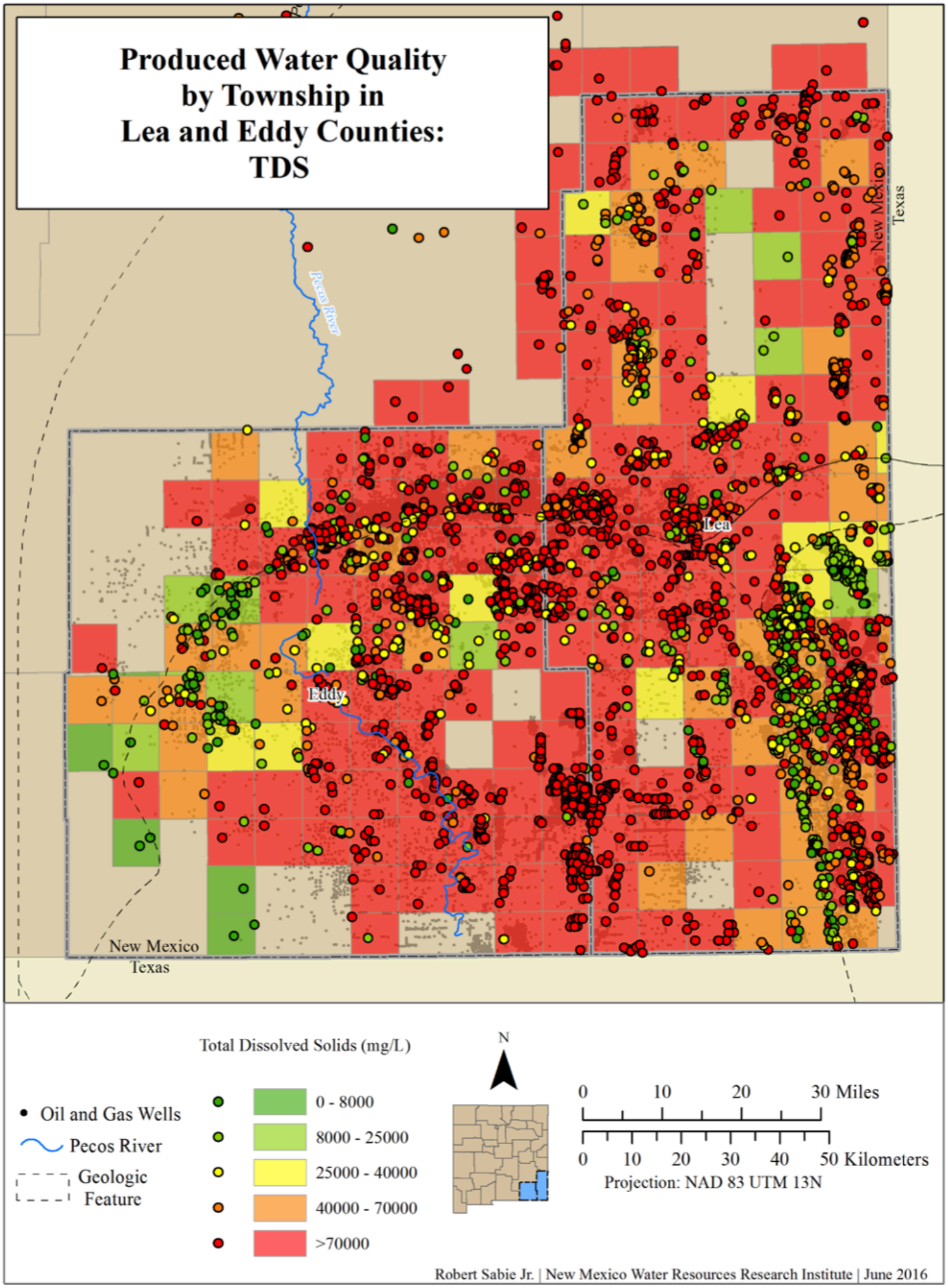
This data and the MCDM results may benefit stakeholders and partners involved with these case studies. Not only will this analysis aid in the decision making about where to invest to ensure water sustainability, but it will also provide clarity of the details of effects within the communities at hand. Although this analysis delivers a preliminary assessment of the variety of impacts that water resources engineering will cause, there is much more to be discovered.

APPENDIX A

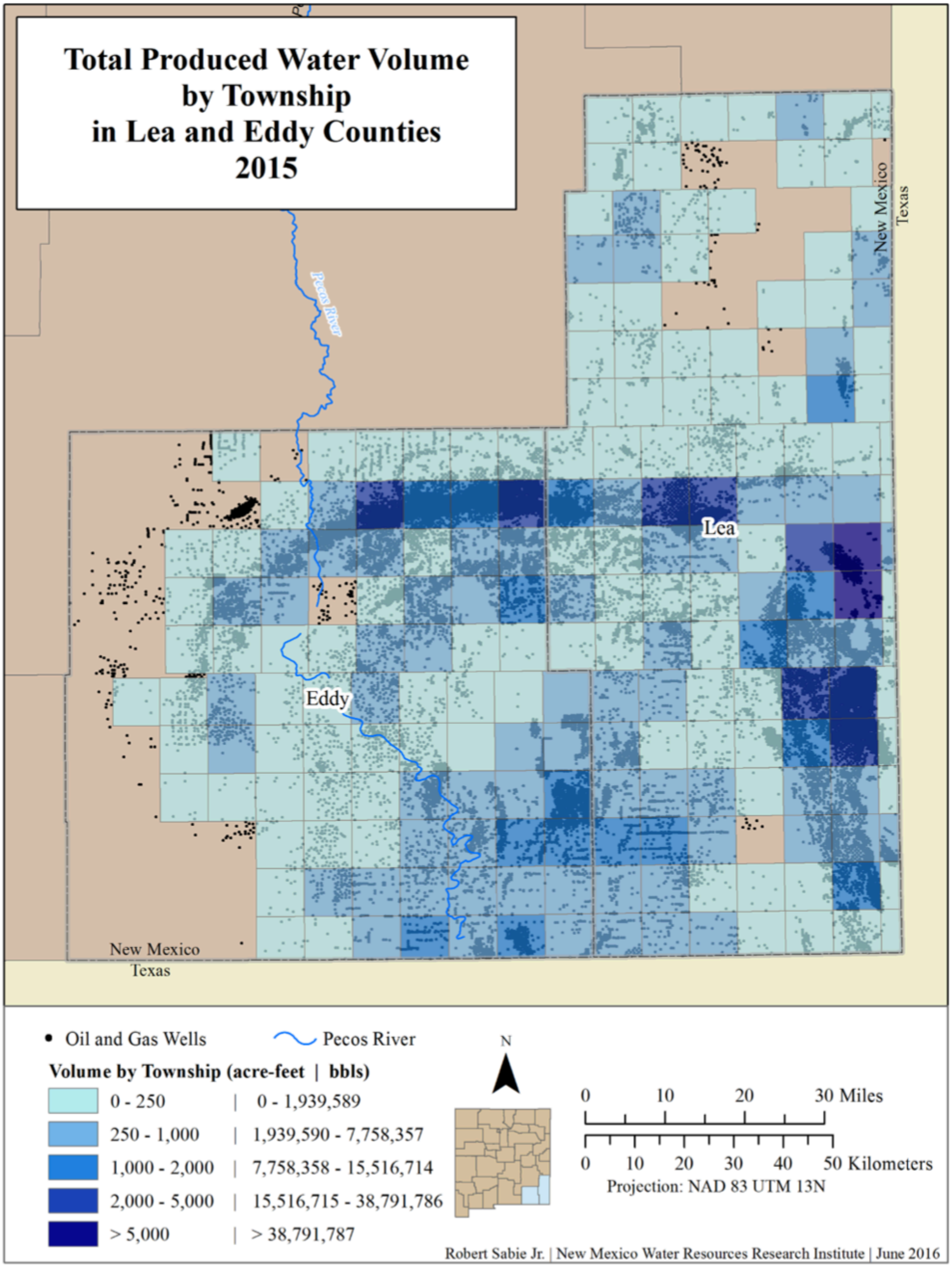
PRODUCED WATER QUALITY AND VOLUME MAPS FOR EDDY AND LEA COUNTIES
CARTOGRAPHY BY ROBERT SABIE, JR.
NEW MEXICO WATER RESOURCES RESEARCH INSTITUTE
JUNE 2016

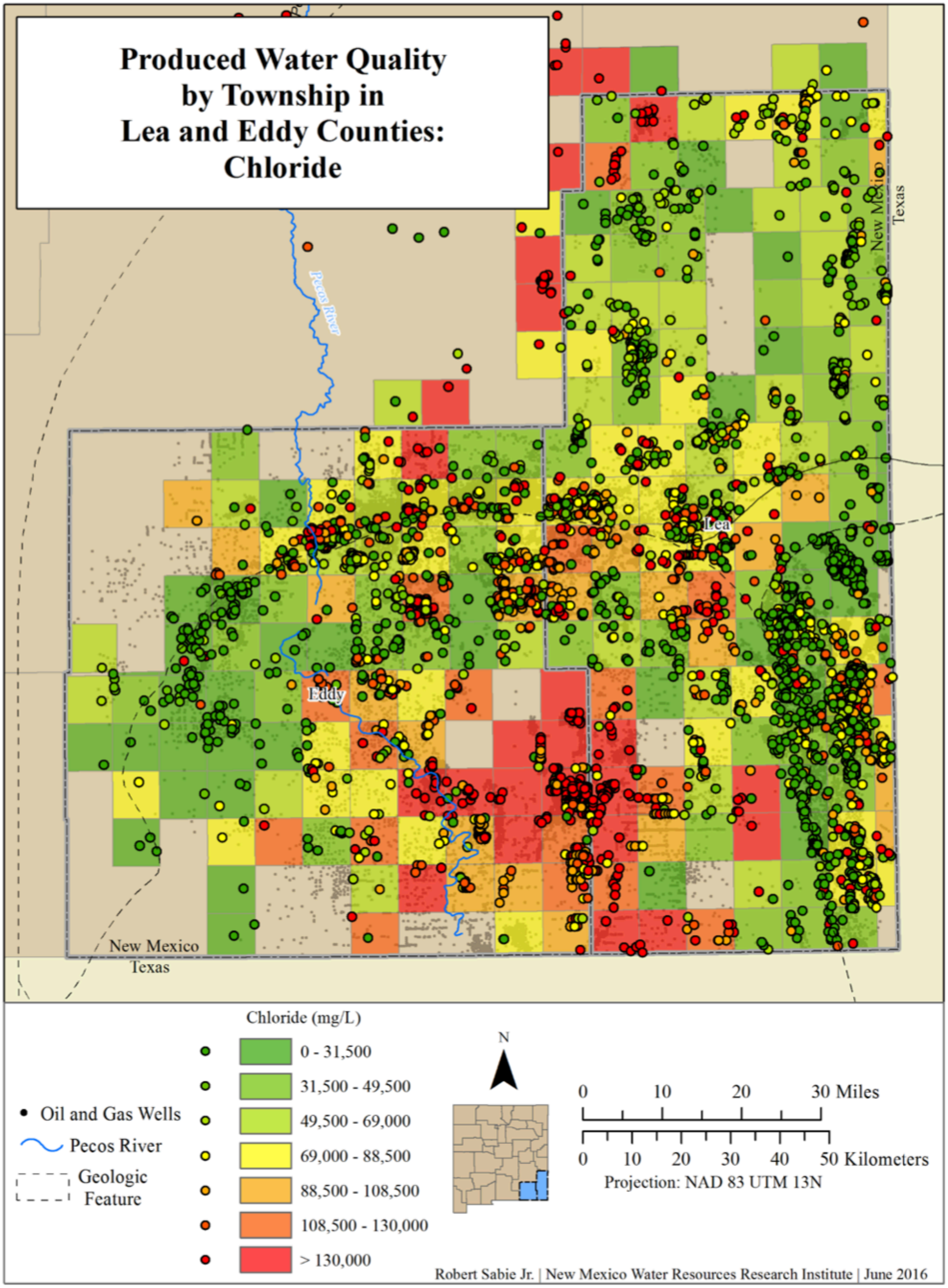



Produced Water Quality
in Lea and Eddy Counties:
pH
Pecos River
Lea
Eddy
New Mexico
Texas
New Mexico
Texas
Oil and Gas Wells
Pecos River
Geologic Feature
pH
0 - 4
4 - 6
6 - 8
8 - 10
> 10
N
0 10 20 30 Miles
0 10 20 30 40 50 Kilometers
Projection: NAD 83 UTM 13N
Robert Sabie Jr. | New Mexico Water Resources Research Institute | June 2016

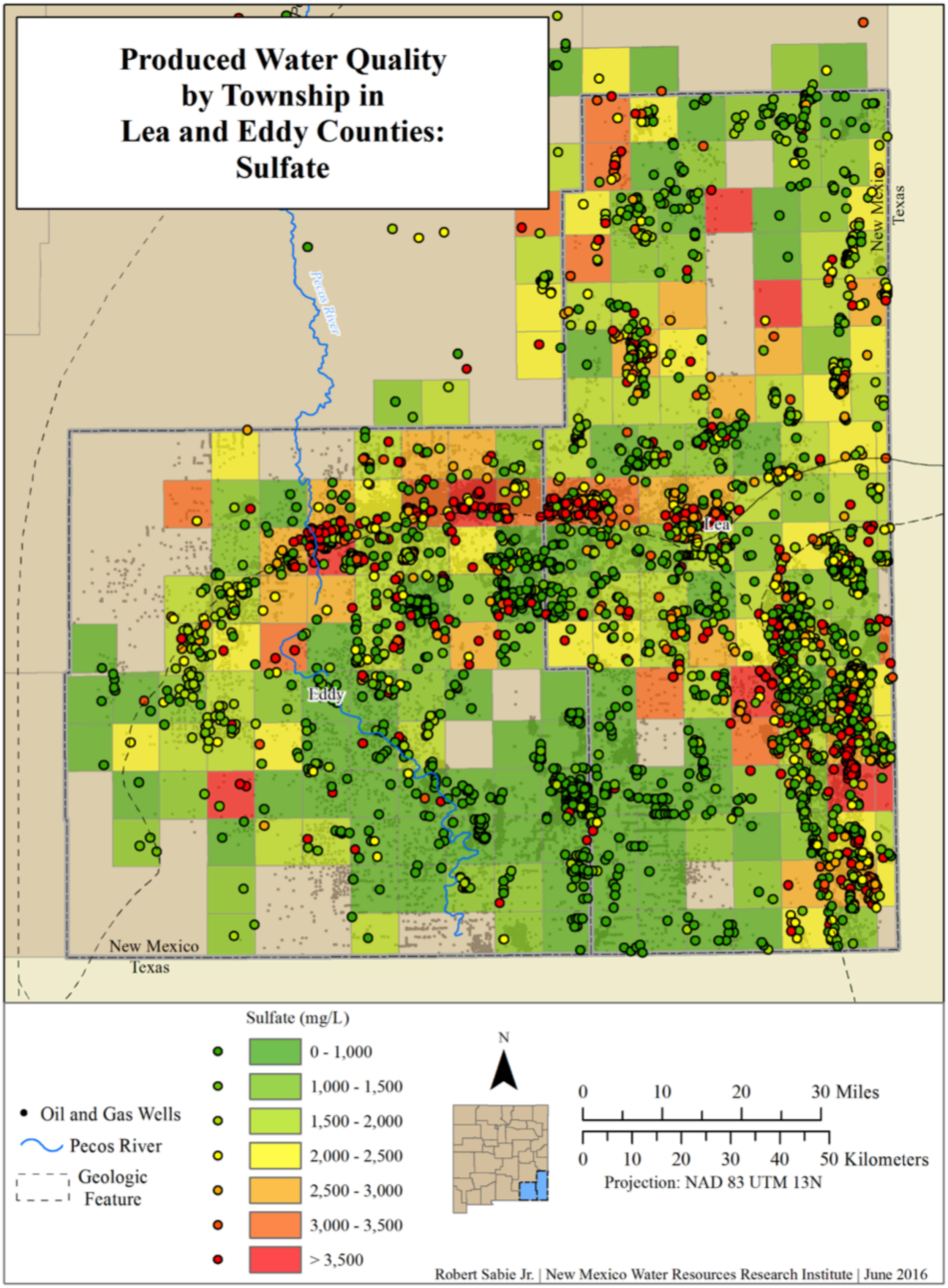


Produced Water Quality
by Township in
Lea and Eddy Counties:
TDS
Pecos River
Lea
Eddy
New Mexico
Texas
New Mexico
Texas
Total Dissolved Solids (mg/L)
Oil and Gas Wells
Pecos River
Geologic Feature
0 - 8000
8000 - 25000
25000 - 40000
40000 - 70000
>70000
N
0 10 20 30 Miles
0 10 20 30 40 50 Kilometers
Projection: NAD 83 UTM 13N
Robert Sabie Jr. | New Mexico Water Resources Research Institute | June 2016


Total Produced Water Volume
by Township
in Lea and Eddy Counties
2015
Pecos River
Lea
Eddy
New Mexico
Texas
New Mexico
Texas
Oil and Gas Wells
Pecos River
Volume by Township (acre-feet | bbls)
0 - 250 | 0 - 1,939,589
250 - 1,000 | 1,939,590 - 7,758,357
1,000 - 2,000 | 7,758,358 - 15,516,714
2,000 - 5,000 | 15,516,715 - 38,791,786
> 5,000 | > 38,791,787
N
0 10 20 30 Miles
0 10 20 30 40 50 Kilometers
Projection: NAD 83 UTM 13N
Robert Sabie Jr. | New Mexico Water Resources Research Institute | June 2016

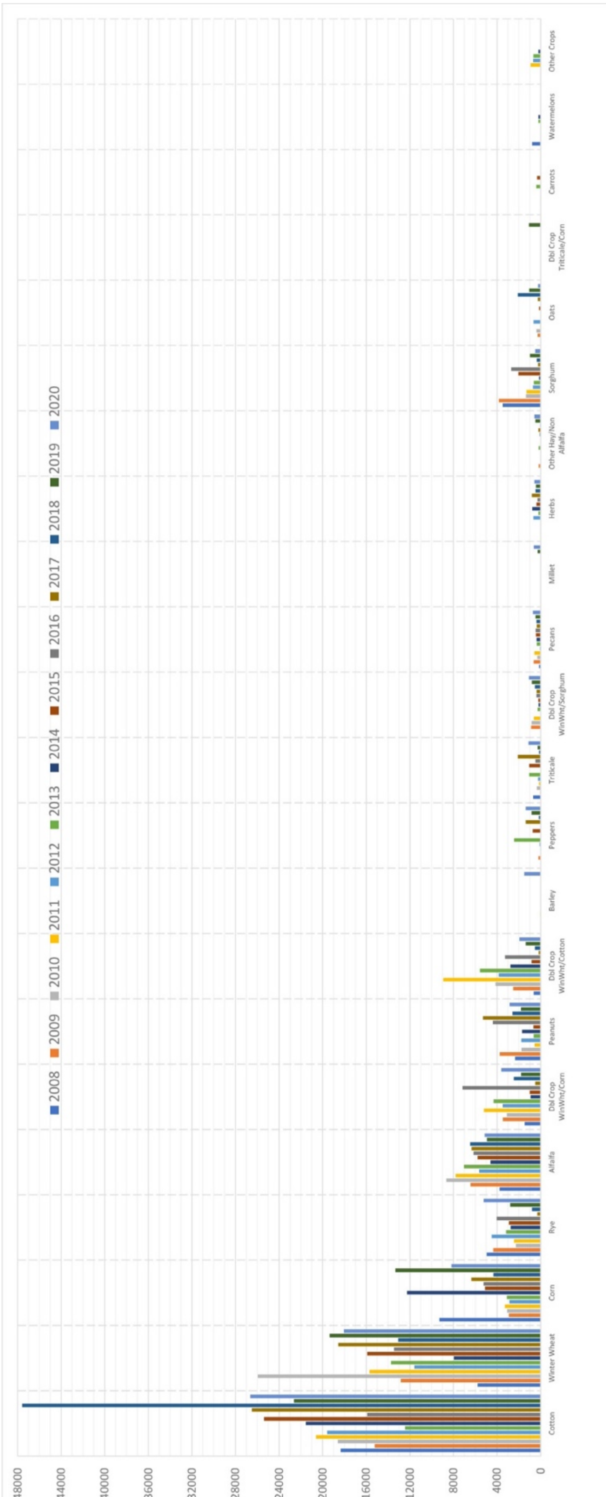


Produced Water Quality
by Township in
Lea and Eddy Counties:
Chloride
Pecos River
Lea
Eddy
New Mexico
Texas
New Mexico
Texas
Chloride (mg/L)
0 - 31,500
31,500 - 49,500
49,500 - 69,000
69,000 - 88,500
88,500 - 108,500
108,500 - 130,000
> 130,000
Oil and Gas Wells
Pecos River
Geologic
Feature
N
0
10
20
30 Miles
0
10
20
30
40
50 Kilometers
Projection: NAD 83 UTM 13N
Robert Sabie Jr. | New Mexico Water Resources Research Institute | June 2016

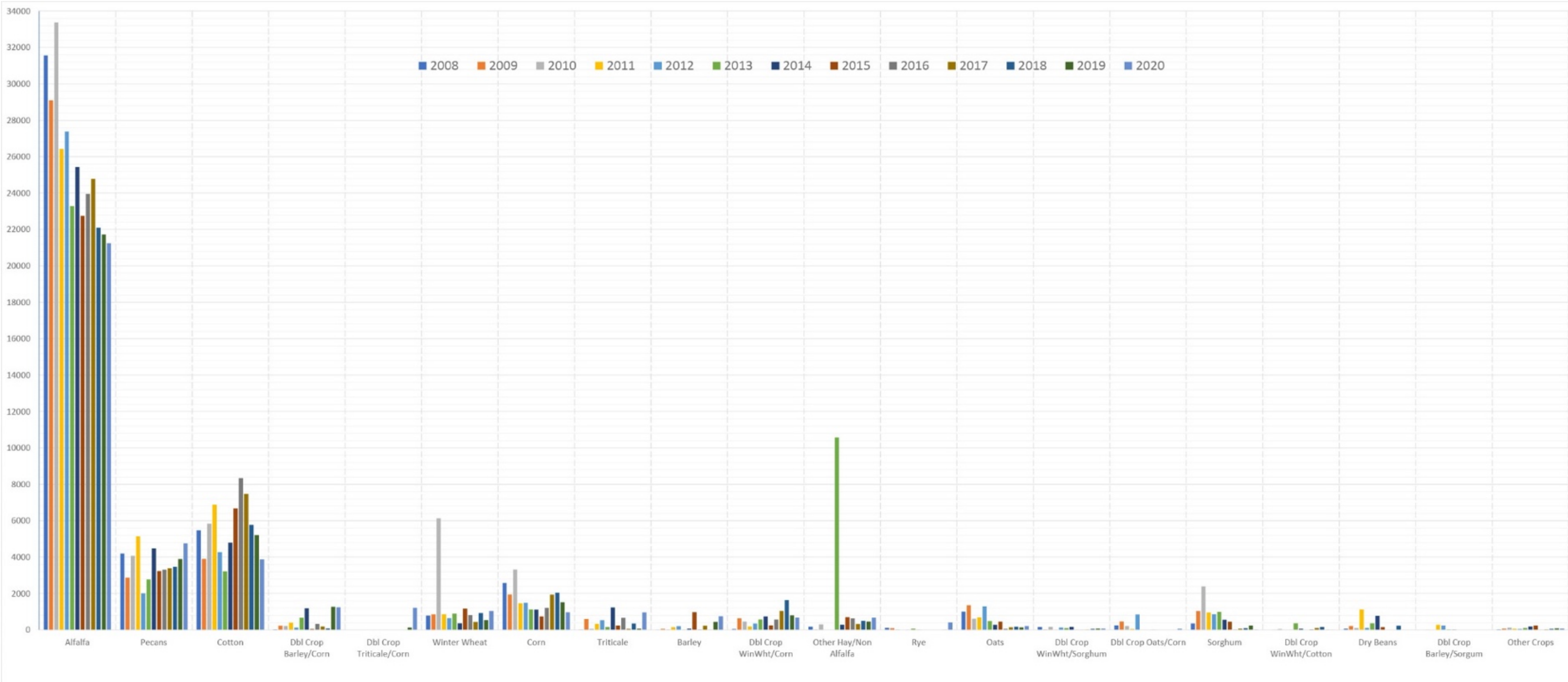


Produced Water Quality
by Township in
Lea and Eddy Counties:
Sulfate
Pecos River
Lea
Eddy
New Mexico
Texas
Sulfate (mg/L)
0 - 1,000
1,000 - 1,500
1,500 - 2,000
2,000 - 2,500
2,500 - 3,000
3,000 - 3,500
> 3,500
Oil and Gas Wells
Pecos River
Geologic Feature
N
0 10 20 30 Miles
0 10 20 30 40 50 Kilometers
Projection: NAD 83 UTM 13N
Robert Sabie Jr. | New Mexico Water Resources Research Institute | June 2016

APPENDIX B



Acreage by crop type in Lea County over time. Data sourced from USDA Cropland Data Layers.



Acreage by crop type in Eddy County over time. Data sourced from USDA Cropland Data Layers.

APPENDIX C

El Paso Water Utility rates as of February 28, 2022:

Meter Size	Minimum Monthly Bill*
Less than 1"	$8.70
1	$13.56
1 1/2"	$23.26
2"	$27.98
3"	$55.87
4"	$83.40
6"	$126.44
8"	$216.59

These values are based on size of meter with a 400 cubic feet (4CCF's) volume allowance.

Charges for water service are based on the customer's average winter consumption (AWC), which is the average of the amount of water used during the previous December, January, and February billings. (Customers who have not established an AWC are assigned an AWC based on meter size for their classification.) Up to 400 cubic feet (CCF) are included in the minimum charge for residential customers.

Block	Charge per CCF*	Volume Charge
1	$2.62	Over 4 CCF-150% of AWC
2	$6.20	Over 150%-250% of AWC
3	$8.86	Over 250% of AWC

Non-residential customer rates do not include 400 cubic feet allotment in minimum monthly charges.

Average Winter Consumption (AWC) is the average amount of water used during the most recent, December, January and February billing periods. Any customer that at the time of service has not established an AWC will be assigned the class average AWC by meter size for their customer classification.

All single family residential accounts with ¾" to 2" meters who have an AWC lower than the average AWC for ¾" single family residential class will be assigned the ¾" single family residential class AWC.

Properties located outside the El Paso city limits are charged 1.15 times the rate for the same service to customers whose properties are inside the city limits.

FY2020 CRRUA RATE & FEE SCHEDULE

Effective 07/01/2019

Fiscal Year 2020 - 07/01/2019--06/30/2020

RESIDENTIAL RATE AND FEE SCHEDULE

ADMINISTRATIVE CHARGES AND FEES

Administrative Set - Up Charge	$150
Non-Compliance to Mandatory Connection (>6 months to connect)	$300
Customer Deposit	$100
Late fee on outstanding balances remaining on the 5th day after the due date.	$5
Reconnection within regular works hours after disconnection due to unpaid balances	$50
Reconnection outside regular work hours after disconnection due to unpaid balances	$75

WATER RATES

RESIDENTIAL

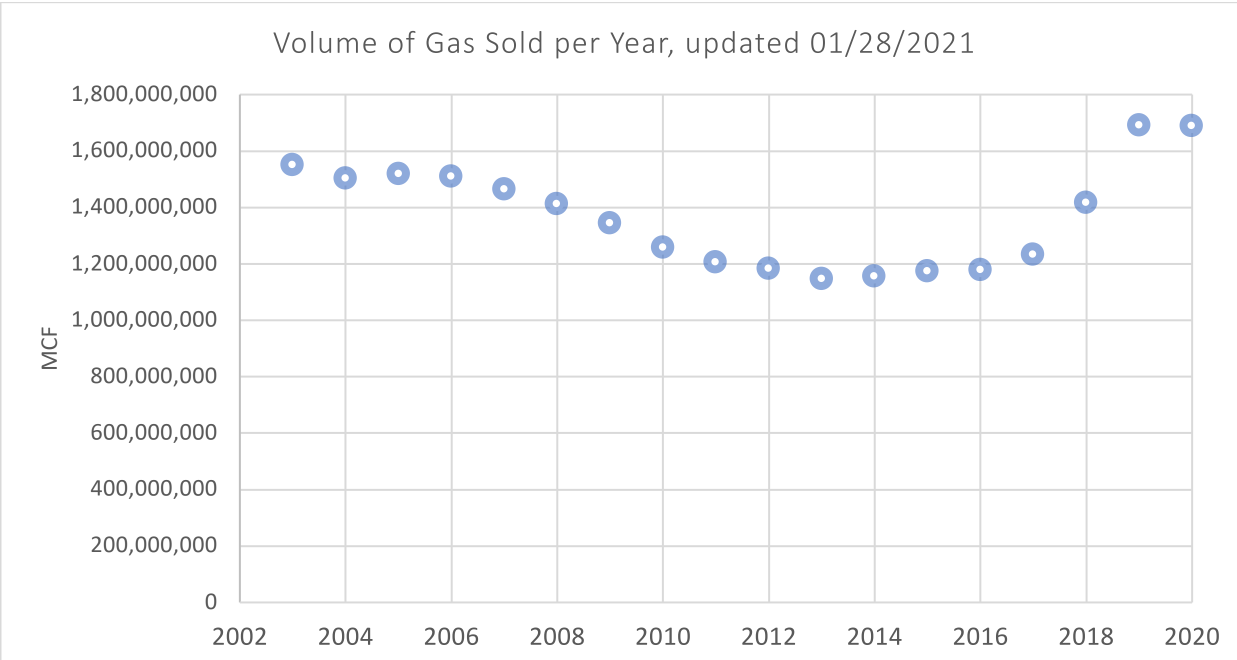
RATE	DESCRIPTION
$15.00	MINIMUM FIRST 3,000 GALLLONS
$1.50	PER 1,000 ON NEXT 6,000 GALLLONS
$3.00	PER 1,000 ON NEXT 3,000 GALLONS
$4.00	PER 1,000 ON NEXT 8,000 GALLONS
$5.00	PER 1,000 ON NEXT 30,000 GALLONS
$10.00	PER 1,000 GALLONS AFTER 50,000 GALLONS

APPENDIX D

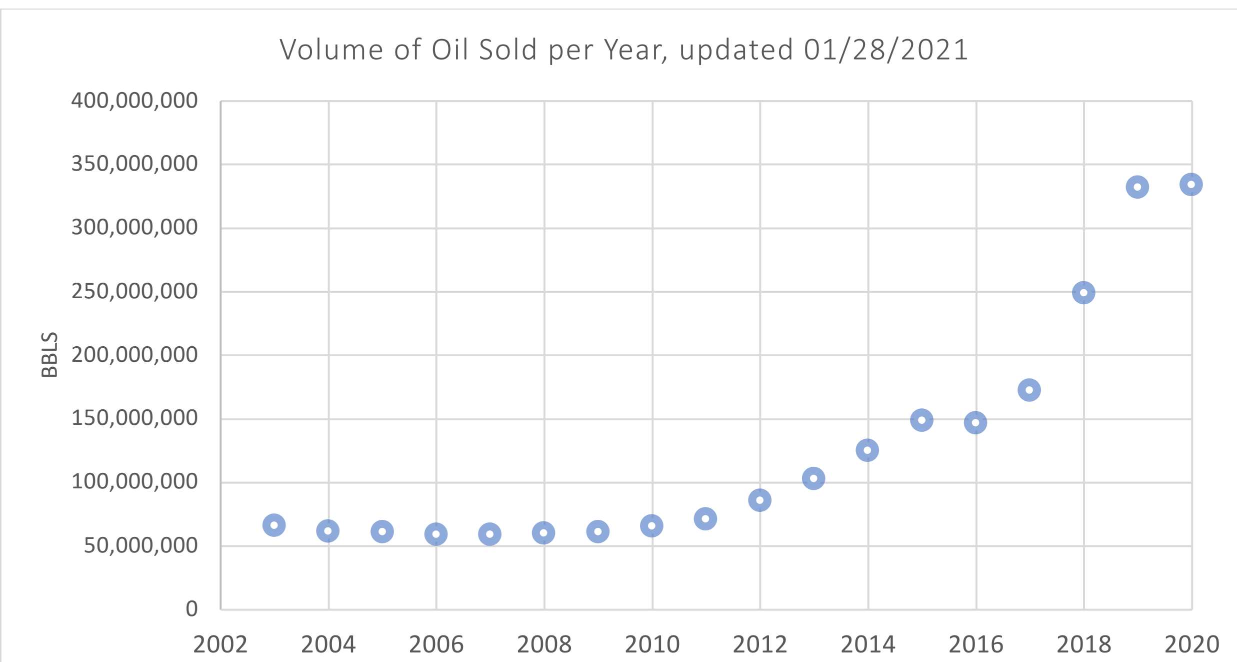
Raw PROMETHEE model:

	MCDM	Product Wat...	Source (feed...	Longevity of...	Effect on wa...	System main...	Return on in...	Employment	Capital plus ...	Effect on wa...	Public accept...	Disaster miti...	Effect on loc...	Energy coms...	Disposal (ha...
	Unit	5-point	5-point	5-point	5-point	5-point	5-point	5-point	$/bbl	5-point	5-point	5-point	5-point	5-point	5-point
	Cluster/Group														
	Preferences														
	Min/Max	max	max	max	max	max	max	max	min	max	max	max	max	max	max
	Weight	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	Preference Fn.	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual	Usual
	Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
	- Q: Indifference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	- P: Preference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Statistics														
	Minimum	2,0	1,0	4,0	5,0	2,0	4,0	3,0	$0,08	3,0	1,0	5,0	3,0	1,0	2,0
	Maximum	4,0	2,0	4,0	5,0	3,0	5,0	5,0	$2,43	4,0	3,0	5,0	3,0	2,0	2,0
	Average	2,5	1,3	4,0	5,0	2,3	4,5	4,0	$1,33	3,3	1,5	5,0	3,0	1,8	2,0
	Standard Dev.	0,9	0,4	0,0	0,0	0,4	0,5	0,7	$1,03	0,4	0,9	0,0	0,0	0,4	0,0
	Evaluations														
☑	PW Project 1	bad	very bad	good	very good	bad	good	average	$2,26	average	very bad	very good	average	bad	bad
☑	PW Project 2	bad	very bad	good	very good	bad	very good	good	$0,55	good	very bad	very good	average	bad	bad
☑	PW Project 3	bad	very bad	good	very good	bad	very good	very good	$2,43	average	very bad	very good	average	very bad	bad
☑	Desalination	good	bad	good	very good	average	good	good	$0,08	average	average	very good	average	bad	bad

APPENDIX E



Source: NM Oil Conservation Division



Source: NM Oil Conservation Division

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