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Desalination and Water Purification Research and Development Program Report No. XXX

Assessment and Implementation Framework for Transboundary Brackish Groundwater Desalination in South-central New Mexico

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

May 2024

NM WRRI Miscellaneous Report 36

		Form Approved OMB No. 0704-0188
05-31-2024	Final	(From - To) From March 2019 to February 2024

Assessment and Implementation Framework for Transboundary Brackish Groundwater Desalination in South-central New Mexico	Agreement No. R18AC00118
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Available from the National Technical Information Service,
Operations Division, 5285 Port Royal Road, Springfield VA 22161

Online at https://www.usbr.gov/research/dwpr/DWPR_Reports.html

This project developed an assessment and implementation framework for transboundary brackish groundwater desalination to diversify the water portfolio and to reduce conflicts in water supplies in South-central New Mexico. The study involved the Hydrogeologic Framework of the Mesilla Basin to assess the brackish water resource for water supply and concentrate disposal. An engineering design report was prepared to estimate desalination costs and to lay the foundation for the process of obtaining permitting and financial assistance for development of a desalination project in Santa Teresa, New Mexico. The technical, economic, environmental, societal, regulatory, and financial aspects of the desalination project was assessed in this project. Laboratory and pilot studies were conducted to evaluate desalination performance using electromagnetic field (EMF) pretreatment and reverse osmosis membranes with 3D printed feed spacers to reduce membrane fouling and scaling, and to enhance desalination efficiency.

Brackish water desalination, transboundary brackish water aquifer, reverse osmosis, electromagnetic field, techno-economic analysis, multi-criteria decision making analysis, engineering design report

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(Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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by

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

Acknowledgments

This work was financially sponsored by the Desalination and Water Purification Research and Development Program, Bureau of Reclamation (R18AC00118). The authors also thank Kay Bailey Hutchinson Desalination Plant (KBHDP) and Brackish Groundwater National Desalination Research Facility (BGNDRF) for hosting the pilot testing. The research team gratefully acknowledges the following individuals and organizations for their valuable contributions to the project:

- Bureau of Reclamation: Chandrika Nasstrom, Diana Blake, Anisha Lamsal, Janeen Koza, and Katherine Guerra for managing the project.
- New Mexico State University: Dr. Juliano Penteado De Almeida, Dr. Zachary Stoll, Dr. David Johnson, Dr. Xuesong Xu, Dr. Xuewei Du, Dr. Wenbin Jiang, Abdiel Hugo Montes, Helani Mahapatunage, Thilini Ranasinghe, Tarek Ahasan, Dr. Huiyao Wang, Dr. Yanxing Wang, Dr. Fangjun Shu, David Vazquez, Lucijia Josipovic, Annie Carrillo, Kim Fetherlin, and Michael Justesen, for conducting laboratory and field testing, characterization of electromagnetic field, and sample analysis; Lana Pillsbury and Taylor Stutely for conducting multiple criteria assessment of the desalination project; and Gamaliel Zepeda for investigating the binational potential of the desalination project.
- CDM Smith: Ege Richardson, Evan J. Babcock, Isaac Campos Flores, Robert Fowlie, and Rachel A. Harris for developing the Engineering Design Report for Santa Teresa Desalination Plant.
- Dr. John W. Hawley, New Mexico Bureau of Geology & Mineral Resources
- Mr. Ed Archuleta, for technical support and guidance

- Border Industrial Association (BIA)
- Camino Real Regional Utility Authority (CRRUA)
- Universidad Autónoma de Chihuahua
- Elephant Butte Irrigation District (EBID)
- International Boundary and Water Commission (IBWC/CILA) of the United States and Mexico
- Aqua Membranes LLC
- Randall Shaw and Daniel Lucero at Brackish Groundwater National Desalination Research Facility, for assisting in pilot testing and providing technical support.
- Art Ruiz and Hector Sepulveda at Kay Bailey Hutchinson Desalination Plant, for assisting in pilot testing and providing technical support.

Acronyms and Abbreviations

%	Percent
AC	Alternating Current
ACEMF	Alternating Current Induced Electromagnetic Field
ADD	Average Daily Demand
ATF	Arsenic Treatment Facility
AWC	Average Winter Consumption
AWWA	American Water Works Association
$BaSO_4$	Barium Sulfate
BGNDRF	Brackish Groundwater National Research Facility
BIA	Border Industrial Association
BoR	US Bureau of Reclamation
BPS	booster pump station
BRATF	Border Region Arsenic Treatment Facility
BWRO	Brackish Water Reverse Osmosis
$CaCO_3$	Calcium Carbonate
CaF_2	Calcium Fluoride
$CaSO_4$	Calcium Sulfate
CCF	Charge Per Cubic Foot
CF	Cubic Foot
CILA	Comision Internacional de Limites y Aguas - the Mexican counterpart of IBWC
CIP	Clean-in-place
CONAGUA	National Water Commission of Mexico
CRRUA	Camino Real Regional Utility Authority
DAC	Doña Ana County

DCMI	Domestic, Commercial, Municipal, and Industrial
DI	Deionized
DOC	Dissolved Organic Carbon
DWSRF	Drinking Water State Revolving Fund
EBID	Elephant Butte Irrigation District
EDR	Engineering Design Report
EDS	Energy Dispersive X-ray Spectroscopy
EIS	Environmental Impact Statement
EMF	Electromagnetic Field
EP1	El Paso County Water Improvement District No. 1
EPW	El Paso Water
EPWU	El Paso Water Utilities
F-EEM	Fluorescence Excitation Emission Matrix
ft/s	Feet Per Second
FY	Fiscal Year
GCD	Groundwater Conservation Districts
GHG	Greenhouse Gas
gpd	Gallons Per Day
gpm	Gallons Per Minute
GWQB	Ground Water Quality Bureau
H_2SO_4	Sulfuric Acid
HCl	Hydrochloric Acid
HDPE	High-Density Polyethylene
HNO_3	Nitric Acid
HP	Horsepower
Hz	Hertz
IBWC	International Boundary and Water Commission - The US counterpart of CILA
IC	Ion Chromatography
ICP-MS	inductively coupled plasma mass spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
ISARM	Internationally Shared Aquifer Resource Mana
JMAS	Juarez's Municipal Board of Water and Sanitation
k	The Slope of Membrane Permeate Flux Decline Rate (LMH/kPa-h)
KBHDP	Kay Bailey Hutchinson Desalination Plant
kg/day	kilograms per day
KNSB	Kilbourne-Noria Subbasin
KOH	Potassium hydroxide
LPOE	Land Port of Entry
LRG	Lower Rio Grande basin
LS	Lump Sum
MCDM	Multi-Criteria Decision Making
MCL	Maximum Contaminant Limits

MF	Microfiltration
MG	Million Gallons
mg/L	Milligrams Per Liter
MGD	Million Gallons Per Day
MHz	Megahertz
NaOH	Sodium Hydroxide
NDF	Net Driving Pressure
NF	Nanofiltration
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMGRT	New Mexico Gross Receipts Tax
NMOSE	New Mexico Office of the State Engineer
NMSU	New Mexico State University
NMWRRI	New Mexico Water Resources Research Institute
NPDES	National Pollutant Discharge Elimination System
NWP	Normalized Water Permeability
O&M	Operating and Maintenance
OPCC	Opinion of Probable Construction Cost
OSE	Office of the State Engineer
PDD	Peak Daily Demand
PHD	Peak Hourly Demand
PLC	Programmable Logic Controller
PMD	Permanent Magnet Device
PMF	Permanent Magnetic Field
PMP	Pure Water Permeability
ppb	Parts Per Billion
ppm	Parts Per Million
PROMETHEE	Visual Preference Ranking Organization Method for Enrichment Evaluation
psi	Pounds Per Square Inch
PV	Present Value
PVC	Polyvinyl Chloride
PWP	Pure Water Permeability
RGP	Rio Grande Project
RGP	Rio Grande Project
RGPA-DRT	Rio Grande Project Area Drought Resiliency Team
RO	Reverse Osmosis
ROSA	Reverse Osmosis System Analysis
SEM/EDX	Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy
SHC	Sodium Hypochlorite
SiO_2	Silicon Dioxide
SP	Sunland Park

SP ATF	Sunland Park Arsenic Treatment Facility
STC	Santa Teresa Community
STC ATF	Santa Teresa Community Arsenic Treatment Facility
STIP	Santa Teresa Industrial Park
STIP ATF	Santa Teresa Industrial Park Arsenic Treatment Facility
SWS	Strategic Water Supply
TAAP	Transboundary Aquifer Assessment Program
TCEQ	Texas Commission on Environmental Quality
TCF	Temperature-corrected Factor
TDS	Total Dissolved Solids, expressed as mg/L or parts per million (PPM)
TOC	Total Organic Carbon
UIC	Underground Injection Control
UNESCO	United Nations Educational, Scientific and Cultural Organization
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WTB	Water Trust Board
WWTP	Wastewater Treatment Plant
XRD	X-ray Diffraction

Measurements

°C	degree Celsius
mm	millimeter
m	meter
cm	centimeter
µg/L	microgram per liter
mg/L	milligram per liter
g/L	gram per liter
mS/cm	milli-siemens per centimeter
gpd	gallons per day
GPM	gallons per minute
LMH	liter per m^2 per hour
MGD	million gallons per day
kWh	kilowatt hour
ppm	parts per million
psi	pounds per square inch

Contents

Figures

Tables

Executive Summary

Improving the resiliency of water supply in an increasingly arid climate is a key challenge for water planners and managers in New Mexico. The large volumes of economically recoverable, slightly to moderately brackish water (<5,000 mg/L total dissolved solids concentration) in the Mesilla aquifer system of southern New Mexico and northern Chihuahua in the vicinity of the Santa Teresa-San Jeronimo area make desalination an attractive alternative for augmenting water supplies. Due to the complexity and uncertainty of maintaining a reliable water supply in an over-appropriated, salty, arid basin, the goal of this project was to develop an assessment and implementation framework for the United States or transboundary brackish groundwater desalination to diversify the water portfolio and to reduce conflicts in water supplies. The project also included laboratory and pilot demonstrations of innovative electromagnetic field (EMF) pretreatment to minimize reverse osmosis (RO) membrane fouling and scaling and to reduce operational costs, energy consumption, and environmental impacts of desalination. This study assessed the technical, economic, environmental, societal, regulatory, and financial aspects of developing the desalination project near Santa Teresa, New Mexico.

The specific objectives for the proposed project were: (1) to use the Hydrogeologic Framework of the Mesilla Basin to preliminarily assess the brackish water resource for water supply and concentrate disposal; (2) to develop an engineering design report for desalination options to lay the foundation for the process of obtaining permitting and financial assistance for the development of the desalination project; (3) to assess the desalination project through multiple criteria assessment; (4) to conduct laboratory and pilot testing to evaluate the effect of different types of EMF as non-chemical pretreatment to reduce membrane fouling and scaling, and to enhance desalination efficiency.

The proposed project examined the potential for providing water for increasing Domestic, Commercial, Municipal, and Industrial (DCMI) economic development in the Santa Teresa area using water that is either not connected to the Rio Grande or distantly connected. The preliminary hydrogeologic study estimates tens of millions of acre-feet of economically extractable brackish water in storage, which the resource can provide water for several generations of DCMI water users. It can also provide time for continued economic development in the border region while water users and uses adapt to the realities of a changing climate. Based on Dr. John Hawley's study, the area identified for further study for source water for desalination is the Kilbourne-Noria Subbasin (KNSB). The KBSN is about 10 miles from the Santa Teresa Land Port of Entry, but it has the advantage of being to the west of a mid-basin high, which may provide isolation from hydrologic effects on the Rio Grande. The subbasin is underlain by approximately 2,000 feet of the Upper, Middle, and Lower Santa Fe groups, which have potential as source aquifers for the desalination project. Further field investigation is necessary to fully assess the suitability of the KNSB and to provide a sufficiently detailed understanding of the aquifer system to design a well field for source water extraction and to identify suitable concentrate disposal points if injection through wells is to be used.

This aquifer in the Mesilla Bolson crosses into the area of west Texas (El Paso) and northern Mexico (Chihuahua) and faces interstate and binational use. Although there are no formal treaties in place for transboundary groundwater basins and more policy challenges to overcome, there are also some opportunities to conduct research in the desired region, which may open the door for cooperation between New Mexico, Texas, and the country of Mexico for a groundwater desalination plant. Research-driven transboundary aquifer programs such as the Transboundary Aquifer Assessment Program (TAAP) and Internationally Shared Aquifer Resource Mana (ISARM) have proven to be examples of official programs that encourage cooperation of the two nations to study and research transboundary aquifers.

The Engineering Design Report developed by CDM Smith provides an overview and feasibility study for a brackish water reverse osmosis (BWRO) facility capable of treating potential brackish groundwater in the Santa Teresa area. The cost associated with the construction of a 5 million gallons per day (MGD) BWRO treatment facility is estimated at $115.5 million. This is equivalent to $4 per 1,000 gallons of treated water and is comparable to previously completed desalination plant projects in the United States. The total project cost, including supporting infrastructure and engineering services, is $269.5 million based on 2023 prices. The permitting and funding sources for a desalination facility in south-central New Mexico are discussed in the report.

A multi-criteria decision making (MCDM) analysis was used to evaluate the benefits and challenges of developing a brackish water aquifer in Santa Teresa to supplement municipal and industrial water demand and to address the increasing water scarcity. Based on the goals of stakeholders and sustainability targets, four major categories of criteria and 14 sub-criteria were developed, including System Performance, Economics, Social, and Environmental. For this analysis, all of the criteria were weighted evenly. Weights may be easily changed with stakeholder input in the future. Each of these criteria can be assigned a measurement per system based on scientific evaluation with the goal to maximize or minimize it. The brackish water resource is a relatively uncontroversial source, and the potential for acceptance of desalinated water through public outreach and involvement is high. Because of the nature of the source water, energy demand is higher than for traditional water treatment. By investing in a solar farm to power the desalination facility, both the environmental and social impacts could be positively influenced. Charges may increase for ratepayers, which is ultimately unavoidable, no matter the water resources investments made locally. Enhancing rural economic development could ensure an attractive return on investments in more impoverished regions. The success of this option is dependent on the economic arrangement and reduced treatment costs. The MCDM results may benefit stakeholders and partners developing the Santa Teresa desalination project about where to invest to ensure water sustainability and to provide clarity on the effects within the communities.

Desalination technologies such as RO and nanofiltration membranes are principal methods for treating brackish groundwater. Despite advances in membrane technologies, membrane fouling and scaling remain a key impediment to successfully implementing membrane processes. This study conducted laboratory and pilot experiments to evaluate the effect of EMF as a non-chemical pretreatment on membrane scaling control during brackish water desalination and concentrate treatment at the Brackish Groundwater National Desalination Research Facility (BGNDRF), Alamogordo, New Mexico, and the Kay Bailey Hutchison Desalination Plant (KBHDP), El Paso, Texas. Three different types of EMF devices were used, including two alternating current (AC) induced EMF devices with different peak-to-peak voltages and frequencies, and one permanent magnet device. Feed spacers are important for the impact of fouling on the performance of spiral-wound membrane systems. This study compared the effect of spacers and EMF on membrane performance, including traditional mesh spacers and 3D printed open channel feed spacers. Pilot testing at BGNDRF treating brackish groundwater demonstrated that both AC-induced EMF and permanent magnet devices were effective in reducing permeate flux decline and improving water recovery. EMF could provide a chemical-free alternative to control membrane fouling and scaling by alleviating the formation of a compact scaling layer on the membrane surface. Periodic hydraulic flushing could restore membrane performance and recover declined flux. Laboratory and pilot testing at the KBHDP showed inconclusive results that EMF and 3D printed feed spacers could alleviate membrane scaling during treatment of RO concentrate. The 3D printed feed spacers developed by Aqua Membranes are aimed to increase permeate output. The thin feed spacer reduced the water flow channel for the scales and precipitates formed under EMF in RO concentrate to be flushed out of the RO element. A comprehensive understanding of crystal particle growth and size formation following exposure to EMF is crucial for designing effective spacers capable of crystal removal and improving the cleanability of spiral-wound membrane systems.

New Mexico has identified brackish water desalination as a strategic water supply to offset unmet demand for freshwater and to meet the water demands for new economic development without reducing the availability of freshwater for human consumption, growing crops and raising livestock, as well as cultural and ecological purposes. This project has provided valuable technical, economic, and environmental information to support developing a brackish water desalination project in the Santa Teresa area for industrial, commercial, and municipal uses.

1. Introduction

1.1. Project Background

South-central New Mexico is the hardest-hit area in the state due to the current severe and chronic drought. The region is experiencing drastically reduced surface water supplies, declining groundwater quality and quantity, and the cumulative effects of more than two decades of drought. The outlook is made even bleaker by the converging climate science, indicating that the current conditions are exacerbated by the local effects of global climate change, specifically a permanent shift to a more arid climate (Dunbar et al., 2002). As if the climatic calamity was not enough, litigation between Texas and the United States against New Mexico in the US Supreme Court may limit the options for water management in the Lower Rio Grande basin (LRG). At the same time, huge development plans are being implemented in the Santa Teresa/San Jeronimo Land Port of Entry (LPOE) area along the US/Mexican border.

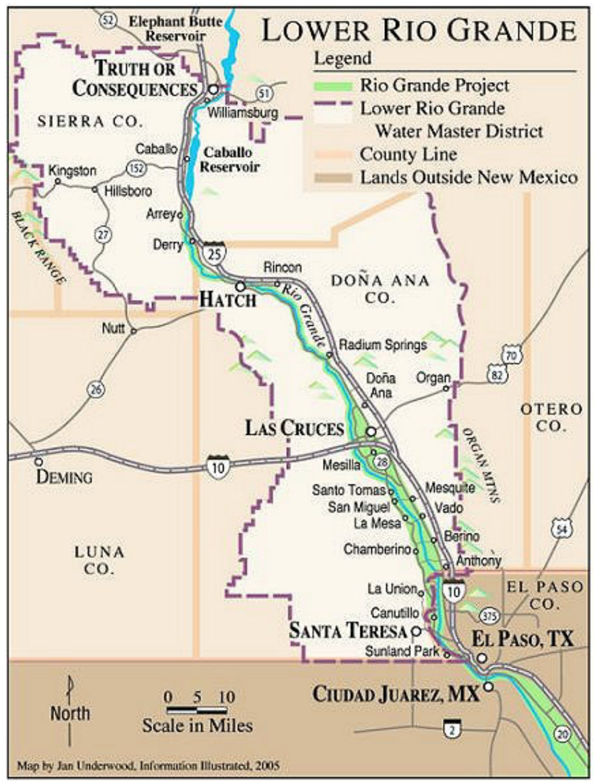


Figure 1: Map of the Lower Rio Grande, NM.

The project site is located in New Mexico's LRG Groundwater Basin. One of the major features of the LRG is the New Mexico portion Rio Grande Project (RGP), a single-purpose Bureau of Reclamation irrigation project that also serves land in Texas and delivers water to Mexico (Figure 1). The RGP was authorized by Congress in the early 1900s, and in 1906 and 1908, Reclamation reserved all unappropriated waters of the Rio Grande and its tributaries in the basin for the RGP. Subsequent development of groundwater use relying on aquifer systems that are hydrologically connected to the surface water RGP has depleted the surface water supply of the RGP. This reduction in water supply negatively affects Elephant Butte Irrigation District (EBID), the New Mexico beneficiary of the RGP, and is a major economic and socio-cultural element in the LRG. It has also created legal conflicts that came to a head in a lawsuit filed by the state of Texas, US No. 141, Original, in the US Supreme Court. The suit alleges that groundwater withdrawals cause interference with project supply via capture, thereby reducing the supply available to the RGP. It is clear that alternatives to depletions of groundwater in New Mexico that is hydrologically connected to the Rio Grande are necessary, both to mitigate the impact on the RGP and to restore the sustainability and resilience of the river-aquifer system.

While the challenges are formidable, water managers in southern New Mexico have long been tenacious and creative, necessary for survival in the Chihuahuan Desert. Geohydrological investigations over the past half-century have revealed very large volumes of groundwater in storage in the southwestern part of the Mesilla Basin Aquifer, which underlies the Santa Teresa border region. Much of the groundwater has not been developed because it is brackish, having a total dissolved solids (TDS) content of 1,000 to 10,000 parts per million (ppm, or mg/L). The historical focus for water supply in the LRG has been the surface water of the Rio Grande for irrigation, and hydrologically connected fresh groundwater for municipal and industrial uses, as well as domestic supply and irrigation. The surface water and groundwater require no treatment for irrigation, and the groundwater generally requires no advanced treatment for potable use. This is the easy water to use, but also the water that is most affected by drought and climate change, and the water that is the subject of the Supreme Court litigation.

1.2. Project Needs and Objectives

1.2.1. Needs

Improving the resilience of water supply in an increasingly arid climate is a key challenge for water planners and managers in southern New Mexico. Santa Teresa is a small community with a population of 6,040 (in the 2021 US census) on the Mexican border east of El Paso, Texas. Fresh groundwater is limited in the Santa Teresa area, and the intrusion of brackish and saline water limits its extraction. Similar problems existed in nearby El Paso, where the El Paso Water (EPW) developed the largest inland desalination plant, Kay Bailey Hutchinson Desalination Plant (KBHDP), in the United States as part of an effort to diversify their water supply (EPWU, 2007). A similar approach has great potential for the Santa Teresa area, possibly including a binational component with San Jeronimo, Mexico.

1.2.2. Objectives

The overarching goal of the project has been to develop an assessment and implementation framework for brackish groundwater desalination in south-central New Mexico to diversify the water portfolio and reduce conflicts in water supplies. The project also includes laboratory studies and pilot testing of innovative electromagnetic field (EMF) pretreatment to reduce reverse osmosis membrane scaling, improve water recovery, and reduce operational costs, energy consumption, and environmental impacts of desalination.

Previous studies have conservatively estimated about 65 million ac-ft of economically recoverable slightly to moderately brackish water (<5,000 mg/L TDS) in the Mesilla aquifer system of southern New Mexico and northern Chihuahua in the vicinity of the Santa Teresa-San Jeronimo area (Hawley, 2016; Hawley and Swanson, 2022; Hawley et al., In press). Although the benefits of a desalination plant would be very significant for regional economic development and augmenting water supplies, local water utilities and private-sector entities are not able to make the full investment and assume all the risks necessary for the completion of such a project.

The project team worked with local entities, state and federal agencies, and stakeholders to assess the technical, economic, environmental, societal, regulatory, and financial aspects of the desalination project. The specific objectives for the proposed project were to:

1. Assess the brackish water resource for water supply and concentrate disposal based on the Hydrogeologic Framework of the Mesilla Basin developed by Hawley et al. (In press).
2. Evaluate the binational potential with the participation of Mexican partners.
3. Work with the engineering firm CDM Smith to prepare an engineering design report for desalination options to lay the foundation for the process of obtaining permitting and financial assistance for developing the desalination project. The report includes existing facilities and resources; wells, siting, storage, transmission and distribution systems; estimate of desalination capacity, treatment processes, concentrate disposal options, techno-economic assessment, permitting, and potential funding sources.
4. Develop multi-criteria assessment framework to evaluate the technical, economic, environmental, and social impacts of groundwater desalination to the region.
5. Conduct laboratory and pilot testing to evaluate innovative pretreatment using electromagnetic field (EMF) and reverse osmosis (RO) membranes with 3D printed open feed channel spacers to reduce membrane scaling during brackish water desalination and concentrate treatment.

The research has completed the following Milestone / Task / Activity

- Task 1. Update test protocol and safety plan
- Task 2. Equipment, material acquisition and site development
- Task 3. Pilot testing
- Task 4. Evaluate concentrate options
- Task 5. Systems analysis
- Task 6. Engineering design report
- Submitted Interim Technical Project Reports
- Submitted Final Technical Project Report

- Completed Final Presentation

1.3. Project Overview

1.3.1. Overall Approach and Concepts

An overall approach was developed to implement the objectives discussed above, including the key elements discussed below.

1. ***Assessment of water demand, binational potential, and social impacts:*** The research team collaborated with the Border Industrial Association (BIA), a non-profit organization consisting of about 100 industry members that coordinates economic development activities in the study area, and the Camino Real Regional Authority (CRRUA), the organization responsible for Santa Teresa and nearby Sunland Park water and wastewater systems to assess projected needs, alternatives, and current conditions of the water supply. We also worked through BIA and the International Boundary and Water Commission (IBWC) and Comision Internacional de Limites y Aguas (CILA, the Mexican counterpart of IBWC) to assess interest on the Mexican side in San Jeronimo in developing a binational desalination plant to serve both sides of the Land Port of Entry area along the US/Mexican border.
2. ***Engineering design report (EDR):*** CDM Smith and the NMSU research team developed an EDR for the process of obtaining financial assistance for the development of a desalination project. The EDR includes existing facilities and resources, number of wells and siting, estimate of desalination capacity, desalination processes, techno-economic assessment, organizational structure needs, and identification of financial opportunities. Different options for concentrate management were discussed, including deep well injection, evaporation, and sewer discharge.
3. ***Development of assessment metrics:*** a multi-criteria assessment framework was developed to evaluate the technical, environmental, economic, and social impacts of the desalination project on the state water budget. Investigations conducted regarding the social sustainability of desalination have assessed management systems for the new alternative water supply that account for economics, socioeconomics, and public health.
4. ***Laboratory and pilot studies of EMF pretreatment and RO membranes with 3D printed spacers to improve water recovery*****:** In this study, bench-scale experiments were conducted to understand the mechanisms of EMF on membrane scaling. Pilot testing used 2-stage skid-mounted 4-inch membrane systems that allowed field testing under typical hydraulic operating conditions. The desalination performance of EMF pretreatment and 3D-printed feed spacers were evaluated in parallel with the traditional

RO system treating brackish water and RO concentrate. Membrane performance was evaluated based on permeate water flux, water recovery, flux decline, and salt rejection. Membrane fouling and scaling were characterized during bench and pilot testing.

1.3.2. Overall Method

1.3.2.1. Building Dialogue with Federal, State, and Local Communities

Implementing a desalination project and developing an alternative water supply requires a meaningful and early dialogue with stakeholders, especially those closest to existing freshwater resources and those sharing the same aquifer. To improve dialogue and relationships with stakeholders potentially impacted by this project, we conducted the following activities:

- Outreach with the results of our findings, including local community meetings, public and professional society presentations, journal article publications, and technical reports;
- A schedule of tasks to take the desalination plant concept through to implementation, including necessary additional studies, permitting and water rights issues, and public input and interaction;
- Exploring the required organizational structure for the development and operational phases of a large desalination plant, presumable operated by or through CRRUA;
- Seeking potential funding and financing opportunities, including the Bureau of Reclamation (BoR), the Transboundary Aquifer Assessment Program, the Border Environment Cooperation Commission; The State of New Mexico; and utility rates and fees.
- Expanding the lines of communication with Governors, state representatives, state natural resource offices, Fish and Wildlife offices, water authorities, county commissioners, and local communities.

1.3.2.2. Engineering Design Report

CDM Smith was subcontracted to develop an Engineering Design Report to provide a clear technical and institutional understanding of the feasibility of desalination in the Mesilla/Conejos Medanos, and if feasible, to describe how best to advance the development of infrastructure. This report aimed to develop an implementation framework for brackish groundwater desalination and provide an overview of the RO treatment process requirements for brackish groundwater with TDS less than 5,000 mg/L. This report also described the major components of the brackish water reverse osmosis (BWRO) treatment plant, including the treatment process, concentrate disposal, as well as finished water storage, pumping, and distribution. Potential treatment plant site locations were also evaluated, and a preliminary engineer's opinion of probable construction cost (OPCC) estimates and annual operating and maintenance (O&M) cost estimates were provided. This report provides a basis for seeking funding and/or financing for subsequent project phases.

1.3.2.3. Multi-criteria Assessment of Santa Teresa Brackish Water Desalination Project

The drawbacks and benefits of developing a new brackish groundwater desalination facility in Santa Teresa, New Mexico, were evaluated using a multi-criteria assessment approach. The criteria for this project were 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 analysis are tabled with a value or ranking for each subcategory. It was found that the success of this project may hinge on the economic arrangement and established technology. The goal is to share this data with stakeholders and partners involved in the Santa Teresa desalination project to ensure clarity of details of effects within these communities and to make decisions about where to invest to ensure water sustainability.

1.3.2.4. Bench and Pilot Testing of RO Desalination with EMF Pretreatment

Three EMF devices and four waters were studied to evaluate the efficacy of EMF in controlling fouling and scaling during RO desalination. The feedwater sources included brackish water rich in sodium sulfate, calcium carbonate, and calcium sulfate and RO concentrate from brackish water desalination, with total dissolved solids (TDS) concentrations of 1,712 mg/L, 2,183 mg/L, 5,850 mg/L, and 12,880 mg/L, respectively.

Currently, there is no existing brackish water well in Santa Teresa that represents the project water salinity in the region for the future brackish water desalination plant because the past development strategy has been specifically to avoid brackish groundwater. Pilot testing using two stages RO systems was conducted at the Brackish Groundwater National Desalination Facility (BGNDRF) in Alamogordo, New Mexico, treating brackish water, and the Kay Bailey Hutchinson Desalination Plant (KBHDP) in El Paso, Texas, treating RO concentrate. These two test sites were chosen because of their proximity to Santa Teresa as well as having a wide range of brackish water quality. This allows the study to have a broader applicability. Three types of EMF devices were used, including two alternating current (AC) induced EMF devices with different peak-to-peak voltages and frequencies and one permanent magnet device. Feed spacers are important for the impact of fouling on the performance of spiral-wound membrane systems. This study compared the effect of spacers and EMF on membrane performance, including traditional mesh spacers and 3D printed open channel feed spacers.

Membrane performance was evaluated based on permeate water flux, water recovery, flux decline, salt rejection, hydraulic flushing, and membrane autopsy results to characterize fouling and scaling.

2. Technical Approach and Methods

2.1. Project Facility/Physical Apparatus

2.1.1. Source Water

The effects of EMF on RO membrane fouling and scaling control were studied using four sources of natural water, including three types of brackish groundwater (sodium sulfate type, calcium sulfate and calcium carbonate type, sodium chloride types), and one desalination concentrate saturated with silica. The brackish water was collected from Well 1 and Well 2 at the Brackish Groundwater National Desalination Research Facility (BGNDRF), Alamogordo, New Mexico. The second source of brackish water and desalination concentrate (concentrate at 82.5%) was from the Kay Bailey Hutchison Desalination Plant (KBHDP), El Paso, Texas. Table 1 summarizes the water quality data for the source waters.

Table 1. Summary of Source Water Quality Data

Constituent	Unit	BGNDRF Well 1 brackish water	BGNDRF Well 2 brackish water	KBHDP brackish water	KBHDP RO concentrate
Calcium	mg/L	60 ± 21	476 ± 4	122 ± 12	675 ± 89
Magnesium	mg/L	14.4 ± 4.8	336 ± 15	31 ± 2	177 ± 18
Sodium	mg/L	305 ± 30	678 ± 25	566 ± 38	2,772 ± 212
Potassium	mg/L	4.7 ± 0.4	2.2 ± 0.1	15 ± 2	71 ± 6
Sulfate	mg/L	641.2 ± 191.1	3,170 ± 158	221 ± 28	1,207 ± 199
Chloride	mg/L	36.6 ± 1.3	535 ± 2	990 ± 97	4,918 ± 488
Silica	mg/L	25.4 ± 2.7	22 ± 2	33 ± 4	162 ± 19
Alkalinity	mg/L as $CaCO_3$	151 ± 14	248 ± 6	84 ± 1	419 ± 45
pH		7.6 ± 0.2	7.3 ± 0.2	7.7 ± 0.1	7.8 ± 0.1
Temperature	^oC	37.2 ± 5.1	22 ± 3	26 ± 1	26 ± 1
EC	μS/cm	1,712 ± 304	6,185 ± 21	3,353 ± 632	18,083 ± 1,871
TDS	mg/L	1179 ± 267	5,674 ± 202	1,972 ± 150	9,817 ± 910

2.1.2. EMF Devices

The effectiveness of EMFs in reducing fouling and scaling on RO membranes during the desalination of brackish water was investigated using three types of EMF devices (Table 2). The AC-induced EMF (ACEMF) devices were designed with specialized inductors to directly or indirectly apply pulsed, decaying sinusoidal electric signals to water pipes at frequencies of 100-400 kHz and different peak-to-peak voltages (Figure 2). The ACEMF devices were measured by oscilloscopes and a 3DHALL magnetic sensor that allows the acquisition of all three magnetic-field components. The simulation of spatiotemporal evolution of the electric and magnetic fields was conducted using the multiphysics platform of commercial software COMSOL to characterize the EMF strength and penetration through water pipes to water. The electric field is dominant by the ACEMF devices while the strength of the induced magnetic field is weak. The COMSOL simulation indicated that the electric field strength was not affected significantly by the electrical conductivity of the water solution.

Table 2. Properties of EMF devices

	EMF Devices	Frequency (KHz)	Peak-to-Peak Voltage (V)	EMF induction method
EMF-A	ACEMF-14V	120-126	14-17	Indirect inductor through ferrite ring
EMF-B	ACEMF-24V	200-400	24	Direct inductor by applying electrical current to pipe
EMF-C	PMF	Permanent magnetic field unit grounded to generate current between 20-97 μA to RO feed water		

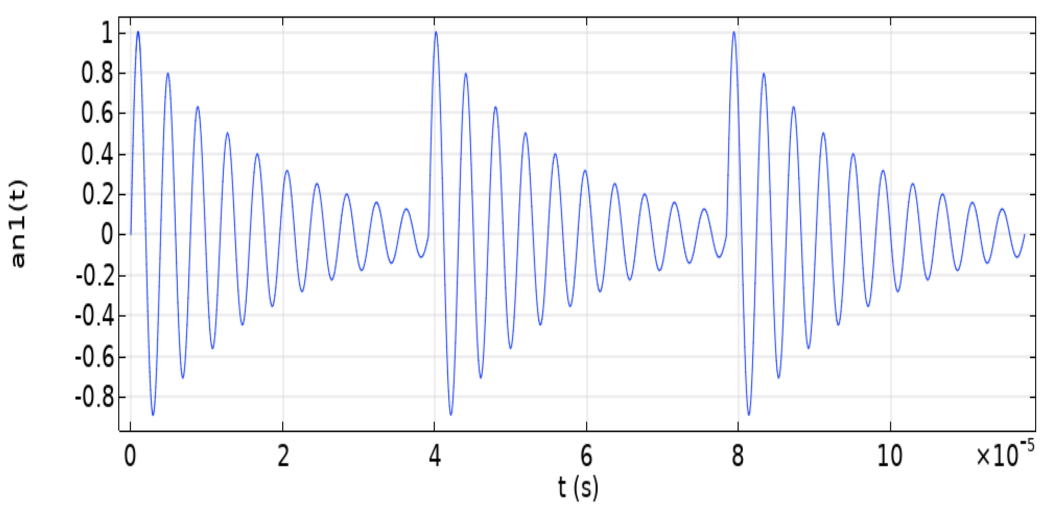


Figure 2. Example of voltage input of an AC-induced EMF device

The permanent magnetic field (PMF) device requires a high flow rate (recommended at 113.5 L/min, or 30 gpm) for the fluid passing through the chamber so that the charged ions would be separated by the permanent magnet under the influence of the Lorenz force. A small potential difference was generated between the PMF device and the ground; electrons were drawn into the system by a dedicated ground rod which may cause scaling control. Effective grounding of the device is critical to its performance, and the effectiveness can be estimated by measuring the current from the device to the ground. The system was designed to be powered by the energy of the flowing fluids; no external power source was required. In this research, the PMF device was installed before the cartridge filters. The current from the device to the ground was 20 μA - 97 μA. Higher current indicates higher magnetic strength and effectiveness of the PMF device.

2.1.3. Set Up

A bench-scale RO unit and two pilot-scale RO systems were used to evaluate EMF effectiveness on membrane scaling control and desalination performance in this study. Figures 3 and 5-8 show the bench membrane unit and two pilot-scale RO systems deployed at BGNDRF and KBHDP, respectively.

2.1.3.1. Bench-scale RO Unit

The bench-scale system was built and designed to evaluate the membrane fouling and scaling, simulating pilot and full-scale RO desalination processes in a semi-batch process. Two crossflow flat-sheet membrane units were employed in this study. The test units consisted of two rectangular plate-and-frame SEPA cells with dimensions of 14.6 cm × 9.5 cm × 0.86 mm (34 mil) for channel length, width, and height, respectively. These channel dimensions provide an effective membrane area of 139 cm^2 per unit and a cross-sectional flow area of 0.82 cm^2. The test cell and tubing for rejection tests are made of stainless steel to induce EMF.

Deionized (DI) water was used to measure pure water permeability (PMP). Synthetic water with 1,500 mg/L of NaCl solution served to verify and compare the salt rejection. Brackish groundwater from BGNDRF Well 2, KBHDP brackish water and RO concentrate were used for membrane scaling experiments. A 25 L plastic feed tank was constructed to store the feed solution. The RO system was operated in a feed-and-bleed operation mode, recirculating all the concentrate and discharging the permeate so that the water recovery of the system continuously increased over time. The feedwater flow rate was controlled at 1 L/min (crossflow velocity 0.21 m/s) using a Hydra-cell pump (M03EKSGSFSHA, Wanner Engineering, Inc., MN). The flow rate was controlled by a Dayton motor (1F798, Grainger, IL). Feed pressure was set from 50 to 300 psi and measured by a Cole Parmer 0-1000 psi pressure transducer and controlled using a manual Swagelok pressure valve and an automated Hass pressure valve. A 0.5 L tank was used to gather permeate. Permeate conductivity was measured using an Oakton 1K conductivity probe and an Oakton Cond6+ Meter. Permeate pressure was measured using a Megadyne 0-1 psi pressure transducer and the volume change was used to calculate the permeate produced. The RO system was monitored and controlled using a Labview (Version 2016, National Instruments, TX) data acquisition system. Throughout the testing, pressure, flow rate, conductivity, pH, temperature, and turbidity were monitored on all the streams of the RO system. Turbidity measured by a LaMotte 2020t Turbidity Meter was used as an indicator of the crystallization formation of the concentrate in the RO system. The membrane autopsy was done using an S-3400N II Scanning electron microscope (SEM-EDS). Figure 3 shows the bench-scale RO system. The EMF devices were installed in the feedwater pipe to the RO cells.

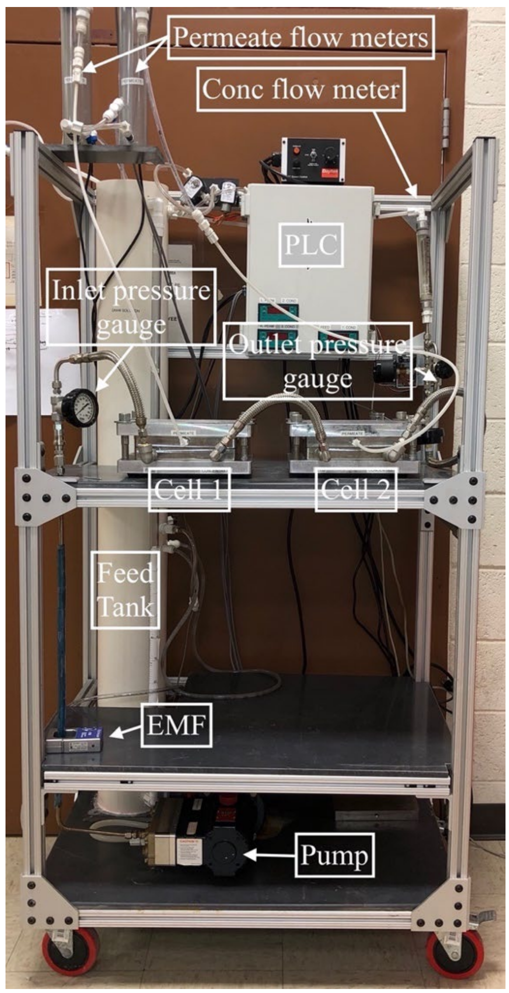


Figure 3. Bench-scale membrane unit with two SEPA cells in series at the NMSU Water Research Lab

The EMF effect on membrane performance was investigated using Hydranautics RO membrane ESPA2-LD with traditional mesh spacer and two different 3D printed open feed channel spacer patterns (see Figure 4). RO membranes with 3D printed open flow channel spacers were manufactured by Aqua Membranes LLC in Albuquerque, NM. The feed spacer was created by printing materials directly on the membrane surface. The printing process did not damage the membrane, and salt rejection was not compromised. The spacers were printed on a Hydranautics RO membrane ESPA2-LD flat sheet.

The study started with membrane experiments to: (i) compare desalination performance and water production of RO membranes with conventional mesh spacer and 3D printed membranes with open flow channels (dotted and striped 3D printed membranes); (ii) evaluate the impact of EMF on the performance of different types of spacers during desalination of challenging brackish groundwaters with different salt compositions; and (iii) perform autopsy on the membranes to characterize fouling and scaling.

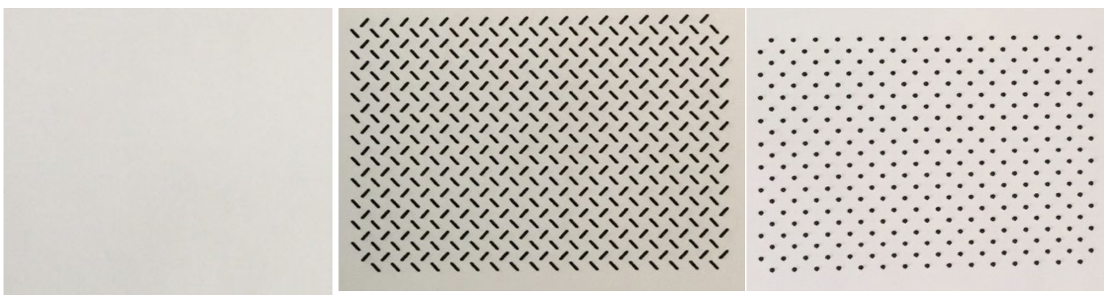


Figure 4. Regular flat-sheet membrane (left), 3D printed membrane in striped pattern (middle), and 3D printed membrane in dotted pattern (right)

2.1.3.2. Pilot-scale RO systems at BGNDRF

Two RO skids were used at BGNDRF to evaluate the effect of ACEMF and PMF on membrane scaling control. The RO skid 1 (Figure 5a and Figure 6) is a 2-stage system that includes eighteen BW30-4040 RO membrane elements by DOW FILMTEC^{TM} (DOW, Midland, MI, USA), which was used for testing PMF. The RO skid 2 (Figure 5b and Figure 7) is a 1-stage system with three BW30-4040 RO membrane elements, which was used for testing both PMF and ACEMF. Currently, most of the RO systems are running at water recovery from 50% to 85% depending on the feed water quality, pretreatment, and design configuration. To determine suitable water recovery, ROSA (Reverse Osmosis System Analysis) model was used to simulate the scaling tendency under different experimental conditions. Considering no acid or antiscalant was added for scaling control in this study, the water recovery was set to ~50% for the RO skid 1 treating higher TDS Well-2 water. The ROSA model predicted that the major scales in PMF-P1 would be calcium carbonate, and the major scales in PMF-P2 would be calcium carbonate and calcium sulfate. Although barium sulfate and strontium sulfate may precipitate on the membrane surface, the amounts would be very low due to their low concentrations in groundwater.

In PMF-P1, the RO system was operated for 150 h at 50% water recovery to induce scaling on the membrane surface (to generate "pre-formed scale", NWP decreased by 42%). Then the PMF was turned on without changing other experimental parameters to test the effectiveness of PMF in removing the pre-formed scale on the RO membrane. The total operating time was 726 hours (30 days). Two system shutdowns were performed after 240 h and 320 h of operation; chemical cleaning was performed after 440 h of operation. In the PMF-P2, the PMF was turned on from the beginning of the experiment to test the effectiveness of PMF on RO membrane scaling control. The total operating time was 1,308 hours (55 days). The operating pressure for RO skid 1 and RO skid 2 during the study started at 2,070 kPa (300 psi) and 1,103 kPa (160 psi), respectively. The feedwater flow rate for RO skid 1 and RO skid 2 started at 106 L/min (liters per minute, or 28 gpm (gallons per minute)) and 18.9 L/min (5 gpm), respectively. The feedwater flow rate gradually decreased due to membrane scaling. New membranes were used for each experiment to ensure the defensible comparison between the tests conducted. Two LG05-20 cartridge filters with a length of 20" (50 cm) and 5 µm pore size were installed before RO to remove suspended solids in groundwater.

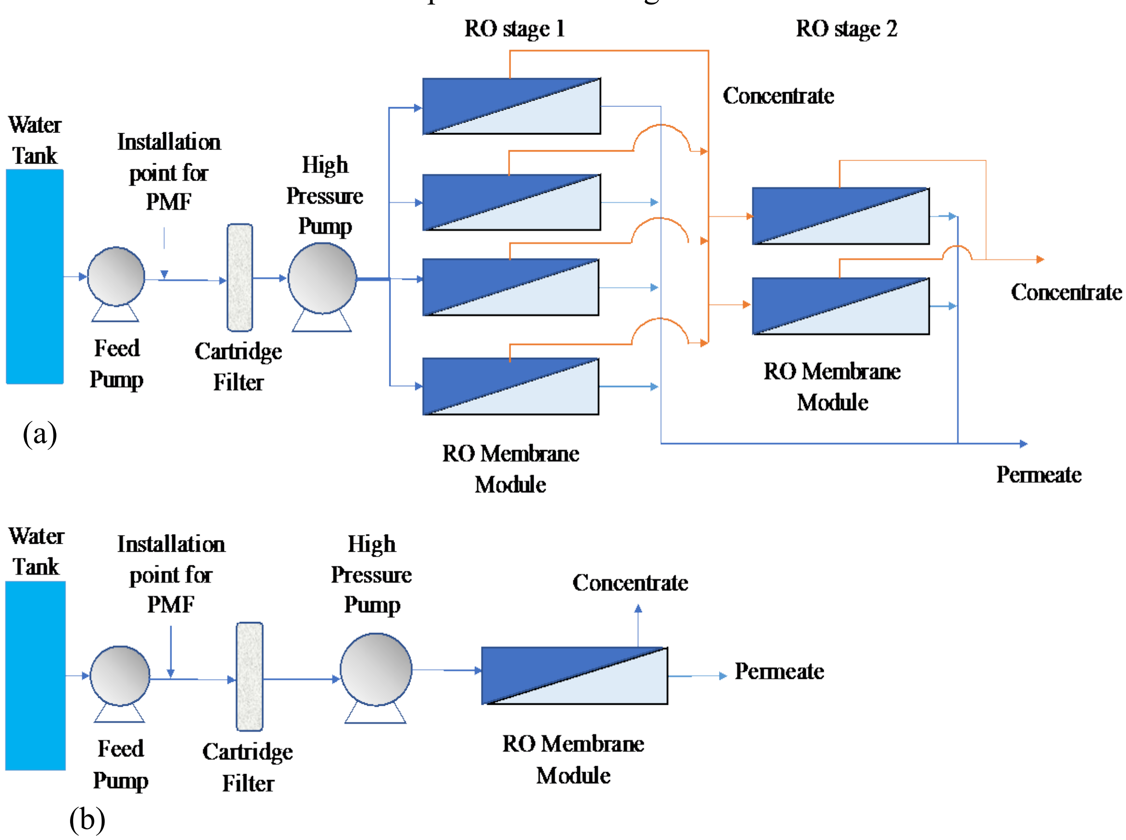


Figure 5. Schematic diagram of groundwater desalination RO systems at BGNDRF. (a) 2-stage RO skid 1 for PMF-P1 testing. In stage 1, there are four pressure vessels in parallel. In stage 2, there are two pressure vessels in parallel. Each pressure vessel has three RO elements in series. (b) 1-stage RO skid 2 with three RO

membrane elements in series within one pressure vessel, used for PMF-P2 and ACEMF testing.

For the ACEMF testing using the RO skid 2, pilot-scale experiments were conducted in two phases independently; new membranes were used in each phase to ensure a defensible comparison between the tests. In both phases, water recovery increased gradually from 20% (6 h) to 30% (24 h) to 45% (47 h), then remained at 50% throughout the testing. The operating pressure for the RO skid during the study was kept at 1241 ± 69 kPa (180 ± 10 psi). The initial feedwater flow rate was 22.7 L/min, but gradually decreased due to membrane fouling and clogging of feed flow channels. In Phase 1 (P1, the control phase), two EMF-A devices were installed and turned on when the permeate flux declined by 35% after 150 h of operation, for the purpose of investigating the RO membrane fouling and scaling without the ACEMF and the effectiveness of the ACEMF in cleaning of fouled and scaled membranes. In Phase 2 (P2), the two EMF-A devices were installed and turned on from the beginning of testing with installation of new membranes. The total operating elapsed time was 381 h for P1 and 844 h for P2. The RO system was turned off and flushed using Well 1 water to recover the membrane performance when the normalized water permeability (NWP) declined by more than 60% during the P1 experiment and 80% during the P2 experiment. Also, no chemicals (e.g., acid or antiscalant) were added to the RO feedwater in order to accelerate and challenge membrane fouling and scaling.

The cartridge filters used in this study were GE LD 05-20, with a length of 50.8 cm (20") and 5 μm nominal pore size.

Figure 6. 2-stage pilot-scale RO skid 1 using 18 BW30 4040 elements in 4:2 array at BGNDRF.

Figure 7. 1-stage pilot-scale RO skid 2 using three BW30 4040 elements at BGNDRF.

2.1.3.3. Pilot-scale RO System at KBHDP

The RO skid in KBHDP includes 2-stage three RO membrane elements in 2:1 array (Figure 8). The operational mode was in a batch process or single pass. Each process goal was to reach 91% of water recovery overall. The first stage has two housings with one element each, and the second stage has one membrane and one housing. The cartridge filter is 1 μm pore size. The RO spiral wound membranes are 4”x40”. The RO membranes used were: a) Dow Filmtec BW30-4040, with regular mesh spacer, and active area of 7.20 m^2, and b) AquaMembranes ConZerv 4040, with 3D printed feed spacers, and active area of 9.29 m^2. The microfiltration (MF) membrane was SiC ceramic membrane with 1200 mm (length), 0.1 μm pore size, 37 channels (DJSC-40/37/4/1200-AD 100), and an area of 2,400 cm^2. The EMF devices evaluated were EMF A (EMF device with 14.4 V of peak-to-peak voltage, 811 V/m of the electric field, and 0.51 mT of the magnetic field) and EMF-B (24.5 V of peak-to-peak voltage and frequency of 255 kHz).

All the concentrate from the first stage flows to the second stage. All the concentrate from the second stage flows to an intermediate tank. This intermediate tank serves as a feed tank for the MF system. All the concentrate from RO membranes passes through an MF membrane, and its permeate is recirculated through the RO membranes. All the permeate is stored in the permeate tank. The pilot system was equipped with flow, turbidity, electrical conductivity, and pH meter sensors, and a programmable logic controller (PLC) to record data in line from all the water streams.

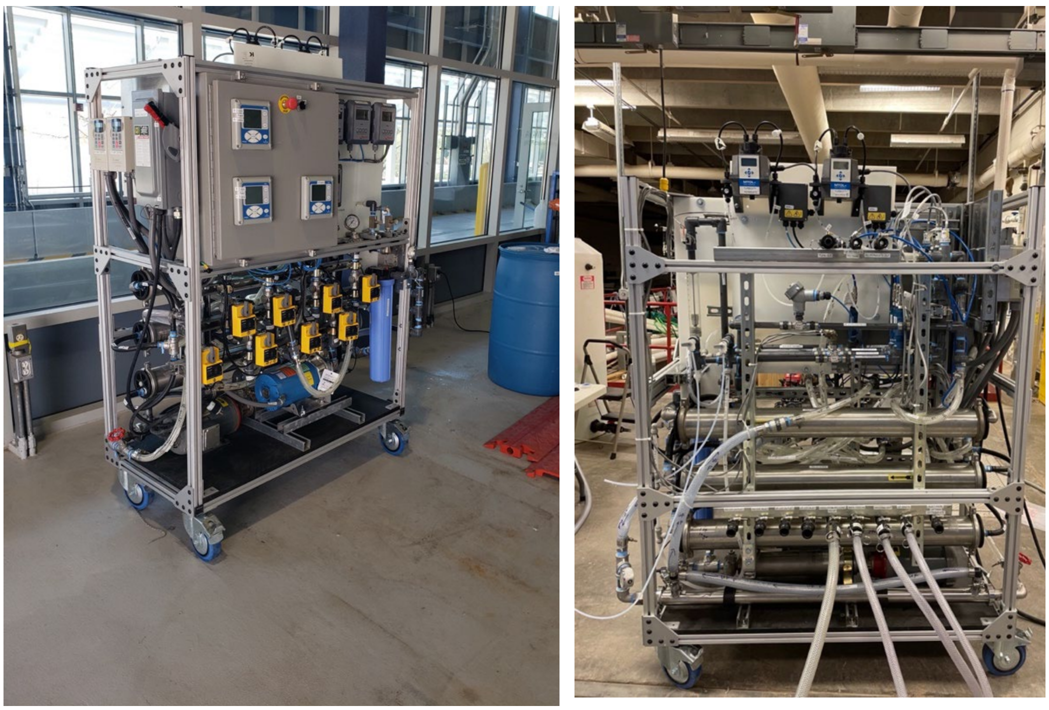


Figure 8. Pilot-scale RO skid using three ESPA-LD 4040 elements in 2:1 array at the KBHDP.

2.2. Analysis

2.2.1. Water Quality Analysis

Water quality of the feed, permeate, and concentrate streams was monitored throughout the experiments, using either online sensors or hand-held conductivity, pH, and turbidity meters. Common cations and anions including sodium, calcium, magnesium, potassium, chloride, and sulfate were measured using an ion chromatograph (IC, ICS-2100, Dionex, Sunnyvale, CA, USA). Metals were measured using inductively coupled plasma optical emission spectroscopy (ICP-OES) or inductively coupled plasma mass spectrometry (ICP-MS, Elan DRC-e, PerkinElmer, Waltham, MA, USA). A spectrophotometer was used for the full wavelength scan of UV and visible light absorbance (DR6000; Hach Company, Loveland, Colorado, USA). Total organic carbon (TOC) was quantified using a carbon analyzer (Shimadzu TOC-L, Kyoto, Japan). The groundwater quality and water temperature remained relatively stable during the experiments.

2.2.2. Membrane Characterization

After testing, membrane samples or elements were removed from the RO skid for autopsy. The specimens were stored in sterile polystyrene Petri dishes and kept in a refrigerator (~4 °C, unexposed to light) prior to analysis. The membrane morphology, surface structure, and elemental composition were characterized by a scanning electron microscopy (SEM, S-3400N II, Hitachi High-Technologies Corp., Pleasanton, CA, USA) and energy dispersive X-ray spectroscopy (EDS, Noran System Six 300, Thermo Electron Corp., Madison, WI, USA). To quantify membrane fouling and scaling under different operating conditions, chemical extractions were conducted on membrane samples, using a virgin membrane as baseline control. The membranes were cut into pieces of 16 cm^2 and further into smaller pieces, and then they were soaked separately in 0.8 M nitric acid (HNO_3) solution and 0.1 M potassium hydroxide (KOH) solution to extract inorganic scalants and organic foulants, respectively. All membranes and solution samples were ultrasonicated for 120 min and then centrifuged for particle separation from the solution. DOC (dissolved organic carbon) and F-EEM (Fluorescence Excitation Emission Matrix) were used to determine organic fouling. The concentrations of inorganic scalants were measured using IC and ICP-OES.

The crystalline structure of the deposits on the membrane surface was analyzed by X-ray diffraction (XRD, Empyrean Powder Diffractometer, PANalytical, Netherlands), carried out in a Rigaku Miniflex-II with Cu Kα (λ = 1.5406 Å) radiation, 40 kV/40 mA current and kβ-filter. The spectra were obtained at the photoelectron takeoff angles of 5° to 85° in 2θ. The evaluation of the XRD spectra was performed using Jade software (Version 6.5.26, Materials Data, Inc., Livermore, CA, USA).

2.2.3. Calculations

Salt rejection is defined as:

$$\text{Salt rejection, \%} = 100 \times \left(\frac{\text{Feedwater conductivity} - \text{Permeate water conductivity}}{\text{Feedwater conductivity}}\right)$$

Water recovery is defined as:

$$\text{Water recovery (\%)} = \frac{\text{Permeate flow rate}}{\text{Feed flow rate}} \times 100$$

In the feed-and-bleed operation mode, the water recovery was defined as:

$$\text{Water recovery (\%)} = \frac{\text{Initial feedwater volume} - \text{Final feedwater volume}}{\text{Initial feedwater volume}} \times 100$$

Water flux decline or permeate flux decline is defined as:

$$\text{Flux decline (\%)} = \frac{\text{Max permeate flow} - \text{Actual permeate flow}}{\text{Max permeate flow}} \times 100$$

Removal efficiency is defined as:

$$\text{Removal efficiency (\%)} = \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \times 100$$

Pure Water Permeability (*PWP*), under different operating conditions is defined as:

$$PWP\ (\frac{\mathrm{L}}{\mathrm{m^2h}}) = \frac{\text{Permeate flow rate, L/h}}{\text{Membrane effective area, m}^2}$$

The normalized water permeability (*NWP*) corrected to 25 °C is calculated based on:

$$NWP = \frac{60 \times Q_p}{A \times NDP} \times TCF$$

where Q_p is the permeate flow rate, *A* is the membrane active surface area, and *NDP* is the net driving pressure. The temperature-corrected factor (*TCF*) is calculated by

$$TCF = e^x$$

where the variable '*x*' is calculated by

$$x = U \times (\frac{1}{T_a + 273} - \frac{1}{T_s + 273})$$

where T_a is the actual water temperature, T_s is the standard temperature of 25 °C, and U is the temperature-corrected flux coefficient that is membrane specific (2300 for most thin film polyamide membranes).

The decreasing rate *k* (Lmh/kPa-h) of the *NWP* is calculated using the absolute slope value of the *NWP* decline curve as a function of operation time:

$$k = \frac{\Delta NWP}{\Delta T}$$

where ΔT is the operation time (h) for the changed *NWP*.

3. Results and Discussion

3.1. Hydrological and Geochemical Framework

3.1.1. Geochemistry of the Mesilla Basin

Nickerson and Myers (1993) presented a description of the Mesilla Basin that included geochemistry from selected wells in the proposed study area. It showed an extensive brackish water resource in the study area, ranging in TDS from 1,000 to 3,000 mg/L. A USGS/BoR report by Teeple (2017) assessed the geophysical and geochemical characteristics and groundwater-flow system of the United States part of the Mesilla Basin/Conejos-Médanos aquifer system in Doña Ana County, New Mexico, and El Paso County, Texas (Teeple, 2017). This comprehensive report includes TDS data collected during 1922–2007 for 239 wells with water depth from 0-1,750 ft. In general, the TDS concentrations in the northern part are <1,000 mg/L, while in the southern part, TDS concentrations >1,000 mg/L are common, and 3,000–35,000 mg/L water is also found, especially with increasing depth. Of the 44 groundwater samples collected, 82% represented Na-dominated water types, especially Na-Cl-SO_4 or Na-HCO_3 water types, with the Na-Cl-SO_4 water type being the most common (70.5%); 18.2% near the Mesilla Valley Fault zone represented Ca-Cl-SO_4 or Ca-HCO_3 water types. The combined nitrate plus nitrite (NO_3+NO_2) concentrations were <8.4 mg/L as N, and the concentrations of selected pesticides were below the detection limit. However, there are sparingly soluble salts in groundwater that may cause scaling, e.g., silica concentration between 14.5 and 85.1 mg/L.

We conducted a water quality analysis on five groundwater samples collected from the west side of Ciudad Juárez in Mexico. The water quality analysis showed the TDS varied in the range of 900-2,600 mg/L. The levels of arsenic (7-25 µg/L) and sodium (270-610 mg/L) didn't meet Mexico's Rule No. 127 standards for drinking water and the drinking water standards set by the United States Environmental Protection Agency (USEPA). The dissolved organic carbon (DOC) concentrations of the groundwater samples were less than 2 mg/L.

With the continuous extraction of groundwater to meet the rapid economic development of both Mexico and United States users, the groundwater quality in the Santa Teresa-San Jeronimo area will likely become worse as declining fresh water exacerbates brackish water intrusion.

3.1.2. Hydrogeology and Geochemistry of the Mesilla Basin Region

This assessment project was very fortunate to have collaborated with a parallel project of the New Mexico Water Resources Research Institute (NMWRRI) focusing on the hydrogeology and geochemistry of the Mesilla Basin region in New Mexico and Chihuahua. That project was led by Dr. John Hawley, a preeminent hydrogeologist with more than 50 years of experience in the Mesilla Basin. The final report (Hawley et al., In press) covers the study region in great detail. During this project, Dr. Hawley conducted a seminar for and frequently consulted with the NMSU project team regarding the hydrogeology and geochemistry of the study area. The final report's publication is imminent, and a pre-press digital version is available from the project PIs.

In a presentation and a white paper to the Urban Land Institute, Hawley (2016) presented an excellent review of the state of knowledge of the hydrogeology in the Santa Teresa area of the Mesilla Basin. He also characterized it as one of the best examples of an aquifer system with great potential for resilient groundwater resource utilization. His conservative estimate of the volume of economically recoverable fresh to moderately brackish groundwater in storage on the West Mesa of the Mesilla Basin, extending from roughly Las Cruces into Mexico, is 65 million acre-feet.

Based on Dr. Hawley's report (In press) and supporting discussion, the area identified for further study for source water for desalination is the Kilbourne-Noria Subbasin (KNSB), shown in Figure 9. The KBSN is about 10 miles from the Santa Teresa LPOE, but it has the advantage of being to the west of a mid-basin high, which may provide isolation from hydrologic effects on the Rio Grande. The subbasin is underlain by approximately 2,000 feet of the Upper, Middle and Lower Santa Fe groups, which have potential as source aquifers for the desalination project. Figure 10 shows a geologic cross section just north of the US-Mexico border, with the KNSB to the left of center and mid-basin high roughly center.

Further field investigation is necessary to fully assess the suitability of the KNSB and to provide a sufficiently detailed understanding of the aquifer system to design a well field for source water extraction and to identify suitable concentrate disposal points if injection through wells is to be used.

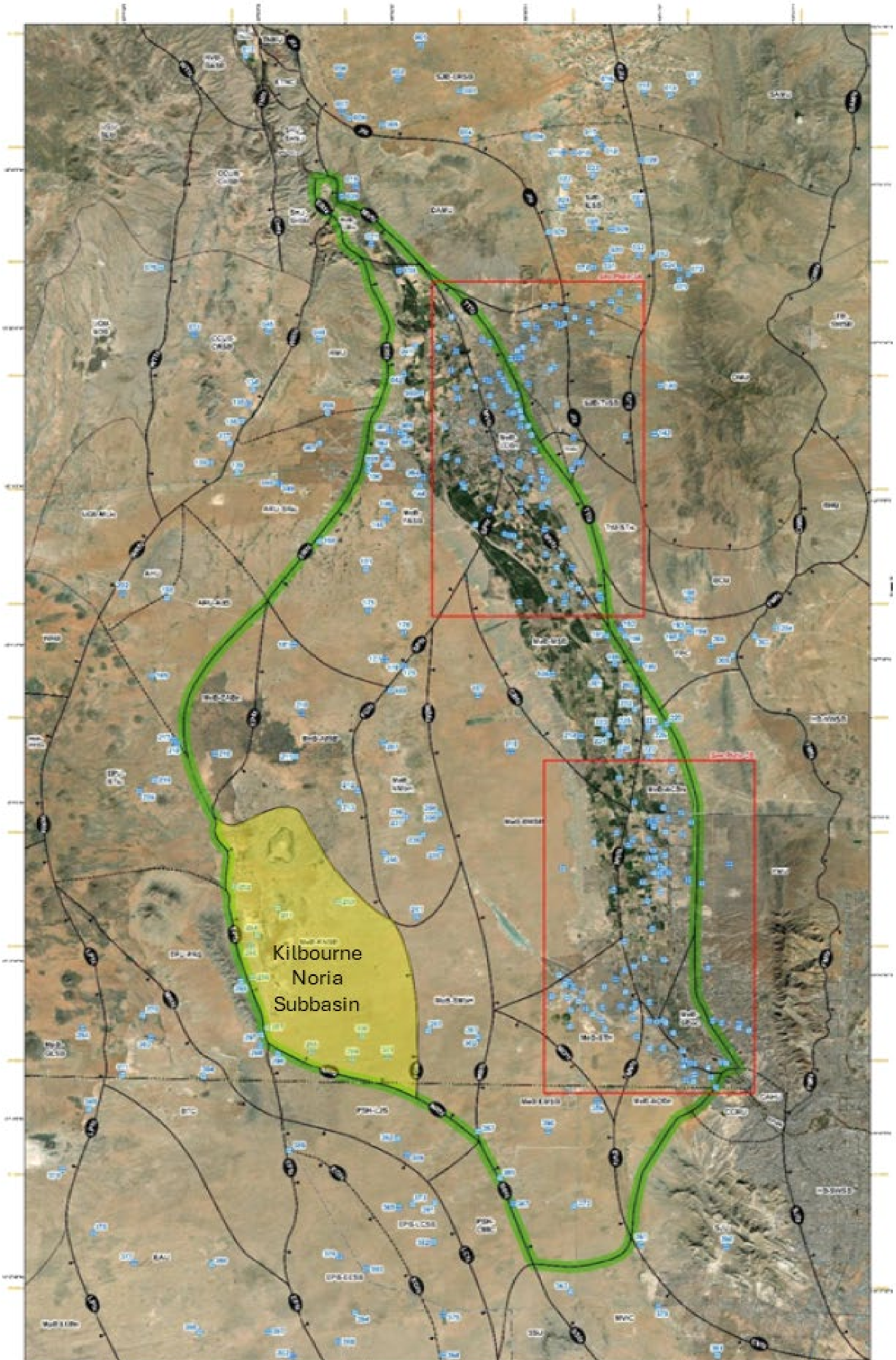


Figure 9. Mesilla Basin map showing the Kilbourne-Noria Subbasin. Base map from Hawley et al. (In press).

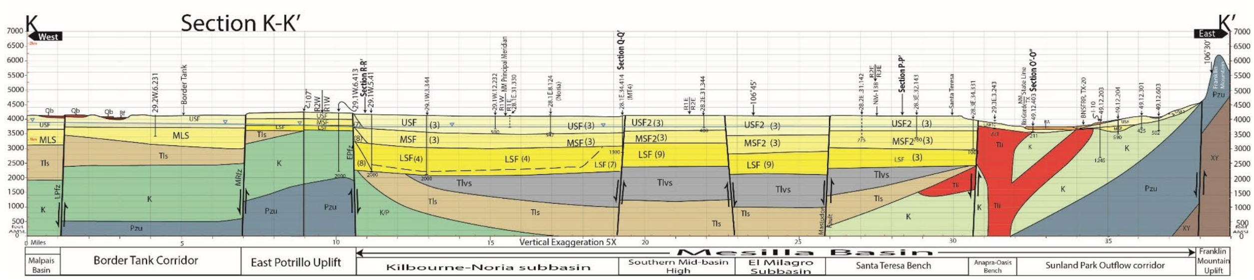


Figure 10. Geologic cross section just north of the US-Mexico border showing Kilbourne-Noria Subbasin and Mid-basin High.

3.1.3. Ongoing Efforts for Developing Brackish Groundwater Supplies and Desalination in New Mexico

More than a decade of litigation among Texas, New Mexico, and the United States over the effects of groundwater pumping in New Mexico on the surface water supply of the Rio Grande Project in southern New Mexico and far west Texas (US Supreme Court No, 141 Original) has been a key motivating factor for this study. In that proceeding, a working group currently called the Rio Grande Project Area Drought Resiliency Team (RGPA-DRT) was developed to assess infrastructure needs to improve the water supply of the area and to maintain compliance with any outcome of the court proceedings. The RGPA-DRT participants include the state of New Mexico, the US Bureau of Reclamation, Elephant Butte Irrigation District, and several other stakeholders in the region. Issue-specific subgroups developed, one of which is concerned with Brackish Groundwater Development and Importation. The subgroup is co-chaired by project PI J. Phillip King and Senior Advisor to the State Engineer John Longworth.

While Hawley et al. (In press) synthesized the available data from well drilling and exploration going back over a century, brackish groundwater has historically not been useful or of interest. The logical next step in characterizing the hydrogeology and geochemistry to support desalination system design is a hydrogeological field investigation specifically targeting the brackish resource. A follow-on project to this effort and Hawley et al. is underway by the New Mexico Office of the State Engineer (NMOSE), in coordination with the subgroup. While it is still early in the project, NMOSE personnel are currently evaluating the potential for an airborne electromagnetic survey of the southern KNBS in the fall of 2024 with an eye toward characterizing the aquifer system structure and boundaries, and to support the development of an exploratory drilling plan. In parallel, a modeling effort is underway to assess the effects of source water extraction from the KNSB on aquifer storage and water quality, and the nature and timing of effects on the Rio Grande.

Reclamation's Albuquerque Area Office is also embarking on a broader study of the brackish resources of the Mesilla Basin and other aquifers in southern New

Mexico and west Texas. In addition, the New Mexico Environment Department (NMED) has tasked NMSU to characterize the brackish groundwater aquifers in southern New Mexico (including the Mesilla Bolson) and prepare a summary report on the state of research and technology availability for the treatment of brackish water fit for various uses, including energy production, energy storage, industrial applications, and potable uses.

3.2. Opportunities and Challenges for Binational Desalination in the Santa Teresa/San Jerónimo Area

This Mesilla Bolson basin crosses into west Texas (El Paso) and northern Mexico (Chihuahua) and is subject to interstate and binational use. Since the aquifer is shared by three separate states in two countries, it brings unique questions that have yet to be addressed by current policies or administrations. The literature review shows that although there are no formal treaties in place for transboundary groundwater basins and there are more policy challenges to overcome, there are also some opportunities for conducting research in the desired region, which may open the door for cooperation between New Mexico, Texas, and the country of Mexico for a groundwater desalination plant.

To identify the challenges and opportunities for the binational desalination project, we consulted professionals from New Mexico State University (NMSU), Elephant Butte Irrigation District (EBID), International Boundary and Water Commission (IBWC), New Mexico's Office of the State Engineer (NMOSE), as well as reviewed many articles from online research sites. This study discusses the most prevalent themes regarding opportunities and challenges of transboundary groundwater and groundwater policies.

3.2.1. Challenges

The most prevalent obstacles are due to a lack of defined agreements between neighboring nations and states, each state or country involved appropriating or managing groundwater differently from one another, current litigation disputes, and the state of differing administration agendas and/or political climate.

The first and most crucial obstacle is the lack of an agreed-upon regulatory framework over groundwater in general or the Mesilla Bolson in particular, among the three states. Currently, there are no established treaties for groundwater between the United States and Mexico. The only kind of water-related treaties between the U.S. and Mexico are regarding surface water (IBWC, 2019). With no formal transboundary regulations or agreements in place, in regard to how much water can be taken out of the shared groundwater aquifer, the demand on the aquifer will likely continue to grow. In May 2009, Mexican billionaire Carlos Slim's company Grupo Carso won a contract from Juarez's Municipal Board of Water and Sanitation (JMAS) to extract 24 million cubic meters of water a year from the Mesilla Bolson aquifer and deliver it to the nearby Juárez northern community (Villagran, 2017). JMAS had known about the groundwater source but had not been financially able to start extracting the water until that time. This could potentially present a situation where it becomes a "race to the bottom" and the first and longest "straw" wins (Fuchs, 2019).

Another obstacle is the difference in how New Mexico, Texas, and Mexico appropriate and govern groundwater. In the U.S., the federal government normally defers to the state to govern and make its own laws regarding water and groundwater (with few exceptions). The state of New Mexico relies on the principle of prior appropriation, which is written into the state's constitution, to determine water rights. The state uses the Office of the State Engineer (OSE) to administer control of declared groundwater basins within its boundaries (Oglesby and Bushnell, 2013) using New Mexico statute NMSA 1978 chapter 72, article 12 to appropriate groundwater. The NMOSE specifically uses NMSA 1978 section 72-12-3 when any "person, firm or corporation or any other entity" wants to make use of underground waters (NMSA, 2019). The OSE has further defined administrative area guidelines for the Mesilla Valley (NMOSE, 1999) that address surface water and groundwater administration for the New Mexico portion of the Mesilla Bolson.

In Texas, surface water is owned by the state and administered through the Texas Commission on Environmental Quality (TCEQ), which exerts property ownership over its rivers and springs. In contrast, groundwater is owned by the person who owns the land where the groundwater is found. This right to groundwater by the landowner is protected by Texas water code section 36.002, which states that "a landowner owns the groundwater below the surface of the landowner's land as real property" (TWC, 2019). This law is also known as "Rule of Capture". Texas also uses Groundwater Conservation Districts (GCD) to provide local management of groundwater, though no GCD exists in the Texas portion of the Mesilla Bolson.

In the nation of Mexico, most issues related to water, groundwater, and water law are under the jurisdiction of the federal National Water Commission (CONAGUA), but recently there has been a change in the direction of "decentralizing water management by providing for the formation of various water authorities regionally and locally" (Foster, 2018). Mexico also allows its people to extract groundwater on their property as long as it does not interfere with conservation or restrictive zones (Foster, 2018). The result of each entity involved having its own way of legally managing groundwater within its boundaries is that conflicting tactics are used to extract groundwater from the same shared aquifer.

Entities in New Mexico and Texas have had previous and present disputes over how the Rio Grande is managed in lower New Mexico (Paskus, 2019), which necessarily involves hydrologically connected groundwater. The 1938 Rio Grande

Compact was signed by Colorado, New Mexico, and Texas, which was approved by Congress to equitably apportion the water in the Rio Grande. The compact states that each state is obligated to deliver water to the state downstream on the Rio Grande (OSE, 2019). Interestingly, New Mexico delivers water to Texas not at the Texas state line, but 110 miles upstream at Elephant Butte Reservoir. This places the New Mexico portion of the Mesilla Bolson downstream of the Compact delivery point. In 2013, Texas filed suit against New Mexico alleging that groundwater depletions in New Mexico between Elephant Butte Dam and the Texas state line were impairing the delivery of water to the Texas state line, violating the Rio Grande Compact. The case is ongoing, and while the outcome is uncertain, it is clear that the use of Mesilla Bolson groundwater that is hydrologically connected to the surface water supply of the Rio Grande is likely to remain a contentious issue for the foreseeable future.

3.2.2. Opportunities

It might seem as if there are insurmountable obstacles to overcome in implementing a desalination plant that draws water from a shared aquifer. Fortunately, however, opportunities do exist. In 1973, the U.S. and Mexico's International Boundary and Water Commission (IBWC) met to incorporate minute 242 into existing treaty administration. Within minute 242, section 6 was added as a way to "avoid future problems" for both U.S. and Mexico in regard to surface or groundwater resources that "might adversely affect the other country" (IBWC, 1973). IBWC's minute 242 was effective in this regard to develop cooperation between both nations to solve shared groundwater related issues. With minute 242 in place, the U.S.-Mexico Transboundary Aquifer Assessment Act was passed in 2006, which started the Transboundary Aquifer Assessment Program (TAAP). The TAAP is a collaborative program between U.S. and Mexico, which helps fund joint research to assess "priority transboundary aquifers" (USGS, 2017). The TAAP has helped identify four transboundary aquifers to focus on: San Pedro, Santa Cruz, Hueco Bolson, and Mesilla/Conejos Medanos. Funded by TAAP, an updated binational report on the Mesilla/Conejos Medanos aquifer was published in 2011 (IBWC, 2011) and a research study report on the San Pedro aquifer, which looked to define the framework and state of knowledge of the aquifer, was published in 2016 (IBWC, 2016). TAAP is an example of using research to overcome prevalent obstacles to study and learn about shared aquifers. Another example of nations cooperating to study and research transboundary aquifers is the United Nations Educational, Scientific and Cultural Organization's (UNESCO) program named the Internationally Shared Aquifer Resource Management (ISARM). ISARM was established in 2000 to research, study, and inventory transboundary aquifers through close cooperation of multiple global agencies and entities (ISARM, 2019). Through collaboration from different nations to work in research, ISARM has been successful in implementing various international and regional initiatives and has been able to analyze many transboundary aquifer systems across nations (Puri and Aureli, 2005). Cooperative research to gain knowledge of transboundary aquifers could be seen as the mechanism needed to overcome most of the obstacles mentioned previously.

3.2.3. Summary

The Mesilla/Conejos Medanos area has many obstacles to cooperation in groundwater management. The three states in two countries have fundamentally different approaches to groundwater governance, few agreements on groundwater management, as well as more than a century of transboundary and intersectoral water disputes. With an already limited water supply dwindling due to multidecadal drought and climate change, competition for the valuable resource makes cooperation and collaboration difficult but all the more necessary. Still, there are opportunities for collaborative research that can help to overcome said challenges. TAAP and ISARM have shown to be examples of official programs that encourage cooperation between the two nations to study and research transboundary aquifers. Research-driven transboundary aquifer programs such as TAAP and ISARM show that by working together in research, nations can benefit from the knowledge of their shared aquifer. Cooperation through research does not necessarily require a formal treaty or agreement process and helps avoid a race to the bottom or having the biggest straw win (Villagran, 2017).

3.3. Engineering Design Report

The Camino Real Regional Utility Authority (CRRUA) is the main utility that provides water service to the area. Therefore, the implementation framework described in this Engineering Design Report by CDM Smith is based on CRRUA's water system as an example application.

3.3.1. Project Planning

3.3.1.1. Project Location

The project location mainly includes the Santa Teresa Community and its surroundings in south central New Mexico. The brackish water reverse osmosis (BWRO) facility implementation framework described in this report is based on the water distribution system owned and operated by CRRUA.

CRRUA provides water service to 22,000 residents as well as commercial, industrial, and institutional customers. The service area covers approximately 36 square miles of the southern end of Doña Ana County and is located south of Las Cruces and west of El Paso. The service area is bounded with Mexico's international border on the south and the Texas state boundary on the east. CRRUA consists of four separate water systems: City of Sunland Park (SP), Santa Teresa

Community (STC), Santa Teresa Industrial Park (STIP), and the Border Region. Figure 11 shows the CRRUA service area with the four water system boundaries outlined (CDM, 2023).

3.3.1.2. Population Trends

Table 3 presents population data from the U.S. Census Bureau and the annual growth rates in the CRRUA service area (CDM, 2023).

Table 3. U.S. Census Population 2000 through 2020 in the CRRUA Service Area

	2000 Census Population	2010 Census Population	2020 Census Population
Total population	15,990	18,532	21,752
Annual growth rate	**-**	**1.6%**	**1.7%**

Projected population trends over the next 20 years were estimated in the 2023 CRRUA Water Infrastructure Plan Update (CDM, 2023). Table 4 presents the projected population growth in each of the service areas within CRRUA. There are no residential developments in the Border Region. The only service area included in Table 4**,** but not shown in Figure 11**,** is the proposed Alta Mesa residential subdivision. The Alta Mesa development will be located on the southwest border of the STC service area and will extend west to Pete Domenici Highway.

Table 4. Projected Population (2020 through 2042) in the CRRUA Service Area

Year	SP	STC	STIP	Alta Mesa[2]	CRRUA System Total
2000[1]	12,918	1,455	1,617	0	15,990
2010[1]	12,982	2,629	2,921	0	18,532
2020[1]	12,019	4,610	5,123	0	21,752
2027	12,752	11,122	9,185	2,182	35,241
2032	13,366	19,195	11,709	8,675	52,945
2042	13,789	22,269	29,504	13,509	79,071

[1] U.S. Census population.

[2] The STIP service area will initially serve Alta Mesa.

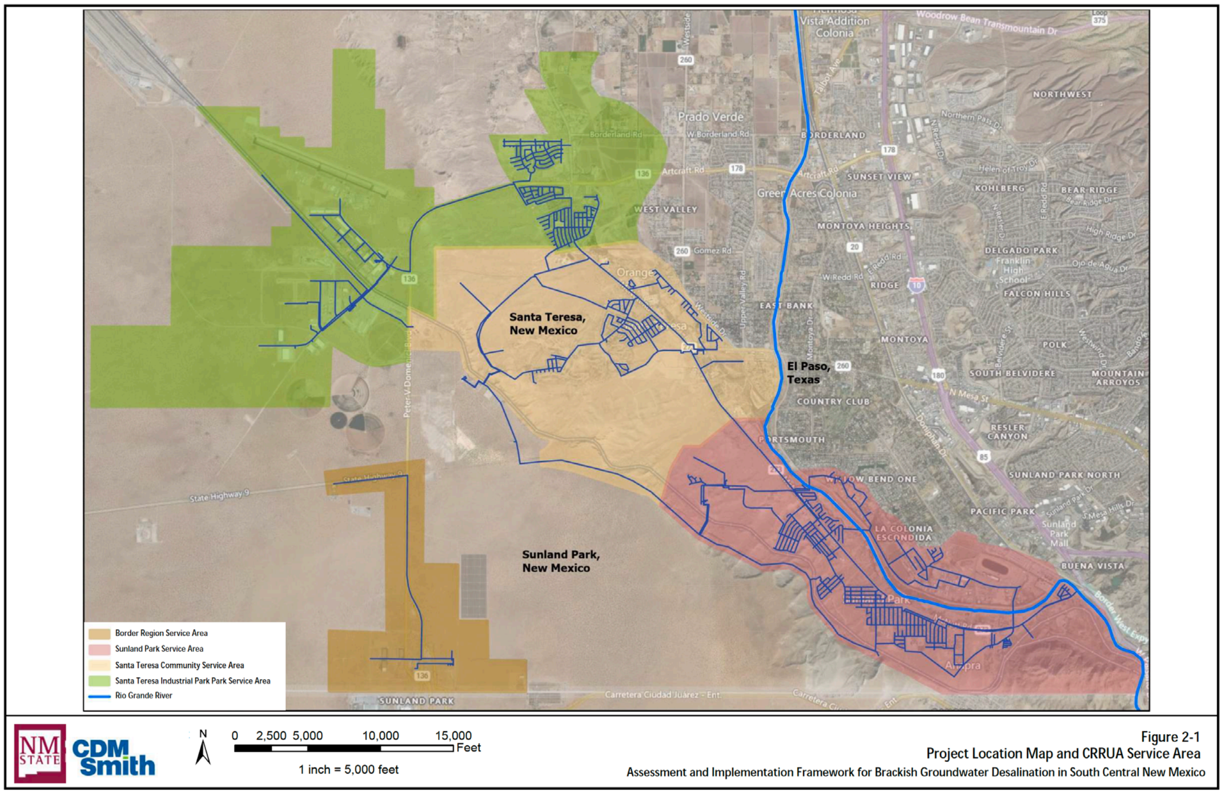


Figure 11. Project Location Map and Camino Real Regional Utility Authority Service Area

3.3.1.3. Future Water Demand

The 2023 CRRUA Plan provides estimated future water demands for each service area for 2027 through 2042. Table 5 provides a summary of the estimated average daily demand (ADD), peak daily demand (PDD), and peak hourly demand (PHD). Industrial and commercial water demands were added by estimating acreage of future land development and demand density using a water demand of 1,200 gallons per day (gpd) per acre. Table 5 presents the projected future water demand in each of CRRUA's four service areas (CDM, 2023). Table 5 also presents the 2020 water demand for reference. Total future water demand in the area is estimated at approximately 20,000 gallons per minute (gpm), which is equivalent to 28.6 million gallons a day (MGD).

Table 5. Projected Future Water Demand in Each Service Area

Service Area	Existing Demand 2020 (gpm)			Future Demand 2027 (gpm)			Future Demand 2042 (gpm)		
	ADD	**PDD**	**PHD**	**ADD**	**PDD**	**PHD**	**ADD**	**PDD**	**PDH**
SP	866	1,734	3,004	1,007	1,968	3,387	1,066	2,076	3,589
STC	391	760	1,264	1,363	2,879	5,461	3,392	7,190	17,580
STIP[1]	841	1,675	2,733	1,705	3,569	6,253	5,741	11,777	16,619
Border Region	38	77	132	66	122	217	194	326	616
Total water system (gpm)	**2,136**	**4,246**	**7,133**	**4,141**	**8,538**	**15,318**	**10,393**	**19,854**	**33,227**
Total water system (MGD)	**3.1**	**6.1**	**10.3**	**6.0**	**12.3**	**22.1**	**15.0**	**28.6**	**47.9**

[1] The STIP service area includes projected demands for the Alta Mesa development.

3.3.2. Existing Facilities

The four areas within the CRRUA service area, namely, SP, STC, STIP, and the Border Region, operates under Water System Number NM3502507. The following subsections describe the existing water infrastructure in the area. Figure 12 shows the existing water system components for CRRUA. Information in this section is provided as a framework to identify facilities that would be needed for a possible BWRO in south central New Mexico in Doña Ana County.

3.3.2.1. Existing Wells

Existing wells in the CRRUA service area pump water from the local shallow groundwater aquifer. There are 14 wells of which four are currently inactive. The 10 active wells supply the area with a total water production capacity of 8.15 MGD. The four inactive wells have the potential to provide an additional 2.44 MGD of water supply.

Sunland Park: There are four wells in the SP service area. Of the four, one well (Well 4) is currently inactive because of failure in 2020 due to corrosion from iron-reducing bacteria. The three active wells (Well 2, Well 3, and Well 11A) have a total production capacity of 2.09 MGD. The potential future reactivation of Well 4 would provide SP with an additional capacity of 0.43 MGD.
Santa Teresa Community: Of the four wells in the STC service area, only two are currently in operation. The two wells in operation are Well 19 and Well 30, which have a reported total production capacity of 2.36 MGD. Well 8A in the area has been out of service since 2001 when high uranium and arsenic levels were initially observed. Since then, redevelopment of Well 8A has been underway, although

observed casing failure mandating redrilling of the well has further delayed reactivation. The potential water supply of these two inactive wells is 1.73 MGD.

Santa Teresa Industrial Park: The STIP service area contains three active wells with a total production capacity of 2.68 MGD. These wells are Well 5, Well 6A, and Well 14.

Border Region: Of the three wells located in the Border Region service area, one well has been out of service since 2014. The well taken out of service is Well Doña Ana County (DAC) 1, with a production capacity of 0.29 MGD. Well DAC 2 and Well DAC 3 are the two active wells in this area that have a combined production capacity of 1.02 MGD.

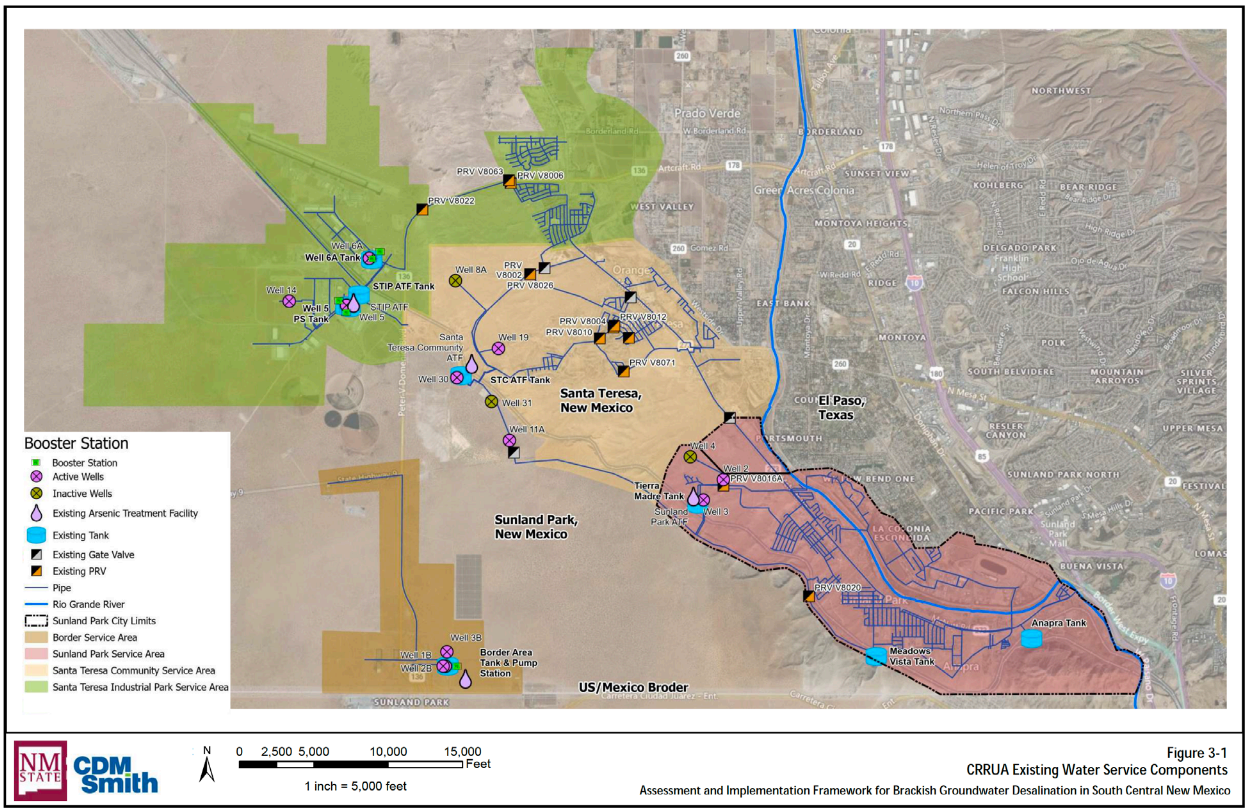


Figure 12. Camino Real Regional Utility Authority Existing Water System Components

3.3.2.2. Ground Storage Reservoirs

There are eight existing water storage tanks in the CRRUA service area with a total water storage capacity of 7.81 million gallons (MG).

Sunland Park: The three water storage tanks in SP are the Meadows Vista tank (1 MG), Anapra tank (1 MG), and the Tierra Madre tank (0.27 MG). Combined total water storage capacity of these tanks is 2.27 MG. The Tierra Madre tank is the high point, which serves as a balancing tank, and typically supplies water to the distribution system directly. Water is conveyed to the Meadows Vista tank through a 10-inch transmission main, and to the Anapra tank through a 12-inch transmission main.

Santa Teresa Community: The STC arsenic treatment facility (ATF) storage tank currently serves the entire STC. The tank was replaced in 2015 to increase the storage capacity from 0.5 to 2 MG. Water from the STC ATF storage tank is conveyed to the STC service area through two 12-inch transmission lines.

Santa Teresa Industrial Park: Storage tanks in STIP are the Well 5 tank (0.27 MG), Well 6A tank (1 MG), and STIP ATF tank (2 MG). Combined total water storage of the tanks is 3.27 MG. Well 5 tank and STIP ATF tank are hydraulically connected and store water from Wells 5, 6A, and 14. Water is pumped from the STIP ATF tank to the Well 6A tank where it is then distributed through a 10-inch transmission line.

Border Region: Figure 13 shows the 0.27 MG Border Region tank and the booster pump station (BPS) (CDM, 2014). Water from the Border Region tank is pumped to the Bi-National Industrial Park, and the Border Patrol Station through a 16-inch transmission line.

Figure 13. Border Region Tank and Booster Pump Station

3.3.2.3. Pumping Stations

There are four BPS in operation throughout the CRRUA service area. There are three in STIP and one in the Border Region.

Santa Teresa Industrial Park: The three pump stations in the STIP system are the Well 5 BPS, Well 6 BPS, and the STIP BPS. Three domestic pumps and two fire pumps operate the Well 5 BPS. The domestic pumps and fire pumps cannot be operated simultaneously. The three domestic pumps have a combined capacity of 783 gpm and are designed to maintain 75 pounds per square inch (psi) of pressure. During higher water demand, the three domestic pumps at Well 5 BPS are shut down, and the two fire pumps are operated to provide 2,250 gpm capacity. Well 6 BPS contains four domestic pumps (one pump on standby) with a pumping capacity of 1,175 gpm. When the system pressure drops below 60 psi, there are three fire pumps at Well 6 BPS, with a combined capacity of 3,000 gpm that are signaled to operate. Finally, the STIP BPS contains two pumps (one primary and one standby) that convey finished water from the STIP ATF tank to the Well 6A tank. Each pump at the STIP BPS has a capacity of 850 gpm.

Border Region: The Border Region BPS conveys water through a 6-inch transmission main from the Border Region tank to supply the Border Crossing Area, Bi-National Industrial Park, and the Border Patrol Station. There are three domestic pumps (one standby), with capacities of 300 gpm each, and two fire pumps (one primary and one standby), with capacities of 1,500 gpm each.

3.3.2.4. Arsenic Treatment Facilities (ATF)

Arsenic is a naturally occurring element found in groundwater across New Mexico. The U.S. Environmental Protection Agency (USEPA) has established a maximum contaminant limit (MCL) for arsenic as 10 parts per billion (ppb). Arsenic concentrations in the CRRUA wells exceed the MCL and therefore require treatment. CRRUA currently operates four ATFs, one ATF for each of the four service areas in the CRRUA system, to bring arsenic concentration below the MCL.

Sunland Park: The SP Arsenic Treatment Facility (SP ATF), with a capacity of 2.7 MGD, has been in operation since 2011. The facility is designed to treat water from all four wells in the SP service area. Treatment is achieved by treating 75 percent (%) of the total flow from these wells and blending it with the remaining untreated 25% water supply.

Santa Teresa Community: The STC ATF has been in operation since 2017. The facility is designed to treat water from all four wells in the STC with extra capacity to treat water from Well 11A. The total capacity of the ATF is 4.5 MGD. The STC ATF treats 75% of the raw water it receives and blends it with the remaining 25% of untreated water to achieve arsenic concentrations less than 8 ppb.

Santa Teresa Industrial Park: STIP ATF has been in operation since 2013 and treats the raw water supply from the three STIP wells. The total capacity of the facility is 3.6 MGD, and it currently treats approximately 1.8 MGD. Because of high arsenic concentrations from Well 5 and Well 6A, there is no bypassing and blending at this facility. Figure 14 shows the ATF building and the storage tank (CDM, 2014).

Figure 14. Santa Teresa Industrial Park Arsenic Treatment Facility and Storage Tank

Border Region: The Border Region ATF (BRATF) was placed online in August 2023. The current treatment capacity of 1.2 MGD allows treatment of the raw water supply from Wells DAC 2 and DAC 3 (Figure 15). The BRATF has the capacity to treat the water supply from Well DAC 1, if the well is rehabilitated and placed in service in the future.

Figure 15. Border Region Arsenic Treatment Facility and Evaporation Pond

3.3.2.5. Transmission and Distribution System

The transmission and distribution system in the CRRUA service area consists of more than 120 miles of water transmission and distribution mains. The system primarily includes 6-inch and 8-inch pipes, with larger transmission mains ranging from 10 to 16 inches. There are approximately 47 miles of water lines in SP, 41 miles in STIP, 26 miles in the STC, and 6 miles in the Border Region. There are 12 pressure-reducing valves located throughout the service area. There are two service areas with interconnected distribution systems. These are the STC and SP systems. The two systems are connected by a 12-inch main that can convey water from STIP to the STC service area.

3.3.3. Desalination Plant

The purpose of this report is to define a framework for implementation of desalination for brackish groundwater as a new water source in the south-central New Mexico to increase water supply resiliency. While there are other desalination methods for brackish groundwater, BWRO is the primary method evaluated in this report because it is a commonly used and proven technology. This section describes the design requirements for a BWRO facility and its associated infrastructure.

3.3.3.1. Plant Capacity

For the purposes of this report, the BWRO facility production capacity is assumed to range from 1 to 10 MGD. The preliminary design presented in this section is based on a 5 MGD BWRO facility. If a BWRO facility is considered for southern New Mexico, additional water supply and demand analyses are required to determine the appropriate treatment capacity of the facility.

3.3.3.2. Brackish Water Supply

The conceptual design presented in this report assumes that the brackish water for the region could be supplied from deep groundwater wells that would be installed in the Mesilla Bolson aquifer. The following subsections describe previously published studies, deep-well test results, and conceptual design basis established for a proposed BWRO facility for the area.

3.3.3.2.1. Supply Well Locations

Groundwater for the brackish water supply to a BWRO plant would come from the Mesilla Bolson aquifer, which lies beneath the entirety of Santa Teresa, a majority of Doña Ana County in New Mexico and west of El Paso in Texas and extends south into Ciudad Juárez in Mexico. Currently, there are no brackish water wells in operation in the region. To identify and characterize the potential brackish source water supply for the region, previously published studies for the Mesilla Bolson aquifer were evaluated.

Nickerson and Meyers (1993), Teeple (2017), and Hawley and Swanson (2022) analyzed groundwater throughout the Mesilla Bolson aquifer. For the conceptual framework presented in this report, data presented in these studies were used to develop a baseline for brackish water location and water quality. Of the 76 wells included in these studies, data for wells that are relatively close to the Santa Teresa area were evaluated to characterize the brackish groundwater that may exist beneath Santa Teresa. These two locations are, namely, Noria and Lanark test holes, as shown in Figure 16. Additional hydrogeological evaluations and pilot studies are required to properly locate brackish well fields, size the production of supply wells, and eventually secure water rights for brackish groundwater diversion.

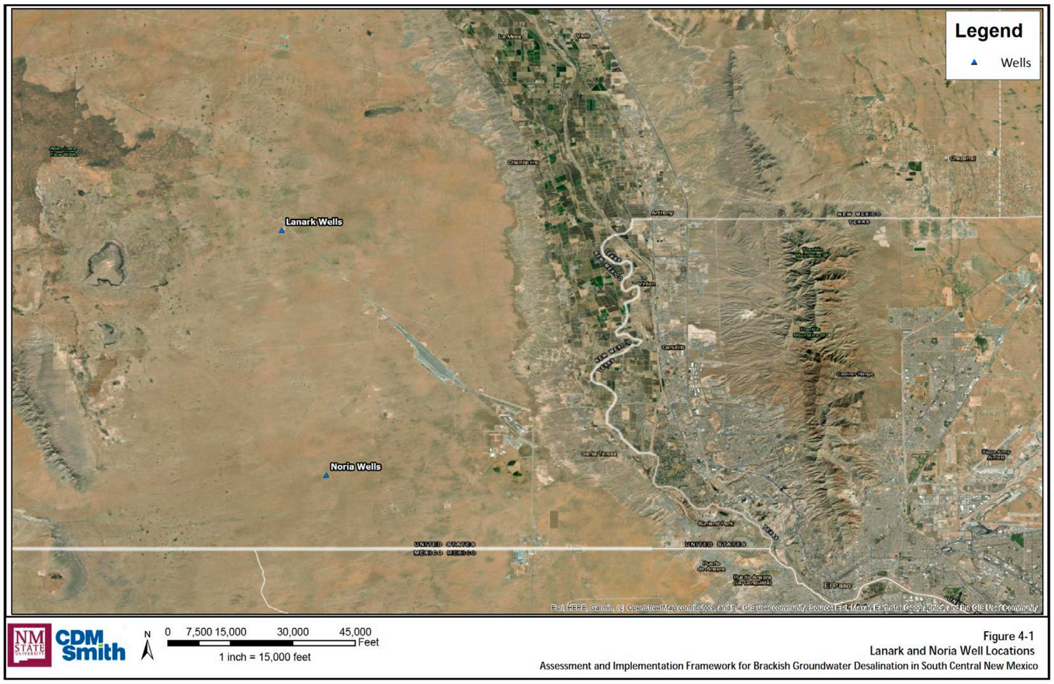


Figure 16. Lanark and Noria Well Locations

Nickerson and Meyers (1993) report that the City of El Paso drilled hydrogeologic test holes to depths ranging from 1,295 to 2,463 feet below land surface. Table 6 shows the approximate thickness of freshwater in the four test holes of Lanark and Noria wells. Locations of the test holes were chosen to assist in determining the effects of structural geology on the thickness, lithology, and water quality of the aquifer in the area. The Lanark test hole was drilled to a depth of 1,560 feet below land surface. The Noria test hole was drilled to a depth of 1,295 feet below land surface in the southern part of West Mesa and was completed as an observation well to a depth of 533 feet below land surface.

Table 6. Noria and Lanark Well Information

Test Hole and Location	Depth of Well, feet	Estimated Base of Freshwater, feet Below Surface	Estimated Thickness of Freshwater Zone, feet
Lanark 27S.01E.04.121	560	930	550
Noria 28S.01E.34.414	533	540	210

3.3.3.2.2. Water Chemistry

There are two service wells located at Noria and two wells at Lanark. Of these four wells, two wells from the Noria location and one well from the Lanark location were used in this study. Samples from the other well at Lanark were excluded because the TDS concentration measured was much greater than the other three wells in the area. The TDS concentration measured at this excluded well was 6,900 mg/L, while the average TDS measured at the other three nearby wells was 2,100 mg/L.

In addition to the water quality data for the Lanark and Noria wells, water quality data from two wells in Anapra, Mexico, were analyzed. NMSU collected and tested water quality samples from the wells Pez Aguja 413 and Calle Calamar 49 in Mexico. The purpose of this sampling study was to gather additional information about the brackish water quality of the Mesilla Bolson and demonstrate variability of water quality across the aquifer.

The Nickerson and Meyers (1993) and Teeple (2017) data as well as data collected in Anapra wells show a considerable variance based on the location of the wells. Table 7 provides a summary of the water chemistry data for all well locations.

Table 7. Major Groundwater Quality Parameters of Wells of Interest

Parameter	Water Quality in Santa Teresa, USA			Water Quality in Anapra, Mexico	
	Lanark	Noria		Pez Aguja 413	Calle Calamar 49
Calcium, mg/L	20	84	30	241	258
Magnesium, mg/L	12	24	4	8.1	7.3
Iron, mg/L	0.017	0.03	0.03	1.4	1.1
Sodium, mg/L	370	1,200	460	566	611
Potassium, mg/L	13	9.1	5.3	3.4	6.2
Arsenic, mg/L	0.002	0.008	0.036	0.0074	0.0065
Barium, mg/L	0.1	<0.1	<0.1	0.04	Non-detect
Chloride, mg/L	400	1,200	330	460	482
Fluoride, mg/L	0.9	1	1.3	0.57	0.67
Nitrate, mg/L	0	0	0	4.16	4.01
Silica, mg/L	52	34	37	NA	NA
TDS, mg/L	1,200	3,600	1,500	2,554	2,681
pH	8.7	7.8	7.8	6.72	7.03
Manganese, mg/L	0	0.04	0.01	0.01	0.002
Boron, mg/L	0	0	0	NA	NA
Cadmium, mg/L	0.002	<0.001	<0.001	Non-detect	Non-detect
Chromium, mg/L	<0.01	<0.01	<0.01	0.0128	Non-detect
Copper, mg/L	0.004	0.001	0.001	0.061	0.002
Lead, mg/L	0.005	<0.005	<0.005	0.016	Non-detect
Silver, mg/L	<0.001	<0.001	<0.001	0.013	0.008
Zinc, mg/L	0.07	0.29	0.5	0.581	0.052
Selenium, mg/L	0.002	<0.001	<0.001	0.0037	0.0006
Phosphorus, mg/L	0	0	0	0.30	0.18

Parameter	Water Quality in Santa Teresa, USA			Water Quality in Anapra, Mexico	
	Lanark	Noria		Pez Aguja 413	Calle Calamar 49
Alkalinity, mg/L as bicarbonate (HCO_3^-)	240	81	118	87.84	85.4
Sulfate, mg/L	180	1,000	560	1,179	1,230

Data presented in Table 7 indicate that one of the wells at the Noria location exceeds the EPA MCL of 10 ppb for arsenic concentration. It is assumed that the supply from this well can be blended with the other wells to achieve an arsenic concentration below the MCL; therefore, no arsenic treatment is included in this study. If arsenic concentrations are found to be higher, or blending is found to be unfeasible, arsenic treatment may be incorporated at the BWRO facility since RO membranes can provide arsenic removal. Table 8 provides the main water quality constituents of concern for the RO treatment. The table also presents the water quality goals of the treatment process.

Table 8. Major Groundwater Quality Parameters Selected for Modeling

Water Quality Parameter	Influent Value Used in Conceptual Design	Regulatory Level	Water Quality Goal
Calcium (mg/L)	127	NA	80 to 120
pH	7.6	6.5 to 8.5	8.0
TDS (mg/L)	2300	500	800
Chlorides (mg/L)	575	250	225
Alkalinity (mg/L)	122	NA	80 to 120

For the purposes of this study, the bypass and blending percentages were maximized, which resulted in a treatment goal of 800 mg/L TDS and 225 mg/L chlorides. The current water supply in CRRUA contains lower levels of these two quality parameters. Additional analysis of water quality in the CRRUA distribution system is required to verify the water quality goals used in this conceptual design. The water quality goals should be adjusted to match the levels found in the CRRUA distribution system. This practice is used to avoid degradation of the distribution system.

3.3.3.3. Basis of Design

Table 7 presents data used as a benchmark to develop a conceptual design for a BWRO facility and to identify its components. If the brackish groundwater that may be found beneath the project location differs in water quality than the data presented in Table 7, additional analysis will be required to adjust the design elements presented in this section, especially for the RO system. Table 9 provides a summary of the basis of design for the proposed BWRO facility. The table lists the major parameters that were used in modeling of the RO membranes.

Table 9. Design Basis for the 5-MGD BWRO Facility

Design Parameter	Value Used in Conceptual Design
Finished water flow, MGD	5
Influent water flow, MGD	6.15
Bypass flow for blending, MGD	1.54
Concentrate flow, MGD	1.15
Operation, days per year	365
Array	Two stage
Elements per vessel	7
RO recovery	75%
Overall recovery	81%
Number of skids	At least two

3.3.3.4. Raw Water Transmission Pipelines

Groundwater supply well pumps will pump the water to the new BWRO facility. Raw water pipeline alignment will need to be finalized based on actual location of these facilities. Raw water transmission line diameter will be determined to minimize headloss and pumping requirements. For the purposes of this evaluation, a well collector pipeline diameter of 18 inches was assumed.

Assuming that the brackish water supply wells are located near the Lanark and Noria well sites, approximately 25 to 30 miles of raw water transmission pipeline will be required. Since both Lanark and Noria wells are located at higher ground elevations, it is possible that supply well pumps will be sufficient in transporting raw water to the BWRO facility. BWRO feed pumps, sand strainers, and filter cartridges require about 50 psi of operating pressure. The supply well pumps and headloss calculations will need to be completed when siting of facilities is finalized.

3.3.4. Treatment Facility

The BWRO treatment facility will include pretreatment, RO, post-treatment, and clean-in-place (CIP) processes. Figure 17 shows a simplified process flow diagram for the proposed BWRO facility. Following are descriptions of the treatment units for a BWRO facility with a 5 MGD finished water production capacity. The processes described in this section are based on commercially available and proven technologies. If innovative modifications can be applied based on the information collected during the pilot testing, the process details can be revised to achieve higher efficiencies.

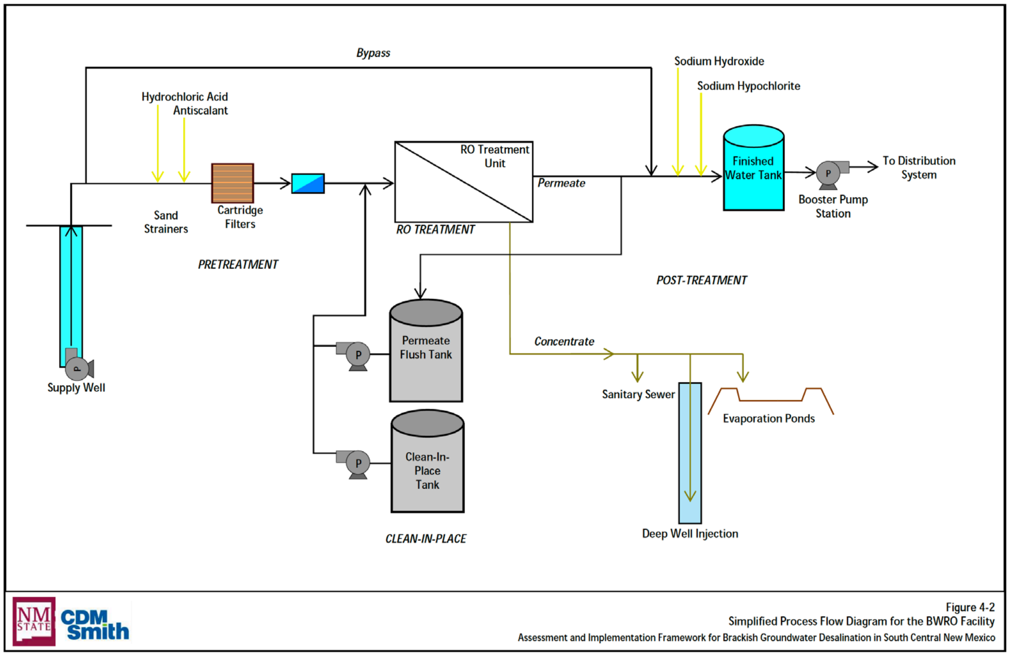


Figure 17. Simplified Process Flow Diagram for the Brackish Water Reverse Osmosis Facility

3.3.4.1. Pretreatment Processes

Suspended solids such as sand and silt that exist in raw water may block feed channels and decrease the water recovery of an RO system. To minimize this, pretreatment that consists of preliminary filtration is required upstream of the RO membranes. The pretreatment filtration can be achieved through sand strainers that filter out particles 25 microns and larger. Two 25-micron sand strainers, to be used as one duty and one standby, are required for the facility.

To filter smaller particles (less than [<]5 microns) prior to the RO membranes, cartridge filtration can be used. For 5 MGD of finished water, three cartridge filter vessels, each with approximately 30 cartridge filter elements, are required. The quantity of cartridge filter vessels was determined to optimize the filtration rates. If the number of filter vessels is less than three, frequent cartridge filter replacements may be required. More than three cartridge filter vessels may be installed, but the number must be balanced with space constraints and costs. While the desired treatment can be achieved by splitting flow between two cartridge filter vessels, it is necessary to have a third vessel as standby to perform maintenance and cleaning without disrupting plant operations.

Feed water entering the system is expected to have a relatively high pH value (7.6 to 8), which can cause a lime scale to build up within the facility's pipes and membranes. Scaling can severely reduce the water production efficiency of the facility. Therefore, the pH of the raw water must be reduced before the RO treatment.

Hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) were evaluated as chemicals for pH reduction. Although sulfuric acid is less expensive than hydrochloric acid, it may adversely precipitate out into calcium sulfate ($CaSO_4$), which causes scaling of the RO membranes. To prevent scaling and subsequent reduction in production efficiency of the RO membranes, hydrochloric acid was selected over sulfuric acid. For a plant capacity of 5 MGD, the hydrochloric acid injection rate was calculated as 432 kg/day. Although antiscalants are typically used in BWRO facilities and typically eliminate the need for pH adjustment, this addition of hydrochloric acid may still be required based on actual water quality parameters. Once available, water quality of potential sources for the proposed BWRO plant should be evaluated to determine if pH adjustment is needed.

To further prevent the precipitation of calcium carbonate ($CaCO_3$), barium sulfate ($BaSO_4$), calcium fluoride (CaF_2), iron oxides, and silicon dioxide (SiO_2) on the RO membranes, an antiscalant chemical also can be added to the feedwater.

To reduce the likelihood of precipitation of these constituents at the desired recovery and flow rate, an injection rate of 62 kg/day of antiscalant was calculated. To allow for more chemical mixing time, the antiscalant and hydrochloric acid should be added to the raw water before entering the sand strainers and cartridge filters.

3.3.4.2. Reverse Osmosis Process

In this study, TDS is the main contaminant evaluated for removal as seen in Table 8. To achieve the required TDS levels in finished water, 75% of the feed water is treated by the RO system, while the remaining 25% of feed water is bypassed and blended with the RO permeate. Assuming an RO recovery of 75%, the total system water recovery of 81% is achieved through blending.

The RO process conceptual design was developed using Winflows 3.3.2 software by Suez Water Technologies & Solutions (Winflows RO System Design Software). By providing source water quality data and design parameters such as flow rate, projected recovery rate, and membrane type, the software estimates system design characteristics through the number of passes and stages necessary to produce desired water quality parameters.

The analysis performed showed that to produce 3.46 MGD of permeate, a two-stage configuration would be accurate. The design will include two or three skids to reach this total of 3.46 MGD of permeate. This will allow for at least one skid to be operated at all times including maintenance and cleaning. The configuration is estimated to include 75 pressure vessels, with 50 vessels in the first stage and 25 vessels in the second stage. Each vessel will contain seven elements that consist of 525 low-energy RO membranes (Figure 18).

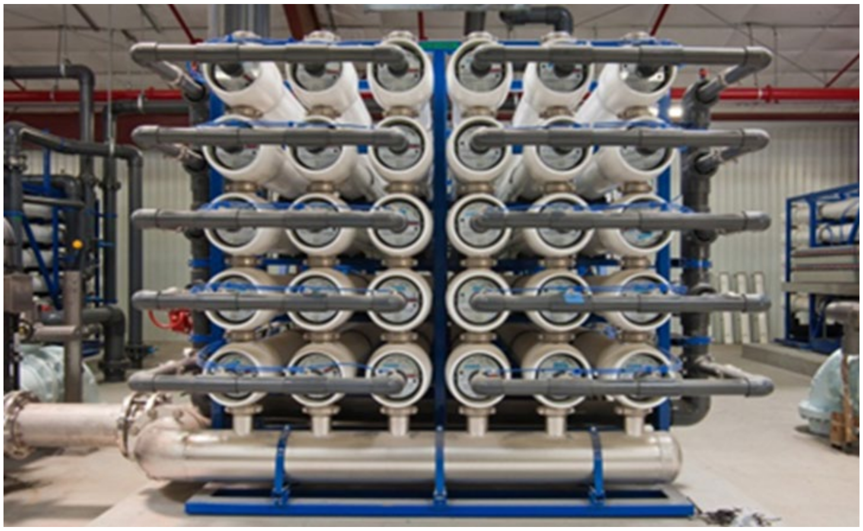


Figure 18. Typical RO Skid (1 MGD Unit)
Source: LRGPWWA PER Surface Water and Brackish Groundwater Treatment Plant Project, CDM Smith.

3.3.4.3. Post-Treatment Process

The finished water after blending will be disinfected before storage and distribution. Sodium hypochlorite (SHC) will be used for disinfection. Additionally, sodium hydroxide (NaOH) will be added to the finished water to decrease corrosion potential and bring the pH of the finished water up to match that of the rest of the water supply.

Sodium hypochlorite will be stored and dosed at a concentration of 12.5%, since this is widely available. Sodium hydroxide will be stored and dosed at 50% concentration since this concentration is the most readily available. Sodium hypochlorite and sodium hydroxide may be stored together (both are high pH), but they must be separated from the pretreatment chemicals (low pH).

It is noted that a corrosion inhibitor may also be required, but such determination should be made when raw water quality data is available from the brackish water supply wells.

3.3.4.4. Clean-in-Place Process

RO membranes will need to undergo routine flushing to clean them. A chemical CIP system that consists of two storage tanks and two pumps is required. To perform the CIP flushing, RO skids will need to be shut down and, therefore, will require the permeate in the RO skids to be flushed from the system upon shutdown. This process can take place for one RO skid at a time, so while one skid undergoes CIP, the other skid can continue operation. One tank and pump will perform the RO permeate flushing while the other tank and pump will perform the chemical CIP circulation subsequently. It is estimated that this shutdown and CIP procedure should be conducted once every three to four months of operation. A typical CIP process takes about 4-8 hours per skid. CIP chemicals will be neutralized and discharged with permeate flush from this process to the sanitary sewer.

3.3.5. Concentrate Disposal

The RO treatment process produces a waste flow stream called concentrate or brine. The concentrate typically contains a high concentration of TDS at approximately 10,000 mg/L and must be properly disposed of. RO treatment facilities commonly use a variety of concentrate disposal methods. The selected method used is dependent on the RO system treatment capacity and location. RO treatment facilities typically use one or more of the following concentrate disposal methods:

- Deep injection wells
- Evaporation (passive or mechanically enhanced)
- Sanitary sewer disposal

Selection of the preferred method(s) of concentrate disposal requires careful planning and understanding of the volume and quality of the concentrate, and local factors such as cost and availability of land, subsurface hydrogeologic conditions, weather, and permitting requirements.

3.3.5.1. Concentrate Quantity

The assumed recovery of the RO treatment process is 75%. The conceptual design presented in this study is based on the BWRO operating continuously year-round. Table 10 shows the concentrate volumes calculated for the BWRO.

Table 10. Concentrate Volumes for Final Disposal

Facility	gpd	MG per year
1 MGD BWRO facility	231,000	84.3
5 MGD BWRO facility	1,154,000	421.2

3.3.5.2. Deep-Well Injection Alternative

Concentrate from the RO process can be disposed of via deep-well injection, which injects the concentrate into a deep aquifer that ideally contains water with the same or higher TDS concentration as the injected concentrate. A hydrogeological analysis will have to locate a deep aquifer that can receive the concentrate injection.

For the conceptual analysis presented in this report, it is assumed that a deep aquifer suitable for this purpose is located close to the project site and the proposed injection well can be injecting to deeper than 1,000 feet. The well will be constructed with a PVC sounding tube for continuous monitoring of fluid level and an eductor pipe for conveying disposed RO concentrate.

Concentrate from the BWRO facility will be conveyed to the injection well site and pumped into the deep well. It may be desirable to locate the concentrate injection wells away from the water supply wells depending on the geological formations.

3.3.5.2.1. Siting Analysis

A siting analysis, hydrogeological analysis, and permitting evaluation will need to be completed before the project can be implemented. The siting analysis will include the following parameters:

Land ownership. Land ownership is important because having ownership of the land will help demonstrate control over the injection well site. Total required area is approximately 0.5 acres with reasonable access.

Proximity to existing wells and springs. There can be risk of impacting nearby water supply wells from concentrate injection. Maintaining a reasonable distance from existing wells and springs may facilitate the permitting process, though there are no defined offsets established by the New Mexico Environment Department (NMED), and each case is evaluated independently. A reasonable distance depends on rate and volume of fluids injected, separation between freshwater aquifer and injection zone, and aquifer characteristics such as hydraulic conductivity and degree of fracturing. For this analysis, a reasonable distance is considered to be more than 1,000 feet.

Hydrogeologic conditions. The hydrogeology of the area will need to be evaluated to determine the ability of the subsurface conditions to accept the concentrate. This information will be used to locate the injection well.

3.3.5.2.2. Permitting Considerations

Permitting an injection well for concentrate disposal will be subject to NMED Ground Water Quality Bureau (GWQB) regulations specified in 20.6.2 New Mexico Administrative Code (NMAC) for groundwater and surface water protection. The three components to permitting an injection well for concentrate disposal are as follows:

Land access. For land access, no permit is required if the injection well is located on a parcel owned by the water supply system owner. If the proposed site is on state or federal land, a special use permit may be required. The special use permit also may require an environmental assessment or environmental impact statement.

New Mexico Office of the State Engineer (NMOSE) Well Drilling Permit. The NMOSE well drilling permit is relatively easy to obtain. For an injection well, the NMOSE will require design specifications similar to an artesian plan of operation. The NMOSE permit does not require public notice.

Discharge Permit from NMED GWQB. Based on NMED underground injection control well classification (20.6.2.5002 NMAC), an injection well for concentrate likely would be classified as a Class I (nonhazardous) or Class V (Table 11). The selected injection well location will require monitoring to comply with 20.6.2.3103 NMAC discharge standards for groundwater with 10,000 mg/L or less TDS and 20.6.2.3107 NMAC monitoring requirements (NMAC, 2001; NMED, 2006).

The anticipated timeline for an injection well is about 4 to 5 years, including design, construction, pilot testing, and permitting. Table 11 describes the possible classifications for wells in the area. Additional evaluation of the aquifer in the area is required to identify formations and the TDS levels in the aquifer.

Table 11. Injection Well Classification

Injection Well Classification	Regulated by	Code Sections	Comments
Class I (nonhazardous) Description: Class I wells inject fluids beneath the lowermost formation that contains 10,000 mg/L or less TDS.	NMED	20.6.2.50 02.B.(1) NMAC	Minimized perception that the concentrate disposal is impacting the water quality of a freshwater aquifer. A subsurface investigation drilling program will be needed to confirm subsurface formations and groundwater TDS concentration.
Class V (dry well) Description: Class V wells inject a variety of fluids and are those wells not included in Class I, II, III, or IV. “Dry” well refers to injection in the vadose zone and not the aquifer itself.	NMED	20.6.2.50 02.B.(5) NMAC	If dry injection zone above the water table exists, a water quality comparison of the concentrate will be needed to demonstrate no degradation of the water quality to the underlying aquifer. A pilot testing program may be needed to demonstrate that the dry injection zone can take the concentrate disposal rate and volume. Investigation will be needed to determine permeability of the dry injection zone, which could impact pumping requirements and cost.

3.3.5.2.3. Cost Considerations

To estimate costs of implementing deep-well injection at the proposed BWRO facility, costs associated with deep-well injection at six different RO facilities were compiled. Table 12 provides a summary of these costs (Archuleta, 2015; AWWA, 2019).

To comply with permitting requirements, a backup method must be provided for injection wells for the times that the injection well must be taken offline for maintenance. The backup method can be a second injection well or another concentrate disposal method.

The injection well site is estimated to be approximately 20 miles away, and slightly downstream from the proposed BWRO facility to allow enough distance from the existing source water wells.

Table 12. Summary of Recent Construction Costs for Deep-Well Injection

	El Paso, Texas	San Antonio, Texas	East Cherry Creek, Colorado	Vero Beach, Florida	Sterling, Colorado	North Miami Beach, Florida
Number of wells	3	2	1	1	2	1
Injection depth (feet)	3,700–4,000	4,200–4,800	10,500	1,650 and 3,000	6,000–7,000	2,858
Injection tubing inner diameter (inches)	--	--	7	16.6	7	14.46
Injection flow (gpm)	--	--	200	840	200	0
Cost (million US $)	$7.75 (3 wells)[1]	$4.40 (1 well)[2]	$3.20[3]	$4.44[4]	$4.50 (2 wells)[5]	$4.90[6]
Year	2007	2012	2011	2010	2011	2009

(1) Drilling and well casing only. Surface facilities (tanks, controls, piping) were an additional $4.94 million; injection tubing, instrumentation, and controls were an additional $1.55 million; all costs updated to 2012.
(2) For construction of the first well, there was an additional $0.64 million for planning, design, and permitting.
(3) Does not include permitting, engineering, and construction management.
(4) Injection wells (drilling, casing) were $4.44 million; about 3 miles of concentrate pipeline was $2.83 million; pump stations, emergency generators, and 3 MG storage facility was $3.37 million; design, permitting, and construction services were $0.92 million.
(5) Two wells were drilled to provide redundancy.
(6) Capital expenditure (minus pump and pipe) was $4.9 million; piping and pump costs were comparatively small at $350,000 because the system is near the desalination plant.

3.3.5.3. Evaporation Ponds

In arid climates, concentrate can be disposed of effectively using evaporation ponds. The evaporation ponds can be constructed as passive systems or as ponds equipped with mechanical enhancements. As an example, for the existing 1.0 MGD BWRO facility in Alamogordo, New Mexico, 13.3 acres of passive evaporation ponds were designed to retain 0.1 MGD concentrate. The Alamogordo ponds were sized to dispose of concentrate based on a seasonal (4-month) operation of the plant.

Design was later modified to reduce construction costs. About 5-acres of evaporation ponds were constructed and the remaining concentrate will be discharged to the sewer.

3.3.5.3.1. Climate Data and Evaporation Rates

The ability to evaporate concentrate passively (i.e., by natural evaporation) depends on the net evaporation rate throughout the year. Evaporation rates typically are established using measured evaporation from a shallow pan (referred to as "pan evaporation") and adjusted using a factor to estimate the evaporation from a lake or pond. In this study, a "pan-to-pond" factor of 95% is assumed. For brackish or saline water, an additional factor is applied to account for the reduced evaporation rates of concentrate with high TDS. It is recognized that over time, the TDS concentrations in evaporation ponds will increase as more and more concentrate is added. In this study, evaporation rates were reduced to account for the salinity factor.

Table 13 shows monthly net evaporation rates estimated for the area. The annual evaporation rate is 92.9 inches (7.7 feet) based on the data recorded at the NMSU weather station for 1959 through 2005. The precipitation data recorded at the Las Cruces weather station for 1991 through 2021 were used in the water balance. For the proposed BWRO facility, ponds were sized to dispose of concentrate from a new BWRO facility producing concentrate year-round.

Table 13. Evaporation Data for the Santa Teresa Area

Month	Pan Evaporation (inches)[1]	Pond Evaporation with Salinity (inches)[2]	Average Precipitation (inches)	Net Evaporation (inches)
January	3.00	2.52	0.59	1.93
February	4.33	3.64	0.51	3.13
March	7.40	6.22	0.35	5.86
April	9.90	8.32	0.24	8.08
May	12.03	10.11	0.31	9.79
June	12.91	10.84	0.43	10.41
July	12.05	10.12	1.34	8.78
August	10.34	8.69	1.26	7.43
September	8.14	6.84	1.34	5.50
October	6.17	5.18	0.87	4.32
November	3.85	3.32	0.59	2.64
December	2.79	2.34	0.83	1.52
Total	**92.9**	**78.0**	**8.7**	**69.4**

[1] Evaporation data source: https://wrcc.dri.edu/Climate/comp_table_show.php?stype=pan_evap_avg
[2] Precipitation data source: https://en.climate-data.org/north-america/united-states-of-america/new-mexico/las-cruces-17229/#google_vignette

3.3.5.3.2. Evaporation Pond Sizing

Assuming 365 days per year of operation and a concentrate generation rate of 231,000 gpd for a 1 MGD BWRO facility, the volume of concentrate to evaporate is 84.3 MG. Based on a net annual evaporation rate of 69.4 inches (5.78 feet) as shown in Table 13, 45 acres of water surface area and 20 MG storage volume are required to evaporate and store the concentrate produced from a 1 MGD BWRO facility in a year. This surface area increases to 224 acres and 93 MG for the 5 MGD facility. Figure 19 shows the storage capacity required for the 1 and 5 MGD passive evaporation ponds.

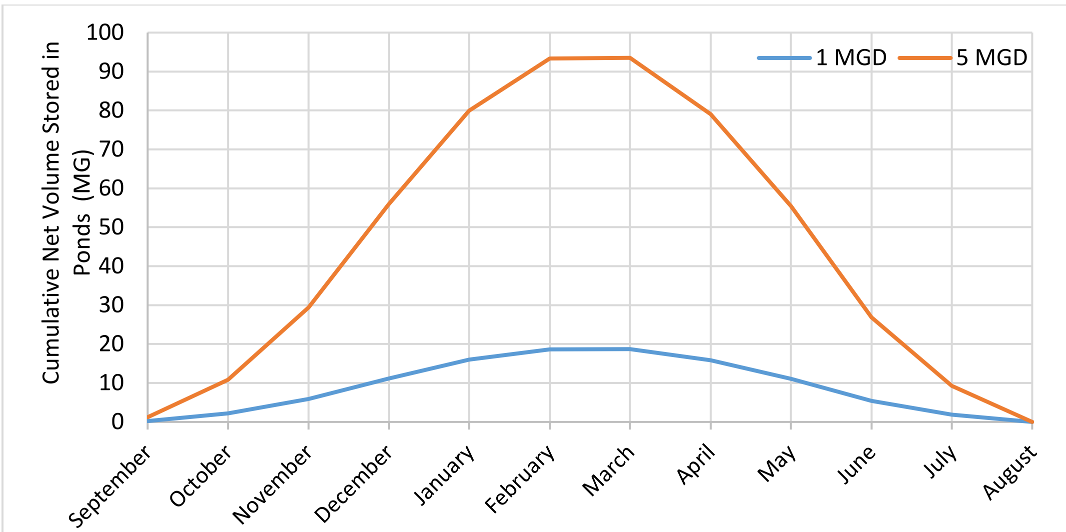


Figure 19. Water Balance for Evaporation Ponds for 1 and 5 MGD Desalination Facilities

The water surface area required may be decreased if mechanical evaporators are used to increase evaporation rates. Various types of mechanical evaporators are available, most commonly incorporating spray nozzles with or without blowers. One disadvantage of sprayer-style evaporators is droplet drift during windy conditions and resulting overspray, which can create an environmental issue with salts accumulating on the ground surface. Use of mechanical aerators may be evaluated further for smaller BWRO facilities with production capacities around 1 MGD.

3.3.5.3.3. Permitting Considerations

Permitting of evaporation ponds is subject to the NMED GWQB regulations specified in 20.6.2 NMAC for groundwater and surface water protection (NMAC, 2001 and NMED, 2006). There are numerous evaporation ponds in New Mexico and no pilot testing is anticipated. NMED GWQB must approve the calculation basis showing adequate pond surface area and storage volume. Monitoring wells also will be required. The estimated timeline for design, construction, and permitting of evaporation ponds is about 2 years.

3.3.5.3.4. Cost Considerations

Past recent projects indicate that construction cost for evaporation ponds is approximately $500,000 per acre, excluding land acquisition costs. Earthwork and liner costs are the two major cost items in this alternative. The passive evaporation ponds are impractical because of the large area required and the associated construction costs. Just the cost of liner for 45 acres of water surface area is estimated at $6 million. Therefore, passive evaporation ponds are considered unfeasible for the proposed BWRO if the facility is operated year-round. Passive or mechanical evaporation ponds may be considered for seasonal operations for the 1 MGD BWRO facility.

3.3.5.4. Sanitary Sewer Disposal

One of the common methods of RO concentrate removal is disposal into the sanitary sewer system if the wastewater treatment plant can handle the increased TDS concentrations and provide enough dilution with municipal wastewater flows. A sewer line would be needed to transport the concentrate to the treatment plant.

There are three wastewater treatment plants serving the project area. Figure 20 shows the locations of these plants.

Sunland Park Wastewater Treatment Plant (WWTP): This plant, together with the North WWTP, mainly serves the City of Sunland Park. The plant was constructed in 1988 with a 2.1 MGD treatment capacity. The existing influent flows are less than 1 MGD; however, the plant has several aging components that are hindering its ability to provide reliable treatment. A preliminary engineering report will be prepared in 2024 to identify necessary improvements for the plant. Existing developments surround the WWTP and so its ability to expand is limited unless a membrane bioreactor technology is used.

North WWTP: The new North WWTP was constructed in 2019 with a design capacity of 1 MGD. The plant is receiving wastewater from the residential and commercial developments as well as industrial institutions, including the Stampede meat processing facility. The plant is currently at capacity in terms of the organic loads it is receiving. Current flows are at about 0.8 MGD. There are ongoing discussions about expanding the North WWTP to 2 MGD to provide service to future developments in the area.

West Mesa WWTP: The West Mesa WWTP (also known as the Santa Teresa or the County WWTP) serves the unincorporated Santa Teresa Border Region as well as La Union. Three lift stations pump wastewater collected from the La Union area to the plant. Built in 2001, and expanded in 2016, the existing design capacity for West Mesa is 0.6 MGD and the plant is currently receiving about 0.05 MGD.

Concentrate disposal to the sewer system is not recommended for the area for the following reasons:

- Existing plants do not have the hydraulic capacity to accept the additional concentrate flows identified in Table 10.
- Even if the existing WWTPs were expanded, the additional concentrate volume is comparable to the actual municipal flows. The mixed wastewater would result in TDS concentrations of 2,500 mg/L or higher depending on actual wastewater flows.
    - The high TDS would adversely impact the treatment process efficiency. In general, bacteria are known to adapt to elevated TDS concentrations and continue its functions under close monitoring of operations. However, it is more likely that TDS concentrations of 2,500 mg/L or more will reduce the relative abundance of microbial species necessary for removing nitrogen and organic matter and, therefore, decrease microbial activity and denitrification efficiency.
    - The high TDS would increase scaling and adversely impact equipment operation and maintenance at the WWTPs. The diffusers and the aeration system would likely experience frequent fouling, which would impact treatment efficiency.
- The high TDS would impact effluent permitting.
    - Sunland Park WWTP and North WWTP discharge the treated effluent to Rio Grande under National Pollutant Discharge Elimination System (NPDES) permits. Discharge of high TDS concentrations to the Rio Grande would need to be evaluated and discussed with EPA to obtain approval, if possible.
    - West Mesa WWTP land applies its treated effluent under an NMED GWQB permit. NMED will not allow land application of effluent with TDS concentrations higher than 1,000 mg/L (NMED, 2006).

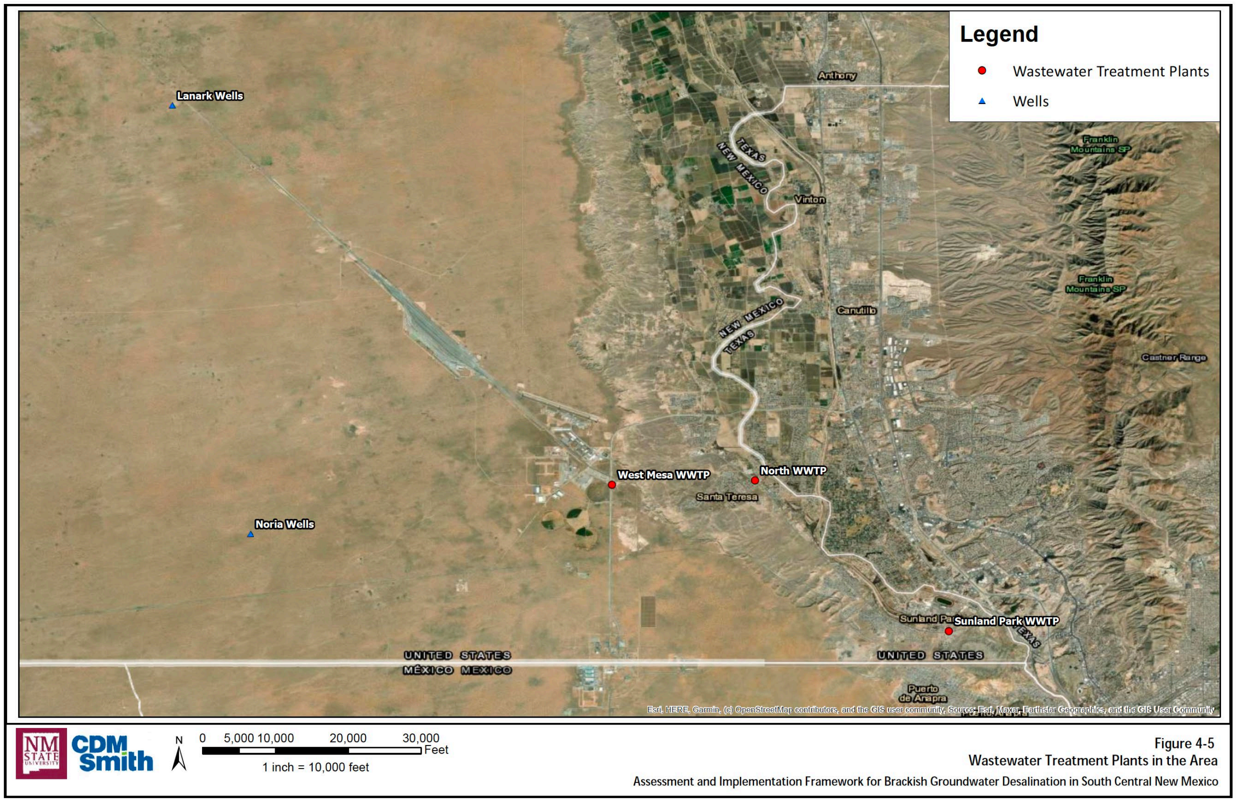


Figure 20. Wastewater Treatment Plants in the Area

3.3.6. Finished Water Storage and Distribution

The treated water from the BWRO facility will be stored in a clean water storage tank and will be pumped to the distribution system.

3.3.6.1. Finished Water Storage

An aboveground finished water storage tank is needed to store water and serve as a clearwell upstream of the BPS.

According to the American Water Works Association (AWWA) M32 manual (AWWA, 1989), the storage volume available to the system should be capable of supplying the maximum required fire event as well as the equalization storage for one day of PDD. Since domestic demand changes with time throughout the day in accordance with the diurnal curve, there will be times during the day when the supply of water from the BWRO facility will be larger than the demand, which will allow the tank to fill. There also will be times during the day when the demand exceeds the supply of water, which will drain the tank. The volume drained from the tank is called equalization volume and is equal to the volume that must already be in the tank at the beginning of a draining period. This will assure that the tank's water level does not drop below the minimum level required to provide adequate system pressure or dip into fire protection storage.

The conceptual design presented in this study assumes a 1 MG storage tank downstream of the BWRO facility. Storage capacity of the tank should be finalized after additional evaluation of existing peak day water demands, fire flows, and emergency storage in the system.

3.3.6.2. Finished Water Booster Pump Station

A BPS will be used to pump water from the storage tank into the distribution system. Pumps will be skid-mounted and will include discharge piping, a flowmeter, and a surge-anticipator/relief valve. The pumps will be equipped with variable frequency drive controls paired with water level sensors in the storage tank. A building will house the pumps and all related infrastructure.

The booster pumps will need to be sized based on the transmission line length as well as peak demands of the water system. Additional analyses will be required to adequately determine pumps operating point and motor horsepower (HP). For this study, the total operating motor HP for the booster pumps is estimated to be 300 HP for a 16-hour-per-day operation.

3.3.6.3. Finished Water Transmission / Distribution Lines

A transmission line will be constructed to convey flow from the BPS into the distribution system. In the design of transmission lines, maximum velocities and headloss are considered to balance the cost of pipe materials and the energy required to provide adequate hydraulic head to the system. The new transmission line will be designed to limit velocities to 5 feet per second (ft/s). Headloss in long, large-diameter transmission pipelines is typically limited to 1 to 3 feet per 1,000 feet to minimize pressure surges and energy consumption. An upper velocity limit of 7 ft/s can be allowed for short periods of time, but flows exceeding this velocity will begin to erode the pipe and eventually cause leaks or breaks in water lines. Since fire flow events occur very rarely and for relatively short periods of time, velocities can exceed the maximum values during a fire flow.

For this study, an 18-inch-diameter transmission line of about 5 miles is assumed to pump finished water from the 5 MGD BWRO facility into the distribution system. The length and size of the transmission line and the connection point to the distribution system would be finalized based on the location of the BWRO facility.

3.3.7. Brackish Water Reverse Osmosis Facility Location

A preliminary siting evaluation was performed to identify potential locations for the BWRO facility. Existing zoning, land use patterns, location of existing facilities, and roads were considered in this analysis. The BWRO facility and its auxiliary infrastructure, excluding the brackish water supply and concentrate injection well sites, may require approximately 5 to 10 acres of land. The facility siting analysis considered the following approaches:

- *Brackish water supply well sites*. Locating the BWRO facility near the brackish water supply wells may offer the advantage of minimizing raw water pipeline length. Since the raw water supply line conveys more flow than the finished water transmission line, it will be the largest pipe in diameter. However, based on the possible location of brackish water wells (Figure 16), the remote location of the sites and accessibility will be significant disadvantages for plant construction and operation. Additionally, pumping costs into the distribution system would increase because this distance to the facility increases. Therefore, it is not recommended locating the BWRO facility at brackish water supply well sites.
- *Existing water infrastructure sites.* Locating the BWRO facility at one of the existing water system infrastructure sites such as shallow groundwater wells, ATFs, or storage tanks will offer the advantage of minimizing treated water transmission line, minimizing additional storage volume, and using existing facilities including electric service and existing buildings. Upgrading an existing BPS or increasing storage tank capacity could be easier than constructing new infrastructure.

Analysis suggest that it is most beneficial to locate the BWRO facility on ground elevations higher than the community to allow connection to the distribution system at the highest pressure zone. This configuration will minimize pumping needs for the treated water. Existing water pipelines can be used as much as possible. Locating the BWRO near the existing STC ATF or the STIP appear to be the most feasible locations. Figure 21 show potential sites that can be used for the BWRO facility. The existing zoning for these sites is Cl-2, intended to provide for medium-intensity industrial activities that serve a community.

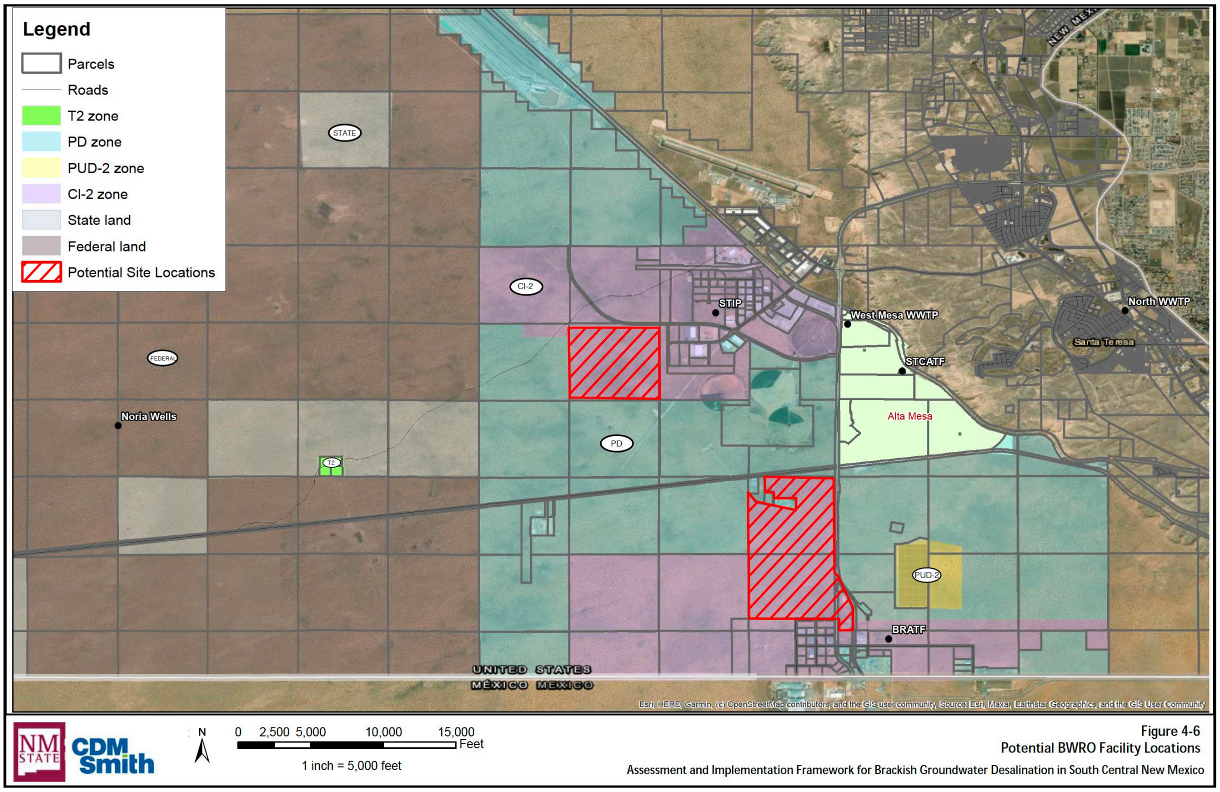


Figure 21. Potential Locations for the Brackish Water Reverse Osmosis Facility

3.3.8. Permits and Easements

The following permits and easements are likely required for a BWRO facility in New Mexico:

- Water rights for the brackish water supply
- NMED Drinking Water Bureau approval and permit
- NMED permit for injection wells and/or exploratory wells for concentrate disposal
- Easements or rights-of-way for raw water, finished water, and concentrate pipelines
- Building permit, construction permit, and stormwater handling permit

3.3.9. Cost Estimates

3.3.9.1. Construction Cost Estimates

Table 14 presents the engineer's OPCC for the 5 MGD BWRO facility and its supporting infrastructure (water storage tank, BPS, and treated water transmission line). Following are the key assumptions and cost factors:

- Major equipment and materials were based on quotes available for similar projects that have been completed within the last 5 years or are currently being designed.
- Raw water supply line will be 18 inches in diameter and 25 miles from the wells to the BWRO.
- BWRO facility will produce 5 MGD treated water using RO technology.
- BWRO system will be installed in a 14,000-square-foot pre-engineered metal building.
- Building space includes no laboratories or maintenance shops.
- Finished water storage tank will be a 1 MG ground-level tank located at the BWRO facility.
- BPS will be located at BWRO facility site.
- BPS will be installed in a 4,000-square-foot pre-engineered metal building.
- Treated water transmission line will be 16-inches in diameter and 5 miles to the connection to the existing water distribution system.
- Two injection wells (one operating and one backup) will be used for concentrate disposal.
- Concentrate disposal line will be 8 inches in diameter and 20 miles to the injection wells.
- Construction soft costs (contractor general conditions, mobilization / demobilization, overhead, profit, bonds, insurance, temporary facilities, stormwater handling, facility commissioning, and startup) are included at 12% of total construction cost.
- Construction contingency is included at 30% of total construction cost.
- Land acquisition costs for the BWRO facility, brackish water supply wells, and concentrate injection wells are not included.
- Engineering services included at 15% of total construction cost. These services consist of planning, facility design, and engineering services during bidding and construction phases.
- Water rights costs are not included.
- All costs are year 2023 prices. Costs should be updated for inflation for the year construction is expected to occur.

Table 14. Engineer's Opinion of Probable Construction Costs for 5-MGD Desalination Plant

Item	Item Description	Unit	Cost
A. General			
1	Construction soft costs	LS[1]	$38,380,000
2	Site improvements	LS	$740,000
B. BWRO facility			
3	Yard piping	LS	$1,000,000
4	BWRO including membranes, equipment, process piping	LS	$8,700,000
5	BWRO building	LS	$4,200,000
6	Chemical storage and feed facility	LS	$1,000,000
7	Electrical, instrumentation, and controls	LS	$20,000,000
C. Other infrastructure			
8	Raw water supply line	LS	$46,200,000
9	Finished water storage tank	LS	$2,140,000
10	BPS including pumps, piping, building	LS	$7,500,000
11	Finished water transmission line	LS	$9,240,000
C. Concentrate management			
12	Injection wells including well pumps	LS	$6,000,000
13	Concentrate disposal line	LS	$21,200,000
D. Contingencies			
14	Construction contingency (30%)	LS	$49,900,000
E. Nonconstruction costs			
15	Permitting	LS	$500,000
F. Construction total			
Subtotal of Items A through EF			$216,700,000
NMGRT for construction at 8.1875%			$17,743,000
	CONSTRUCTION TOTAL		**$234,443,000**
G. Professional engineering services			
Engineering services at 15%			$32,505,000
NMGRT for engineering at 7.625%			$2,479,000
	ENGINEERING TOTAL		**$34,984,000**
H. Project total cost			
PROJECT COST TOTAL			**$269,427,000**

(1) LS: Lump sum. (2). NMGRT: New Mexico Gross Receipts Tax

3.3.9.2. Construction Cost Estimates for Different Design Flows

This study presents the implementation framework for a desalination plant in south central New Mexico for a conceptual production capacity of 5 MGD. Since the final capacity of the BWRO facility is unknown, a cost-capacity method was used to estimate the costs for a desalination facility for 1 and 10 MGD.

The cost-capacity method equation is a Class 4 (study or feasibility) and Class 5 (concept screening) cost estimate approach (Aguinaldo and Bond, 2019; Voutchkov, 2018). Using the construction costs for a facility and the plant capacities (i.e., design flow rates), construction costs for different capacities can be estimated using the following equation:

$$\text{Cost}_{\text{for unknown capacity}} = \text{Cost}_{\text{known capacity}} \times (\text{Unknown capacity} / \text{Known capacity})^{Y}$$

where Y is the cost exponent for the technology being considered. For a modular unit process such as a BWRO, an exponent of 0.74 is applied (Wittholz et al., 2008)

Table 15 shows the estimated construction costs for 1 and 10 MGD BWRO facilities based on the conceptual costs presented for the 5 MGD BWRO. Table 15 includes the costs for the RO treatment facility construction costs only; it excludes professional engineering services as well as construction costs for other supporting infrastructure (such as storage tank, BPS, and treated water transmission line).

Table 15. Construction Costs for RO Treatment Facility for Different Design Flows

Design Flows	BWRO Treatment Only[1]
1 MGD	$35,140,000
5 MGD	$115,545,000
10 MGD	$192,877,000

[1] Construction costs for the BWRO treatment system including contingency, soft costs, and NM Gross Receipts Tax (NMGRT). Engineering services are not included.

3.3.9.3. Operating and Maintenance Cost Estimates

O&M costs associated with the new facilities include power consumption, membrane replacement, chemicals, and general RO system maintenance. Table 16 includes the rates and costs used to calculate O&M costs for the proposed BWRO facility at different design flows.

Antiscalant costs are based on the current price for totes. If the chemicals are purchased in bulk quantities, costs would be expected to be lower than those used in this cost estimating exercise. Electricity rates are based on the average rates from El Paso Electric charged to the Kay Bailey Hutchinson (KBH) desalination plant over the July-Sep 2023 period since power to this facility in Santa Teresa is also expected to be supplied by El Paso Electric.

For the RO membranes, the annualized membrane replacement rate is based on a 5-year membrane age. Each RO skid is projected to contain 525 membranes. The annualized cost was calculated for the replacement of 2 skids.

General Preventative Maintenance includes both operator time and minor consumables (e.g. vessel caps, bolts, etc.). The equipment costs associated with this percentage include the RO treatment system and deep well injection system.

Table 16. O&M Rates and Costs

Item	Value	Units
Antiscalant	$4.01	$/lb
Membrane Replacement (Every 5 Years)	$131,000/yr	$600/membrane
Electricity Rates	0.059398	$/kWh
Hours in Operation Per Day	24	Hours
Days in Operation Per Year	365	Days
General Preventative Maintenance	(1% of Equipment Cost)	

3.3.9.4. Life Cycle Costs

O&M rates presented in the previous section were used to calculate annualized costs for each item in Table 16. These annualized costs were then used to calculate Net Present Value (NPV) costs based on the following parameters:

Inflation and discount rates are challenging to predict accurately in the current economic environment. For this report, an inflation value of 3.5% and a discount rate of 5% were used. A life cycle of 20 years was used, which is common for capital improvement projects of this nature. Life cycle costs were calculated by adding total capital costs (Table 15) and the calculated NPV of annual O&M costs. Table 17 provides a summary of the life cycle costs for the desalination facility at the three different design flows of interest. A breakdown of the life cycle costs at each of the three design flows presented in Table 17 are presented below in Figure 22. The conceptual costs estimated in this study and presented below are meant to provide a comparison in the magnitude between the life cycle costs of the different potential capacities for the proposed BWRO facility.

Table 17. Life Cycle Costs of RO Treatment Facility for Different Design Flows

Item	Cost (1 MGD BWRO)	Cost (5 MGD BWRO)	Cost (10 MGD BWRO)
Annualized electricity-RO	$114,000	$566,000	$1,131,000
Annualized membrane replacement	$132,000	$132,000	$132,000
Annualized antiscalant	$61,000	$301,000	$602,000
Annualized general RO and injection well maintenance	$48,000	$157,000	$263,000
Yearly O&M cost	$360,000	$1,160,000	$2,130,000
Total capital cost [1]	$35,140,000	$115,550,000	$192,880,000
NPV of O&M cost [2]	$6,212,000	$20,016,000	$36,750,000
20 Year life cycle cost	**$41,400,000**	**$135,570,000**	**$229,700,000**

[1] Total capital cost of BWRO facility only including contingency, soft costs, engineering services, and NM Gross Receipts Tax.

[2] PV based on 20 years and 2% interest rate.

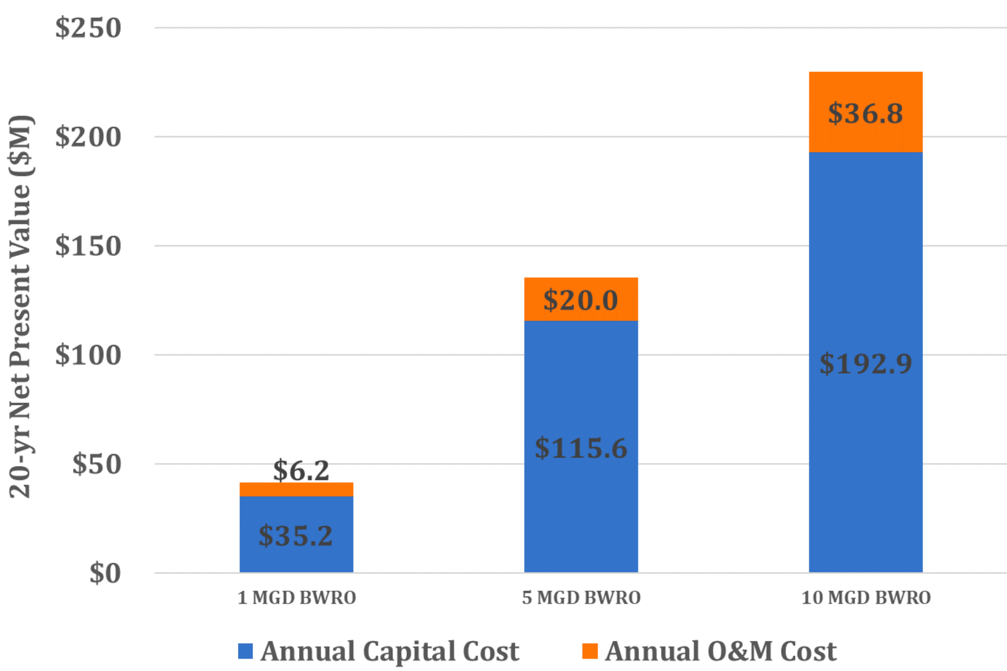


Figure 22. Capital Cost and Annual O&M Cost Comparisons Between 1, 5, and 10 MGD BWRO Facilities.

3.3.9.5. Unit Cost of Water

The conceptual costs estimated in this study were used to calculate the unit cost of water using the following formula:

Unit cost of water = Life cycle cost /Total volume of water treated over a 20-year period

Table 18 shows the conceptual costs estimated for the BWRO facility in this project compared with other desalination facilities that are built in the United States. The unit cost of water for the BWRO facility excluding other supporting infrastructure (storage tank, BPS, treated water transmission line) is $4.0 per 1,000 gallons. The unit cost calculated for this project is higher than previously constructed plants because the construction costs today are significantly higher than the costs from 2020. In addition, costs presented in this study are conceptual costs with 30% contingency, whereas the other examples in Table 18 are costs for projects that were actually designed and constructed.

Table 18. Comparison of Proposed Facility with Other Desalination Plants in the U.S.

	Kay Bailey Hutchison Desalination Plant, Texas [4]	**Eastern Municipal Water District Desalters, California [4]**	**Alamogordo Desalination Plant, New Mexico [2]**	**This project**
Year of construction and operation	2007	2002, 2006, 2021	2020	To be determined 2027+
Design capacity (MGD)	27.5–33 MGD	Menifee (3.1 MGD) Perris I (5.6 MGD) Perris II (3.5 MGD)	1 MGD	5 MGD
Desalination technology	RO	RO	RO	RO
Concentrate management	22 miles to 3 injection wells	70 miles through a pipeline to the ocean	Evaporation ponds and sewer disposal	Deep-well injection
Feed TDS (mg/L)	2,000–3,600	2,300	2,330	2,500
Water recovery of desalination systems	BWRO 83%	BWRO 70–75%	BWRO 70%	BWRO 75%, Overall recovery 81.3%
BWRO construction costs	$91 million	$143.4 million	$10 million	$115.5 million [1]
Unit cost of water ($/1,000 gallons)	$1.6–2.1[3]	$3.0–3.8[3]	$2.9[3]	$4.0

[1] Based on BWRO treatment cost only shown in Table 4-12, excluding the supporting infrastructure, treated water transmission pipeline, storage tank, BPS as well as engineering costs.
[2] Plant currently not in use.
[3] Based on 2020 U.S. dollars.
[4] Reference: (Xu et al., 2022)

3.3.10. Potential Funding Sources

Funding sources for a desalination facility in south central New Mexico could be obtained from the following sources:

- Drinking Water State Revolving Fund (DWSRF) administered by the New Mexico Finance Authority
- Water Trust Board (WTB) funding administered by the New Mexico Finance Authority
- Colonias funding administered by the New Mexico Finance Authority
- Capital Outlay (legislative appropriation)
- BOR Title XVI – WaterSMART Program

The aforementioned funding sources are the most appropriate sources for funding a water treatment plant. Funding from DWSRF, WTB, and Colonias is typically a combination of grant and loan; in the case of WTB funding, the utility would need to provide matching funds. Interest rates are currently low and loan forgiveness is available in the form of a grant for DWSRF funding. Capital Outlay funding could be used for design or for supplementing other funding sources for construction.

BOR Title XVI funding also could be used for the desalination facility. Title XVI funding requires an application, completion of a feasibility study, and an environmental information document. The amount of funding available for a Title XVI project is 50% of the total project cost, meaning the utility will need to provide the other 50% in matching funds, which could come from DWSRF, WTB, or other nonfederal funding sources. Title XVI funding is also a competitive selection and highly dependent on the program receiving funding from Congress.

Currently, Governor Michelle Lujan Grisham is seeking a $500 million investment from the New Mexico legislature through capital funding over two years to create the Strategic Water Supply (SWS). As envisioned, the State of New Mexico will purchase treated brackish water under a contract agreement with individual vendors. Initially, the State of New Mexico will utilize the contract agreements with individual vendors to facilitate expanded industrial uses of the treated water (NMED, 2024). The State of New Mexico intends to utilize the funding set aside for the SWS to enter into contracts for the procurement of treated brackish water or treated produced water that meets certain standards for quantity and quality. Those SWS funds will not be provided to fund engineering studies, capital expenditures or operational expenditures. That said, the State of New Mexico is open to discussing other sources of public funding that might support individuals or organizations for these costs. Such funding opportunities may complement the dedicated SWS funding and be used to complement the resources necessary to develop the specific supplies developed under SWS (NMED, 2024).

3.3.11. Conclusions and Recommendations

The purpose of this report is to develop an implementation framework for brackish groundwater desalination in south central New Mexico near Santa Teresa Community and the City of Sunland Park. The report provides an overview and feasibility study for a BWRO facility capable of treating brackish groundwater in the Santa Teresa area. If a viable brackish water supply was found in the area through hydrogeological investigations, the conceptual design presented in this report can be used as a framework for project implementation.

A desalination project will consist of the following elements:

- New brackish water supply wells and a raw water supply line to the BWRO facility
- BWRO facility comprising sand strainers, cartridge filters, RO membranes, and chemical feed systems in a building
- Two deep injection wells and disposal line for concentrate
- Supporting infrastructure including:
    - Treated water storage tank
    - BPS
    - Treated water transmission line to connect to the distribution system

The cost associated with the construction of a 5 MGD BWRO treatment facility is estimated as $115.5 million. This is equivalent to $4 per 1,000 gallons of treated water and is comparable to previously completed desalination plant projects in the United States (Table 18). The total project cost including supporting infrastructure and engineering services is $269.5 million based on 2023 prices. Additional time requirements associated with future studies and permitting procedures necessary before constructing the facility are expected to increase this cost in proportion to inflation.

The following additional studies are required before the project can be implemented:

- Hydrogeological investigations to locate the brackish water supply wells and injection wells
- Permitting of injection wells
- Water rights purchase for brackish water supply
- Land acquisition for the BWRO facility, brackish water supply wells, and injection wells
- Preliminary engineering report for the BWRO facility to finalize the conceptual design presented in this report
- Final design of the system, plant commissioning, and operator training

3.4. Multi-criteria Decision Making (MCDM) Analysis

3.4.1. Introduction of MCDM

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 19. Each of these criteria has a goal to maximize or minimize and will be assigned a measurement per system based on scientific evaluation. Criteria will be assigned a weight to vary their relative importance. The Visual Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) software was used to create a complete table with subsequent values found in the results and discussions section 3.4.7 of this report. 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 19 were selected based on the goals of stakeholders and sustainability targets. Some were sourced from other published MCDM analyses evaluating water systems. For this analysis, all of the criteria are weighted evenly. Weights may be easily changed with stakeholder input in the future. 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. Many of these criteria are related. Source and product water quality is 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 operation and maintenance 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.

Table 19. 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	Effect on local ecology
Return on investment	Energy consumption/GHG emissions
Employment	Disposal (hazardous waste & safety)

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, some 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 the desalination project.

3.4.2. Methodology of MCDM

Similar facilities in the region of Santa Teresa 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 KBH Desalination Plant were used to inform the potential impacts of a new desalination plant and supporting facilities in the southern New Mexico region. 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 analysis.

3.4.3. System Performance

3.4.3.1. 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 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. The pilot testing and Engineering Design Report demonstrated that using brackish water RO can meet the water quality standards for targeted uses.

3.4.3.2. 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 and 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 apply 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 be a 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.

3.4.3.3. Effect on Water Resources

Overpumping has occurred from freshwater being withdrawn from the aquifers faster than its natural recharge rate. However, the nearby KBH Desalination Plant slows the intrusion of brackish water into freshwater wells by intercepting brackish groundwater flows that could intrude on freshwater sources and reduce the withdrawals of fresh groundwater (Landreth and 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 for end uses like irrigated agriculture and livestock where the standard of potable water is not needed. Therefore, this entire flow may be used for municipal drinking water and industries that require drinking water quality.

If the RO concentrate is to be disposed of 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 be done before permitting and full implementation of this disposal method. For example, the Texas Underground Injection Control (UIC) regulations specify the injection well construction requirements followed by the KBH Plant (Landreth and 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.

3.4.3.4. System Maintenance & Operation Complexity

Routine system cleaning is needed to remove fouling of membranes. 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 injection site at the KBHDP (Landreth and 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 KBHDP, 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 and 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 estimated. According to the KBHDP EIS report, their depths would be approximately 900 to 925 feet, their diameter 26 inches with a 16-inch diameter lining, and backfilled with gravel (Landreth and Sansone, 2004).

3.4.4. Economic Impacts

3.4.4.1. Return on Investment

The projected life span of the KBHDP and its pipelines is 50 years. For the Santa Teresa facility, a life span of 20 years is assumed based on usual engineering economics. The economic valueof 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 and 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 and 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 has 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.

3.4.4.2. Employment

For the construction of the KBHDP and its injection wells, 25 full-time employees were hired. For operation and maintenance, 16 full-time workers are employed at the 27.5 MGD KBH Plant. It is estimated 5 staff may be needed for a proposed 5 MGD Santa Teresa facility. Even though the intended end use for the brackish groundwater facility is industrial and 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 and Raucher, 2011).

3.4.4.3. Capital Plus Operation & Maintenance

It was predicted that the capital cost of the KBHDP 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 and Sansone, 2004). However, the total capital project cost ended up being about $91 million, with a disposal cost of $19 million. The KBHDP is a much bigger facility than the one proposed in Santa Teresa, since it has a design capacity of 27.5 MGD compared 5 MDG (Texas Water Development Board, 2014).

According to the Engineering Design Report, the cost associated with the construction of a 5 MGD BWRO treatment facility is estimated at $115.5 million. This is equivalent to $4 per 1,000 gallons of treated water and is comparable to previously completed desalination plant projects in the United States (Table 18). The total project cost, including supporting infrastructure and engineering services, is $269.5 million based on 2023 prices. Additional time requirements associated with the future studies and permitting procedures necessary before constructing the facility is expected to increase this cost in proportion to inflation.

3.4.4.4. Effect on Water Rates

Any change in water rates for residential and industrial end users will have the most impact on those experiencing poverty. The demographic index of the southern New Mexico and western Texas region is shown in Figure 23. 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 (US Environmental Protection Agency, 2022):

$$\text{Demographic Index} = (\%\ \text{people of color} + \%\ \text{low-income})/2.$$

A census of the population served by the intended brackish water desalination plant is recommended to determine the 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 the Appendix A. For the El Paso Water Utility ratepayers, a 19 percent increase was projected in 2004 to cover water infrastructure costs like the KBHDP. 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 and 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 increase was determined for three major crops grown with Bureau of Reclamation water (Moore and 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.

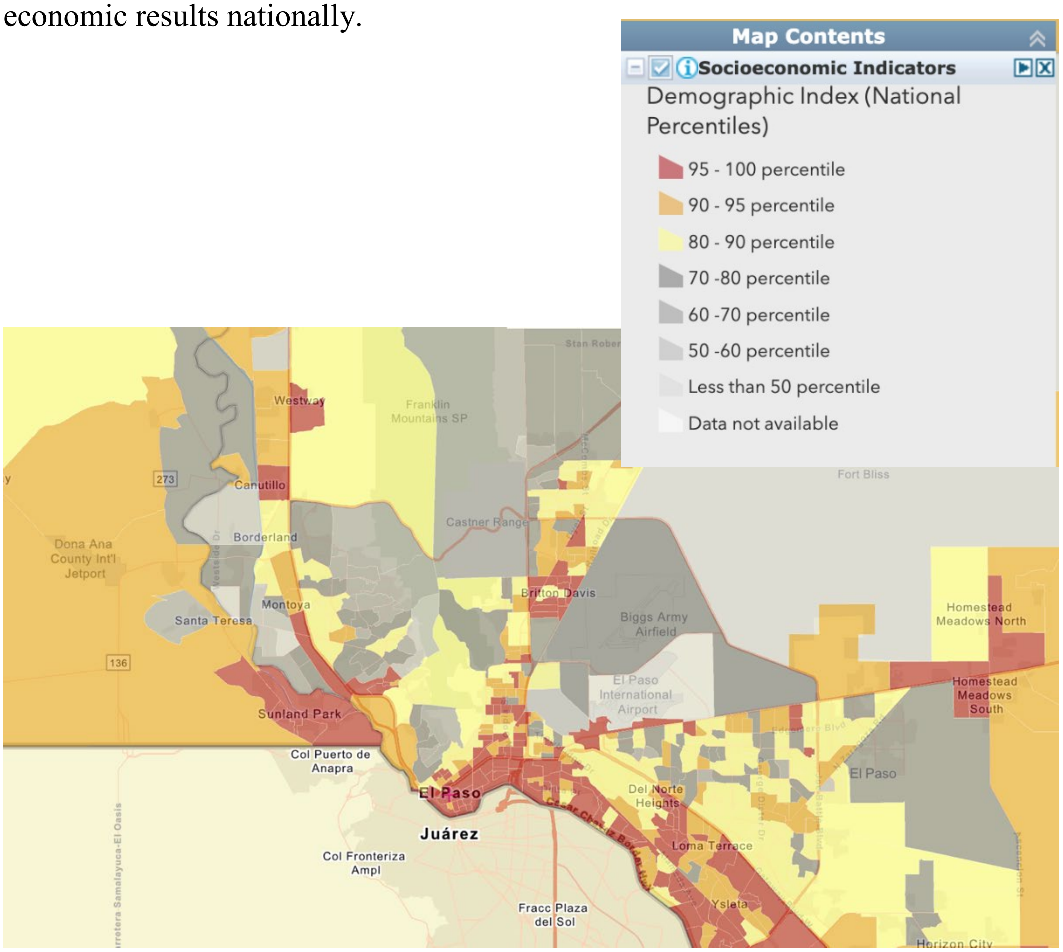


Figure 23. Demographic index by Census block in the southern New Mexico and western Texas regions. Source: EPA Environmental Justice Screening and Mapping Tool (Version 2.0)

3.4.5. Social Impacts

3.4.5.1. 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. For example, in promotion of involvement and sharing information, the public had an opportunity to comment on the KBHDP'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 and Sansone, 2004). The KBHDP 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, for convention areas, and for other public education.

While concerns about the aesthetics and impact on traffic patterns were raised for the KBHDP, 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 KBHDP, and contact with the appropriate tribes and tribal governments was initiated (Landreth and Sansone, 2004).

3.4.5.2. 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 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 necessarily 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 benefit for 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 and Raucher, 2011). Furthermore, water conservation in irrigation can actually lead to increased water use, rendering this strategy counterproductive (Ward and Pulido-Velazquez, 2008). What needs to be considered with the implementation of desalination in this area is that consumption from the Mesilla Basin may come quickly without proper cooperation and management between New Mexico, Texas, and Mexico (Ward et al., 2018).

3.4.6. Environmental Impacts

3.4.6.1. Effect on Local Ecology

The construction of the Santa Teresa 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 KBHDP 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 KBHDP 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 and 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 or evaporation ponds if not managed properly. 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 Chihuahuan Desert, where there is a relatively low density of wildlife. Desert shrubland exists in this region today and vegetation has already been disturbed. Any chemical storage tanks will include a 110 or 150% volume secondary containment structure to prevent spilling from leaks or tank failures (Landreth and Sansone, 2004). Use of non-chemical pretreatment such as EMF can reduce the chemical uses and reduce environmental impacts.

3.4.6.2. 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 KBHDP. This 18-month construction period may slightly increase air pollution emissions (Landreth and Sansone, 2004).

Operational air emissions are considered minor and will not require permitting. The bulk of air emissions will result from energy use. The KBHDP 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 KBHDP's water wells and pipeline pumps. This does not include the injection wells, which would be utilized for disposal of the concentrate (Landreth and 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) are an option that is being considered for powering 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 a negligible part of the power requirements for the facility.

3.4.6.3. Disposal (Hazardous Waste & Safety)

The concentrated brine removed from the feed water in the desalination process is disposed of through an underground pipeline of 22 miles to a 2,000-ft deep well injection site at the KBHDP. The pipeline material of high-density polyethylene (HDPE) and polyvinyl chloride (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 and Sansone, 2004).

Should there be a leak or break in the pipeline that travels from the desalination treatment facility to the injection site, 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 brine disposal site 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 and 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 KBHDP. These chemicals are not unique to desalination facilities and are commonly found in water treatment plants across the U.S. (Raucher and Raucher, 2011).

3.4.7. Discussion

The evaluation of criteria for the Santa Teresa desalination project is summarized in Table 20 based on stakeholders inputs. 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 20. 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	$4/thousand gallons product water for 5 MGD desalination plant
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 to be moderately positive because of the high quality of RO product water. 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 water quality standards (Table 7). However, these are chemicals that may be effectively removed with RO treatment technology (Table 8).

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.

As an alternative, municipal wastewater reuse may be considered. However, there may be water rights issues with this option because of requirements set by the New Mexico Office of the State Engineer. Because the public water supply is pumped from groundwater close to the Rio Grande, this water needs be replaced with the wastewater return flow. If the wastewater effluent were to be recycled, this return flow would no longer offset the pumping for municipal uses. However, according to CRRUA, if the feed water is sourced far enough west away from the Rio Grande, this water may be able to be recycled without concern for water rights. Another option is to ensure that the effluent of the recycled wastewater is applied to land, completing the offset requirements.

3.4.8. Results & Conclusions

The MCDM analysis evaluates the benefits and challenges of developing the brackish water aquifer in Santa Teresa to supplement municipal and industrial water demand and to address the increasing water scarcity.

Brackish water reverse osmosis is a mature technology and is capable of producing product water meeting USEPA drinking water standards. 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.

This water resource is a relatively uncontroversial source, and the potential for acceptance through public outreach and involvement is high. Because of the nature of the source water, energy demand is higher than for traditional water treatment. By investing in a solar farm to power the desalination facility, both the environmental and social impacts could be positively influenced. Charges may increase for ratepayers, which 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. The success of this option is dependent on the economic arrangement and reduced treatment costs.

This data and the results may benefit stakeholders and partners involved in developing the Santa Teresa desalination project. 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.

3.5. Laboratory and Pilot Testing of EMF for Membrane Scaling Control

3.5.1. Introduction

Desalination technologies such as reverse osmosis (RO) and nanofiltration (NF) membranes are principal methods for treating brackish groundwater. Despite advances in membrane technologies, membrane fouling and scaling remains a key impediment to the successful implementation of membrane processes. Colloidal particles, microbes, and sparingly soluble salts (e.g., $CaCO_3$, $CaSO_4$, SiO_2, and $BaSO_4$) in feed water can attach and precipitate within the membrane polymer matrix or on membrane surfaces leading to membrane fouling and scaling (Xu et al., 2010). Expenditures derived from membrane fouling and scaling consist of direct costs associated with feed water pretreatment, periodic chemical cleaning, increased energy demand, and shortened membrane life as well as indirect costs resulting from reduced water production (Bereschenko et al., 2010; Flemming, 2011; Van Geluwe et al., 2011).

Among various methods developed to prevent or minimize membrane fouling and scaling, such as pretreatment of feed solution, adjustment or modification of membrane properties, hydraulic, chemical and electrical cleaning, and optimization of operating conditions (Noble and Stern, 1995), electromagnetic field (EMF) treatment is a simple chemical-free pretreatment technology (Benson et al., 2000; Lipus et al., 2011). EMF can be applied by permanent magnets (Al-Qahtani, 1996), or by using wires wrapped around or positioned near a metal pipe through which water flows or directly around membrane vessels (Pelekani et al., 2005; Rouina et al., 2016). There are no electrodes in direct contact with the treated water and an EMF is induced due to the alternating current. Treated water is subject to a quick variation of coil voltage in the hertz (Hz) to megahertz (MHz) frequency range (Piyadasa et al., 2017).

Different mechanisms could be involved in the EMF for scaling prevention. EMF was reported to activate colloidal silica present in water to adsorb Ca^{2+}, Mn^{2+} or other metal ions, and then precipitate same from the solution through enhanced particle coagulation processes (Gorey et al., 2009; Sehn, 2008; Zeppenfeld, 2010). Kim et al. stated the EMF anti-fouling technology involved splitting of particles into smaller sizes and an increase of particle zeta potential with an increase in electric field intensity (Kim and Kim, 2007). On the other hand, it was found that calcium carbonate existed as clusters of small, loosely connected, hexagonal-shaped calcite in EMF, rather than dense, sticky aragonite without EMF (Xiaokai et al., 2005). They also reported that EMF increased crystal collision frequency, suggesting that the particle growth was supported predominantly by an agglomeration mechanism instead of nucleation growth (Xiaokai et al., 2005).

However, EMF treatment has been sometimes proven to be ineffective for retarding scale formation (Vedavyasan, 2001). The reported controversial results are likely related to the use of different types of magnetic or electromagnetic devices, their frequency and intensity; non-standardized methods; variations in water composition; or differences in the course of the treatment (Szkatula et al., 2002). The efficiency of magnetic water treatment could also depend on the nature of the pipe materials through which the EMF is transported (Gabrielli et al., 2001). Moreover, there are critical limits beyond which the EMF could not adequately control scaling (N.T. et al., 2005; Pelekani et al., 2005). Therefore, further research is required to better understand the EMF mechanisms and demonstrate its effectiveness in scale control with different water matrices.

There are a number of factors affecting the EMF effectiveness on membrane fouling and scaling control (Lin et al., 2020). These include EMF properties and configurations (e.g., intensity, waveform, frequency, placement locations, and exposure time), water chemistry and composition (e.g., pH, temperature, suspended particles, salinity level, presence of SiO_2, $CaCO_3$, and $CaSO_4$) membrane operations (membrane properties and types, water flux, and water recovery), and pipe materials and thickness (e.g., PVC, stainless steel). Although there are demonstrated beneficial effects of EMF on scale control, there are no systematic studies of the mechanisms by which EMF processes work, and more importantly, the underlying complex physicochemical mechanisms involved in water treatment processes themselves are not well understood.

Feed spacers are important for the impact of fouling on the performance of spiral-wound membrane systems (Siddiqui et al., 2016). Commonly used feed spacers in spiral-wound membrane modules are thin, polypropylene sheets with diamond mesh or web of thin fibers of varying dimensions in both thickness of the fibers and size of the mesh. The feed spacer stimulates localized vorticity which helps to reduce the effects of concentration polarization. Numerical modeling on the hydrodynamic behavior of various feed spacer geometries suggest that the impact of spacers on hydrodynamics and membrane fouling can be improved (Herrington et al., 2018; Siddiqui et al., 2016). The combination of numerical modeling of feed spacers and experimental testing of 3D printed feed spacers is a promising strategy (rapid, low cost, and representative) to develop advanced feed spacers aiming to reduce the impact of fouling/scaling formation on membrane performance and to improve the cleanability of spiral-wound membrane systems.

Aqua Membranes LLC in Albuquerque, NM, manufactures spiral-wound membranes with 3D spacer technology. The feed spacer has been replaced by printing material directly on the membrane surface (Figure 24). The printing process does not damage the membrane, and salt rejection is not compromised. To avoid pressure loss from feed to reject in 40” long elements, the feed spacer height is modified and reported to result in 40% more permeate flow for the same size conventional element (Herrington et al., 2018). The innovative 3D-printed spacers can be combined with EMF to minimize the entrapment of particulates with open channel spacers, minimize membrane scaling potential, and increase water recovery.

The objective of this study has been to evaluate the desalination performance of EMF pretreatment and 3D-printed feed spacers in parallel with the traditional RO system treating brackish water and RO concentrate.

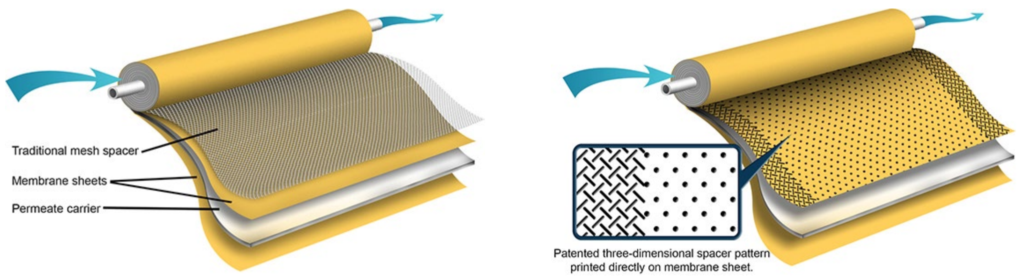


Figure 24. Spiral-wound element with conventional feed spacer (left) and with Aqua Membranes 3D printed spacer technology (right). Source: Aquamembranes.com

3.5.2. Methods

In this study, bench- and pilot-scale experiments were conducted to investigate the effects of EMF technologies on RO membrane scaling control during desalination of synthetic brackish water, brackish water from BGNDRF in Alamogordo, New Mexico; and RO concentrate from the KBHDP in El Paso, Texas. Because there is no brackish water well in Santa Teresa, the pilot testing conducted in these two facilities represents a broad range of brackish water quality that could be applicable for the Santa Teresa desalination project.

3.5.3. Pilot Testing of Different EMF Devices at BGNDRF

3.5.3.1. Effect of AC-induced EMF on Membrane Performance

3.5.3.1.1. Water Flux

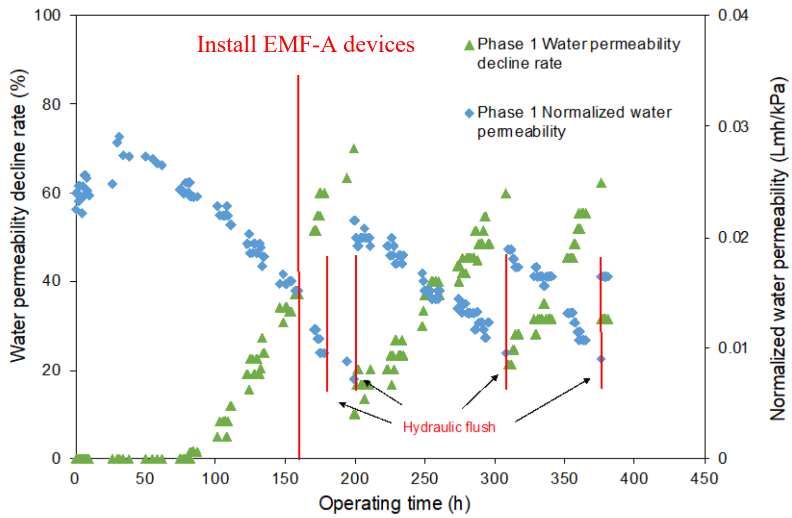
Water recovery reached 50% after 77 h operation for both phases treating Well 2 water. AC-induced EMF devices EMF-A were turned on after 150 h operation for Phase 1 (P1) and from the beginning for Phase 2 (P2). The decreasing rate of the water permeability is slower in P2 than in P1 and the difference increases with the operation time, indicating that the EMF-A devices retarded the fouling and scaling on the RO membrane surface (Figure 25). However, the NWP decreased continuously despite the installation of EMF devices, revealing the EMF can only retard, not completely eliminate, fouling and scaling on the membrane surface at 50% water recovery in this study. ROSA simulation indicated severe calcium-based scaling at 50% water recovery.

When the EMF devices were turned on after 150 h operation in P1, the feedwater flow experienced an abrupt decline due to the clogging of the feedwater flow channels (spacers) inside the RO elements; water recovery increased from 47.5% to 70.6% as a result of reduced feedwater flow. The EMF induced a high-frequency electric signal, which can loosen colloidal particles, fouling, and scaling layer on cartridge filters, membranes, and pipelines, and the shredded fine solids accumulated and clogged the spacers in the RO feed flow channel. Under oscillating electric fields, charged particles start to vibrate and lift off from filters and the pipeline surface. It has been reported that the applied EMF would potentially lift charged particles from the membrane surface and release them into the bulk fluid, which could be used as a cleaning method to restore the already fouled membranes.

RO membrane autopsy indicated some scale in the water pipeline was broken down and accumulated in the membrane surface by the EMF devices. Hence, the presence of the AC-induced EMF-A devices released particles, obstructed the RO water flow channels, and caused the abrupt decrease of feedwater and concentrate flow. Hydraulic flushing using Well 1 groundwater was performed for 2 h to rinse the system and to decrease the water recovery to 50% at the 175 h point. However, the NWP was not completely restored, which indicated this flush only removed the clogged materials in the flow channel. Another 5 h hydraulic flushing occurred after 24 h to reinstate the membrane performance, and increased NWP from 0.0072 to 0.022 LMH/kPa. In both phases thereafter, a 5 h hydraulic flush was performed when the NWP decreased to less than 0.01 LMH/kPa. After the hydraulic flush, the NWP recovered partially for both phases, indicating that the outer fouling layer could be detached but the inner scaling layer was difficult to remove.

To better evaluate the NWP, the absolute slope value of the NWP as a function of operating time was used to describe the NWP decreasing rate of the RO membranes, referred to as the k value (LMH/kPa-h). A large k means a fast decrease in NWP and indicates a high scaling rate and low desalination performance.

Table 21 summarizes the calculated k values for different operating conditions in this study. Between 77 h to 150 h operation, k for P2, $(0.74 \pm 0.17) \times 10^{-4}$ LMH/kPa-h, decreased by 38.3% compared to the k, $(1.2 \pm 0.32) \times 10^{-4}$ LMH/kPa-h, for the same operation period in P1, which implies the EMF devices reduced membrane scaling and improved RO membrane performance. After 370 h operation, even though P1 had three hydraulic flushes compared to one for P2, k for P2, $(1.2 \pm 0.11) \times 10^{-4}$ LMH/kPa-h, was still 14.3% lower than the k for P1, $(1.4 \pm 0.51) \times 10^{-4}$ LMH/kPa-h. It is worth noting that after over 700 h operation and four hydraulic flushes, the k value for P2 remained almost the same as the first 150 h period. This observation suggests that hydraulic flushing can partially remove the scaling layer; however, it is not sufficient to remove the fouling layer formed in P1, due to a denser and more compact fouling layer formed on the RO membrane surface than that in P2, which is also verified by the membrane autopsy.



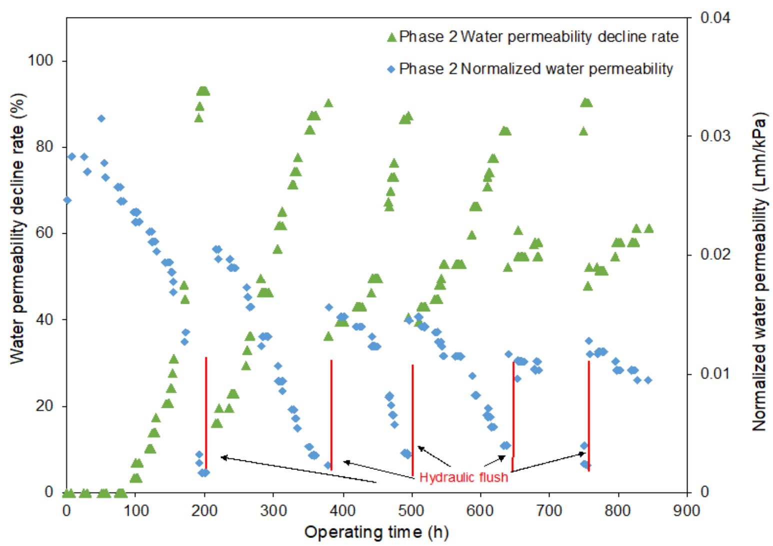


Figure 25. Normalized water permeability and decline rate during (a, top) Phase 1 testing and (b, bottom) Phase 2 with EMF-A devices.

Table 21. *k* values of different operation periods (P1: Phase 1, P2: Phase 2).

Operation Period	Operating Time (h)	Total Elapsed Operating Time (h)	*k* (LMH/kPa-h)
P1 at water recovery 50% and 150 h operation	77	150	$(1.2 \pm 0.32) \times 10^{-4}$
P1 between 2nd and 3rd flush	110	308	$(0.89 \pm 0.14) \times 10^{-4}$
P1 between 3rd and 4th flush	66	376	$(1.4 \pm 0.51) \times 10^{-4}$
P2 at water recovery 50% and 150 h operation	77	150	$(0.74 \pm 0.17) \times 10^{-4}$
P2 between 1st and 2nd flush	163	379	$(1.2 \pm 0.11) \times 10^{-4}$
P2 between 2nd and 3rd flush	115	495	$(1.2 \pm 0.76 \times 10^{-4}$
P2 between 3rd and 4th flush	143	638	$(0.86 \pm 0.32) \times 10^{-4}$
P2 between 4th and 5th flush	116	753	$(0.77 \pm 0.48) \times 10^{-4}$

3.5.3.1.2. Characterization of RO membrane scaling

To characterize the impact of EMF on RO membrane fouling and scaling, RO membrane specimens were cut from the membrane elements for autopsy. The RO membranes from the Phase 1 first element (lead-element) are referred to as P1E1 and the third element (tail-element) as P1E3. Deionized water was used to gently remove the loose foulants and salt residues from the membrane surfaces; those samples are referred to as P1E1-DI and P1E3-DI. Corresponding names are given to the membranes from Phase 2 as P2E1 and P2E3 for the lead and tail elements, and P2E1-DI and P2E3-DI after deionized water rinse, respectively.

In this study, SEM and EDX were used to observe the morphology of the membrane surface and to identify the elements in the foulants and scalants. XRD was used to characterize the crystalline structure of the scales on the deionized water-rinsed membranes.

For the lead element, the deionized water rinse removed most of the loose foulants and salt residues from the membrane surface when comparing the SEM images. For example, Figure 26b (P1E1, with DI rinse) shows a rough and “3D” structure compared to Figure 26a (P1E1, without DI rinse). Furthermore, the P1E1-DI membrane (Figure 26b) shows more compact and denser fouling on the membrane surface, as compared to the fouling layer formed on P2E1-DI (Figure 26d) that is powdery with a lower density, despite that P1 was installed in the EMF-A devices after 150 h operation and P2 (844 h operation) had a longer operation time than P1(381 h operation). This result indicates that the EMF treatment prevented the adhesive fouling layer from forming on the lead element membrane surface at the beginning of the RO process.

The EDX results show the relative ratio of Si in P2E1-DI is much lower than in P1E1-DI, indicating that the EMF had a positive effect in controlling silica-related colloidal fouling in the first element (Figure 27). An important finding from the EDX results is the Fe peak in both P1E1-DI and P2E1-DI. The Fe peak from the membrane surface suggests EMF-A devices descaled some rust inside the pipelines in the BGNDRF facility. The XRD results show the colloidal clay fouling in the lead elements was amorphous and there was no crystal formed on the membrane surface in both phases (Figure 28).

For the tail-end element (E3), the DI water rinse did not significantly change the morphology of the membrane based on the SEM images (Figure 26e vs. Figure 26f and Figure 26g vs. Figure 26h). The scales found in the XRD results for both phases are crystallites. The major crystals are identified as SiO_2, MgO, and $CaSO_4$, consistent with EDX results. The dissolved silica concentration in the groundwater is 21 mg/L, which was not expected to precipitate on the RO membrane surface at the operating water recovery of 50% as predicted by the ROSA model. However, silica scales were detected in both the EDX and XRD analyses, which may be caused by the aggravated concentration polarization due to membrane fouling and scaling.

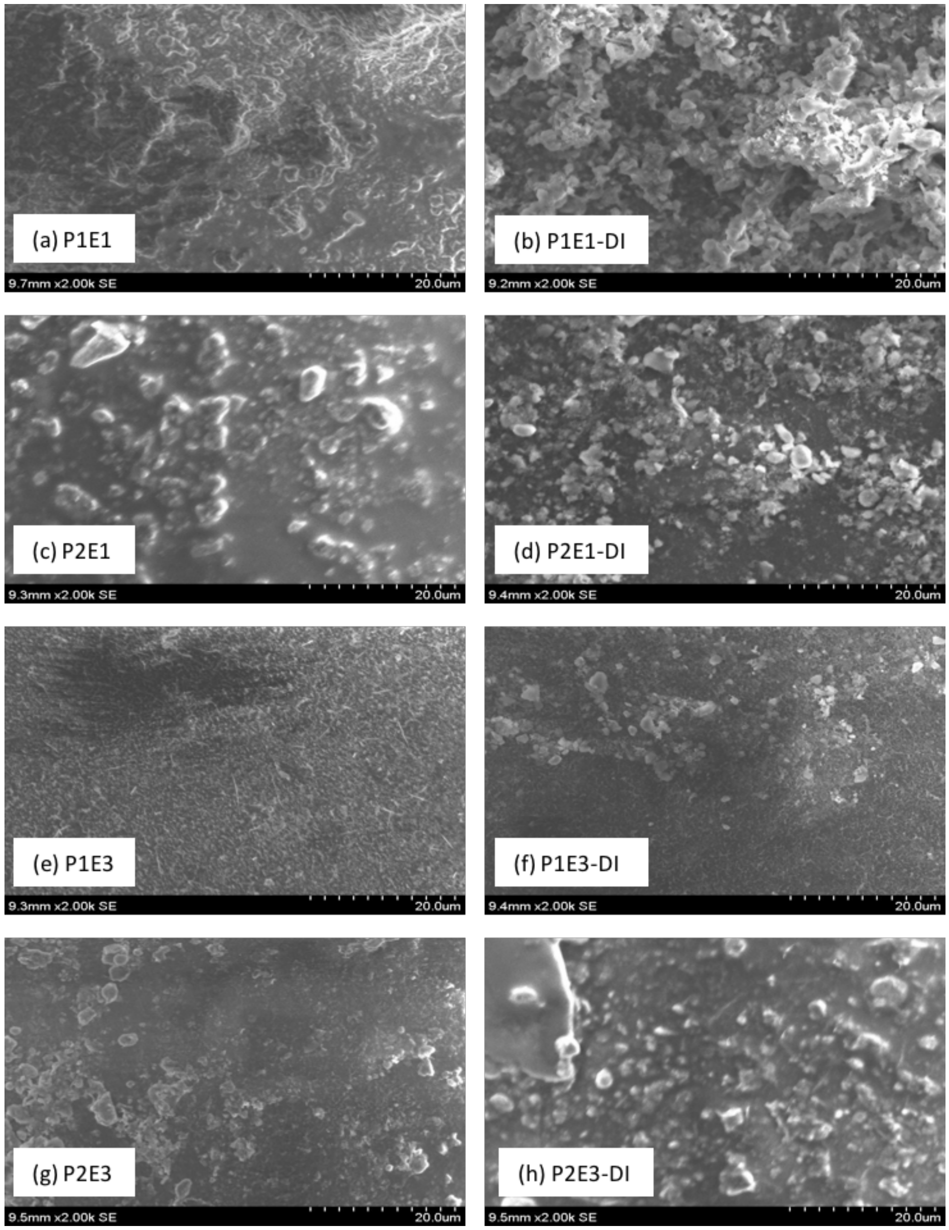


Figure 26. Scanning electron micrographs (SEM) of RO membranes. (a), Phase 1 Element 1 (P1E1); (b), Phase 1 Element 1, DI water rinsed (P1E1-DI); (c), Phase 2 Element 1 (P2E1); (d), Phase 2 Element 1, DI water rinsed (P2E1-DI); (e), Phase 1 Element 1 (P1E3); (f), Phase 1 Element 3, DI water rinsed (P1E3-DI); (g), Phase 2 Element 3 (P2E3); (h), Phase 2 Element 3, DI water rinsed (P2E3-DI).

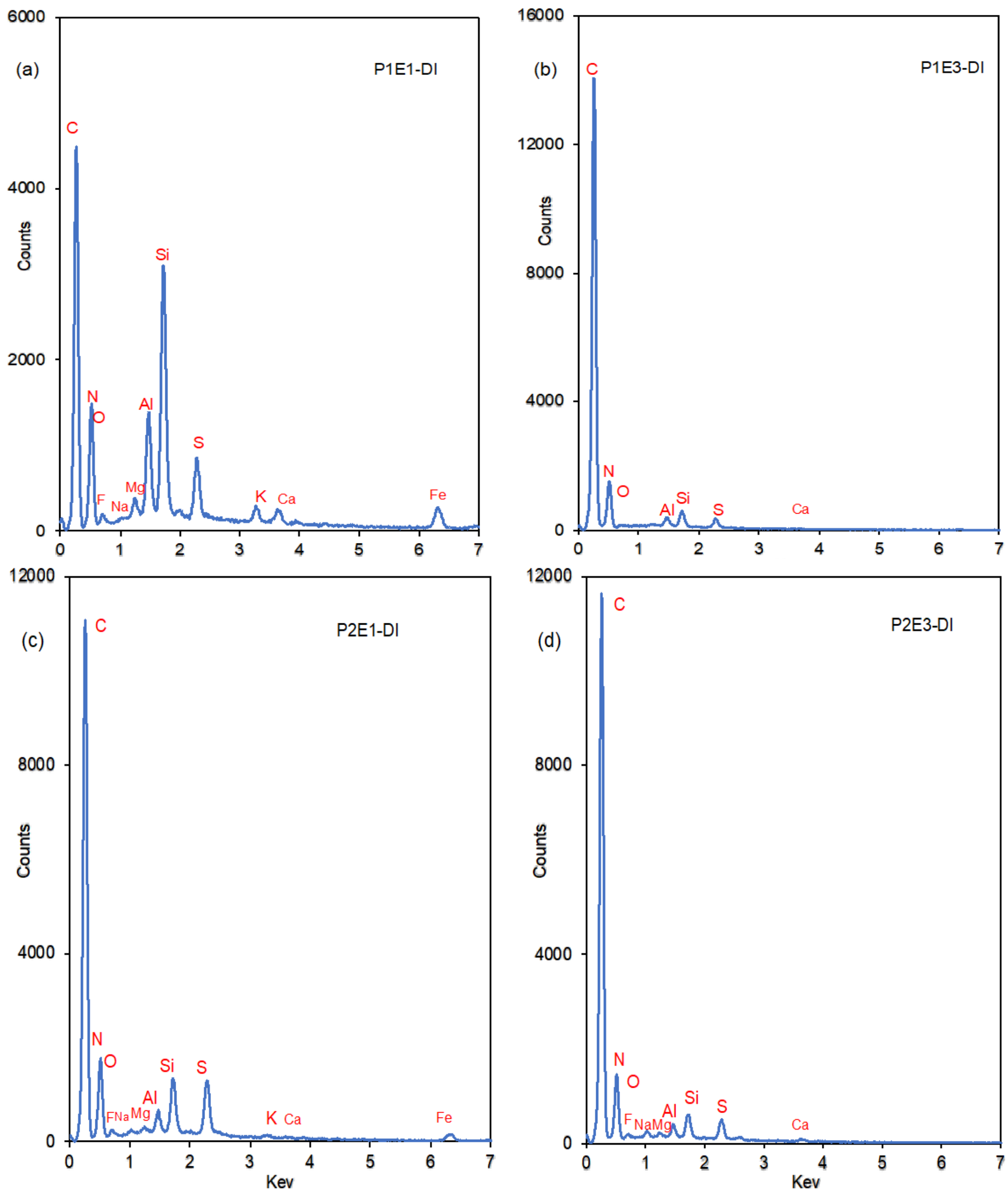


Figure 27. Energy dispersive X-ray microanalysis (EDX) of deionized water rinsed RO membranes. (a), Phase 1 Element 1, DI water rinsed (P1E1-DI); (b), Phase 1 Element 3, DI water rinsed (P1E3-DI); (c), Phase 2 Element 1, DI water rinsed (P2E1-DI); (d), Phase 2 Element 3, DI water rinsed (P2E3-DI).

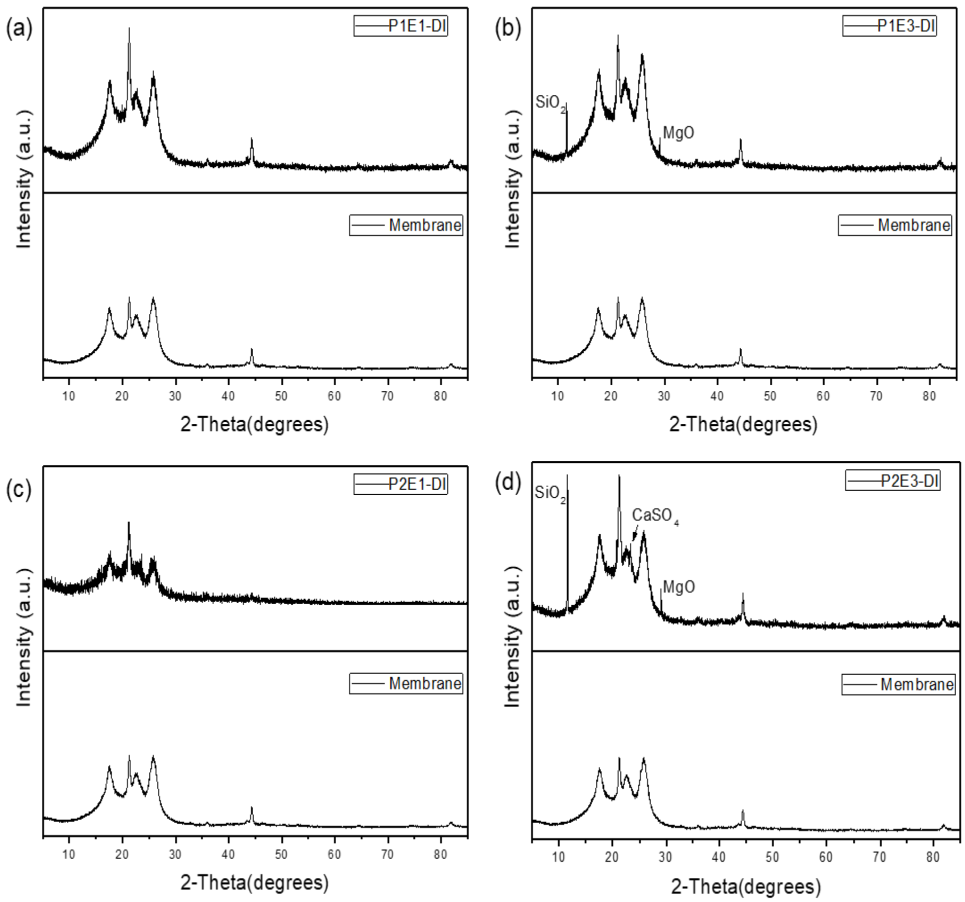


Figure 28. X-ray diffraction (XRD) of deionized water rinsed RO membranes. (a), Phase 1 Element 1, DI water rinsed (P1E1-DI); (b), Phase 1 Element 3, DI water rinsed (P1E3-DI); (c), Phase 2 Element 1, DI water rinsed (P2E1-DI); (d), Phase 2 Element 3, DI water rinsed (P2E3-DI).

3.5.3.2. Effect of Permanent Magnet Field on Membrane Performance

To investigate the effect of the PMF on the pristine RO membrane during desalination and compare the effect of different EMF configurations, the RO skid 2 was used to treat Well-2 water (TDS of 5,670 ± 345 mg/L), and the PMF device EMF-C was turned on at the beginning of testing the new membranes (PMF-P2), the same experimental conditions as the ACEMF-P2.

3.5.3.2.1. Water Flux

The operating pressure and water recovery with NWP during the PMF-P2 are shown in Figure 29. The 1st and 2nd hydraulic flush used Well-1 water (TDS of 1,179 ± 267 mg/L) to clean the system to recover the NWP when total elapsed operation time reached 380 hours and 620 hours, respectively. The highest NWP after the 1st hydraulic flush was 0.019 LMH/kPa, 17.3% lower than the highest

NWP after water recovery reached 50%, 0.0231 Lmh/kPa. This decrease showed that the PMF with hydraulic flush was not able to completely restore the performance deterioration caused by the irreversible fouling. The k values before the 1st and 2nd hydraulic flush were close to each other, 6.0×10^{-5} and 5.0×10^{-5} LMH/kPa-h, indicating the scale-forming rates were similar for both periods.

The 2nd hydraulic flush was performed when the NWP decreased to 0.004 LMH/kPa, only 21% of the highest NWP after the 1st hydraulic flush. After the flush, the NWP recovered to 0.017 LMH/kPa, 10% lower than the highest NWP (0.019 LMH/kPa) before the flush. This result indicated that with the PMF, most of the scale could be removed from the membrane by hydraulic flushing, indicating the scale formed in a loose morphology. It was assumed that if the 2nd hydraulic flush had been performed earlier, not until the severe scaling occurred on the membrane surface, the NWP recovery would have been better. Thus, to test the effectiveness of the PMF on maintaining the RO performance by only using hydraulic flushes, more frequent hydraulic flushes of 30 minutes were performed during the pilot experiment (Figure 29). After 1,308 hours (55 days) of operation, the NWP decreased gradually to 0.011 LMH/kPa, 65% of the highest NWP after the 2nd hydraulic flush and 48% of the highest NWP when water recovery reached 50% (75 h). However, with more hydraulic flushes, the k value decreased 8 times from 5.0×10^{-5} (Between 1st and 2nd flush) to 6.0×10^{-6} LMH/kPa-h (After 2nd flush to the end, Table 22).

The k values with and without the effect of EMF were compared with the baseline data for 150 h of operation (Jiang et al., 2019). The baseline had the same experimental conditions as the PMF-P2 except without any EMF device. After water recovery for both experiments reached 50% after around 75 hours of operation, the NWP for PMF-P2 and baseline were 0.0231 LMH/kPa and 0.0240 LMH/kPa, respectively. The baseline had a slightly higher NWP. However, after another 75 hours of operation, the NWP for PMF-P2 and baseline decreased to 0.0213 LMH/kPa and 0.0166 LMH/kPa, respectively. It was evident that NWP of the RO system decreased slower with the presence of PMF, and the k value (Table 22) decreased almost 4 times from 1.0×10^{-4} LMH/kPa-h (Baseline) to 2.6×10^{-5} LMH/kPa-h (PMF-P2).

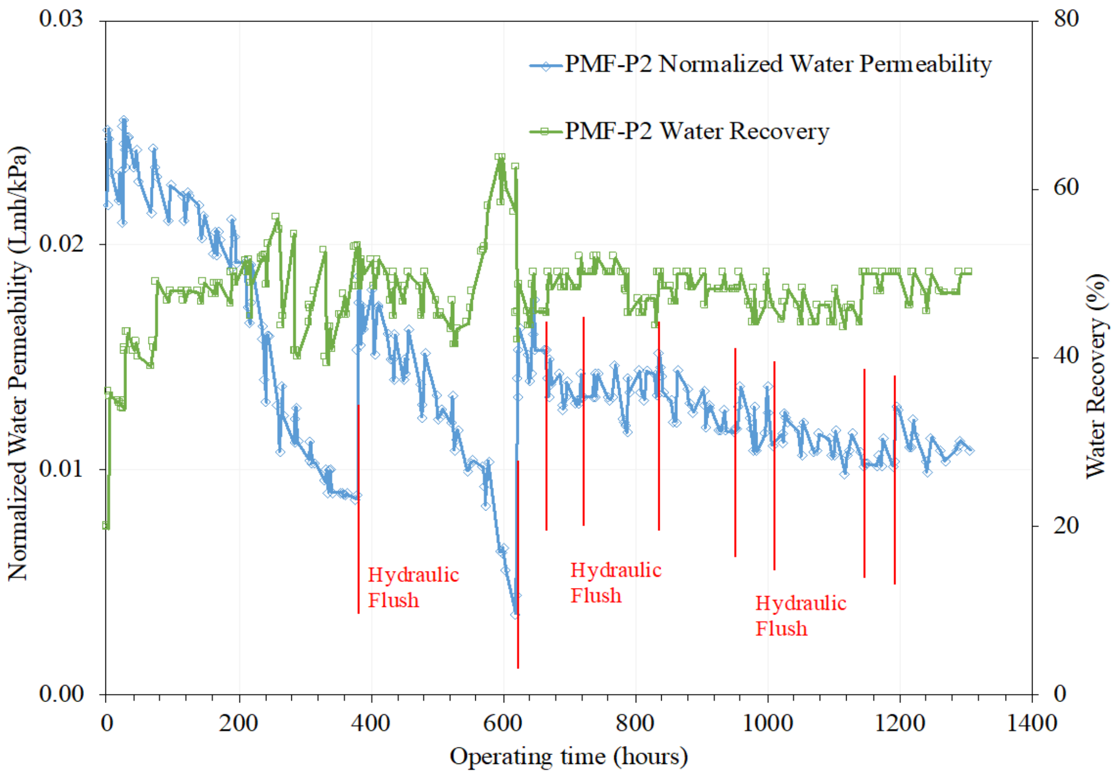


Figure 29. Water recovery and normalized water permeability (NWP) during the PMF-P2 (PMF turned on from the beginning of the test).

Table 22. *k* values from different operation periods of PMF-P2 and Baseline.

Operation period	Operation time (h)	Total elapsed operation time (h)	*k* (LMH/kPa-h) PMF-P2	*k* (LMH/kPa-h) Baseline
Between 75* and 150 hours	75	150	2.6×10^{-5}	1.0×10^{-4}
Between 75* hours and 1st flush	305	380	6.0×10^{-5}	
Between 1st and 2nd flush	390	620	5.0×10^{-5}	
After 2nd flush till the end	688	1308	6.0×10^{-6}	

Note: *Water recovery reached 50% after 75 hours of operation. PMF-P2: PMF turned on at the beginning of the experiment. Baseline: same experiment as PMF-P2 except without EMF for 150 hours.

These results implied that the PMF alone or combined with hydraulic flushes could control the scaling process on the membrane surface, although they can only partially remove the formed scales. Without any other pretreatment (acid or antiscalant), scaling inevitably occurred on the membrane surface during the 1,308 hours (55 days) of operation and deteriorated the performance of the RO system.

However, another aspect may be related to the chemical composition of the feed water (high concentration of SO_4^{2-}) used in this study. As reported, EMF has an effect on scaling control in the order of $BaSO_4$ > $CaCO_3$ > $CaSO_4$ (Salman et al., 2015).

During the PMF-P2 experiment, the RO system retained high salt rejection for the major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}) between 98.7-99.8%. The permeate conductivity fluctuated between 50 and 90 μS/cm, slightly better than the permeate conductivity without EMF-A (100 to 120 μS/cm) (Jiang et al., 2019).

3.5.3.2.2. Characterization of RO membrane scaling

Figure 30a shows the scale formation on the membrane surface after the PMF-P2 experiments. After the DI water rinse, the PMF-P2 membrane showed a relatively uniform and loose morphology, some scale was formed, but no large solids were observed in the lead element E1 and tail-end element E3. Also, the XRD showed that no crystal was formed on the membrane surface (Figure 9a). These observations further validated that the PMF was effective in controlling the scaling process and changing the nature of the formed scale, such that the small amount of scale formed on the membrane surface could be removed by hydraulic flush.

Figure 30b shows the SEM of the membranes from the ACEMF-P2 experiments (Jiang et al., 2019). Considerably more scale was formed during the experiment. Large particles and dense scale were still observed after DI water rinse. XRD results showed that SiO_2, MgO, and $CaSO_4$ crystals were formed on the membrane surface under the ACEMF treatment; however, no calcite was observed (Figure 31). These results suggest that although ACEMF was proven effective in scaling control as compared to no EMF, they were not as effective as the PMF. However, the different results may be caused by the different strengths and fields of the devices; an increase of the ACEMF power may produce different results.

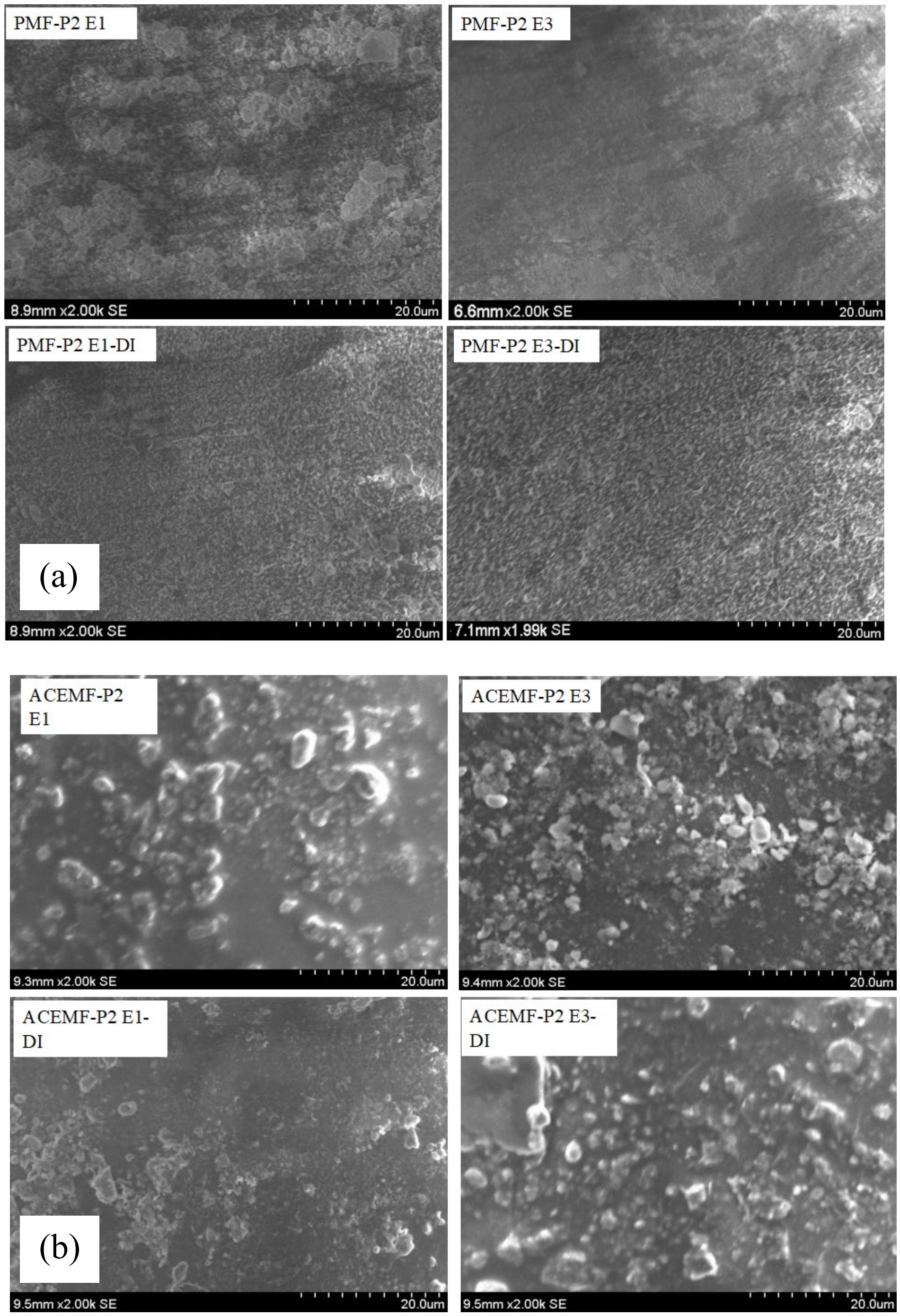


Figure 30. Scanning electron micrographs (SEM) of RO membranes from (a) PMF-P2. (b) ACEMF-P2. E1: first element; E3: last element; DI: deionized water rinse.

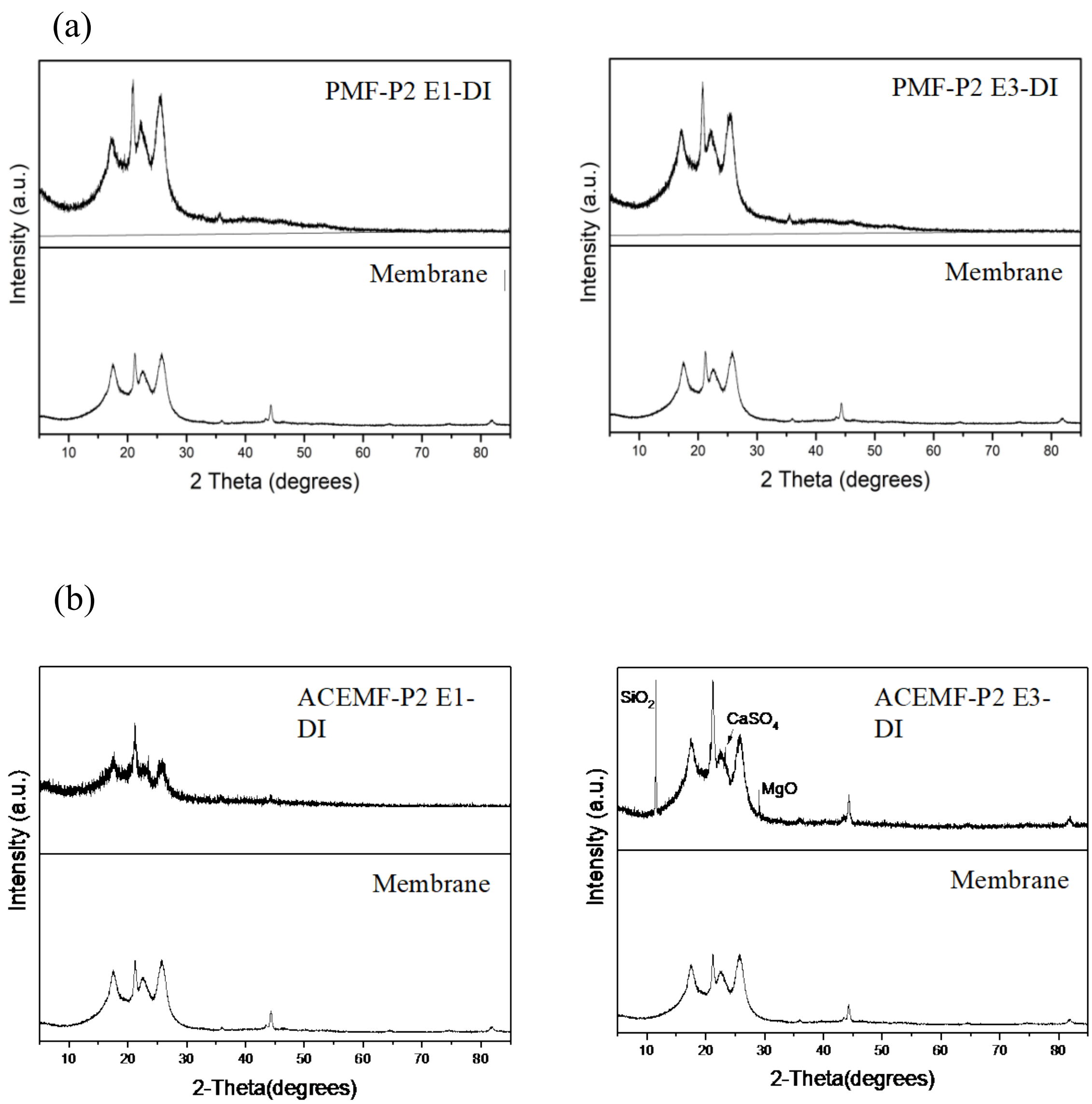


Figure 31. X-ray diffraction (XRD) of deionized water rinsed RO membranes from (a) PMF-P2. (b) ACEMF-P2. E1: first element; E3: last element; DI: deionized water rinse.

3.5.3.3. Summary

This study demonstrated that both AC-induced and permanent magnet EMF devices reduced the scaling process on the RO membranes and the NWP decline rate. EMF prevented the formation of large and sticky calcite; only loose and powdery scales were formed during the experiment. Periodic hydraulic flushing could restore membrane performance and recover declined flux. EMF could provide a chemical-free alternative to control membrane fouling and scaling by alleviating the formation of a compact scaling layer on the membrane surface.

However, EMF could alleviate the fouling only to a certain level, and was not able to completely prevent it in the accelerated fouling process.

3.5.4. Bench- and Pilot Testing of EMF and RO Membranes with 3D printed Open Feed Channel Spacers

3.5.4.1. Bench testing of EMF and Different Types of Membrane Spacers Treating BGNDRF Well 2 Brackish Groundwater

A flat-sheet, bench-scale RO system was employed to investigate the effect of alternating current induced EMF on low-pressure, brackish water RO membranes with different types of spacers. The process was designed to evaluate the unique features of the project: (i) comparing desalination performance and water production of RO membranes with conventional mesh spacer, and 3D printed membranes with open feed channels (dotted and striped 3D printed spacers); (ii) evaluating the impact of EMF on the performance of different types of membranes during desalination of a challenging brackish groundwater.

Hydranautics RO membrane ESPA-DHR was tested in three different configurations. Firstly, regular ESPA-DHR flat sheet membranes with conventional mesh spacer (spacer thickness 34 mil, or 0.86 mm) were tested to desalinate synthetic water and brackish groundwater (Figure 4 left). Then two types of ESPA-DHR flat sheet membranes with 3D printed dot and strip spacers (spacer thickness 22 mil, or 0.56 mm) were studied (Figure 4 middle and right). Thirdly the impacts of EMF on regular membranes and 3D printed membrane spacers were tested with brackish groundwater. Different types of feed water were tested, including DI water to measure the pure water permeability of the membranes; 1,500 mg/L of NaCl solution to verify the salt rejection and membrane water permeability in comparison with membrane manufacturer data; and a brackish groundwater collected from Well 2 in BGNDRF, for membrane scaling experiments.

The EMF-A device was calibrated using an Owon HDS handheld digital storage oscilloscope and digital multimeter (Model HDS1021M-N, Canada) before installation. The voltage of the EMF-A sine wave signal was measured to be 17.2 volts. The EMF device was installed in the inlet of the RO units to control membrane scaling.

3.5.4.1.1. Pure Water Permeability of the Membrane

Firstly, the performance of different types of membranes was evaluated in terms of member permeability using DI water, i.e., Pure Water Permeability (PWP), under operating conditions of 50, 100, 150, 200 and 250 psi (Figure 32). The PWP of all three membranes increased linearly with increasing pressure. The regular membrane showed the highest PWP of 0.53 L/m^2-h-psi (calculated from the slope of the trendline), while the striped and dotted membranes exhibited similar PWPs of 0.32 and 0.34 L/m^2-h-psi.

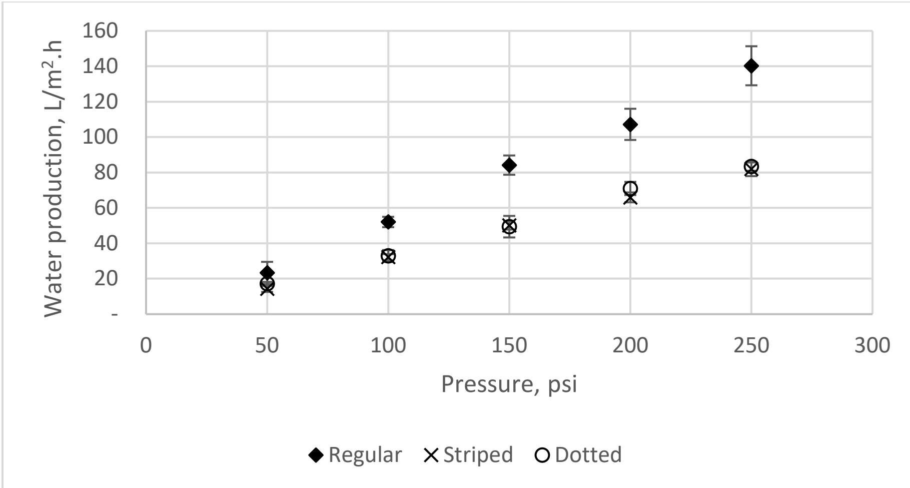


Figure 32. PWP of different membranes. Error bars represent the standard deviation of duplicate membranes

3.5.4.1.2. Salt Rejection Testing

To compare with the membrane manufacturer's datasheet, the salt rejection of the membranes was verified based on manufacturer's standard testing conditions using 1,500 mg/L NaCl solution and at 150 psi. The differences in salt rejection were not significant for all three membranes (Figure 33). The values varied from 95.3% to 97.8%, with an average between 96.7% to 97.0%, slightly lower than the Hydranautics data that the regular spiral-wound membrane should achieve a minimum salt rejection of 99%. Our previous experiments demonstrated that the salt rejection in spiral-wound elements is typically higher than the flat-sheet testing results. Therefore, the salt rejection of the membranes was demonstrated as normal and considered to meet the membrane manufacturer's standards.

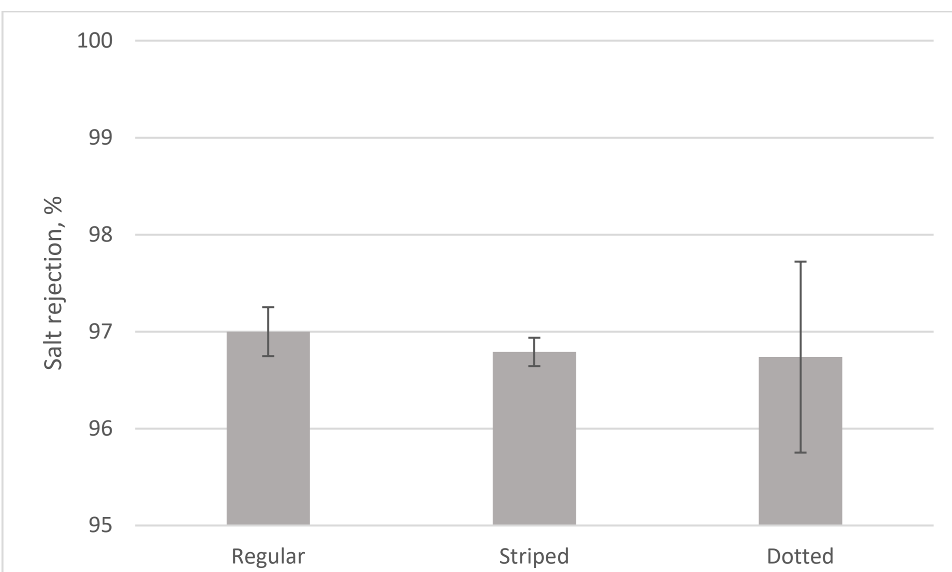


Figure 33. Salt rejection of the membranes with 1,500 mg/L NaCl solution at 150 psi

3.5.4.1.3. Membrane Performance during Treatment of Well 2 Water

Membrane scaling experiments were conducted at 150 psi using the brackish groundwater collected from Well 2 at BGNDRF. The groundwater has a total dissolved solids concentration of 5850 mg/L, a hardness of 2550 mg/L, primarily $CaSO_4$ type of water (Table 1). The simulation using the latest version of Hydranautics membrane projection software IMSDesign (Integrated Membrane Solutions Design) showed membrane scaling of $CaCO_3$, $CaSO_4$, $SrSO_4$, $BaSO_4$ at 50% water recovery. It indicates the addition of an antiscalant is required to control membrane scaling at 50% water recovery for regular membranes.

It was decided to work only with regular membrane and striped membrane in the membrane scaling test, because PWP and salt rejection tests did not show a significant difference between striped and dotted membranes. No antiscalants were added in this experiment to accelerate the scaling process and evaluate the effect of EMF on scaling control.

The water production decreased with the increasing water recovery due to membrane scaling (Figure 34 and Figure 35) and the water flux decline increased over time (Figure 36 and Figure 37).

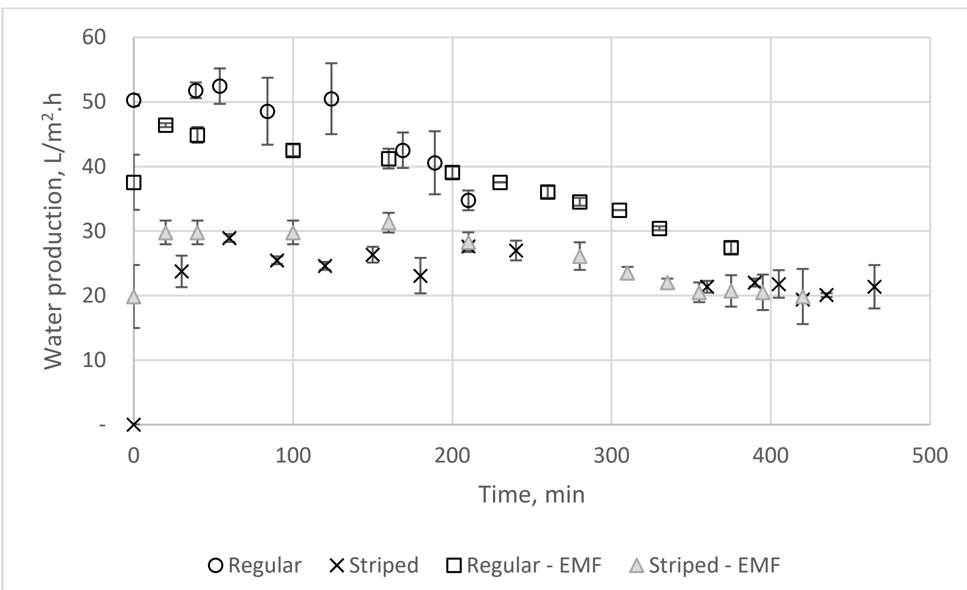


Figure 34. Water production *versus* time during desalination of Well 2 brackish groundwater

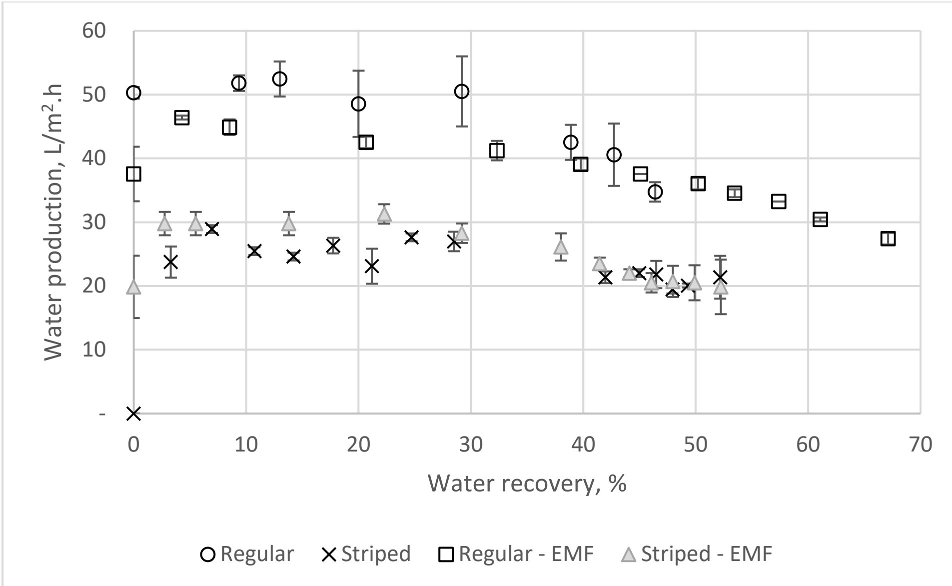


Figure 35. Water production *versus* water recovery during desalination of Well 2 brackish groundwater

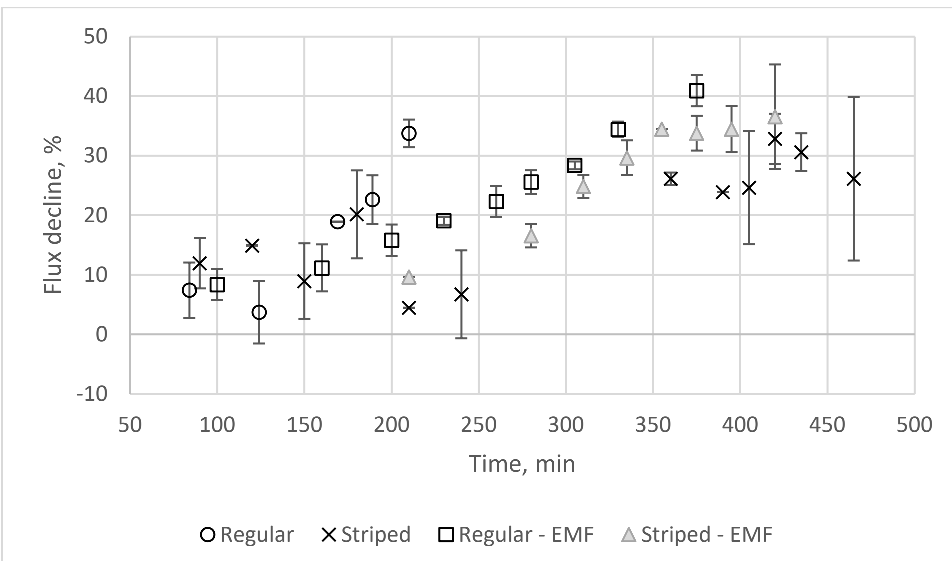


Figure 36. Water flux decline *versus* time during desalination of Well 2 brackish groundwater

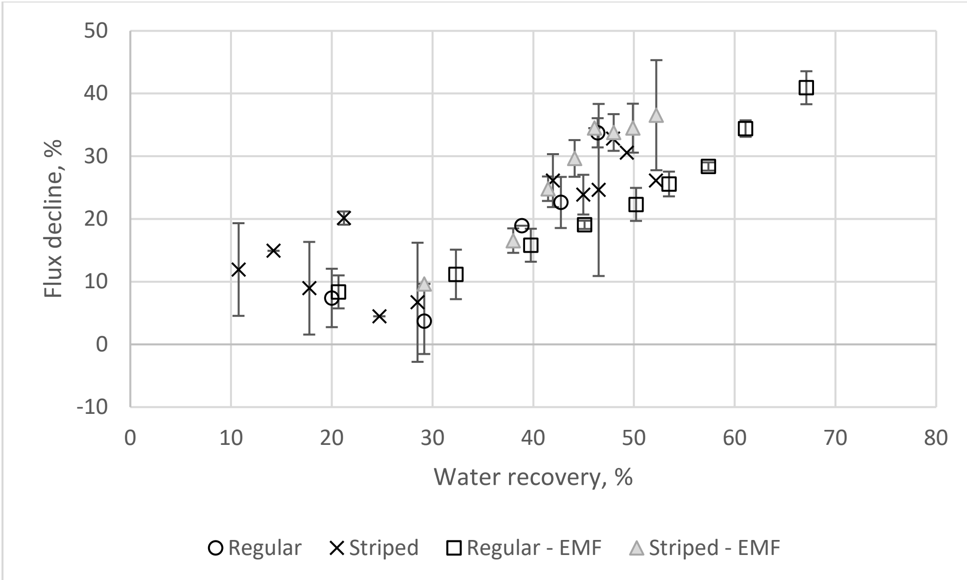


Figure 37. Water flux decline *versus* water recovery during desalination of Well 2 brackish groundwater

The regular membrane had initial higher water production, but faster permeation flux decline. Its time of operation was short due to severe membrane scaling. Regular membrane with EMF showed an initial lower water production than the regular one, but its flux decline was also lower, and for this reason it can operate for more time; i.e., it took more time to reach the same flux decline, resulting in higher water recovery.

Running the system using EMF permitted reaching a higher recovery of 70% than the 50% without EMF. Regular membranes with EMF took more time to reach the same flux decline as regular membranes without EMF. However, the EMF did not have a significant impact on the striped membranes due to a higher standard deviation obtained in the experiments. In both tests using EMF, the same flux decline was reached with higher water recovery, with the best result for regular membrane with EMF. Flux decline of 34% was reached with 47% of water recovery for regular membrane and for regular membrane with EMF; when water recovery was 45%, the flux decline was only 19% (56.5% lower). The flux declined for regular membrane with EMF reached 35% of the flux decline when the water recovery was 61% (35.4% higher).

3.5.4.1.4. Summary of Bench-scale Testing Results

The bench-scale testing demonstrated that EMF provides an effective pretreatment to control membrane scaling during desalination of BGNDRF Well 2 brackish groundwater. The primary research findings from the bench-scale testing are summarized below:

- The EMF remarkably enhanced water recovery from 50% to 70% during desalination of the challenging brackish groundwater.
- For regular membranes, the EMF reduced the water flux decline rate and significantly improved membrane performance by 57%.
- PWP and salt rejection tests did not show a significant difference between RO membranes with striped and dotted feed channel spacers.
- Regular membranes exhibited better PWP and salt rejection than the membranes with 3D printed spacers.
- For the striped membranes, EMF did not have significant impact due to a higher standard deviation obtained in the experiments.
- Similar results were observed using EMF and RO membranes with 3D printed spacers to treat municipal secondary effluent (data shown in Penteado de Almeida et al., 2023). Open feed channel spacers did not show a significant impact in the tested design, possibly because of the lower spacer thickness (22 mil versus 34 mil of conventional mesh spacer). The hydraulics of the SEPA cell are not ideal for simulating the 3D-printed spacer pattern in a spiral wound element.
- More studies are needed to evaluate the 3D printed spacers with higher thickness in a hydraulic situation that better simulates the cross-section as in spiral wound elements due to its different spacer design.

3.5.4.2. Pilot testing of EMF and Membranes with different Types of Spacers at KBHDP

Moving the research studies to a pilot scale allowed an investigation of the EMF effect on RO spiral wound elements under field operating conditions and a comparison with the bench-scale experimental results. Pilot-scale experiments bring a better understanding of the technology on a commercial level. The study's purpose was to control membrane fouling and scaling to achieve a higher water recovery during treating brackish groundwater and desalination concentrate at KBHDP.

The feedwater was the concentrate generated from the brackish water desalination in the KBHDP in El Paso, TX. The concentrate is generated after 82.5% of water recovery. This study aimed to achieve at least 90% overall water recovery for treating the KBHDP brackish groundwater. For instance, considering that the KBHDP brackish water concentrate is produced at 82.5% water recovery, achieving 90% water recovery in the entire system requires a 41% water recovery in the pilot system. Moreover, to achieve 95% overall water recovery, a 70% water recovery in the pilot system is necessary. It is important to note that achieving water recovery rates above 90% may not be feasible in all situations as it depends on factors such as feedwater quality, system size, operational conditions, and economic considerations. Each application requires careful evaluation to determine the optimal water recovery rate that balances water production, energy consumption, and cost-effectiveness. Overall, high water recovery systems with water recovery rates exceeding 90% represent a significant advancement in desalination, enabling more efficient utilization of water resources.

The operation mode was in a batch process or single pass. Each process goal was to reach 91% of water recovery overall. The feedwater passed through a cartridge filter and then 2-stage RO. The first stage has two housings with one element each, and the second stage has one membrane and one housing. A cartridge filter has 1 µm pore size. The RO spiral wound membranes are 4"x40". The RO membranes used were: a) Dow Filmtec BW30-4040, with regular mesh spacer, and active area of 7.20 m^2, and b) AquaMembranes ConZerv 4040, with 3D printed feed spacers, and active area of 9.29 m^2. The MF membrane was SiC ceramic membrane with 1200 mm (length), 0.1 µm pore size, 37 channels (DJSC-40/37/4/1200-AD 100), and an area of 2,400 cm^2. The EMF devices evaluated were alternating current induced EMF-A with 14.4 V of peak-to-peak voltage, and EMF-B with 24V of peak-to-peak voltage.

All the concentrate from the first stage flows to the second stage. All the concentrate from the second stage flows to an intermediate tank. This intermediate tank serves as a feed tank for the MF system. All the concentrate from RO membranes passes through an MF membrane, and its permeate is recirculated through the RO membranes. All the permeate is stored in the permeate tank.

The cumulative operational time amounted to 106 hours, encompassing 54 hours employing DOW Filmtec BW30-4040 RO membrane and 52 hours utilizing AquaMembranes technology (3D printed spacers).

3.5.4.2.1. Treating KBHDP Brackish Water

Figure 38 depicts the results of a series of batch experiments conducted to evaluate different configurations for fouling and scaling mitigation using EMF treating KBHDP brackish water. Six batches were examined, including: a) no EMF, b) EMF-A, and c) EMF-B. The no EMF configuration served as the baseline. In the first three batches, the normalized water production for the no EMF configuration was approximately 0.18 L/m^2·h·psi. However, starting from the fourth batch, the initial normalized water flux was not fully recovered and decreased to 0.14 L/m^2·h·psi (23% lower than the first batch), necessitating a hydraulic flush. The hydraulic flushing successfully restored the water flux in the fifth and sixth batches. In contrast, the EMF-A and EMF-B configurations maintained a stable initial water flux throughout all six batches. EMF-A exhibited an increase in flux production from the first batch (0.16 L/m^2·h·psi) to the third batch (0.19 L/m^2·h·psi), indicating its possible capability to remove fouling and scaling. EMF-B demonstrated an initial flux of approximately 0.17 L/m^2·h·psi across all six batches, suggesting its potential for controlling fouling and scaling when compared to the no EMF experiments.

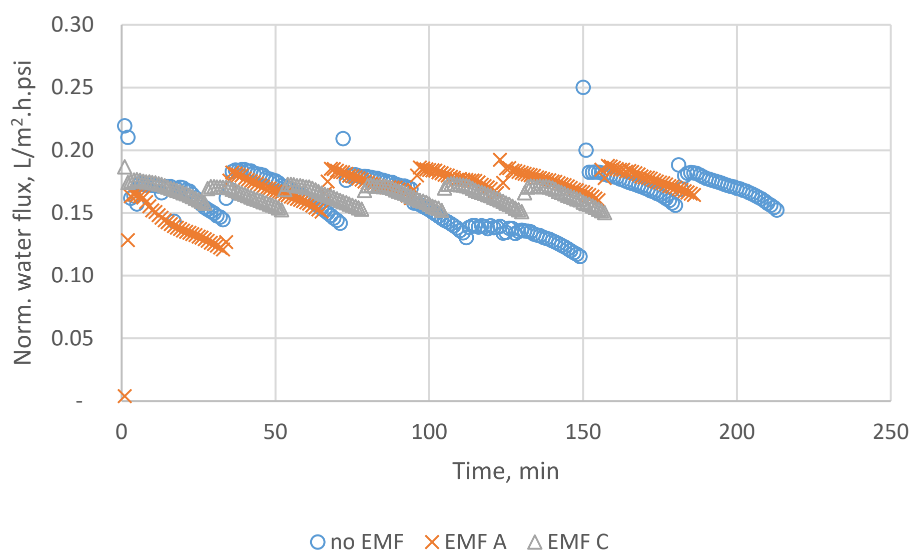


Figure 38. Normalized permeate water flux treating brackish water in six batches with RO BW30 membrane

To ensure the reproducibility of the interesting preliminary findings, eight consecutive batches were conducted without the application of an EMF, as illustrated in Figure 39. Notably, no hydraulic flushing was employed during this series of experiments. However, the permeation flux remained uncompromised throughout these batches. This suggests that further testing is required to determine the threshold at which fouling and scaling would lead to a reduction in flux within the pilot system. The overall water recovery rate achieved during these experiments reached 90%.

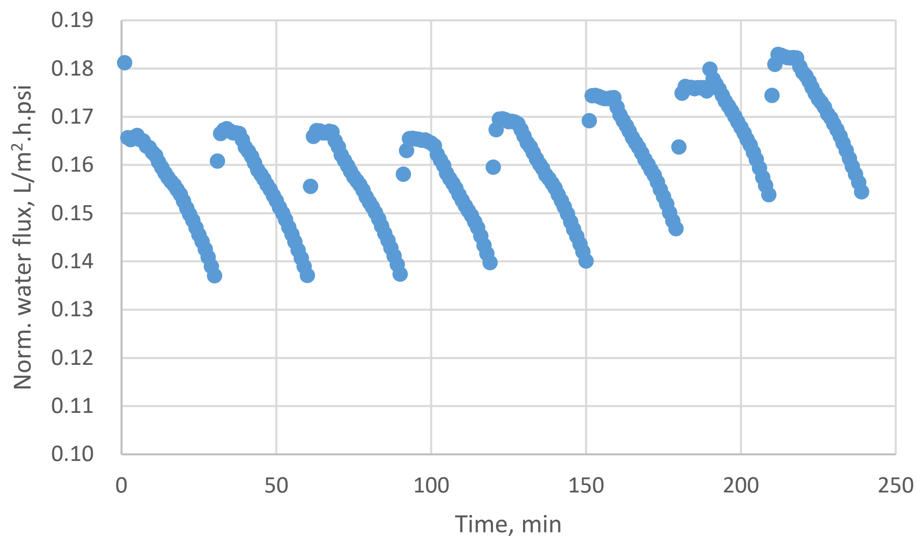


Figure 39. Normalized permeate water flux treating brackish water in 8 batches with RO BW30 membrane, using MF, without EMF

3.5.4.2.2. Treating KBHDP RO Concentrate

Figure 40 presents the permeate flux observed during the desalination process of RO concentrate generated at the KBHDP. This configuration used MF and RO BW30 membranes in a single pass filtration setup, without the application of an EMF. The achieved overall water recovery rate was 91% (as depicted in Figure 41). Notably, after 900 minutes of treatment, no decline in the permeate flux was detected. This result suggests that the antiscalant employed in the RO concentrate exhibited effective control over fouling and scaling precipitation, enabling a water recovery rate of up to 91% overall. KBHDP operates its facility with a water recovery rate of 82.5%. The salt rejection rate, illustrated in Figure 41, reached 96% on average and remained stable throughout the experimental duration. This consistent salt rejection rate indicates that fouling and scaling did not compromise the performance of the RO membrane, as evidenced by the sustained quality of the permeate over time.

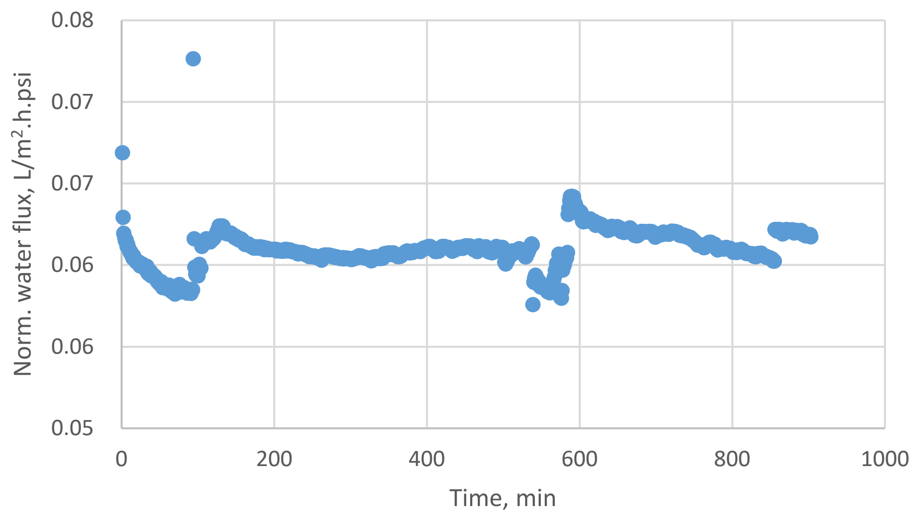


Figure 40. Normalized permeate flux treating RO concentrate at 91% of water recovery overall, using RO BW30 membrane and MF, filtration in single pass, without EMF.

Based on the absence of fouling and scaling observation in the hydraulic experiments, a decision was made to modify the testing protocol. Consequently, longer-duration experiments were conducted, and the RO BW30 membranes were replaced with 3D-printed feed spacer membranes. The operation mode employed was single-pass filtration, with only RO membranes utilized to filter the RO concentrate obtained from the KBHDP.

Figure 42 presents the results of a continuous 48 hours experiment. Overnight, when the system's pressure and water recovery were arbitrarily reduced, the permeation flux dropped below 0.01 $L/m^2 \cdot h \cdot psi$. While applying pressure higher than 250 psi, the system operated at an overall water recovery rate of 91%. The permeate flux initially started at 0.05 $L/m^2 \cdot h \cdot psi$ and decreased to 0.03 $L/m^2 \cdot h \cdot psi$ within 24 hours of the experiment. This lower flux level persisted at the 48-hour mark, prompting the implementation of a hydraulic flushing procedure to restore the water flux production.

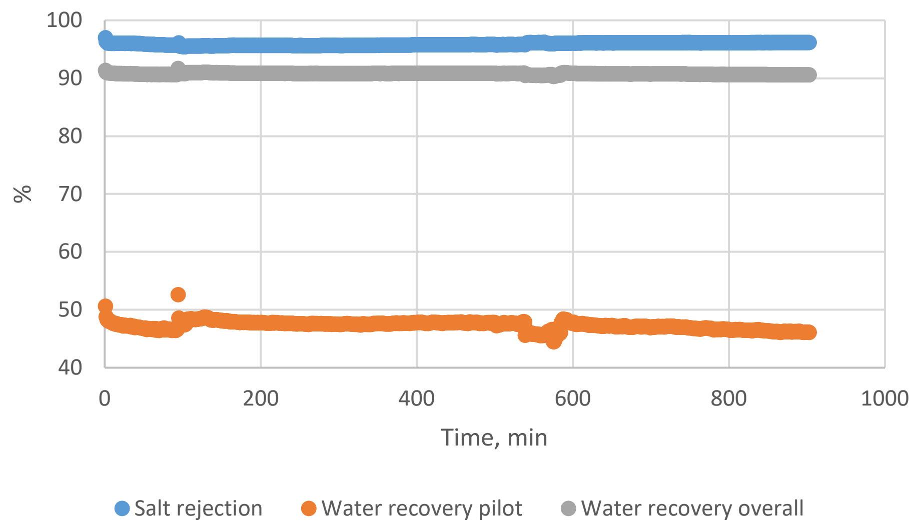


Figure 41. Salt rejection and water recovery of the desalination of RO concentrate, using BW30 membrane without EMF, antiscalant, and MF

Because of the unsuccessful recovery of water production through hydraulic flushing, further measures were taken to address the issue. Chemical cleaning using Avista products, specifically p903 and p192, was carried out. The cleaning procedure involved the use of a low pH solution (below 4) created with p903, followed by a high pH solution (above 12) created with p192. Each chemical cleaning was performed for a duration of 3 hours.

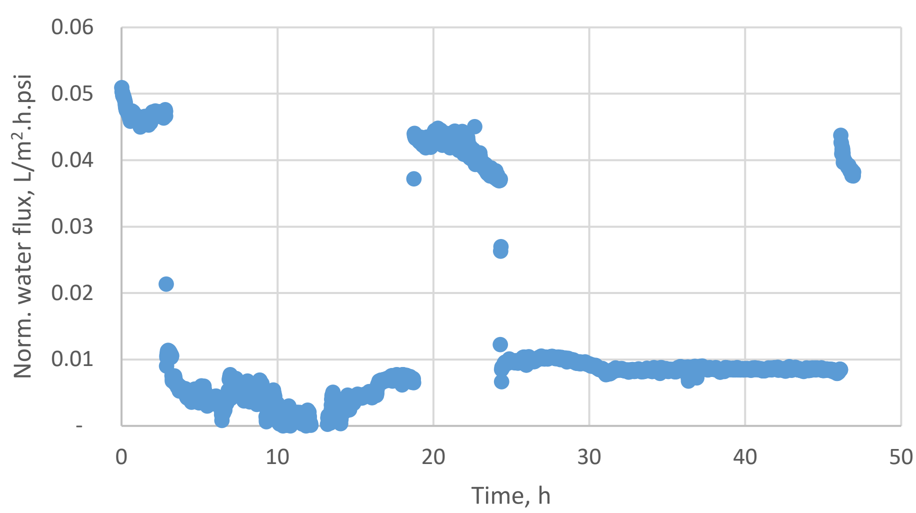


Figure 42. Normalized water permeation flux treating RO concentrate in single pass using AquaMembranes with 3D printed feed spacers.

Subsequent to the chemical cleaning procedure, a PWP test was conducted to evaluate the effectiveness of the cleaning in recovering water flux. Figure 43 illustrates the normalized water flux, comparing the results obtained after the chemical cleaning to the flux when the membrane was new. Surprisingly, the flux achieved after the cleaning process (~0.35 L/m^2·h·psi) was higher than the flux observed when the membrane was new (~0.30 L/m^2·h·psi). While this indicates that the water flux was indeed restored, it raises concerns regarding the potential compromise in membrane salt rejection performance. Further investigation was warranted to assess the impact on salt rejection and ensure the overall performance integrity of the membrane.

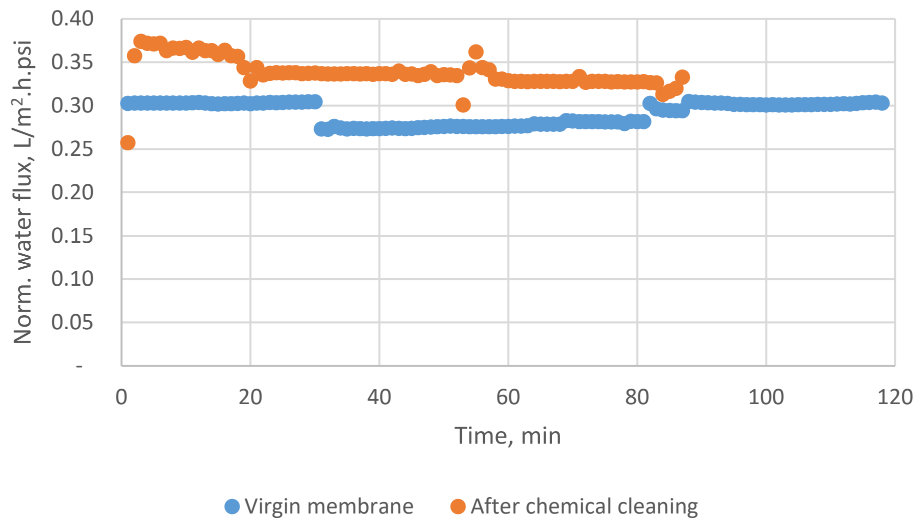


Figure 43. PWP for AquaMembranes with 3D printed feed spacers.

Figure 44 and Figure 45 present the data of three batches desalting KBHDP RO concentrate, conducted after the PWP test. The batches were carried out to reach 91% of water recovery overall. The water flux production decreased 15% from the first (0.07 L/m^2·h·psi) to the second batch (0.06 L/m^2·h·psi), as shown in Figure 44, indicating the occurrence of fouling and scaling. Figure 45 demonstrates the salt rejection performance was not compromised by the chemical cleaning. The salt rejection remained similar to the preliminary experiments using 3D printed membrane feed spacers, reaching 86%. This suggests that the chemical cleaning procedure did not negatively impact the membrane's ability to reject salts.

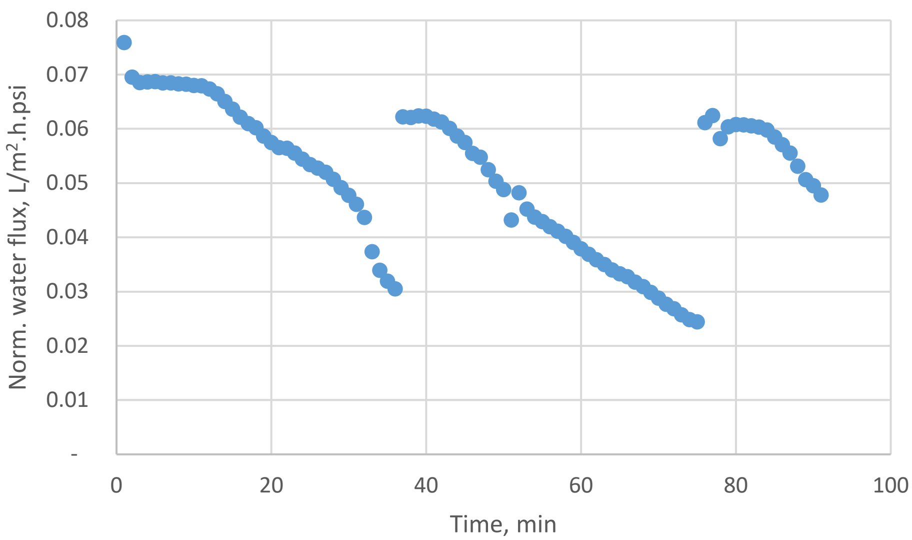


Figure 44. Normalized permeate flux treating RO concentrate, in batches, using AquaMembranes with 3D printed feed spacers.

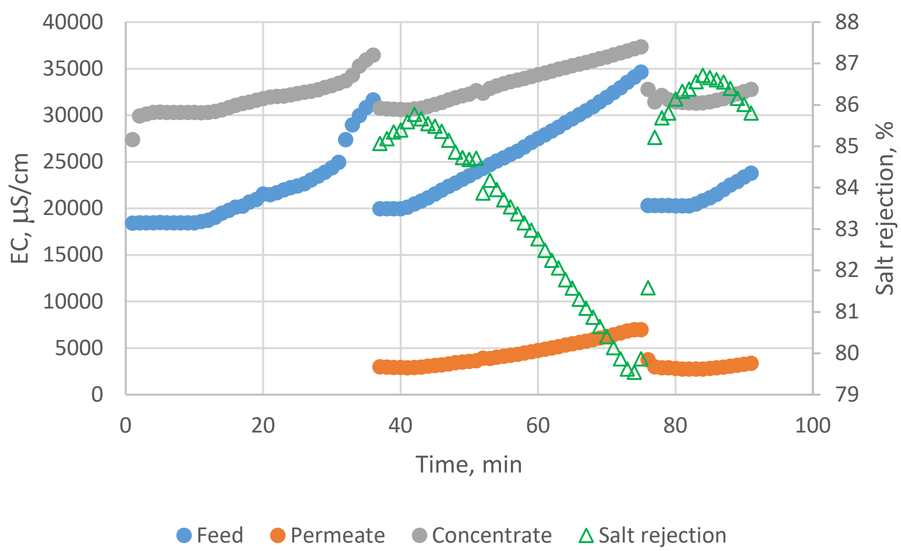


Figure 45. Electrical conductivity and salt rejection during the desalination of RO concentrate, in batches, using AquaMembranes with 3D printed feed spacers.

3.5.4.2.3. Summary of Pilot Testing at KBHDP

Pilot experiments pose greater challenges compared to bench experiments. Our investigations involving MF-only, EMF-only, or their combination did not reveal any significant differences when compared to running only the KBHDP RO concentrate without MF or EMF. Therefore, the efficacy of EMF in controlling and scaling at the pilot scale remains inconclusive for treating the KBHDP RO concentrate. The same statement may be extended to the utilization of 3D printed membrane feed spacers, where the results were inconclusive. Similar to the bench-scale testing results, the 3D printed feed spacers developed by the AquaMembranes are supposed to increase permeate output. The thin feed spacer reduced the capacity of the water flow channel for the scales and precipitates formed under EMF in RO concentrate to be flushed out of the RO element. A comprehensive understanding of crystal particle growth and size formation following exposure to EMF is crucial for the design of an effective MF system capable of crystal removal. Additionally, it is essential to understand the difference in particle size growth after a single pass and multiple passes through an EMF.

We hypothesize if MF can successfully remove crystals formed after EMF exposure, the system has the potential to achieve higher water recovery rates, reducing fouling and scaling on RO membranes. The future pilot testing at the KBHDP will employ an ultrafiltration unit to advance toward the development of a high RO water recovery system. Further fundamental research is required to enhance our understanding of the combination of EMF and 3D printed spacer membranes.

4. Conclusions and Future Work

4.1. Conclusions

New Mexico has experienced chronic droughts, and it is predicted that New Mexico will have approximately 25% less water available in rivers and aquifers in the next 50 years. According to New Mexico's 50-Year Water Action Plan, the development of new water resources is critical to meet the freshwater demand and the shortfall of 750,000 acre-feet of water. Developing a brackish groundwater desalination plant in the Santa Teresa area will have a significant effect on the hydrologic budget of the area, particularly because the water is planned to support significant economic development in south-central New Mexico. The effects of this added source of water will propagate through economic, social, hydrologic, and environmental consequences.

Improving the resiliency of water supply in an increasingly arid climate is a key challenge for water planners and managers in southern New Mexico. The large volumes of economically recoverable, slightly to moderately brackish water (<5,000 mg/L TDS) in the Mesilla aquifer system of southern New Mexico and northern Chihuahua in the vicinity of the Santa Teresa-San Jeronimo area, make desalination an attractive alternative to augmenting water supplies. Due to the complexity and uncertainty of maintaining a reliable water supply in an over-appropriated, salty, arid basin, the goal of this project has been to develop an assessment and implementation framework for transboundary brackish groundwater desalination to diversify the water portfolio and to reduce conflicts in water supplies.

The project examined the potential for providing water for increasing Domestic, Commercial, Municipal, and Industrial (DCMI) economic development in the Santa Teresa area. With preliminary estimates of tens of millions of acre-feet of economically extractable brackish water in storage, the resource can provide water for several generations of DCMI water users. It can also provide time for continued economic development in the border region while water users and uses adapt to the realities of a changing climate. Based on Dr. John Hawley's study, the area identified for further study for source water for desalination is the Kilbourne-Noria Subbasin (KNSB) (Hawley et al., In press). The KBSN is about 10 miles from the Santa Teresa Land Port of Entry, but it has the advantage of being to the west of a mid-basin high, which may provide isolation from hydrologic effects on the Rio Grande. The subbasin is underlain by approximately 2,000 feet of the Upper, Middle and Lower Santa Fe groups, which have potential as source aquifers for the desalination project. Further field investigation is necessary to fully assess the suitability of the KNSB and to provide a sufficiently detailed understanding of the aquifer system to design a well field for source water extraction and to identify suitable concentrate disposal points if injection through wells is to be used.

This aquifer in the Mesilla Bolson basin crosses into the area of west Texas (El Paso) and northern Mexico (Chihuahua) and faces interstate and binational use. Although there are no formal treaties in place for transboundary groundwater basins and there are more policy challenges to overcome, there are also some opportunities to conduct research in the desired region, which may open the door for cooperation between New Mexico, Texas, and the country of Mexico for a groundwater desalination plant. Research-driven transboundary aquifer programs such as the Transboundary Aquifer Assessment Program (TAAP) and Internationally Shared Aquifer Resource Mana (ISARM) have shown to be examples of official programs that encourage cooperation of the two nations to study and research transboundary aquifers.

The Engineering Design Report developed by CDM Smith has provided an overview and feasibility study for a brackish water reverse osmosis (BWRO) facility capable of treating a potential brackish groundwater supply in the Santa Teresa area. The cost associated with the construction of a 5 MGD BWRO treatment facility is estimated as $115.5 million. This is equivalent to $4 per 1,000 gallons of treated water and is comparable to a previously completed desalination plant projects in the United States. The total project cost, including supporting infrastructure and engineering services, is $269.5 million based on 2023 prices. The report discussed the potential funding sources for a desalination facility in south central New Mexico, which include state and federal funds and a combination of grants and loans. The permits and easements likely required for a BWRO facility in New Mexico include:

- Water rights for the brackish water supply
- NMED Drinking Water Bureau approval and permit
- NMED permit for injection wells and/or exploratory wells for concentrate disposal
- Easements or rights-of-way for raw water, finished water, and concentrate pipelines
- Building permit, construction permit, and stormwater handling permit

A multi-criteria decision making (MCDM) analysis was used to evaluate the benefits and challenges of developing the brackish water aquifer in Santa Teresa to supplement municipal and industrial water demand and to address increasing water scarcity. Based on the goals of stakeholders and sustainability targets, four major categories of criteria and 14 sub-criteria were developed, including System Performance, Economics, Social, and Environmental. For this analysis, all of the criteria were weighted evenly. Weights may be easily changed with stakeholder input in the future. Each of these criteria can be assigned a measurement per system based on scientific evaluation and the goal is to maximize or minimize it. The brackish water resource is a relatively uncontroversial source, and the potential for acceptance of desalinated water through public outreach and involvement is high. Because of the nature of the source water, energy demand is higher than for traditional water treatment. By investing in a solar farm to power the desalination facility, both the environmental and social impacts could be positively influenced. Charges may increase for ratepayers, which 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. The success of this option is dependent on the economic arrangement and reduced treatment costs. The MCDM results may enlighten stakeholders and partners developing the Santa Teresa desalination project about where to invest to ensure water sustainability, and how to provide clarity on the effects within the communities.

Despite advances in membrane technologies, membrane fouling and scaling remain a key impediment to successfully implementing membrane processes. This study conducted laboratory and pilot experiments to evaluate the effects of EMF as a non-chemical pretreatment on membrane scaling control during brackish water desalination and concentrate treatment at BGNDRF and KBHDP. Three different types of EMF devices were used, including two alternating current (AC) induced EMF devices with different peak-to-peak voltages and frequencies and one permanent magnet device. Feed spacers are important for the impact of fouling on the performance of spiral-wound membrane systems. This study compared the effect of spacers and EMF on membrane performance, including traditional mesh spacers and 3D printed open channel feed spacers. Pilot testing at BGNDRF treating brackish groundwater demonstrated that both AC-induced EMF and permanent magnet devices were effective in reducing permeate flux decline and improving water recovery. EMF could provide a chemical-free alternative for controlling membrane fouling and scaling by alleviating the formation of a compact scaling layer on the membrane surface. Periodic hydraulic flushing could restore membrane performance and recover reduced flux.

Novel RO elements with 3D printed feed channel spacers were also evaluated in bench and pilot scale testing. The bench-scale experiment demonstrated the EMF's capability in controlling fouling and scaling in three brackish waters, increasing their water recovery to 90%, and reducing the water permeation flux decline rate. This study shows that EMF strength plays an important role depending on the water chemistry. With respect to the membranes with 3D printed feed spacers, the bench scale experiments did not show a significant improvement with their usage. This is likely because these membranes were not designed for flat-sheet bench-scale experiments.

Pilot testing at the KBHDP showed inconclusive results that EMF and 3D printed feed spacers could alleviate membrane scaling during treatment of RO concentrate. The 3D printed feed spacers developed by Aqua Membranes are intended to increase permeate output. However, the thin feed spacer reduced the water flow channel's capacity to flush out the scales and precipitates formed under EMF in RO concentrate. A comprehensive understanding of crystal particle growth and size formation following exposure to EMF remains a crucial prerequisite for designing effective spacers capable of crystal removal and for improving the cleanability of spiral-wound membrane systems.

4.2. Recommended Next Steps

New Mexico has identified brackish water desalination as a strategic water supply to offset demand for freshwater and meet the new water demands without reducing the availability of freshwater for human consumption, growing crops and raising livestock, and cultural and ecological purposes. The research team will continue to engage elected officials, water agency officials, regulators, as well as other stakeholders and interested parties, with technical, economic, and environmental information to support developing a brackish water desalination project in Santa Teresa area for industrial, commercial, and municipal uses.

The logical next step in characterizing the hydrogeology and geochemistry to support desalination system design is hydrogeological field investigation specifically targeting the brackish resource. A follow-on project to this effort and Hawley et al. (In press) is underway by the New Mexico Office of the State Engineer (NMOSE), in coordination with the stakeholders. While it is still early in the project, NMOSE personnel are currently evaluating the potential for an airborne electromagnetic survey of the southern KNBS in the fall of 2024 with an eye toward characterizing the aquifer system structure and boundaries, and to support the development of an exploratory drilling plan. In parallel, a modeling effort is underway to assess the effects of source water extraction from the KNSB on aquifer storage and water quality, and the nature and timing of effects on the Rio Grande.

Reclamation's Albuquerque Area Office is also embarking on a broader study of the brackish resources of the Mesilla Basin and other aquifers in southern New Mexico and west Texas. In addition, the New Mexico Environment Department has tasked NMSU to characterize the brackish groundwater aquifers on southern New Mexico (including the Mesilla Bolson) and to prepare a summary report on the state of research and technology availability for the treatment of brackish water for fit-for-purposes uses, including energy production, energy storage, industrial applications and potable uses.

Further fundamental and experimental research is needed to better characterize the EMF properties and elucidate the mechanisms of EMF fouling and scaling control under different operating conditions. Many factors still need to be investigated individually and holistically, including water chemistry, EMF generation source, shape and strength of the field, exposure time to EMF, RO membrane materials, and membrane operating conditions. As they materialize, the research findings will be applied to the design and optimization of EMF to achieve optimal effects in water treatment and for the investigation of the electromagnetic effect on the crystallization and precipitation of minerals in water pipes and on membranes.

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Metric Conversions

Unit	Metric equivalent
1 gallon	3.785 liters
1 gallon per minute	3.785 liters per minute
1 gallon per square foot of membrane area per day	40.74 liters per square meter per day
1 inch	2.54 centimeters
1 million gallons per day	3,785 cubic meters per day
1 pound per square inch	6.895 kilopascals
1 square foot	0.093 square meters
°F (temperature measurement)	(°F–32) × 0.556 = °C
1 °F (temperature change or difference)	0.556 °C

APPENDIX A

Table A-1: 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 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 (CF) are included in the minimum charge for residential customers.

Table A-2: Charge per cubic foot (CCF) and overall volume use charge

Block	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. 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