FINAL Pilot Study Report
Texas Seawater Desalination Demonstration Project

October 2008

NRS
engineering better communities

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October 24, 2008

Mr. Jorge Arroyo, P.E.
Director Innovative Water Technologies
Texas Water Development Board
P.O. Box 13231
1700 N. Congress Avenue
Austin, TX 78711-3231

RE: Brownsville Public Utilities Board
Final Seawater Pilot Plant Study Report

Dear Mr. Arroyo:

On behalf of the Brownsville Public Utilities Board, please find enclosed the "Final Seawater Pilot Plant Study Report". This report contains findings, conclusions and recommendations as a result of the 18-month pilot study and incorporates draft report review comments received from the Board, Mr. Frank Leitz with Reclamation, and Mr. Robert Reiss, P.E. with Reiss Engineering, Inc.

This report recommends constructing a demonstration seawater desalination facility at 10% of the projected full-scale 25 mgd capacity to provide the needed alternative supply to Brownsville and further refine the findings and development of final design data for the full-scale plant. The Demonstration Project will allow the State of Texas and Brownsville to prove the validity of seawater desalination as a legitimate water supply alternative for the Texas gulf coast while advancing technology for this and future projects across the State.

As part of contract requirements, we have included one unbound, camera-ready original, nine (9) double-sided copies, one (1) electronic copy in pdf format, and one (1) electronic copy of any referenced report attachments.

We appreciate working with the TWDB and BPUB on this important project for the State of Texas and this region. If you have any question, please advise.

Sincerely,

Joseph W. Norris, P.E.
Principal

STATE OF TEXAS
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LICENSED
PROFESSIONAL ENGINEER

CC: John S. Bruciak, P.E., General Manager, BPUB (w/encls)

Enclosures

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Acknowledgements

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Project Sponsors
Brownsville Public Utilities Board
Texas Water Development Board
Port of Brownsville

Equipment Suppliers
Doosan
GE Zenon
Norit
Pall

Pilot Study Team
Dietrich Consulting Group
TRC
URS
WaterPR

Executive Summary

Pilot Study results have confirmed that seawater desalination at the Brownsville Ship Channel is technically feasible. Although the ship channel presents a challenging water source due to extreme variations in quality (especially turbidity, suspended solids, and temperature), a microfiltration pretreatment system followed by reverse osmosis (RO) adequately treated raw seawater to potable standards. The data and information gained during the Pilot Study is sufficient to develop a full-scale, 25 mgd desalination plant. This design, however, must be conservative (and therefore expensive) to accommodate the raw water variability and probable environmental events, such as red tides and hurricanes, that were not experienced during piloting but are likely under long-term production.

The Brownsville Public Utilities Board (BPUB) therefore proposes to construct a 2.5 million gallons per day (mgd) demonstration-scale seawater desalination plant and research facility at the Port of Brownsville. The proposed Demonstration Project would have several advantages. First, the additional water provided by the demonstration facility will provide 9 percent of the total BPUB demand by 2012, further diversifying their water supply sources. Next, this phased approach will allow for an evaluation of system performance over several years of operation prior to an investment in full-scale capacity. This data is expected to yield a more efficient overall treatment system design and lower the cost of future expansions as they occur. Finally, the demonstration facility will include the capability for continued testing of the latest desalination technologies for this and other future seawater desalination facilities along the Texas coast. Such technologies include applications for pretreatment, energy recovery, sustainable energy supply, and larger (potentially more efficient) membranes.

The total estimated cost for the proposed 2.5 mgd Demonstration Project is $67,479,000. Approximately half of this amount reflects an investment in full-scale capacity infrastructure, such as the intake and concentrate disposal systems. This investment is expected to significantly reduce the costs of future expansions at the facility. BPUB proposes to finance a portion of this project using a $20 million loan from the Texas Water Development Board (TWDB). In addition, implementation of the proposed project will also require supplemental funding in the form of a $28.2 million grant from the State and $19.3 million financed under the TWDB State Participation Fund.

BACKGROUND

In 2004, a Feasibility Study determined that the Lower Rio Grande Valley region would be confronted with a water supply deficit by 2050 and that seawater desalination was a viable alternative (Dannenbaum and URS 2004). Based on data and information available at the time, the Feasibility Study estimated the total probable costs for a full-scale 25 mgd facility to be approximately $152 million. The study recognized that some form of supplemental (grant) funding would have to be provided to bridge the gap between what such a facility would cost and what local utilities could afford to pay. Since that time, substantial increases in the costs for fuel, electricity, steel, and petroleum-based products have been observed.

In 2007, BPUB and TWDB partnered together to implement a seawater desalination Pilot Study. The pilot facility was located on the north shore of the Brownsville Ship Channel on land made available by the Port of Brownsville. The primary purpose of the pilot was to provide an opportunity to evaluate actual performance of proposed water treatment systems under site-specific conditions. Piloting results would then be used to refine the designs and cost estimates for a full-scale (25 mgd) seawater desalination facility. The *Brownsville Seawater Desalination Pilot Project* operated from February 2007 to July 2008, and this Final Pilot Study Report presents its results and recommendations.

PILOT STUDY APPROACH

Two alternative site locations were considered for the pilot facility: Boca Chica Beach (coastal) and the Brownsville Ship Channel (inland approximately 11 miles) (Figure ES-1). Although the raw water quality was expected to be generally poorer at the ship channel site, the pilot facility was located there because of power supply, cost, security, and access considerations. As such, the site represents a worst-case source water quality testing scenario.

Because the objective of a seawater desalination project is to produce potable drinking water from the ocean, the Pilot Study established testing protocols approved by the Texas Commission on Environmental Quality. The performance of each pretreatment and primary treatment (RO) process was then evaluated and documented. The original study scope developed by BPUB and TWDB called for the comparison of two types of pretreatment technologies: 1) conventional (rapid mix/flocculation/clarification/filtration), and 2) ultrafiltration (a membrane-based technology). However, at the outset of the project, BPUB decided to increase the scope and value of the Pilot Study by including two additional membrane-based pretreatment units. The project budget was thereby increased by almost $1.0 million and funded by BPUB. This side-by-side comparison of four different pretreatment technologies resulted in an unprecedented level of study complexity (Figure ES-2).

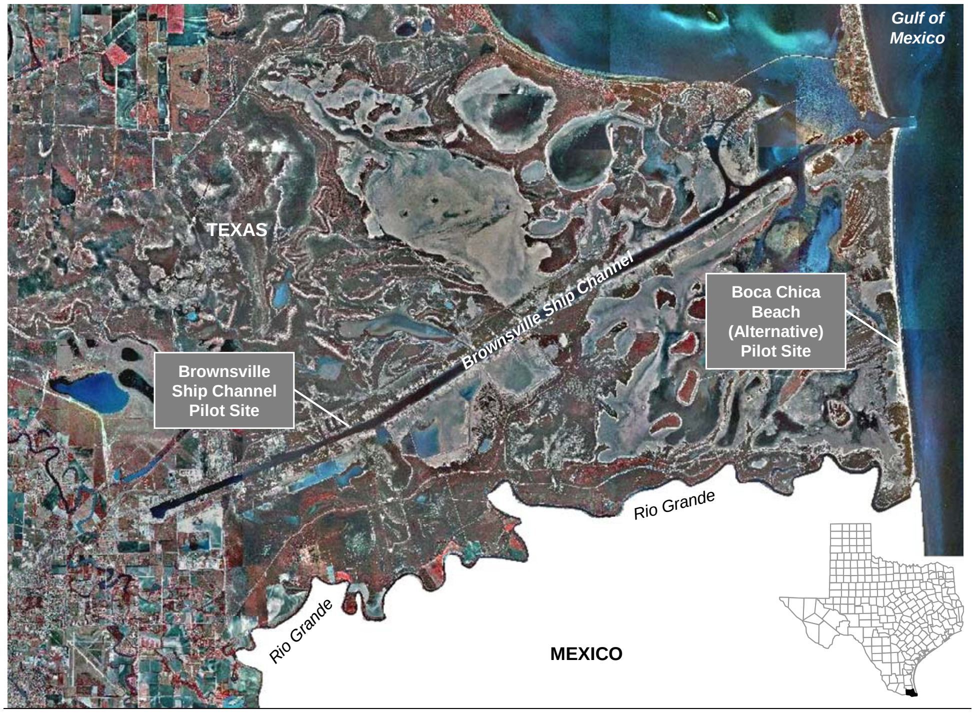

Figure ES-1: Location of the Brownsville Seawater Desalination Pilot Project.

LEGEND

1 Intake
2 Intake pumps
3 Norit ultrafiltration pretreatment unit
4 GE Zenon ultrafiltration pretreatment unit
5 Pall microfiltration pretreatment unit
6 Eimco conventional pretreatment unit
7 Pretreatment filtrate storage tanks
8 Reverse Osmosis treatment
9 Water storage tanks
10 Mixing tanks
11 Lagoon
12 Neutralization tank and discharge point
13 Discharge ditch
A Chemical storage building
B Operations building

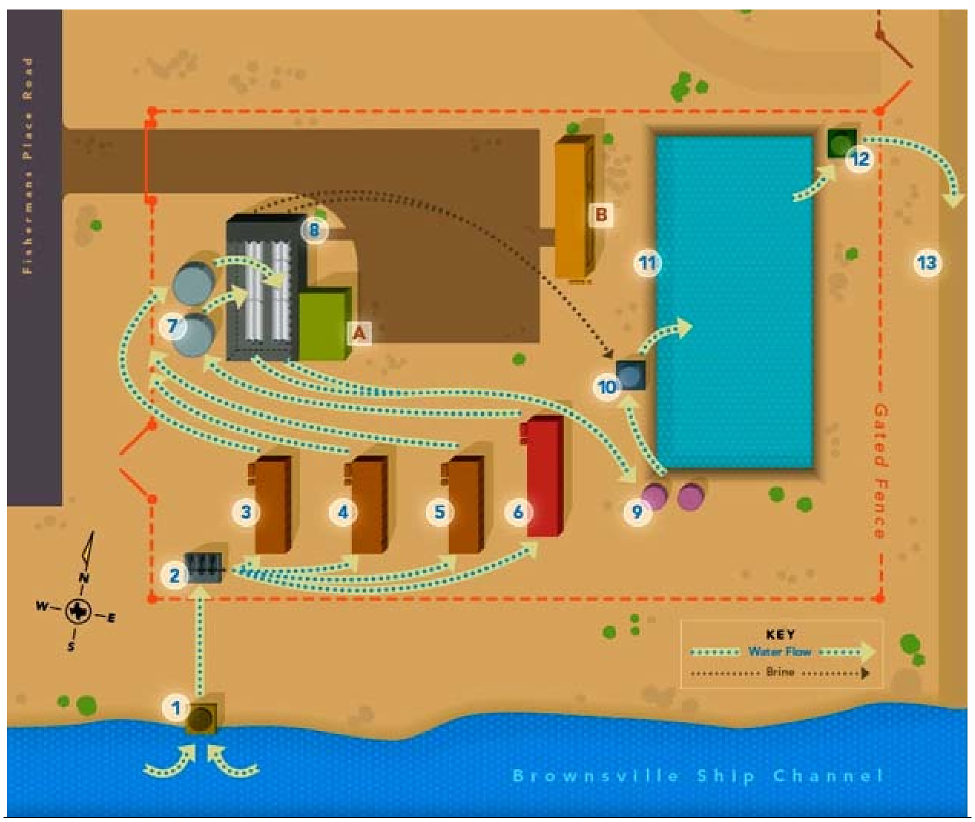

Figure ES-2: Layout of the Brownsville Seawater Desalination Pilot Project.

RESULTS AND CONCLUSIONS

Raw Water Characterization

During the Pilot Study, source water quality was characterized at both potential full-scale site locations, including the inland site on the Brownsville Ship Channel and the ocean site off-shore of Boca Chica Beach in the Gulf of Mexico. In the ship channel, large fluctuations in turbidity and suspended solids were observed. These variations were attributed mainly to the passing of cargo ships in the Brownsville Ship Channel (Figure ES-3) and predominant (southeasterly) wind direction and speed. Water quality in the Gulf of Mexico varied less, but samples were not taken during adverse weather conditions when variability would be expected to increase and overall quality decrease. Therefore, pilot data for the Gulf of Mexico do not reflect the worst-case water quality scenario for the open ocean that would occur during hurricane or other severe storm events.

Figure ES-3: Photograph of the effect of a cargo ship passing on raw water turbidity in the Brownsville Ship Channel.

Intake System

The Pilot Study utilized a wetwell, pumps, and intake screen to provide raw water from the ship channel to the pretreatment systems. Although this configuration was effective at the pilot-scale, a permanent intake system for a seawater desalination production facility will incorporate features that provide sufficient feed volume while minimizing the collection of suspended solids and protecting marine life. The recommended design includes a lengthy and wide constructed intake channel that connects the Brownsville Ship Channel to the intake screen assemblies and raw water pump station. This design would increase raw water settling time, thereby minimizing total suspended solids and turbidity introduced into the pretreatment systems. In addition, locating the facility on the south side of the ship channel may also reduce adverse water quality conditions imposed by prevailing southeasterly winds at the site.

Pretreatment System

It is widely understood that pretreatment is the most critical component of a successful seawater desalination facility. This is especially true given the raw water quality variability observed at the Brownsville Ship Channel. During the Pilot Study, four pretreatment systems were subjected to protocol tests: 1) Eimco Conventional System, 2) GE Zenon Ultrafiltration, 3) Norit Ultrafiltration, and 4) Pall Microfiltration. Each pretreatment system was tested at various operating conditions to document loading rates, pressure losses, water production efficiency, filter backwash rates and frequencies, and chemical types and dosing rates. For each, optimum process settings were established in which water production was maximized while minimizing chemical use and waste generation. The removal efficiency of potential membrane fouling agents (i.e., particulates, total organic carbon, etc.) was also measured and system reliability evaluated in terms of treatment consistency. Robustness was evaluated in terms of raw water quality variations. The overall goal was to maximize runtime by minimizing downtime associated with mechanical and membrane failures, thereby developing a cost effective pretreatment system for the production facility.

Of the four tested, only one pretreatment unit was able to meet the pretreatment objectives (i.e., operate for a minimum of 30 days without performing a clean-in-place, providing high quality filtrate, minimizing chemical consumption, maximizing filtrate flux, and performing without exhibiting irreversible fouling tendencies on the membrane surface). This unit was the Pall Microfiltration system, which successfully operated for periods of 66 days and 72 days during two separate pilot runs. The Norit Ultrafiltration, GE Zenon Ultrafiltration, and conventional pretreatment systems failed to prove sustainable operation without exhibiting significant fouling tendencies and, in the extreme case, irreversible fouling on the membrane surface.

Reverse Osmosis System

Three RO membranes were tested during the pilot: 1) Toray TM820C-400, 2) FilmTec SW30HR LE-400i, and 3) Toray TM820-400. Two RO pressure vessels (Trains A and B) were loaded with seven membrane elements each (Figure ES-4). The RO piloting objective was to determine the optimum operating parameters that could be carried over to the full-scale production facility. This objective included maximizing operation of the RO units while evaluating salt passage, normalized permeate flow, flux, recovery, cartridge filter changeout frequency, and intervals between cleanings. Results of the Pilot Study determined that both FilmTec and Toray were successful in meeting the project goals and would therefore be acceptable for use at the full-scale facility.

Figure ES-4: Photograph showing the loading of an RO element into the pressure vessel.

Finished Water Quality

Pilot Study results indicate that a treatment system consisting of microfiltration followed by RO and post-treatment is capable of treating raw seawater from the Brownsville Ship Channel to a quality that meets all primary and secondary water quality standards without the need for additional treatment. Post treatment requirements include a combination of chemicals such as caustic soda (pH control), sodium bicarbonate for alkalinity, and calcium chloride for addition of calcium. This combination of chemicals will produce stable, non-corrosive water.

Concentrate Disposal

During the Pilot Study, concentrate produced from the desalination process was recombined with the permeate and other filtered materials in an on-site lagoon prior to discharge back into the ship channel. However, for a full-scale facility producing 25 mgd of potable water, approximately 30 mgd of concentrate with salinity twice that of the raw water would require disposal.

Two potential methods of concentrate disposal were evaluated as part of the Pilot Study: 1) Class I injection wells, and 2) diffusion into the Gulf of Mexico. Both methods were determined to be technically feasible, but diffusion was found to be significantly less expensive to construct and operate. The diffusion method would include a transfer pump station and 12-mile pipeline from the desalination plant to a location approximately 0.5 miles into the Gulf of Mexico east of Boca Chica Beach.

A preliminary design for a multi-port diffuser array in the Gulf of Mexico was developed and flow and dispersion characteristics modeled. Based on longshore currents and water depths in the vicinity, the model predicted brine concentrations to be near ambient conditions within 125 feet of the diffuser array. Chemical water quality standards in the Gulf of Mexico exist only for dissolved oxygen and pH, which are not expected to be affected by concentrate discharge. There are no standards for total dissolved solids. Regulatory requirements for the discharge of RO concentrate will likely be focused on avoiding adverse impacts to the coastal ecosystem.

RECOMMENDATIONS

Full-Scale Facility

Based on Pilot Study results, a full-scale (25 mgd) seawater desalination plant at the Brownsville Ship Channel would cost approximately $182 million (2008 dollars) (Table ES-1). To ensure long-term operational success of the plant, about 26 percent of this total accounts for a conservative pretreatment design consisting of conventional treatment elements ahead of the microfiltration pretreatment system.

Table ES-1: Comparison of Feasibility Study and Pilot Study total project cost estimates for a full-scale (25 mgd) seawater desalination plant.

Project Component	Feasibility Estimate [a] (2004)	Pilot Study Estimate (2008)
Desalination Plant	$90,167,000	$126,612,000
Concentrate Disposal System	$30,583,000	$21,217,000
Finished Water Transmission System	$9,232,000	$12,180,000
Project Implementation Costs	$21,406,000	$22,400,000
Total Capital Costs	**$151,388,000**	**$182,409,000**

[a] *Source*: Dannenbaum and URS (2004).

After considering the costs of other water supply alternatives available for the future needs of Brownsville, BPUB determined that it could afford up to $70 million for a 25 mgd seawater desalination project. This would leave an infeasible funding gap well over $100 million. In addition, the full anticipated regional water demand envisioned for the full-scale facility is not expected to materialize for several years. Therefore, **it is recommended that a full-scale (25 mgd) seawater desalination facility NOT be implemented at this time due to the magnitude of the required funding gap and the current lack of full demand by BPUB and regional partners.**

Demonstration Production Facility

Based on the Pilot Study results and conclusions, **it is recommended that a 2.5 mgd demonstration-scale seawater desalination plant be designed and constructed on the south shore of the Brownsville Ship Channel.** In anticipation of future expansion to full-scale (25 mgd) capacity, several key components of the Demonstration Project would be implemented at full-scale, including the intake system, concentrate disposal system, and land acquisition.

A phased project development approach will best mitigate the risks and uncertainties associated with seawater desalination (Figure ES-5). Such an approach will allow an evaluation of system performance over several years of operation prior to an investment in full-scale capacity. This data is expected to yield a more efficient overall treatment system design and lower the cost of future expansions as they occur. The demonstration facility will also include the capability for continuous testing of the latest desalination technologies for this and other future seawater desalination facilities along the Texas coast. Such technologies include applications for pretreatment, energy recovery, sustainable energy supply, and larger (potentially more efficient) RO membranes.

Project Phase	**FEASIBILITY**	**PILOT**	**DEMONSTRATION**	**PRODUCTION**	**PRODUCTION**
Knowledge of Costs and Process at End of Phase	*Uncertainty*			*Certainty*	
Status of Brownsville Seawater Desalination Project	*Completed (2004)*	*Completed (2008)*	Pending (2012)	Future (2025)	Future (2050)
Production Capacity	-	-	2.5 mgd	12.5 mgd	25 mgd
Percent of Full-scale	-	-	10%	50%	100%

Figure ES-5: Phase project approach and the relative degree of risk and uncertainty associated with seawater desalination.

BPUB is willing to continue their investment in seawater desalination because surface and groundwater sources continue to be limited. Surface water in the Rio Grande is vulnerable to recurring drought conditions and Mexico treaty non-compliance, while brackish groundwater is limited by individual well production and aquifer recharge rates. Up until 2004, BPUB was 100 percent dependent on the Rio Grande as a water supply source. In response to the extreme drought early in that decade, BPUB developed the Southmost Regional Water Project, the largest coastal brackish groundwater desalination project in the state. Brackish desalination accounted for 22 percent of BPUB water production in 2007. The proposed demonstration project would account for 9 percent of BPUB total production in 2012 and further reduce dependency on the Rio Grande to 65 percent (Figure ES-6). The proposed project would also set the stage for subsequent expansions of seawater desalination capacity as BPUB water demands increase and regional partners are developed.

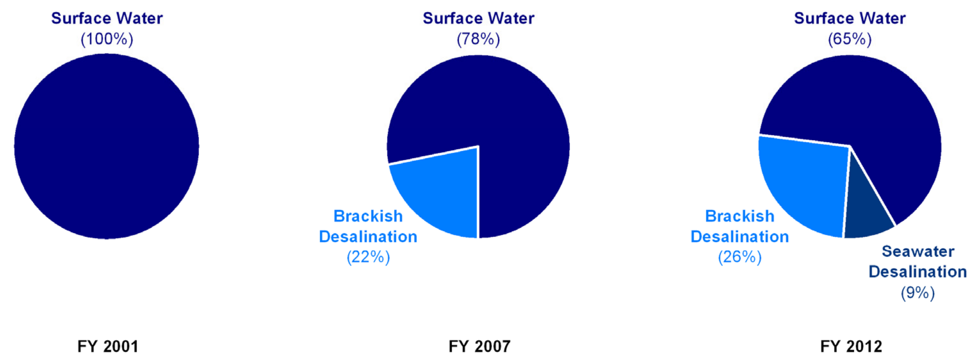

Figure ES-6: BPUB water production by source, current and projected with the proposed Demonstration Project.

Estimated Costs and Required Capital Infusion

The proposed Demonstration Project would cost a total of approximately $67,479,000. Approximately half of the cost of the proposed Demonstration Project ($30.9 million) includes infrastructure developed to provide for future full-scale capacity, especially the intake system, brine discharge pipeline to the Gulf of Mexico, and other site facilities. Implementation will require supplemental funding in the form of a grant from the State of $28.2 million and utilization of $19.3 million from the TWDB's State Participation Fund for a portion of the oversizing of the facility. BPUB proposes to finance $20 million through the TWDB Water Infrastructure Fund toward the implementation of this project (Table ES-2).

Table ES-2: Recommended uses and sources of funds, proposed Demonstration Project.

		Biennium	
	Total	**2010-2011**	**2012-2013**
Use of Funds			
Design Determination Studies	$2,967,000	$2,967,000	-
Environmental Review and Permitting	$1,079,000	$1,079,000	-
Final Design and Specifications	$5,935,000	$5,935,000	-
Construction Support Services	$2,698,000	-	$2,698,000
Startup Support Services	$846,000	-	$846,000
Construction[1]	$53,954,000	$10,791,000	$43,163,000
Total Uses of Funds	**$67,479,000**	**$20,772,000**	**$46,707,000**
Percent of Total	*100%*	*31%*	*69%*
Sources of Funds			
BPUB Loan From WIF	$20,000,000	$8,300,000	$11,700,000
State Grant	$28,200,000	$12,472,000	$15,728,000
State Participation Program	$19,279,000	-	$19,279,000
Total Sources of Funds	**$67,479,000**	**$20,772,000**	**$46,707,000**

[1] A detailed construction cost estimate, including how much is allocated to full-scale infrastructure, is presented in Table 5-7 (Page 5-29) of this report.

From the beginning, it has been understood that seawater desalination would not be the least expensive option to expand treatment capacity. Nevertheless, BPUB has pursued seawater desalination as a means of diversifying its water supply sources by including the only drought resistant supply available. The financial goal of BPUB for the project is to develop a seawater desalination project that is no more costly than one of its other water alternatives. For seawater desalination, this will require a capital infusion from a public source.

Under the proposed funding scenario (see Table ES-2), the cost to BPUB at start up is projected to be $4.06[2] per 1000 gallons (Table ES-3). If grant funding was not provided, the estimated cost would be $7.05[3] per 1000 gallons. However, these values are somewhat misleading considering the amount of the proposed project dedicated to future capacity. As the facility is ultimately expanded and technology improves and is tested, future costs are expected to be much lower due to the initial investment made. With the proposed Demonstration Project, the combined BPUB water cost would increase to $2.43 per 1,000 gallons in 2012, or by approximately 8 percent.

Table ES-3: Current and projected BPUB costs for all water supply sources.

		Current (FY 2007)	Projected (FY 2012)
Water Production			
	Surface Water Plant 1 (Rio Grande)	3,352	2,738
	Surface Water Plant 2 (Rio Grande)	2,970	2,738
	Southmost (Brackish Desalination)	1,763	2,190
	Seawater Desalination	-	803
	Total YTD	**8,085**	**8,468**
Unit Costs of Water Produced ($ per 1,000 gallons)			
Surface Water Treatment	O&M	$1.75	$1.75
	Debt Service	$0.50	$0.50
	Subtotal Surface	$2.25	$2.25
Brackish Groundwater Desalination	O&M	$1.28	$1.28
	Debt Service	$1.02	$1.02
	Subtotal Brackish	$2.30	$2.30
Proposed Demonstration Project	O&M	$0.00	$2.80
	Debt Service[a]	$0.00	$1.26
	Subtotal Seawater	$0.00	$4.06
Total for All BPUB Water Supply Sources	**O&M**	**$1.65**	**$1.73**
	Debt Service	**$0.61**	**$0.71**
	Total Combined BPUB Cost	**$2.26**	**$2.43**

Source: Current data provided by BPUB Public Finance Division, June 2008.
[a] Assumes grant of $28.2 million, debt service of $20 million by BPUP amortized for 25 years at 3%, and $19.3 million financed under the State Participation Program.

[2] Debt service of $20 million (BPUP) amortized for 25 years at 3% utilizing the TWDB Water Infrastructure Fund would be $1.26/1000 gallons plus $2.80/1000 gallons for O&M costs.
[3] Debt service of $67.5 million (BPUP with no grant funding) amortized for 25 years at 3% utilizing the TWDB Water Infrastructure Fund would be $4.25/1000 gallons plus $2.80/1000 gallons for O&M costs.

ADVANTAGES AND CHALLENGES

The proposed Demonstration Project holds several advantages over conventional surface water treatment and brackish desalination facilities. For BPUB, one of the most important advantages is the diversification of its supply. For the State of Texas, the demonstration of the viability of seawater desalination technology in the State is of prime importance. Other key perspectives about the viability of the demonstration project are discussed below:

Advantages

- *Addresses the need for water production for the BPUB* – the 2.5 mgd production capacity of the proposed Demonstration Project will be fully utilized by BPUB. A larger plant at this time would have excess capacity with a much greater investment and risk.
- *Lower near-term investment* – the implementation of the demonstration project has a lower overall initial cost compared to the full-scale plant. A total investment of $67 million compared to $182 million. Nearly 50% of the demonstration cost is for future capacity.
- *Reduction of risk* – A full-scale investment $182 million now incurs some risk in that the Pilot Study yielded good data for a demonstration plant but left some unanswered questions for full production. The Demonstration Project is expected to further refine data in efforts to reduce the overall cost of the full-scale facility.
- *Potential for cost savings in full-scale* – the Pilot Study yielded the need for a higher level of pretreatment and associated costs. The Demonstration Project will be equipped to modify operations to optimize the design data and solicit competition from vendors for the full-scale facility.
- *Development of operational flexibility in demonstration* – the demonstration facility will allow for the testing of a wide variety of conditions such as primary treatment ahead of membrane pretreatment for a portion of the flow to measure cost savings/increases as a result of this flexibility.
- *Provides an opportunity to conditionally permit full-scale facility based on actual demonstration-scale operational data* – the proposed Demonstration Project would provide the opportunity to evaluate the effects of concentrate disposal in the Gulf of Mexico on a smaller scale over a period of years, reducing the environmental risk of full-scale permitting conditions developed solely on artificial modeling results.
- *Operate over a longer term to assure all water qualities* – the Pilot Study operated for a period of 18 months with some short-term successes. The development of the demonstration plant will provide an opportunity for the plant to experience varying conditions over multiple seasons. One potentially complicating phenomenon that did not occur during piloting was the presence of a red tide event.
- *Improvement of intake and its effects on operation and future design parameters* – the pilot was unable to maximize the intake efficiency therefore yielding a highly variable water quality with extreme peaks of turbid water. On the positive side, the pilot yielded good results for poor water conditions. It is anticipated

that an improved intake will yield a reduction in cost and improve the reliability of the demonstration and full-scale plants.

- *Demonstrate to the State the effectiveness of seawater desalination along the Texas coast* – the establishment of an inland desalination facility will give confidence to other areas of the state to evaluate this water supply alternative.
- *Developing excess capacity in certain facility components makes full-scale facility more cost effective to build* – major components of the Demonstration Project, such as intake canals and concentrate discharge lines, would be designed and constructed for full-scale (25 mgd) conditions. These capital costs, sunk in present-day dollars, would reduce the expense of future expansion.

As with any project, there are disadvantages to the implementation of a demonstration plant. The following describes disadvantages to the demonstration plant.

Challenges

- *Higher unit cost of water produced* – economies of scale play a large part in the development of a desalination facility. The demonstration plant includes almost 50 percent in extra cost that cannot be fully utilized until future expansion. For the plant to be cost effective, grants and low interest loans must be utilized to complete the Demonstration Project.
- *Less capacity for future needs* – the initial (smaller) desalination plant would provide less capacity for future needs and regional supply possibilities.
- *Perception of not being "big enough"* – the demonstration plant does not have the "big" or large-scale tag and may be perceived as too small.

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List of Acronyms

ACH	aluminum chlorohydrate
BECC	Border Environmental Cooperation Commission
BEIF	Border Environmental Infrastructure Fund
BPUB	Brownsville Public Utilities Board
CEB	Chemically enhanced backwash
CIP	clean-in-place
CORMIX	Cornell Mixing Zone Expert System
DOC	dissolved organic carbon
EFM	enhanced flux maintenance
EPA	Environmental Protection Agency
$FeCl_3$	ferric chloride
FEMA	Federal Emergency Management Agency
$FeSO_4$	ferric sulfide
fps	feet per second
FRP	fiberglass-reinforced plastic
gpm	gallons per minute
gfd	gallons per square foot of membrane per day
HAA5	haloacetic acids
HB	House (of Representatives) Bill
HDPE	high density polyethylene
HP	horse-power
kV	kilovolt
LAS	liquid ammonium sulfate
LIRF	Low Interest Rate Lending Facility
LRGV	Lower Rio Grande Valley
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	maximum containment level
MF	microfiltration
mgd	million gallons per day
msl	mean sea level
MW	megawatt
NADB	North American Development Bank
NaOCl	sodium hypochlorite

O&M	operation and maintenance.
PCIS	Process Control and Instrumentation System
PCU	platinum-cobalt units
ppm	parts per million
ppt	parts per thousand
psi	pounds per square inch
QA/QC	quality assurance/quality control
Reclamation	U.S. Bureau of Reclamation
RO	reverse osmosis
SASRF	simultaneous air scrub/reverse flush
SCADA	Supervisory Control and Data Acquisition
SDI	silt density index
SH	State Highway
SOC	Synthetic Organic Compounds
SWRO	seawater reverse osmosis
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TEIP	Texas Environmental Infrastructure Program
TMP	transmembrane pressure
TOC	total organic carbon
TSS	total suspended solids
TTHMS	total trihalomethanes
TWDB	Texas Water Development Board
UF	ultrafiltration
USACE	U.S. Army Corps of Engineers
VOC	Volatile Organic Compounds
WHO	World Health Organization
WIF	Water Infrastructure Fund
WRDA	Water Resources Development Act

1.0 Introduction

The purpose of this Pilot Study is to determine the most cost effective method of converting seawater to potable water for use by customers in and around Brownsville, Texas. This pilot represents the continuation of a State of Texas seawater desalination initiative begun in April 2002 when Governor Rick Perry tasked the Texas Water Development Board (TWDB) with developing a proposal to build the first large-scale seawater desalination plant in Texas to produce drinking water. In 2003, the Texas Legislature passed House Bill 1370 directing TWDB to undertake research and studies to advance the development of cost effective water supplies from seawater desalination. In response, TWDB provided $1.5 million for three feasibility studies to assess the technical viability of proposed seawater desalination projects: Lower Rio Grande Valley (Brownsville), City of Corpus Christi, and Freeport.

Upon review of the feasibility studies, the *Brownsville Seawater Desalination Project*, sponsored by the Brownsville Public Utilities Board (BPUB), was selected to proceed to the pilot phase. In its evaluation, TWDB considered the likelihood that the proposed projects would move to design and construction within a reasonable period. The agency determined that the Brownsville project demonstrated the greatest level of commitment and motivation to face the risks of developing a large-scale facility and therefore awarded BPUB with grant funding to implement the Pilot Study. As originally envisioned, the *Brownsville Seawater Desalination Project* would provide 25 million gallons per day (mgd) of treated seawater from the Brownsville Navigation Ship Channel to serve residents of Cameron County, Texas.

1.1 FEASIBILITY STUDY FINDINGS

The Feasibility Report for the Brownsville Seawater Desalination Project (Dannenbaum and URS 2004) was completed in November 2004 and provides the background and planning context for the current Pilot Study. The Feasibility Study addressed the following major tasks:

1. Water supply planning.
2. Analysis of desalination technology alternatives.
3. Evaluation of power components.
4. Development of cost estimates.
5. Preliminary financial analysis.

1.1.1 Water Supply Planning

The Feasibility Study concluded that local water demand in the Brownsville area would make up a major portion of the water need in early years of the seawater desalination project and would be a key foundation for project viability. The Brownsville Public Utilities District service area encompasses a portion of southern Cameron County in the immediate Brownsville vicinity (Figure 1-1).

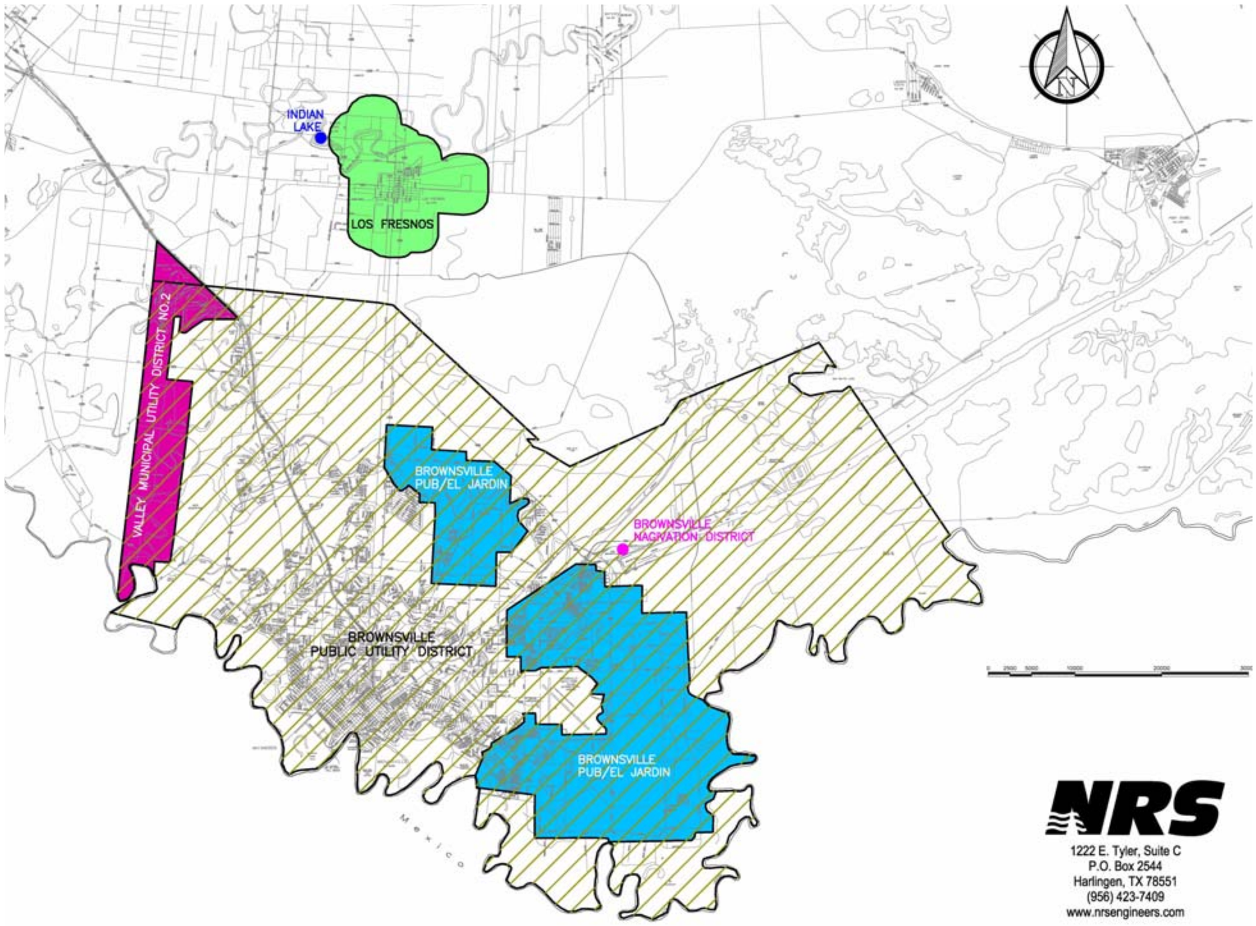

Figure 1-1: Service area of BPUB and other regional water providers.

Based on updated estimates in the 2007 Texas Water Plan, Brownsville is expected to need over 23,300 acre-feet of new water supplies by 2030 (Table 1-1). In the long-term, the majority of the project demand would be from other municipal, industrial, and steam electric users in Region M. Region M (Rio Grande) consists of eight Texas counties along the Texas-Mexico border, including Cameron, Willacy, Hidalgo, Starr, Zapata, Jim Hogg, Webb, and Maverick. The three counties nearest to the proposed seawater desalination facility (Cameron, Willacy, and Hidalgo) are expected to include over 74 percent of the estimated 3.8 million residents in Region M by 2060 (Texas Water Development Board 2007a).

Table 1-1: Projections for population and municipal water demands and needs for Brownsville and Region M.

	2010	2020	2030	2040	2050	2060
POPULATION						
Region M	1,581,207	1,973,188	2,401,223	2,854,613	3,337,618	3,826,001
Brownsville	173,986	210,210	247,653	284,979	322,316	357,828
Brownsville as a Percent of Region M	*11.0%*	*10.7%*	*10.3%*	*10.0%*	*9.7%*	*9.4%*
MUNICIPAL WATER DEMAND (acre-feet)						
Region M	279,633	338,716	403,511	472,632	547,747	625,743
Brownsville	43,655	50,038	60,475	69,270	77,985	86,577
Brownsville as a Percent of Region M	*15.6%*	*14.8%*	*15.0%*	*14.7%*	*14.2%*	*13.8%*
MUNICIPAL WATER NEED (acre-feet)						
Region M	23,936	61,064	113,978	174,120	245,148	321,248
Brownsville	6,569	14,952	23,389	32,185	40,899	49,492
Brownsville as a Percent of Region M	*27.4%*	*24.5%*	*20.5%*	*18.5%*	*16.7%*	*15.4%*

Source: Texas Water Development Board (2007a).

1.1.2 Analysis of Desalination Alternatives

As part of the Feasibility Study, a conceptual design for the full-scale (25 mgd) seawater desalination facility was prepared. The plant was located on the north side of the Brownsville Ship Channel at the location of the pilot plant. An alternatives analysis of all major treatment processes was used to determine the recommended alternative. A summary of the considered alternatives and recommendations for the feasibility-level conceptual design is presented in Table 1-2.

Based on the information known at the time, it was determined that the above described system would reliably provide high quality potable water that complied with all current and anticipated standards for drinking water quality.

1.1.3 Evaluation of Power Components

At the statement of interest phase of the Feasibility Study, the possibility of co-locating the desalination plant with a 500-megawatt (MW) power generating station was considered. There was (and still is) interest in expanding power generating capacity in the Brownsville area, and the alternatives evaluated included natural gas-fired, coal-fired, and wind power electric generation. However, the potential synergies and power cost-saving possibilities from co-location were determined to be much less strong than the feasibility project team had originally envisioned. Therefore, the Feasibility Study recommended independent consideration of the power and water facilities (Dannenbaum and URS 2004).

Table 1-2: Summary of Feasibility Study alternatives and recommendations for a full-scale (25 mgd) seawater desalination facility.

Project System	Alternatives Considered	Feasibility Study Recommendation (2004)
Raw Water Supply Source	• Gulf of Mexico • Brownsville Ship Channel • Brackish groundwater	• Brownsville Ship Channel
Pretreatment	• Two-stage dual-media filtration system • Ballasted flocculation/clarification with single-stage dual-media filtration • Submerged ultrafiltration membrane system	• Ballasted flocculation, single-stage dual-media filtration, cartridge filtration, filter clearwell and transfer pumping, heat exchange, chemical conditioning, and cartridge filtration
Primary Treatment	• Membrane configurations • Thermal solutions	• High pressure seawater reverse osmosis (SWRO) pumping, first pass SWRO units, partial second-pass brackish water reverse osmosis units with pressure booster pumps, energy recovery turbines, and foam reduction chamber for brine stream
Stabilization	• Pebble lime • Calcite filters	• Pebble lime stabilization with pH control
Disinfection	• Gas chlorine • On-site sodium hypochlorite generation • Commercial bleach	• On-site generated sodium hypochlorite disinfection
Brine Disposal	• Industrial water reuse • Diffusion into the Gulf of Mexico via ocean outfall • Surface water discharge to Brownsville Ship Channel • Evaporation ponds • Deep well underground injection	• Brine transfer pump station, brine transmission main, brine outfall diffuser array into the Gulf of Mexico
Solids Dewatering	• Belt filter press • Centrifuges • Solids drying beds • Steam-powered sludge drying system	• Solids equalization basin, thickener feed pumps, flocculation basins, gravity thickeners, solids dewatering feed pumps, belt filter presses
Finished Water Transmission	• Finished water transmission pump station and main • Finished water storage tanks • Finished water distribution pumps	• Transmission main parallel to State Highway 48 before reaching offsite storage near Farm to Market Road 511 where finished water will be pumped into the Brownsville system.
Co-location with Power Generation	• Natural gas-fired electric generation • Coal-fired electric generation • Wind power electric generation	• n/a

Source: Derived from Dannenbaum and URS (2004).

1.1.4 Development of Cost Estimates

In 2004, based on the conceptual design presented in the Feasibility Study, the total project cost for implementing a full-scale seawater desalination project located on the Brownsville Ship Channel was estimated to be approximately $151 million (Table 1-3).

Table 1-3: Feasibility Study estimate (2004) of total project costs for a full-scale (25 mgd) seawater desalination plant.

Project Component	Estimated Cost
Desalination Plant	$90,167,000
Concentrate Disposal System	$30,583,000
Finished Water Transmission System	$9,232,000
Project Implementation Costs	$21,406,000
Total Capital Costs	**$151,388,000**

Source: Dannenbaum and URS (2004).

1.1.5 Preliminary Financial Analysis

The feasibility-level investigation recognized that seawater desalination was a new technology to Texas, and as such was likely to cost more than the region currently pays (or even could pay) for potable water. Therefore, it was anticipated that a full-scale project would require funding sources in addition to revenues provided by local ratepayers to achieve financial viability (Dannenbaum and URS 2004). Such assistance could come in the form of direct grants to offset capital or operating costs, or low interest loans and deferred payment of capital costs. The primary grant and subsidized loan mechanisms identified in the Feasibility Study included those from bi-national institutions, such as North American Development Bank (NADB); federal agencies, such as the Bureau of Reclamation (Reclamation) and U.S. Army Corps of Engineers (USACE); and state agencies, such as TWDB.

In summary, the Feasibility Study concluded that seawater desalination for Brownsville was feasible and recommended a Pilot Study be implemented.

1.2 PILOT STUDY OVERVIEW

Piloting projects provide the opportunity to evaluate actual performance of proposed treatment systems under site-specific conditions (Reiss 2004). Piloting results allow more precision in planning and design of the full-scale facility processes and greatly reduce uncertainty and risk in cost estimation.

1.2.1 Pilot Study Objectives

The primary goal of the Brownsville Seawater Desalination Pilot Study was to address unknowns and uncertainties remaining at the conclusion of the Feasibility Study and obtain sufficient data to serve as a proper basis of design for the full-scale seawater desalination facility. Itemized objectives of the Pilot Study presented in the original BPUB Pilot Study application to the TWDB (Brownsville Public Utilities Board 2006) and the contract work plan are summarized below[4]:

[4] Research goals included in the original Pilot Study application that were not attained include:

- *Verify the performance on the conceptual open water intake design presented in the 2004 Feasibility Study.* The feasibility intake design (stilling well with an excavated channel) did not prove viable during piloting due to excessive construction costs and permitting time requirements. Therefore, only the stilling well implemented for the Pilot Study.
- *Further develop and obtain agreements for the sale of water to entities in the Lower Rio Grande Valley region and international agreements with the State of Tamaulipas and cities along the lower border region.* This level

Raw Water Characterization

- Document and evaluate the quality of seawater at the proposed intake location in terms of dissolved and suspended solids, salinity content, specific ion composition, organic content, biological species, presence of toxic compounds, fouling indices, temperature, and pH.
- Document and assess the potential seasonal variations, diurnal variations, and other events that may affect the above raw water quality parameters.

Pretreatment Requirements

- Evaluate the performance of conventional and membrane pretreatment systems to reliably and consistently manage the quality of the seawater supply.

Permeate and Concentrate Quality and Composition

- Document and characterize the quality of the permeate and brine streams generated by the membrane treatment process and evaluate post-treatment requirements.
- Characterize all residual and waste streams generated by the pilot scale plant.

Estimated Treatment Costs

- Assess the performance of the seawater reverse osmosis membrane treatment process.
- Track and monitor the rate of membrane fouling and establish optimum clean-in-place (CIP) intervals that will be required to maintain adequate operation of the membrane system through time.
- Perform laboratory autopsies of the membrane material to assess and document the type(s) of fouling that may have occurred.
- Establish the most cost effective water source for seawater desalination.
- Develop alternatives for the most cost effective manner to implement the full-scale project.
- Document and verify energy requirements associated with the operation of the membrane desalination process.

Project Financing Alternatives

- Examine a range of local, state and federal financing mechanisms.
- Explore methods for legislative appropriations, state rule changes, and TWDB project funding.
- Explore Federal legislation and funding support mechanisms.
- Explore inclusion of other users in the Lower Rio Grande Valley (LRGV) as project water users and financial supporters.

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of marketing did not prove viable because the project had not progressed sufficiently to allow quantification of quantity and costs of water.

1.2.2 Pilot Study Team

Pilot Study costs were shared by BPUB and TWDB, the latter providing a grant to BPUB. BPUB subcontracted with NRS Consulting Engineers, who assembled a technical team to perform the study (Figure 1-2).

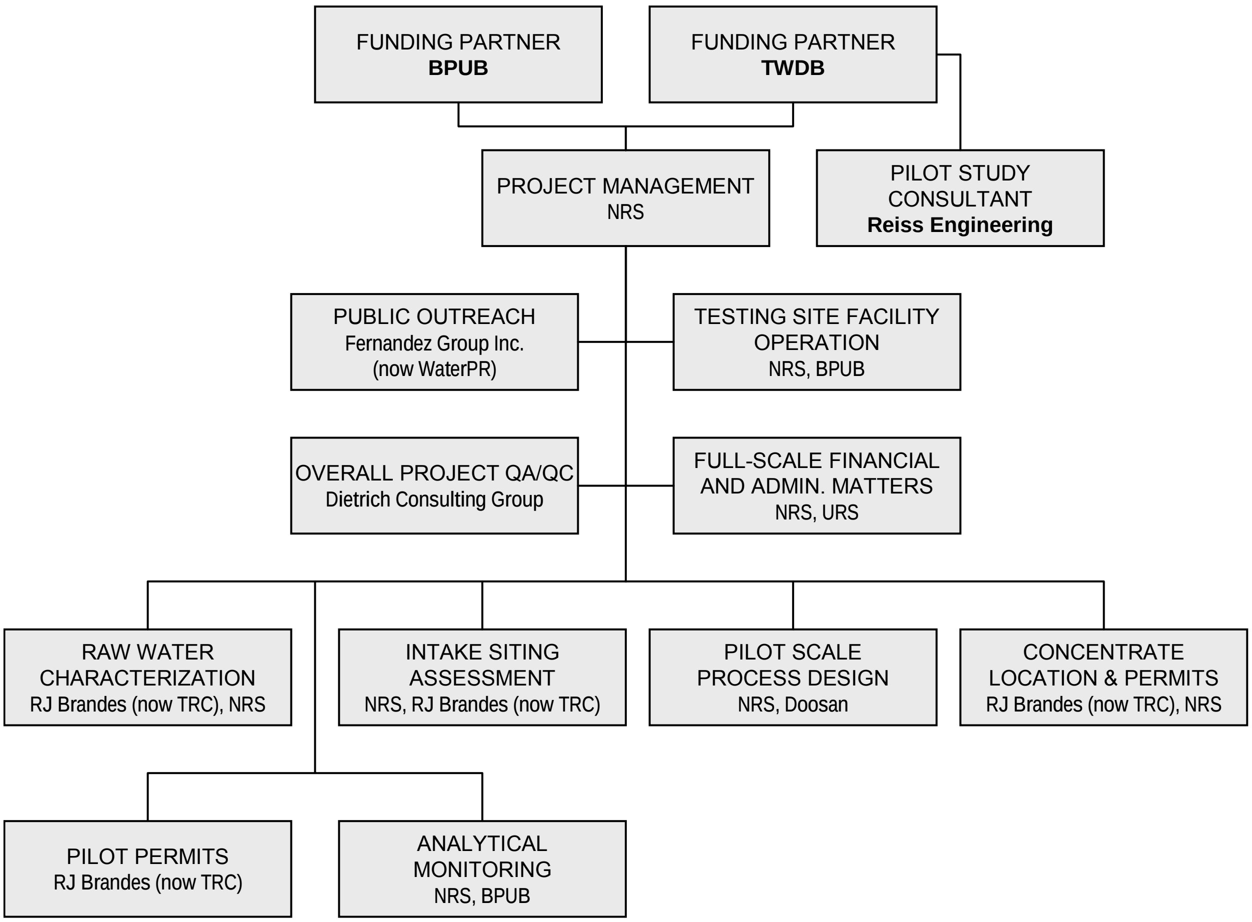


Figure 1-2: Organization and responsibilities of the Pilot Study team.

2.0 Approach and Methods

Upon completion of the Feasibility Study, the TWDB prepared letters of expression of interest for Research Grant assistance for a seawater desalination pilot facility. In January 2006, the TWDB forwarded a research application checklist for pilot plant studies to the BPUB for their consideration. The Grant application listed a number of specific tasks that were to be incorporated into the Pilot Study application to the greatest extent possible. BPUB applied for Grant assistance on March 9, 2006, and the Grant was awarded on April 11, 2006. Specific TWDB study contract requirements and a summary of how they were addressed during the Pilot Study are presented in Appendix 7.1.

2.1 PILOT PLANT SITE LOCATION

A critical aspect of the project that was established in the 2002 proposal, and which had a significant influence on the pilot testing program, is the proposed location of the desalination plant and its seawater intake. The proposed location of the full-scale plant, and subsequently the location of the pilot facility, was to be at the Port of Brownsville using raw water from the Brownsville Ship Channel (Figure 2-1).

Prior to beginning the Pilot Study, an analysis was performed of potential pilot facility locations. Even though the Feasibility Study recommended locating the facility at the Port of Brownsville, research was performed as to the potential to locate the facility at Boca Chica Beach using raw water from the Gulf of Mexico. To make the final decision as to where the site was to be located, factors such as raw water quality, security, cost of implementation, and accessibility were taken into consideration. Based on previous research, Boca Chica beach offered more stable water quality, no security, a high cost of implementation due to a lack of infrastructure (no power, no potable water/sewer), and remoteness causing significant travel time to and from the facility. The Port of Brownsville offered significant variations in raw water quality due to the effects of shipping traffic, winds, tidal influences, and rainfall, security by Port staff, existing infrastructure (power, potable water, and sewer services are existing and provided by BPUB), and convenient physical location in terms of travel time from the BPUB offices and laboratory.

After considering these factors, the pilot facility was located at the Port of Brownsville. Since this location is considered the worst case scenario, no re-piloting would be necessary if the site location was to be moved. The intake was on the north bank of the Brownsville Ship Channel approximately 11 miles from the coastline of the Gulf of Mexico. The Brownsville Ship Channel site represents a worst-case scenario in terms of pretreatment and reverse osmosis (RO) performance. If the Pilot Study was successful at the Port of Brownsville, it would be successful at the Gulf of Mexico.

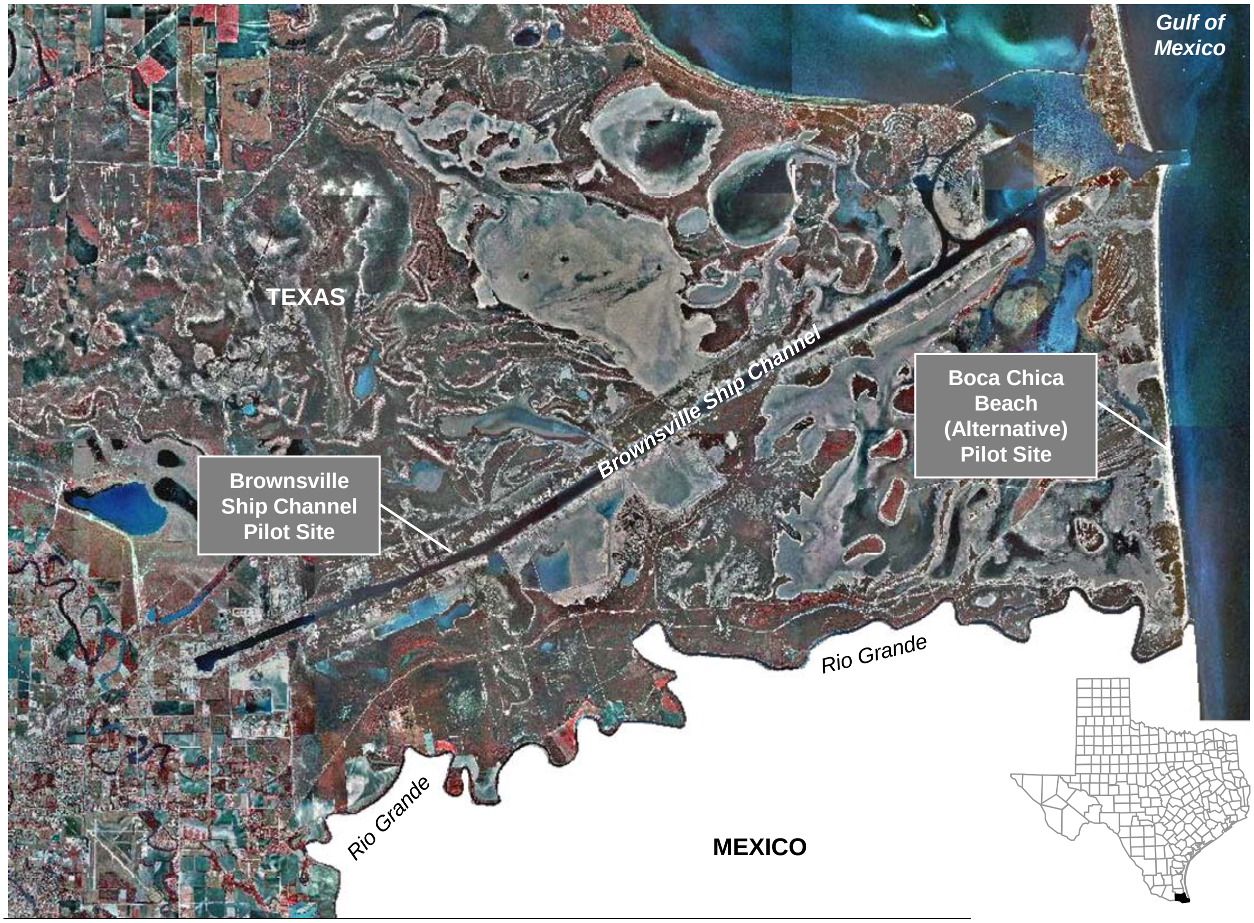


Figure 2-1: Location of the Brownsville Seawater Desalination Pilot Project.

2.1.1 Pilot Plant Permitting

Permitting and activities associated with the construction and operation of the Pilot Plant involved the Port of Brownsville, Texas Commission on Environmental Quality (TCEQ), and USACE (copies of these permits are included in the digital attachments to this report). The Port of Brownsville provided BPUB with land and site access for the Pilot Study.

Permitting discussions with the TCEQ focused on the discharge of concentrate and waste flows from the pilot facility. The pilot design directed all waste streams to a mixing tank, where they were recombined with pretreatment filtrate and RO permeate flows prior to entering an open lagoon. This arrangement allowed all process streams to be individually evaluated prior to mixing. The ultimate discharge stream from the pilot facility was of the same consistency as the raw water entering the plant. Therefore, there were no adverse effects to the receiving body of water. The TCEQ approved of the facility by letter.

Construction of the raw water intake in the Brownsville Ship Channel required (Section 404) authorization from USACE under the Clean Water Act. The permit application package included evaluations of intake velocities and intake screen size to minimize the effects of impingement and entrainment, potential impacts to navigational interests, a brief archeological evaluation, and an analysis of construction methods and potential impacts on receiving waters. Review by USACE concluded the project would not have negative resource impacts and a Nationwide Permit issued.

2.2 PERFORMANCE OBJECTIVES

In the 2004 Feasibility Study, an extensive research effort was conducted during which all available historical water quality data was collected and other critical project information was obtained and reviewed. Using the available historical data, supplemented with some additional analytical data obtained during the Feasibility Study, URS was able to establish an initial characterization of the seawater within the shipping channel. Using the initial seawater characterization, a concept design for the desalination process was developed and documented in the 2004 Feasibility Study.

The Feasibility Study was unable to capture the full range of possible seawater water quality variation that can occur over the course of a year and longer. Therefore, one of the key goals of the Pilot Study was to establish an adequate database of source water quality data to serve as a more complete basis for design of the full-scale desalination facility and to assess the suitability and validity of the concept design presented in the Feasibility Study.

The Feasibility study also recommended a number of additional components be investigated to support a full-scale design and effectively decrease the design and operational risks, including the post-treatment requirements, brine quality and composition, waste sludge characterization, and power requirements. The test plan was designed to collect the data necessary to assess the capability of the pretreatment membrane technology, compare its performance to conventional treatment, and design and cost the full-scale system; membrane flux and operation, raw and finished water quality, membrane integrity testing, cleaning efficiency, and feed water recovery.

2.2.1 TCEQ Pilot Operational Protocol

The protocols and procedures submitted to and approved by the TCEQ were developed to serve as a guide for all pilot activities, while incorporating the necessary Quality Control and Quality (QA/QC) assurance checks to ensure a successful pilot. The TCEQ has published specific criteria that govern the piloting phase of a membrane treatment facility. Using the TCEQ criteria as a blueprint, pilot operational protocols, specific to the BPUB seawater reverse osmosis (SWRO) Pilot Facility, were developed.

In addition, testing goals were established for the pretreatment and RO membrane systems to serve as a reference throughout the Pilot Study. Specifically related to the membrane treatment processes, the TCEQ protocols are broken into three stages.

Stage 1 – Optimization and Operation
During Stage 1, the membrane treatment units were operated to determine the optimum flux rate, chemical dosing requirements and frequencies, backwash

frequencies and duration, and clean-in-place (CIP) procedures. This test period was used to establish site-specific and full-scale treatment and operating parameters for each membrane unit to use in the subsequent TCEQ stages and at the full-scale.

Stage 2 – Performance Testing Under Optimum Conditions
Stage 2 entails testing each membrane treatment system unit under its optimum set of simulated, full-scale water treatment plant design conditions, which were determined from the data collected in Stage 1. During Stage 2 operations, the membrane systems must sustain all of the operating conditions that were laid forth prior to beginning Stage 2. If a CIP procedure were decided to be necessary before the required 30 day run was completed, the Stage 2 run was terminated, a CIP performed, and Stage 2 started over. If the required 30 day run were completed, a CIP procedure was performed and Stage 3 began.

Stage 3 – Loss of Flux and Fouling Evaluation
During Stage 3, the membrane unit was operated under the same simulated full-scale water treatment plant design conditions as was performed during Stage 2. The objective of Stage 3 was to determine the percent loss of original specific flux and if irreversible fouling had occurred.

2.2.2 Treatment Process Objectives

Generally, the objective of the Pilot Study was to develop a sufficient amount of real time information and data to demonstrate the technical feasibility and to support the future full-scale design of the SWRO facility.

The pretreatment systems were tested at various operating conditions to document loading rates, pressure losses, water production efficiency, filter backwash rates and frequencies, and chemical types and dosing rates. Through testing, optimum process settings were established in which water production was maximized while minimizing chemical use, and waste generation. The removal efficiency of potential membrane fouling agents (i.e., particulates, total organic carbon, etc.) was monitored. System reliability was evaluated in terms of treatment consistency. Robustness was evaluated in terms of raw water quality variations. The goal of pretreatment runtime was to maximize runtime by minimizing downtime associated with mechanical and membrane failures.

The SWRO performance was monitored and operating parameters were documented (e.g., applied pressures, DP, flux rates, permeability, salt passage, operating temperatures, and the quality of permeate and brine streams). RO performance was evaluated at a flux of 8.2 gallons per square foot per day (gfd) with recoveries of 50% and 48.8%. Cleaning protocols, solutions, and frequencies were assessed to establish the most effective cleaning program to maintain RO membrane performance. The goal to achieve maximum performance and runtime of the RO units were recognized to be dependent on filtrate water quantity and quality from the pretreatment systems.

TCEQ requirements served as the base point for testing. However, the data required in order to meet these requirements does not provide all necessary information needed to accurately determine the most effective treatment technology for the full-scale facility. Prior to beginning the pilot, the goals listed in Table 2-1 were developed. Due to the unavailability of raw water quality data on a real-time basis, it was difficult to accurately determine piloting setpoints such as flux, backwash frequency and duration, CIP frequency, recovery, etc. The pilot team developed a testing plan that consisted of testing each treatment component on a stand-alone basis. The main goal was to determine the optimum operating conditions of each treatment system in terms of the items listed in Table 2-1. This would provide the most cost-effective treatment options for the full-scale facility.

Table 2-1: Testing goals for pretreatment and RO systems.

Performance Item	Pretreatment Goals	RO Goals
Silt Density Index	Filtrate <3.0 (100%) and <2.0 (95%)	-
Turbidity	Filtrate <0.2 NTU	-
Sustainable flux	Highest	Highest
Particle counts	Lowest	-
Influence on SWRO specific flux	Least	-
Chemical use	Lowest consumption	Least consumption
On-line time	Most utilization	-
Residuals	Least quantity and hazardous	-
Power consumption	Lowest	Lowest
Salt passage	-	Lowest
Cartridge filter change	-	Least frequent
Recovery	-	Greatest

2.2.3 Finished Water Quality Specifications

Water quality goals are defined as measured values used to assess the plant's performance and capabilities to achieve the goals. These goals also serve to guide the changes in the operation of the pilot if necessary. Target values were the desired finished water goals. In general, the primary objective was to comply with current and anticipated future drinking water standards, and while doing so minimize disinfectant by-products by reducing concentration of precursors (when practical). Specific finished water design goals included not-to-exceed (or in some cases under-achieve) target values based on primary and secondary drinking water standards, where applicable (Table 2-2). For some parameters (e.g., chloride, sulfate and total dissolved solids (TDS)), TCEQ standards are less stringent than federal standards.

Table 2-2: Finished water quality goals.

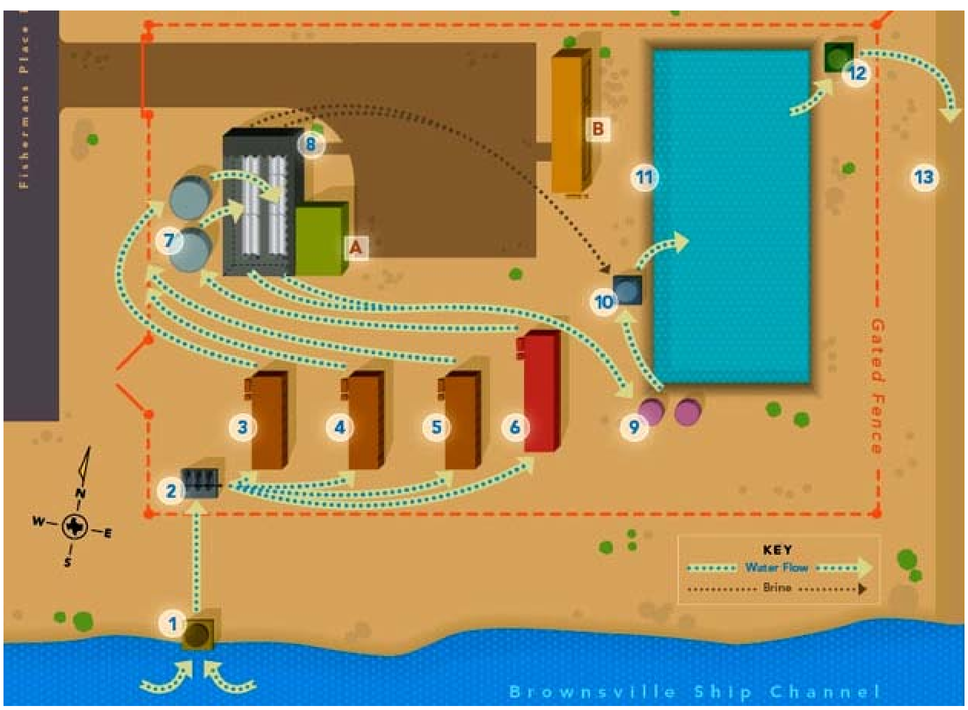
Parameter	Design Goal
pH (laboratory)	7.0 to 8.5
Alkalinity (as $CaCO_3$), mg/L	75 to 150
Total Hardness (as $CaCO_3$), mg/L	<250
Chlorides, mg/L	<300
Turbidity, NTU	0.2 (0.3 max)
Dissolved Organic Carbon, mg/L	<2
Color, color units	<5.0
Total Dissolved Solids, mg/L	<500
Sulfates, mg/L	<300
TTHMs, mg/L	<0.040
HAA5, mg/L	<0.030
Giardia removal and inactivation	>3 log
Virus removal and inactivation	>4 log
Cryptosporidium removal and inactivation	>2 log

TCEQ does not have a boron maximum contaminant level (MCL) as a primary or secondary standard, nor is one expected in the near future. However, the boron-specific membrane was selected because early in the project the regulatory status of boron for drinking water was in flux in the United States. Due to the negligible difference in operation and maintenance (O&M) (acknowledging a difference in capital, however), utilization of a slightly higher-rejecting boron element was justified if World Health Organization (WHO) and the Environmental Protection Agency (EPA) regulations direct reductions to the sub-1.0 parts per million (ppm) level. However, as the project progressed, based on the team's understanding of the WHO revised standards as further developed and refined in mid-2007, the boron standard was expected to be relaxed. Therefore, the capability to test lower boron-rejection elements was created, which is consistent with TCEQ requirements.

Raw water quality was tested for Cryptosporidium with the intent being to determine which EPA/TCEQ Bin Classification would apply for the facility. In addition, potential log removal was tested on the successful pretreatment units.

2.3 FACILITY SPECIFICATIONS

The original study scope developed by TWDB was to compare the performance of conventional pretreatment with ultrafiltration (UF), a membrane-based technology. However, BPUB decided to increase the scope and value of the Pilot Study by including two additional membrane-based pretreatment technologies. The budget was increased by almost $1.0 million and funded by BPUB. By increasing the budget, the project's scope grew to include two additional membrane pretreatment systems. The side-by-side comparison of four different pretreatment technologies resulted in a high level of study complexity (Figure 2-2).



LEGEND

- 1 Intake
- 2 Intake pumps
- 3 Norit UF pretreatment unit
- 4 GE Zenon UF pretreatment unit
- 5 Pall MF pretreatment unit
- 6 Eimco conventional pretreatment unit
- 7 Pretreatment filtrate storage tanks
- 8 RO treatment
- 9 Water storage tanks
- 10 Mixing tanks
- 11 Lagoon
- 12 Neutralization tank and discharge point
- 13 Discharge ditch
- A Chemical storage building
- B Operations building

Figure 2-2: Schematic layout of the Brownsville Seawater Desalination Pilot.

2.3.1 Intake

The raw water intake station for the pilot plant consisted of a suction pump station connected to 20 feet of 12-inch PVC pipe with a 12-inch flange secured to the end. The pipe was submerged in a 6' diameter fiberglass wetwell. A 16" drum screen, specifically designed to keep intake velocities below 0.33 feet per second, was attached to the end of the suction pipe and submerged in the wetwell. The drum screen had 0.125" (3 mm) slots, which is typical for drum screens utilized at other seawater open-intake systems. A 1" air line was attached to the drum screen and allows for periodic air scouring of the intake screen to aid in the removal of sediments and other foulants. The control system utilized three (3) pumps. At any given time, two of the pumps were operational with the third pump being on reserve as a backup. The two pump system transferred raw water from the inlet pipeline to an 8" pressure header that was used to transfer water to each pretreatment unit.

Feed water for the intake station was acquired by contouring the bank of the channel and installing the fiberglass wetwell approximately 10 feet from the existing shoreline thereby creating a short intake channel. Rip-rap was placed on the banks of the channel, and a seal slab was implemented to facilitate flow into the wetwell. A 20" opening, approximately 9' below the top of the wetwell was installed to allow water inflow (Figures 2-3, 2-4, and 2-5).

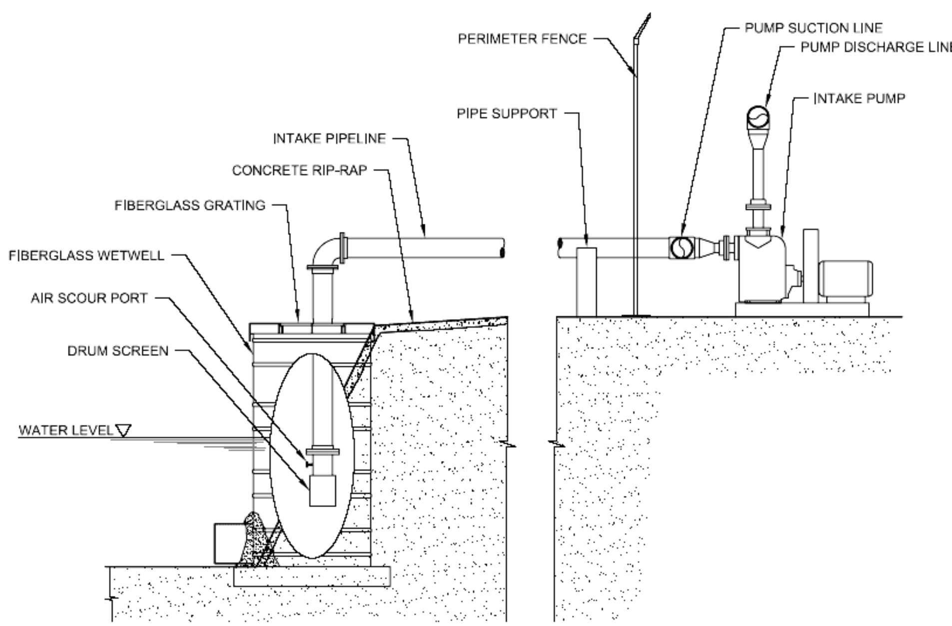


Figure 2-3: Schematic drawing of the intake for the Brownsville Seawater Desalination Pilot Project.

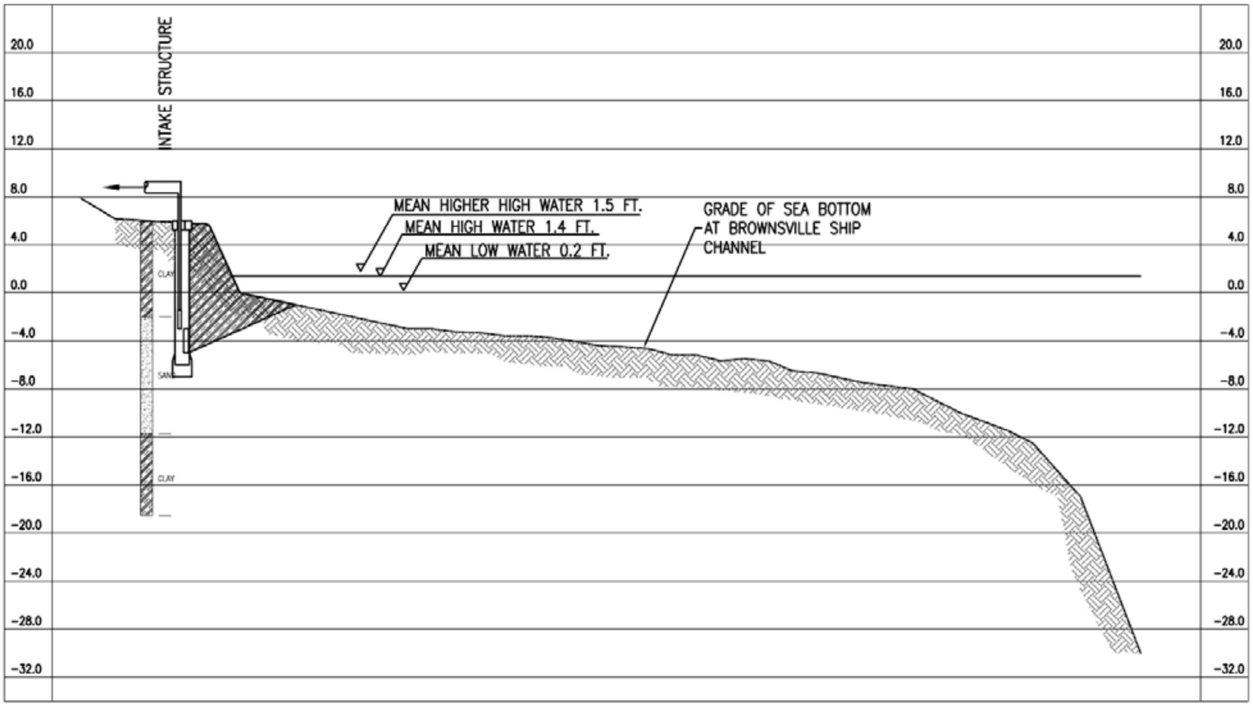


Figure 2-4: **Cross sectional view of the intake structure in relation to the Brownsville Ship Channel.**

Figure 2-5: **Photograph of the raw water intake structure.**

2.3.2 Pretreatment

Four pretreatment units were piloted: Eimco Conventional System, GE Zenon ZeeWeed 100 UF, Norit X-Flow UF, and Pall Microza Microfiltration (MF) (copies of each proposal submitted by individual vendors are included in the digital attachments to this report). Each pretreatment system was operated and tested independently thereby allowing side-by-side comparisons of the effectiveness of each technology in treating identical raw water.

Eimco Conventional System

The conventional treatment system[5] provided by Eimco Water Technologies is a process consisting of a rapid mix basin, two flocculation chambers, and a clarifier equipped with plate settlers to substantially improve efficiency and increase the rate of floc settling within the system (Figure 2-6). Ferric chloride was used to coagulate the water supply. Following the conventional system was a single-stage, dual-media (silica sand and anthracite) filtration system.

Figure 2-6: Photograph of the Eimco conventional pretreatment system.

Flow enters the unit through a 2-inch flange opening, into the rapid mix chamber where coagulants are added. The rapid mix chamber is capable of achieving G-values up to 1,100 per second with an approximate one minute detention time. This speed can be varied to represent values specific to any water treatment plant. The flow then exits at the bottom into the first flocculation chamber. Flocculation is achieved through a two stage process with a total detention time of 30 minutes. Paddle speeds can be adjusted independently to create G-values that would be implemented at full scale. The flow exits the second flocculation chamber through a 6" diameter pipe and enters a flexible 6" diameter hose and enters the inclined

[5] A process and instrumentation diagram for the Eimco conventional pretreatment unit is presented in Appendix 7.2.

settling plate pilot unit. The flow is baffled down to bottom of the plates where it then flows through the plates at a predetermined angle and exits through the submerged orifices into the effluent trough. The flow exits the trough through a 3" diameter pipe where the final turbidity or suspended solids readings may be taken.

The final process of the conventional treatment system included removal of any remaining coagulated particle through a single stage dual media gravity filter. The footprint of the filter sans piping measured forty-eight inches (48") in width by seventy-eight inches (78") in length and one hundred and fifty inches (150") in height. Twenty inches (20") of silica sand and eighteen inches (18") of anthracite, meeting the requirements of the American Water Works Association for a drinking water application, was installed as filtering media. Above the filter media was situated a twelve inch (12") wide by sixteen inch (16") deep trough with stainless steel weirs running lengthwise. The filter included provisions for implementation of an air scour line that was to be used prior to the backwash cycle.

GE Zenon ZeeWeed 1000 UF

The Zenon ultra-filtration pretreatment unit[6] utilized six ZeeWeed® 1000 membrane modules with an active membrane area per module of 600 ft^2. ZeeWeed 1000 water treatment is an immersed membrane process that consists of outside-in, hollow-fiber modules immersed directly in the feed-water. The ZeeWeed 1000 system operates under a vacuum that is induced within the hollow membrane fibers by a connection to the suction side of a permeate pump.

Prescreen

The GE/Zenon UF at the Brownsville Desalination Pilot implemented four Arkal 2" Spin Klin Automatic Disc Filter Batteries (Figure 2-7). The GE/Zenon UF utilized two, 200 micron Arkal Batteries in series with two, 100 micron Arkal Batteries. The Arkal system employs a stack of thin polypropylene discs with diagonally oriented grooves on both sides to a specific micron size. These discs are stacked and compressed along a spring loaded spine inside the Arkal housing and the grooves, which run in opposite directions from top to bottom, trapped solids greater than 200 micron in diameter in the first two batteries and solids greater than 100 micron in the last two batteries. The feed water flows into the Arkal housing via feed pump and water is filtered "outside-in" from the housing towards and through the spine to the outlet. Backwashes for the Arkal prescreening system were initiated at three intervals: once DP reached or exceeded 5 pounds per square inch (psi), at or after one hour of elapsed time since the previous backwash and at UF backwashes. During a backwash, the drain opens and the inlet closes. Then, the spring releases compression on the stack of discs and eliminates the pressure difference between the housing and spine. Clean water is then pumped tangentially at high pressure through jets in the spine in the opposite direction to normal flow. The discs, which are no longer compressed, spin freely along the spine dislodging any solids trapped in the grooves.

[6] A process and instrumentation diagram for the GE Zenon pretreatment unit is presented in Appendix 7.2.

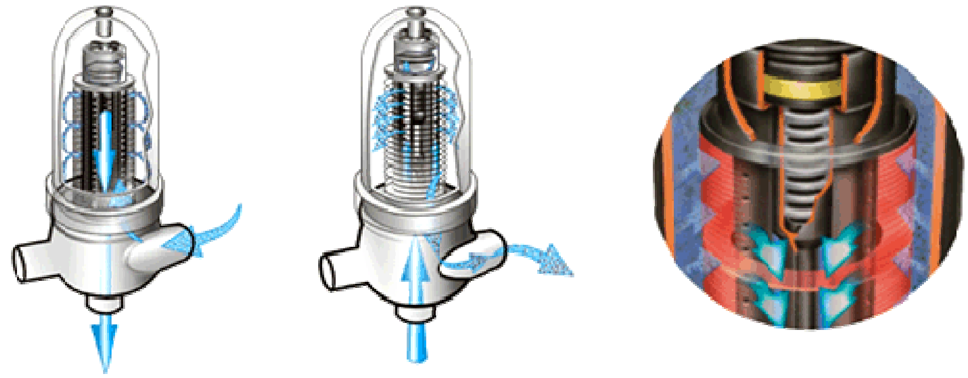


Figure 2-7: Schematic drawing of the Arkal Disc Filter[7].

Filtration and Backwash Modes
The ZeeWeed 1000 system is operated where filtration and backwash alternate in sequence. During the filtration cycle, permeate is withdrawn through the membranes by applying vacuum to the permeate piping using an outside-in process. No aeration is used while in filtration mode. At the end of each filtration cycle, a backwash is performed. During the backwash, the membranes are simultaneously aerated and backpulsed to dislodge solids. Solids are loosened from the surface of the membranes and suspended in the process tank due to the aeration. All waste streams are discarded through a dedicated line. Once the backwash is complete, the process tank is completely drained, which rids the tank of any accumulated solids. The process tank is then refilled with feed water and production resumes.

Chemically Enhanced Backwash
During the Pilot Study, chemically enhanced backwashes (CEBs) were initiated based on the end of the first production cycle following a defined time. At the onset of the CEB, an aerated step-drain procedure is performed in which the membrane tank is aerated, in a number of steps (7), to remove solids from the membrane surface. The tank is then filled with filtrate from the backpulse tank while chemicals are dosed. Typical chemicals used during this step are Sodium Hypochlorite (NaOCl) and/or Citric Acid. The membranes are then soaked in this solution after which the tank is drained. Following the drain, a backpulse is performed, and the backpulse water is allowed to drain. The tank is then filled with raw water, taken post prescreening, and again drained.

Clean-in-Place
The clean-in-place (CIP) procedure begins with 20 minutes of aeration. The number of aeration sequences may be varied depending on the extent of solids accumulation on the membrane surface. The membrane tank is then filled with potable water, recirculated for approximately 10 minutes, and drained. Heated potable water (40 deg C) is then used to fill the membrane tank. While the tank is being filled, NaOCl is added to the heated water (typically 1000 ppm of NaOCl). The membranes are soaked for a period of 6 hours, the solution is drained, the membranes are rinsed with potable water, and heated potable water (40 deg C) with 2000 ppm of citric acid is applied to the membranes. The membranes are again soaked for a period of 6 hours. After the soak, the solution is drained and the membranes are rinsed with potable water. To assess permeability restoration,

[7] *Source*: Image acquired from www.arkal-filters.com.

recirculations using potable water are conducted at a flux of 25 gfd before, during and after the cleanings. At a minimum, the recirculations should be performed once before the NaOCl, once between chemicals, and once following the acid. However, if operator time allows, a recirculation is taken every hour of each soak.

Norit X-Flow UF

The system utilized X-Flow[8] model SXL225 FSFC PVC UFC M5 08 mm membrane elements with approximately 431 ft^2 (40 m^2) of membrane area each. Each membrane element is composed of approximately 11,500 individual 0.8 mm diameter hollow-fiber UF membranes permanently encased in an 8-inch diameter by 60-inch long membrane element.

Two Norit UF pilot units were in service at different times at the pilot facility. The first X-Flow pilot unit was a fully equipped system designed to provide up to 0.06 MGD water treatment capacity in a compact, 24-feet long enclosed trailer while operating with two (2) standard (8-inch diameter, 60-inch long) membrane modules. For reasons discussed in Chapter 3, Norit installed a new skid with additional treatment capacity. The original skid utilized two (2) standard (8-inch diameter, 60-inch long) membranes, and the replacement used four (4) membranes of the same model and size. In addition, the replacement unit was modular by design as opposed to the trailer mount design in the previous unit.

Prescreen

Originally, the Norit UF system utilized two (2) Arkal 2-inch Spin Clean Automatic Disc Filter Batteries. Due to issues associated with maintaining feed flow to the membrane system, the Arkal system was replaced with a Hydrotech/USFilter Discfilter model HSF1702-1F (Figure 2-8). The Hydrotech Discfilter is a 100 micron woven polyester media filter used as a prescreen to the UF for removing suspended particles larger than 100 micron in diameter.

The feed water flows by gravity into the filter segments from the center drum. Solids attach to the inside of the filter panels mounted on the two sides of the disc segments and as the solids attach to the filter media, influent is impeded and the water level inside the discs begins to rise. Once the water level has reached a set height, the discs begin to rotate and a backwash cycle begins. The backwash cycle consists of a high pressure rinse via four nozzles attached to a spray bar header. The nozzles spray previously filtered water that is stored in a reservoir at 60 degrees and perpendicular to the filter panel. The backwash removes any solids attached to the filter panel and are collected in the solids collection trough, then sent to drain. The backwash can be programmed to run either continuously or intermittently.

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[8] A process and instrumentation diagram for the Norit pretreatment unit is presented in Appendix 7.2.

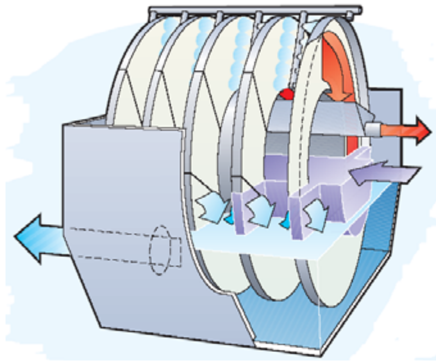

Figure 2-8: Schematic drawing of the Hydrotech Discfilter[9].

Filtration and Backwash Modes

The Norit X-Flow treatment system operates where filtration and backwash are performed in sequence. Filtration is performed by pressurizing the feed water where it comes into contact with the inside of the filtration element. Filtrate is produced using an inside-out process. The pilot unit maintains treatment efficiency with automatic backwash sequences by removing the contaminants that are collected on the membranes during filtration. Backwash cycles consist of using clean permeate to reverse flow through the membrane elements at a high flux for a brief period of time. This process was implemented to remove the suspended material off the lumen surface that was present in the feedwater and accumulated during the filtration process. During backwash the system is taken off-line. Backwash waste is discharged from the unit via a dedicated drain line.

Chemically Enhanced Backwash

The pilot unit is also equipped with two operator selected and configured CEB sequences using acid and/or caustic/chlorine to remove reversible fouling (e.g., biological growth, precipitated minerals, etc.) which is not removed by backwashing alone. Filtration is interrupted while the cleaning chemicals are injected and allowed to soak in the system for a period of approximately 10 minutes. Once complete, the chemical solution is flushed from the membrane system using clean (filtrate) water. CEBs are performed at predetermined intervals and do not require operator intervention or oversight. Since the membrane fibers are highly resistant to a wide variety of chemicals, most acids and caustic solutions can be used. Oxidizing agents may also be used up to certain concentrations.

Clean-in-Place

The CIP procedure begins with a standard backwash and the feed and filtrate tanks are drained. Using potable water, a 1000-ppm citric acid solution is added to the feed tank. This solution is circulated through the membrane housing for a period of 1 hour by manually connecting the backwash waste line and the filtrate line to the feed water tank. A flow rate of 60 gallons per minute (gpm) is used for the circulation. After 1 hour, the membranes are backwashed and the backwash waste is sent to drain. A second citric acid circulation is performed in a similar manner. Upon completion of the second citric acid circulation, the filtrate and feed tanks are drained and refilled with potable water. For a period of 10 minutes, standard

[9] *Source*: Image acquired from www.hydrotech.se.

filtration is performed while sending the filtrate to drain. Filtrate and feed tanks are drained, and both are refilled with potable water. While filling the feed tank, caustic soda is added to achieve a pH of 12. This solution is circulated through the membrane housing for a period of 90 minutes. After the caustic soda circulation, 200 ppm of $NaOCl$ is added to the feed tank and the solution is circulated for 30 minutes. A flow rate of 60 gpm is used for the circulation. When the circulation is complete, a backwash is performed after reconnecting the backwash waste line to the backwash waste connection. Both feed and filtrate tanks are drained, and the feed tank is refilled with potable water. The unit is then placed in filtration mode for 10 minutes while the filtrate is sent to drain.

Pall Microza UNA-620A MF

The Pall pretreatment system[10] utilized Microza UNA-620A hollow-fiber MF membrane elements with approximately 538 ft^2 of membrane area each (Figure 2-9). The Pall Microza system uses outside-in technology that operated with a pressurized feed stream.

Figure 2-9: Photograph showing the placement of the Pall pretreatment unit.

Prescreen

The Pall MF at the Brownsville Desalination Pilot implemented a single, 200 micron Arkal 2" Spin Klin Automatic Disc Filter Battery (see Figure 2-7). The Arkal system employs a stack of thin polypropylene discs with diagonally oriented grooves on both sides at a specific micron size. These discs are stacked and compressed along a

[10] A process and instrumentation diagram for the Pall pretreatment unit is presented in Appendix 7.2.

spring-loaded spine inside the Arkal housing and the grooves, which run in opposite directions from top to bottom, trap solids greater than 200 micron in diameter. The feed water flows into the Arkal housing via feed pump and water is filtered "outside-in" from the housing towards and through the spine to the outlet. Backwashes for the Arkal prescreening system were initiated at three intervals: once DP reached or exceeded 5 psi, at or after one hour of elapsed time since the previous backwash and at UF backwashes. During a backwash, the drain opens and the inlet closes. Then, the spring releases compression on the stack of discs and eliminates the pressure difference between the housing and spine. Clean water is then pumped tangentially at high pressure through jets in the spine in the opposite direction to normal flow. The discs, which are no longer compressed, spin freely along the spine dislodging any solids trapped in the grooves.

Filtration and Backwash Modes

There are four basic modes of operation for the membrane unit. In Feed Flush mode, the feed pump draws water from the feed tank and pumps it through the membrane filter through the feed port at the bottom of the module. The filtrate exits the filtrate port at top end of the module. Dead-end operational mode was used throughout this Pilot Study. Simultaneous Air Scrub/Reverse Flush (SASRF) is another way to clean the membrane hydraulically. During SASRF, air is injected into the module on the feed side of the fibers while filtrate is pumped in the reverse direction through the module. All discharge during the SASRF is sent to drain. The combined water-air flow creates strong turbulent and shearing force to dislodge dirt deposits on the membrane surface. The forward and reverse flow periods are used to flush out the solids dislodged during air scrubbing. The frequency and duration is user defined. During the Feed Flush, the feed pump is used to pump feed water into the module. This process is used following an SASRF to flush waste out of the module through the upper drain/XR port. The waste is directed to drain.

Enhanced Flux Maintenance

At a user defined time interval, the system stopped while in forward filtration mode and initiate Enhanced Flux Maintenance (EFM). During the EFM process, the feed side of the system is drained and filtrate is then pumped from the reverse flush tank off skid to the water heater. Heated water is displaced out of the heater and chemical (NaOCl) is injected as the filtrate returns to the test skid. This solution then flows into the feed tank until a sufficient quantity has been transferred. The solution is then recirculated for 30 minutes through the system on the feed side of the membrane and back to the feed tank. The solution is then drained and the system is flushed using a standard SASRF and feed flush.

Clean-in-Place

The CIP procedure involved a high pH soak followed by a low pH soak. The high pH soak was initiated by manually directing the Pall into CIP mode. Heated potable water filled the feed tank while 1000 ppm of NaOCl and 10,000 ppm of caustic soda were manually added. The program time was then set to 120 minutes and the unit automatically injected and soaked the membranes for the set time. After the 120 minutes of programmed soak time, the solution was left to soak for an additional 120 minutes. The solution was then circulated for 20 minutes through the membranes and feed tank while the pH was neutralized. The solution was then drained and the unit was set to repeat the process for the low pH soak. After redirecting the Pall into CIP mode, 30 gallons of heated potable water then filled the feed tank while 20,000 ppm of concentrated citric acid was manually added. The program time was then set to 90 minutes and the unit automatically injected and soaked the membranes for the set time. The solution was then circulated for 20 minutes through the membranes and feed tank while the pH was neutralized. The solution was then drained and the Pall was restored to filtration mode, which immediately enabled an automatic flush followed by normal filtration. The Brownsville Pall CIP duration was approximately seven hours.

Tables 2-3 and 2-4 provide general specifications and piloting operating conditions for the membrane pretreatment units.

Table 2-3: General specifications for pretreatment modules.

Membrane Element Characteristic	GE Zenon UF	Norit UF	Pall MF
Active Membrane Area per Module (ft^2)	600	431	538
Flow Path (In-Out, Out-In)	Outside-In	Inside-Out	Outside–In
Number of Membranes	6	2/4	3
Molecular Weight Cutoff (Daltons)	100,000	350,000	-
Nominal Membrane Pore Size (microns)	0.02	0.05	0.10
Absolute Membrane Pore Size (microns)	0.1	0.075	NA
Membrane Material/Construction	PVDF	PES	PVDF
Membrane Hydrophobicity	Hydrophilic	Hydrophilic	Hydrophobic
Membrane Charge	Slightly Negative	Neutral	Slightly Negative
Design Operating/Vacuum Pressure (psi)	1 to 13	3.5 to 10.0	NA
Acceptable Range of Operating Pressures (psi)	1 to 13	0 to 14.5	Up to 43.5 psi
Acceptable Range of Operating pH Values	5 to 10	2 to 12	1 to 10
Maximum TMP for System (psi)	13	36	43.5
Maximum Permissible Feed Turbidity (NTU)	250	30	1,500
Chlorine/Oxidant Tolerance	Resistant to Hypochlorite, Chlorine dioxide, and $KMnO_4$	200 ppm continuous, 250,000 ppm hrs life time	Chlorine 10,000 mg/L, Oxidant Resistance
Suggested Cleaning Procedures	Sodium hypochlorite 500 ppm, 2 g/L of citric acid	Chlorine, Acid, Caustic	Air scrub, enhanced flux maintenance, CIP

Table 2-4: General pilot operating conditions for pretreatment modules.

Membrane Element Characteristic	GE Zenon UF	Norit UF	Pall MF
Required Prescreening	100 micron	100 micron	200 micron
Inlet Pressure/Vacuum Pressure (psi)	3 to 13	3.5 to 10	43.5 psi maximum
TMP (psi)	3 to 13	3.5 to 15	5 to 43.5 psi
Backwash (Pulse) Frequency (minutes)	Usually > 45	20 to 45	12 to 30
Backwash (Pulse) Duration (seconds)	30	40	78 to 120
Power	480V, 3Ph, 60Hz	480V, 3Ph	230V, single phase
Interval Between Cleanings	Optimized for at least 30 days	12 – 48 hours (CEB)	Every 30 days
CIP Cleaning Criteria	TMP = about 13 psi	TMP = 12.3 psi[a]	Time or TMP = 43.5 psi

[a] At the onset of the Pilot Study, Norit did not include a recommendation for a standardized CIP procedure based on runtime. Rather, Norit believed that an optimized CEB frequency would prove sustained operation of the system without having to perform a CIP.

2.3.3 Reverse Osmosis

Membrane element diameters from 2.5” up to 18” are available in the market. However, it is known that 2.5” elements may not adequately mimic the full-scale performance in terms of hydraulics. Larger element sizes such as 4” and 8” are more practical and representative for testing purposes on a pilot scale.

A single-pass seven-element vessel design was preliminary modeled at the desktop level and offered the most promising approach for testing purposes. Balancing permeate water quality, flux, and specific pressure, this approach is a very common design for other seawater desalination facilities around the globe. Because high boron rejection is not a design goal for BPUB, a second pass was not required nor necessary. Therefore, the RO setup used at the pilot facility called for membrane elements to be 8 inches in diameter and 40 inches long. These elements are placed into a high-pressure vessel that is approximately 25 feet long, such that 7 membrane elements are installed per vessel (Figure 2-10).

Figure 2-10: Photograph showing the loading of an RO element into the pressure vessel.

All the membrane elements and the RO pressure vessels used in this study adhere to industry standards. Therefore, for each of the three membrane element types studied during the Pilot, seven (7) membrane elements of each type were supplied by the manufacturer and the performance of all seven elements was evaluated together in a single pressure vessel. The results from the Pilot Study can be easily applied to a larger municipal facility by scaling up the results from a single pressure vessel facility (the pilot, production rated at approximately 23,000 gallons per day) to a multiple pressure vessel facility.

Cartridge filters protect the SWRO from large particles that, if accidentally released into the feed to the RO element, could plug the feed spacer and impact RO performance. Though technically a cartridge filter is not a prerequisite since membrane filtration pore sizes are significantly less than the 5-micron filter cartridge, it was decided to include them to allow flexibility to feed the SWRO skid with pretreated filtrate during pilot testing and also because the break tank in-between the pretreatments and the SWRO system could introduce foreign substances. At the pilot facility, each of the RO trains is incorporated with a cartridge filter housing capable of holding up to eight cartridge filters (20" in length with a 2.5"OD and a 1"ID). At the Brownsville Pilot, only six cartridge filters are used, each with a nominal pore size of 5 micron. This set-up allowed a range of cartridge filter loading rates to be implemented, depending on the full-scale design conditions.

The RO process has the capability for all operations including start-up, normal operations, and shutdown automatically sequenced and controlled by a master control panel. The RO system included a CIP skid complete with a chemical mixing tank, heater, feed pump, and cleaning solution cartridge filters. CIP procedures consisted of manually piping the cleaning tank feed line to the RO concentrate line, the cleaning tank discharge line to the RO feed line, and the RO permeate line returned to the cleaning tank. Diaphragm valves were used to mix the cleaning solution in the cleaning tank or to circulate the cleaning solution through the RO pressure vessel.

Toray TM820C-400
The Toray TM820C-400 (boron rejection) element was tested at the Pilot during the summer of 2007. The TM820C-400 is a cross-linked, fully aromatic polyamide composite with a surface area of 400 square feet per membrane. These elements utilize the standard o-ring/interconnector setup. These elements were loaded during the pre-optimization stage of the pilot and were subjected to extreme variations in water quality and quantity.

Filmtec SW30HR LE-400i
The Filmtec SW30HR LE-400i element was tested at the Pilot from fall 2007 to summer 2008. These Filmtec elements implement an interlocking endcap technology, which eliminates the use and the maintenance of interconnectors between the membrane elements. These interconnectors can be the source of o-ring leaks and they require lubrication when loading membrane elements into the membrane vessel. Interlocking endcaps also use an o-ring and require lubrication, so o-ring leaks may still occur, but the frequency and likelihood of an o-ring leak is presumed to be reduced. It should be noted that testing data associated with the reduced risk of o-ring leakage or failure has not been provided.

Toray TM820-400
The Toray TM820-400 element was tested during the Pilot from the early spring of 2008 to the summer of 2008. Similar to the TM820C-400 elements, the TM820-400 is a cross-linked, fully aromatic polyamide composite with a surface area of 400 square feet per membrane but have a slightly lower salt rejection. The TM820-400 model was tested because of the elimination of specific boron limits in the permeate. These elements utilize the standard o-ring/interconnector setup.

General specifications of the three RO membranes tested during the Pilot Study are summarized in Table 2-5.

Table 2-5: Comparison of general specifications for RO membranes tested.

	Toray TM820C-400	Filmtec SW30HR LE-400i	Toray TM820-400
Material	Cross linked fully aromatic polymide composite	Polyamide Thin-Film Composite	Cross linked fully aromatic polyamide composite
Maximum Operating Temperature (°F / °C)	113 / 45	113 / 45[a]	113 / 45
Maximum Element Pressure Drop (psi / Mpa)	20 / 0.14	15 / 1.0	20 / 0.14
pH Range, Continuous Operation	2 to 11	2 to 11	2 to 11
pH Range, Short-Term Cleaning	1 to 12	1 to 13	1 to 12
Maximum Feed Silt Density Index (SDI)	5	5	5
Feed Water Chlorine Concentration	Not detectable	< 0.1 ppm	Not detectable
Area (ft^2 / m^2)	400 / 37	400 / 37	400 / 37
Permeate flow rate (gpd / m^3/d)	6,500 / 25	7,500 / 28	6,500 / 25
Boron rejection (percent)	93[b]	91	N/A
Minimum salt rejection (percent)	99.60	99.60	99.50
Salt rejection (percent)	99.75	99.75	99.75
Length (inches / mm)	40 / 1,016	40 / 1,016	40 / 1,016
Diameter (inches)	8	8	8

[a] Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
[b] 5 mg/L of Boron added to feed water during laboratory testing.

2.3.4 Concentrate Disposal

The pilot facility was designed and constructed to allow all process streams to be reincorporated prior to discharge. Excess raw water flow, pretreatment drain and waste flows, excess pretreatment filtrate, RO permeate, and RO concentrate are all directed to the mixing tank. From the mixing tank, the combined water is diverted to a lagoon where further mixing takes place. As water levels in the lagoon rise, an overflow pipe diverts water from the lagoon into a secondary channel adjacent to the pilot facility that ultimately discharges into the Brownsville Ship Channel. Due to the unique nature of this setup, the water quality of the pilot's discharge is equivalent to the water quality of the receiving stream.

2.3.5 Site Construction

The construction of the raw water intake at this location consisted of setting a fiberglass well with a 24" opening at the bottom, which was placed at approximately 6' below water elevation along the bank of the Brownsville Ship Channel (engineering plans for the pilot facility are included in the digital attachments to this report). In order to provide a more stable foundation a concrete slab was poured and the well was embedded into this slab. To accomplish this installation an excavator was brought to dig out the area needed to accommodate this well. When the area was ready, a 30-ton crane was used to lower the intake well into place. Once the well was in place, the area surrounding the well was lined with concrete to prevent or minimize erosion along the bank.

The construction of the site piping was one to consider carefully as an important aspect of this Pilot. Factors such as availability, quality and cost were taken into consideration. PVC piping was not only more readily available but also allowed for easier installation and access in case of repairs or cleaning.

Electrical construction for this site was specifically based on the power requirements that each individual unit needed in order to operate. All electrical equipment was constructed in accordance with City and NEC requirements.

Site grading was arranged in such a way that it would allow easy access to this Pilot Facility. The entire area of the facility was graded and then proof rolled. A 3" cap of crushed limestone was then laid and proof rolled throughout the area to provide a more stable ground.

2.4 TESTING MATRIX

The following tables were developed to guide the pilot test according to a predetermined outline. Table 2-6 describes the testing matrix developed for all aspects of the pilot test: intake, conventional system, dual media filter, MF/UF, cartridge filters, and SWRO. This matrix was developed to provide guidance for adjusting critical components of each system based on predetermined scenarios. Tables 2-7 and 2-8 were developed to serve as a guide for collecting samples and analyzing water quality parameters at various locations throughout the pilot facility (Figure 2-11).

Figure 2-11: Photograph showing the collection of a sample for testing chlorine residual in RO feed stream.

Table 2-6: Process adjustments and parameter monitoring.

Process	Adjustments	Parameter Monitoring
Intake System	Replace with finer strainer screen (to be determined in the field)	1. Screen size. 2. Backwash frequency and time. 3. Differential pressure 4. Raw Feed Pressure line
Conventional System	Optimize process: Adjust chemical dosage if clarified water turbidity ≥10 NTU	1. G values at flash mixing/flocculation 2. Flash mixing and flocculation retention time 3. Coagulant type and dose 4. Acid dose (if any) 5. Polymer dose (if any) 6. Daily Flow
Dual Media Filter	Optimize process: Backwash filter if filtered water turbidity is ≥0.2 NTU and/or SDI ≥3.0	1. Loading rate 2. Backwash frequency 3. Media type 4. Media depth 5. Media size
MF/UF	Optimize process: Adjust chemical dosage if filtrate turbidity is ≥0.2 NTU and /or SDI ≥3.0	1. Specific flux (GFD Setting) 2. TMP (evolution) 3. Backwashing optimization (time interval) 4. Coagulant dosage (if any) 5. CEB Process (Cl, acid, and NaOH) 6. Last CIP (date, type, acid, Cl, and NaOH)
Cartridge Filter	Replace at differential pressure of 15psi	Pressure Drop Inlet (psi) and outlet (psi)
SWRO	Conduct CIP when normalized parameters exceed manufacturers' recommendations. Replace after the first failure. Adjust flux and recovery Cease after the second failure.	1. Flux 2. Recovery 3. Pressure 4. Antiscalant dosage (if any) 5. Acid dosage (if any) 6. Biocide dosage (if any)

Table 2-7: Pilot test on-site data collection matrix.

Properties, Units	Raw Water	Conventional Streams				MF/UF Streams			RO Streams		
		Feed	Clarified	Filtered	Break Tank	Feed	Filtrate	Break Tank	Feed	Permeate	Concentrate
Temperature, °C	C								C		
Pressure, psi						C	C		C	C	C
Flow, gpm			C	C		C	C		C	C	C
Chemical Dosage[a]	D	D	D	D		D			D		
Turbidity[b], NTU	C	C	C	C	D	C	C	D	C	C	D
UV_{254} Absorbance, cm^{-1}	D	D	D	D	D	D	D	D	D		
Particle[d], number/mL	C		C	C	D	C	C	D	D		
pH	D		C	D	D			D	D		
Alkalinity, mg/L	D										
Conductivity, mS/cm	D								D	D	D
SDI					D			D	D[c]		
Chlorine[e], mg/L			D		D			D	C		
Iron[f], mg/L			D		D			D	D		

Notes: C – continuous; D – daily.
[a] Chemicals include coagulant, polymer, acid/base, chlorine, antiscalant, sodium bisulfite.
[b] Turbidity monitoring of raw water, clarified water and waters in any other stage of treatment prior to MF/UF or RO membranes will need to be conducted with equipment that uses EPA Method 180.1, Standard Method 213B or Great Lakes Instruments Method.
[c] Particle will be reported in 2 to 5 µm at 5 minute intervals.
[d] After the cartridge filter.
[e] Chlorine residual will be reported in total chlorine and free chlorine.
[f] Iron Residual will be measured in total dissolved iron and total iron.

Table 2-8: Pilot test lab data collection matrix.

Properties, Units	Raw Water	Conventional Streams				MF/UF Streams			RO Streams		
		Feed	Clarified	Filtered	Break Tank	Feed	Filtrate	Break Tank	Feed	Permeate	Concentrate
pH,SU	B[1]								B	B	B
Conductivity, μ/cm	B								B	B	B
TDS, mg/L	B								B	B	B
TOC[a],mg/L	B	B	B	B						B	B
DOC[a],mg/l	B	B	B	B						B	B
UV_{254} Absorbance[a], cm^{-1}	B	B	B	B						B	B
TSS, mg/L	B	B	B	B							
Na, mg/L	M								B	B	B
Cl, mg/L	M								B	B	B
SO_4, mg/L	M								B	B	B
Alk, mg/L	M								B	B	B
Free Chlorine, mg/L									B		
Total Chlorine, mg/L									B		
Silica, mg/L	M			M					M	M	
Total Iron, mg/L	M			M					M	M	
Dissolved Iron, mg/L	M			M					M	M	
As, mg/L	M								M	M	
Ca, mg/L	M								M	M	
Mg, mg/L	M								M	M	
Ba, mg/L	M								M	M	
Sr, mg/L	M								M	M	
Al, mg/L	M								M	M	
B, mg/L	M								M	M	M
Mn, mg/L	M								M	M	M
Zn, mg/L	M								M	M	M
K, mg/L	M								M	M	M
Co, mg/L	M								M	M	M
NH_4, mg/L	M								M	M	M
$N0_3$, mg/L	M								M	M	M
Br, mg/L	M								M	M	M
F, mg/L	M								M	M	M
Color (True), PCU	D		M	M			M			D	
Color (App), PCU	D		M	M			M			D	
Odor,TON	M		M	M			M			D	
Total Phosphate, mg/L											M
HPC, cfu/L	S		S	S			S		S	S	
Total Coliforms, #/100ml	S		S	S			S		S	M	
E coli, #/100ml	S								S	M	
Cryptosporidum, oocysts/L	S								S	S	
THM/HAA Formation Potential, mg/l	S									S	
SOC5's, mg/l										S	
VOC's, mg/										S	

Notes: B – biweekly; D – daily; M – monthly; S – seasonal (three month period).
[a] Levels for raw water, effluents from settled/clarification units, effluents from granular media filters, MF/UF membrane effluents, and RO membrane effluents must be monitored and recorded daily or whenever there is a change in the operating parameters during startup and optimization.

2.4.1 Source Water

The pilot facility is located at the Port of Brownsville and utilized raw water from the Brownsville Ship Channel, TCEQ Segment 2494 of the Bays and Estuaries. The Brownsville Ship Channel is a 17-mile long, man-made channel that is connected to the Gulf of Mexico. The channel is not directly fed by any constant freshwater source. However, storm water runoff from the land directly adjacent to the channel can contribute water during rain events.

A raw water characterization sampling program was developed and implemented for the Brownsville Ship Channel and the Gulf of Mexico. Samples were collected in the Ship Channel and off the coast of Boca Chica Beach. At the onset of pilot testing, it was decided that an important component of the pilot project was to dual track water quality in both the Ship Channel and the Gulf of Mexico. The decision was made to dual track raw water quality in the Ship Channel and the Gulf of Mexico to determine feed water quality characteristics of both sources for the pilot and full scale facilities. The intent of the study was to pilot under a worst-case scenario. In order to obtain approval from TCEQ for the full-scale facility based on results of the Pilot Study, testing under the worst-case scenario would provide maximum flexibility in terms of the raw water source for the full-scale facility. However, prior to start-up of the pilot, discussions centered on the ultimate location for the pilot with two potential locations being considered: the Ship Channel and the Gulf of Mexico. Ultimately, the decision was made to locate the pilot at the Ship Channel, but water quality testing at both locations continued. This continued testing of raw water quality in the Ship Channel (probable source water for the full-scale facility) and the Gulf of Mexico (potential source water for the full-scale facility) allowed for a determination to be made regarding the recommended source water supply for the full-scale facility.

All of the samples collected were analyzed by the BPUB laboratory and a commercial laboratory for key testing parameters. Sampling and testing started on June 22, 2006 for the Ship Channel and the Gulf of Mexico and lasted for the duration of the pilot test.

Brownsville Ship Channel

Water quality samples in the Ship Channel were obtained at the pilot intake vicinity. The list of parameters that the BPUB laboratory tested for included pH, temperature, conductivity, turbidity, total hardness, calcium, alkalinity, iron, total coliform, E. coli, total organic carbon (TOC), dissolved organic carbon (DOC), UV_{254}, dissolved oxygen, chlorides, total suspended solids (TSS), and ammonia.

Beginning on May 10, 2007, the characterization of raw water in the Ship Channel was solely based on water samples taken directly from the pilot on a daily basis. The daily water quality samples were tested by the PUB laboratory for key water quality parameters.

On 15 different occasions during the course of the Pilot Study, in-depth water quality tests were performed on grab samples taken from pilot intake in which 136 different water quality parameters were tested. These samples were analyzed by an independent laboratory.

Gulf of Mexico
Water quality testing in the Gulf of Mexico took place approximately ½ mile off the cost of Boca Chica Beach. During the initial stages of the study, all water samples were analyzed by the BPUB laboratory. Samples were taken at a depth of 10'.

On 11 different occasions during the course of the Pilot Study, in-depth water quality tests were performed on grab samples taken from pilot intake in which 136 different water quality parameters were tested. These samples were analyzed by an independent laboratory as well as by BPUB.

2.4.2 Pretreatment

Membrane operation was monitored with quantification of membrane flux decline rates and permeate recoveries. The rate of specific flux (defined in the following section) decline was used to demonstrate membrane module operability at the operating conditions for each vendor's membranes. Operability of a given membrane product was quantified by measuring permeate flow and temperature-corrected flux value (e.g., gfd/psi at 68°F or L/(m^2-hr) at 20°C).

The rate of specific flux decline is a function of water quality and operational conditions. In this task, water quality was monitored and operational conditions varied depending upon membrane flux decline profiles. Flow, pressure, and temperature data shall be collected to quantify the loss of productivity in terms of rate of specific flux decline. A lower rate of specific flux decline implies that a longer operational run was achieved by the membrane system.

2.4.3 Finished Water

Table 2-2 listed the finished water quality goals as outlined at the onset of the pilot project. As indicated in Tables 2-7 and 2-8, finished water quality was monitored on a regular basis in order to evaluate the effectiveness of the SWRO system in providing high quality water that meets TCEQ standards. Finished water quality may be adjusted by making operational or membrane changes to the pretreatment and/or RO process.

2.5 CONCENTRATE DISPOSAL

The Feasibility Study for the Brownsville Seawater Desalination Project (Dannenbaum and URS 2004) evaluated five different full-scale concentrate disposal methods for design or permitting fatal flaws. These potential methods included industrial water reuse, diffusion into the Gulf of Mexico, discharge into the Brownsville Ship Channel, evaporation ponds, and deep well injection.

The feasibility analysis identified fatal flaws for three of the five potential concentrate disposal options for full-scale (25 mgd) seawater desalination facility (Table 2-9) (Dannenbaum and URS 2004). For industrial reuse, the remote location of existing industrial facilities that could use produced brine (some 200 miles away) made the alternative impractical and cost-prohibitive. For discharge into the Brownsville Ship Channel, the concern was that discharged concentrate might adversely impact the quality of raw intake water by raising the salinity concentration and thus decrease the overall efficiency of the plant. In addition, the National

Marine Fisheries Service had indicated a major concern with discharged concentrate creating a hyper-saline condition in the channel that would be detrimental to fishery resources. Finally, for evaporation ponds, the primary flaw was the extreme cost required to secure the land (estimated to be 10,000 to 15,000 acres), construct containment ponds, and line the ponds with a 20-mil membrane liner with an underdrain leak detection system (as per Texas Administrative Code Title 30, Part 1 Chapter 317 Rule 317.4).

Table 2-9: Summary of feasibility-level fatal flaws analysis for full-scale concentrate disposal alternatives.

Disposal Option	Fatal Design Element?	Fatal Permitting Element?
Industrial Water Reuse	YES	-
Diffusion into the Gulf of Mexico	-	-
Discharge into the Brownsville Ship Channel	YES	YES
Evaporation Ponds	YES	YES
Deep Well Injection	-	-

Source: Dannenbaum and URS (2004).

As part of the Pilot Study, the two methods not considered to have fatal flaws, diffusion into the Gulf of Mexico and deep well injection, were further evaluated. In addition, the option of evaporation ponds was also reconsidered as a potential alternative at production capacities less than the full-scale (25 mgd) facility.

2.6 QUALITY ASSURANCE AND QUALITY CONTROL

In order to ensure transparency and accuracy of the Pilot Study, a thorough QA/QC system was developed. The internal piloting team, which consisted of BPUB, NRS, RJ Brandes (now TRC), URS, Raba-Kistner, Dietrich Consulting Group, and Fernandez Group (now WaterPR) was organized in such a manner that each member of the team had a specific role in maintaining quality. Every facet of the project, from raw water quality testing to data analysis, was reviewed by at least two team members. Daily on-site discussions between NRS and BPUB took place in which project status and product operations were discussed. Weekly conference calls were held between the internal team and the individual product vendors with the discussions centering on product performance and adjustments to operations if needed. In addition, in-depth monthly meetings were held between BPUB and NRS to discuss project status and to review water quality sampling procedures, water quality testing and data, pretreatment performance, RO performance, and any other items of interest.

Each month a progress report was submitted on behalf of the internal team to the TWDB and BPUB. This report described the progress of the pilot project based on the 17 work tasks laid forth in the original work plan. Subsequent monthly reports incorporated all comments received.

2.7 PUBLIC INVOLVEMENT

Public outreach was an integral part of the Brownsville Desalination Pilot Project. The objectives of the project's outreach activities were two-fold: to inform the public and policymakers and to encourage participation and partnership in making desalination a viable water supply option for the region.

Public outreach activities focused on encouraging interest and involvement in the seawater desalination pilot, establishing readily accessible mechanisms for disseminating information about the project and addressing concerns, building on existing opportunities to share information, and generating support for further development toward a full-scale facility (examples of some of the public outreach materials developed for this Pilot Study are included in the digital attachments to this report).

Elements of the outreach campaign included:

- *Written material:* an FAQ brochure providing in non-technical terminology the who, what, why, when, where, and how of the project and a one-page summary targeted more toward legislators and other elected officials.
- *Website:* a new section on the existing Brownsville Public Utility Board website ensuring readily accessible information on project partners, goals, and milestones.
- *Press releases/conferences*: releases were distributed to the media at project milestones and to publicize any stakeholder group meetings, such as the ribbon-cutting (Figure 2-10).

Figure 2-12: Photograph of the ribbon-cutting ceremony for the pilot plant.

- *Stakeholder meetings:* opportunities were developed for outreach to stakeholders, the project's environmental committee, potential partners, and local, regional, state, and federal policy makers. These included meetings in Brownsville and upriver; regular reports to the Rio Grande Regional Water Planning Group, Rio Grande Regional Water Authority, and TWDB; and participation in broader forums such as Texas Water Day.
- *Presentations:* In a major in-kind contribution, the BPUB outreach coordinator scheduled and conducted presentations for elected officials, business and economic development organizations, environmental groups, and others.
- *Tours/open houses:* These were periodically scheduled in advance for public, media, elected officials. The tours were augmented by signage, brochures, and, where possible, equipment models.

3.0 Results and Discussion

3.1 OPERATIONAL OVERVIEW

Team members from BPUB and NRS executed the necessary daily operation and maintenance tasks at the Pilot to ensure ongoing equipment functionality and to collect and analyze data generated by the Pilot. Generally, the daily task list at the Pilot can be divided into a dichotomy of (1) data collection and (2) maintenance.

Water quality tests at every water treatment unit as well as at the raw water source consumed four to eight man-hours per day, depending on availability of water from the treatment units. Water quality testing was largely carried out by the BPUB team member but with frequent assistance from NRS. Other tests, which were not a part of the established testing regimen included free chlorine measurements, high resolution turbidity measurements during turbidity spikes, recording of shipping activity in the channel, and conventional unit optimization and performance monitoring. These miscellaneous tests were conducted primarily by NRS team members with frequent assistance from the BPUB.

Like the testing protocols, the maintenance of the Pilot facility resulted from a joint effort between NRS and BPUB team members as well as from the equipment venders. The frequent, spontaneous mechanical breakdowns, due presumably to the open-air facility's exposure to the salty air around the ship channel, required collaboration with BPUB mechanics, BPUB and NRS electricians, NRS construction personnel, and countless others associated with Eimco, Pall Corp, GE Zenon, Veolia, Toray, Dow Chemical and Doosan Hydro. The more routine maintenance activities, such as periodically loading chemicals into the treatment units, rinsing turbidimeters, calibrating lab equipment and cleaning the raw water intake, were executed collectively by team members from BPUB and NRS.

A typical day for the BPUB technician began with calibrating instruments in the onsite lab for use during the day. Instruments calibrated include bench turbidimeter, bench pH meter, handheld conductivity meter, handheld pH meter and a handheld colorimeter. Mid morning, the BPUB technician collected water samples from the 16 sample sites, conducting bench tests and handheld tests before sending the samples off to the BPUB water quality lab, located in Brownsville, for further testing. During the afternoon, the BPUB technician conducted silt density index (SDI) tests on six of the 16 sample sites. Once all water quality tests were completed, the BPUB technician conducted an inspection and recorded performance data in each of the treatment units, per the protocols submitted by the equipment's vender. BPUB, with assistance from NRS, also carried out daily raw water pump rotations and weekly raw water intake inspections.

Routine tasks for the NRS technician included coordinating arrivals and deliveries of equipment, chemicals, supplies and personnel; maintaining the daily operation of the conventional unit under the desired parameters; ensuring the ongoing function of

WaterEye and all other instruments linked to WaterEye via telecommunication cables; and collecting the water quality data from BPUB and distributing this data to project managers at NRS, BPUB and the vendors. The NRS technician was also responsible for conducting any of the large variety of tests to troubleshoot the operation of the plant as a whole and to troubleshoot the operation of the individual treatment units when vendor personnel were not available onsite. These tests primarily included chlorine residual tests, conductivity tests, SDIs, turbidity tests and RO performance data collection and analysis. In addition to these daily tasks and frequently as a result of their troubleshooting efforts, the NRS technician coordinated site repair operations, bringing together the efforts of mechanics, electricians, computer programmers, construction workers and vendors to repair any malfunctioning equipment onsite.

3.2 SOURCE WATER CHARACTERIZATION

Source water characterization took place in both the Brownsville Ship Channel using the pilot intake system and in the Gulf of Mexico approximately 1,500 linear feet east of Boca Chica Beach (Figure 3-1).

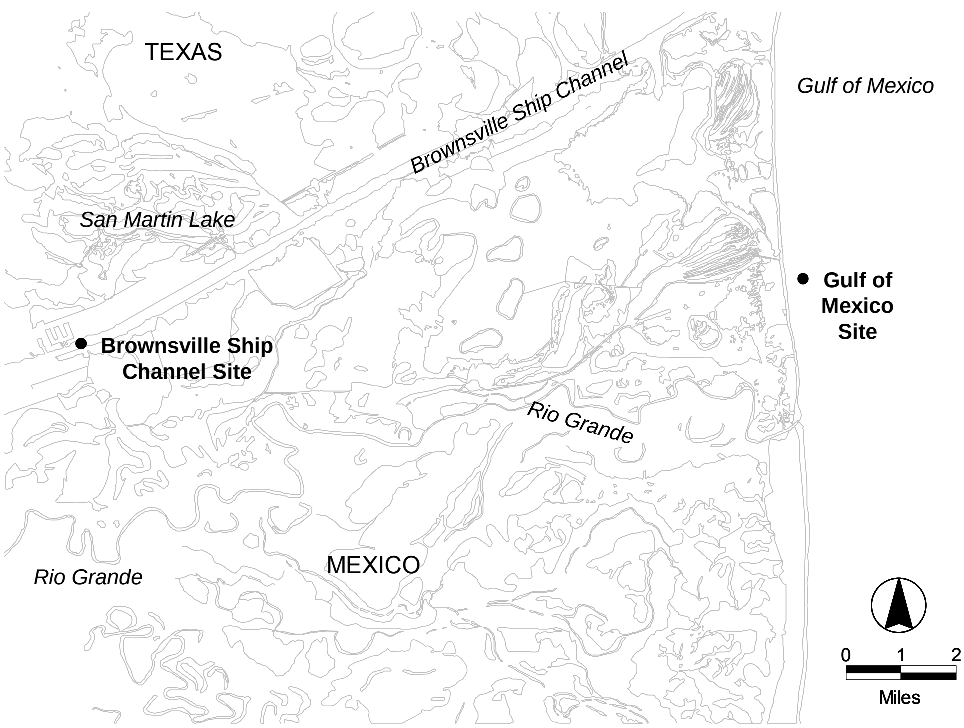

Figure 3-1: Location of raw water quality samples taken during the Pilot Study.

3.2.1 Brownsville Ship Channel

Data associated with raw water quality in the Brownsville Ship Channel, specifically that entering the pilot facility through the raw water intake, was analyzed using three different methods: in-line instrumentation, daily grab samples tested by the BPUB laboratory, and periodic grab samples tested by an independent laboratory.

In-line Instrumentation and Daily Grab Samples

Raw water quality data associated with in-line instrumentation and daily grab sampling accounted for raw water turbidity, TOC, DOC, UV_{254}, alkalinity, temperature, and conductivity (Table 3-1). Turbidity data points were obtained through an in-line instrument (Hach Surface Scatter turbidimeter). The remaining parameters were obtained through daily grab samples at the intake. UV_{254} is a measure of the absorbance of light at a wavelength of 254 nm and is an indication of the amount of natural organic matter in water.

Table 3-1: Summary raw water quality in the Brownsville Ship Channel, BPUB laboratory results for daily grab samples.

Parameter	Number of Points	Maximum	Minimum	Average	95th Percentile
Turbidity (NTU)	54,651	2,745	0.305	44.7	121.8
TOC (mg/L)	403	7.768	2.029	3.525	4.517
DOC (mg/L)	403	6.351	1.664	3.252	4.117
UV_{254} (cm^{-1})	404	0.13	0.019	0.047	0.07
Alkalinity (mg/L as $CaCO_3$)	404	318.5	109.4	140.96	155.2
Temperature (C)	449	31.8	14.5	25.0	30.0
Conductivity (mS)	445	55,500	28,400	48,100	53,800
TDS (mg/L)[a]	445	34,400	17,600	29,800	33,300
pH (SU)	448	8.66	7.12	8.01	8.27

[a] TDS was not tested on site. The information contained here was calculated using a conversion factor of 0.62 to convert conductivity to TDS. This conversion factor was calculated using laboratory testing data from an independent lab.

The raw water turbidity entering into the pilot facility fluctuated from 0.32 NTU to upwards of 2,750 NTU with an average of 44.67 NTU (Figure 3-2). Many of the spikes in turbidity were caused by waves associated with passing ships.

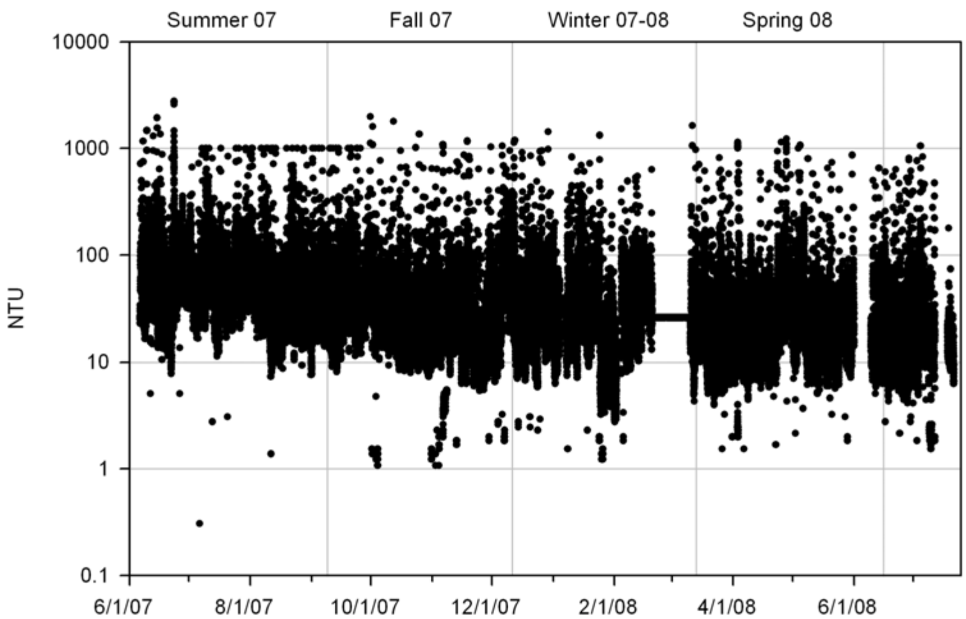

Figure 3-2: Raw water turbidity in the Brownsville Ship Channel.

The effect of ship traffic on average raw water turbidity was evaluated for three different types of common vessels: cargo ships, barges, and shrimp boats. The passing of cargo ships in the Brownsville Ship Channel had a significant impact on raw water turbidities, changing the average turbidity by over 190 NTU. In contrast, the effects of barges and shrimp boats were negligible, changing the average turbidity by 0.3 and 5.2 NTU, respectively. The elevated turbidity as caused by cargo ships passing the intake were found to last about 3.5 hours (Figure 3-3).

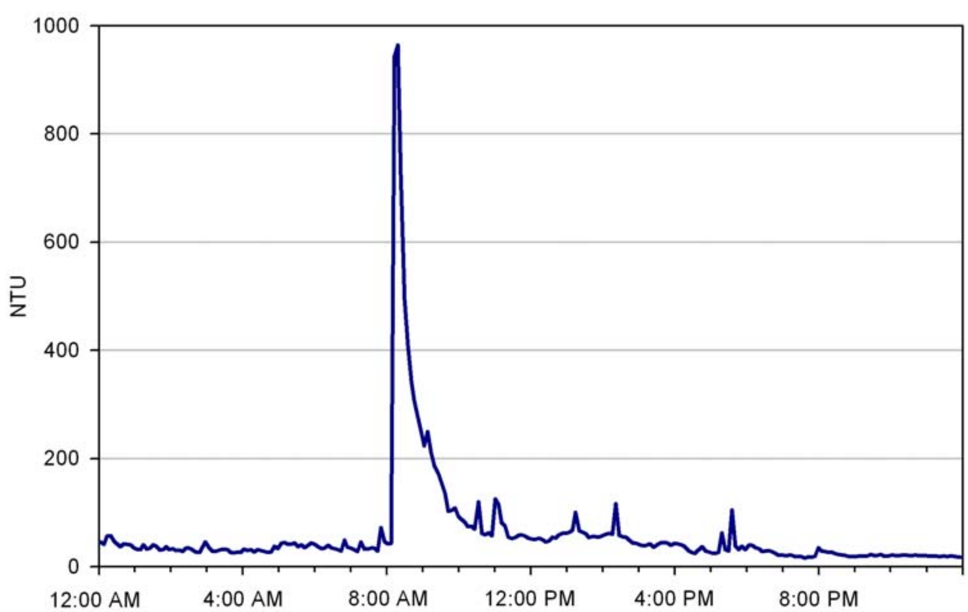

Figure 3-3: Snapshot of raw water turbidity spike caused by a passing cargo ship, 12/26/07.

It was determined that cargo ship speed was a main factor in the severity of turbidity spikes at the pilot intake (Figure 3-4). However, no quantifiable evidence to support this theory was obtained. Due to the nature of the channel, shipping traffic, and its impacts on the full-scale facility, will be ever-present and must be accounted for.

Figure 3-4: Photograph of the effect of a cargo ship passing on raw water turbidity in the Brownsville Ship Channel.

Regarding the effects of rainfall on raw water turbidity, tests have confirmed that significant rainfall (greater than 1 inch) in a short amount of time (less than 2 hours) can lead to changes in raw water turbidity, but these effects are relatively short lived. Figure 3-5 shows representative data associated with raw water turbidity spikes caused by rainfall.

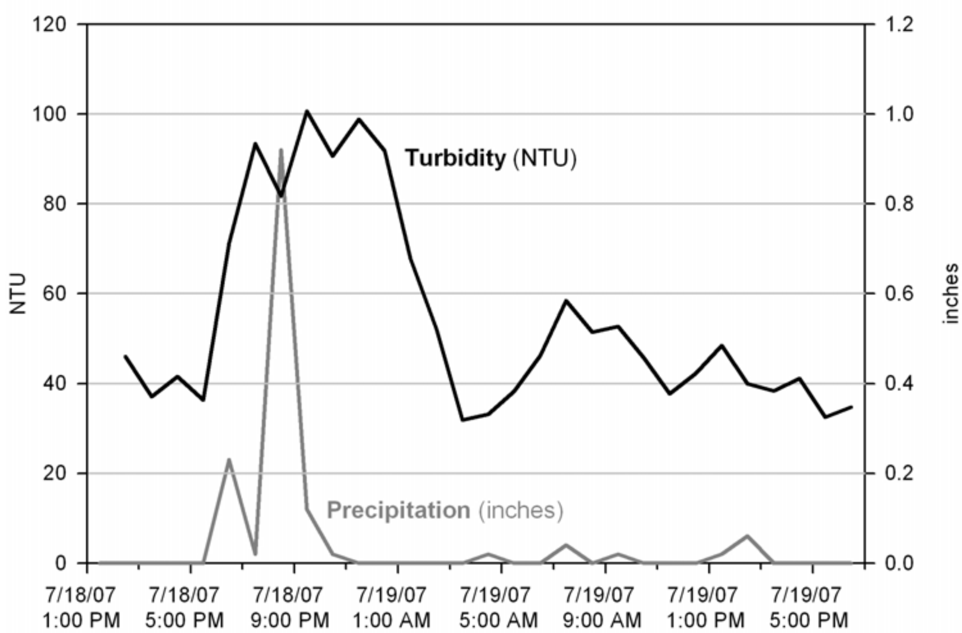

Figure 3-5: An example of the temporal impact rainfall had on raw water turbidity in the Brownsville Ship Channel during the Pilot Study.

The average annual precipitation in the area is 27.55 inches. The wettest month is September with an average of 5.31 inches of precipitation. Due to the limited amount of precipitation historically received on a monthly basis, it is not perceived that rainfall induced turbidity spikes will have any impact on the full-scale facility.

Due to the location of the pilot facility on the northern coast of the ship channel, it was inferred in the field that the predominant winds (from the southeast) seemed to cause higher raw water turbidities when compared to occasions when the wind switched direction. Based on this assumption, an analysis was performed on wind data and turbidities in which it was discovered that raw water turbidity was linked to wind direction (Figure 3-6).

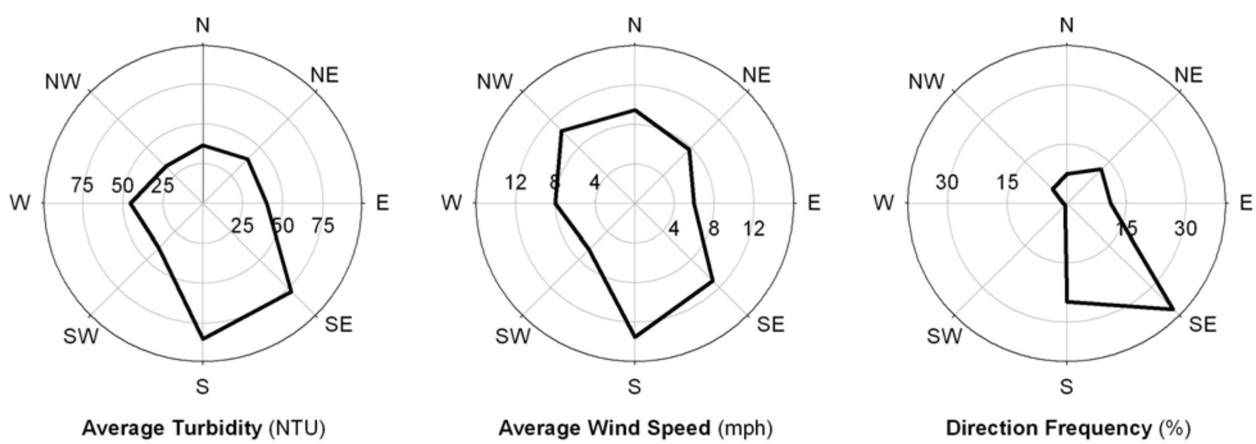

Figure 3-6: Relationship between wind direction and turbidity in the Brownsville Ship Channel during the Pilot Study.

Specifically related to raw water turbidity, there were no additional links to external factors, such as water temperature and other seasonal variations, recognized.

As was expected, raw water temperature fluctuations corresponded directly to the seasons with the summer months producing the highest average water temperature and the winter months producing the lowest (Figure 3-7).

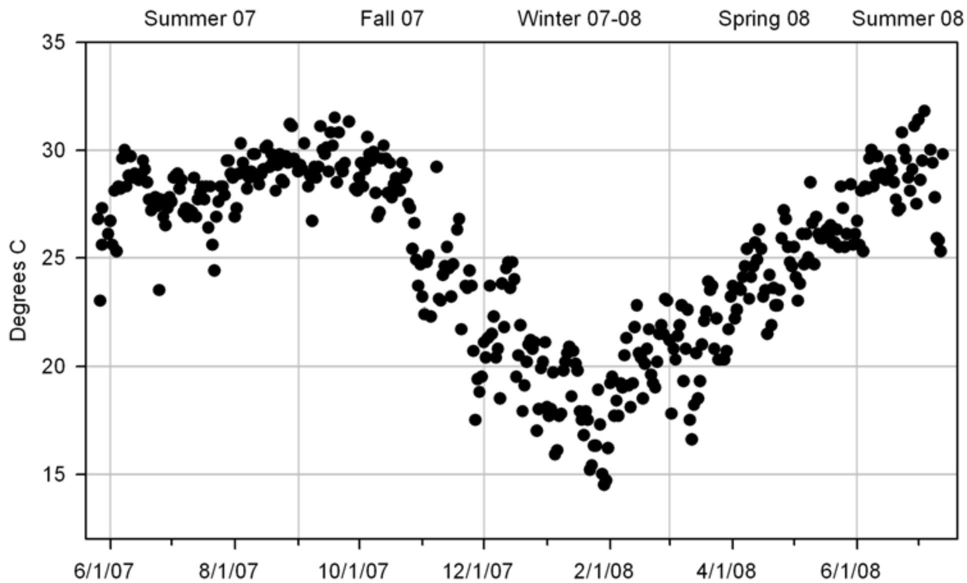

Figure 3-7: Raw water temperature variations during the Pilot Study.

Raw water conductivity and TDS[11] also varied seasonally (Figure 3-8). The lowest conductivity values occurred during the summer months. During the fall, winter, and spring months, conductivity values remained more consistent. One explanation for varying conductivity readings would be the potential impact of rainfall on conductivity. Most of the rainfall during the Pilot Study occurred during the summer months. A correlation can be made that rainfall impacts raw water conductivities (Figure 3-9).

[11] TDS values were derived using a conversion factor calculated from laboratory test data.

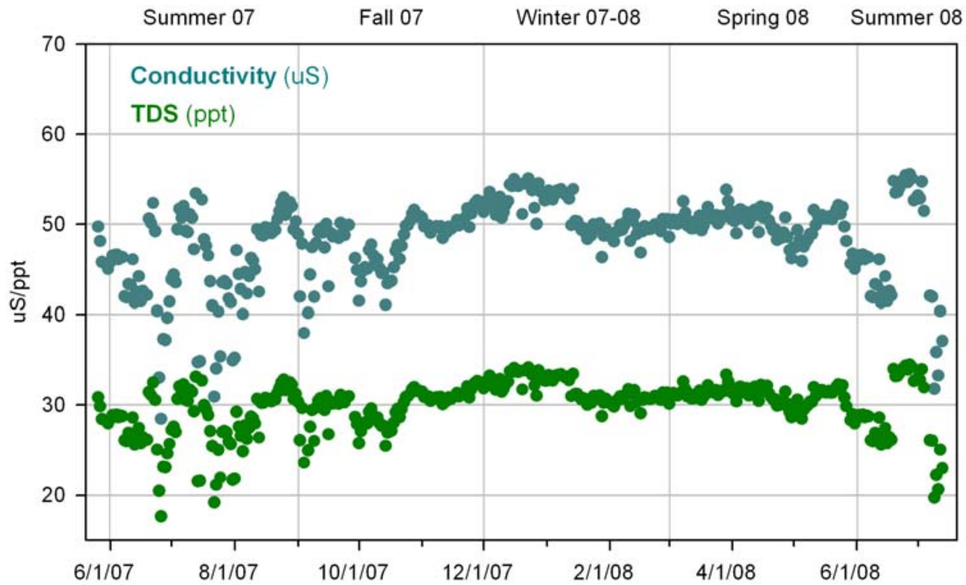

Figure 3-8: Raw water conductivity and TDS during the Pilot Study.

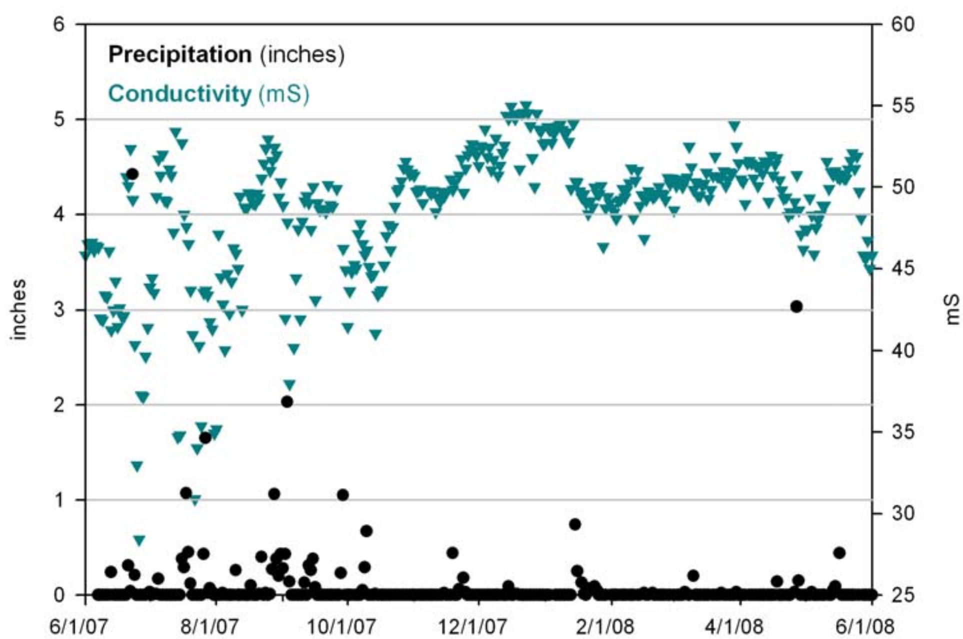

Figure 3-9: The relationship between precipitation and raw water conductivity in the Brownsville Ship Channel during the Pilot Study.

TOC and DOC trend very closely together, with 90% of '% of TOC that is DOC' values exceeding 83.15% (Figure 3-10). Based on seasonal averages, TOC and DOC are traditionally lower during the spring and summer months, UV_{254} is lowest during the winter and spring months, and alkalinity is lowest during the summer and fall months.

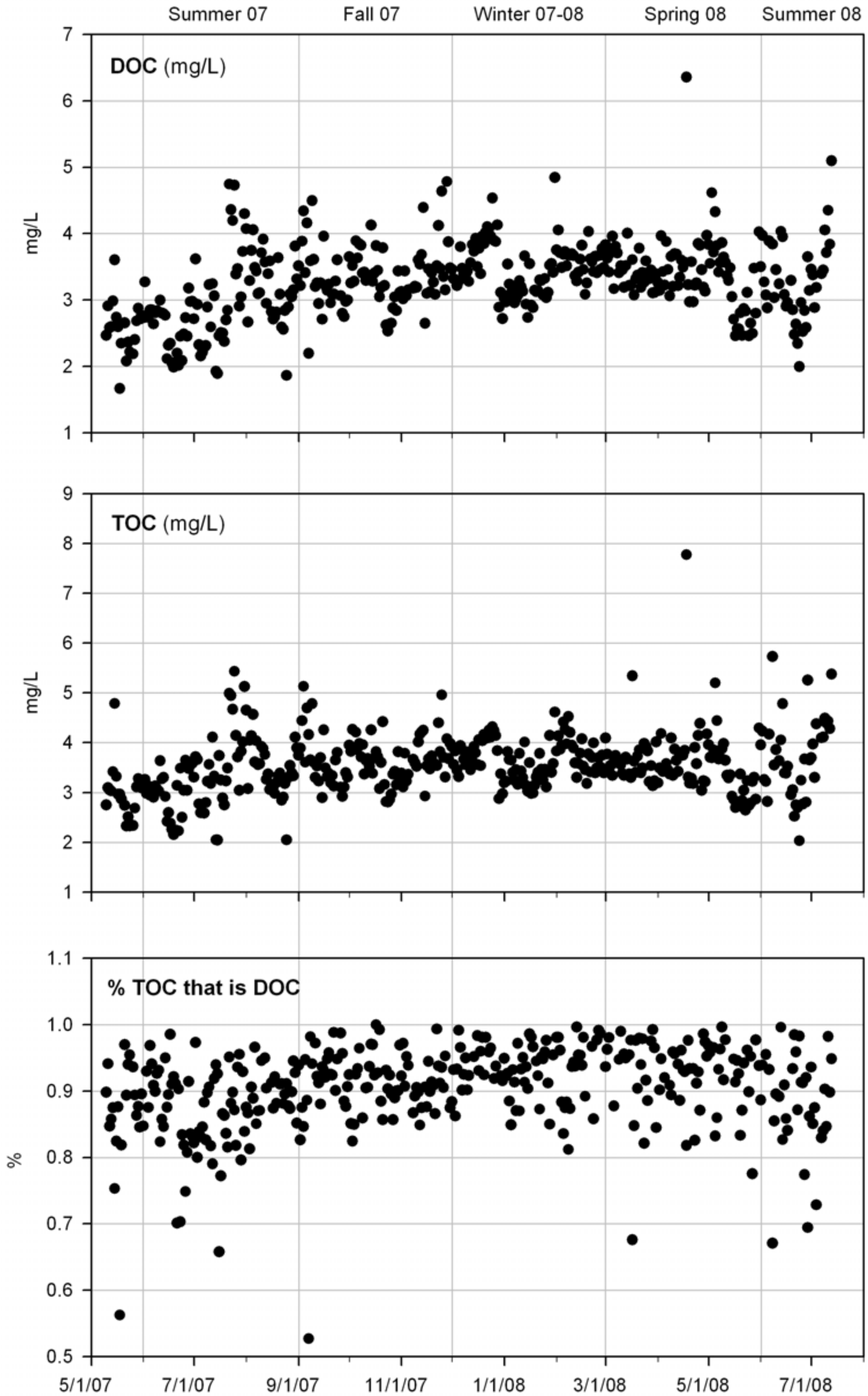

Figure 3-10: Raw water DOC, TOC, and percent of TOC that is DOC during the Pilot Study.

In terms of comparing TOC and UV_{254}, there is no clear correlation between the two (Figure 3-11). An argument could be made that there is a slight linear correlation when UV_{254} is less than 0.06 cm^{-1}. The equation of the linear regression in this case would be UV_{254} =0.0059(TOC)+0.0237 with an R^2 value of 0.2258. When UV_{254} is greater than 0.06 cm^{-1}, the correlation is slightly more discernable with the linear regression being UV_{254} =0.0228(TOC)-0.0169 with an R^2 value of 0.5727. However, the lack of clear correlation between the two parameters offered minimal input into the full-scale design.

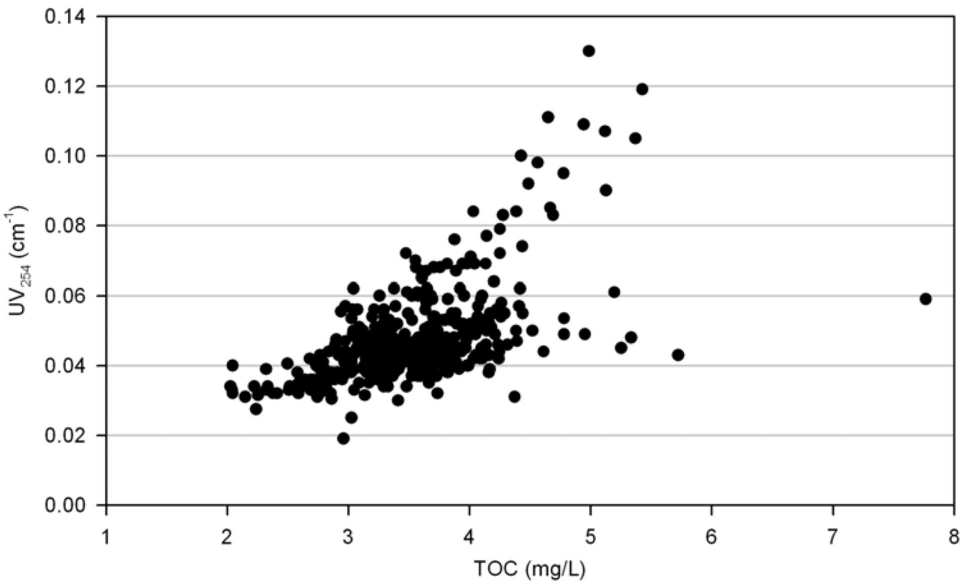

Figure 3-11: Correlation between raw water TOC and UV_{254} during the Pilot Study.

Periodic Grab Samples

All additional water quality testing was performed by AnaLab, a commercial laboratory based out of Kilgore, Texas. During the course of the pilot, it was decided that it would be advantageous to obtain additional water quality data associated with parameters not originally thought to be necessary. Results of the periodic testing are summarized in Table 3-2. The periodic grab samples were used to confirm water quality in the Ship Channel as well as to confirm a correlation between TDS and conductivity. Based on the TDS values reported by the independent laboratory, it was determined that a conductivity multiplier of 0.62 should be used to convert hand-held conductivity readings to TDS.

Additional testing was performed to determine a correlation between raw water turbidity (NTU) and raw water TSS (mg/L). By applying a linear regression model to the data set, it was determined that TSS = 1.0526(Turbidity)+25.021. The R^2 value for this linear regression is 0.9931. Previous analysis recognized the average raw water turbidity at the pilot facility to be 44 NTU. Using the TSS/Turbidity linear regression equation, the average raw water TSS at the pilot facility (over the course of the Pilot Study) was 71.3 mg/L.

Table 3-2: Summary raw water quality in the Brownsville Ship Channel, independent laboratory results for periodic grab samples.

Parameter	Units	No. of Points	Maximum	Minimum	Average	95th Percentile
Oil and Grease	mg/L	3	ND	ND	ND	N/A
Boron	mg/L	13	19.3	3.02	7.75	17.8
Strontium	mg/L	14	7.98	2.23	5.69	7.73
Calcium	mg/L	14	434	357	386	418
Iron	mg/L	14	22.1	ND	4.67	17.36
Magnesium	mg/L	14	1,330	911	1,135	1,310
Potassium	mg/L	13	684	417	487	661
Silica	mg/L	9	116	ND	24	29.5
Sodium	mg/L	14	10,500	6,390	8,468	10,175
Barium	mg/L	14	0.318	ND	0.086	0.242
Sulfate	mg/L	14	6,380	1,850	2,642	4,365
Fluoride	mg/L	13	ND	ND	ND	ND
Nitrate-Nitrogen, Total	mg/L	13	2.62	ND	2.62	1.048
Chloride	mg/L	13	25,500	13,900	17,083	24,360
SOCs	Mg/L	6	ND	ND	ND	ND
VOCs	mg/L	6	ND	ND	ND	ND
HAA5	mg/L	1	ND	ND	ND	ND
Bicarbonate (as $CaCO_3$)	mg/L	10	433	144	171	313
Carbonate (as $CaCO_3$)	mg/L	10	6.46	2.49	3	5.99
Color, True	PCU	9	10	ND	8	10
Color, Apparent	PCU	9	25	ND	12	25
Total Dissolved Solids	mg/L	14	46,800	28,100	30,515	39,585

3.2.2 Gulf of Mexico

An important component of this project was to evaluate raw water quality in both the Ship Channel and the Gulf of Mexico. The decision was made to dual-track raw water quality in the Ship Channel and the Gulf of Mexico to determine feed water quality characteristics of both sources for the pilot and full-scale facilities. The intent of the study was to pilot under a worst-case scenario. In order to obtain approval from TCEQ for the full-scale facility based on results of the Pilot Study, testing under the worst-case scenario would provide maximum flexibility in terms of the raw water source for the full-scale facility. However, prior to start-up of the pilot, discussions centered on the ultimate location for the pilot with two potential locations being considered: the Ship Channel and the Gulf of Mexico. Ultimately, the decision was made to locate the pilot at the Ship Channel, but water quality testing at both locations continued. This continued testing of raw water quality in the Ship Channel (probable source water for the full-scale facility) and the Gulf of Mexico (potential source water for the full-scale facility) allowed for a determination to be made regarding the recommended source water supply for the full-scale facility.

Due to the accessibility of the Ship Channel for water quality testing, real-time and daily water quality parameters were tracked. Grab samples were taken in the Gulf of Mexico, at a location adjacent to Boca Chica Beach, using a boat capable of handling swales periodically exceeding 8'. Water quality samples in the Gulf were taken at a depth of 10'. Due to safety concerns associated with obtaining samples off-shore, sampling events were scheduled around harsh conditions. It can therefore be determined that the results of water quality sampling in the Gulf of Mexico do not exhibit the worst-case scenario that one would typically find during a hurricane or other severe storm.

Testing of raw water from the Gulf of Mexico was performed by both the BPUB laboratory and an independent laboratory. The BPUB lab performed turbidity, TOC, DOC, UV_{254}, and alkalinity tests (Table 3-3).

Table 3-3: Summary raw water quality in the Gulf of Mexico, BPUB laboratory results for periodic grab samples.

Parameter	No. of Points	Maximum	Minimum	Average	95^{th} Percentile
Turbidity (NTU)	27	20.7	0.062	4.89	11.95
TOC (mg/L)	27	4.12	1.36	2.08	3.56
DOC (mg/L)	27	3.19	1.41	1.99	2.96
UV254 (cm-1)	27	0.056	0.008	0.0231	0.0514
Alkalinity (mg/L as $CaCO_3$)	27	133.1	118.5	124.8	131.3
pH (mg/l)	11	8.29	7.86	8.14	8.28

Additional testing for raw water quality in the Gulf of Mexico was performed by an independent lab. Table 3-4 shows the water quality results of key testing parameters.

Table 3-4: Summary raw water quality in the Gulf of Mexico, independent laboratory results for periodic grab samples.

Parameter	Units	No. of Points	Maximum	Minimum	Average	95^{th} Percentile
Oil and Grease	mg/L	3	ND	ND	ND	ND
Boron	mg/L	10	21.1	3.35	7.32	20.16
Strontium	mg/L	10	8.92	2.22	5.73	8.37
Calcium	mg/L	10	460	336	387	456
Magnesium	mg/L	10	1,400	1,010	1,227	1,395
Potassium	mg/L	10	684	394	539	673
Sodium	mg/L	10	1,400	7,750	9,221	11,040
Silica	mg/L	7	12.3	0.387	2.78	9.26
Barium	mg/L	10	0.0424	0.0101	0.0197	0.035
Sulfate	mg/L	10	5010	2280	2830	4160
Fluoride	mg/L	10	5.42	ND	0.542	2.98
Nitrate-Nitrogen, Total	mg/L	10	ND	ND	ND	ND
Chloride	mg/L	10	25,300	14,700	19,450	23,545
SOCs	mg/L	3	ND	ND	ND	ND
VOCs	mg/L	4	ND	ND	ND	ND
HAA5	mg/L	1	ND	ND	ND	ND
Bicarbonate (as $CaCO_3$)	mg/L	10	148	107	125.3	144
Carbonate (as $CaCO_3$)	mg/L	10	2.53	1.4	1.893	2.39
Total Suspended Solids	mg/L	10	206	4.5	41.2	145
Color, True	PCU	10	ND	ND	ND	N/A
Color, Apparent	PCU	10	20	ND	4	15.5
Total Dissolved Solids	mg/L	10	38,200	26,000	34,170	37,930

3.2.3 Comparison of Water Quality in the Brownsville Ship Channel and the Gulf of Mexico

Regarding water quality sampling performed by the BPUB laboratory, on average the TOC and DOC are higher in the Ship Channel by 1.45 mg/L and 1.25 mg/L, respectively. UV_{254} is higher in the Ship Channel by 0.024 cm^{-1}, and alkalinity is higher in the Ship Channel by 16.18 mg/L. An accurate turbidity analysis between the two locations cannot be performed due to the fact that turbidity values in the Ship Channel were found to vary considerably. It is reasonable to assume that turbidity values in the Gulf of Mexico may also vary, and water quality samples taken in the Gulf were not obtained during times of poor weather due to the inability to collect samples during such occasions.

When comparing the water quality characteristics obtained from the independent laboratory testing, many water quality parameters trend very closely together including Oil and Grease, boron, strontium, calcium, barium, fluorite, nitrate-nitrogen, Synthetic Organic Compounds (SOCs), Volatile Organic Compounds (VOCs), Carbonate, and haloacetic acids (HAA5). On average, magnesium, potassium, sodium, sulfate, chloride, and TDS are higher in the Gulf of Mexico. On average, bicarbonate is higher in the Ship Channel.

3.3 PRETREATMENT EVALUATION

Four (4) pretreatment units were piloted during the study: Eimco Conventional System, GE Zenon UF, Norit UF, and Pall MF (Section 2.3 provides an in-depth breakdown of specifications for each unit).

A primary objective of the Pilot Study was to obtain a sufficient amount of real-time information and data to demonstrate the technical viability of each pretreatment unit and to support future full-scale design of the SWRO facility.

The pretreatment systems were tested at various operating conditions to document loading rates, pressure losses, water production efficiency, filter backwash rates and frequencies, and chemical types and dosing rates. Through testing, optimum process settings were established in which water production was maximized while minimizing chemical use, and waste generation. The removal efficiency of potential membrane fouling agents (i.e. particulates, TOC, etc.) was monitored. System reliability was evaluated in terms of treatment consistency. Robustness was evaluated in terms of raw water quality variations. The goal of pretreatment runtime was to maximize runtime by minimizing downtime associated with mechanical and membrane failures.

Due to the unavailability of pertinent raw water quality data at the beginning of the Pilot Study, it was difficult to develop system specific performance objectives and goals prior to beginning the pilot. This fact is evident when taking into consideration the amount of time it took for the pretreatment units to settle on optimized conditions, if at all. The evaluation of pretreatment in terms of full-scale viability ultimately came down to a cost evaluation based on system performance (tabular pretreatment performance data are included in the digital attachments to this report).

3.3.1 Eimco Conventional System

The conventional pretreatment system is a process consisting of a rapid mix basin, two flocculation chambers, and a clarifier equipped with plate settlers to increase the rate of floc settling within the system. Ferric chloride was used to coagulate the raw water feed to the unit. Following the conventional pretreatment system is a single-stage, dual media filtration system used to remove any remaining coagulated particles. EIMCO was the principle equipment supplier of the conventional pretreatment system and the dual media filter.

Bench Scale Testing Results

Bench scale testing of probable coagulants to be used in the conventional pretreatment system was carried out prior to pilot startup. Jar testing was conducted by BPUB staff, the equipment vendor and NRS staff beginning in January of 2007.

Jar testing is a method of simulating the coagulation and flocculation process in a water treatment plant. Jar testing entails adjusting the amount of treatment chemicals and the sequence in which they are added to samples of raw water held in the jar testing apparatus. A Phipps & Bird Jar Tester with four variable speed stirrers was provided by BPUB and used to run the simulations. Raw water is first stirred rapidly while the coagulant is added to the test cell in order to simulate the rapid mixer. The apparatus is then adjusted to slowly stir the sample simulating the two stage flocculator. Finally, the mixer is shut off to begin the settling cycle. The formation, development, and settlement of floc can be observed throughout the simulation. After settling, a sample is extracted for testing.

Typical coagulants used in flocculation and sedimentation process are ferric chloride ($FeCl_3$), ferric sulfate ($FeSO_4$), and aluminum chlorohydrate (ACH). Aluminum Sulfate (alum) was considered but previous research showed incompatibility with the RO membrane. ACH was eliminated from further consideration because of the potential of aluminum residual that could foul or damage the RO membranes. Although popular for use in municipal water treatment, alum when introduced into water disassociates into trivalent aluminum and sulfate. The hydrated aluminum ion reacts with the water to form a number of complex hydrated aluminum hydroxides, which then polymerizes and starts absorbing the negatively charged colloids in water. Aluminum based colloid can cause fouling of the membranes with 0.1 to 1.0ppm of aluminum in the feed water. ACH was eliminated from further consideration because of the potential of aluminum residual (negatively charged aluminum colloids) which could foul or damage the RO membranes.

A summary of jar testing results can be found in Table 3-5. It can be seen that $FeCl_3$ and $FeSO_4$ produced the best water quality in the ranges of raw water quality available during the jar test. Even though $FeCl_3$ and $FeSO_4$ produced similar jar test results, $FeCl_3$ was chosen as the principal coagulant because of its availability. Subsequent testing included the use of a filter aid. The filter aid used was FIBERFLOC 7165, an anionic water-soluble polymer from the Altivia Corporation and was approved for use in SWRO membrane pretreatment process by both membrane suppliers. The variability of the feed water is best illustrated by the difference in raw water turbidity between the days of testing.

Table 3-5: Summary of jar testing, Eimco conventional pretreatment unit.

Date:	Coagulant	Dosage (mg/L)	Raw Water Turbidity (NTU)	Settled Turbidity (NTU)
24-Jan-07	ACH	20	3.5	2.0
	ACH	30	3.5	1.7
	$FeCl_3$	20	3.5	1.5
	$FeCl_3$	30	3.5	2.5
	$FeSO_4$	20	3.5	1.6
	$FeSO_4$	30	3.5	2.0
29-Jan-07	ACH	20	23	2.7
	ACH	30	23	1.8
	ACH	40	22	1.7
	ACH	50	22	1.4
	$FeCl_3$	20	23	3.0
	$FeCl_3$	30	23	2.0
	$FeCl_3$	40	23	2.2
	$FeCl_3$	50	22	2.2
	$FeSO_4$	20	23	2.2
	$FeSO_4$	30	23	2.5
	$FeSO_4$	40	23	2.7
	$FeSO_4$	50	22	2.0
22-Aug-07	$FeCl_3$ & Polymer[a]	10	12.3	12.5
	$FeCl_3$ & Polymer[a]	20	12.3	1.36
23-Aug-07	$FeCl_3$ & Polymer[a]	50	85	5.2
	$FeCl_3$ & Polymer[a]	50	126	8.3

[a] Polymer was dosed at 0.5 mg/L.

Evaluation and Optimization

In conjunction with jar testing, development of a testing matrix was generated by NRS staff. Each run was numbered according to a particular parameter being tested such as coagulant dosage. Each run began and ended with a thorough filter backwash cleaning. Items documented in the testing matrix included run time (hours), coagulant dosage (mg/L), and SDI. Later the matrix was expanded to include polymer dosage (mg/L) and NaOCl (mg/L) dosage.

The testing goal of stage one of the protocol included filtrate turbidities less than 1 NTU and SDI less than 3. Typical SWRO membrane manufacturers require a turbidity of less than one NTU; lower turbidities as specified in Table 2-1 would ensure higher quality feed water and longer run times between membrane cleanings. Once a particular dose meeting the testing goal was selected, the testing matrix was then adjusted with the goal of reducing the dosage of the coagulant (in this case, $FeCl_3$). A minimum of two daily samples of the feed, settled water and filtrate would be taken and analyzed at the on-site lab and at BPUB's lab. Evaluations of the results of a particular test run were carried out by NRS staff in conjunction with BPUB staff via conference call or onsite meetings.

The primary measure of success for the conventional pretreatment unit centered on water quality. If the turbidity and SDI of the filtrate was acceptable, additional factors such as backwash frequency and duration would have been modified to determine the best operating conditions.

TCEQ Testing (Stages 1, 2, and 3)
The pilot plant is designed to test the proposed treatment processes considered for use in the full-scale desalination facility. TCEQ requires that a Pilot Study be conducted for a minimum period of 90 days during a season that represents adverse operating conditions for a full scale facility. TCEQ requires the Pilot Study to be conducted in three stages: Optimization, Full Scale Long Term Pilot, and Loss of Flux and Fouling Evaluation Phase. The main objective was to produce filtered water that meets or exceeds the water quality requirements for RO feed. SWRO membrane manufacturers typically require a turbidity less than 1 NTU to the membrane; however, we have found that, based on our experience and their experience at other facilities, that a much lower feed water NTU ensures a higher quality feedwater and promises longer run times between membrane cleanings. Should the water quality produced by the filter meet these requirements, additional factors (backwash frequency, duration, etc.) could be analyzed to determine full-scale viability of the system. The TCEQ requirements are briefly described below:

In the optimization stage of the pilot program, the conventional treatment/filtration alternative pretreatment system must be operated over a period of 30 days or more if necessary with the objective of achieving a steady-state optimized operation. Stage 2 compared the long-term performance of the SWRO membrane supplier against the two alternative pretreatment systems depending on the success of stage 1 testing. There was the potential for this step to incorporate filtrate produced by the conventional unit or any of the other pretreatment units. This phase of piloting was scheduled to run for approximately 8 to 9 months. Capacity loss determination was to begin as part of Stage 3 pilot testing once performance evaluation was completed as part of stage two testing. The Stage 3 test period was to be conducted to determine the percent loss of original specific flux and if any irreversible fouling had occurred. The membrane unit was then to be operated under the same simulated full-scale water treatment plant design conditions for at least 30 days.

The optimization stage (Stage 1 of TCEQ testing requirements) began in May of 2007. The operational conditions of the conventional units were as follows:

- Loading Rate: ranges from 1.3 to 1.7 gpm/ft^2
- Rapid Mix time: approximately 1 minute
- Flocculator time: approximately 23 minutes
- Settling time: approximately 20 minutes
- G value for Rapid Mixer: 1,077
- G value for Flocculator: 283

Stage 1 was further categorized into four sub-stages. Stage 1a (initialization) consisted of trial and error testing of coagulant dosage and development of operating procedures and maintenance protocols. In this stage, the coagulant dosage ranged between 30 mg/L to 120 mg/L. Several test runs with dosing of coagulant in the 50 to 60 mg/L range produced promising results (SDI < 3.0, filtrate turbidity < 1.0 NTU) although, in the aggregate the system behaved erratically. Chief among the reasons for such erratic behavior was the variability of the raw water entering the system. Various adjustments to the system were made to optimize the system and lower the dosage of coagulant. Flocculator speeds were adjusted and the injection point was reconfigured with no measurable results. Backwashes were carried out between listed operational times for each test run.

During Stage 1a testing, the conventional pretreatment system did not produce sufficient quality filtrate meeting the predetermined SDI and turbidity requirements. Operational testing for the conventional pretreatment then proceeded to Stage 1b. Ultimately, the conventional pretreatment unit did not advance to Stage 2 testing nor was the filtrate fed to the RO unit.

Stage 1b included the addition of a filter aid (polymer) into the water treatment process. An anionic polymer was jar tested along with the principal coagulant. Even though jar testing results using the principal coagulant and a filter aid was marginal, the relative cost of this option and the desire to not abandon the conventional pretreatment unit were reasons enough to proceed with a testing protocol using the filter aid. Beginning in September of 2007 five test runs were initiated with varying dosages of the principle coagulant. The filter aid was never tested above 0.5 mg/L on the advice of the product manufacturer. Overall test results were minimal. During Stage 1b testing, 21 backwashes were initiated. A listing of results attained during this phase of testing is shown in Table 3-6.

Table 3-6: Media filter optimization matrix, September 23, 2007 thru October 16, 2007.

Run No.	Coagulant-Ferric Dose	Filter Aid-Dose	NaOCl	SDI	Operational Time
	mg/L	mg/L	mg/L		hours
1a	20	0.5	0	4.21	23
1a	20	0.5	0	4.04	23
1a	20	0.5	0	5.27	47
2a	25	0.5	0	4.96	25
2b	25	0.5	0	5.00	20
2b	25	0.5	0	3.13	44
2b	25	0.5	0	DNF	68
2b	25	0.5	0	DNF	92
3a	30	0.5	0	DNF	24
3a	30	0.5	0	DNF	48
3b	30	0.5	0	5.27	24
3b	30	0.5	0	6.06	48
4a	35	0.5	0	4.26	25
4b	35	0.5	0	3.84	23
4b	35	0.5	0	3.56	23
4b	35	0.5	0	1.85	25
4c	35	0.5	0	4.56	48
5a	40	0.5	0	5.48	23
5a	40	0.5	0	5.48	49
5b	40	0.5	0	4.40	21
5b	40	0.5	0	1.49	23
5b	40	0.5	0	4.77	47

Note: DNF = did not finish because the filter plugged up.
[a] 5.25% concentration.
[b] 12.0% concentration.

During Stage 1b testing, the conventional pretreatment system did not produce sufficient quality filtrate meeting the predetermined SDI and turbidity requirements. Operational testing for the conventional pretreatment then proceeded to Stage 1c. Therefore, the conventional pretreatment unit did not advance to Stage 2 testing nor was the filtrate fed to the RO unit.

Stage 1c included the addition of NaOCl. The intent of NaOCl addition was to see if chlorine disinfection would control biofilm by oxidizing organic compounds and thereby impact turbidity. Bench scale testing was not instigated. The filtrate was tested frequently for any chlorine residual and subsequently the dosage was adjusted. Acceptable chlorine residual during this phase of testing would be less than 1 mg/L. Overall test results were minimal. A listing of results attained during this phase of testing is shown in Table 3-7.

Table 3-7: Media filter optimization matrix, October 16, 2007 thru December 11, 2007.

Run No.	Coagulant-Ferric Dose	Filter Aid-Dose	NaOCl	SDI	Operational Time
	mg/L	mg/L	mg/L		hours
6a	40	0.5	5[a]	2.02	21
6a	40	0.5	5[a]	1.57	22
6a	40	0.5	5[a]	2.20	25
6a	40	0.5	5[a]	4.64	50
6b	40	0.5	5[a]	2.45	18
6b	40	0.5	5[a]	3.96	20
6b	40	0.5	5[a]	DNF	44
6b	40	0.5	5[a]	3.62	68
6b	40	0.5	5[a]	4.38	92
7a	40	0.5	13[b]	2.90	5
7a	40	0.5	13[b]	5.85	46
7b	40	0.5	6[b]	2.31	4
7b	40	0.5	6[b]	1.71	23
7b	40	0.5	6[b]	1.29	27
7b	40	0.5	6[b]	4.58	47
7b	40	0.5	6[b]	3.58	48
8a	40	0.5	6[b]	2.27	4
8a	40	0.5	6[b]	4.09	24
8a	40	0.5	6[b]	3.04	25
8a	40	0.5	6[b]	5.00	47
8a	40	0.5	6[b]	DNF	69

Note: DNF = did not finish because the filter plugged up.
[a] 5.25% concentration.
[b] 12.0% concentration.

During Stage 1c testing, the conventional pretreatment system did not produce sufficient quality filtrate meeting the predetermined SDI and turbidity requirements. Operational testing for the conventional pretreatment then proceeded to Stage 1d. Therefore, the conventional pretreatment unit did not advance to Stage 2 testing nor was the filtrate fed to the RO unit.

Stage 1d runs excluded further use of the filter aid (polymer). The principle coagulant ($FeCl_3$) was used in addition to NaOCl. Bench scale testing was not instigated. The filtrate was tested frequently for any chlorine residual and subsequently the dosage was adjusted to fall below the 1 mg/L threshold. Acceptable chlorine residual during this stage of testing would be less than 1 mg/L. Overall test results illustrate little reduction in SDI and turbidity needed for feeding the SWRO. A listing of results attained during this stage of testing is shown in Table 3-8.

During Phase 1d TCEQ testing, the conventional pretreatment system did not produce sufficient quality filtrate meeting the predetermined SDI and turbidity requirements. Therefore, the conventional pretreatment unit did not advance to Stage 2 testing nor was the filtrate fed to the RO unit.

After Stage 1d testing was concluded, an examination of the different matrices was initiated with the aim of setting a new course of action on the conventional pretreatment unit. Based on the thorough testing work accomplished and the marginal results, it was concluded that the unit in question was not capable of consistently producing the required feed water for the RO units.

Throughout the testing protocol, several modifications were made with the aim of optimizing the system in terms of providing feed water acceptable for use in the RO module. The chemical injection system was modified by submerging and placing the injection point closer to the mixer's impeller. This limited the amount of residual observable in the rapid mix chamber but overall results were nominal. Break tanks were installed with overflow between the clarifier and the filter after several failed attempts at regulating the flow into the filter. In terms of day to day operation of the plant, the results were noticeable. The improvements added flexibility and ease of operation but failed to meet the requirements to merit advancement to stage two.

Apart from not meeting the pretreatment water quality required to feed the SWRO, the conventional pretreatment unit also suffered various mechanical failures. No one failure seems endemic other than the failure of the feed pump, which occurred twice. Interruption of the testing protocol was attributed to external factors such as electrical power surges experienced at the site that caused the breaker panel of the flocculator and rapid mixer to trip. Another factor effecting results was the variability of the raw water supply, which upset the process.

The conventional pretreatment unit did achieve what can best be characterized as inconsistent results during Stage 1 testing. Sustainable, reliable results were not attained and therefore the conventional unit as configured did not reach Stages 2 or 3 testing (graphical interpretations of this data can be found in the digital attachments to this report).

Table 3-8: Media filter optimization matrix, October 16, 2007 thru December 11, 2007.

Run No.	Coagulant-Ferric Dose	Filter Aid-Dose	NaOCl	SDI	Operational Time
	mg/L	mg/L	mg/L		hours
9a	40	0	6[b]	4.93	1
9a	40	0	6[b]	2.11	8
9a	40	0	6[b]	3.11	26
9a	40	0	6[b]	2.39	29
9a	40	0	6[b]	3.36	49
9b	40	0	6[b]	0.83	22
9b	40	0	6[b]	1.39	25
9b	40	0	6[b]	4.36	47
9b	40	0	6[b]	3.29	93
9b	40	0	6[b]	3.00	119
9c	40	0	6[b]	3.42	75
9c	40	0	6[b]	3.17	92
9c	40	0	6[b]	1.33	96
9c	40	0	6[b]	4.56	116
9d	40	0	6[b]	3.54	23
9d	40	0	6[b]	1.01	47
9e	40	0	6[b]	3.56	27
9e	40	0	6[b]	1.33	45
9f	40	0	6[b]	2.77	27
9f	40	0	6[b]	2.64	31
9f	40	0	6[b]	3.35	46
9f	40	0	6[b]	2.98	75
9f	40	0	6[b]	3.45	77
9f	40	0	6[b]	3.86	95
9g	40	0	6[b]	2.75	25
9g	40	0	6[b]	3.61	27
9g	40	0	6[b]	1.65	49
9h	40	0	6[b]	2.85	22
9h	40	0	6[b]	5.19	47
9i	40	0	6[b]	3.30	22
9i	40	0	6[b]	6.19	46
9j	40	0	6[b]	2.68	24
9j	40	0	6[b]	5.40	46
9k	40	0	6[b]	2.93	23
9k	40	0	6[b]	5.90	46
9l	40	0	6[b]	DNF	49
10a	40	0	8[b]	1.46	48
10b	40	0	8[b]	1.69	26
10b	40	0	8[b]	4.41	48
11a	40	0	10[b]	3.25	22
11a	40	0	10[b]	3.50	46
12a	40	0	10[b]	4.41	16
12b	40	0	10[b]	2.60	19
13a	45	0	10[b]	1.91	21
14a	40	0	10[b]	2.95	23
15a	35	0	10[b]	3.46	25

Note: DNF = did not finish because the filter plugged up.
[a] 5.25% concentration.
[b] 12.0% concentration.

Cleaning and Chemical Use
The cleaning and maintenance of the conventional pretreatment system was considerable and labor intensive. Rapid mixer and flocculator principally required scrub down and removal of any algae present in the chamber. Cleaning was reduced after Stage 1c, which included the addition of NaOCl. The dual media filter utilized both backwash and air scour for cleaning. Initialization of a backwash event was prompted by the following:

- High head loss – Daily measurement of the water level in the filter were taken to gauge filter plug up. Once the water level was within twelve inches (12"+ or -) from the top of the filter a backwash was initialized.
- High turbidity – Daily samples were taken of the filtrate. Turbidity was measured from the sample and the results were used to schedule a backwash event.
- SDI – Daily samples were taken of the filtrate and tested.

Backwash of the dual media filter was initiated after several poor SDI readings. Scheduled cleaning of the clarifier was instituted to reduce the buildup of iron. Despite the scheduled draw off of sludge, it was observed that complete drainage and cleaning of the clarifier was required to reduce the buildup of sludge.

3.3.2 GE Zenon UF

The system utilized ZeeWeed 1000 hollow-fiber UF membrane elements with 600 ft^2 of membrane area each. The ZeeWeed 1000 system uses outside-in technology that is immersed directly in the feed water. The maximum transmembrane pressure (TMP) of the system is 13 psi. Through testing, optimum process settings were established in which water production was maximized while minimizing chemical use, waste generation, and energy requirements. The removal efficiency of potential membrane fouling agents was monitored, and system reliability in terms of treatment consistency and robustness was evaluated in terms of raw water quality variations. In terms of pretreatment runtime, it was the goal to maximize runtime through the minimization of downtime associated with mechanical and membrane failures. A minimum runtime of 30 days was required.

System Testing
Table 3-9 summarizes the GE Zenon system's operation during the Pilot Study. It was noted that the lowest water temperature during the course of the pilot was 14.5 deg C. Therefore, the following table gives average temperature corrected flux rates (at 14.5 °C) for each individual performance run at various fluxes.

Table 3-9: Summary of GE Zenon UF operational runs.

Flux During Run	Start Date	End Date	Flux (14.5 °C)	Cycle Time (minutes)	Percent Recovery
Optimization	5/15/2007	11/21/2007	-	-	-
25 gfd	11/22/2007	12/6/2007	21.65	35	92.0
20 gfd	1/31/2008	2/25/2008	17.5	37	92.0
15 gfd	2/25/2008	4/14/2008	12.68, 11.64	45	92.0

Optimization Run

The Zenon UF system began operation on May 15, 2007. During the initial stage of testing, the goal was to optimize the treatment process in terms of flux, cleaning frequency, cycle time, and overall system recovery. The system was operated with filtrate fluxes ranging from 25 to 31 gfd (Figure 3-12). In terms of TCEQ compliance with pilot testing, this run was considered TCEQ Stage 1.

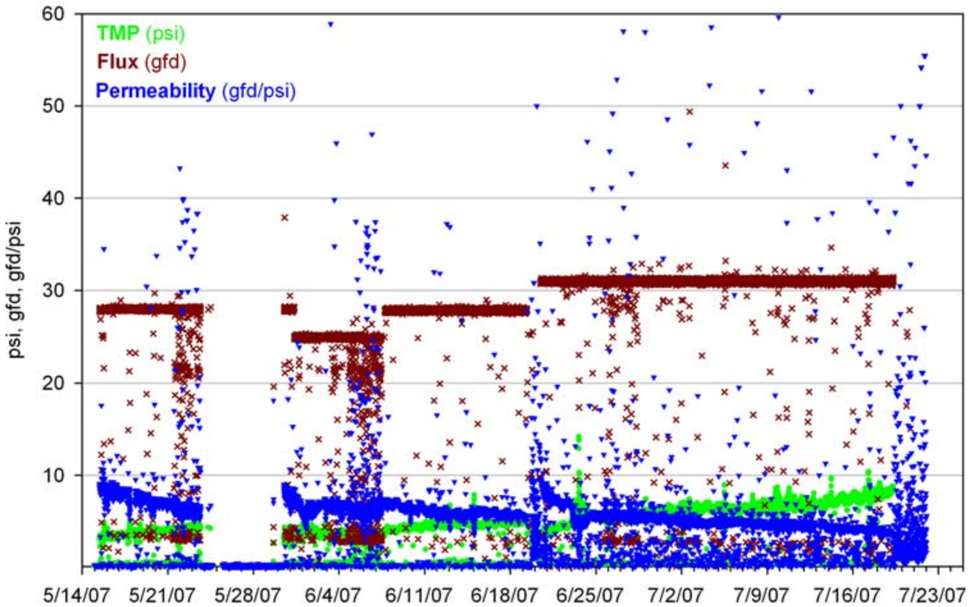

Figure 3-12: Optimization run No. 1 (TCEQ Stage 1), GE Zenon UF membrane performance.

During the Optimization stage, the Zenon unit experienced a number of mechanical issues that delayed the optimization process. These mechanical issues were associated with the booster pump, permeate pump, blower, and the feed turbidimeter. In addition, the original pre-screening system (two 100 micron Arkal filter pods) was deemed ineffective in providing necessary raw water flow to the Zenon unit. During times of high feed water turbidity, it was common for the Zenon system to shut down due to low feed flow. This was a direct result of the inability of the prescreens to maintain pass-through flow (Figure 3-13). Therefore, the pre-screening system was expanded to four 100 micron Arkal filter pods. The optimization stage lasted for approximately 190 days.

After completing the initial stage of pilot testing, a series of performance tests were performed. In terms of TCEQ compliance, each performance test following the initial stage of testing was labeled either TCEQ Stage 2 or TCEQ Stage 3. TCEQ Stage 2 requirements were such that the membrane system was to utilize set operating conditions. TCEQ Stage 3 objective was to determine the amount of irreversible fouling or membrane damage that occurred during the TCEQ Stage 2 test. Stages 2 and 3 were to use the same operating conditions.

Figure 3-13: Photograph of sediment buildup in the discs (left) and hood (right) of one of the GE Zenon Arkal units.

Operation at a Flux of 25 gfd

The Zenon unit began Stage 2 operation with a flux of 25 gfd, a filtration cycle of 35 minutes, and a daily CEB. The recovery of the system at these conditions was 92%. Shortly after beginning operations, it was evident that the operation of the unit could not complete a 30 day run without performing a CIP due to a rapid rise in TMP (Figure 3-14). The maximum TMP of the system is 13 psi, and the unit exhibited a loss of filtrate flow. The average temperature corrected flux (at 14.5 gfd) during the run was 21.65 gfd.

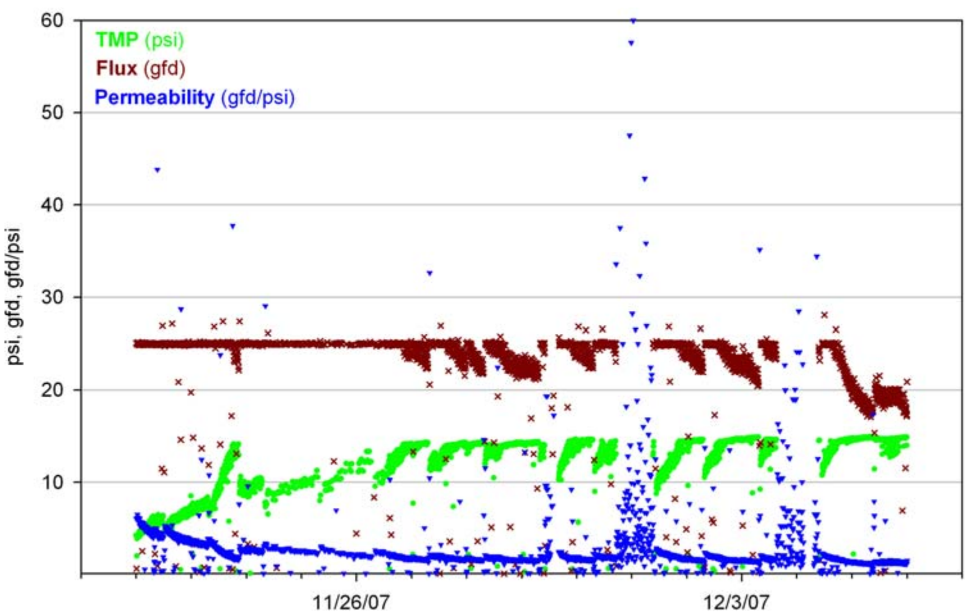

Figure 3-14: Operation at 25 gfd (TCEQ Stage 2), GE Zenon UF membrane performance.

In order to determine the cause of premature fouling on the membranes, one of the membrane modules was sent for autopsy. GE/Zenon performed an autopsy on their membrane element to determine the extent and type of fouling present on the membrane surface. It was determined that a lack of regular cleaning and extensive fouling during the optimization stage contributed to the system's poor performance. An advanced cleaning regimen was developed to target the fouling matrix. A copy of the autopsy report was not provided.

Operation at a Flux of 20 gfd

Based on the inability of the system to operate at a flux of 25 gfd, the decision was made to resume operation, following the advanced cleaning regimen, with a flux of 20 gfd. The daily cleaning regimen incorporated 5 hypochlorite cleans per week and 2 citric acid cleans per week with only one such clean being performed per day. After operating the system for a period of 20 days, it was determined that sustained operation for 30 days was improbable (Figure 3-15). The unit was taken out of service, and a CIP was performed. The average temperature corrected flux (at 14.5 °C) during the run was 17.5 gfd.

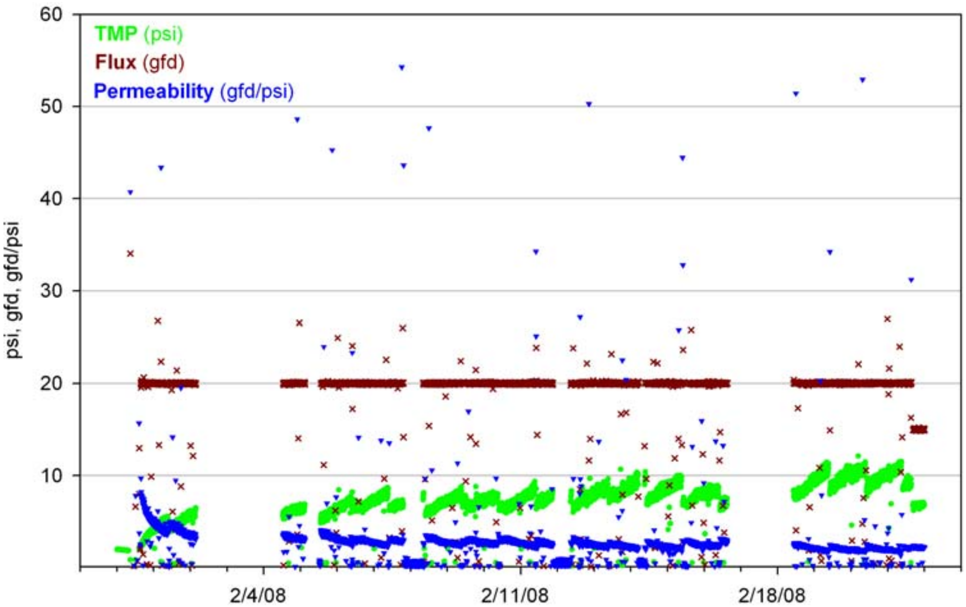

Figure 3-15: Operation at 20 gfd (TCEQ Stage 2), GE Zenon UF membrane performance.

Operation at a Flux of 15 gfd

Due to the performance of the system at a flux of 20 gfd, the unit was restarted, post CIP, with a flux of 15 gfd. The daily cleaning regimen was also altered to incorporate 7 hypochlorite cleans (200 ppm) per week and a single citric acid (2 g/L) clean per week immediately following the hypochlorite clean.

The unit was able to operate without substantial fouling on the membrane (Figure 3-16) over the course of a 30 day run. The average temperature corrected flux (at 14.5 °C) during the run was 12.68 gfd.

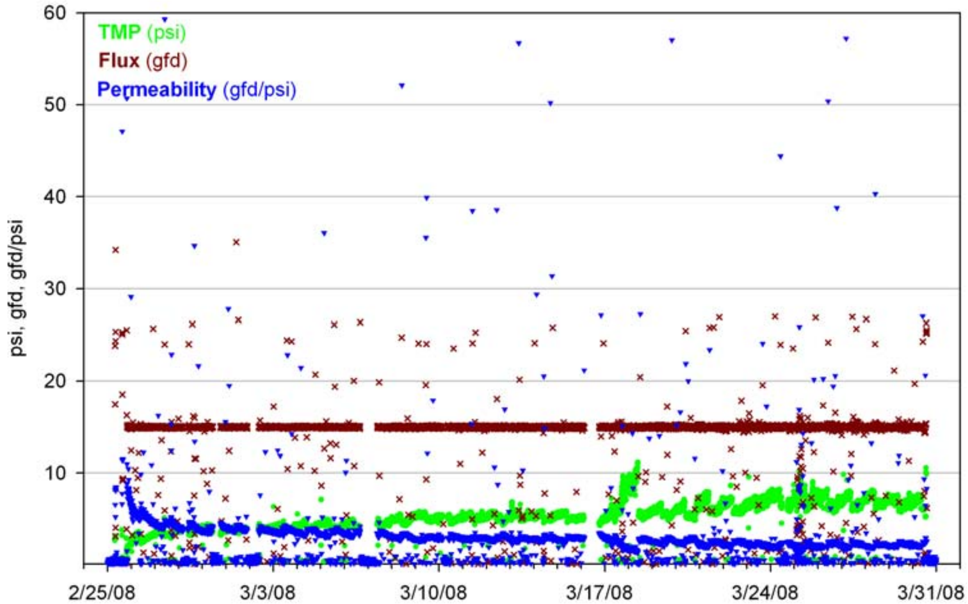

Figure 3-16: Operation at 15 gfd (TCEQ Stage 2), GE Zenon UF membrane performance.

The beginning TMP during the run was 2.0 psi, and the TMP at the conclusion of the Stage 2 run was 7.8 psi. A CIP procedure was performed using the modified method, and the unit was put back into operation. Upon restarting the unit post CIP, the TMP was 2.9 psi. When compared to the TMP immediately following the CIP performed on February 25 (2.0 psi), the unit exhibited a 45% increase in TMP. It can therefore be determined that the unit was unable to recover to acceptable levels due to irreversible fouling and/or damaged membranes (Figure 3-17).

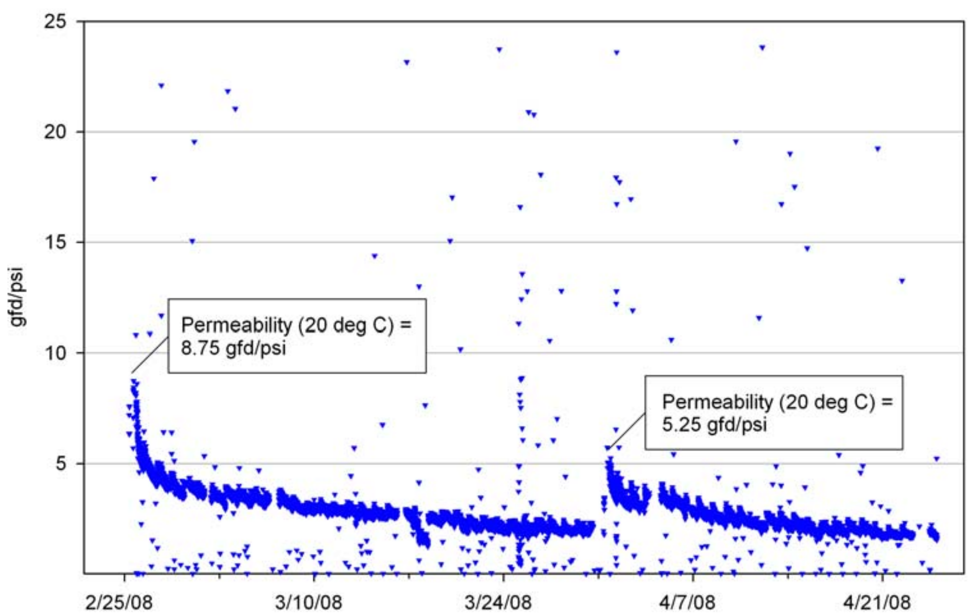

Figure 3-17: Operation at 15 gfd (TCEQ Stage 2), GE Zenon UF membrane performance.

After the CIP, the system operated at a flux of 15 gfd for 24 calendar days without losing filtrate flow (Figure 3-18). During the run, the average temperature corrected flux (at 14.5 °C) was 11.64 gfd.

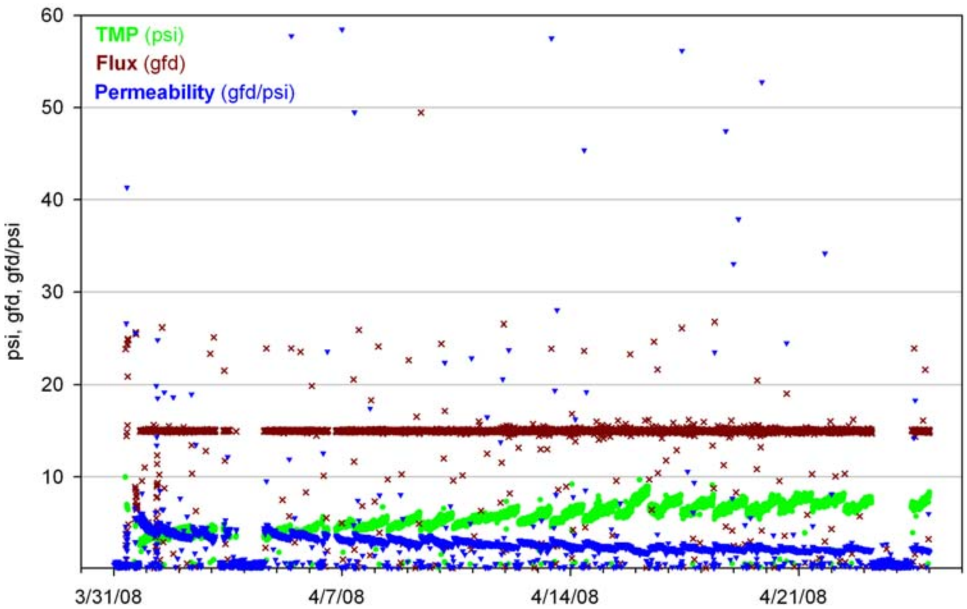

Figure 3-18: Operation at 15 gfd (TCEQ Stage 3), GE Zenon UF membrane performance.

On April 24, 2008, the decision was made to terminate pilot testing of the Zenon unit at the pilot facility. Even though the unit was able to operate at a flux of 15 gfd for the minimum required 30 days, subsequent testing indicated the presence of irreversible fouling or membrane damage. This is evident by the inability of the unit to restore permeability after completing the modified CIP procedure. An argument can also be made that fouling was present on the membrane surface due to the inability of the system to operate with a flux of greater than 15 gfd in a sustainable fashion. However, continued testing of the GE/Zenon system at a flux of 15 gfd could possibly have lead to the determination that sustained operation of the system could be possible.

The decision was made by GE/Zenon to terminate additional pilot testing based on three factors: 1) problematic operation of the prescreening system resulting in unit downtime, 2) extended down-time associated with pilot mechanical and process set-up issues causing higher than expected permeability loss of the membranes in conjunction with challenging water quality, and 3) technical and commercial interests colliding under the weight of increasing piloting costs.

Prescreening

Early in the piloting process, the GE Zenon pilot system utilized two Arkal 2" Spin Klin Automatic Disc Filter Batteries, each with 100 micron discs. During times of high feedwater turbidity, the Arkal system was unable to supply consistent prescreened water to the GE Zenon unit causing the system to shut down.

Testing was performed on the Arkal system in order to mitigate membrane downtime as a direct result of the prescreen being unable to provide feedwater, and the resultant setup utilized four Arkal 2" Spin Klin Automatic Disc Filter Batteries. The Arkal system utilized two, 200 micron Arkal Batteries in series with two, 100 micron Arkal Batteries. The prescreening surface area was 3.77 ft^2. Backwashes occurred when DP reached or exceeded 3 psi, on a time basis, and when the GE Zenon pretreatment unit was performing a backwash. During a period of time, an average of 48 backwashes were performed each day with 14.68 gallons of water being used per backwash. On average, 705 gallons of water per day were used for Arkal backwashing purposes. The four battery Arkal prescreening system provided consistent run time and prescreened flow to the GE Zenon unit.

Based on feedwater flows entering the unit during operation of the GE Zenon system at a flux of 15 gfd (31.3 gpm), it can be concluded that 1.5% of feed water flow was rejected by the Arkal system during backwashing.

Filtrate Water Quality

At the onset of the Pilot Study, the goals of the filtrate water quality were to be analyzed in terms of SDI and turbidity. The filtrate water quality goals were to obtain SDIs less than 3.0 100% of the time and less than 2.0 90% of the time. Filtrate water quality results during the Pilot Study for the GE Zenon UF pretreatment unit are summarized in Table 3-10 and Figure 3-19. The filtrate water quality produced by the GE Zenon unit met the pretreatment water quality goals in terms of SDI (less than 3.0 100% of the time and less than 2.0 95% of the time) and filtrate turbidity (less than 0.2 NTU).

Table 3-10: Summary of GE Zenon filtrate water quality results.

	SDI		**Turbidity** (NTU)	
Flux (gfd)	Maximum	95^{th} Percentile	Maximum	Average
25	2.33	2.17	0.09	0.07
20	1.85	1.71	0.10	0.07
15	2.80	1.80	0.11	0.08

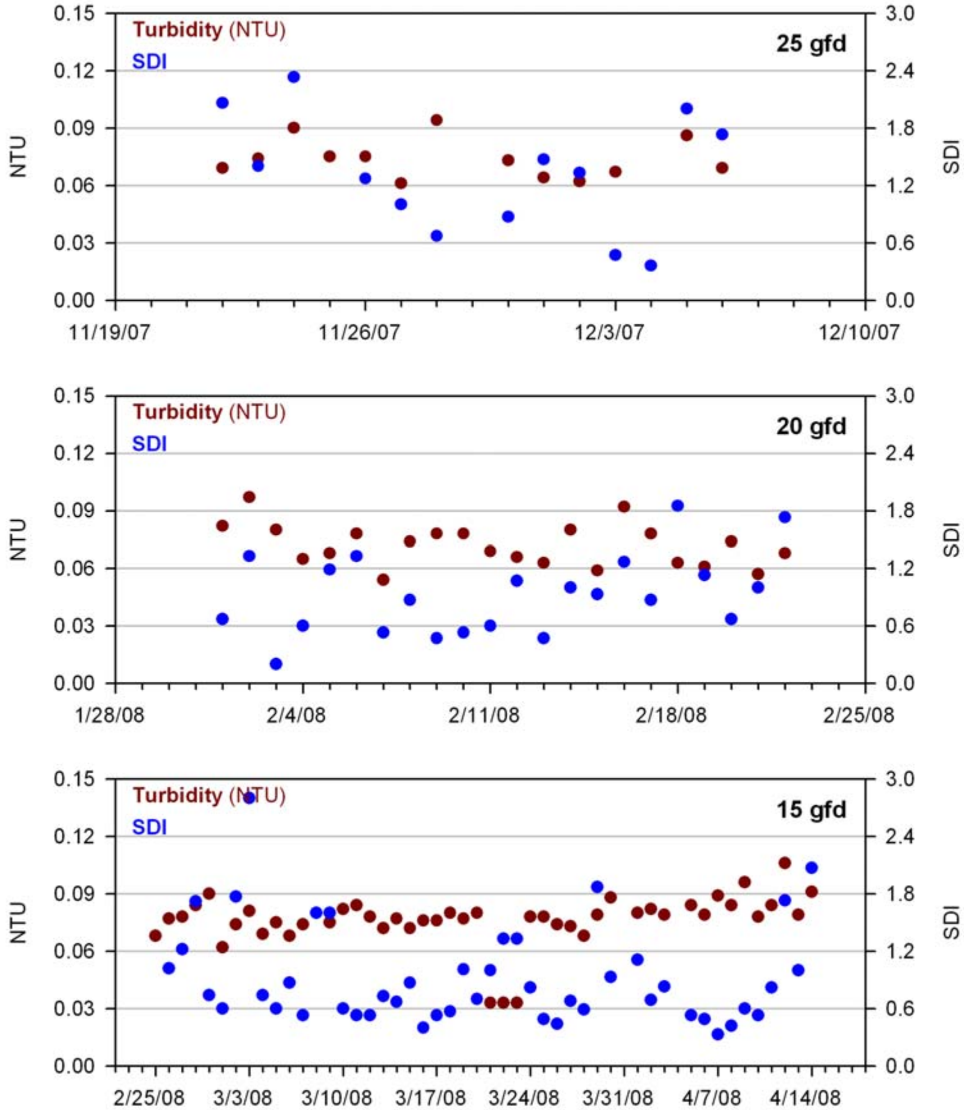

Figure 3-19: Summary of filtrate water quality results for GE Zenon UF.

Raw Water Quality

Figure 3-20 shows the raw water quality during each individual Zenon run. As can be seen, there are some variations in the raw water quality throughout the Pilot Study. Directly comparing the water quality during the 15 gfd run to that of the other performance runs, it should be noted that many of the key water quality parameters are similar to previous runs, specifically TOC, DOC, UV_{254}, and turbidity. However, turbidity during the first 15 gfd run was notably lower.

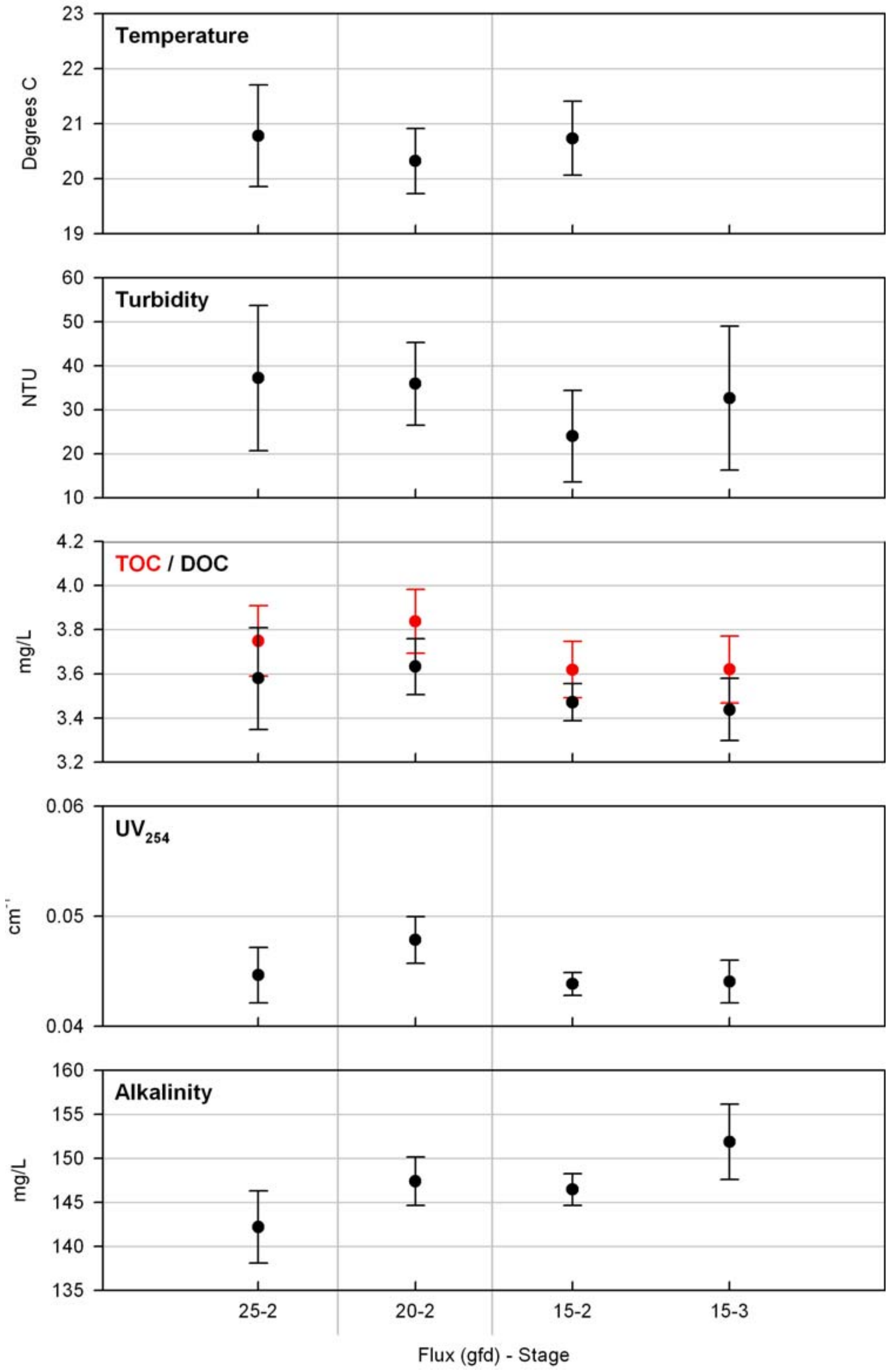

Figure 3-20: Raw water quality for selected parameters during the GE Zenon UF runs.

Residuals

Operation of the GE Zenon pretreatment at the Pilot produced three waste streams that can be uniquely characterized: 1) the Arkal prescreening unit produced a waste stream of macro-scale sediment and debris during each backwash of the Arkal unit; 2) the membrane backwash produced a waste stream of smaller particles, which bypassed the Arkal 100 micron screens but entrained against the membranes; and 3) the chemical cleans produced a waste stream of particles, which had to be dislodged chemically, and residual amounts of the chemical used in these daily cleans. A detailed analysis of solids and chemical residuals was not performed during the Pilot Study.

Cleaning and Chemical Use

The GE Zenon system employed CEBs and CIPs in their overall operation. The CEBs were programmed to automatically occur after the end of the first production cycle after a set amount of time. Two types of CEBs were utilized during the study. CEB1 utilized 200 ppm NaOCl, and EFM2 utilized 2000 ppm of citric acid. For the CIP procedure, heated potable water (40 deg C) was used to fill the membrane tank. While the tank was being filled, NaOCl is added to the heated water (typically 1000 ppm). The membranes are soaked for a period of 6 hours, the solution is drained, the membranes are rinsed with potable water, and heated potable water (40 deg C) with 2000 ppm of citric acid is applied to the membranes. The membranes are again soaked for a period of 6 hours. After the soak, the solution is drained and the membranes are rinsed with potable water. To assess permeability restoration, recirculations using potable water are conducted at a flux of 25 gfd before, during and after the cleanings. At a minimum, the recirculations should occur before the NaOCl, between chemicals, and following the acid. However, if operator time allows, a recirculation is taken every hour of each soak. The basic CIP procedure typically lasted between 12 and 15 hours.

Due to the presence of an enhanced fouling matrix on the membranes, a revised CIP procedure was implemented during the Pilot Study. For this revised procedure, an attempt was made to remove all solids from the membrane bundles using aeration and heated water. The membranes were then rinsed with clean potable water. Heated potable water (40 deg C) and NaOCl was used to raise the pH of the system to between 11.7 and 12.0. Approximately 2000ppm of NaOCl was used. This solution was allowed to soak for 18 hours. After draining and rinsing the tank, 5000ppm of citric acid was added to heated potable water (40 deg C) and allowed to soak for 6 hours. After draining and rinsing the tank, 20,000 ppm of Kleen MCT442 or Avista P303 (citric acid and detergent blend) was added to heated potable water. The resultant pH was approximately 3.0.

The membranes were soaked in this solution for 6 hours. After draining and rinsing the tank, 20,000 ppm of Kleen MCT411 or Avista P101 (caustic, surfactant, sequestering, oxidant blend) was added to heated potable water. The resultant pH was 11.5 to 12.0. The membranes were soaked in this solution for 6 hours. After draining and rinsing the tank, hydrochloric acid was added to heated potable water (30 deg C) until a pH of 6.5 +/- 0.5 was reached. The solution was mixed, and 1000 ppm of NaOCl was added. This solution was allowed to soak for 4 hours. This revised CIP procedure typically lasted between 40 and 45 hours. Even though the revised CIP was utilized on two different occasions at the pilot facility, it is not a recommended component of a regular cleaning regimen.

Air Integrity Test
The air integrity test procedure consisted of feeding approximately 10 psi of air to the modules for a period of 10 minutes to purge the system of air. After 10 minutes, the air feed is shut off and the initial pressure is recorded. The air pressure is allowed to decay for 120 seconds after which the final pressure is recorded. All integrity tests throughout the Pilot Study passed.

3.3.3 Norit UF

The system utilized Norit X-Flow hollow-fiber UF membrane elements with 431 ft^2 of membrane area each. The X-Flow system uses inside-out technology that operates with pressurized feed water. During operation, the maximum recommended TMP of the system is 15 psi. Through testing, optimum process settings were established in which water production was maximized while minimizing chemical use, waste generation, and energy requirements. The removal efficiency of potential membrane fouling agents was monitored, and system reliability in terms of treatment consistency and robustness was evaluated in terms of raw water quality variations. In terms of pretreatment runtime, it was the goal to maximize runtime through the minimization of downtime associated with mechanical and membrane failures. A minimum runtime of 30 days was required.

System Testing
Table 3-11 summarizes the Norit system's operation during the pilot study.

Table 3-11: Summary of Norit UF operational runs.

Flux During Run	Start Date	End Date	Flux (14.5 °C)	Cycle Time (minutes)	Percent Recovery
Optimization	5/15/2007	7/24/2007	-	-	-
Optimization	11/16/2007	12/5/2007	-	-	-
65 gfd	12/5/2007	1/24/2008	54.61, 59.6	92.9	92.89
60 gfd	1/24/2008	1/31/2008	56.87	92.3	92.3
50 gfd	1/31/2008	2/5/2008	47.58	90.8	90.76
40 gfd	2/11/2008	2/29/2008	33.39	88.5	88.45

Optimization Run No. 1
The Norit UF system began operation on May 15, 2007. During the initial stage of testing, the goal was to optimize the treatment process in terms of flux, cleaning frequency, cycle time, and overall system recovery. The system was operated with filtrate fluxes ranging from 50 to 70 gfd (Figure 3-21). In terms of TCEQ compliance with pilot testing, this run was considered TCEQ Stage 1.

During the optimization run, the unit experienced a number of mechanical problems that prevented the system from beginning its performance testing. In addition, the pilot system was limited in the amount of water that could be produced. The decision was made to terminate pilot testing using the trailer mounted pilot unit while a new pilot unit was being fabricated.

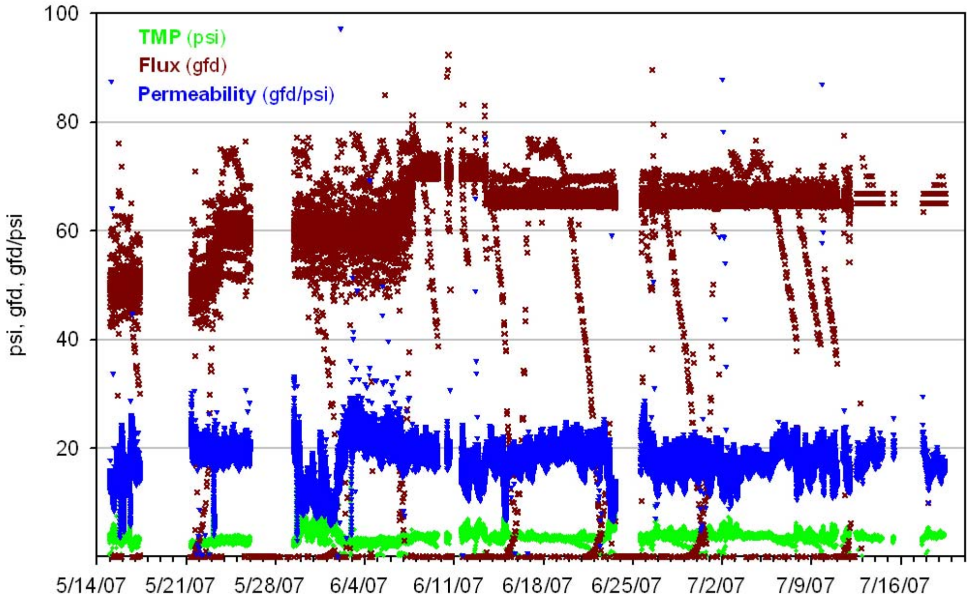

Figure 3-21: Optimization Run No. 1 (TCEQ Stage 1), Norit UF membrane performance.

Optimization Run No. 2

A new pilot unit was delivered and installed on site which reduced the number and severity of mechanical problems associated with the previous pilot unit. In addition, the new unit incorporated four (4) membrane modules instead of two (2) in the previous unit. This allowed the pilot unit to potentially feed an RO train. During the second optimization run (Figure 3-22), minor modifications were made to chemical dosing pumps, programming, and unit piping.

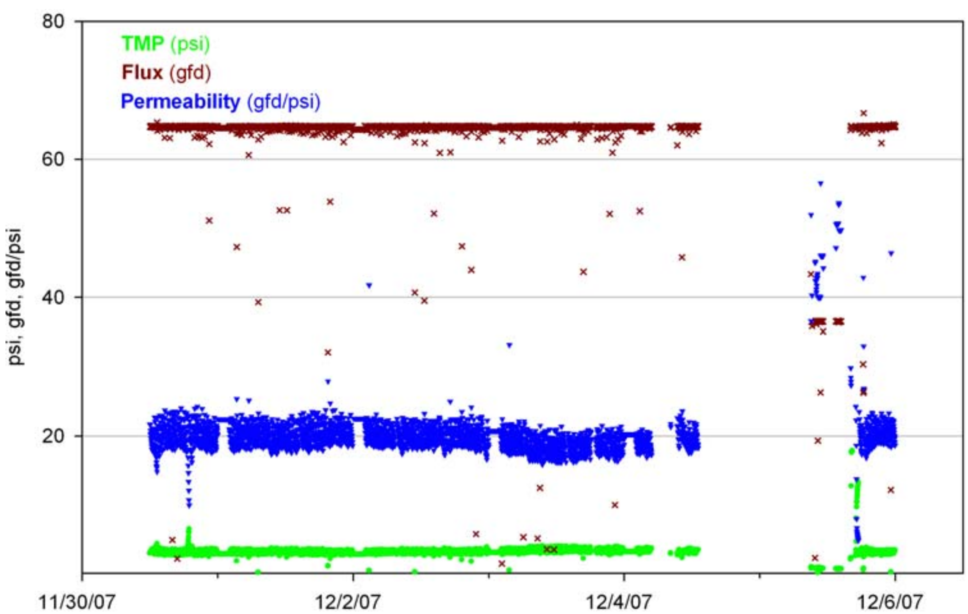

Figure 3-22: Optimization Run No. 2 (TCEQ Stage 1), Norit UF membrane performance.

Operation at a Flux of 65 gfd

The Norit system began TCEQ Stage 2 operations with a flux of 65 gfd, coagulant dose of 0.5 ppm as iron, a backwash every 28 minutes (duration of 45 seconds with a backwash flow rate of 176 gpm), a CEB1 (50ppm of hypochlorite) for 5 minutes after every 16 backwashes, and a CEB2 (1000ppm of citric acid) for 10 minutes after every 4 CEB1s (Figure 3-23). Dosing of iron coagulant is consistent with the need to reduce or provide the opportunity to eliminate suspended material from the SWRO feedwater prior to entering the membrane including TSS, TDS, coliform, and other analytes. The recovery of the system at these conditions was 92.9%, at which the system was able to achieve the minimum required 30 days of runtime.

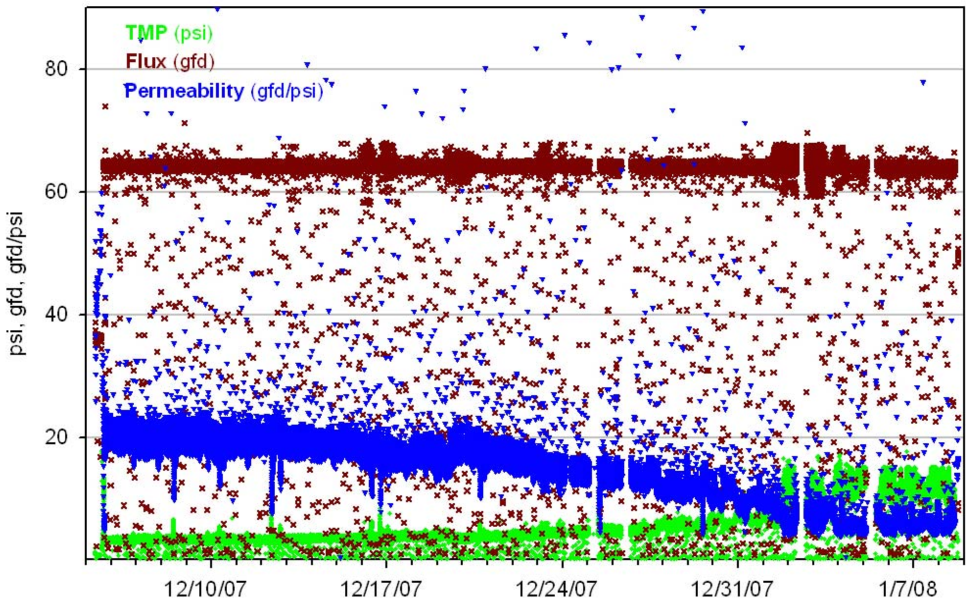

Figure 3-23: Operation at 65 gfd (TCEQ Stage 2), Norit UF membrane performance.

Upon completion of the first 65 gfd run, a CIP was performed in anticipation of beginning a confirmation run. Soon after completing the CIP, it was discovered that the results of the air integrity test were not being downloaded. Modifications were made to the program, and the air integrity test was completed. The unit was put into operation with a flux of 65 gfd (Figure 3-24). Upon restarting the unit, it was determined that the previous CIP was not effective at reducing the TMP to previous levels. A revised CIP procedure was developed and executed, and the unit was placed into operation. After running for approximately 5 days, it was evident that the operation of the unit was not sustainable for the required 30 days due to a linear rise in TMP (and a related linear decline in permeability) after placing the unit in operation. In addition, immediately after placing the unit in service post CIP, the TMP rose dramatically. Comparing this data to that in which was obtained when the membranes were new (at the beginning of the first 65gfd run), it was determined that the rapid decline in TMP at the beginning of the second 65 gfd run would significantly hinder the ability for the unit to sustain operation for 30 days. This is justified when comparing similar TMP levels. During the second 65 gfd run, the TMP reached 7.6 psi after approximately 5 days. During the first 65 gfd run, the unit was in operation for approximately 26 days when the TMP reached this level.

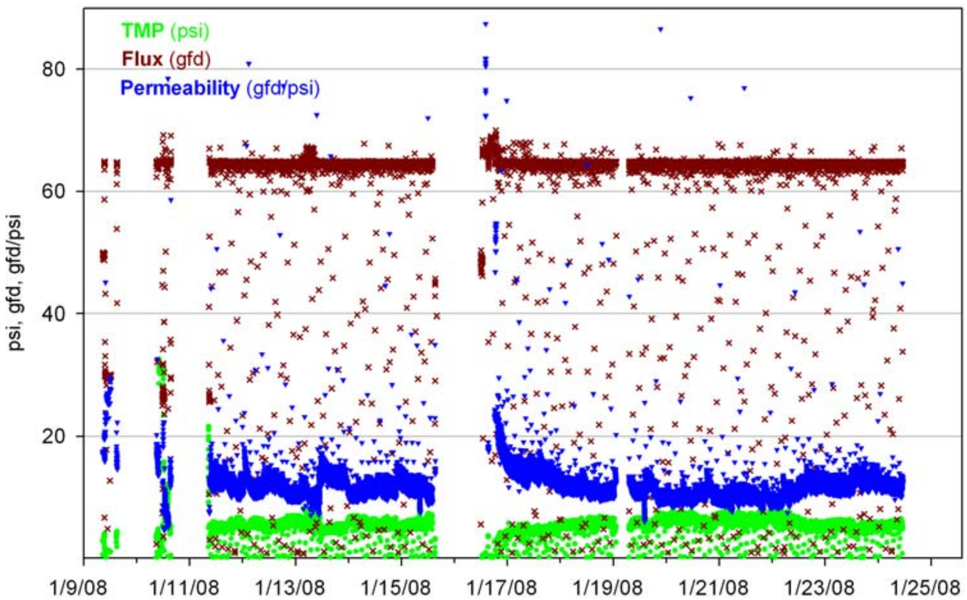

Figure 3-24: Operation at 65 gfd (TCEQ Stage 3), Norit UF membrane performance.

After operating the unit, during the second 65 gfd run, for 5 days, operational modifications were made to the system in which alternative coagulant dosages were tested (from 1ppm to 2 ppm as iron). This resulted in a temporary decrease in TMP. However, the TMP levels experienced similar linear declines when compared to the results obtained with 0.5 ppm as iron.

Operation at a Flux of 60 gfd

Based on the results of the 65 gfd run, the decision was made to reduce the flux. After performing a CIP, the unit was restarted with a flux of 60 gfd (Figure 3-25) with the same operating parameters (with the exception of flux) as the 65 gfd run. After operating for a period of 7 days, the TMP rose to a point where it was evident that sustained operation for 30 days was unlikely. In-depth discussions were held between the project team and Norit in which performance of the membranes was discussed. It was concluded that the performance of the membranes post-CIP was not consistent with performance exhibited at other locations, and the rapid rise in TMP was indicative of membrane fouling or damage.

Operation at a Flux of 50 gfd

Keeping consistent with the pilot protocols, the flux of the system was lowered to 50 gfd (Figure 3-26). The system maintained the same operating procedures of a coagulant dose of 0.5 ppm as iron, a backwash every 28 minutes (duration of 45 seconds with a backwash flow rate of 176 gpm), a CEB1 (50ppm of hypochlorite) for 5 minutes after every 16 backwashes, and a CEB2 (1000ppm of citric acid) for 10 minutes after every 4 CEB1s.Immediately following the CIP, the TMP of the unit was 1.77 psi. During the first filtration cycle, the TMP rose to 4.02psi. Due to this rapid increase in TMP (and a subsequent decrease in permeability), it was evident that sustained operation of the unit for 30 days was not possible. Again, based on recommendations from Norit, the performance was not consistent with proper and acceptable performance.

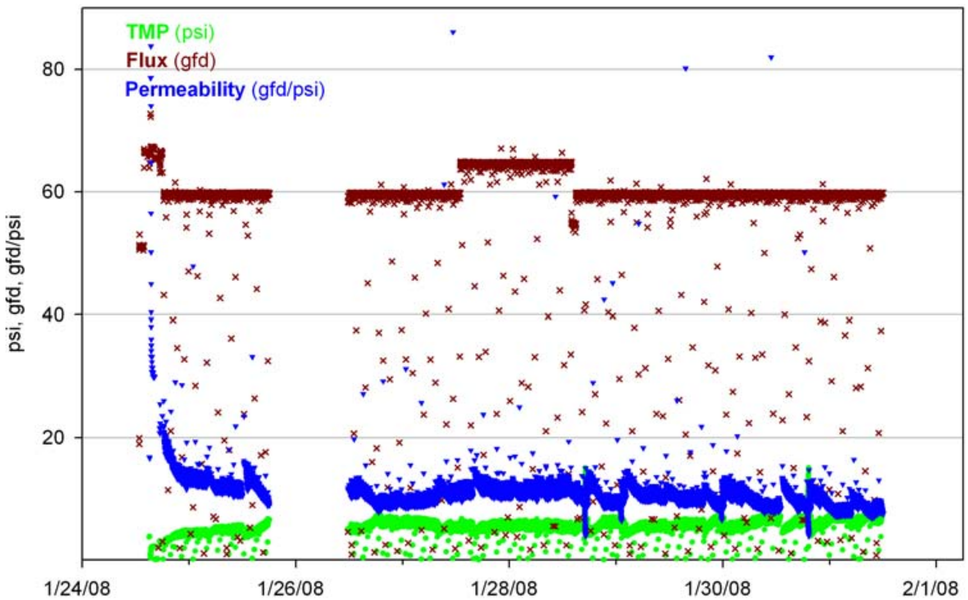

Figure 3-25: Operation at 60 gfd (TCEQ Stage 2), Norit UF membrane performance.

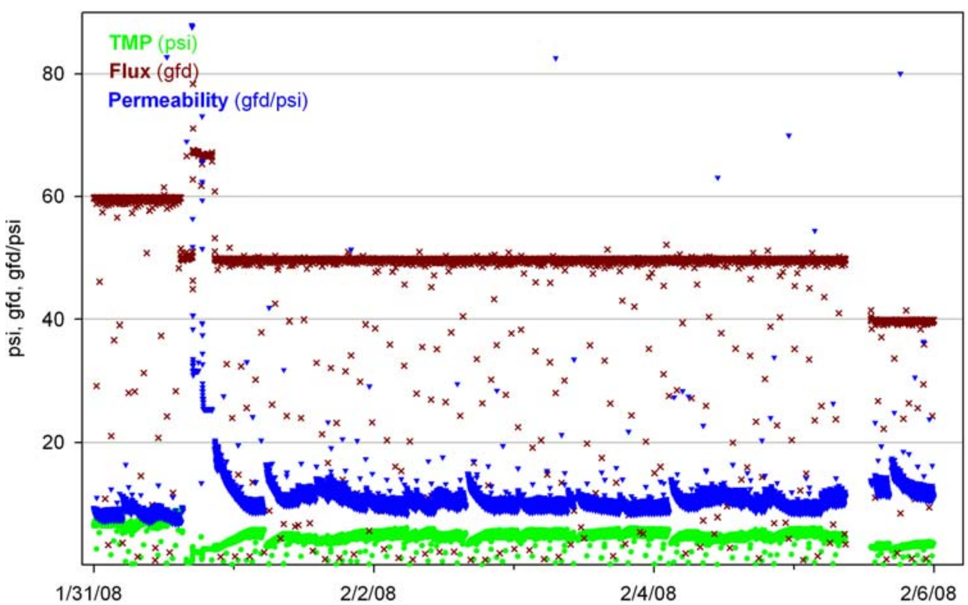

Figure 3-26: Operation at 50 gfd (TCEQ Stage 2), Norit UF membrane performance.

Operation at a Flux of 40 gfd

After it was discovered that sustained operation at a flux of 50 gfd would not meet the minimum required 30 days of runtime, the flux was dropped to 40 gfd (Figure 3-27). The unit was operated at this flux for a period of 6 days. The intent of this step was to determine if a flux of 40 gfd would potentially allow the unit to successfully operate for 30 days without performing a CIP. It was determined that operating the unit at a flux of 40 gfd could possibly allow for sustained operation. A CIP was performed, and the unit was restarted with a flux of 40 gfd and the same backwash and CEB frequencies as previous runs. After operating at a flux of 40 gfd for 18 days, it was determined that the operation of the unit would not be sustainable for 30 days due to a rapid rise in TMP (the TMP rose to 11.53 psi).

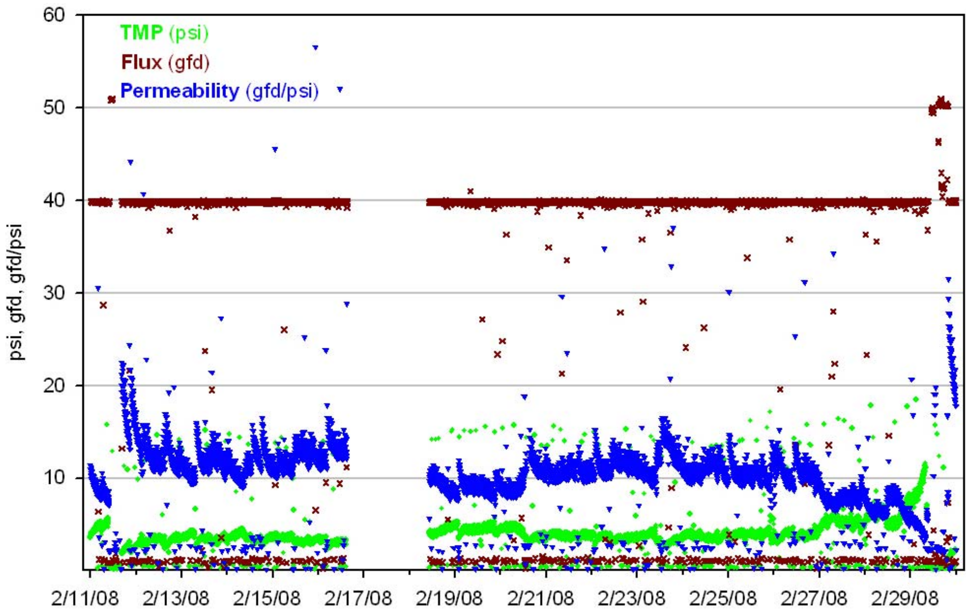

Figure 3-27: Operation at 40 gfd (TCEQ Stage 2), Norit UF membrane performance.

Numerous discussions took place with Norit regarding the extent and type of fouling that was affecting the membrane performance. Based on the performance of the membrane, it was theorized that oil/grease could be a possible fouling agent even though raw water sampling for oil and grease yielded non-detect. A modified CIP, aimed at attacking oil/grease fouling, was performed. After the modified CIP, the unit was restarted with a flux of 40gfd. During the first filtration cycle (from CIP to CEB), the permeability dropped significantly. The following CEB yielded minimal results. At this point, official piloting of the unit was suspended.

Further testing was performed on the Norit system in which modified coagulant dosages were integrated into the operation. During this time, discussions with Norit were taking place regarding the performance of their unit at the pilot facility. On March 7, 2008, pilot testing of the unit officially concluded due to the inability of the Norit pretreatment system to prove sustainable operation.

Prescreening

The Norit UF at the Brownsville Desalination Pilot implemented a Hydrotech/USFilter Discfilter model HSF1702-1F. The Hydrotech Discfilter is a 100 micron woven polyester media filter used as a prescreen to the UF for removing suspended particles larger than 100 micron in diameter. The prescreening surface area was 16.6 ft^2. Backwashes were initiated based on head loss across the membrane surface. Over the course of the study, an average of 24 backwashes were performed each day with 1.5 gallons of water being used per backwash.

The Hydrotech 100 micron Discfilter system provided consistent run time, and the only maintenance performed on the filter were manual cleans when the Pall unit was performing a CIP. Consistent prescreened flow was afforded to the Norit unit, and at no time during the pilot was the Norit unit shut down (either manually or automatically) due to low prescreened flow from the Discfilter. The surface area of the Hydrotech Discfilter was excessive in terms of the feed water flow rate required by the Norit pretreatment system. Therefore, an accurate determination of full-scale operation in terms of backwash frequency and water consumption could not be determined during the pilot test.

Filtrate Water Quality

At the onset of the Pilot Study, the goals of the filtrate water quality were to be analyzed in terms of SDI and turbidity. The filtrate water quality goals were to obtain SDIs less than 3.0 100% of the time and less than 2.0 90% of the time. Filtrate water quality results during the Pilot Study for the Norit UF pretreatment unit are summarized in Table 3-12 and Figure 3-28. The filtrate water quality produced by the Norit unit during the 50 gfd and 40 gfd runs met the pretreatment water quality goals in terms of SDI (less than 3 100% of the time and less than 2 95% of the time) and filtrate turbidity (less than 0.2 NTU).

Table 3-12: Summary of Norit filtrate water quality results.

	SDI		**Turbidity** (NTU)	
Flux (gfd)	Maximum	95th Percentile	Maximum	Average
65	2.47	2.37	0.19	0.08
60	2.53	2.31	0.08	0.07
50	1.87	1.87	0.09	0.07
40	2.10	1.95	0.10	0.07

Raw Water Quality

Raw water quality varied throughout the Norit UF runs during the Pilot Study (Figure 3-29). It can be deduced that each performance run was subject to challenging water quality. However, there is no evidence that one specific run was subject to disproportionately adverse water quality.

Residuals

Operation of the Norit pretreatment at the Pilot produced three waste streams that can be uniquely characterized: 1) the prescreening unit produced a waste stream of macro-scale sediment and debris during each backwash; 2) the backwash produced a waste stream of smaller particles, which bypassed the 100 micron prescreen but entrained against the membrane; and 3) the chemical cleans produced a waste stream of particles, which had to be dislodged chemically, and residual amounts of the chemical used in these daily cleans. A detailed analysis of solids and chemical residuals was not performed during the Pilot Study.

Cleaning and Chemical Use

The Norit UF employed two different CEBs and a four step CIP procedure. The CEB procedures were programmed to occur automatically and were based on 28 minute filtration cycles. After every filtration cycle the Norit performed a backwash that utilized stored filtrate water pumped in the opposite direction of normal flow. The CEB 1 procedure began with a backwash followed by the hydraulic injection of 50 ppm of 10% concentrated NaOCl in filtrate water.

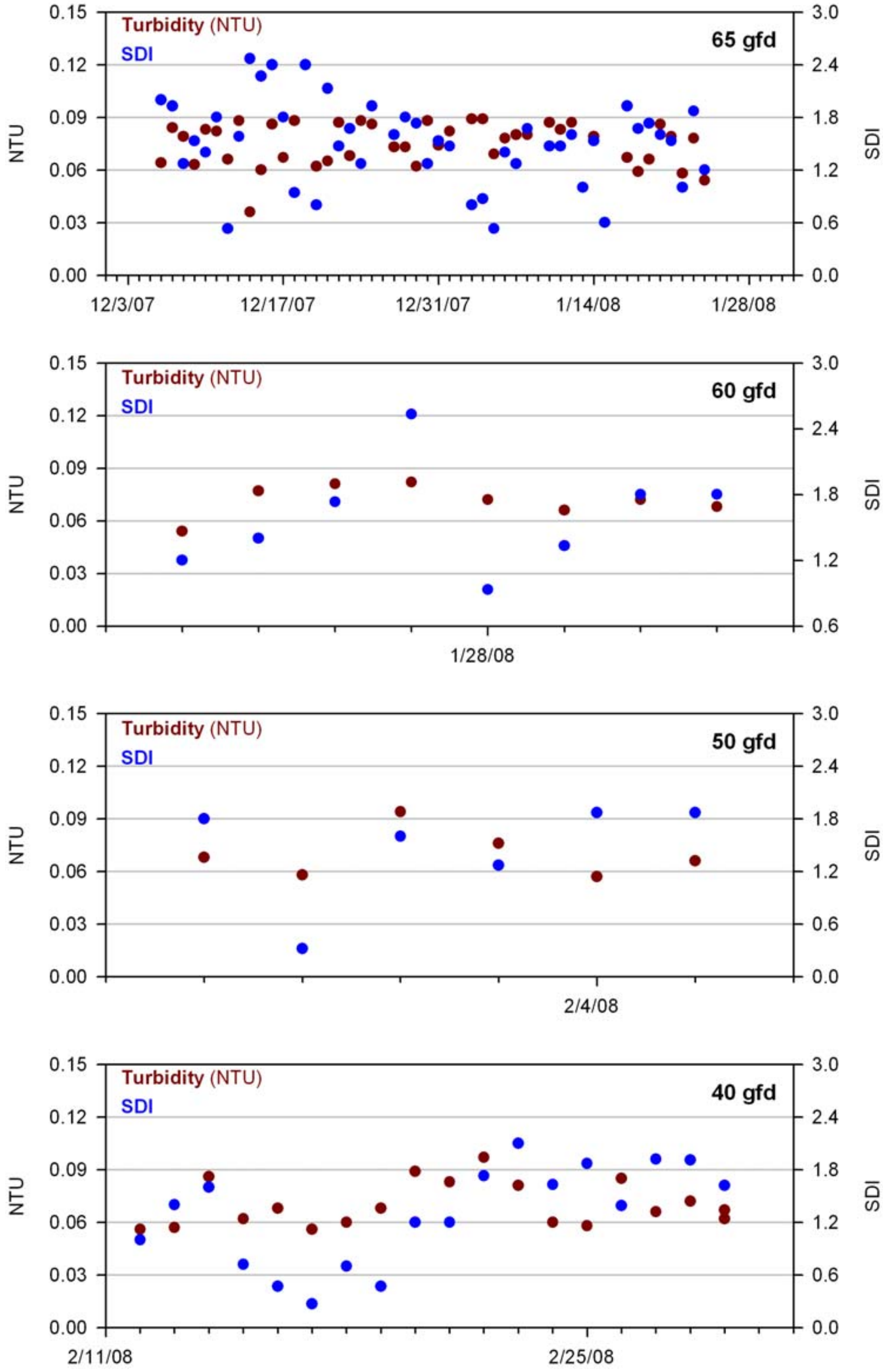

Figure 3-28: Summary of filtrate water quality results for Norit UF.

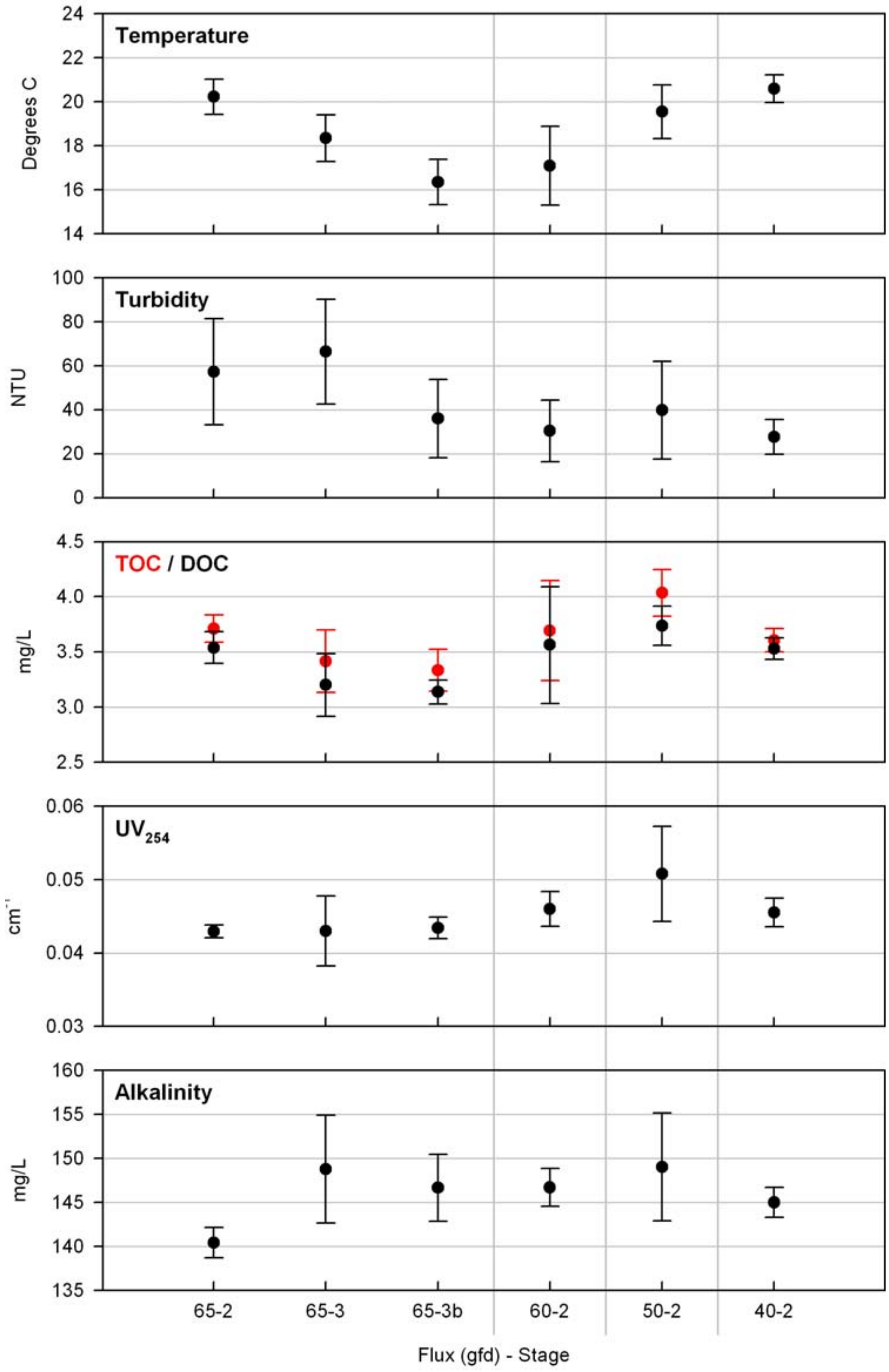

Figure 3-29: Raw water quality for selected parameters during the Norit UF runs.

The solution was then allowed to soak in the vessels for 10 minutes and a backwash followed immediately after. The CEB 1 was automatically performed after every 16 filtration cycles. Similar to the CEB 1, the CEB 2 procedure began with a backwash followed by the injection of 1000 ppm of 50% concentrated citric acid in filtrate water. The solution was then allowed to soak in the vessels for 10 minutes and a backwash followed immediately after. The CEB 2 was automatically performed after and immediately followed every 4th CEB 1.

The Brownsville Norit CIPs were performed between TCEQ stages and implemented a four step process. The process consisted of an extended CEB 1, an extended CEB 2, a NaOCl CIP and a citric acid CIP. The extended CEBs were similar to normal CEBs except the soaks were lengthened from 10 minutes to 30 minutes, and the extended CEB 1 implemented a 200 ppm solution as opposed to 50 ppm. After the two extended CEBs were performed, the NaOCl CIP was enabled and consisted of the injection of 200 ppm, 10% concentrated NaOCl in filtrate water that was circulated throughout the vessels for 30 minutes while potable water backwashes occurred every 10 min. Finally, the citric acid CIP was performed and consisted of the injection of 1000 ppm, 50% concentrated citric acid in filtrate water circulated throughout the vessels for three hours while potable water backwashes occurred every 28 min. The Brownsville Norit CIP duration was approximately six hours.

Air Integrity Test
An air integrity test was performed following the conclusion of each CIP. The feed side of the membranes were drained and pressurized to 15 psi with air. The water flow leaving the filtrate side of the membranes was measured to determine the amount of water displaced. Displaced water can be correlated to a failed membrane.

3.3.4 Pall MF

The system utilized Microza UNA-620A hollow-fiber MF membrane elements with approximately 538 ft^2 of membrane area each. The Pall Microza system uses outside-in technology that operates with a pressurized feed stream. The maximum TMP of the system is 43.5 psi. Through testing, optimum process settings were established in which water production was maximized while minimizing chemical use, waste generation, and energy requirements. The removal efficiency of potential membrane fouling agents was monitored, and system reliability in terms of treatment consistency and robustness was evaluated in terms of raw water quality variations. In terms of pretreatment runtime, it was the goal to maximize runtime through the minimization of downtime associated with mechanical and membrane failures. A minimum runtime of 30 days was required.

System Testing
Following is a summary of the Pall system's operation during the Pilot Study. It was noted that the lowest water temperature during the course of the pilot was 14.5 °C. Table 3-13 gives average temperature corrected flux rates (at 14.5 deg C) for each individual performance run at various fluxes.

Table 3-13: Summary of Pall MF operational runs.

Flux During Run	Start Date	End Date	Flux (14.5 °C)	Cycle Time (minutes)	Percent Recovery
Optimization	5/15/2007	6/22/2007	-	-	-
45 gfd	6/22/2007	7/7/2007	31.74	15	93.5
40 gfd	7/7/2007	9/24/2007	27.64, 26.99	15	92.7
Optimization	9/25/2007	11/15/2007	-	-	-
36 gfd	11/16/2007	12/5/2007	29.63	15	92.0
30 gfd	12/14/2007	2/24/2008	26.94, 27.11	15	90.4
25 gfd	2/24/2008	7/18/2008	20.32, 17.74	15	88.6

Optimization Run No. 1

The Pall MF unit began testing on May 15, 2007. During the initial stage of testing, the goal was to optimize the treatment process in terms of flux, cleaning frequency, cycle time, and overall system recovery. The system was operated with filtrate fluxes ranging from 42 to 50 gfd (Figure 3-30). In terms of TCEQ compliance with pilot testing, this run was considered TCEQ Stage 1.

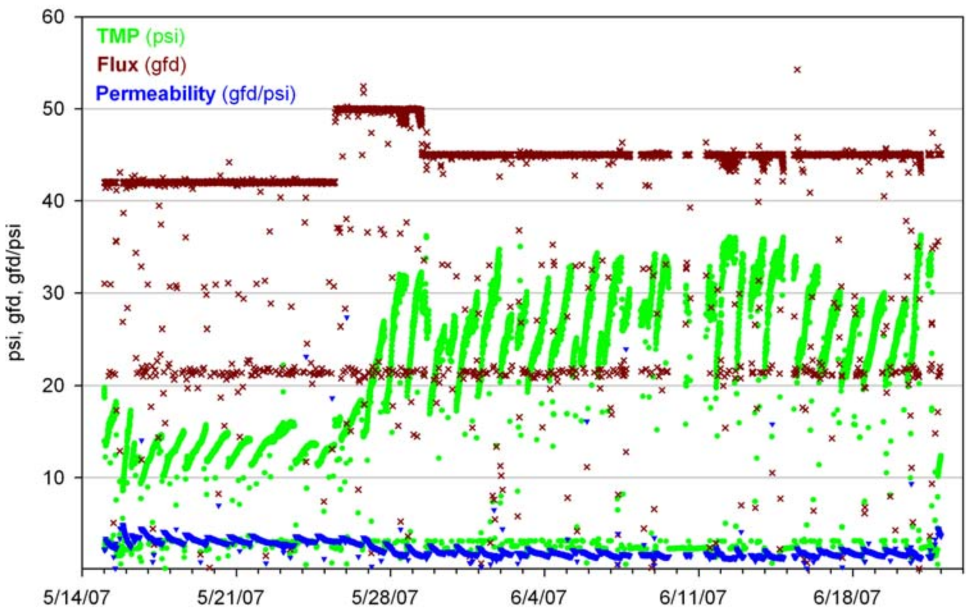

Figure 3-30: Optimization Run No. 1 (TCEQ Stage 1), Pall MF membrane performance.

After completing the initial stage of pilot testing, a series of performance tests were performed. In terms of TCEQ compliance, each performance test following the initial stage of testing was labeled either TCEQ Stage 2 or TCEQ Stage 3. TCEQ Stage 2 requirements were such that the membrane system was to utilize set operating conditions. TCEQ Stage 3 objective was to determine the amount of irreversible fouling or membrane damage that occurred during the TCEQ Stage 2 test. Stages 2 and 3 were to use the same operating conditions.

Operation at a Flux of 40 gfd

The Pall unit began performance testing with a filtrate flux of 45 gfd, a filtration cycle of 15 minutes, air scrub duration of 60 seconds, flush duration of 30 seconds, and a daily EFM.

The system experienced a mechanical problem with the air scrub supply solenoid valve in the early stages of the run that required the system flux to be lowered from 45 gfd to 40 gfd (Figure 3-31). Towards the latter part of the run, it was discovered that the NaOCl pump was malfunctioning and air flow to the membranes was low. Repairs to the system were made, and upon restart the TMP was less than 20 psi and filtrate flow had stabilized. During the 40 gfd run, the average temperature corrected flux (at 14.5 °C) was 27.64 gfd.

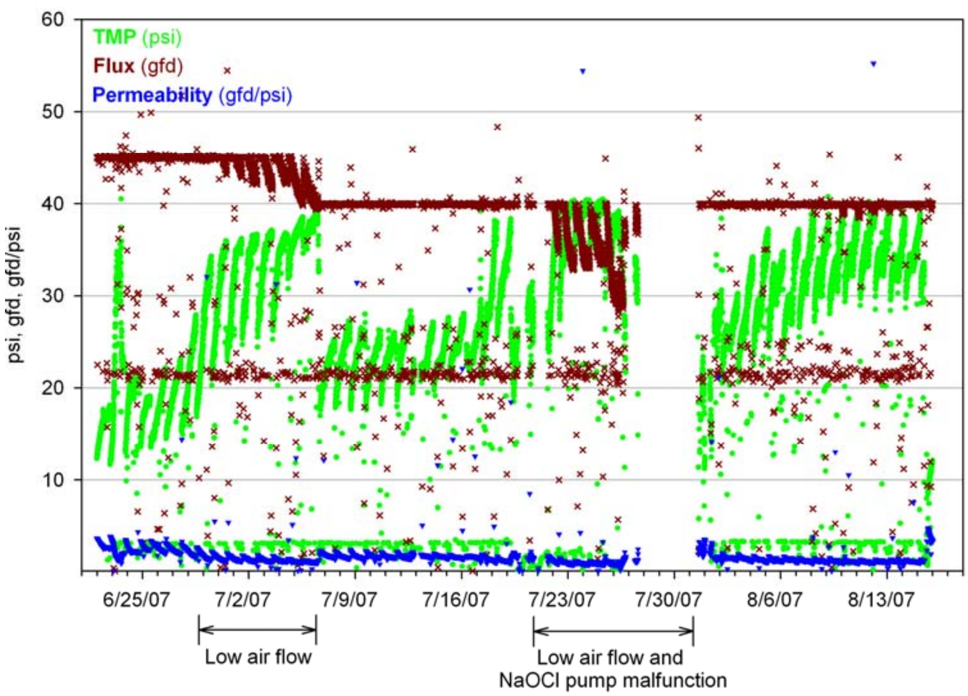

Figure 3-31: Operation at 40 gfd run (TCEQ Stage 2), Pall MF membrane performance.

At the conclusion of the 40 gfd run (TCEQ Stage 2), the TMP of the system was below the maximum recommended TMP of 43.5 psi and the unit was putting out consistent filtrate flow.

Following the completion of the 40 gfd run (TCEQ Stage 2), a CIP was performed. When analyzing the unit's permeability (at 20 deg C) it can be calculated that, throughout the TCEQ Stage 2.1 run, the unit recovered approximately 99% of its original specific flux (3.61 gfd/psi post CIP compared to 3.66 gfd/psi at the beginning of Stage 2.1). It can therefore be deduced that no irreversible fouling or membrane damage occurred (Figure 3-32).

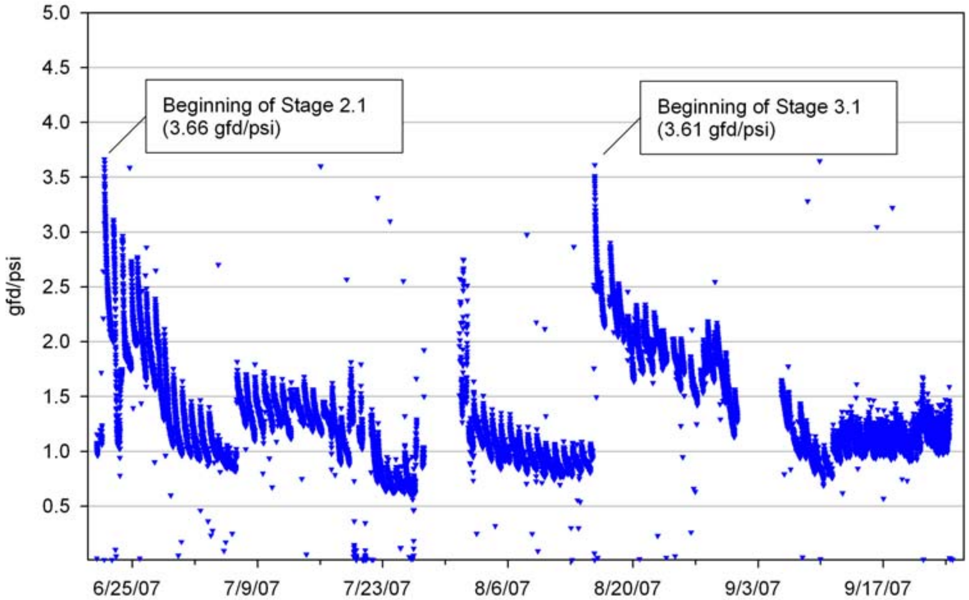

Figure 3-32: Permeability at 20°C, 40 gfd (TCEQ Stages 2 and 3), Pall MF membrane performance.

According to the requirements of TCEQ, the 40 gfd confirmation run (TCEQ Stage 3) utilized the same operating parameters as the original 40 gfd run (TCEQ Stage 2) (Figure 3-33). Toward the end of the confirmation run, multiple EFMs per day were required to maintain the set flux of 40 gfd due fouling and subsequent high TMPs. Based on the predetermined goal of minimizing chemical consumption, the two EFMs per day were found excessive and the run was terminated. The average temperature corrected flux (14.5 °C) during the run was 26.99 gfd.

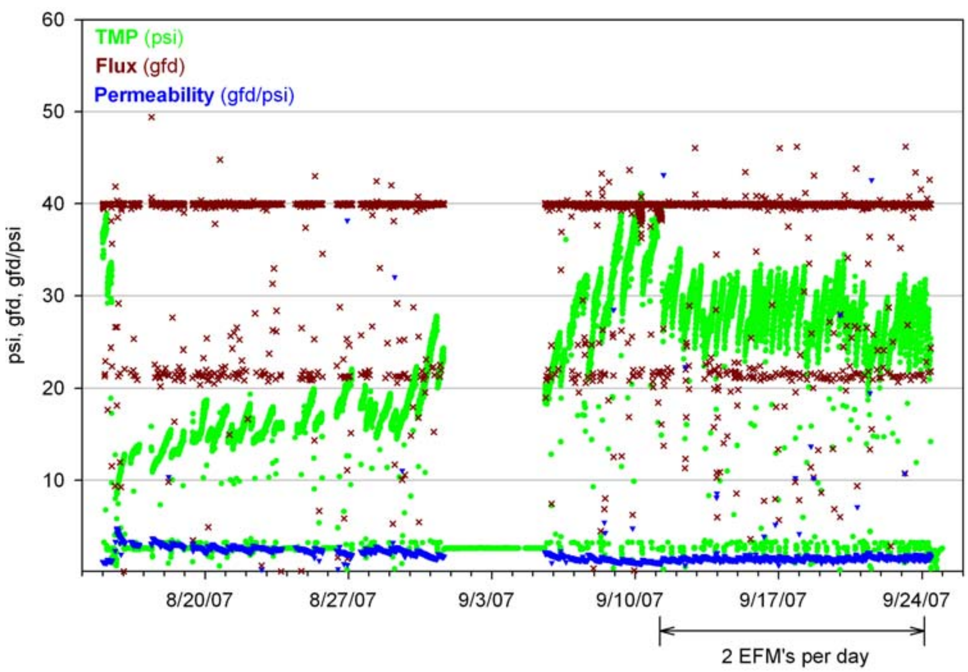

Figure 3-33: Operation at 40 gfd (TCEQ Stage 3), Pall MF membrane performance.

Optimization Run No. 2
After the completion of the 40 gfd run, another optimization run took place (Figure 3-34). During the run, the unit exhibited a significant loss of permeate flow due to membrane fouling. Multiple EFMs were required per day. The objective of this run was to determine the effect of multiple EFMs on the performance of the system while operating at a flux of 44 gfd.

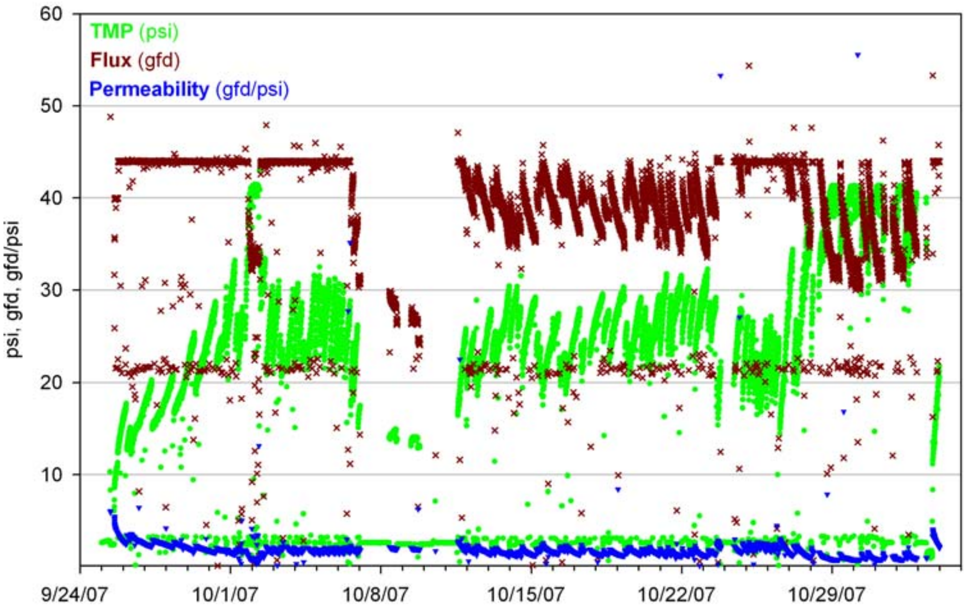

Figure 3-34: Optimization Run No. 2a (TCEQ Stage 1), Pall MF membrane performance.

A CIP was performed on the system, and a brief run using the same flux rate of 44 gfd ensued. The run was terminated shortly thereafter. It was determined that the performance of the unit at 44 gfd with multiple EFMs per day was not effective in terms of sustainability as well as chemical usage (Figure 3-35).

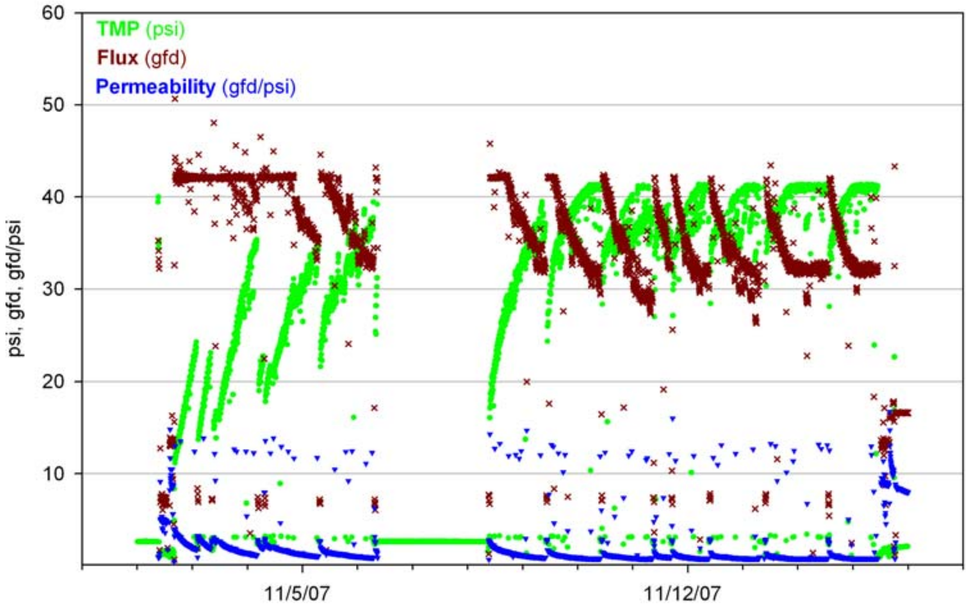

Figure 3-35: Optimization Run No. 2b (TCEQ Stage 1), Pall MF membrane performance.

Operation at a Flux of 36 gfd

Based on the information gained during Optimization Run No. 2, it was decided to proceed with a lower flux (36 gfd) with only a single EFM per day (Figure 3-36). Shortly after beginning the run at 36 gfd, it was evident that the membranes were fouling at an excessive rate and the system would not be able to sustain operation for 30 days. After 19 days of runtime, a CIP was performed. During the run, the average temperature corrected flux (at 14.5 deg C) was 29.63 gfd.

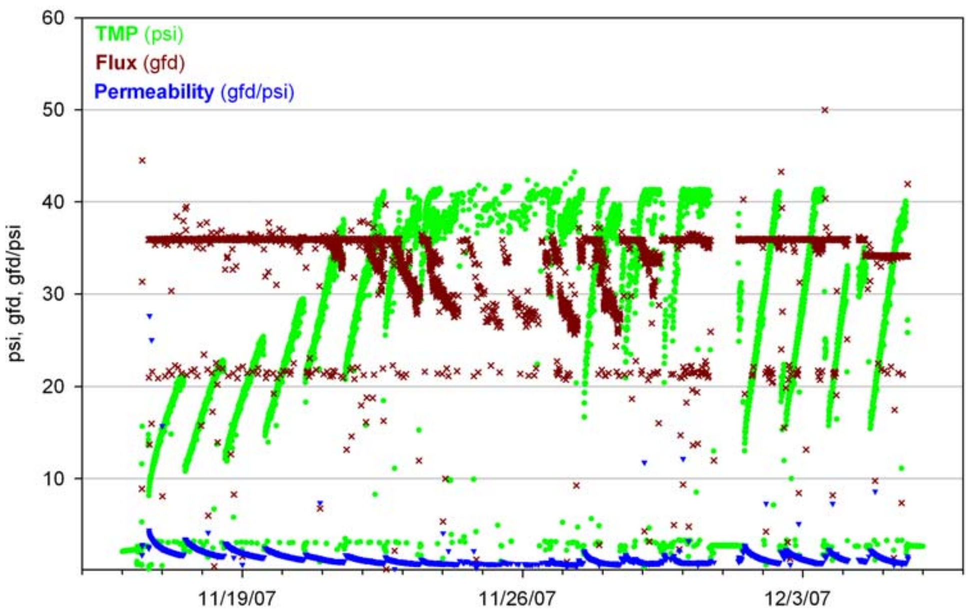

Figure 3-36: Operation at 36 gfd (TCEQ Stage 2), Pall MF membrane performance.

Operation at a Flux of 30 gfd

Due to the performance of the system at a flux of 36 gfd, the decision was made to reduce the flux rate to 30 gfd (Figure 3-37). The system was able to continuously operate without performing multiple EFMs per day over the course of the 34 day run, which exceeded the aforementioned minimum required runtime of 30 days. The average temperature corrected flux (at 14.5 °C) during the run was 26.94 gfd.

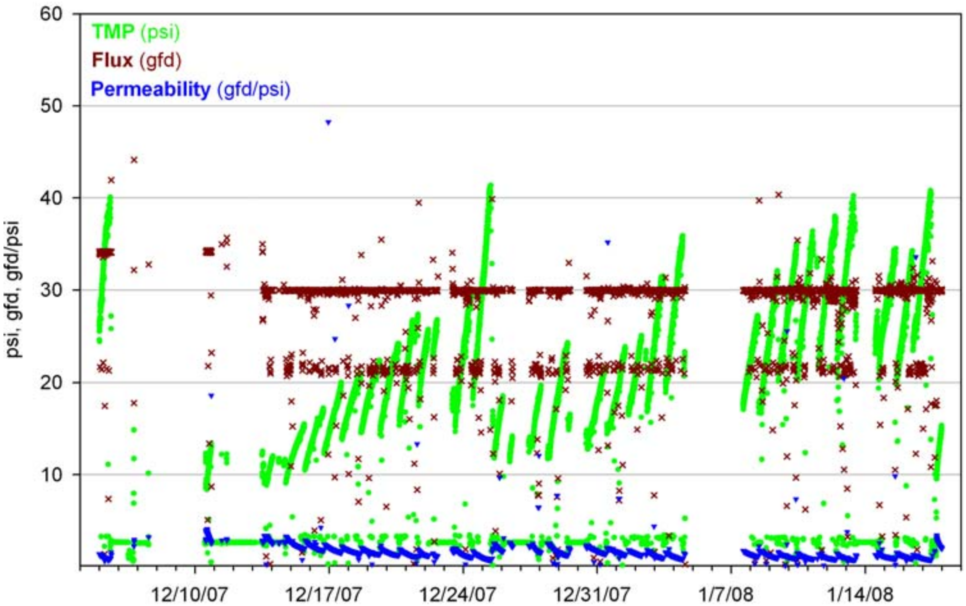

Figure 3-37: Operation at 30 gfd (TCEQ Stage 2), Pall MF membrane performance.

A CIP was performed on the Pall unit after 34 days of runtime. When analyzing the unit's permeability (at 20 °C) after the CIP, it can be calculated that, throughout the 30 gfd run, the unit recovered approximately 114% of its specific flux (3.48 gfd/psi post CIP compared to 3.06 gfd/psi at the beginning of Stage 2.4) (Figure 3-38). When comparing the permeability (20 °C) of the system after the January 17, 2008 CIP (3.48gfd/psi) to the permeability (20 °C) of the system after the August 15, 2007 CIP (3.66gfd/psi), the unit recovered 95.1% of its original flux.

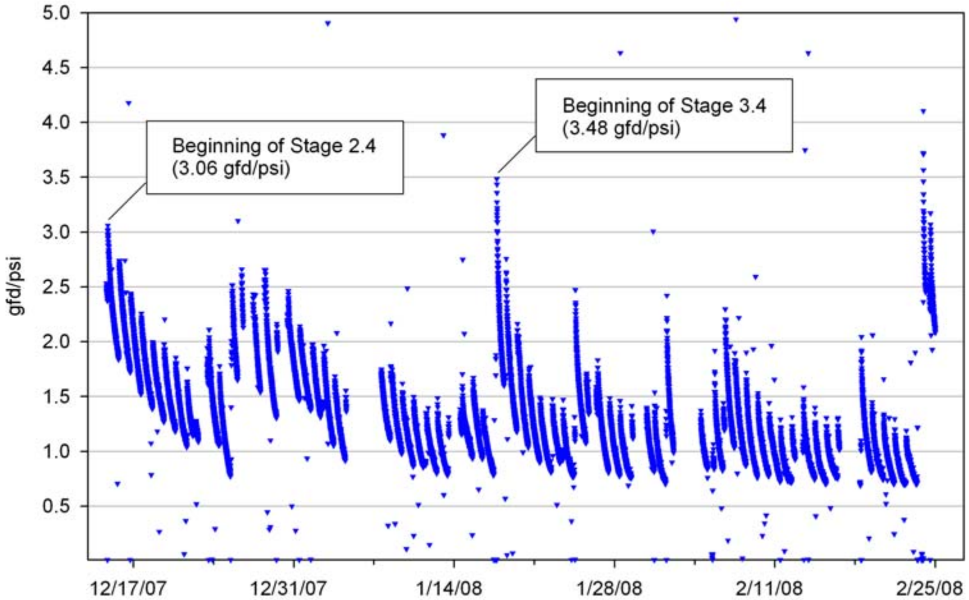

Figure 3-38: Permeability at 20°C, 30 gfd (TCEQ Stages 2 and 3), Pall MF membrane performance.

It was anticipated to operate with a flux of 30 gfd for an additional 30 days to verify the results of the previous 30 gfd run. During the verification run, the unit was unable to maintain an operating flux of 30 gfd because the TMP rose rapidly from the onset of the run (Figure 3-39). At various times throughout the run, the filtrate flow rate dropped signifying fouling on the membrane. During the run, the average temperature corrected flux (at 14.5 °C) was 27.11 gfd.

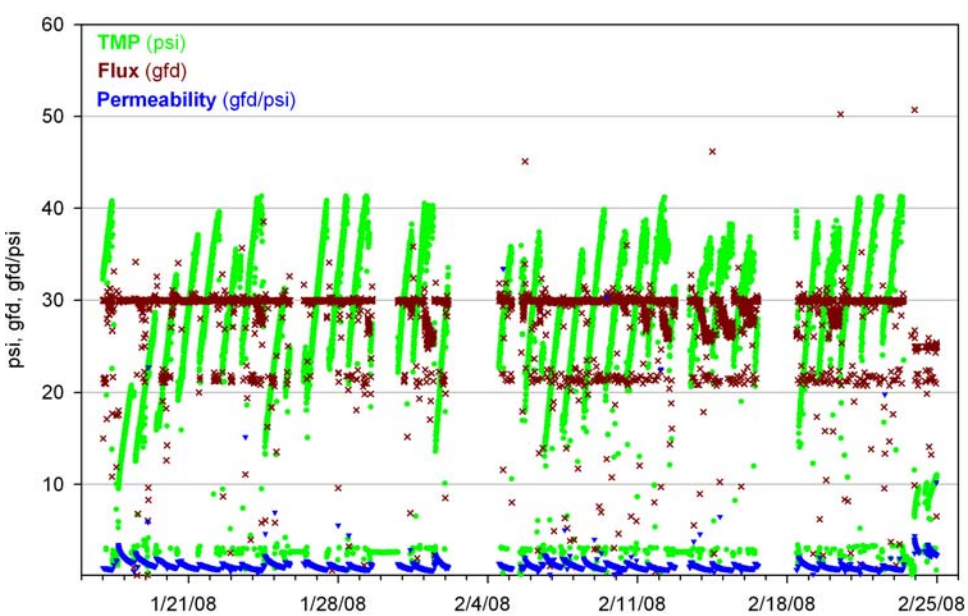

Figure 3-39: Operation at 30 gfd (TCEQ Stage 3), Pall MF membrane performance.

Operation at a Flux of 25 gfd

After performing a CIP, the unit was restarted with a flux of 25 gfd. The Pall system operated at this flux rate, without performing a CIP, until May 5, 2008, a total of 69 calendar days of runtime (Figure 3-40). The average temperature corrected flux (at 14.5 °C) during the run was 20.32 gfd. When reviewing the following data plot, one can pick up two instances of non-uniform performance. On March 6, 2008, an EFM was not performed. The unit was shut-down due to site maintenance, and when it was restarted, an EFM did not occur. The other instance of non-uniform performance occurred from April 10, 2008 to April 16, 2008. During this time, there was low air flow to the membrane unit during the air scour stage due to a malfunctioning motor operated valve. This valve actuator was replaced, and the performance of the unit returned to previous levels.

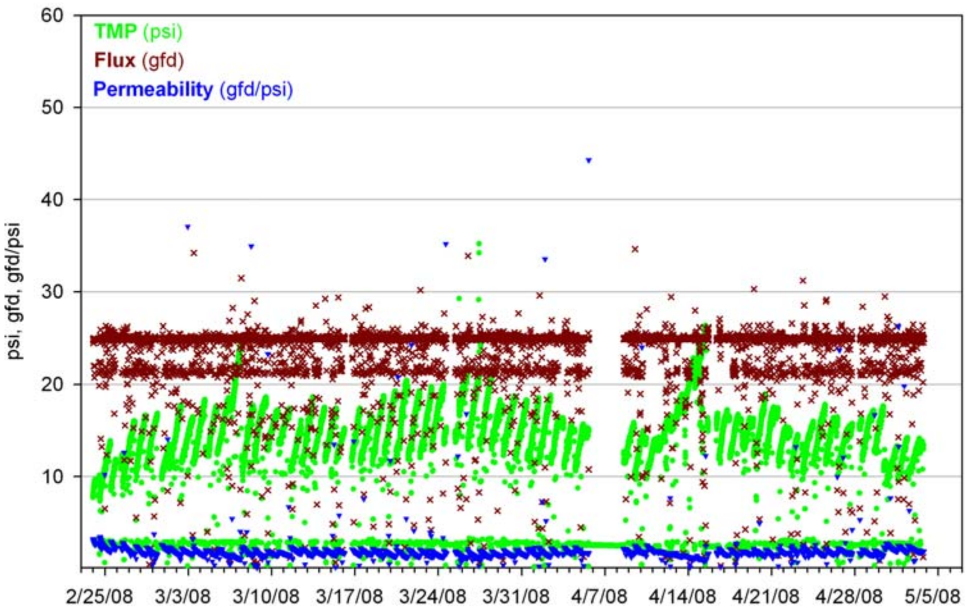

Figure 3-40: Operation at 25 gfd (TCEQ Stage 2), Pall MF membrane performance.

After 66 days of runtime, the decision was made to perform a CIP even though the performance of the unit did not signal a need to clean. The decision to perform a CIP was based on the potential that extended run-time could damaging the membranes or create a layer of irreversible fouling, however small it may be. When analyzing the unit's permeability (at 20 °C) after the CIP, it can be calculated that, throughout the 15 gfd run (TCEQ Stage 2), the unit recovered approximately 92.5% of its specific flux (3.44 gfd/psi post CIP compared to 3.72 gfd/psi at the beginning of Stage 2.5).

When comparing the permeability (20 °C) of the system after the May 5, 2008 CIP (3.44gfd/psi) to the permeability (20 °C) of the system after the August 15, 2007 CIP (3.66gfd/psi), the unit recovered 94.0% of its original flux (Figure 3-41).

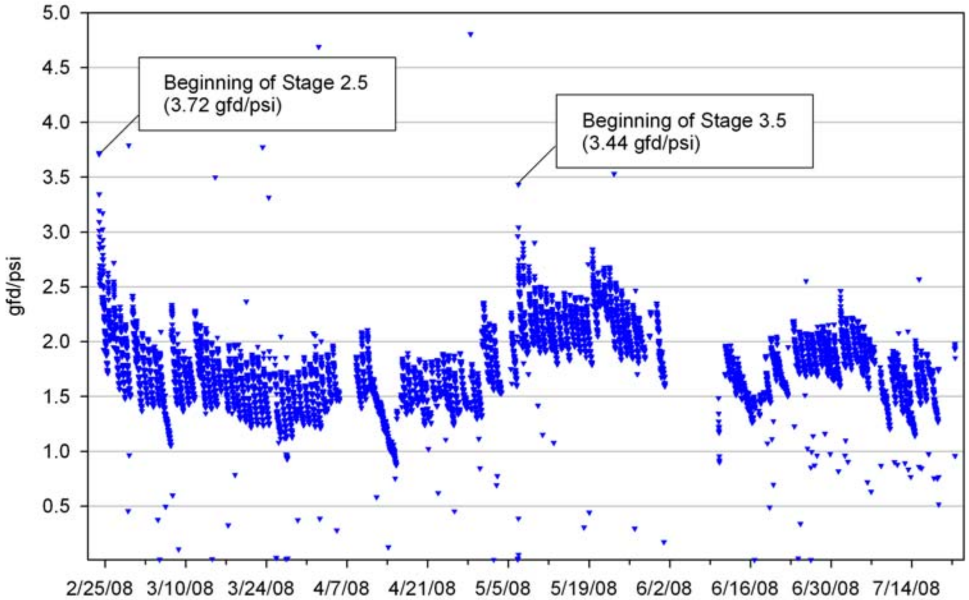

Figure 3-41: Permeability at 20°C, 25 gfd (TCEQ Stages 2 and 3), Pall MF membrane performance.

A confirmation run at 15 gfd (TCEQ Stage 3) ensued. The system operated successfully for 72 days without having to perform a CIP. The average temperature corrected flux (at 14.5 °C) during the confirmation run was 17.74 gfd. When analyzing Figure 3-42, one will notice a gap in data. This gap is due to the on-site Supervisory Control and Data Acquisition (SCADA) system being down. During this time, the unit was in operation.

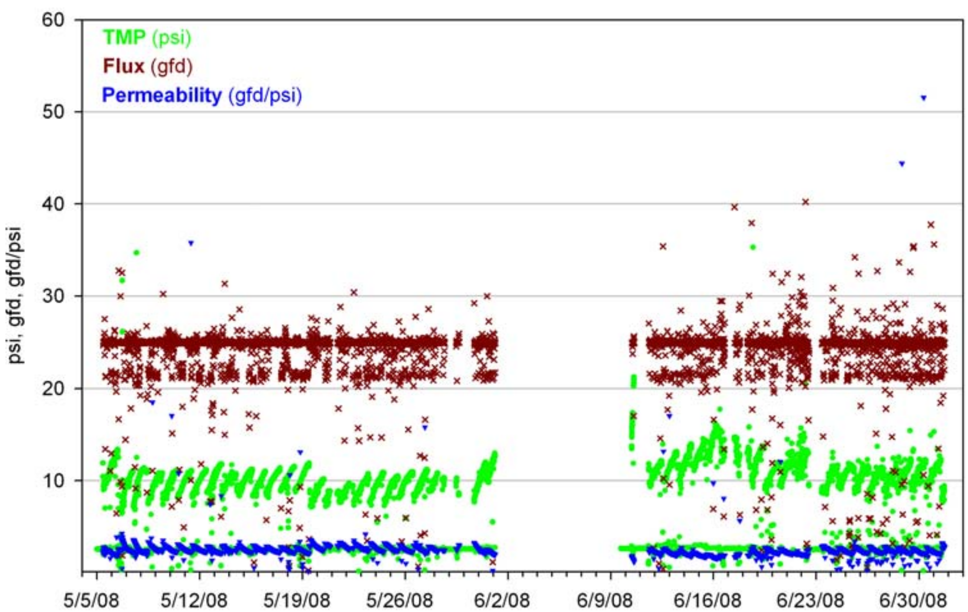

Figure 3-42: Operation at 25 gfd (TCEQ Stage 3), Pall MF membrane performance.

At a flux rate of 25 gfd with a unit recovery of 88.6%, the Pall unit was able to successfully produce quality filtrate while maintaining consistent filtrate flow rates during back-to-back runs. Overall, the system successfully operated for a period of 145 days while only performing a single CIP procedure.

Prescreening
The Pall pilot system utilized single, 200 micron Arkal 2" Spin Klin Automatic Disc Filter Battery. The prescreening surface area was 0.94 ft^2. Backwashes were initiated once DP reached or exceeded 3 psi. Over the course of the study, an average of 16 backwashes were performed with 3.6 gallons of water being used per backwash.

The Arkal 200 micron prescreening system provided consistent run time, and the only maintenance performed on the filter were manual cleans when the Pall unit was performing a CIP. Consistent prescreened flow was afforded to the Pall unit, and at no time during the pilot was the Pall unit shut down (either manually or automatically) due to low prescreened flow.

Filtrate Water Quality
At the onset of the Pilot Study, the goals of the filtrate water quality were to be analyzed in terms of SDI and turbidity. The filtrate water quality goals were to obtain SDIs less than 3.0 100% of the time and less than 2.0 95% of the time. Filtrate water quality results during the Pilot Study for the Pall MF pretreatment unit are summarized in Table 3-14 and Figure 3-43. Based on the performance objectives of the system (runtime, chemical usage, maintaining filtrate flow), the Pall unit successfully operated at a flux of 25gfd. The filtrate water quality during that run also met the pretreatment water quality goals with turbidities less than 0.2 NTU.

Table 3-14: Summary of Pall filtrate water quality results.

	SDI		**Turbidity** (NTU)	
Flux (gfd)	Maximum	95th Percentile	Maximum	Average
40	2.00	1.84	0.12	0.07
36	2.40	2.34	0.13	0.08
30	2.80	2.31	0.12	0.08
25	2.80	1.78	0.10	0.07

Raw Water Quality
Review of the raw water quality data during each individual Pall run reveals some variations throughout the Pilot Study (Figure 3-44). Directly comparing the water quality during the 25 gfd run to that of the other performance runs, it should be noted that many of the key water quality parameters are similar to previous runs, specifically TOC, DOC, and turbidity. However, turbidity during the initial stages of the project was notably higher, as was UV_{254}.

Residuals
Operation of the Pall pretreatment at the Pilot produced three waste streams that can be uniquely characterized: 1) the Arkal prescreening unit produced a waste stream of macro-scale sediment and debris during each backwash of the Arkal unit; 2) the half-hourly SASRF produced a waste stream of smaller particles, which bypassed the Arkal 200 micron screens but entrained against the Pall MF Microza;

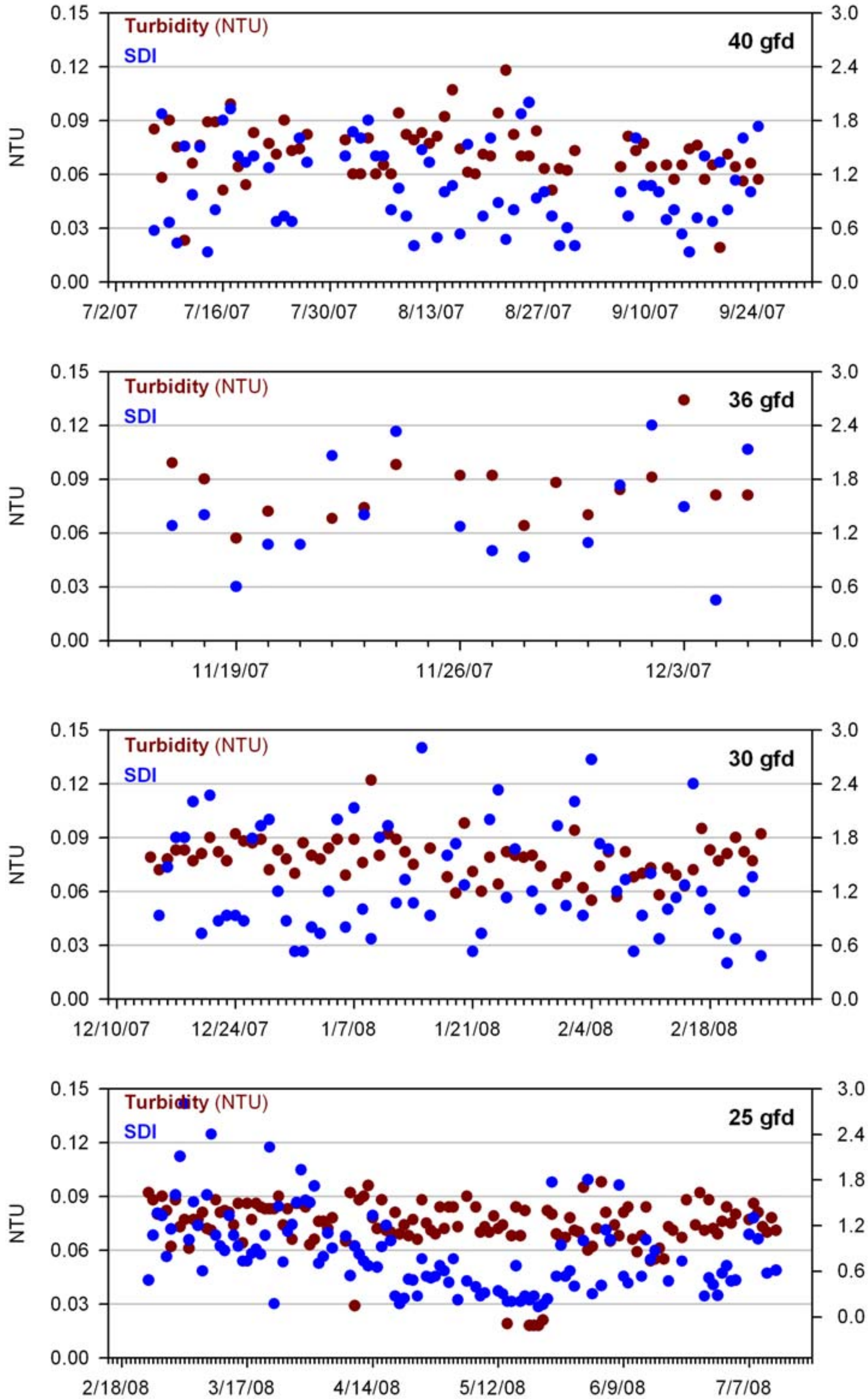

Figure 3-43: Summary of filtrate water quality results for Pall UF.

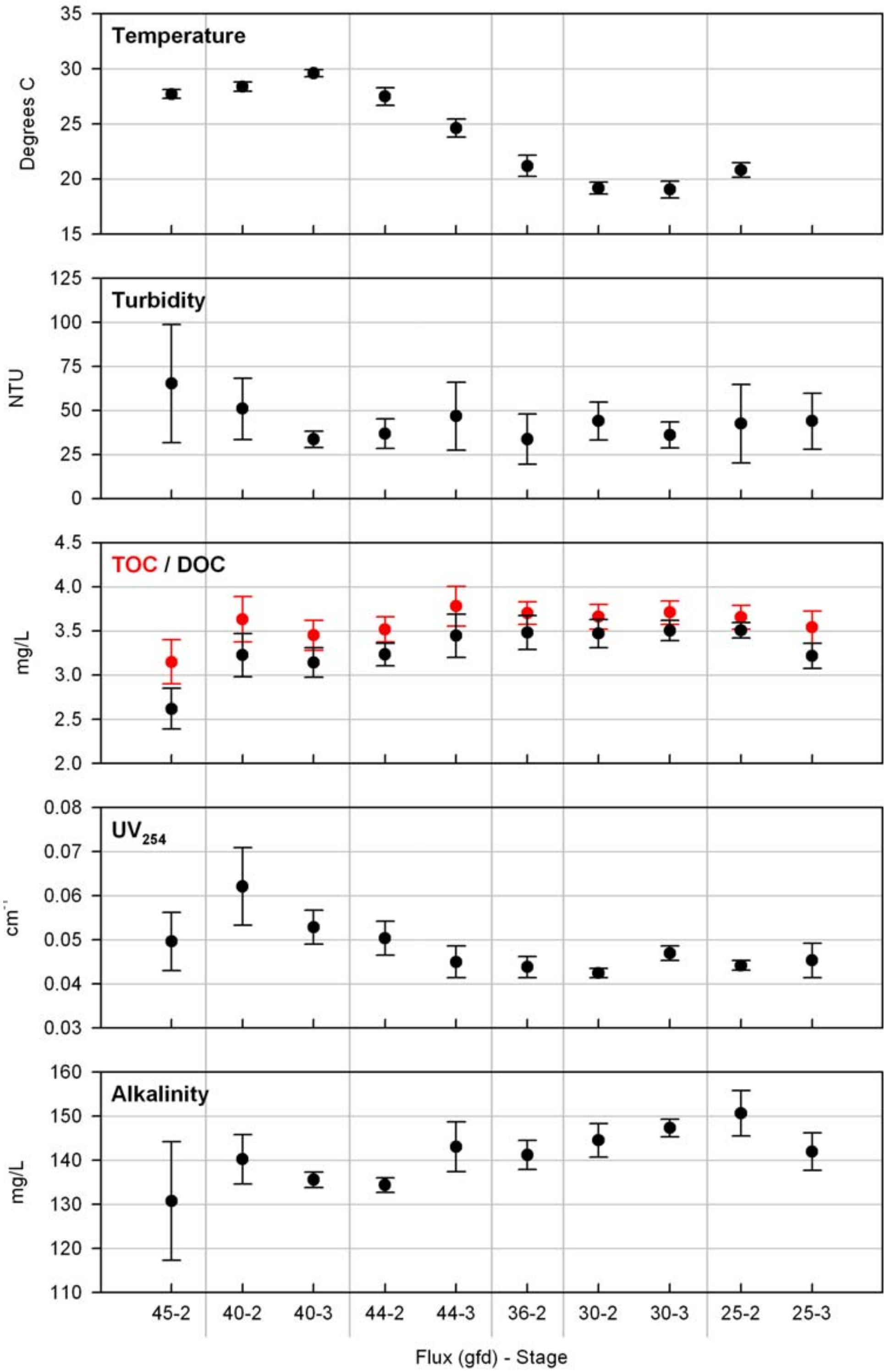

Figure 3-44: Raw water quality for selected parameters during the Pall MF runs.

and 3) the chemical cleans (EFM) produced a waste stream of smaller particles, which had to be dislodged chemically, and residual amounts of the chemical used in these daily cleans.

Using a mass balance, the measured rejection of the system as a whole was 96.7% of all incoming suspended solids. The majority of suspended solids were collected and sent to drain by the Microza fibers' clean and flush cycles. While the waste stream of the Arkal system contained less suspended solid mass, the Arkal system sifted through and sent to drain the larger of the incoming suspended particles and debris.

The EFM wastewater streams contain chlorine residual levels that ranged from 0.2 mg/L to 39.2 mg/L at various times during the EFM drain and flush cycle. These chlorine residuals are the cause of increased pH in this wastewater stream, with a pH level of 8.78.

Cleaning and Chemical Use

The Pall MF employed EFMs and a dual stage CIP. The EFMs were programmed to automatically occur every 24 hours. However, during the 40 gfd run, multiple EFMs were required per day to maintain filtrate flow. Two types of EFMs were utilized during the study. EFM1 utilized 400 ppm NaOCl, and EFM2 utilized 5000 ppm of citric acid. The duration of the EFM processes was 37 minutes. EFM2 was utilized as needed during the 36 gfd and 30 gfd runs. However, the EFM2 was not needed during the 25 gfd run. Related to the full scale facility, the option should exist to utilize the EFM2 procedure should the EFM1 procedure prove to be ineffective.

The Pall CIP procedure was performed between runs and involved a high pH soak followed by a low pH soak. The high pH soak was initiated by manually directing the Pall into CIP mode. 30 gallons of heated potable water then filled the feed tank while 1,000 ppm of NaOCl and 10,000 ppm of caustic soda were manually added. After the caustic/hypo operation was performed, 30 gallons of heated potable water then filled the feed tank while 20,000 ppm of concentrated citric acid was manually added. The solution was then drained and the Pall was restored to filtration mode, which immediately enabled an automatic flush followed by normal filtration. The CIP lasted about seven hours.

Integrity Testing and Log Removal

An air integrity test was performed at the end of each performance run. The procedure consists of draining the filter module and pressurizing the feed side of the membrane while exposing the filtrate side to atmosphere. A pressure decay rate of less than 0.2 psi/min confirms the integrity of the membrane. All air integrity tests performed throughout the study yielded pressure decay rates of less than 0.2 psi/min. Therefore, membrane integrity was maintained throughout the Pilot Study.

Table 3-15 represents data over the entire Pilot Study. As can be seen, the turbidity log removal of the Pall system averaged 3.21, particle log removal from 2-5 μm averaged 4.24, and particle log removal from 5-15 μm averaged 4.70. The cryptosporidium log removal corresponds to the particles in the 2-5 μm range, and giardia log removal corresponds to the particles in the 5-15 μm range. The resultant log removal values exceed the treatment goal log removal for cryptosporidium and giardia of >2 log for cryptosporidium and >3 log for giardia.

Table 3-15: Log removal of the Pall MF unit.

Description	No. of Data Points	Minimum	Maximum	Average	95th Percentile
Feed Turbidity (NTU)	142175	0.0	99.99[a]	35.27	61.44
Filtrate Turbidity (mNTU)	142175	0.0	69.69	22.04	54.06
Turbidity Log Removal	142175	NA	NA	3.21	3.06
Feed Counts >2μm	142175	0.0	26279	17541	21056
Feed Counts 2-5 μm	142175	0.0	19678	11234	14022
Feed Counts 5-15 μm	142175	0.0	14647	6543	8102
Feed Counts > 15 μm	142175	0.0	4995	445	2118
Filtrate Counts > 2 μm	142175	0.0	20	0.76	2.80
Filtrate Counts 2 – 5 μm	142175	0.0	20	0.65	2.19
Filtrate Counts 5 – 15 μm	142175	0.0	20	0.13	0.60
Filtrate Counts > 15 μm	142175	0.0	20	0.20	0.39
Particle Log Removal 2-5 μm	142175	NA	NA	4.24	3.81
Particle Log Removal 5-15 μm	142175	NA	NA	4.70	4.13

[a] Maximum instrument reading.

3.4 REVERSE OSMOSIS EVALUATION

The objective of the pilot test, in terms of RO operation, was to determine the optimum operating parameters that could be carried over to the full scale facility. It was the goal to maximize operation of the RO units and evaluate salt passage, normalized permeate flow, flux, recovery, cartridge filter changeout frequency, and interval between cleanings. Three types of RO membranes were tested at the pilot facility: Toray TM820C-400, FilmTec SW30HR LE-400i, and Toray TM820-400. All of the elements used at the pilot were 8" diameter, 40" long, had a surface area of 400 square feet, and were tested in two pressure vessels (Trains A and B) (Figure 3-45).

Figure 3-45: Photograph of seawater RO pressure vessels used during the Pilot Study.

Figure 3-46 shows the overall time line and operational summary for the SWRO skids. Each SWRO skid was operated in accordance with TCEQ pilot protocols (when qualifying for TCEQ testing purposes) and the protocols established within the NRS Pilot Operations Manual.

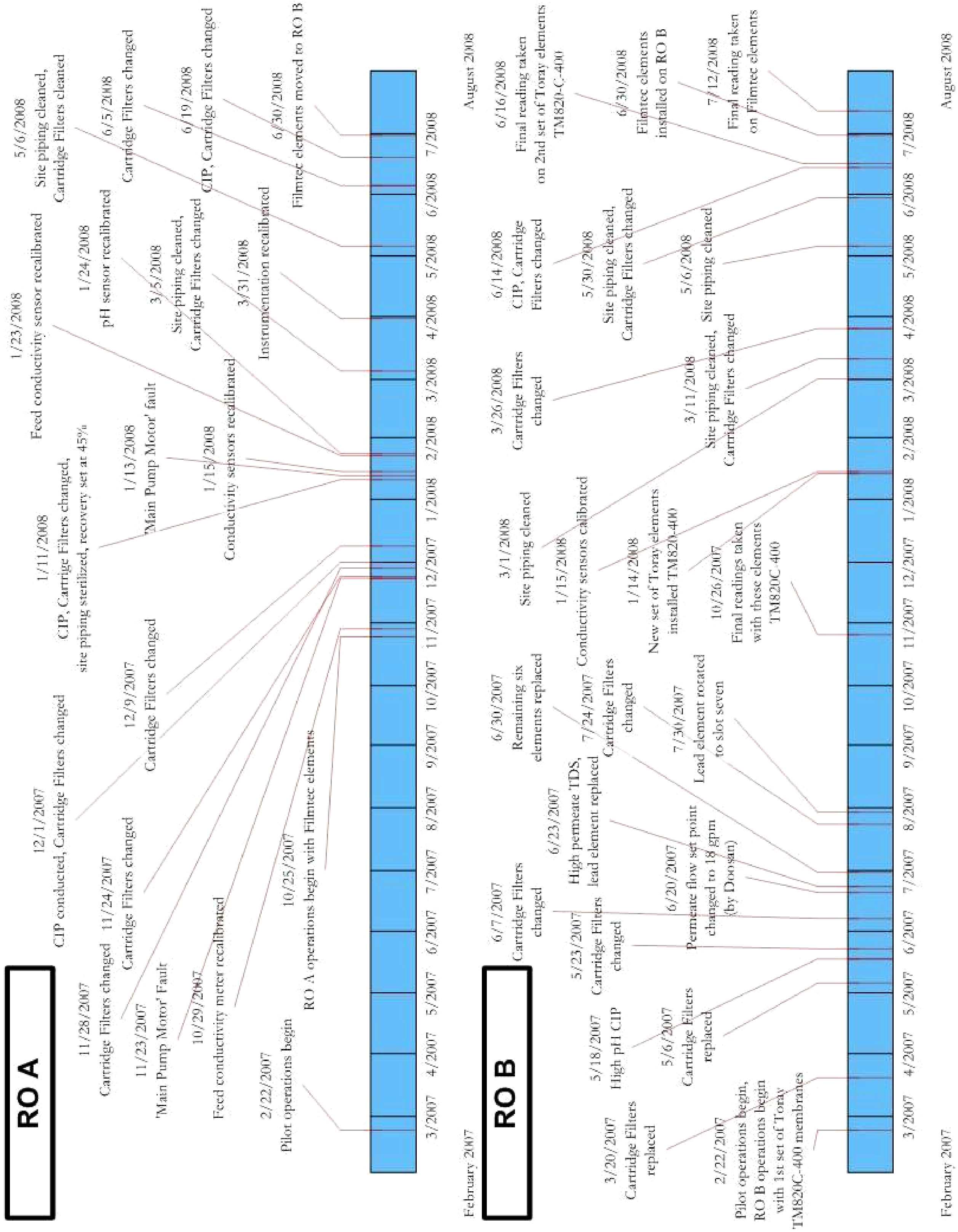

Figure 3-46: Summary of RO piloting operations.

A summary of significant events that occurred during the operation of the SWRO systems are:

- The original Toray elements (TM820C-400) were removed from operation when excessive permeate conductivity was exhibited as a result of membrane surface oxidation
- SWRO recovery on the FilmTec elements was reduced from 50% to 48.8%
- 5 CIP events were performed
- Vessel profiling activities were performed to quantify and troubleshoot specific individual elements' performance
- Cartridge filters were replaced for each system
- TCEQ testing was completed for both Filmtec and Toray SWRO elements
- Mechanical problems forced the FilmTec elements to be relocated to the other SWRO skid to finish pilot testing
- Insufficient quantities of feed water from pretreatment units were available for certain blocks of time, impeding continuous 24/7 operation of the SWRO skids

Over the course of the pilot, the tested equipment had a number of mechanical and instrumentation faults, some of which could be anticipated for this or any other seawater pilot program. However, other more serious issues required resolution such as motor faults and variable frequency drive overheating concerns causing intermittent SWRO skid operation. Most mechanical and electrical faults appeared to be vendor-specific and presented significant challenges to the team's desire to operate the SWRO skids on a continuous basis.

The mechanical and instrumentation challenges posed to the operations staff resulted in a delayed startup and commissioning time frame for SWRO Train A; and an extended commissioning time frame for SWRO Train B – both of several months' time.

The primary performance parameters considered to assess the ability of the SWRO membranes to meet the requirements of the project are discussed in Chapter 2. In that Chapter (and in the digital attachments to this report), the qualifications criterion are contained in the pilot testing protocols and are also determined by the TCEQ testing requirements.

The criterion for consideration in the design and scale-up includes the following:

- Normalized salt passage
- Differential pressure (Feed to-concentrate)
- Normalized permeate flow and Mass Transfer Coefficient
- Permeate dissolved salt content (TDS)
- Cleaning frequency
- Cartridge filter service life
- Other monitored and/or measured parameters integral to the pilot testing plan evaluated on a regular basis throughout the operation of the systems and discussed in Chapter 2

Similar to the pretreatment units' testing cycles, each SWRO performance test began with an initial stage of startup operating parameters which then progressed to TCEQ Stage 2 and, if successful, TCEQ Stage 3. TCEQ Stage 2 requirements were such that the membrane system was to utilize set (unchangeable) operating conditions throughout, demonstrating sustainable operation at the operating condition. If a sustainable operating condition or other qualifying parameter was not met an operating condition was changed and the Stage re-started. The subsequent TCEQ Stage 3 objective was to determine if any irreversible fouling or membrane damage occurred during the TCEQ Stage 2 testing phase. Therefore Stage 3 operating conditions were unchanged from Stage 2, as-required by TCEQ (tabular RO performance data are included in the digital attachments to this report).

3.4.1 Toray TM820C-400 RO Membrane

The Toray TM820C-400 elements were installed in SWRO Train B when the pilot was first commissioned. While in operation, the pretreatment systems were undergoing optimization and mechanical/instrumentation challenges associated with the SWRO train operation. Salt rejection was not consistent with typical SWRO permeate and permeate conductivity approached 1 ms/cm – approximately three times greater than what typically is expected for permeate quality at startup. This turn of events and potential consequences were discussed with the team members at length; and a troubleshooting strategy involving integrity checks (membrane profiling) and hand-held and laboratory instrument water quality verification was performed, to no avail. Because of what was apparently an irreversible degradation of permeate water quality, the skid was shut down and elements removed for autopsy.

The results of the autopsy were that the membrane surface was halogenated from oxidation: free chlorine making contact with the membranes. The free chlorine was present due to bleed-through from the pretreatment units. The team therefore spent a significant amount of time troubleshooting this concern to identify the cause. Based on experience at other facilities; the potential for chlorine bleed-through existed and was originally accounted for in the design and daily operation of the facility. However, not to the extent experienced.

The cause of chlorine breakthrough was diagnosed, located, and fixed (the cause being the failure of a solenoid valve controlling the chlorine injection timing at the Zenon pretreatment system). The solenoid malfunctioned, resulting in intermittent spikes in filtrate chlorine. In addition to fixing the solenoid, the membrane pretreatment flushing procedures were also extensively modified to account for an extended flush time.

As a result of this experience, the ORP set-point alarm sensitivity was also adjusted further downward to less than 300 mV, lower than what would normally be necessary based on the teams experience at other SWRO installations. Additionally, the sodium metabisulfite (chlorine scavenger) system dose was increased by several mg/L in case of future chlorine spikes resulting from potential bleed-through from the post-CEB operation.

Therefore, the SWRO data collected from these Toray elements are not incorporated into this Report.

3.4.2 Filmtec SW30HR LE-400i RO Membrane

The Filmtec SW30HR LE-400i elements have a surface area of 400 square feet, are 40 inches long, and are 8 inches in diameter. They utilize interlocking endcaps in lieu of brine spacers. The application of these elements at the pilot facility did not use interlocking endcaps due to the long lead time associated with obtaining such items. More information on these membranes can be found in Chapter 2.

Performance Summary

Continuous operation of the RO trains was hampered by a lack of pretreated feedwater and mechanical problems associated with the RO trains. Figure 3-47 gives a representative view of pilot operations in terms of actual runtime over the course of the study.

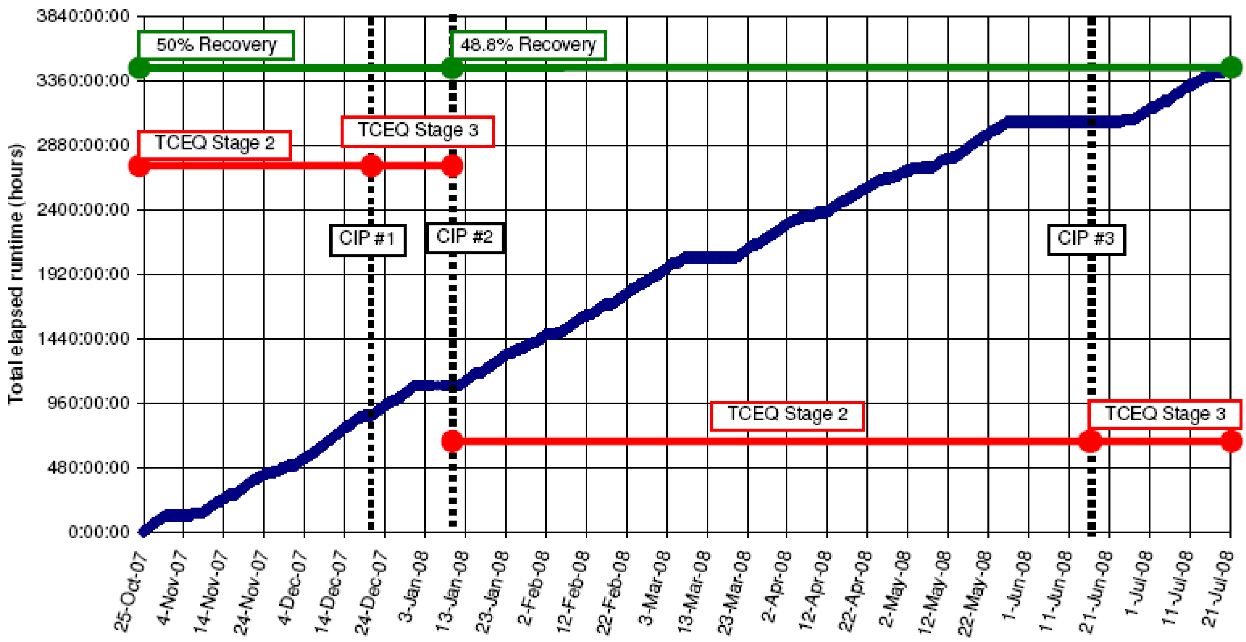

Figure 3-47: Filmtec operational summary.

It should be recalled that the purpose of TCEQ Stage 2 is to evaluate the performance of the SWRO membranes while operating the system under constant set-points (flux, recovery, etc.). TCEQ Stage 3 is performed in order to determine the percent loss of permeability and the potential amount of irreversible fouling or damage on the membrane. The FilmTec elements were subjected to two Stage 2 and two Stage 3 runs.

The Filmtec elements were loaded into SWRO Train A on October 25, 2007. Over the course of the study, performance that was monitored on a daily basis included normalized permeate flow, DP, salt passage, and water mass transport coefficient, shown as Figure 3-48.

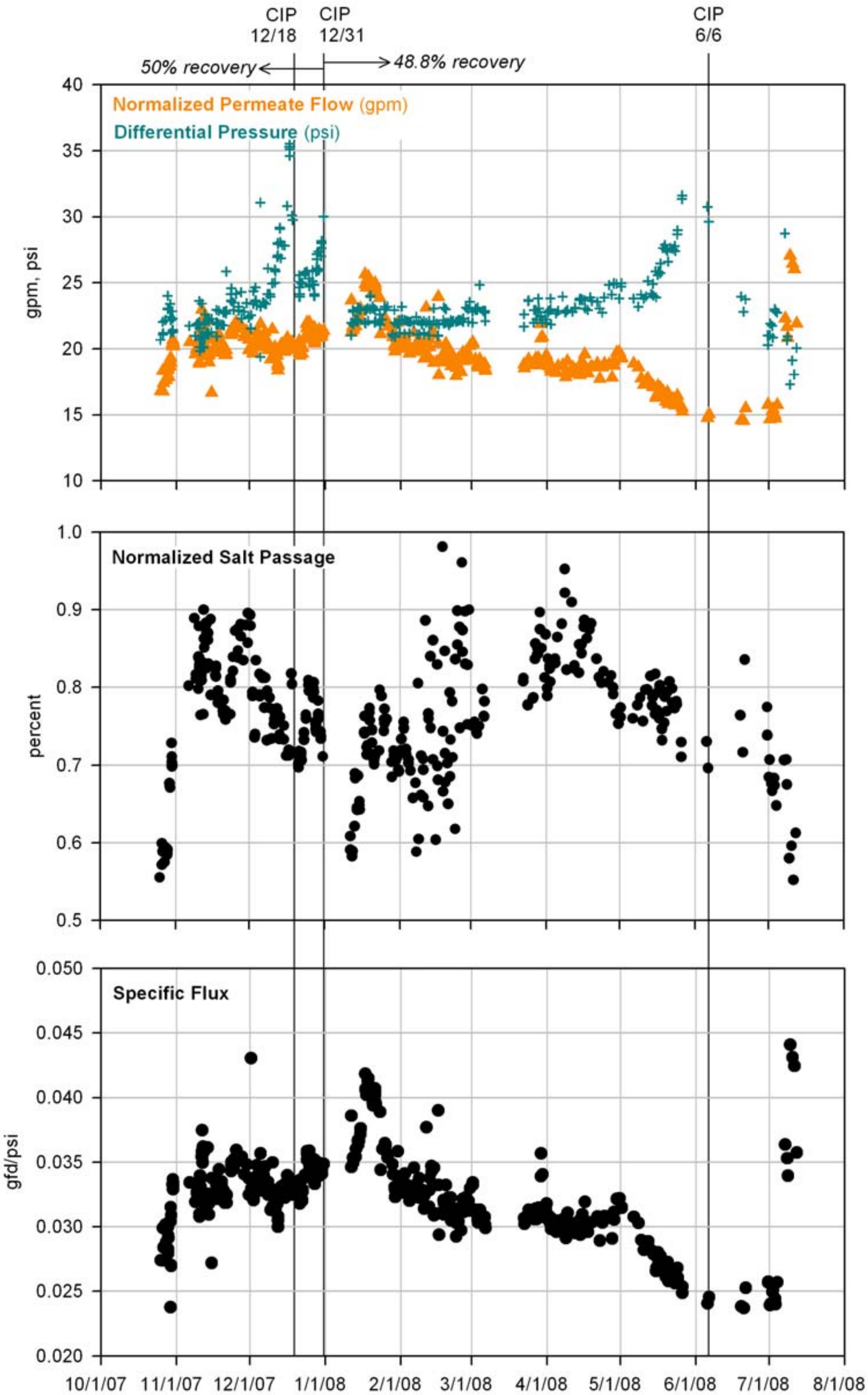

Figure 3-48: Filmtec RO membrane performance.

Operation at 50% Recovery

In accordance with the protocol, the FilmTec SWRO membranes began operation at a permeate recovery of 50% and a flux of 8.22 gfd. During the run, water was being provided to the unit by Norit and Pall. Train operation at these settings demonstrated stable permeability (water mass transfer coefficient), salt passage, and normalized permeate flow. However, the feed to concentrate DP increased from 22 to 30 psig by December 20, 2007 (or after 36 days of operation). The typical trigger point for performing a clean on the SWRO membranes is either a 15% decrease in normalized permeate flow or a 15 to 20% increase in DP. Any existing SWRO plant may clean at a higher or lower rate of change since the trigger point for existing installations is based on the previous historical operation and maintaining membrane manufacturer's warranty conditions; however there was no operating history to direct specific alternatives.

Therefore the determination was made to clean the membrane elements. The team discussed the possible cleaning regimes and after consulting with the membrane manufacturer, decided to perform a high pH cleaning with American Water Chemicals c-237 (a description of which is included in the digital attachments to this report). Consistent with TCEQ protocol adherence, the cleaning event ended the Stage 2 run.

Train A was then re-started and entered Stage 3 of the TCEQ protocols, using the same operating conditions. At that time the DP was 24 psi, marking a 2 psi increase when compared to the newly installed elements. Additionally, DP was observed to increase at an alarming rate. After troubleshooting instruments and sampling procedures, the increase was confirmed – and the decision was made to perform another CIP after operating under TCEQ Stage 3 conditions for an equivalent of 10 days. It is important to note that in particular for SWRO elements, re-starting as closely as possible to the "clean" or as-originally loaded conditions greatly enhances the long-term stable and sustainable performance of the membrane elements. Therefore, cleaning with an improved "recipe" if the first CIP is not effective enough is part and parcel of the operation a SWRO plant.

However, prior to re-starting the skid after the second cleaning, one segment of piping was disassembled for inspection and it was found to be heavy biofouled. All of the RO piping was then disassembled and thoroughly cleaned. In order to effectively clean the piping, the FilmTec elements were removed from the pressure vessel and preserved with a mixture of permeate and 1% sodium bisulfate. Cleaning of the system piping and pressure vessels then ensued with chlorine as the disinfectant.

Operation at 48.8% Recovery

After the RO piping was cleaned, the elements were reloaded on January 10, 2008, and the unit was put back online on January 11, 2008. To effect a change on the potential rate of biofouling, the decision was made to increase the feed-brine flow rate by reducing the recovery to 48-percent and maintaining the same flux of 8.22 gfd (the resulting 48.8% recovery is based on the staff's desire to maintain accurate in-place gauge readings). An RO runtime goal of operating without performing a clean for 90 days was established. During the run, filtered water was being provided to the RO train by Norit and Pall. The reason for using 2 types of pretreated filtrate is due to the fact that, over the course of the Pilot Study, the pretreatment flux was routinely lowered leading to less pretreatment production. Therefore, water from 2 pretreatment units was required to provide enough water to feed both RO trains.

Upon startup, the FilmTec membranes exhibited the following normalized performance: normalized permeate flow = 21.43 gpm, DP = 22 to 24 psi, salt passage = 0.59%, and water mass transport coefficient = 0.39 gfd/psig. The second cleaning event also reduced the DP gap to startup conditions.

After operating for an equivalent period of 69 days (118 calendar days), the normalized permeate flow decreased 15% from the value recorded at the beginning of the 48.8% recovery run. Discussions were held with the project team, including the membrane vendor, and it was decided to extend the performance test due to the previously confirmed ability of the membranes to restore performance - specifically DP and normalized permeate flow after cleaning. After operating for an equivalent period of 79 days (127 calendar days), the DP increased 20% from the value recorded at the beginning of the 48.8% recovery run. At this time, the normalized permeate flow had decreased 18.7% from its initial value. The membrane manufacturer and project team agreed to initiate a cleaning at a DP of 32 psi. After 90 effective days of runtime, the DP across the membranes was 32 psi, and a membrane cleaning was performed.

The results of the cleaning were such that DP recovered somewhat, but the normalized parameters were not completely restored to their original startup conditions. Therefore after the minimum required TCEQ Stage 3 run was completed, three membranes were sent for autopsy and a cleaning analysis. The objective of the cleaning analysis was to ideally determine an optimal cleaning regimen to restore the performance of the membranes to startup conditions (the autopsy results may be viewed in the digital attachments to this report).

Once received at Filmtec, the elements were inspected, performance was compared to as-new conditions, cleaning recommendations were made, and the elements were autopsied. These test results indicated that rejection and flow on 2 of the elements was within the specification for new elements. However, flow for the third element was below the minimum specification for new elements and was returned to within the flow specification with routine cleaning procedures. Oxidation was not observed for any of the elements.

Based on the results of the Filmtec performance runs, it has been proven that, on the conservative side, the membranes operated for 69 days without performing a clean based on a 15% reduction in normalized permeate flow. When looking at the conservative DP trigger point, the membranes successfully operated for 79 days.

If the pretreatment units were able to provide ample flow to the RO train, it is possible that extended runtime, above the 90 days that was tested, would be possible. Frequent shutdowns can cause mechanical problems with the membranes as well as increase the likelihood of biological growth on the membrane surface, both of which can cause premature increases in DP and salt passage as well as decreases in normalized permeate flow and water mass transport coefficient.

Cartridge Filters

The RO pilot utilized six (6) 5 micron, spiral wound cartridge filters each with a length of 20 inches and an outside diameter of 2.5 inches. During the initial stages of pilot testing, the feed water flow rate into the RO elements was 32 gpm, which correlates to a SWRO recovery of 50% and an RO element flux of 8.2 gfd/psi. At this flow rate, the cartridge filter loading rate is 2.5 gpm per 10-inch of cartridge filter equivalent length, within normal loading rates for pre-RO cartridge filters.

When the SWRO recovery was reduced, feed flow through the cartridge filters increased to 2.7 gpm per 10-inch cartridge filter equivalent. These cartridge filter loading rates fall in line with the anticipated full-scale loading rate of 2.5 to 3 gpm per 10 inch equivalent. The protocols established for this project established a cartridge filter changeout pressure differential of 15 psi. However, circumstances discovered during the pilot warranted cartridge filter changeout independent of pressure differential. At no time during the pilot test were the filters changed due to reaching maximum pressure drop. Rather, cartridge filters were changed due to SDI increases, the presence of biological or organic growth, or because CIP procedures were performed on the RO membranes.

Following is a summary and reasoning for cartridge filter changeouts:

- November 28, 2007: cartridge filters replaced due to higher SDI leaving the cartridge filter than entering. Cartridge filters were installed for 33 days.
- December 13, 2007: cartridge filters replaced due to higher SDI leaving the cartridge filter than entering. In addition, DP across the RO membranes began to increase. The changeout was performed in order to determine if changing the cartridge filters would have an impact on membrane DP (reduce fouling). This hypothesis was not proven. Cartridge filters were installed for 15 days.
- December 21, 2007: cartridge filters were replaced after the CIP was performed on the membranes. Cartridge filters were installed for 8 days.
- December 28, 2007: cartridge filters replaced due to the presence of a brown residue on the filter (most likely organic). Special concern was given to the presence of organic and biological growth in the RO piping. Cartridge filters were installed for 7 days.
- January 11, 2008: cartridge filters replaced after the CIP was performed on the membranes. Filters were installed for 14 days.
- March 5, 2008: cartridge filters replaced due to the presence of biological or organic growth on the filters. DP across the filters was 7 psi at the time of changeout. Filters were installed for 54 days.
- June 5, 2008: cartridge filters replaced due to extended downtime of the RO train and subsequent biological or organic growth on the filter. Pressure drop across the filters was 3.5 psi at the time of changeout. Filters were installed for 92 calendar days.
- June 19, 2008: cartridge filters were replaced after the CIP was performed on the membranes. Filters were installed for 14 days.

This time log shows that the cartridge filters were installed for up to 92 calendar days without changeout. It is possible that the cartridge filter run times could have extended beyond that time frame; however 92 days is consistent with the goal of at least 3 months of run time between cartridge filter changeouts. There is a potential correlation between cartridge filter changeout caused by biological and/or organic growth on the filters and the amount of downtime attributed to a lack of pretreated water flow to the train; however this was not studied.

3.4.3 Toray TM820-400 RO Membrane

The Toray TM820-400 elements have a surface area of 400 square feet, are 40 inches long, and are 8 inches in diameter. More information on these membranes can be found in Chapter 2.

Performance Summary

Continuous operation of the RO trains through the entire testing time period was intermittently hampered by a lack of sufficient pretreated feedwater volume and mechanical issues associated with the SWRO equipment trains. However, Figure 3-49 gives a representative view of pilot operations in terms of actual runtime over the course of the study.

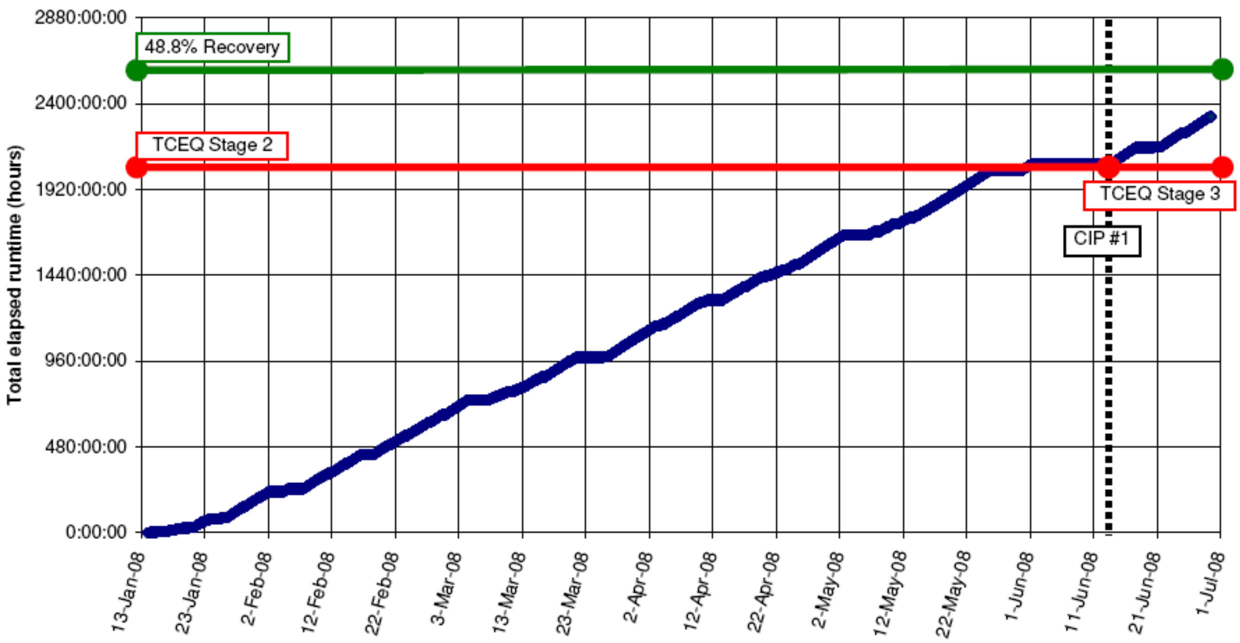

Figure 3-49: Toray operational summary.

The Toray elements were loaded into RO Train B on January 14, 2008. During the run, filtered water was being provided to the RO train by Norit and Pall. The reason for using 2 types of pretreated filtrate is due to the fact that, over the course of the Pilot Study, the pretreatment flux was routinely lowered leading to less pretreatment production. Therefore, water from 2 pretreatment units was required to provide enough water to feed both RO trains. Over the course of the study, normalized performance was monitored on a daily basis in terms of normalized permeate flow, DP, salt passage, and water mass transport coefficient (Figure 3-50).

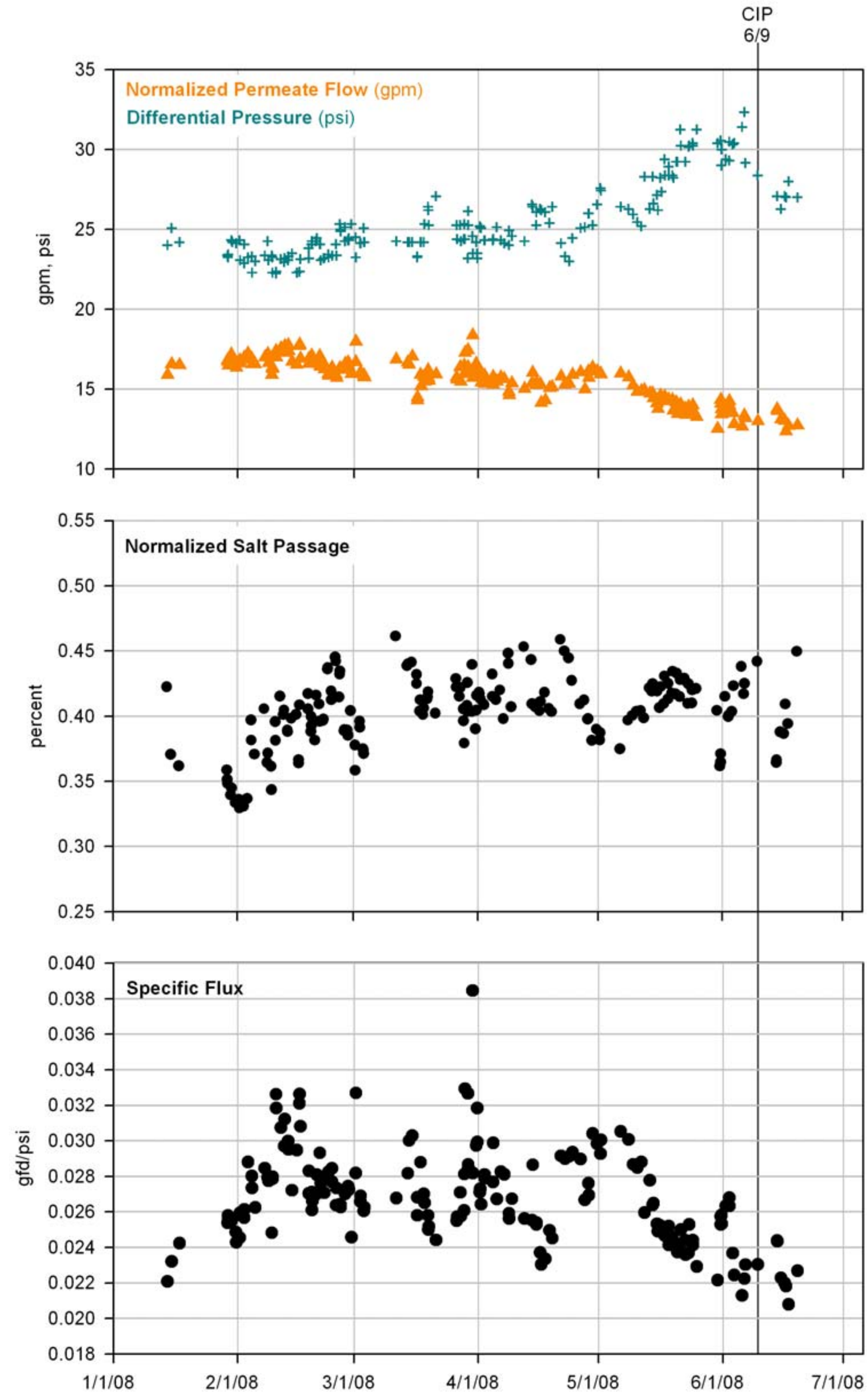

Figure 3-50: Toray RO membrane performance.

Operation at 48.8% Recovery
Toray RO elements were loaded into RO Train B on January 13, 2008. The unit began operation with a recovery of 48.8% and a flux of 8.22 gfd. An RO runtime goal of operating without performing a clean for 90 days was established.

Upon startup, the Toray membranes exhibited the following performance: normalized permeate flow = 15.9 gpm, DP = 24 psi, salt passage = 0.39%, and water mass transport coefficient = 0.0221 gfd/psi. After operating for an equivalent period of just over 90 days (148 calendar days), the normalized permeate flow decreased 15% from the value recorded at the beginning of the 48.8% recovery run.

The graphs show that the normalized salt passage was stable; however the normalized flow decreased and the normalized DP increased. After operating for an equivalent period of 79 days (123 calendar days), the DP increased 20% from the value recorded at the beginning of the 48.8% recovery run. The typical trigger point for performing a clean on the SWRO membranes is either a 15% decrease in normalized permeate flow or a 15 to 20% increase in DP. Any existing SWRO plant may clean at a higher or lower rate of change since the trigger point for existing installations is based on the previous historical operation and maintaining membrane manufacturer's warranty conditions; however there was no operating history to direct specific alternatives.

However, after discussion with the team and the membrane manufacturer, it was decided to continue the run until 31 psi differential was reached.

A high pH CIP was performed on June 14, 2008. After re-starting the skid, the determination was made that fully restored membrane conditions were not reached. Although the DP was restored to previous levels, normalized permeate flow, water mass transport coefficient, and normalized salt passage were not apparently restored. The normalized permeate flow was 12% below the startup value and the normalized DP about 8% above the startup value.

Therefore after the minimum required TCEQ Stage 3 run was completed, all seven membranes were sent for autopsy and a cleaning analysis. The objective of the cleaning analysis was to ideally determine an optimal cleaning regimen to restore the performance of the membranes to startup conditions (the autopsy results may be viewed in the digital attachments to this report).

The factory re-test results indicate the average salt rejection decreased slightly during the 6 month test. The re-test results also show a slight decrease in productivity. However, the lead element flow declined 21% compared to as-new condition. The lead element underwent a thorough cleaning analysis involving low and high-pH (which restored productivity to within 15% of new) with the addition of an extended soak time. The second cleaning event incorporating a 12 hour soak time was deemed successful, restoring the productivity of the lead element within 2% of the original wet test productivity.

Based on the results of the Toray performance runs, it has been proven that, on the conservative side, the membranes performed for 79 days without performing a clean based on a 20% reduction in DP. When looking at the conservative normalized permeate flow trigger point, the membranes proved they can operate for the full 90 days.

If the pretreatment units were able to provide ample flow to the RO train, it is possible that extended runtime, above the 90 days that was tested, would be possible. Frequent shutdowns can cause mechanical problems with the membranes as well as increase the likelihood of biological growth on the membrane surface, both of which can cause premature increases in DP and salt passage as well as decreases in normalized permeate flow and water mass transport coefficient.

Cartridge Filters

The RO pilot utilized six (6) 5 micron, spiral wound cartridge filters each with a length of 20 inches and an outside diameter of 2.5 inches. The RO recovery was set at 48.8% with a flux of 8.2 gfd/psi. This correlated to an RO feed flow rate of 32.8 gpm. At this flow rate, the cartridge filter loading rate was calculated to be 2.7 gallons per minute per 10-inch cartridge filter equivalent. These cartridge filter loading rates fall in line with the anticipated full-scale loading rate of 2.5 to 3 gpm per 10 inch equivalent.

The protocols established for this project established a cartridge filter changeout pressure differential of 15 psi. However, circumstances discovered during the pilot warranted cartridge filter changeout independent of pressure differential. At no time during the pilot test were the filters changed due to reaching maximum pressure drop. Rather, cartridge filters were changed due to SDI increases, the presence of biological or organic growth, or because CIP procedures were performed on the RO membranes.

Following is a summary and reasoning for cartridge filter changeouts:

- March 11, 2008: cartridge filters replaced due to higher SDI leaving the cartridge filter than entering. In addition, biological or organic growth was present on the filters. Cartridge filters were installed for 58 days.
- March 26, 2008: cartridge filters replaced due to the presence of biological or organic growth on the filters. Cartridge filters were installed for 15 days.
- May 30, 2008: cartridge filters were replaced due to the presence of biological growth on the filter. Cartridge filters were installed for 65 days.
- June 14, 2008: cartridge filters replaced after the CIP was performed.

This time log shows that the cartridge filters were installed for up to 58 calendar days without changeout. It is possible that the cartridge filter run times could have extended much farther beyond that time frame; however 58 days falls short of the goal of at least 3 months of run time between cartridge filter changeouts.

There is a potential correlation between cartridge filter changeout caused by biological and/or organic growth on the filters and the amount of downtime attributed to a lack of pretreated water flow to the train; however this was not studied as a part of the project.

3.5 FINISHED WATER QUALITY

Permeate produced by the SWRO process is typically very aggressive to metals and requires stabilization, disinfection, re-hardening and carbonation. Permeate may also require addition of a corrosion inhibitor to protect existing distribution system pipe, and/or fluoride addition.

TCEQ does not have a boron limit distribution system standard. The boron-specific membrane was utilized because early-on in the project because it was decided that the status of the limits on boron for drinking water were in flux in the United States and due to the negligible difference in O&M (acknowledging a difference in capital, however), utilization of a slightly higher-rejecting boron element would be justified if WHO and EPA regulations direct reductions to the sub-1.0 ppm level. However, as the project progressed and based on our understanding of the WHO revised standards as they were further developed and refined in mid 2007, the boron standard is expected to be relaxed; therefore the capability to test lower boron-rejection elements was created which is consistent with TCEQ requirements.

The BPUB currently owns and operates the Southmost Brackish Water Reverse Osmosis Membrane Filtration Facility and is in the planning stages of determining the most beneficial mixture of brackish, surface water, and seawater-sourced water to commingle in the distribution system. Once that determination is made, a paper-study of distribution system compatibility can be undertaken. In the future, a distribution system simulation and mixing test program would also support the ideal level of post-treatment necessary for the SWRO plant.

Water quality testing at the pilot consisted of analyzing permeate from the Filmtec and Toray membranes during the 48.8% recovery runs. Table 3-16 gives a summary of Federal primary and secondary water quality standards, results of the permeate water quality testing work performed from both the Filmtec and Toray SWRO trains, and additional selected water quality data. Permeate water quality from both SWRO membranes meet all of the primary and secondary standards with the exception of pH and alkalinity, which is expected.

In addition to testing permeate water quality, water quality testing associated with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Eight water quality samples were obtained from the Gulf of Mexico, and ten samples were taken from the Gulf of Mexico from August 2007 through May 2008. All of the analytical results for Cryptosporidium came out below the minimum detectable level. Based on these monitoring results, the bin classification for the facility falls in Bin Classification 1. According to the LT2ESWTR, no additional treatment is required. Formation potentials were acquired by dosing 21 3ppm of chlorine and letting the sample incubate for 7 days.

Regarding total coliform, of three samples taken from Toray permeate, two samples tested positive for Total Coliform. Multiple tests were performed on the piping, o-rings were replaced, and additional shims were installed on the endcap adapters, however a specific cause was not identified. It not typical for total coliform to show up in the permeate stream unless the line was contaminated or membrane integrity is breached. Normalized salt passage and autopsy results confirmed the integrity of the membranes. It is possible that through the course of loading or unloading the elements, or during vessel probing activities, contamination might have occurred.

Table 3-16: Permeate water quality.

Parameter	Units	Filmtec RO Permeate	Toray RO Permeate	Design Goal/ TCEQ Standard
PRIMARY MCL				
Antimony	mg/L	<0.002	<0.002	0.006
Arsenic	mg/L	<0.002	<0.002	0.01
Barium	mg/L	<0.001 to 0.00459	<0.005	2
Beryllium	mg/L	<0.001	<0.001	0.004
Cadmium	mg/L	<0.001	<0.001	0.005
Chromium	mg/L	<0.001	<0.001	0.1
Cyanide	mg/L	<0.005	<0.005	0.2
Fluoride	mg/L	<0.5	<0.5	4.0
Mercury	mg/L	<0.00015	<0.0015	0.002
Nitrate	mg/L	<0.25	<0.25	10
Nitrite	mg/L	<0.01	<0.01	1
Selenium	mg/L	<0.002	<0.002	0.05
Thallium	mg/L	<0.001	<0.001	0.002
SECONDARY LEVEL				
Aluminum	mg/L	<0.01	<0.01	0.05 to 0.2
Chloride	mg/L	74.1 to 139	68.8 to 161	300
Color	PCU	<5	<5	<5
Copper	mg/L	<0.001 to 0.00443	<0.001	1.0
Fluoride	mg/L	<0.5	<0.5	2.0
Hydrogen Sulfide	mg/L	<0.02	<0.2	0.05
Iron	mg/L	<0.1	<0.1	0.3
Manganese	mg/L	<0.001 to 0.00387	<0.001	0.05
Odor	Threshold odor number	None	None	3
pH	-	6.4 to 6.9	6.3 to 6.9	>7.0
Silver	mg/L	<0.001	<0.001	0.1
Sulfate	mg/L	<1.5	3.34 to 5.23	100
TDS	mg/L	188 to 306	132 to 320	<500
Zinc	mg/L	<0.02	<0.03	5
OTHER				
Alkalinity	mg/L	2.9 to 6.4	5 to 6	75 to 150
Hardness – total	mg/L	<5	<2.5 to 9.28	<250
Turbidity	NTU	0.017 to 0.098	0.033 to 0.096	<0.2
DOC	mg/L	<0.9	<1.5	<2
THM FP	mg/L	<0.001	<0.001 to 0.0073	<0.040
HAAs	mg/L	<0.005	<0.005	<0.030
Total Coliform	in 100 mL	Negative	Positive	
Boron	mg/l	0.798 to 1.38	0.712 to 1.55	n/a

Ultimately, treated permeate must be compatible with the existing distribution system and fall within regulatory requirements for disinfection. Specific finished water quality requirements and needs will vary based on the end-user (independent laboratory testing results and tabular water quality data may be found in the digital attachments to this report).

3.6 CONCENTRATE

3.6.1 Concentrate Water Quality

One of the major unknowns at the end of the Feasibility Study, and therefore a major objective of the Pilot Study, was to determine the quality and composition of the concentrate produced by the seawater desalination process. The RO portion of the pilot facility was successfully operated at a recovery of 48.8%. Concentrate water quality was sampled at this recovery, and it was found that the TDS ranged from 55,800 mg/L to 68,700 mg/L.

During the RO performance runs at 48.8% recovery, the average feed conductivity was 51,000 uS, which correlates to a feed TDS of 30,932 mg/L. The permeate recovery averaged 438 uS (211 mg/L). The average concentrate TDS, as calculated using a mass balance of feed and permeate TDS at an RO recovery of 48.8%, is 60,212 mg/L. This value falls within the range of laboratory tested values. At a recovery of 45%, the calculated TDS of the concentrate stream is approximately 56,000 mg/L.

3.6.2 Concentrate Disposal

Two potential methods for disposing of the concentrate of a production desalination facility were analyzed: diffusion into the Gulf of Mexico and deep well injection.

Diffusion into the Gulf of Mexico

To facilitate a preliminary design of a multi-port diffuser outfall for the concentrate stream of the proposed full-scale seawater desalination plant, the Cornell Mixing Zone Expert System[12] (CORMIX) model was used to simulate various discharge scenarios (Machin 2007) (a copy of this anaylysis is included in the digital attachments to this report). CORMIX is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The system's major emphasis is on predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be evaluated.

The modeled discharge location was approximately ½ mile offshore from Boca Chica beach, approximately 2 miles north of the mouth of the Rio Grande. Field measurements were made on two occasions at five locations in the vicinity (Figure 3-51). Water depths at these sampling sites ranged from 25 to over 50 feet (Table 3-17).

[12] CORMIX was developed under several cooperative funding agreements between U.S. EPA and Cornell University during the period 1985-1995 and has been updated several times since then. It is a recommended analysis tool in EPA guidance documents on the permitting of industrial, municipal, thermal, and other point source discharges to receiving waters (Machin 2007).

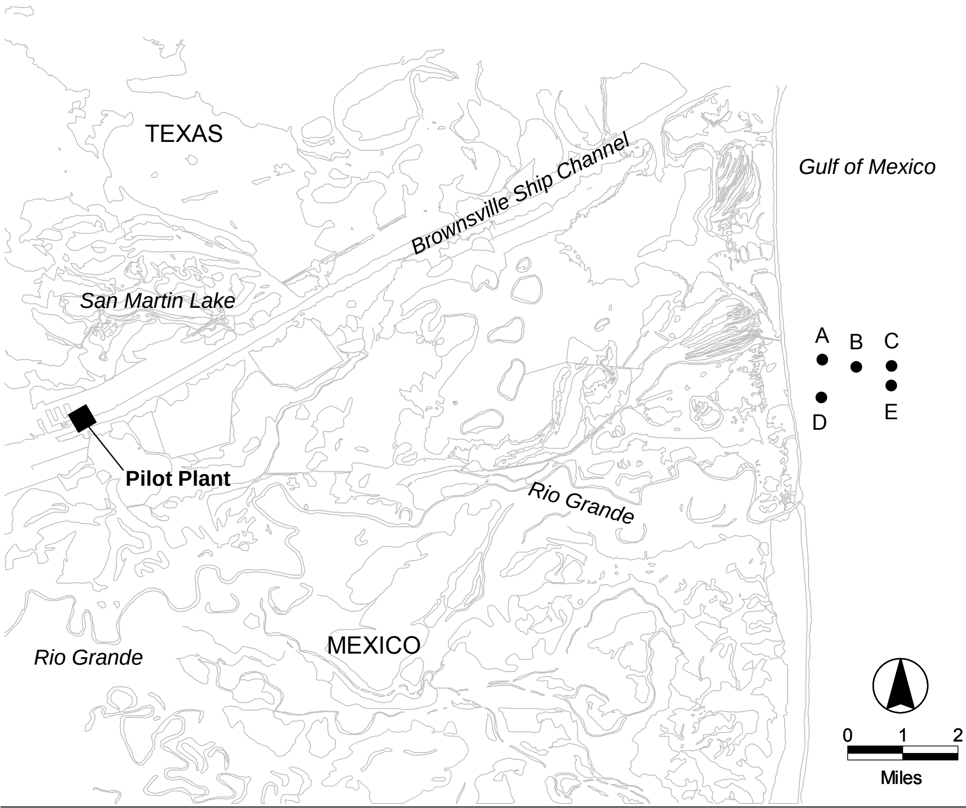

Figure 3-51: Location of off-shore field measurement sites for ocean depth and distance from shore. Graphic reproduced from Machin (2007).

Table 3-17: Depth measurements in the area of the modeled concentrate diffusion outfall.

Site	Depth (feet)	Distance from Shore (miles)	Date Measured
A	25	0.60	August 2006
B	40	1.15	August 2006
C	53	1.70	August 2006
D	25	0.49	January 2007
E	>42	1.65	January 2007

Source: Machin (2007).

In concept, the diffuser would be a straight pipeline lying on the bottom of the Gulf extending perpendicular to the ambient flow direction with the ports along the line projecting upward at a 45° angle and outward perpendicular to the current. At the proposed discharge location, the U.S. Coast Guard indicates a strong near-shore longshore current that typically moves from south to north, although flow reversals can also occur at various times of the year. Ambient currents are important because, in general, the stronger the near-shore longshore flow, the more rapidly the diffused concentrate is dispersed in the water column.

Estimates of current velocities are available in existing field and model data along the south Texas coast, specifically for sites 5 to 13 miles offshore northeast of the proposed discharge location where depths range from 70 to 110 feet. Here the U.S.

Coast Guard reports that current velocities range from 5 to 7 feet per second (fps), while TPWD reports the much lower values of 0.3 to 0.7 fps with a maximum of about 6 fps (Machin 2007). This large (10-fold) discrepancy was accommodated by modeling the extreme ranges of each estimate.

Because the longshore current in the area of the proposed discharge is reportedly a result of the prevailing southeasterly winds causing waves that break at an angle to the beach, it is reasonable that current velocities are stronger near the shore. Therefore, model runs were made to address a range of ambient current velocities (7.0, 1.0, and 0.12 fps) were evaluated to determine the sensitivity to this variable. Other input data included an assumed 50 percent recovery, which would result in a concentrate flow rate (25 mgd); concentration of salts in the brine stream (80 parts per thousand (ppt) salinity), ambient seawater salinity (35 ppt salinity), diffuser length (98 feet), and number of diffuser ports (5).

Model output results for each scenario are presented in Figures 3-52, 3-53, and 3-54. In summary, the results show that the concentrate discharge plume is completely mixed from substrate to surface (cross-section view), and that concentrations are reduced to near ambient conditions within 125 ft of the diffuser.

Class I Disposal Well

During the Pilot Study, the potential for using Class I disposal wells for subsurface injection of concentrate from seawater desalination project was evaluated (Weegar-Eide & Associates 2008) (a copy of this anaylysis is included in the digital attachments to this report). House Bill (HB) 2654 established that TCEQ can grant general permits instead of individual permits for Class I (non-hazardous) injection wells used for the disposal of desalination concentrate. The proposed rulemaking that is currently ongoing based on HB 2654 is intended to streamline the TCEQ's permit review process from the current duration of approximately one year, and would reduce some of the current permit requirements for Class I (non-hazardous) injection wells. However, for the purpose of this screening review, it was assumed that the rule changes remained proposed, but not yet approved, and it was assumed that the current permit technical requirements under 30 Texas Administrative Code (TAC) 331 (summarized in Form TCEQ-0623) were in force.

Other major assumptions used to prepare the evaluation included:

- The data analysis process would be limited to reviewing the maps and logs to determine the most likely target injection interval based only on the local geology, which assumed no interference with local oil/gas production, no fault-related compartmentalization of the injection reservoir, and no fault-related leakage potential. Therefore, the project assumptions presumed that subsurface injection was possible and focused on the estimated cost of drilling and completing a Class I injection well system.
- The concentrate will be classified as non-hazardous and will be appropriate for disposal into a Class I (non-hazardous) injection well system according to the technical requirements established in 30 TAC 331 using Form TCEQ-0623 as the operative guidance.
- Surface piping, pump/control/filtration system, and real estate costs were not to be included in this screening study.

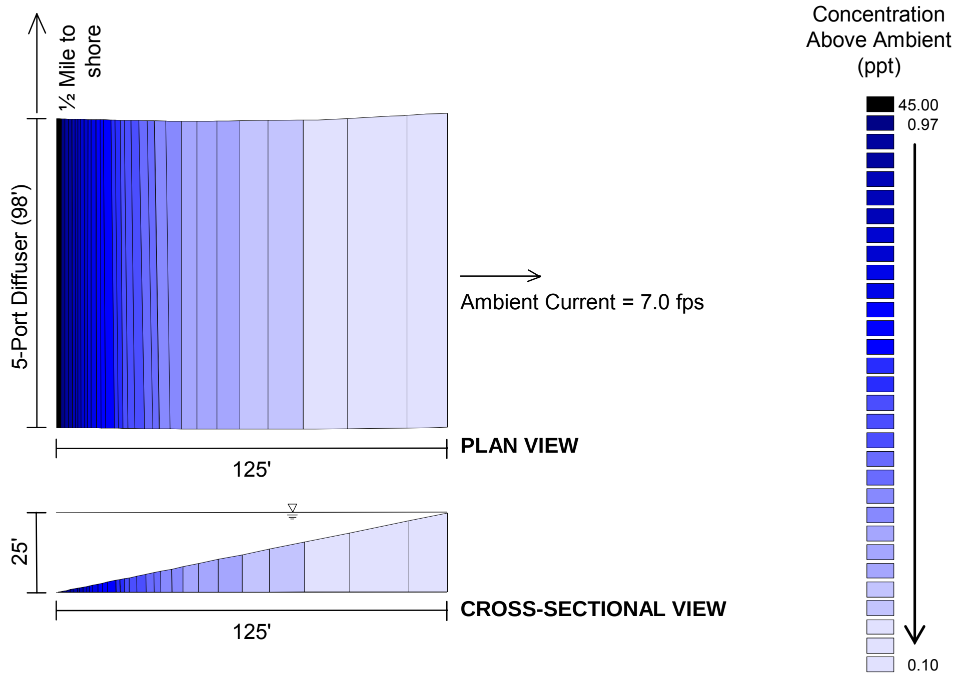

Figure 3-52: CORMIX model results for concentrate discharge of 25 mgd assuming an ambient current of 7.0 fps and concentrate of 80 ppt[13].

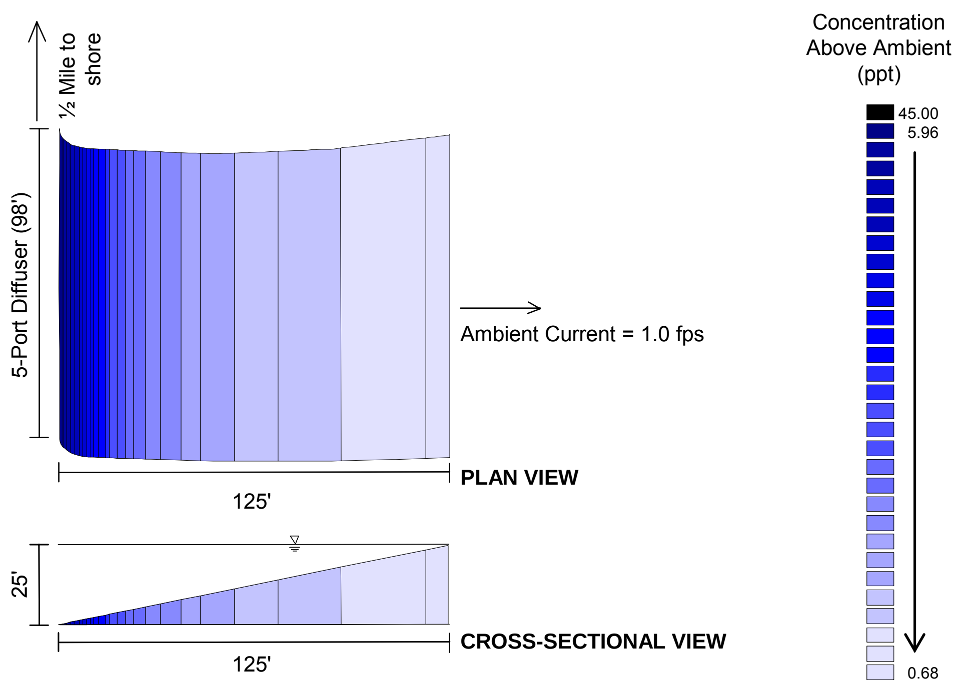

Figure 3-53: CORMIX model results for concentrate discharge of 25 mgd assuming an ambient current of 1.0 fps and concentrate of 80 ppt [14].

13 *Source*: Machin (2007).
14 *Source*: Machin (2007).

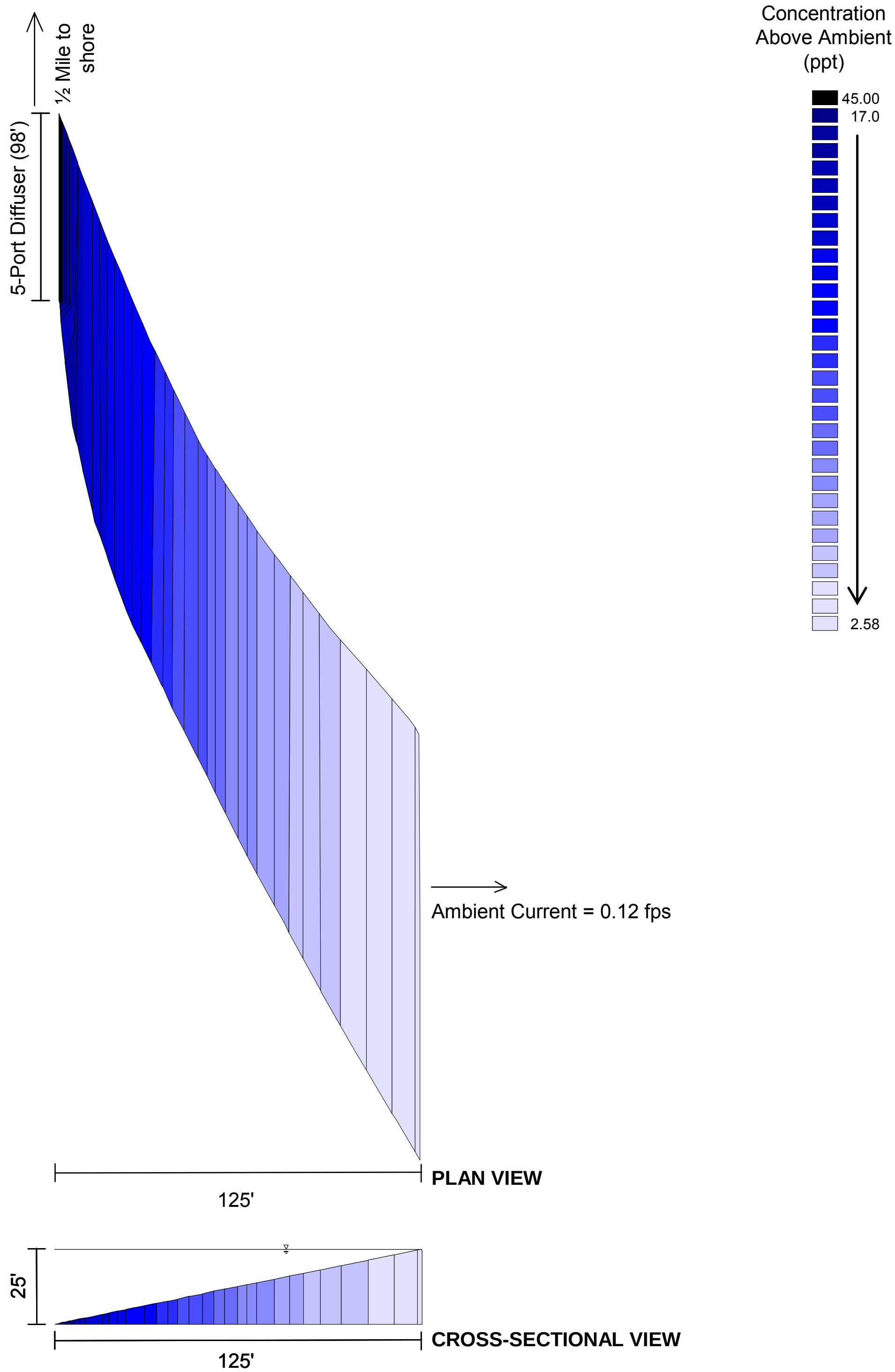

Figure 3-54: CORMIX model results for concentrate discharge of 25 mgd assuming an ambient current of 0.12 fps and concentrate of 80 ppt[15].

15 *Source*: Machin (2007).

- The cost analysis was to be based on current information available to Weegar-Eide and its subcontractors from the permitting, drilling, completion, testing, and operation of similar Class I injection wells and oil/gas wells in Texas (i.e., no bid requests were sent out for this project).
- Data acquisition was to be limited to obtaining commercial structure maps and approximately three geophysical logs (four logs were actually obtained) for only the primary BDP area (not the alternate plant site location).
- An excess capacity contingency of 10 percent would be needed to allow for wells to be taken out of service for testing, maintenance, repair, and replacement without impacting plant operations.
- Well count calculated in this screening review was based on an assumed concentrate production rate of 17,360 gpm (25 mgd).

Based on the sand intervals present at the proposed site (in the absence of reservoir compartmentalization) and assuming proper vertical containment conditions and no interference with local oil or gas production, an individual injection well performance of 200 to 400 gpm at 800 to 1,000 psi in this part of South Texas would be a reasonable expectation. Assuming a required total system injection rate of 17,360 gpm, the estimated well count would be between 49 wells (at 400 gpm per well) and 96 wells (at 200 gpm per well). This well count includes a 10 percent excess capacity contingency to allow wells to be taken out of service for testing, maintenance, repair, and replacement without interrupting facility operation.

Conceptual Injection Well System Costs
The project cost estimate assumes that the wells would be completed with standard grade carbon-steel tubular products (J or K grade) consisting of 10 3/4-inch surface casing, 7 5/8-inch long-string casing, 4 1/2-inch injection tubing, and standard trim packers. The surface casing set depth for these wells has not been established, but is assumed to be less than 2,000 feet. Based on this, the estimated well price (at current rates for services, materials, and fuel) is $750,000. This well price includes costs for permit preparation, post-completion mechanical integrity testing, and certification under current Class I injection well regulations.

The high TDS content of the wastewater and the potential for relatively high dissolved oxygen concentrations due to contact with air at the surface could create a corrosive wastewater stream. If so, then material upgrades (e.g., stainless steel packers and injection zone casing, coated steel injection tubing, or fiberglass injection tubing) might be needed and would add cost. This would result in an estimated well price (at current rates for services, materials, and fuel) of $850,000.

As stated above, it is assumed that the wells will accept injection at between 400 gpm and 200 gpm, requiring a wellfield of between 49 and 96 wells (respectively), at a cost of between $750,000 and $850,000 per well. Based on this, the estimated well cost is between $36.75 million and $81.6 million.

The well costs summarized in this report are from the wellhead down, and do not include surface flow pipe, pumps, filters, instrumentation, land prices, annual testing and repair, replacement, permit renewals, or other costs. However, this well cost does assume some economy of scale for such a large drilling project, and assumes that the field efficiency would be increased by concessions from the TCEQ for such tasks as coring. As an example, given how many wells would be completed within such a relatively small regional area, it is possible that instead of coring every well, the TCEQ might reduce the coring requirement to some mix of whole core and side-wall core from a subset of the wells.

Annual O&M costs could easily add an additional $100,000 or more per well for electricity, general well maintenance, testing, and reporting under current Class I injection well regulations. However, similar to the previously stated capital cost estimate for the wells, this annual O&M cost estimate does not include charges for well repairs and replacement, or costs for maintenance associated with the surface piping, pump, filtration, and control systems.

While land acquisition costs were not evaluated in this screening review, if a typical spacing of 500 to 1,000 feet between wells is assumed, then it becomes apparent that a substantial amount of land would need to be purchased to accommodate the surface facilities for such a large injection well system. However, if multiple angled or horizontal wells are drilled from a limited number of common well pad locations, then this could help to reduce the surface footprint of the injection well system (saving space), but would also increase the cost per well for drilling and completion as compared to vertical wells.

3.7 ENVIRONMENTAL CONSIDERATIONS

The Texas Water Development Board (2007), in cooperation with the Texas Parks and Wildlife Department and TCEQ, prepared a tool to assist potential project developers with environmental considerations for desalination facilities. This planning-level document provides a useful general overview of environmental concerns associated with seawater desalination in Texas, as well as a discussion of the roles and permitting responsibilities of different state agencies. Three general categories of environmental resource issues were identified for desalination along the Texas coast; namely, water quality consideration associated with concentrate disposal, the potential for bio-fouling from marine organisms, and potential impingement and entrainment associated with the raw water intake.

3.7.1 Water Quality Considerations (Concentrate Disposal)

The seawater desalination process produces liquid wastes that contain large concentrations of salt ions and other elements present in the raw water, as well as residual chemicals used for pretreatment and biofouling control. The desalination process may also produce small amounts of solid waste (e.g., spent filters and solid particles separated during the pretreatment process). Discharge of these liquid and solid wastes will likely require permits that address potential adverse environmental impacts. Liquid waste disposal alternatives can include deep-well injection, evaporation ponds, and diffusion into a surface water body, while solid waste disposal is usually accomplished in landfill applications.

For (liquid) concentrate disposal, planning-level models (such as the CORMIX system) were used during the Pilot Study to assess brine loading on ambient salinity conditions in the receiving water body. More complex models would likely be necessary for permitting-level evaluations. Such analytical tools are important because changes in ambient water chemistry (especially salinity) may result in negative impacts to fish, shellfish, shorebirds, macroinvertebrates, and other marine wildlife, especially when seasonal species life-cycle habitat requirements are considered. Effective evaluation tools are also critical because the high degree of hydraulic interaction between the Gulf of Mexico, inlets (including ship channels), bays, estuaries, and coastal rivers along the South Texas coast can limit whether concentrate disposal impacts remain localized.

3.7.2 Potential for Bio-fouling from Marine Organisms

A critical planning consideration for the full-scale seawater desalination facility is the risk of biofouling of intake and membrane equipment caused by marine organisms. The biofouling risk is dynamic, changing with seasonal variances in source water quality parameters, such as nutrient loading, freshwater inflow, contamination, oil spills, and algae blooms. Once it has occurred, fouling usually requires some form of back-flushing with anti-fouling compounds. Discharge of these waste streams should be anticipated and included in the overall disposal strategy for the plant.

The primary biofouling risk to intake, screening, and pumping equipment is from sessile suspension feeders such as barnacles. These types of shelled organisms attach themselves to hard substrates and use feathery appendages to draw plankton and detritus from the water column into the shell for consumption. Fast individual growth rates and swamping reproductive strategies allow colonization by vast numbers over large areas in relatively short amounts of time (Figure 3-55).

Figure 3-55: Photograph of biogrowth and barnacles attached to the inner wall of the raw water manifold. The intake had been operational for approximately 12 months prior to this photograph.

Initial screening equipment removes the (mobile) larval stages of these types of organisms from the raw water supply. However, the primary threat to pretreatment membrane equipment is from smaller biofoulants agents that are not removed by screening. One possible risk that was not able to be tested during the pilot period was a “red tide” event. The South Texas coast, including the Brownsville Ship Channel, is subject to the occurrence of significant algal blooms, known as red tides.

Red tide is caused by blooms of neurotoxic plankton in the Gulf of Mexico and usually results in major fish kills.

Red tide results from an algae that can make the ocean appear red or brown and that releases a toxin that paralyzes fish and other marine organisms. There can also be neurotoxic and other human health effects, particularly from eating shellfish that feed on the algae. The blooms occur occasionally under certain conditions, with effects lasting for weeks or months. The blooms move based on winds and tides, so predicting their occurrence and movement is difficult. They can potentially occur every year somewhere along the Texas coast and have impacted the lower coast near South Padre Island in the past. There would likely be many years between occurrences at any one location. The last known major bloom in this area was in September 2005. It is possible that a red tide event could migrate up the Brownsville Ship Channel. However, the Ship Channel's northeast-southwest alignment combined with prevailing southeasterly winds and low tidal range of 1-2 feet make it less likely that a bloom in the Gulf or Laguna Madre would migrate to the vicinity of the proposed desalination plant.

3.7.3 Potential Impingement and Entrainment Impacts

The intake of raw water for seawater desalination involves large volumes of water that can entrain[16] marine organisms within the flow stream to the intake structure and those organisms may become impinged[17] on the intake screen (Texas Water Development Board 2007b). The withdrawal of such volumes of raw water can affect phytoplankton (tiny, free-floating photosynthetic organisms suspended in the water column), zooplankton (small aquatic animals, including fish eggs and larvae, which may consume phytoplankton and other zooplankton), fish, crustaceans, shellfish, seagrass, and many other forms of marine aquatic life. The potential impacts of impingement and entrainment should be evaluated with regard to ecosystem function and facility operation and maintenance.

The Brownsville Ship Channel maintains a close hydraulic connection with the Gulf of Mexico. As a result, raw water from the ship channel will contain a wide variety of marine organisms. Therefore, design considerations for the intake structure of the full-scale facility will evaluate a combination of effective screen size with low intake velocity to minimize impingement and entrainment issues. The low intake velocity is also expected to improve water quality (reduce turbidity) of the raw feed water.

[16] Entrainment refers to the transport of living organisms in the water column or current, as occurs when organisms enter a water intake structure.
[17] Impingement refers to the accumulation of living organisms on a water intake screen.

3.8 POTENTIAL FINANCING MECHANISMS

3.8.1 State

The primary state vehicles for water infrastructure projects are offered by TWDB, which serves as a multi-billion dollar lending and granting institution with existing programs and relationships that could provide benefits to the project sponsor or other entities participating in the seawater desalination project (Table 3-18). In addition, special legislative appropriations through the State of Texas in the form of grants could be pursued.

Table 3-18: Major Texas Water Development Board assistance programs for water related projects.

Program	Type	Use	Applicants	Availability
Clean Water State Revolving Fund Loan Program	Loan	Planning, acquisition and construction, wastewater treatment, stormwater and non-point source pollution control, and reclamation/ reuse projects.	Political subdivisions and individuals.	An annual priority rating process applies to projects.
Drinking Water State Revolving Fund Loan Program	Loans and additional subsidies (subsidies are for disadvantaged communities only).	Planning, acquisition and construction of water related infrastructure, including water supply and Source Water protection.	Community water system owners and nonprofit non-community water system owners, including political subdivisions of the state and private individuals.	An annual priority rating process applies to projects.
Rural Water Assistance Fund Program	Loan	Planning, acquisition, and construction of water supply related infrastructure, including water treatment, water distribution pipelines, reservoir construction, and storage acquisition.	Political subdivisions and nonprofit water supply corporations.	Not restricted.
State Participation in Regional Water and Wastewater Facilities Program	Deferred interest loan (with temporary ownership transfer)	Construction of regional water or wastewater construction project when the local sponsors are unable to assume debt for the optimally sized facility.	Political subdivisions of the State and water supply corporations, which are sponsoring construction of a regional water or wastewater project.	Limited Funds.
Water and Wastewater Loan Program	Loan	Planning, acquisition, and construction of water related infrastructure, including water supply, wastewater treatment, storm-water and non-point source pollution control, flood control, reservoir construction, storage acquisition, and agricultural water conservation projects, and municipal solid waste facilities.	Political subdivisions and nonprofit water supply corporations.	Not restricted.
Economically Distressed Area Program for Water and Sewer Service	Grant, loan, or a combination grant/loan.	To bring water and wastewater services to economically distressed areas (designated by TWDB) where the present water and wastewater facilities are inadequate to meet the minimal needs of residents.	Political subdivisions, and nonprofit water supply corporations, provided they meet certain program requirements.	Limited Funds.

Source: TWDB

While the range of state program types covers most foreseeable water-related needs, only three programs, the State Participation Program, the Water and Wastewater Loan Program, and the Economically Distressed Program, appear to offer potentially viable financial subsidies to the seawater desalination project. The nature and application of this assistance would appear to be limited, however. The State Participation Program offers the best legal and financial opportunity for successful implementation of seawater desalination, but will require new appropriation and some flexibility in administration.

3.8.2 Federal

The two most likely agencies that could provide federal funding assistance to a seawater desalination project are Reclamation and USACE. Like the State of Texas alternative, the pursuit of legislative appropriations should be pursued from the federal level as well.

U.S. Bureau of Reclamation

The U.S. Bureau of Reclamation presently has two possible funding assistance mechanisms for seawater desalination: Desalination and Water Purification Research and Development Program and Title XVI Water Reclamation and Reuse Program.

Desalination and Water Purification Research and Development Program[18]

Through this program, Reclamation forms partnerships with private industry, universities, water utilities, and others to address a broad range of desalting and water purification needs. Reclamation is particularly interested in research where the benefits are widespread but where no private-sector entities are willing to make the investment and assume the risks. Reclamation is also interested in research that would have a national significance - where the issues are of large-scale concern; they are more than locally, state, or regionally specific; and the benefits accrue to a large swath of the public.

The program has three major goals: 1) augment the supply of usable water in the United States; 2) understand the environmental impacts of desalination and develop approaches to minimize these impacts relative to other water supply alternatives; and 3) develop approaches to lower the financial costs of desalination so that it is an attractive option relative to other alternatives in locations where traditional sources of water are inadequate.

The Program includes three research categories: Research and Laboratory Studies, Pilot Scale Projects, and Demonstration Scale Projects. Applicants (other than institutions of higher education) must cost-share at least 75% of the project cost. This cost-share may be reduced to 50% if the applicant can demonstrate financial need. Applicants proposing to provide additional cost-share will be given greater consideration. Cost-sharing may be made through cash or in-kind contributions from the applicant or third party, non-Federal, participants. Cost-sharing is not mandatory from institutions of higher education, but is strongly encouraged. The authorizing legislation for this program provides for up to a total of $1,000,000 per year to be awarded to institutions of higher education, including United States-Mexico bi-national research foundations and inter-university research programs

[18] The authorizing legislation for this program is the Water Desalination Act of 1996, P.L.104-298, as amended, and the Reclamation Wastewater and Groundwater Study and Facilities Act of 1992, P.L. 102-575, Title XVI, as amended, Sect. 1605, codified in 43 USC Sec 390h-3).

established by the two countries, without any cost-sharing requirement. No profit or fee is allowed.

The original FY 2008 announcement for applications (No. 08SF811411) stated that Reclamation anticipates awarding a total of $2.5 million dollars. For each project, up to $150,000 may be awarded for research and laboratory studies, $200,000 per year for pilot scale projects, and $500,000 per year for each demonstration scale projects. However, this announcement was withdrawn in May 2008 by Reclamation for reasons relating to funding.

The Desalination and Water Purification Research and Development Program represents an excellent opportunity to cost-share some components of developing a seawater desalination project. Although the amount of federal funding may be limited (e.g., up to $500,000 per year for demonstration-scale projects up to three years in length), the proposed project could compete very favorably.

Title XVI Water Reclamation and Reuse Program
Reclamation's water reclamation and reuse program was authorized by the Reclamation Wastewater and Groundwater Study and Facilities Act of 1992 (Title XVI of Public Law 102-575), as amended, directs the Secretary of the Interior to undertake a program to investigate and identify opportunities for water reclamation and reuse, including naturally impaired waters (or desalination). Congress specified prerequisites that must be met before construction funds can be appropriated for Title XVI projects. These prerequisites are:

6. Reclamation or the non-Federal project sponsor has completed a feasibility study that complies with the provisions of the Act;
7. The Secretary has determined that the non-Federal sponsor is financially capable of funding the non-Federal share of the project costs; and
8. The Secretary has approved a cost-sharing agreement with the project sponsor.

In addition, Reclamation must ensure completion of appropriate environmental compliance under the National Environmental Policy Act during the feasibility stage before construction funding can be disbursed.

Under Title XVI, Reclamation is authorized to participate in all of the currently authorized water recycling projects at funding levels up to 25 percent of the total project cost. However, section 1631 limits the Federal contribution to a maximum of $20 million (1996 dollars) per project for all projects that did not receive construction funding prior to January 1, 1996. For demonstration projects, the Federal contribution is limited to a maximum of $20 million per project. A Federal contribution in excess of 25 percent for a demonstration project cannot be made unless the Secretary determines that the project is not feasible without such Federal contribution. In this case, the maximum Federal share may be up to 50 percent of the total project costs.

The original act authorized Reclamation to participate in the construction of 5 recycling projects and 3 feasibility studies. In 1996, Congress amended Title XVI (P.L. 104-266) and authorized Reclamation to participate in an additional 18 projects, including two desalination research and development projects. Since 1996, additional projects have been authorized under the program by line-item write-in.

However, funding from Congress for implementation is not keeping pace authorized projects and the program is currently about $150 to $200 million behind.

The Title XVI program is focused on demonstrating new technologies, but funding for projects authorized under the Title XVI program has experienced a significant backlog. Sufficient political support for write-in authorization and appropriations specific to a seawater desalination project would be essential. However, if such support were available, it may be preferable to seek an individual authorization and appropriation outside of the context of the Title XVI program to avoid competition among other authorized but unfunded projects.

U.S. Army Corp of Engineers
On November 8, 2007, U.S. Legislators passed the Water Resources Development Act (WRDA) (P.L. 110—114), establishing the Texas Environmental Infrastructure Program (TEIP) in Section 5138. TEIP, authorized at $40,000,000, establishes a general, programmatic authority for planning, engineering, design and construction of water supply, wastewater, water quality, and environmental projects. USACE would administer the program, but funding priorities would be provided by TWDB.

TEIP is essentially intended to provide federal support in implementing the water management strategies in the State Water Plan, and the provision explicitly states that projects to be funded under TEIP will be identified by TWDB. The provision would also allow for cost-share credit based on prior work, such as activities conducted through the regional water planning process. Because seawater desalination is included in the Region M Water Plan, the Brownsville Seawater Desalination Project would qualify for TEIP funding.

When Congress appropriates Federal funding under WRDA, USACE has stated that they will defer to TWDB to determine project priority. TWDB has indicated a strong preference for implementation projects over planning or design activities. Therefore, TEIP may represent a good funding mechanism once the design process has been concluded and appropriations are available.

Stand-alone Project Authorization and Appropriation
A direct Congressional authorization and appropriation could be sought specifically for a seawater desalination project. Such "earmarks" are common features of federal authorization and appropriations bills and could be made under an existing program (such as those above) or as a stand-alone project.

3.8.3 International

North American Development Bank
NADB has two primary water supply infrastructure assistance programs; Loan Program and Border Environmental Infrastructure Fund (BEIF).

Loan Program
NADB can make loans to public and private borrowers, at market and low-interest rates, for the implementation of environmental infrastructure projects located in the U.S.-Mexico border region. Loans are available for the implementation of projects in all environmental sectors in which the NADB operates, including water supply. A project is eligible for NADB financing if it meets the following criteria:

- The project must be located within 100 kilometers (62 miles) north of the international border in boundary in the four U.S. states of Texas, New Mexico, Arizona and California and within 300 kilometers (about 186 miles) south of the border in the six Mexican states of Tamaulipas, Nuevo Leon, Coahuila, Chihuahua, Sonora, and Baja California.
- It must remedy an environmental and/or human health problem, which includes water supply.
- It must be certified by the Border Environmental Cooperation Commission (BECC). (The BECC's primary role is to develop and authorize projects, which are subsequently funded by NADB or other funding institutions. To fulfill this role, the BECC gives primary importance to technical and financial aspects of each project, such as the use of appropriate non-polluting technologies with low operating and maintenance costs, and a viable financial structure that reflects affordable rates. Additionally, BECC makes a significant contribution to the project development process by ensuring project information availability, broad public participation and implementation of sustainability principles. BECC also facilitates coordination between different government agencies at the federal, state, and local levels, in order to ensure that projects comply with the requirements and standards of each institution.)

Through its Loan Program, NADB is prepared to finance a portion of the capital costs of a project. Eligible capital costs may include the acquisition of land and buildings; site preparation and development; system design, construction, rehabilitation, and improvements; and the procurement of necessary machinery and equipment. NADB can provide financing as direct loans, interim financing, or participation in municipal bond issues.

NADB project financing operations must be structured with a view toward preserving the bank's resources and credit rating for the benefit of current and future border residents. Funding from other sources in the form of grants, equity or co-financing is required as NADB generally cannot finance more than 85 percent of the eligible costs of a project. However, in the case of projects with eligible costs of up to and including one million dollars (U.S.), NADB may provide a loan for up to 100 percent of those costs, depending on project risks and other characteristics. Loan maturities generally will range up to 25 years, depending on individual project requirements, but cannot exceed the useful life of the project. Grace periods for principal repayment are negotiable and may cover the anticipated project construction and start-up phase. The borrower must maintain the debt coverage ratio set by NADB at the time of funding, usually a minimum of 1.2.

Interest rates for particular loans are established at loan closing, and payments may be made on a monthly, quarterly or semi-annual basis. NADB currently offers two interest rate structures: market-based rates and lower-than-market rates under its Low-Interest Rate Lending Facility (LIRF). LIRF loans may be made to public borrowers who meet the applicable eligibility requirements.

The cost effectiveness for BPUB the NADB Loan Program appears to be limited by the interest rates on loans provided under this program. A comparison of actual rates offer by NADB with those of other loaning institutions would determine the best available terms.

Border Environmental Infrastructure Fund

NADB established the BEIF to administer grant resources provided by EPA to help finance the construction of water and wastewater projects in the U.S.-Mexico border region. This webpage outlines the eligibility criteria, authorized uses, and procedures for accessing EPA funds administered through the BEIF.

The objective of the BEIF is to make environmental infrastructure projects affordable for communities throughout the U.S.-Mexico border region by combining grant funds with loans and other forms of financing. It is designed to reduce project debt to a manageable level in cases where users would otherwise face undue financial hardship and projects could not be implemented.

Only water and wastewater infrastructure projects located within 100 kilometers (62 miles) of the U.S.-Mexico border will be considered for funding. BEIF funds may be used to support projects that serve a single community or regional approaches that serve multiple communities and/or outlying areas. Eligibility is based on a set of project selection criteria and affordability guidelines.

BEIF grant assistance is determined based on an affordability assessment of the community's project. The basic concept is that grant funds be applied toward projects so that the value of the grant funds has the greatest marginal benefit. In general, the marginal benefit is increased when the grant funds are used in tandem with other financial resources and when the assistance is targeted toward project costs that are above what could normally be financed by the project sponsor's sources of credit. Furthermore, grant funding is very important when the costs to the ultimate users (ratepayers) from the use of credit mechanisms result in rate increases that are not sustainable.

Two financial mechanisms are available to make projects affordable; 1) transition assistance, which makes loan repayments affordable to the ultimate users, or 2) construction assistance, which buys down project costs. Transition assistance is designed to ease a community's adjustment to higher user fees over time. Grant funds are used to help pay system debt up to a seven year period, so that user fees may be gradually raised to the level required for the system to become self-sustaining with proper operations and maintenance. Transition assistance may be applied to debt service and certain reserves. Construction assistance may be applied towards the costs of final design and construction, including residential hook-ups and construction management.

BEIF assistance for construction grants and other mechanisms to reduce debt service payments for local governments is limited by lack of available funding and project competition. However, this program is an eligible source of funding for the desalination project, and NADB officials have expressed an interest in helping with this project if funds are available.

4.0 Conclusions

The seawater desalination pilot plant at the Port of Brownsville was in operation for over one year. During that time, a copious amount of data was gathered and analyzed with the goal of determining if a 25 mgd seawater desalination facility could provide a reliable, drought-proof source of high quality drinking water to users throughout the region. The data collection and analysis components of the Program were divided into seven main categories: site location, intake, pretreatment, RO, concentrate disposal, finished water quality, and environmental review and permitting. Each component of the pilot project offered specific challenges, and the perspective of the piloting team was such that the worst-case scenario should be, and was, piloted.

There is no doubt that conditions during the pilot test were challenging due to the inherent characteristics of the Brownsville Ship Channel. At the completion of the pilot test, one phrase sums up the results: a full-scale desalination facility is technologically feasible at the Port of Brownville.

4.1 SITE LOCATION

Testing of the pilot facility at the Port of Brownsville was performed with the pilot intake being installed on the northern bank of the ship channel. As was described in Chapter 3, wind direction and velocity have an impact on raw water turbidity levels entering the pilot facility. The predominant wind was from the south and southwest. Due to the location of the pilot facility, these predominant winds proved to increase the turbidity entering the pilot by approximately 25 NTU. This effect was quantifiable on a day-to-day basis as real-time data was not available regarding wind speed and frequency. Any increase in turbidity provides more challenging pretreatment conditions and enhances the need to incorporate robust contingencies in the pretreatment step (such as pre-settling in the channel, addition of polymer, increased size of solids handling facilities, etc).

The inherent characteristics of the Brownsville Ship Channel proved to be difficult. Shipping traffic directly influenced turbidity and TDS entering the facility. Based on testing data, a correlation between TSS and turbidity was calculated using a linear regression model. The average turbidity during the Pilot Study was 44.7 NTU. Using the linear regression equation, the average TSS entering the plant through the intake was calculated to be 71.3 mg/L.

It was also learned (with the exception of TSS and turbidity) that water quality in the ship channel had more variation when compared to that in the Gulf of Mexico. However, it should be noted that water quality sampling in the Gulf could not be taken during periods of poor weather and presumably poor water quality. In addition to turbidity and TSS, it is reasonable to assume that there would be more variation in the Gulf of Mexico if samples could be taken during poor weather conditions.

Regarding water quality sampling performed by the BPUB laboratory, on average the TOC and DOC were higher in the Ship Channel than the Gulf of Mexico by 1.45 mg/L and 1.25 mg/L, respectively. UV_{254} was higher in the Ship Channel by 0.024 cm^{-1}, and alkalinity was higher in the Ship Channel by 16.18 mg/L. An accurate turbidity analysis between the two locations was not performed due to the fact that turbidity values in the Ship Channel were found to vary considerably. It is reasonable to assume that turbidity values in the Gulf of Mexico may also vary, and water quality samples taken in the Gulf were not obtained during times of poor weather due to the inability to collect samples during such occasions.

When comparing the water quality characteristics obtained from the independent laboratory testing, many water quality parameters trend very closely together including Oil and Grease, boron, strontium, calcium, barium, fluorite, nitrate-nitrogen, SOC, VOC, and Carbonate. On average, magnesium, potassium, sodium, sulfate, chloride, and TDS are higher in the Gulf of Mexico. On average, bicarbonate and carbon dioxide are higher in the Ship Channel.

The proposed location of the full-scale desalination facility will be different than the location where the pilot plan study took place. The new proposed site location lies on the south side of the Brownsville Ship Channel directly across from the pilot plant site location. The proposed site is at a higher ground elevation than the original proposed location near the pilot facility, thus, requiring less site work to keep support facilities such as buildings and other structures above the flood elevation. The proposed location also allows greater flexibility than the location of the pilot plant for implementation of the full scale intake structure and the orientation is less susceptible to wind-influenced turbidity, though turbidity caused by ship traffic will be similar unless additional modifications are made to the raw water intake system. The new location has the requisite infrastructure in-place such as electrical power, road access, and a distribution system (approximately 5 miles from the proposed plant) for implementation of the proposed full-scale desalination facility.

4.2 INTAKE

The intake at the pilot facility was designed and implemented in order to pilot the design laid forth in the 2004 Feasibility Study. This design incorporated features aimed at minimizing the impacts of turbidity and TSS spikes in the raw water through the construction of an underwater intake channel. The construction would entail removing significant amounts of material from the shoreline of the ship channel approximately 300 linear feet into the channel proper. Time and financial restrictions prevented the full implementation of such a design. A USACE Nationwide Permit was applied-for and granted for the construction of the intake as described in Chapter 2. If an Individual Permit were to have been applied for, the timeframe associated with such is approximately 1 year from the time of permit application. Therefore, the Nationwide Permit option was deemed necessary to advance pilot operations.

The Brownsville Ship Channel is a constructed channel. Approximately 200 feet from the channel bank, the water depth is only 8 feet. Due to the cross sectional layout of the channel, rapidly moving water, specifically caused by passing cargo ships, caused a greater than expected quantity of sediment to be stirred up and subsequent high turbidity and TDS to enter the pilot facility.

The raw water intake system at the pilot facility incorporated three pumps, two of which were operated at any given time. The water from these pumps was transferred to a common manifold that was used to supply water to the four pretreatment units. A pressure sustaining valve was placed on the tail end of the manifold to maintain pressure and raw water flow through the manifold. Water passing through the pressure sustaining valve was diverted directly to the on-site lagoon. Should a pretreatment unit be out of operation, the sustaining valve maintained the necessary flow to the other units. On a weekly basis, the intake manifold had to be flushed out to remove sediment buildup (Figure 4-1).

Figure 4-1: Photograph of discharge into the lagoon from flushing the raw water manifold. Flushing was periodically required to eliminate the buildup of sediment and other debris in the manifold line.

The growth of barnacles and other aquatic life was recognized during the Pilot Study. The only instance of problems associated with such growth was related to the operation of the prescreening devices. On a number of different occasions, shell fragments were found in the pre-screens. This caused an increase in DP across the strainers and associated backwashes. Even though these issues were noted at the Pilot Plant, any open intake in the Ship Channel or the Gulf of Mexico would realize similar impacts.

Figure 4-2 shows sampling for shell fragments and other large debris being discharged during flushing of the raw water manifold (left) and examples of some shell materials recovered (right). The conceptual design approach for the pilot team was to eliminate or minimize chemical addition to the greatest extent possible. However, since barnacles were observed during the study, it is common practice to apply periodic shock-chlorination as a pipeline maintenance management strategy for bivalve and mussel control. The design of the intake system will therefore incorporate provisions for periodic shock-chlorination. This is a common practice at SWRO facilities throughout the world. It is understood that dechlorination is a necessary safety feature of any well designed SWRO facility.

The Pilot Study intake setup allowed for ample water quantities to be supplied to the pretreatment units. However, the intake as implemented did little to decrease raw water turbidity and TSS spikes caused by shipping traffic. With the tested intake configuration the pilot tested the pretreatment units under the worst-case scenario. Any improvements resulting in reduction of feedwater suspended solids content in the full-scale intake would likely improve pretreatment performance.

Although the pilot tested configuration was effective, it is recognized that the implementation of an effective intake system with potential for incorporating features that allow a sufficient supply volume of feed water while minimizing the collection of suspended solids and protecting marine life is a prime consideration. Therefore, the new site location will provide for construction of an intake channel directly connected with the Brownsville Ship Channel, intake screen assemblies, and a raw water pump station aimed at leveling off TSS and turbidity spikes.

Figure 4-2: Photograph of sampling for shell fragments and other large debris being discharged during flushing of the raw water manifold (left) and examples of some shell materials recovered (right).

4.3 PRETREATMENT

Due to the pilot location and intake design, the pretreatment units were piloted under a worst-case scenario. Throughout the Pilot Study, each pretreatment unit had to operate with high turbidity and TSS spikes while operating under a range of raw water temperatures. Early in the piloting process, each membrane pretreatment unit attempted to optimize their operation.

In terms of raw water quality, the turbidity spikes present at the pilot facility exceeded the general specifications of each pretreatment vendor. This was known to be a potential issue at the onset of the pilot, and through discussions with the vendors, the decision was made to proceed with piloting the three membrane pretreatment units and the conventional unit.

Only one pretreatment unit was able to meet the pretreatment objectives of being able to operate for a minimum of 30 days without performing a CIP, providing filtrate with low SDI and turbidity, minimizing chemical consumption, maximizing filtrate flux, and being able to perform without exhibiting irreversible fouling tendencies on the membrane surface. Table 4-1 is a summary of operational parameters such as flux and recoveries for the different pretreatment units piloted during the period of the study.

Table 4-1: Operational summary for pretreatment units tested during the Pilot Study.

Flux During Run	Start Date	End Date	Flux (14.5 deg C) (gfd)	Percent Recovery	Notes
GE ZENON					
Optimization	5/15/2007	11/21/2007	-	-	-
25 gfd	11/22/2007	12/6/2007	21.65	92.0	Unable to operate for 30 days (high TMP)
20 gfd	1/31/2008	2/25/2008	17.5	92.0	Unable to operate for 30 days (high TMP)
15 gfd	2/25/2008	4/14/2008	12.68, 11.64	92.0	Successfully operated for 30 days, but the membranes exhibited irreversible fouling (loss of permeability)
NORIT					
Optimization	5/15/2007	7/24/2007	-	-	Pilot unit was removed from the site at the end of the optimization run
Optimization	11/16/2007	12/5/2007	-	-	New pilot unit with greater production capacity was delivered and installed at the beginning of the optimization run
65 gfd	12/5/2007	1/24/2008	54.61, 59.6	92.9	Successfully operated for 30 days, but unable to sustain operation during confirmation run (high TMP)
60 gfd	1/24/2008	1/31/2008	56.87	92.3	Unable to operate for 30 days (rapid rise in TMP)
50 gfd	1/31/2008	2/5/2008	47.58	90.8	Unable to operate for 30 days (rapid rise in TMP)
40 gfd	2/11/2008	2/29/2008	33.39	88.5	Unable to operate for 30 days (rapid rise in TMP)
PALL					
Optimization	5/15/2007	6/22/2007	-	-	-
45 gfd	6/22/2007	7/7/2007	31.74	93.5	Unable to sustain operation (high TMP)
40 gfd	7/7/2007	9/24/2007	27.64, 26.99	92.7	Operated for 30 days, but multiple EFM's required during confirmation run. Therefore, full-scale design cannot be substantiated.
Optimization	9/25/2007	11/15/2007	-	-	-
36 gfd	11/16/2007	12/5/2007	29.63	92.0	Unable to operate for 30 days with a single EFM per day
30 gfd	12/14/2007	2/24/2008	26.94, 27.11	90.4	Successfully operated for 30 days, but unable to sustain operation during confirmation run (high TMP)
25 gfd	2/24/2008	7/18/2008	20.32, 17.74	88.6	Successfully operated for 66 days. 72 day follow-up confirmation run also successful.

Three of the four tested pretreatment units (the conventional system, GE Zenon, and Norit) failed to prove sustainable operation without exhibiting significant fouling tendencies and, in the extreme case, irreversible fouling on the membrane surface. It should be noted that the GE Zenon (ZW-1000) system was able to operate without performing a CIP for the minimum required 30 days. Fouling was present on the membranes due to the inability of the system to operate at greater than 15 gfd in a sustainable fashion. What is known is that organic fouling occurs in seawater applications similarly to other surface water sources; though the exact mechanism at Brownsville cannot be determined with the Zenon fiber. The Zenon system has operated consistently at fluxes of approximately 25 gfd at other seawater pilot locations such as Carlsbad, West Basin, Sydney (Australia) and others. However, due to the site-specific interaction of organics and inorganics at these locations, it cannot be determined if the cause was attributed to an accumulation of organic foulants throughout the piloting study or due to the hydrophilicity (slightly negative) charge of the membrane surface. It is possible that coagulant addition might have delayed the fouling effect. Should the GE Zenon, Norit, or conventional pretreatment units have proven sustainable operation throughout the course of the Pilot Study, an analysis of capital and O&M costs would have been performed in order to evaluate the most cost-effective method to move forward with a production seawater desalination facility. However, since sustainable operation was never proved with these systems, no such analysis was performed.

The fourth pretreatment unit (Pall Microza system) did successfully operate for periods of 66 days and 72 days during two separate runs performing TCEQ Stage 2 and Stage 3 of the pilot protocols. Therefore, Chapter 5 presents the results of the capital and O&M costs associated with using Pall as the pretreatment system for a production seawater desalination facility.

The Pilot Study met the objective of developing a sufficient amount of real time information and data to demonstrate the technical feasibility of a successful pretreatment system. The following known conclusions apply to the successful pretreatment system for this Pilot Study:

1. The Pall Microza MF system proved to have the capability to operate under the worst case scenarios of high turbidity, TSS spikes, and variable raw water temperatures.
2. A flux of 25 gfd with a filtration duration per cycle of 15 minutes, daily EFMs utilizing 400 ppm of NaOCl and a system recovery of 88.6% were determined to be the optimum operational settings for the design of a Pall MF system at this site specific location.
3. The system is capable of sustainable operations for greater than 60 days at the optimum flux of 25 gfd without having to perform a CIP.
4. The Pall pretreatment system consistently removed greater than 97% of the raw water TSS.
5. The Pall MF system at 25 gfd achieved established testing goals and water quality guidelines of the pilot protocols which included:
    a. SDI<3 (100%) and <2.0 (95%)
    b. Filtrate Turbidity of <0.2 NTU at the optimum flux of 25 gfd
    c. >3-log removal for Giardia
    d. >2-log removal for Cryptosporidium

Although sufficient amount of information and data was developed during the Pilot Study, the following conclusions, albeit unfounded during pilot testing, may apply to the successful pretreatment system for this Pilot Study:

1. The capability to operate at higher fluxes if a conventional system was implemented ahead of the Pall MF system.
2. Potential capital and O&M cost savings with a combination of conventional and MF systems as pretreatment for seawater RO.

Therefore, the following recommendations are suggested to become part of the design criteria for the demonstration-scale desalination facility:

1. Make provisions on the design phase to implement two separate stand alone Pall microfiltration trains. Train A is to be designed as piloted during the pilot plan study. Train B is to be designed with a conventional (rapid mix and solids contact clarifier) system ahead of the microfiltration process. This will develop operational flexibility during the demonstration phase and provide data for implementation of future expansions.
2. The flexibility of Train B (conventional with microfiltration) to be tested in different scenarios as further described in Section 5.

4.4 REVERSE OSMOSIS

Two separate RO membranes were piloted at the facility: FilmTec Model SW30HR LE-400i and Toray Model TM820-400. RO recovery is an important factor when analyzing salt precipitation in addition to the impacts of boundary layer biomass and permeability. The FilmTec elements were operated at recoveries of 50% and 48.8%. At 50% recovery, the membranes exhibited an unacceptable rate of fouling, and subsequently the recovery was lowered to 48.8%. In addition to lowering the recovery to 48.8%, site piping was cleaned and the RO elements were subjected to a high pH CIP prior to inception of the performance test. The Toray elements were operated at a recovery of 48.8% throughout their pilot test.

The conservative trigger point for performing a clean on the RO membranes is either a 15% decrease in normalized permeate flow compared to start-up (clean) conditions, and/or normalized salt passage, or a 20% increase in DP. Based on the results of the FilmTec performance run, the system exhibited a 15% decrease in normalized permeate flow after accumulating an equivalent of 69 days of runtime. Mechanical issues with pretreatment equipment prevented the continuous operation of the RO system. Due to a lack of pretreated water available to the RO system, the system was actually in operation for a period of 118 calendar days. The system exhibited a 20% increase in DP after accumulating an equivalent of 79 days of runtime. This corresponds to 123 calendar days. At this time, the normalized permeate flow had decreased 18.7% from the initial value.

Based on corroborating discussions with Filmtec, it was believed that initiation of a membrane cleaning would be performed when the DP reached 31 psi (the DP at the onset of the run was 24 psi). After an equivalent of 90 days of runtime, the system reached a DP of 31 psi. A clean was performed, and the post clean DP was 24 psi marking a 100% recovery of DP. However, normalized permeate flow did not recover to previous levels.

A cleaning test and autopsy were ordered to determine a cleaning recipe that would recover the normalized permeate flow. The elements were inspected, performance was compared to as-new conditions, cleaning recommendations were made, and the elements were autopsied. These test results indicated that rejection and flow on two of the elements was within the specification for new elements. However, flow for the third element was below the minimum specification for new elements and was returned to within the flow specification with routine cleaning procedures. Oxidation was not observed for any of the elements.

Upon startup, the Toray membranes exhibited the following performance:

- Normalized permeate flow = 15.9 gpm
- Differential pressure = 24 psi
- Salt passage = 0.39%
- Water mass transport coefficient = 0.0221 gfd/psi.

After operating for an equivalent period of just over 90 days (148 calendar days), the normalized permeate flow decreased 15% from the value recorded at the beginning of the 48.8% recovery run.

During the run, the normalized salt passage was stable; however the normalized flow decreased and the normalized DP increased. After operating for an equivalent period of 79 days (123 calendar days), the DP increased 20% from the value recorded at the beginning of the 48.8% recovery run. The typical trigger point for performing a clean on the SWRO membranes is either a 15% decrease in normalized permeate flow or a 15 to 20% increase in DP. Any existing SWRO plant may clean at a higher or lower rate of change since the trigger point for existing installations is based on the previous historical operation and maintaining membrane manufacturer's warranty conditions; however there was no operating history to direct specific alternatives. After discussion with the team and the membrane manufacturer, it was decided to continue the run until 31 psi differential was reached.

A high pH CIP was performed on June 14, 2008. After re-starting the skid, the determination was made that fully restored membrane conditions were not reached. Although the DP was restored to previous levels; normalized permeate flow, water mass transport coefficient, and normalized salt passage were not apparently restored. The normalized permeate flow was 12% below the startup value and the normalized DP about 8% above the startup value.

An autopsy was performed on all seven Toray elements at the conclusion of the piloting test. The factory re-test results indicate the average salt rejection decreased slightly during the 6 month test. The re-test results also show a slight decrease in productivity. However, the lead element flow declined 21% compared to as-new condition. The lead element underwent a thorough cleaning analysis involving low and high-pH (which restored productivity to within 15% of new); with the addition of an extended soak time. The second cleaning event incorporating a 12 hour soak time was deemed successful; restoring the productivity of the lead element within 2% of the original wet test productivity.

It is concluded that, at a minimum, the RO system was able to perform without the need to clean for an equivalent of 69 days (118 calendar days) based on normalized permeate flow of the FilmTec elements. The Toray elements exhibited slightly better performance in this regard. In terms of DP, the system was able to operate without the need to clean for an equivalent of 79 days (123 calendar days) for both the Toray and FilmTec elements. If the pretreatment units were able to provide ample flow to the RO train, it is possible that extended runtime, above the 90 days that was tested, would be possible. Frequent shutdowns can cause mechanical problems with the membranes as well as increase the likelihood of biological growth on the membrane surface, both of which can cause premature increases in DP and salt passage as well as decreases in normalized permeate flow and water mass transport coefficient.

It is recommended that the cleaning schedule for the full-scale desalination facility incorporates a clean between 69 and 90 days of runtime. The implication with an increase in cleaning intervals is a reduced useful life of the membranes.

The Pilot Study met the objective of developing a sufficient amount of real time information and data to demonstrate the technical feasibility of a successful treatment system. The following conclusions apply to the SWRO membrane elements piloted for this study:

1. The FilmTec Model SW30HR LE-400i and the Toray Model TM820-400 seawater membrane elements proved to have the capability to operate under the worst case scenarios of variable raw water temperatures and TDS.
2. A flux of 8.2 gfd at a maximum recovery of 48.8% was determined to be the optimum operational settings for the design of this site specific SWRO system.
3. The SWRO systems for both membrane suppliers are capable of sustainable operations for up to 70 days at the optimum flux of 8.2 gfd and 48.8% recovery.
4. The tested membrane suppliers achieved established testing goals and water quality guidelines of the pilot protocols to include:
    a. Compliance with current and future water standards
    b. THM formation potential of <40 μg/L
    c. Permeate turbidity of <0.1 NTU

Although sufficient amount of information and data was developed during the Pilot Study, the following conclusions, albeit unfounded during pilot testing, may apply to the successful pretreatment system for this Pilot Study:

1. Effects of operating a SWRO membrane system at changes above or below the standard recommended percentages of 15% and 20% for delta P, normalized permeate flow, and normalized salt passage. A membrane autopsy and cleaning analysis was performed for each set of membranes but results were not available at the time of the report.
2. The capability for a cartridge filter changeout frequency of 90 days
3. Potential elimination of cartridge filters.
4. Testing and evaluation of a biocide for improved performance of the SWRO membranes.
5. Testing of chlorine dioxide for control of potential biogrowth and improved performance of SWRO.

It is suggested that the following recommendations become part of the design criteria for the demonstration-scale desalination facility:

1. Operate at a recovery of 45% with a flux of 8.1 gfd
2. Provide a bypass around the cartridge filters.

3. Include additional space in the chemical feed systems to test a biocide.
4. Include chlorine dioxide as part of the chemical feed systems.

4.5 CONCENTRATE DISPOSAL

Both concentrate disposal methods (diffusion into the Gulf of Mexico and injection wells) would be technologically feasible at the full-scale facility. However, a cursory analysis of implementation costs revealed that deep well injection is cost prohibitive at higher flow rates.

Deep Well Injection
Based on the full scale concentrate flow rate of 30.6 mgd (25 mgd RO permeate at 45% RO recovery), it was estimated that the wells will accept injection at between 400 gpm and 200 gpm, requiring a wellfield of between 49 and 96 wells (respectively). The concentrate would most likely be considered non-hazardous and will be appropriate for disposal into a Class I (non-hazardous) injection well system according to the technical requirements established in 30 TAC 331 using Form TCEQ-0623. On a technical level, concentrate disposal via deep-well injection is a feasible method of concentrate disposal.

As previously discussed in Chapter 3.0, assuming an individual well cost of approximately $850,000 and individual well injection between 400 gpm and 200 gpm, a wellfield of between 49 and 96 wells would be required for a full-scale (25 mgd) seawater desalination facility. Therefore, the total cost of this wellfield is estimated to be between $36.8 million and $81.6 million.

Diffusion in the Gulf of Mexico
To facilitate a preliminary design of a multi-port diffuser array in the Gulf of Mexico, a flow and dispersion model was utilized. A discharge location approximately 0.5 miles east of Boca Chica Beach and approximately 2 miles north of the mouth of the Rio Grande was modeled. Based on long shore currents and water depth in the vicinity, the model predicted brine concentrations to be near ambient within 125 feet of the diffuser array. The model considered full-scale, worst-case conditions of 25 mgd effluent at 80,000 mg/L TDS.

During the RO performance test runs at 48.8% recovery, the concentrate TDS ranged from 55,800 mg/L to 68,700 mg/L. These values fall below the concentrate TDS that was utilized when modeling the multi-port diffuser array in the Gulf of Mexico. It can therefore be inferred that dispersion in the Gulf of Mexico is a feasible method of concentrate disposal. At an RO recovery of 45%, the average concentrate TDS, using a mass balance of feed and permeate data acquired during the pilot, would be approximately 56,000 mg/L.

Major components of this concentrate disposal method include the transfer pump station, open cut (land) and ocean installation of the main pipeline, diffuser array, and easement acquisition. For a full-scale (25 mgd) seawater desalination facility, the total estimated cost for this system is approximately $19.9 million.

Chemical water quality standards in the Gulf of Mexico exist only for dissolved oxygen and pH. These would not be affected by a discharge from a desalination plant. There are no TDS standards. Regulatory requirements for the discharge would be more qualitative in nature, seeking to prevent adverse impacts on the ecosystem in the vicinity of the discharge, such as the creation of a significant "dead zone." The modeling showed that such an impact is extremely unlikely with a properly designed diffuser array.

4.6 FINISHED WATER QUALITY

Permeate water quality, as produced by the RO process, met all primary and secondary water quality standards without the need for additional treatment with the exception of pH (Table 4-2). In addition to these standards, design goals for finished water quality were established prior to commencing pilot testing. Of these additional parameters, the RO process was able to produce a quality of water that met the design goals, with the exception of alkalinity and total coliform (Toray membranes only). Ultimately, treated permeate must be compatible with the existing distribution system and fall within regulatory requirements for disinfection.

The following conclusions apply to the finished water quality, as produced by the RO process, for this study:

1. A system consisting of MF and RO is capable of treating raw water from the Brownsville Ship Channel to a quality that exceeds the primary and secondary standards, with the exception of pH.
2. Of the additional water quality components deemed important, a system of MF and RO is capable of treating raw water from the Brownsville Ship Channel to a quality that exceeds these additional water quality components, with the exception of alkalinity and total coliform (Toray only).
3. The finished water quality complies with the Stage 1 Disinfectant and Disinfection Byproducts Rule. The total trihalomethanes (TTHMs) and HAA5 levels were below the maximum contaminant limits. TTHM and HAA potentials were obtained by dosing chlorine and incubating the sample with the method described in Chapter 3.
4. The feed water quality results for cryptosporidium over a one year testing period indicated that the system will be classified as a Bin 1 with less than 0.0075 oocysts/L. This demonstrates that the process system will have the capability to meet the requirements of the LT2ESWTR.

Although sufficient amount of information and data was developed during the Pilot Study, the following conclusions, albeit unfounded during pilot testing, may apply to the successful pretreatment system for this Pilot Study:

1. The root cause of total coliform being present in the permeate produced by the Toray elements was most likely caused by contamination of the permeate piping and not a mechanical problem with the membrane.

Table 4-2: RO permeate water quality at a recovery of 48.8% and a flux of 8.2 gfd.

Parameter	Units	FilmTec RO Permeate	Toray RO Permeate	Design Goal/ TCEQ Standard
PRIMARY MCL				
Antimony	mg/L	<0.002	<0.002	0.006
Arsenic	mg/L	<0.002	<0.002	0.01
Barium	mg/L	<0.001 to 0.00459	<0.005	2
Beryllium	mg/L	<0.001	<0.001	0.004
Cadmium	mg/L	<0.001	<0.001	0.005
Chromium	mg/L	<0.001	<0.001	0.1
Cyanide	mg/L	<0.005	<0.005	0.2
Fluoride	mg/L	<0.5	<0.5	4.0
Mercury	mg/L	<0.00015	<0.0015	0.002
Nitrate	mg/L	<0.25	<0.25	10
Nitrite	mg/L	<0.01	<0.01	1
Selenium	mg/L	<0.002	<0.002	0.05
Thallium	mg/L	<0.001	<0.001	0.002
SECONDARY LEVEL				
Aluminum	mg/L	<0.01	<0.01	0.05 to 0.2
Chloride	mg/L	74.1 to 139	68.8 to 161	300
Color	PCU	<5	<5	<5
Copper	mg/L	<0.001 to 0.00443	<0.001	1.0
Fluoride	mg/L	<0.5	<0.5	2.0
Hydrogen Sulfide	mg/L	<0.02	<0.2	0.05
Iron	mg/L	<0.1	<0.1	0.3
Manganese	mg/L	<0.001 to 0.00387	<0.001	0.05
Odor	Threshold odor number	None	None	3
pH	-	6.4 to 6.9	6.3 to 6.9	>7.0
Silver	mg/L	<0.001	<0.001	0.1
Sulfate	mg/L	<1.5	3.34 to 5.23	100
TDS	mg/L	188 to 306	132 to 320	<500
Zinc	mg/L	<0.02	<0.03	5
OTHER				
Alkalinity	mg/L	2.9 to 6.4	5 to 6	75 to 150
Hardness – total	mg/L	<5	<2.5 to 9.28	<250
Turbidity	NTU	0.017 to 0.098	0.033 to 0.096	<0.2
DOC	mg/L	<0.9	<1.5	<2
THM FP	mg/L	<0.001	<0.001 to 0.0073	<0.040
HAAs	mg/L	<0.005	<0.005	<0.030
Total Coliform	in 100 mL	Negative	Positive	
Boron	mg/l	0.798 to 1.38	0.712 to 1.55	n/a

2. A determination must be made to determine the most beneficial use of desalinated seawater in the distribution system. Once that determination is made, a paper-study of distribution system compatibility shall be undertaken. In addition, a distribution system simulation and mixing test program would also support the ideal level of post-treatment necessary for the SWRO plant.

It is suggested that the following recommendations become part of the design criteria for the demonstration-scale desalination facility:

1. Implement post treatment to raise the alkalinity and pH of the finished water. The post treatment could include a combination of chemicals such as caustic soda (pH control), sodium bicarbonate for alkalinity, and calcium chloride for addition of calcium. This combination of chemicals will produce stable, non-corrosive water.

4.7 ENVIRONMENTAL REVIEW AND PERMITTING

4.7.1 Permitting Assessment for Full-scale Plant

Permitting activities for a production seawater desalination plant will include many agencies. A list of probable required federal, state, and county and local permits and approvals are presented in Tables 4-3, 4-4 and 4-5.

Table 4-3: List of federal permits and approvals necessary for a full-scale seawater desalination plant.

Federal Agency	Permit or Approval	Action
U.S. Army Corps of Engineers	Sections 404 and 10 Permits (Clean Water Act)	Facility construction impacting navigable waters (including dredge and fill operations, wetlands)
U.S. Fish and Wildlife Services	Endangered Species Act Consultation	Review for habitat, endangered and threatened species, including seasonal or migratory
National Marine Fisheries Service	Consultation on Marine Habitat	Essential Fish Habitat for Laguna Madre, Gulf of Mexico waters
U.S. Environmental Protection Agency	SPCC Plan	On-site storage of fuel for plant facilities, construction equipment and pipeline ROW activities
	Acid Rain Program Designated Representative	Assignment of a Designated Representative and Alternate for the Acid Rain Program
	Certification of Continuous Emission Monitoring System (CEMS)	Operation of CEMS System in compliance with Title IV of the Clean air Act (CAA) – Acid Rain Program for power plant
	Risk Management Plan	Storage or use of hazardous air pollutants (such as ammonia)
Advisory Council on Historic Preservation	Section 106 Compliance	Required if SHPO mandates cultural survey, and if site is found to require mitigation.
Federal Aviation Administration	Determination of Obstruction Hazard	Construction of tall structures such as power plant stack
U.S. Department of Energy	Alternative Fuels Capability Certification	Construction and operation of base load power plants
Federal Energy Regulatory Commission	Qualifying Facility Certification	Cogeneration Facilities
	Exempt Wholesale Generator	Wholesale electricity sales

Source: Derived from Dannenbaum and URS (2004) with modifications and revisions.

4.7.2 Critical Permitting Issue: Concentrate Disposal

Many of the permits and approvals identified above are standard requirements for constructing or operating water treatment and distribution facilities. Others, however, represent more specialized approvals such as intake design and concentrate disposal. Such permitting issues could significantly affect the cost and timeline to develop a seawater desalination facility due to the unique nature of the water treatment technology. The most critical of these appears to be that of concentrate disposal.

Of the alternative methods evaluated in at the Feasibility Level, it appears that disposal by discharge into the Brownsville Ship Channel or by evaporation both have fatal design and permitting flaws at full-scale (25 mgd) capacity. The viability of the two alternatives evaluated in this Pilot Study (diffusion into the Gulf of Mexico and deep well injection) depends largely on cost effectiveness.

Table 4-4: List of state permits and approvals necessary for a full-scale seawater desalination plant.

State Agency	Permit or Approval	Action
Texas Parks and Wildlife Department	Protected species consultation	Facility construction impacting essential habitat for federally protected species
Texas State Historic Preservation Office	Texas Antiquities Code consultation	Project activities that will potentially affect cultural and /or historic resources subject to state protection requirements.
Texas General Land Office	Coastal Use Permit, Coastal Zone Management Act	Project activities that will potentially impact navigable waters of the US in coastal zone Texas
	Right-of-way	Construction of off-shore facilities, such as concentrate disposal line
Texas Commission on Environmental Quality	Small-Quantity Hazardous Waste Generator Identification Number	On-site presence of hazardous waste in quantities greater than threshold amounts
	Texas Pollutant Discharge Elimination System Permit	Discharge of wastewater to surface waters during construction
	TPDES – Storm Water General Permit Operational Site	Industrial storm water runoff during construction
	Wastewater Facility Construction Approval	Construction of wastewater treatment equipment (oil separators, etc.)
	TPDES – Construction Storm Water General Permit	Temporary storm water discharge during construction period and until revegetation
	Section 401 (Clean Water Act) Certification Consultation	Facility construction near rivers, streams, lakes (including deep waters), and wetlands
	Well Drilling/Installation Permit	Installation of new groundwater wells used for non-public drinking water system
	Water Quality Certification	Issuance of USACE 404 permit
	Wetlands Alteration Review	Construction in a wetlands (in conjunction with USACE 404 permit)
	New Source Review and Title V Operating Permit	Operation of major source of air pollution, including facilities required to have an Acid Rain Permit
	Phase II Acid Rain Permit	Operation of an affected source under Phase II of the Acid Rain Program
Texas Department of Transportation	Highway Alteration Permit	Construction of access road connection to state highway

Source: Derived from Dannenbaum and URS (2004) with modifications and revisions.

Table 4-5: List of county and local permits and approvals necessary for a full-scale seawater desalination plant.

County or Local Agency	Permit or Approval	Action
County	County Zoning Permits	Contact to determine existence of zoning law and obtain permits, if warranted
	Noise Requirements	Nuisance standard for noise
	Conditional Use Permit/Zoning Changes	Construction of facilities not specifically allowed by local zoning ordinances
	Beach construction certificate, Beach Protection Act	Construction of facilities within protected beach set-back areas
	Dune protection permit, Dune Protection Program	Construction of near-shore facilities in stabilized, vegetated dune areas
	Building/Occupancy Permits	Construction of plant buildings
TCEQ – County Authorized Agent	On-Site Sewage Facility Permit	Construction and operation of septic systems with inflow less than or equal to 5,000 gpd
County and/or Township Highway Department	Local Road Construction Permit(s)	Construction of access road connection to local road
County Soil and Water Conservation District	Soil Erosion and Sediment Control Plan	General site development

Source: Derived from Dannenbaum and URS (2004) with modifications and revisions.

Permitting for diffusion into the Gulf of Mexico or injection wells appears to be viable, especially given the precedent established in permitting discharges from exploration, development, and production facilities. However, for diffusion into the Gulf of Mexico, predictive models more elaborate than the CORMIX model previously discussed may be required to address concerns about potential habitat impacts to the five endangered sea turtle species along the Texas Gulf Coast or other Essential Fish Habitats established by the National Marine Fisheries Service.

4.7.3 Environmental Advisory Group

Full-scale seawater desalination for municipal purposes is new to Texas, the Brownsville project representing the first such project in the state. As a result, the process to identify and minimize potential adverse environmental impacts from the construction and operation of a full-scale facility will be a significant part of subsequent phases. In addition to the many different agencies that will have a regulatory (permitting) role in implementing a seawater desalination plant in Brownsville, many other organizations maintain a strong interest in environmental resources along the South Texas coast.

In 2008, in anticipation of the conclusion of the piloting phase and initiation of the production phase of the overall project, BPUB began to canvass state and federal resource agencies, non-governmental entities, and local organizations about potential resource concerns. It is the goal of BPUB to proactively involve these groups during the development of the production phases of the project by assembling a technical advisory group.

The proposed Environmental Advisory Group would provide a science-based forum where environmental issues associated with the construction and operation of a full-scale seawater desalination facility may be identified and solutions integrated into the design process, specially with regard to minimizing adverse impacts from the construction and operation of the raw water intake and concentrate disposal systems. The group would meet periodically during the project design and permitting phases and fulfill the following responsibilities:

- Attend periodic briefing meetings on the status and scope of the proposed full-scale desalination project.
- Provide constructive review of proposed facilities and identify potential environmental resource issues.
- Provide references to relevant existing data, research, and personnel that could assist in addressing resource issues in the study area.
- Assist in the development and evaluation of conceptual ideas to avoid or minimize any identified adverse impacts.
- Identify regulatory and permitting requirements for construction and operation of the proposed full-scale facility.

To date, the following organizations have expressed a willingness to serve on the proposed seawater desalination Environmental Advisory Group:

- Brownsville Public Utilities Board
- U.S. Fish and Wildlife Service
- Texas Parks and Wildlife Department
- Texas Water Development Board
- Sierra Club
- Harte Research Institute for Gulf of Mexico Studies
- Center for Research in Water Resources

Other entities will also be included in the advisory group as the next phase of the project is initiated.

5.0 Recommendations

5.1 PRIMARY RECOMMENDATION

It is recommended that a 2.5 mgd demonstration-scale seawater desalination project be designed and constructed on the south shore of the Brownsville Ship Channel. This demonstration plant will provide BPUB with additional water supply and allow for the development of technology for other seawater desalination plants in Texas.

Approximately half of the cost of the proposed demonstration project includes infrastructure to provide for future full-scale capacity; especially the intake system, brine discharge pipeline to the Gulf of Mexico, and other site facilities. The largest cost component of a full-scale facility will be for water treatment; especially the pretreatment system. Given the raw water quality challenges at the ship channel site, the cost for the pretreatment system is much higher than at other locations. For the proposed demonstration project, the water treatment system will initially be sized to provide only 2.5 mgd of production capacity.

This stepped approach for this system will allow operational comparisons of various pretreatment applications during several years of production conditions prior to an investment in full-scale pretreatment capacity. This information is expected to yield a more efficient overall treatment system design and lower the cost of the future expansions when they occur. The demonstration facility will also include the capability for continuous testing of the latest desalination technologies for this and other future seawater desalination facilities along the Texas Gulf Coast. Such technologies include applications for pretreatment, energy recovery, sustainable energy supply, and larger membranes (lower cost per size of membrane).

5.1.1 Pilot Study Implications for a Full-scale Facility

Early in 2008, TWDB requested a conceptual facility layout and cost estimate for the envisioned full-scale 25 mgd desalination plant based on piloting results obtained to date. Although testing was still underway, it had become clear that current membrane technology could reliably provide potable water from seawater in the ship channel. Therefore, a preliminary facility design (Table 5-1) and construction estimate (Table 5-2) were prepared for a full-scale 25 mgd seawater desalination plant and compared with the previous Feasibility Study estimates.

Based on preliminary pilot results, a full-scale (25 mgd) seawater desalination plant at the Brownsville Ship Channel was determined to require a total cost of approximately $182 million (2008 dollars). To ensure long-term operational success of the plant, about 26 percent of this preliminary estimate had to be allocated to pretreatment facilities alone. After considering the costs of other water supply alternatives available for the future needs of Brownsville, BPUB determined that it could afford up to $70 million for a full-scale (25 mgd) seawater desalination project. This would leave an infeasible funding gap of over $100 million. In addition, the full anticipated regional water demand envisioned for the full-scale (25 mgd) facility is not expected to materialize for several years.

Table 5-1: Comparison of Feasibility and Pilot Study recommendations for a full-scale (25 mgd) seawater desalination plant.

Project Component	Feasibility Study Design Recommendation [a]	Pilot Study Design Recommendation
Intake	Side channel from the Brownsville Ship Channel with screened intake	Side channel from the Brownsville Ship Channel with inlet canal and screened intake
Pretreatment	Ballasted flocculation, dual-media filtration, cartridge filtration	Clarification, microfiltration, cartridge filters
Primary Treatment	Two-pass high pressure RO with energy recovery	Single pass high pressure RO with energy recovery
Post-treatment	Pebble lime stabilization, on-site generated sodium hypochlorite disinfection	Lime stabilization, chlorination
Finished Water Transmission	Pipeline to offsite storage	Pipeline to onsite storage
Brine Disposal	Diffusion into the Gulf of Mexico via ocean outfall	Diffusion into the Gulf of Mexico via ocean outfall
Solid Handling	Flocculation basins, gravity thickeners, belt line presses	Sludge lagoons

[a] *Source*: Dannenbaum and URS (2004).

Table 5-2: Comparison of Feasibility Study and Pilot Study total project cost estimates for a full-scale (25 mgd) seawater desalination plant.

Project Component	Feasibility Estimated Cost [a] (2004)	Pilot Study Estimated Cost (2008)
Desalination Plant	$90,167,000	$126,612,000
Concentrate Disposal System	$30,583,000	$21,217,000
Finished Water Transmission System	$9,232,000	$12,180,000
Project Implementation Costs	$21,406,000	$22,400,000
Total Capital Costs	**$151,388,000**	**$182,409,000**

[a] *Source*: Dannenbaum and URS (2004).

A summary comparison of major facility components of the full-scale (25 mgd) and the proposed demonstration-scale (2.5 mgd) seawater desalination facilities is presented in Figure 5-1.

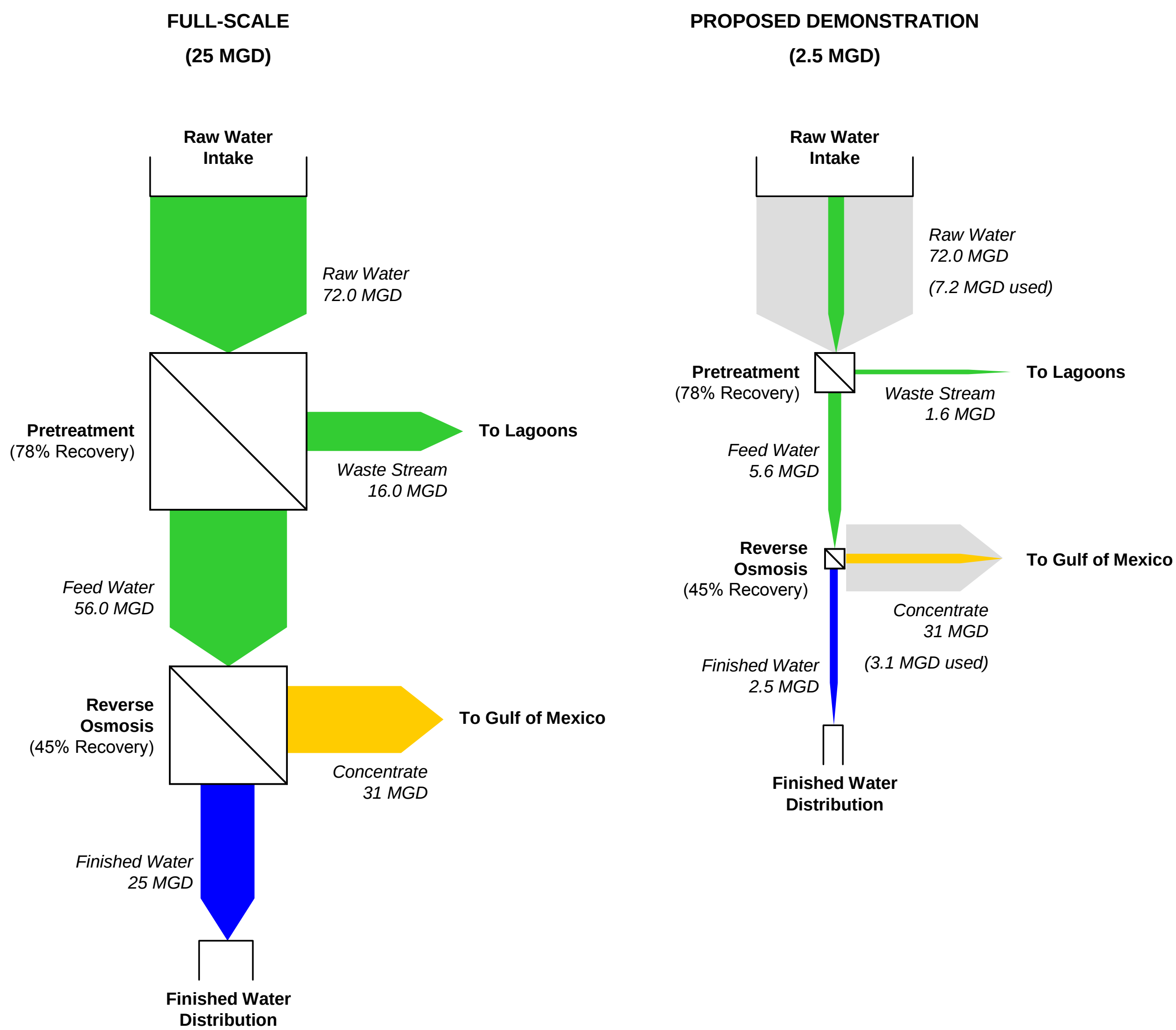

Figure 5-1: Comparison schematic between the full-scale (25 mgd) and recommended demonstration-scale (2.5 mgd) seawater desalination projects.

5.1.2 Why a Phased Approach

Pilot Study results proved currently available desalination technologies are capable of producing high quality freshwater from seawater extracted from the Brownsville Ship Channel. However, constructing a full-scale facility now would involve some uncertainty and risk. For example, prolonged adverse raw water conditions are possible that were not tested during the pilot period, such as from a "red tide" event or major hurricane. Also, permitting for concentrate disposal into the Gulf of Mexico would be required based only on modeling and actual field measurements would be lacking. Finally, considerable improvement to raw water quality (and therefore capital and operational costs) is suspected to be gained by the proposed demonstration project relocation of the intake to the south side of the ship channel (away from the prevailing winds) and expansion of the intake channel to allow for longer settling times prior to treatment. The recommendation to pursue a phased project development approach will best mitigate these risks and uncertainties associated with seawater desalination (Figure 5-2 and Table 5-3).

Project Phase	**FEASIBILITY**	**PILOT**	**DEMONSTRATION**	**PRODUCTION**	**PRODUCTION**
Knowledge of Costs and Process at End of Phase	*Uncertainty*			*Certainty*	
Status of Brownsville Seawater Desalination Project	*Completed (2004)*	*Completed (2008)*	Pending (2012)	Future (2025)	Future (2050)
Production Capacity	-	-	2.5 mgd	12.5 mgd	25 mgd
Percent of Full-scale	-	-	10%	50%	100%

Figure 5-2: Phase project approach and the relative degree of uncertainty and risk associated with the Brownsville Seawater Desalination Project.

Table 5-3: Summary of a phased project development approach for seawater desalination.

Phase	Description	Typical Duration
Feasibility Study	Desktop evaluation of existing data and information to determine the engineering, environmental, and economic feasibility.	Varies by scope
Research and Laboratory Studies	Bench-scale tests or laboratory studies used to determine whether use of a process or technology could be successful. Such activities can be conducted as part of a Pilot Study.	13 months or less
Pilot Study	Small-scale facility used to evaluate actual performance of proposed treatment systems under site-specific conditions to determine the physical and economic suitability of a process. Project objectives include developing capital and operating cost estimates.	25 months or less
Demonstration Project	Moderate-scale facility used demonstrate physical and economic viability of treatment process that can include production capacity. Capital and operation costs are developed in detail based on actual performance.	37 months or less
Full-production Project	Large-scale facility used to provide potable water supply.	20 years or more

Source: U.S. Bureau of Reclamation Desalination and Water Purification Research and Development Program

This approach will allow a more informed comparison of seawater desalination with other water supply alternatives available to the BPUB prior to a commitment to costs of a full-scale production facility and may provide an opportunity to lower the ultimate cost of that facility.

5.1.3 The Precedent of Demonstrating Brackish Groundwater Desalination

The concept of a smaller, demonstration plant requires less investment to prove an operational facility yet still meets the immediate water supply needs of the Brownsville area. The value of such a phased approach has already been established in the area with brackish groundwater desalination. In 1995, TWDB teamed with the BPUB to perform a feasibility study and implement a pilot plant for the development of brackish groundwater desalination. This project proved the feasibility of the technology in and around Brownsville. At the time, sufficient treatment capacity was available from the river and the education toward desalination was still new, especially in Texas. Therefore, BPUB was not ready to implement a large-scale groundwater desalination project.

It is difficult for most entities to be the first to implement a large-scale project where a major investment is required. With new technology, there is some risk, even if only perceived. One regional entity, however, did decide to implement a small (demonstration-scale) groundwater desalination project. Utilizing the feasibility and piloting information derived from the previous project, the Valley Municipal Utilities District No. 2 constructed 250,000 gallon per day, brackish desalination plant in 1999. This plant, located adjacent to the BPUB service area, would provide about 30 percent of the total water need.

Successful demonstration of the technology had major significance in the development of brackish groundwater in South Texas. The small production plant developed by Valley Municipal Utilities District No. 2 demonstrated the viability of groundwater desalination in the area and provided actual cost and treatment data. In addition to providing actual capital and operation costs, other entities could also actually visit the plant in operation.

Since 1999, five major brackish groundwater desalination plants have been completed or are nearing completion in the three county area. This includes completion of the 7.5 mgd Southmost Regional Water Project in 2004, which was first evaluated under the original BPUB feasibility study and now provides 40 percent of the Brownsville water supply. The project has proven that it is as cost effective, if not more so, than conventional surface water treatment.

Regional water planning was also impacted by the initial facility completed by the Valley Municipal Utilities District No. 2 project. Out of 61 municipalities in the Region, there were no entities shown in the 2001 Regional Plan that listed desalination as a water management strategy to meet future needs. When the update to the plan was completed, over half of the entities indicated desalination as a strategy to meet current and/or future needs.

Based upon this experience in the phased development of brackish groundwater desalination, it is believed that there should be a similar process for seawater desalination in the state. This type of facility, inland from the Gulf, would be similar to other facilities that could be located along the Gulf Coast of Texas. Implementing a facility would show the rest of Texas that this alternative will have a significant impact on the water supply in the future from the State's only unlimited supply of water.

5.2 DEMONSTRATION PROJECT CONCEPTUAL DESIGN

The following section presents an overview of the conceptual design developed for the demonstration-scale seawater desalination facility (Demonstration Project). The facility will be capable of producing an initial potable water supply of 2.5 mgd for the City of Brownsville.

5.2.1 Design Considerations

The conceptual design for the Demonstration Desalination Project was based on the following considerations:

- An initial production capacity of 2.5 mgd.
- The established raw water characterization of the seawater source at the Brownsville Ship Channel.
- The operational flexibility of a demonstration facility to continue research of several pretreatment systems. These systems include conventional treatment (rapid mix/flocculation/clarification) followed by microfiltration, microfiltration as a stand alone pretreatment process piloted during the Pilot Study and any other pretreatment systems not tested.
- The conventional pretreatment system will be the same as that piloted during the Pilot Study. This design includes an overflow rate for the clarifier of 0.6 gpm/ft2. This design will allow the flexibility to test the process at higher overflow rates if proved to be optimum for the operation of the plant. As piloted, the conventional pretreatment system was not capable of providing high quality filtrate to feed the RO system. In regards to the demonstration facility, the conventional system will not be depended upon to feed the RO. Rather, it will be used for bulk removal of organics and inorganic constituents that may be present in the seawater supply.
- The microfiltration system will be the same as the successful microfiltration system piloted during the Pilot Study. This design includes optimum process operating conditions of the successful tested pretreatment system with a flux of 25 gfd. The Pall Corporation Microfiltration System successfully completed the requirements of the Pilot Study, and the pretreatment concept will be designed based on this microfiltration system.
- The reverse osmosis sytem will be the same as that as piloted during the Pilot Study. This design includes optimum process operating conditions of successfully tested pretreatment system with a flux of 8.1 gfd at 45% recovery. Toray and FilmTec successfully completed the requirements of the Pilot Study. The reverse osmosis treatment concept will be designed based on these two types of membranes.
- By oversizing select components of the facility (treatment building, site piping, and chemical feed systems), future expansion of the Demonstration Desalination Project up to a total of 5.0 mgd will be possible as necessary for additional water production to serve the local area.
- Additional components that would be required to support the operation of the demonstration desalination facility.

- The potential for biofouling will be mitigated through the use of shock chlorination (and subsequent dechlorination), the addition of chlorine dioxide, and the potential use of biocides.
- The total land area identified for the site will accommodate potential expansion up to a full-scale, 25 mgd seawater desalination facility.

5.2.2 Site Location and Land Use

Based on conversations between BPUB and the Port of Brownsville, a suitable site for the Demonstration Project was identified that did not conflict with future plans at the Port and met the needs of the project. Use of the proposed site is anticipated to be part of a partnership agreement between the BPUB and the Port of Brownsville.

The intake component of the desalination project will be located off the southern side of the Brownsville Ship Channel, which is in the boundaries of the Port (Figure 5-3). The Demonstration Project facilities will be located along the South Port Road on the south side of the Brownsville Ship Channel approximately 11 miles southwest inland from the Gulf of Mexico entrance into the ship channel jetties. It is anticipated that locating the facility on the south side of the ship channel will enhance water quality when compared to that of the pilot facility. It is not anticipated that water quality at this location will be adversely impacted by shipping traffic when compared to the impacts that were realized at the pilot facility.

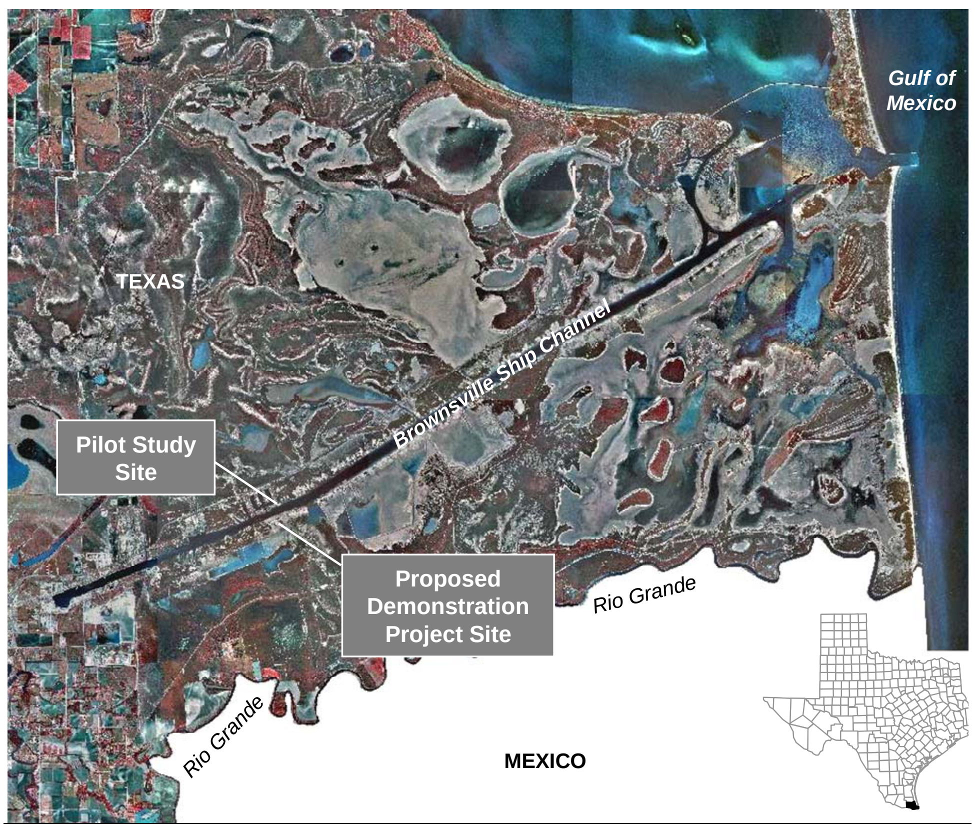

Figure 5-3: Location of the proposed 2.5 mgd Demonstration Project.

The total facility area for the initial 2.5 mgd capacity of the Demonstration Project is estimated to be 6 acres. However, a total of 50 acres will be reserved for the potential full-scale desalination facility initial capacity of 25 mgd with future potential expansion up to 50 mgd.

5.2.3 Facility Layout

This section describes the conceptual configuration for the proposed Demonstration Project, including all anticipated site development requirements and features needed to support the plant and its operations. Only the principal components of the facility (such as structures, major yard piping, and certain site development features) are shown (Figure 5-4). The final configuration and layout of the plant will be optimized during the design stage. A total land area of approximately 50 acres is required to accommodate the conceptual configuration of the demonstration-scale plant and the future full-scale desalination facility.

All seawater for the site would be collected directly from the Brownsville Ship Channel through an excavated inlet channel located along the western most portion of the site. Seawater would be directed into the interior of the site where the pretreatment, primary treatment, and post-treatment facilities would be located. Through these various water treatment systems, a stabilized, desalted water supply would be produced and distributed to a ground storage tank west of the treatment facilities with subsequent transmission off-site to the BPUB distribution system.

Overall Process Flow

The physical arrangement of the plant will allow all water treated by the desalination plant to be routed from the west to the east through the site, while all waste byproducts including sludge and brine streams created within the central portion of the site will be routed southward for proper management and disposal. By segregating, physically separating, and routing treated water streams away from the wastewater streams generated by specific operations within the plant site, these streams can be better managed. All solids waste streams generated from the pretreatment system would be routed to the solids handling system located on the eastern portion of the site. Similarly, a brine stream generated as a consequence of the primary treatment system will also be routed southward through a dedicated concentrate disposal system.

In anticipation that additional quantities of water may be needed to support future growth and development in the local area, consideration was given to expanding the Demonstration Project's initial design configuration. The current conceptual design will allow potential future configurations for the seawater desalination plant in 25 mgd capacity increments up to a potential build out configuration of 50 mgd.

Topography and Site Work

The current topographic data for the Demonstration Project site indicates existing grade elevations ranging from approximately 10 feet to 12 feet above msl (mean sea level). A review of the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps confirmed that the minimum finished grade needed to address potential flooding effects is of 12 feet msl, which is the grade proposed for site development. However, the unfamiliar effects of a storm surge may require certain equipment and buildings to have a higher finished floor elevation than the recommended 12-foot elevation.

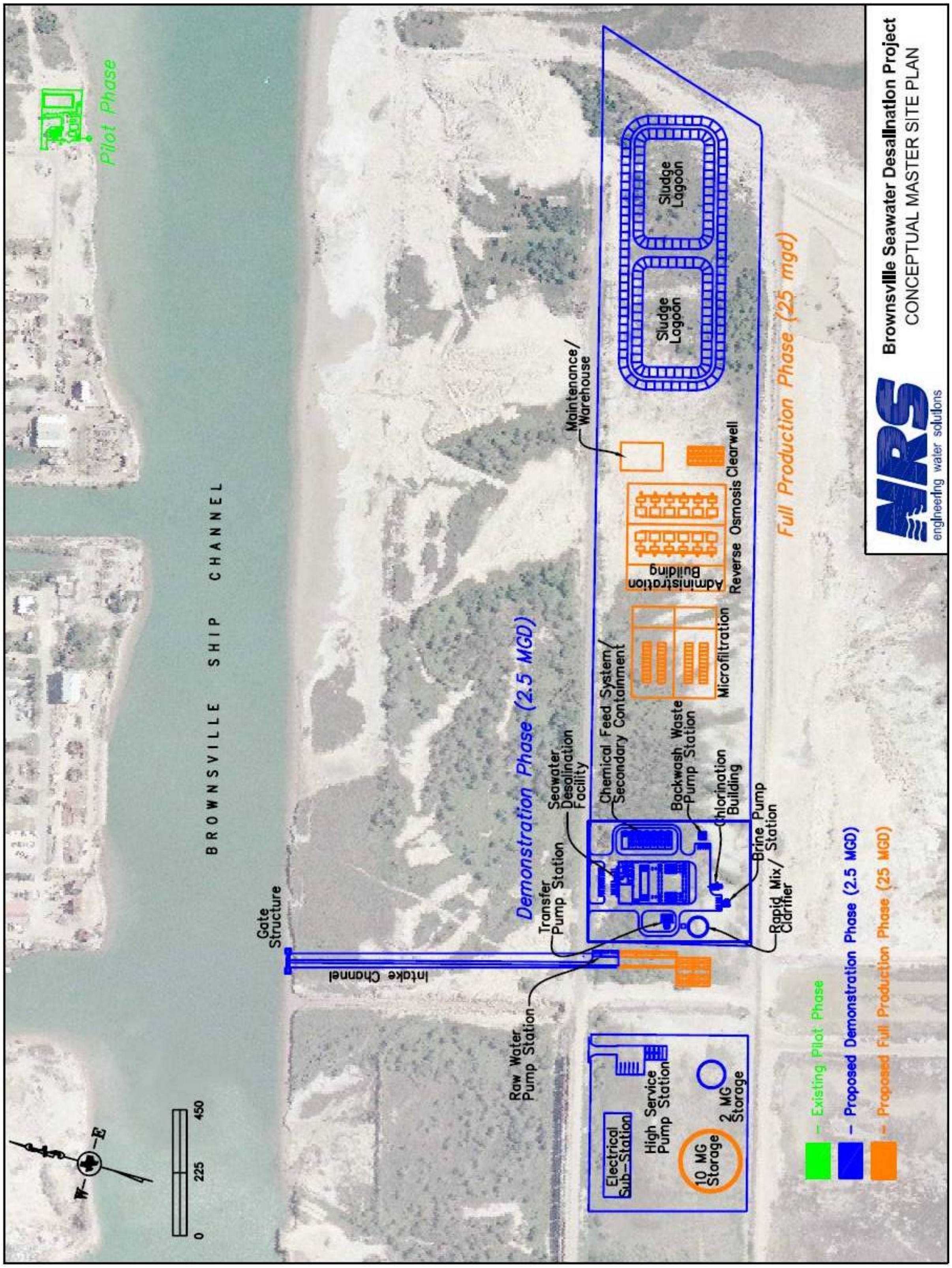

Figure 5-4: **Conceptual site layout for the proposed 2.5 mgd Demonstration Project.**

The overall site would be cleared and grubbed to remove any undesirable or unusable materials. By grading the site to 12 feet msl from the south through grading of swales and storm water detention ponds along the sloped transition near the South Port Road, proper storm water management would be provided. This would protect the existing road and development areas along this road from flooding as a consequence of development of the site.

Utility Systems and Other Support Infrastructure
Utility systems and other infrastructure necessary to properly support the desalination plant taken into account during the conceptual design include:

Stormwater Drainage and Management
Stormwater drainage and management components are needed to properly collect, treat, and route stormwater through and off the site. This system would be composed of a series of stormwater culverts and reinforced-concrete pipe along the various internal roads, as well as natural swales and ditches for unpaved areas of the site. All stormwater collected on site would be routed through either dedicated stormwater detention or retention ponds for proper management before being discharged off site. To the extent possible, stormwater would be routed northward across the site toward the Brownsville Ship Channel where it would be discharged via a permitted stormwater National Pollutant Discharge Elimination System outfall.

Potable Water Supply System
A potable water supply system would be provided for the desalination plant to support its staff and operations. This system would receive water from the desalination plant itself. A distribution piping system would be used to route water from the high service pump station to various locations in the desalination plant. The internal water mains would be properly sized to convey the amount of water needed for each location at the plant site. Finally, properly selected and sized backflow preventers would be installed at all critical and potentially hazardous service areas to address cross-connection control requirements.

Sanitary Wastewater Collection System
A sanitary wastewater collection system would be provided to collect all wastewater generated at the site. A series of gravity collection mains would be provided to properly route wastewater from each location where wastewater could be generated to a plant lift station for subsequent routing. This lift station would be a duplex pumping system for purposes of redundancy and would be properly sized to handle the anticipated quantity of wastewater that could be generated at each location within the plant. The force main from this pump station would be routed off site to the Brownsville Navigation Sewer Plant for final processing and disposal.

Electrical Supply and Distribution System
An electrical supply and distribution system will be properly sized and configured to serve all components at the plant site. This local electrical power grid shall be utilized to serve the plant. The power feed to the plant will be provided from the 15 kilovolt (kV) distribution system of the local power company. However, in the event that the commercial supply of electricity is interrupted, a standby generator complete with automatic switch gear will be included in the plant electrical design.

PCIS Network and Communication System
A Process Control and Instrumentation System (PCIS) will be used to provide centralized control and monitoring capability for the project. A communications network will be established throughout the plant site to allow for the efficient transfer of information among the various elements and components that will comprise the PCIS.

5.2.4 Process Design

The following design description describes the proposed (2.5 mgd) Demonstration Project and is based on the design considerations and site layout features described above. A conceptual process flow schematic for the treatment process is presented in Figure 5-5. The treatment plant's primary systems and main components in each system are summarized in Table 5-4.

Table 5-4: Summary of principal systems and subsystems for the proposed Desalination Plant.

	System Description	Subsystem Description/Capacity
1	Seawater Intake System	Intake Channel 50 MGD Intake Screen Assemblies 10.8 MGD Raw Water Pumping System 10.8 MGD
2	Pretreatment System	Train A 3.6 MGD Strainers Microfiltration Filtered Water Clearwell Booster Pump Station Cartridge Filtration Train B 3.6MGD Rapid Mix Solids Contact Clarifier Settled Water (SW) Clearwell SW Transfer Pump Station Strainers Microfiltration Filtered Water Clearwell Booster Pump Station Cartridge Filtration
3	Primary Treatment System	High Pressure SWRO Pumping System 5.6MGD First Pass SWRO Units Energy Recovery Turbines
4	Post Treatment System	Degasification to remove CO_2 Addition of caustic soda and sodium bicarbonate to control pH and alkalinity Addition of calcium sulfate to increase calcium concentration in the product All Vacuum Chlorine Gas Disinfection System 2.5 MGD
5	Solids Handling System	Backwash Wastewater/Sludge Pump Station 7.2 MGD Sludge Lagoons 7.2 MGD Decant Station 7.2 MGD
6	Brine Disposal System	Brine Transfer Pump Station 3.5 MGD Brine Transmission Main 3.5/62.0 MGD Brine Outfall Diffuser Array 3.5 MGD
7	Finished Water Transmission and Distribution System	Finished Water Storage Tanks 2.0 MG Finished Water Distribution Pump Station 2.5 MGD Finished Water Distribution Lines 2.5 MGD

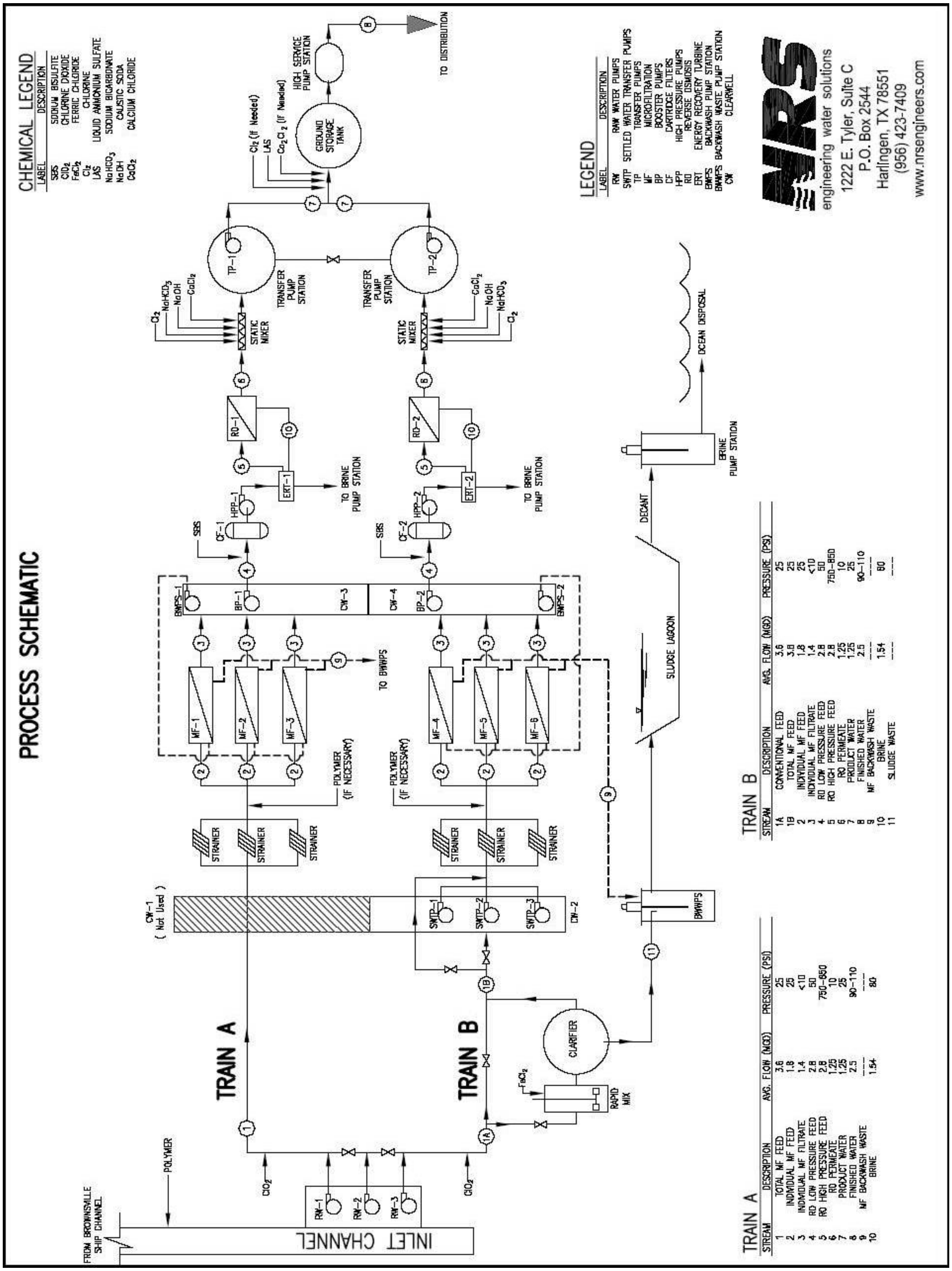

Figure 5-5: Process schematic for the proposed 2.5 mgd Demonstration Project.

Intake System
The construction of an intake system will be necessary to provide seawater as the source of feed water to the proposed demonstration-scale desalination facility. The conceptual design of a dedicated seawater intake system must incorporate features that allow a sufficient supply volume of feed seawater while minimizing the collection of suspended solids and protecting marine life. The proposed intake system consists of a side channel approximately 1,500 ft long connected directly with the Brownsville Ship Channel, intake screen assemblies, and a raw water pump station equipped with vertical turbine pumps.

Intake Channel
The intake channel shall limit the approach velocity to a maximum intake velocity of 0.1 fps at the point of collection to minimize potential impingement and entrainment issues. The low approach velocity will aid in reducing suspended solids collection, management, and disposal within the desalination facility. The effective intake velocity for the demonstration facility would be 0.015 fps. This would create a more favorable velocity than the full scale plant. If full scale design had turbidity problems it could require the enlarging of the full scale intake channel if the 0.1 fps posed a problem in the future. The channel is conceptually configured with a trapezoidal cross-section with 2:1 side slopes. This channel will begin at the deep, central section of the Brownsville Ship Channel and terminate at the southern bank of the Ship Channel at the entrance to the side channel described below. Based on these dredging limits and the proposed geometry of the channel, the total volume of soils, sands and other sediments that must be excavated is approximately 15,000 yd^3.

A considerable quantity of dredged materials would be removed from the Brownsville Ship Channel during the construction of the intake channel. This material could be spread across the site, mixed with other site soils, and subsequently graded and used to develop the site reserved for the treatment facilities. However, an allocation was assigned in the cost estimate for the disposal of excess dredged material from the ship channel, if necessary.

Side Inlet Channels
From the main intake channel, two side inlet channels are proposed, one for the demonstration plant and the second to be constructed during the full plant production phase. These inlet channels were included to cost-effectively and reliably address the issues of oil spills, floating debris, and improved hydraulic performance. The initial inlet will be 20 feet wide as measured along the inlet channel and 10 feet long (into the site). Each inlet will have a depth of 28 feet as measured from the proposed site grade of 12 feet msl, with an "entrance barrier wall" located at the mouth of the inlet channel to address the previously described issues. The entrance wall will be a reinforced concrete structure of sufficient thickness to protect the interior portion of the side inlet from any floatable debris and/or light, and non-aqueous phase liquids. In addition, the entrance wall will also protect the intake screens that will be located behind the wall by limiting access to them. Finally, the angle and structure of the entrance wall will dampen wave energy that approaches the side inlet, thereby normalizing and improving hydraulics at the final point of seawater collection for the project.

The top of the entrance barrier walls will match the top elevation of the channel seawall at 16 feet msl. The base of the wall will extend down to an elevation of approximately -5 feet msl to span the entire potential tidal fluctuations that may occur. A set of piles (total of two) would be driven and installed directly below the entrance barrier walls to better support the overall wall span. Directly below the bottom of the entrance barrier wall would be the seawater intake inlet measuring 20 feet in width and 11 feet in height. At these dimensions, the approach velocity into the side inlet will be minimized to 0.1 fps. A relatively tall seawall will be needed to support the construction of the side inlets. Based on the dimensions for the proposed intake depth, the interior walls of the side inlets will be approximately 37 feet deep, measuring from 16 feet to -21 feet msl.

The base elevation of 16 ft msl for retaining walls and the process buildings would offer a significant level of protection. The FEMA flood maps show the flood elevation at 12 feet msl. The storm surge from a hurricane will have significant time to dissipate in all but the more severe hurricanes. However, the final design of the facility should take into consideration the potential dangers posed by storm surge.

The conceptual physical configuration of the seawall intake opening at the side inlet would facilitate the closure of the inlet area under the barrier wall when needed to conduct major maintenance events within the inlet. Major maintenance events would include the removal and replacement of the screen assemblies and or repairs and rehabilitation work needed within the inlets from time to time.

Seawater Screening
At the interior of the side inlet, a total of three water intake screens constructed of copper-nickel alloy will be installed. These screens will reduce entrainment and impingement of aquatic life by excluding larvae, swimming organisms, and other objects greater that 1/8-inch in diameter. The screens are sized to limit the maximum approach velocity at the face of the screens to 0.5 fps. The three screen assemblies will be installed within the inlet at a center line elevation of approximately -7 msl. At this elevation, the top of the screen assembly would be at approximately -5 msl, thereby maintaining at least 2-foot water freeboard above the top of the screens during mean low tide conditions. Each screen assembly will have the capability to be isolated if necessary for maintenance, repair or replacement while maintaining water supply to the plant by the standby screen assembly. Each screen assembly would be mounted directly to the mechanical yard piping that would be cast into the side wall of the inlet.

A compressed air supply will be used to provide a periodic "air burst" along the face of the screens to keep them clear of solids. An air burst of the screen assemblies would occur when the DP drop across the screens exceed 2 psi. This air burst also may be used more periodically using an automated timer. A 15 horsepower (HP) air compressor will supply compressed air to each screen assembly through a high-pressure receiver tank and a manifolded air supply line leading to a series of nozzles located along the length of the screen assembly.

Raw Water Pumps
The raw water pump station consists of a total of three vertical turbine pumps. There will be one raw water pump for each process train. The third pump serves as a backup for either train process raw water pump. The raw water pumps are interchangeable for both process trains. The raw water pumps will collect seawater from the side inlet channel via the intake screen assemblies and will route it to the two proposed trains. Each pump will be rated for design flow rate capacity of 3.6 mgd (2,520 gpm) at 60 feet of discharge head and be equipped with a 60 HP motor

to be controlled by a variable frequency drive. The pumping system will include all necessary valves and other mechanical appurtenances necessary for the proper and optimized operation to maximize the service life of the system. A flow meter assembly for each raw water pump will be installed directly downstream to control the flows into the two proposed process trains.

Pretreatment System Components
The conceptual pretreatment for the demonstration-scale facility consists of two pretreatment trains: Train A consists of a stand alone MF system. Train B consists of a conventional pretreatment process followed by a MF system.

Train A – MF Pre-Treatment
In Train A, the demonstration-scale facility will operate a stand alone MF process. This train will be used for the bulk removal of organics and inorganic constituents that may be present in the seawater supply. Raw seawater pumped from the intake channel will be routed directly to the proposed MF system. Three strainers are proposed downstream of the raw water pump for removal of solids. The strainers will be manifolded for flexibility of operation into the three proposed MF systems. The proposed strainers will consist of three banks of 6" Spin Klin strainers from Arkal (2+1 configuration). Two (2) strainers can provide the feed to the proposed MF systems if one is under a backwashing operation or not operational.

MF membrane technology will be utilized as the polishing step to provide filtered water with the quality needed for the proposed SWRO. The proposed MF system operates in an outside-in mode with a small pressure requirement. The MF system for Train A includes a total of three MF Pall Microza module racks. Each module rack is conceptually designed with a hydraulic capacity of 1.8 mgd at a design flux of 20 gfd at 20 ˚C. Each module rack consists of 134 modules (2+1 configuration). The filtered water from each module rack is discharged into a proposed filtered water clearwell (see Figure 5-5).

Train B – Conventional/MF Pre-Treatment
In Train B, the demonstration-scale facility will have the capability to test a conventional system combined with a MF process. A conventional pre-treatment system will be used for the bulk removal of organics and inorganic constituents that may be present in the seawater supply. This conventional system includes a rapid mix structure and a 75 ft solids contact clarifier. A chemical coagulant such as a ferric salt (ferric chloride or ferric sulfate) will be used to coagulate the raw water supply at the rapid mix. The coagulant dosage could range from 20 to 40 mg/L. The coagulated water will then be directed to the solids contact clarifier. The high rate solids contact unit uses a solids contact process that combines in a single tank: mixing, flocculation, recirculation, clarification, sludge concentration and removal. The proposed clarifier will be hydraulically rated for a feed flow rate of 3.5 mgd at an overflow rate of 0.6 gpm/ft^2. The sludge from the clarifier will be directed to a backwash waste pump station and then to a sludge lagoon for final disposal into a landfill. Reduction of TOC levels and suspended solids can significantly reduce the fouling potential associated with the downstream components including MF, cartridge filters, and, most importantly, the SWRO membranes.

From the solids contact clarifier, the settled water will flow to a clearwell. A settled water transfer pump station consisting of three vertical pumps directs the settled water from the clearwell to the MF system. The three pumps are manifolded for flexibility of operation. The proposed vertical pumps will be Fybroc fiberglass pumps each rated at 1.8 mgd (1,260 gpm). These pumps will have 30 HP motors with variable frequency drives for speed control. Two pumps can provide the feed to the proposed MF systems while one is on standby.

Three strainers are proposed downstream of the pumps for additional removal of solids. The strainers are also manifolded for flexibility of operation into the three proposed MF systems. The proposed strainers consist of three banks of 6" Spin Klin strainers from Arkal (2+1 configuration). The 2+1 configuration is defined as two strainers in service at any given time with one strainer as a standby. Two strainers can provide the feed to the proposed MF systems if one is under a backwashing operation or not operational.

Train B has the capability to operate three different scenarios. The first scenario is as described above and as illustrated in Figure 5-5. The second scenario includes reverting to the same set up as Train A by bypassing the rapid mix, clarifier and settled water transfer pumps. The third scenario includes the capability to bypass only the rapid mix and clarifier to incorporate the settled water transfer pumps as part of the train process.

MF membrane technology will be utilized as the polishing step to provide filtered water with the quality needed for the proposed SWRO. The proposed MF system operates in an outside-in mode with a small pressure requirement. The MF system for Train B includes a total of three MF Pall Microza module racks. Each module rack is conceptually designed with a hydraulic capacity of 1.8 mgd at a design flux of 20 gfd at 20 °C. Each module rack consists of 134 modules (2+1 configuration). The 2+1 configuration is defined as two filter racks in service at any given time with one filter rack serving as a standby. The filtered water from each module rack is discharged into a proposed filtered water clearwell.

Filtered Water Clearwell and Transfer Pumping Subsystem

A filtered water transfer pump station will consist of one vertical turbine pump for Train A and one vertical turbine pump for Train B. The proposed pumps will be mounted on top of a proposed filtered water clearwell to route the pretreated water supply through or around the cartridge filters and to the suction side of the high-pressure SWRO feed pumps. The proposed vertical pumps will be Fybroc fiberglass pumps each rated at 2.8 mgd (1,945 gpm). These pumps will have 100 HP motors with variable frequency drives for speed control. The plant will maintain an off the shelf pump as a spare.

The vertical turbine pumps will be installed in a parallel configuration along the top of the filters' clearwell. Since it will be necessary from time to time to conduct maintenance within the interior of the clearwell, the structure will have internal division walls to separate it into six chambers. Each chamber will house a vertical turbine pump, thereby allowing for periodic maintenance and/or repair of any portion of the clearwell while only losing the use of one train.

Cartridge Filtration

The filtered water stream from each MF train system will be routed through a cartridge filter before the primary treatment system. The cartridge filters will be used as the last physical barrier to prevent the passage of suspended solids greater than 5 microns in diameter. In addition, the cartridge filters will improve mixing and dispersion of sodium bisulfate to be added to the feed water on an intermittent basis upstream of the filters, thereby ensuring a more homogenized water supply prior to membrane treatment.

Each RO train will be equipped with one 48-inch diameter cartridge filter 316 stainless steel filter housing containing 195 cartridge filter elements 40" long. Each cartridge filter vessel has a rated hydraulic capacity of 2.8 mgd (1,945 gpm) at a design flow of 2.5 gpm per 10" cartridge. It is anticipated that the filter elements replacement frequency will be approximately three months.

Primary Treatment System

The primary treatment system consists of two independent SWRO trains. Each train will consist of specific components piloted during the Pilot Study. These components will ensure a finished water product meeting safe drinking water standards. Each RO train consists of the following major components: high-pressure RO feed pumps, energy recovery turbines, RO trains (Train A and B), and membrane cleaning and flushing systems (Figure 5-6).

High-Pressure SWRO Feed Pumps

Each SWRO train will consist of a high-pressure pump used to provide the required feed water train at the required feed pressure to produce a permeate flow of 1.25 mgd. The SWRO high pressure pumps will be equipped with a 1,000-HP motor controlled by a variable frequency drive to accomplish the desired permeate design flow. A mechanical connection to an energy recovery turbine installed on the brine discharge main from each train, as described below, will also contribute work energy for the SWRO pumps, thereby defraying operating costs.

Energy Recovery Turbines

Each high-pressure SWRO pump will be coupled to an energy recovery turbine to reduce the electrical demand required for each pump. The energy turbine is the current choice considering the fact that bio-fouling is an issue that must be incorporated into the design. ERI's pressure transfer device is more efficient but is susceptible to biofouling. It is also much more expensive than the energy recovery turbine device in the light of the sensitive budget for this project. It is believed that the ERI's device would be a good candidate for research at this site. The energy recovery turbine uses the high-pressure brine stream from the single pass SWRO banks to spin a turbine that is coupled to the SWRO pumps. Energy obtained from the brine stream reduces the total amount of electrical energy needed to run the pumps by about 30%, thereby conserving a significant amount of electrical energy.

Seawater RO Trains

The two proposed SWRO trains will be independent from one another and arranged in a parallel configuration. Each train will be capable of producing 1.25 mgd of permeate water. The Pilot Study tested SWRO membrane elements from two different membrane suppliers, including Toray and FilmTec. These will be the approved membrane elements for the Demonstration Project. Each SWRO train will be designed as a single pass system using 55 pressure vessels each with seven-elements. The system will be designed at a 45% recovery and a design flux of 8.1 gfd. It is anticipated that a product water quality of approximately 350 ppm TDS will be produced at a worst-case temperature of 30 ˚C. The permeate water will then be routed to downstream post-treatment processes for proper stabilization and disinfection.

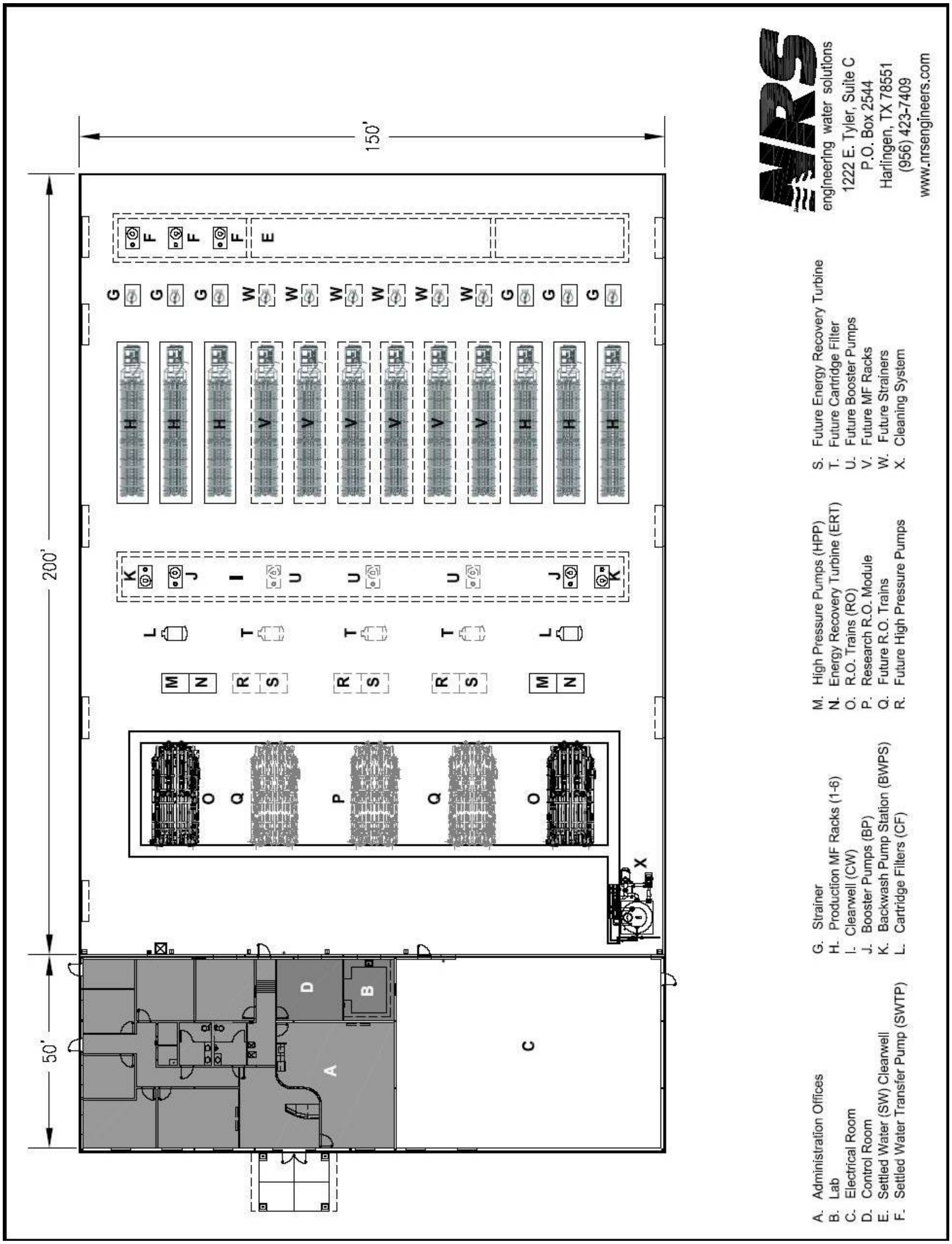

Figure 5-6: Layout of the treatment systems and building for the proposed 2.5 mgd Demonstration Project.

Brine will be produced by each SWRO train at a rate of 1.54 mgd, assuming a 45% recovery factor is maintained for the overall membrane system. Therefore, at a brine generation rate of 1.54 mgd per train, a total concentrate disposal rate of 3.1 mgd would result in the demonstration-scale facility's initial 2.5 mgd finished water production rate. The brine generated by each SWRO train will be directed to a common header that will in turn be routed to the brine transfer pump station. The brine pump station will route the brine for ocean disposal.

Membrane Cleaning and Flushing System

A membrane cleaning system will be needed to periodically clean the membranes to the highest degree possible. This cleaning event will include the use of a combination of cleaning chemicals and clean permeate. The cleaning solution generated by the membrane cleaning system will be routed, after neutralization, to a dedicated wetwell structure equipped with a duplex pumping system. The pumping system will extract spent solutions for subsequent routing to the sludge lagoons for final disposal. The cleaning system will be equipped with a 3,000 gallon high-density polyethylene (HDPE) tank and an electric heater, a 316 SS cleaning pump rated at 500 gpm at 73 psig, a stainless steel cartridge filter rated for 500 gpm, and associated instrumentation for proper operation of the cleaning system.

Post-Treatment System

The post-treatment system will include two unit treatment processes: final stabilization and final disinfection.

Final Stabilization System

A stabilization system will be needed to properly condition the water supply before it is routed into the downstream transmission and distribution systems. Stabilization is the process whereby the corrosive permeate stream is physically and chemically conditioned to make it non-corrosive.

The permeate water will be routed to the head of the transfer pump station. The transfer pump station acts as a contact time chamber. Each treatment train will have its own contact time basin. The pH and alkalinity of the permeate will be controlled with the use of caustic soda and sodium bicarbonate. Calcium chloride will also be added to increase the calcium concentration in the product water. The combination of all of these chemicals will provide for well stabilized product water. This process has been successful with stabilizing the water at the BPUB Southmost brackish RO Facility and produces water compatible with the surface water in the BPUB system

Disinfection System

The disinfection process will accomplish two objectives: comply with disinfection requirements; and residual into the distribution system. Compliance with disinfection requirements will be achieved with chlorine addition at the head of the transfer pump station. The transfer pump station also acts as a chlorine contact basin for the water to have a T_{10} detention time of approximately 2 to 3 minutes at a chorine residual of 2 to 3 mg/L to comply with disinfection requirements.

A disinfectant residual into the distribution system will be accomplished with the use of chloramines. Chloramines will be formed with a combination of LAS (liquid ammonium sulfate) and chlorine. Additional chlorine will be added to the water, if necessary, after the transfer pumps followed by the LAS. A chloramine residual of 2 to 3 mg/L will be maintained in the distribution system.

Solids Handling System

The solids handling system will be constructed to provide a place for the settling and dewatering of sludge and will include five primary components: backwash waste pump station, MF/RO cleaning solutions pump station, two sludge lagoons, and decant system.

Backwash Waste Pump Station

The backwash waste pump station will collect the backwash from the MF systems and the sludge from the solids contact clarifier and directs it to a sludge lagoon. The backwash waste pump station will consist of two submersible pumps and associated accessories. One will be in operation while the other is in standby. The submersible pumps are to be installed in a 6-ft diameter fiberglass wetwell. The proposed submersible pumps will each be rated at 800 gpm at 50 feet of dynamic head equipped each with a 30 HP motor.

MF/RO Cleaning Solutions Pump Station

A separate small pump station will be implemented to collect and reroute to the operating sludge lagoon neutralized spent cleaning solutions from the MF/RO systems. The spent cleaning solutions pump station will consist of two submersible pumps. One will be in operation while the other is in standby. The proposed pumps will be implemented inside a 4-ft fiberglass wetwell. The proposed submersible pumps will be each rated at 200 gpm at 50 feet of total dynamic head.

Sludge Lagoons

Two lagoons will be constructed for disposal of backwash waste from the MF system from Trains A and B, clarifier sludge from Train B, and any neutralized spent cleaning solutions from the MF/RO processes. The lagoons could be alternated every year, while one lagoon is in operation, the other could be decanted and used for drying of solids. The bottom of each lagoon occupies approximately 2 acres. Each lagoon will have a 3:1 inside slope with a total depth of 11 feet (9 ft operating depth).

Decant System

The decant water from each lagoon will be routed by gravity to the brine pump station to comingle with the brine generated by the proposed SWRO systems.

Chemical Feed Systems

Various chemicals will be needed to properly condition and treat both the seawater supply as well as residuals produced by the pretreatment system. All chemicals that will be used in the desalination facility will be NSF approved and/or compliant with the applicable federal and state regulations pertaining to drinking water supplies. The following chemicals, at a minimum, will be needed to support the conceptual design of the desalination facility:

- Polymer
- Chlorine Dioxide
- Ferric Chloride
- Sodium Bisulfite

- Chlorine
- Sodium Bicarbonate
- Liquid Ammonium Sulfate
- Calcium Chloride
- Sodium Hypochlorite
- Caustic Soda
- Citric Acid

All of the chemicals will be stored in a secondary containment to support treatment processes and operations. The chlorine and chlorine dioxide systems will be the only chemicals not located in the secondary containment location. Table 5-5 summarizes the various types and estimated quantities of chemicals that may be required to properly support the various treatment operations. Sufficient storage capacity will be provided to maintain a 60 to 90 day stock of each chemical, thereby reducing the frequency of chemical deliveries to the site.

Table 5-5: Summary of process chemical stocks and storage quantities for the proposed Demonstration Project.

Chemical	Estimated Dosage (mg/L)	Process Flow (mgd)	Daily Average Quantity Used	Monthly Storage Volume Required
Polymer	1	7.2	7 gallons	210 gallons
Chlorine Dioxide	0.8	7.2	n/a	n/a
Ferric Chloride (40%)	30	3.8	200 gallons	6,000 gallons
Sodium Bisulfite (40%)	5	5.6	54 gallons	1,621 gallons
Chlorine	3	2.5	65 lbs	2-Ton Containers
Caustic Soda (50%)	25	2.5	81 gallons	2,430 gallons
Sodium Bicarbonate (35%)	20	2.5	108 gallons	3,250 gallons
Calcium Chloride (38%)	25	2.5	122 gallons	3,660 gallons
Liquid Ammonium Sulfate (40%)	1	2.5	5 gallons	150 gallons
Sodium Hypochlorite (10%)[a]	400	-	50 gallons	1,500 gallons
Citric Acid	-----	-	10 gallons	300 gallons

[a] Sodium Hypochlorite and citric acid are used for daily EFM (Enhanced Flux Maintenance) cleans for the MF system.

Table 5-6 summarizes the proposed locations for all of the chemical stocks conceptually proposed for the desalination facility along with the number and type of storage capacity provided for each chemical stock.

Table 5-6: Location of process chemicals, storage provisions, and bulk storage capacities for the proposed Demonstration Project.

Chemical	Location	Vessel Type	No. of Tanks	Total Bulk Capacity
Chemical	**Location**	**Vessel Type**	**No. of Tanks**	**Total Bulk Capacity**
Polymer	Secondary Containment	HDPE	2	Totes
Sodium Chlorite (For ClO_2)	Secondary Containment	HDPE	2	5,000 gallons
Ferric Chloride	Secondary Containment	HDPE	2	12,000 gallons
Sodium Bisulfite	Secondary Containment	HDPE	2	5,000 gallons
Chlorine	Chlorination Building	-	2	Ton Containers
Caustic Soda	Secondary Containment	FRP	2	10,000 gallons
Sodium Bicarbonate	Secondary Containment	HDPE	2	12,000 gallons
Calcium Chloride	Secondary Containment	HDPE	2	12,000 gallons
Liquid Ammonium Sulfate	Secondary Containment	HDPE	1	5,000 gallons
Sodium Hypochlorite (10%)	Secondary Containment	HDPE	2	5,000 gallons

The conceptual configuration developed for most of these chemical feed systems includes bulk storage tanks, drums or totes, a transfer pump, and a chemical metering system with associated chemical day tank (in some cases) housed in a fiberglass enclosure. At least two bulk storage tanks will be provided for each chemical stock, with the exception of the polymer stock, which would be stored in the drums or totes in which they were delivered to the site. This will ensure both a sufficient chemical supply between chemical deliveries and that the specific unit treatment process can be maintained if one of the bulk storage tanks must be taken out of service for any reason (e.g., replacement, repair, maintenance, etc.).

The secondary containment is conceptually sited to allow easy delivery of chemicals. The design concept incorporates the implementation of each of these chemical feed systems inside an appropriately sized secondary containment area. By having all components of each chemical feed system (bulk storage tanks, transfer pump, day tank, and chemical feed pumps housed in fiberglass enclosure) within a secondary containment, it addresses the potential for chemical leaks. A day tank will be provided for all chemicals in liquid form. As the name implies, a day tank is used to store approximately one day's worth of volume for each chemical used at the plant. This design provision would allow the plant operator to confirm the daily use of chemical as well as to minimize the potential for larger chemical releases if a day tank were to rupture or be damaged in any way. In all cases, a duplex metering pump system including the metering appurtenances will be installed directly adjacent to the day tanks. Then the chemical will be directed to the point of chemical application to the particular unit treatment process. The Process Schematic (see Figure 5-5) illustrates the various chemicals that would be used in the conceptual design of the demonstration-scale desalination plant along with their respective points of application within the conceptual layout of the plant.

The conceptual layout of the secondary containment housing all chemical feed systems was configured to allow for additional chemicals than those listed above if it is determined, for any reason in the future, that different or additional chemical stocks are needed. For instance, while not initially proposed, it may be possible that scale inhibitor may be needed for the membrane system during the demonstration-scale plant operations. Other chemicals may be needed to meet future water quality regulations. Sufficient space within the secondary containment structure will be reserved for the stocking and metering of additional chemicals, if they are determined to be needed at some time in the future.

Brine Disposal System

The concentrate disposal system will include five primary components: brine transfer pump station, concentrate disposal main and route, and Gulf outfall and diffuser array.

Brine Transfer Pump Station

The brine pump station will consist of a concrete wet well that will receive the brine from the SWRO units and the decant water from the sludge lagoons. Two vertical turbine pumps, each rated at 3.5 mgd, will discharge into the brine line. The wet well structure will be arranged to provide space for one future brine pump. The two proposed pumps provide redundancy, and the pumps will be made of materials resistant to the brine. The pumps will have 60 HP motors and be constant speed pumps. The pumps will require initial control valves for start up against an empty pipe.

Concentrate Disposal Main and Route

The concentrate disposal main will proceed south and east approximately 12 miles to the coastline then continue half a mile offshore to where the water depth is approximately 25 to 50 feet in depth (Figure 5-7). The initial disposal main will have a 16-inch diameter to provide a velocity of 4 fps. The 16-inch pipe requires a velocity of 3.4 fps at 3.0 mgd, and the initial pressure will be 80 psi. The concentrate disposal main will be HDPE or other pipe material resistant to the corrosive properties of brine water. The concentrate disposal main will be installed by open cut methods most of the distance to the coast to just short of the sand dunes (approximately 2,000 feet west of the Gulf shoreline) at a depth that provides a minimum of 4 feet soil cover.

The concentrate disposal main will go south in a 40-foot wide easement to State Highway 4 (Boca Chica Road). The 40-feet wide easement is required for construction of the concentrate disposal main and space for two future concentrate disposal mains when the desalinization plant is expanded. The concentrate disposal main will turn east and continue parallel to State Highway 4 in a 40-foot wide easement along the north side of the highway right of way (ROW). The concentrate disposal main will cross under the highway near Richardson Road and continue east in a straight line to the back side of the dunes.

The onshore alignment for the concentrate disposal main appears to be primarily within property owned either by the Port of Brownsville or the U.S. Fish and Wildlife Service. There appears to be one private tract located along the north side of State Highway 4 west of Kingston Road. This site is labeled as a mobile park and appears to be less than forty feet from the state highway ROW, posing a problem with acquisition.

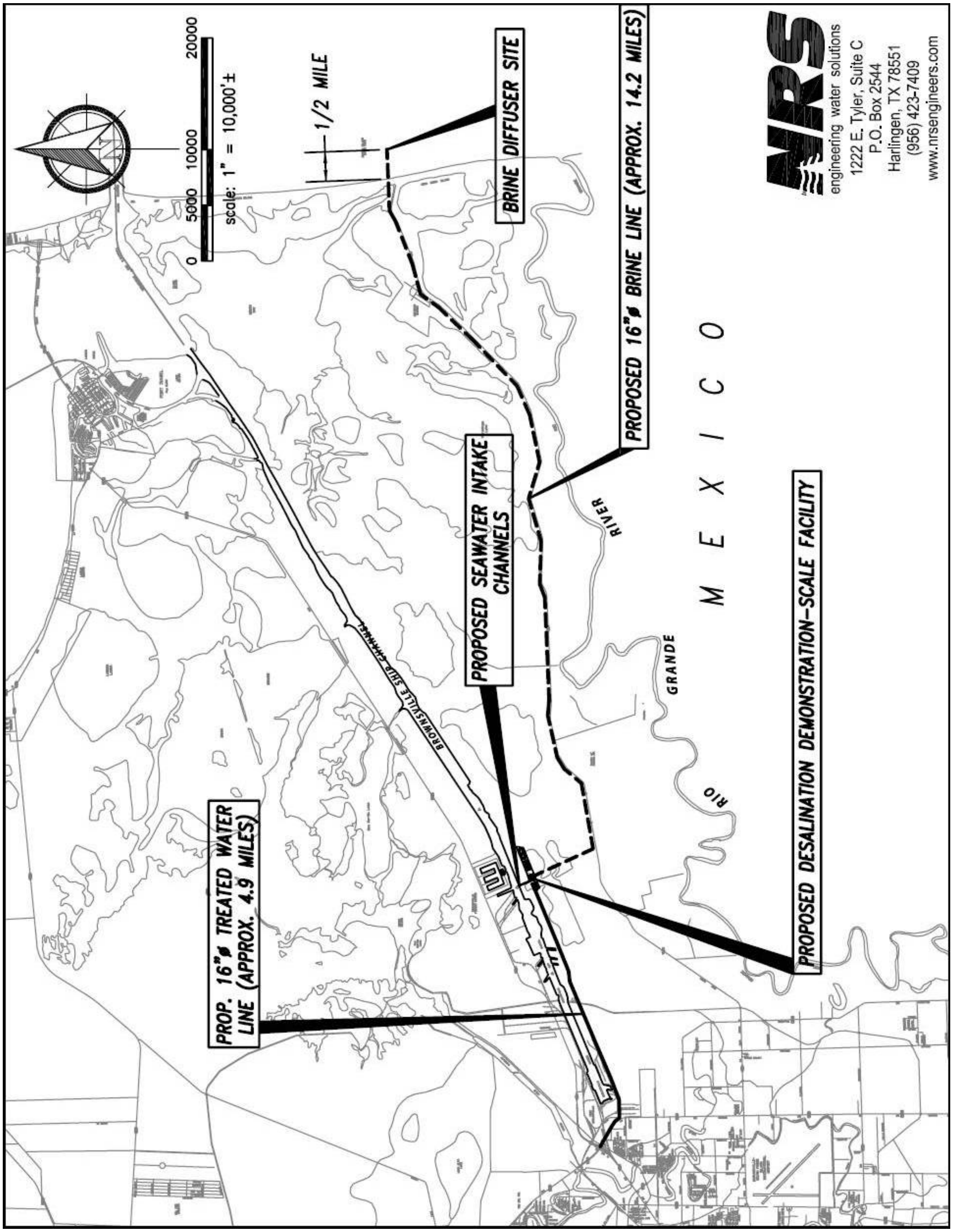

Figure 5-7: **Proposed alignment of the concentrate disposal line for the proposed 2.5 mgd Demonstration Project.**

Aligning the concentrate disposal main along the south side of State Highway 4 appears to involve more private property. Since the sand dunes are environmentally sensitive, the open cut pipe installation will be stopped west of the dunes. At this point, the pipe will be directionally drilled 2,000 feet to the shoreline and an additional 1,000 feet into the Gulf, for a total of 3,000 feet of directional drilling. The 1,000-foot directional drill into the Gulf will be required such that a water depth of 8 feet is reached, where barge mounted equipment can be utilized to install the diffuser array.

Gulf Outfall and Diffuser Array

A conceptual design for a diffuser array was developed to support the discharge of brine that would be generated by the desalination plant while minimizing environmental impacts within the local area surrounding the array. The following guidelines were used in developing a preliminary design of the diffuser for brine discharge:

- The brine flow is equally distributed across the various ports of the diffuser
- The velocity in the diffuser should be sufficient to prevent deposition of solids carried with the flow, if any. Minimum flow velocities of approximately 2 to 3 fps (0.6 to 0.9 meters per second) should be achieved for peak flows.
- The overall head losses should be kept as low as possible to minimize the level of pressure head at the upstream end of the line and dynamic pumping head required.
- All the ports should be fully occupied by brine, i.e., no seawater intrusion should occur. This can be achieved by assuring a Froude number greater than one for all ports.

The diffuser array will be sited and installed at the end of the brine transmission main and will consist of several ports equipped with 1-meter (3.3-foot) high risers oriented upward in a vertical position. The risers on the diffuser will help achieve higher discharge dilutions. Since the concentrated brine stream is heavier than the surrounding seawater, it will exit the ports along the array in an upward direction before falling toward the seabed. During its fall, concentrated brine will be diluted with ambient seawater. Thus, the upward orientation of the brine discharge will enhance dilution while also minimizing head losses.

Preliminary dispersion modeling was conducted for a full-scale (25 mgd) project. The diffuser array design evaluated in the concentrate modeling study was scaled back to provide a conceptual configuration of the diffuser array for this Demonstration Project. At the proposed discharge location within the Gulf, the seabed floor is sloped, and the total fall between the head and tail of the diffuser array would be approximately 1-2 feet. For the initial plant capacity of 2.5 mgd, the array would be approximately 33 ft long and 24 inches in diameter.

Finished Water Storage and Transmission System

The finished water storage and transmission system will include three primary components: ground storage tank, high service pump station, and a transmission system.

Ground Storage Tank

The finished water ground storage tank will be located in the western area of the desalination plant on the south side of Port Road. The proposed ground storage tank will have an initial capacity of 2.0 million gallons. The tank can also provide additional disinfection credits, if necessary.

High Service Pump Station and Transmission Systems

The high service pump station is located next to the proposed ground storage tank on the north side. The pumps will be housed in a building with capacity for the two proposed pumps with room for additional pumps to increase pumping capacity when needed. The proposed pumps will each have a capacity of 2.5 mgd at a total dynamic head of 100 feet. The pumps will be equipped with a 150 HP motor, variable frequency drives, and pump control valves. Also in the building, a climate control room will house the electrical equipment and control systems. The control system will include a variable frequency to allow either motor to operate as a variable speed driver to allow flows less than 2.5 mgd to be pumped into the distribution system. The proposed high service pump station shall be sited in a way that it will allow the construction of a second pump station when the desalination plant is expanded beyond the demonstration-scale phase.

Transmission System Line and Route

The proposed 16" transmission line will extend along the south side of Port Road to approximately 5 miles from the plant to connect to the BPUB distribution system. The proposed 16" line was selected to maintain the maximum velocity in the pipe at below 4 fps. The transmission line will be constructed in a 40-foot wide easement along the south side of the Port Road ROW. The 40-foot wide easement will provide room for construction and allow for the installation of future transmission lines when the desalination plant is expanded. The alignment is primarily located within property owned by the Port of Brownsville. There are two areas where the Port of Brownville is not the owner and easements will be needed from the property owners. As planned, the line will leave the desalination plant site going west, cross under State Highway (SH) 511 in a steel casing, and then turn north parallel to SH 511, pass under SH 48 and then tie into the BPUB distribution system.

Support Facilities and Ancillary Considerations

Various facilities will be needed to support the day-to-day operations of the desalination facility. In addition, ancillary considerations regarding various aspects of the Demonstration Project should be taken into account when preparing a complete and accurate conceptual, operational description of the plant.

Support Facilities

Various support facilities are proposed for the initial configuration of the proposed Demonstration Project. Sufficient space for each facility was estimated based on the minimum needs of various support functions for the plant as well as the number of staff that would be needed to operate the plant.

Demonstration-Scale Desalination Building

The administrative portion of the desalination building includes visitor parking, reception area, staff offices, conference room, control room, laboratory, storage room, and restroom facilities. A dedicated control room will be included to properly control and monitor the various unit treatment processes and operations of the desalination plant. For conceptual design and costing, a total administration footprint area of 7,500 ft^2 will be allocated for this facility. An analytical laboratory is proposed for the desalination facility because of the nature of the demonstration-scale facility and the need to establish consistent sampling and analytical work to provide sufficient documentation regarding the operational efficiency of the plant. Better quality control through consistent handling and overall site-specific knowledge of the various plant processes is a reason and justification for an on-site analytical laboratory.

The desalination building will be constructed above the 100-year flood elevation. For conceptual design and costing purposes, a total process building footprint area of 30,000 ft^2 will be allocated for this facility.

Primary and Secondary Power Supplies
Based on the conceptual configuration of the desalination demonstration-scale facility, a total power load of approximately 3 MW will be required. The primary source of electrical power will be from the local electrical power company in the area. Low voltage (480 V) service(s) and a medium voltage service (2,400 V or 4,160 V) will be required from the serving utility. Alternately, one medium voltage service or one high voltage (15 kV) service can be obtained from the power company and the step-down facilities can be incorporated into the plant distribution system. Standby diesel (or natural gas) fired generator(s) and automatic (or manual) transfer switch(es) will be included in the plant electrical distribution system design. The demonstration phase could investigate the possibility of alternate power sources like solar or wind to power this facility.

Process Control and Instrumentation System
A PCIS will be developed for the desalination facility, which would be used to maintain proper control and monitoring of the various plant components to ensure that sufficient quantities of water are produced and properly treated at all times to meet fluctuations in water demands of the local population. The PCIS would include a series of programmable Logic Controllers (PLCs) which will serve as the "electronic brain" of the overall desalination facility. Each PLC would be programmed to conduct automated control functions in response to receiving operating data from various processes. The PCIS will include the capacity to interface with the owner's existing Supervisory Control and Data Acquisition system(s), as applicable.

Materials of Construction
Because of the corrosive nature of the seawater supply for this project, specific attention and consideration will be given to proper materials of construction during conceptual level planning. If this specific consideration is not taken into account, the resulting capital cost estimated for the project would be too low. Special metal alloys, such as AL6XN and Zeron, or suitable plastics, such as HDPE, and fiberglass are needed for any mechanical or related process component between the point of collection of seawater at the Intake System and the fresh water permeate stream produced by the membrane units in the Primary Treatment System.

Waste Production and Disposal
As a consequence of routine plant operations, the desalination facility will produce various solid and liquid wastes that will require disposal. It is proposed to direct these wastes for disposal to the local wastewater treatment facility.

5.3 COST ANALYSIS

5.3.1 Construction Cost Projections

Approximately half of the cost of the proposed Demonstration Project includes infrastructure developed to provide for future full-scale capacity; especially the intake system, brine discharge pipeline to the Gulf of Mexico, and other site facilities (Table 5-7). "Future Capacity" refers to parts of the facility that can accommodate expansion or a part of expansion (i.e., building size, pipeline size, etc.). "Demonstration Project" refers to specific items that relate only to the construction of the facility (i.e., RO system, pretreatment system, etc.).

By far the largest cost component of a full-scale facility will be for water treatment; especially the pretreatment system. Given the raw water quality challenges at the ship channel site, the cost for the pretreatment system is much higher than at other locations. For the Demonstration Project, the water treatment system will be sized to provide only 2.5 mgd of production capacity.

5.3.2 Operation and Maintenance Cost Projections

The major cost component to the operational cost is power and accounts for nearly 40% of the cost. It is assumed the plant will operate as an interruptible supply and therefore will be eligible for reduced rates from the BPUB. Interruptible supply means that with notice the plant will be taken off-line from power and run on stand-by generation. This results in a reduced rate from the power utility. It is assumed that the power cost is $0.60 per kWh. Also included in the total costs are labor, chemical and a sinking fund for replacement of membranes, filters and channel maintenance. The total projected O&M cost is $2.80 per 1000 gallons (Table 5-8). The only item that will improve with economies of scale would be the labor cost, albeit only slightly for a larger facility. The rest of the items are specific to water produced.

Table 5-9 lists various power driven units incorporated into the demonstration facility. It is estimates a total load of 2 megawatts will be required to operate this facility. Table 5-10 estimates the manpower required to operate this facility. Some cost savings could be realized if the demonstration plant shared some labor with the brackish desalination plant. Table 5-11 projects the chemical usage in the demonstration plant.

A sinking fund, as shown in Table 5-12, should be set up in the budget each year for the replacement of membranes and filters. These are rather large items, occurring every 5 years. Creating a sinking fund will eliminate large capital expenditures every 5 years but will spread this expense over the life of the membranes.

5.3.3 Proposed Financing Mechanism

BPUB proposes to finance $20 million through TWDB toward the implementation of this project. The total project cost of $67,479,000 will need supplemental funding in the form of a grant from the State of $28.2 million and utilization of $19.3 million from the TWDB's State Participation Fund for a portion of the oversizing of the facility. The recommended use and sources of funds for the proposed Demonstration Project is presented in Table 5-13.

Table 5-7: Construction cost projections, proposed Demonstration Project.

Item	Description	Total Cost	Future Capacity	Demonstration Project
Desalination Plant				
1	Site Development	2,526,051	1,263,025	1,263,025
2	Seawater Intake System	4,054,575	3,649,118	405,458
3	Pretreatment System	7,647,300	0	7,647,300
4	Primary Treatment System	4,629,188	0	4,629,188
5	Post Treatment System	157,500	0	157,500
6	Solids Handling System	664,125	166,031	498,094
7	Yard Piping	472,500	118,125	354,375
8	Support Facilities	3,443,125	860,781	2,582,344
9	Electrical and Instrumentation	2,625,000	656,250	1,968,750
10	**Subtotal**	**26,219,363**	**6,713,330**	**19,506,033**
11	Effective Contingency	2,621,936	671,333	1,950,603
12	**Total Desalination Plant [a]**	**28,841,000**	**7,385,000**	**21,457,000**
Brine Disposal System				
13	Brine Transfer Pump Station	1,000,000	800,000	200,000
14	Brine Disposal Main (Open-cut Land Installation)	13,967,000	12,570,300	1,396,700
15	Brine Disposal Main (Ocean Installation)	505,000	0	505,000
16	Brine Disposal Main (Beach head)	1,500,000	0	1,500,000
17	Diffuser Array	500,000	0	500,000
18	Easement Acquisition	580,000	522,000	58,000
19	**Subtotal**	**18,052,000**	**13,892,300**	**4,159,700**
20	Contingency	1,805,200	1,389,230	415,970
21	**Total Brine Disposal [a]**	**19,857,000**	**15,282,000**	**4,576,000**
Finished Water Transmission System				
22	Finished Water Transfer & HS Pumps	910,000	227,500	682,500
23	Finished Water Transmission System	2,280,000	798,000	1,482,000
24	2.0 MG Ground Storage Tank	1,287,900	1,159,110	128,790
25	Land and Right of Way	300,000	270,000	30,000
26	**Subtotal**	**4,777,900**	**2,454,610**	**2,323,290**
28	Effective Contingency	477,790	245,461	232,329
29	**Total Finished Water [a]**	**5,256,000**	**2,700,000**	**2,556,000**
30	**TOTAL Capital Costs [a]**	**53,954,000**	**25,367,000**	**28,589,000**
Project Implementation Costs				
31	Design Determination Studies	2,967,000	2,670,300	296,700
32	Design and Specifications	5,935,000	1,483,750	4,451,250
33	Environmental Review and Permitting	1,079,000	971,100	107,900
34	Construction Support Services	2,698,000	269,800	2,428,200
35	Startup Support Services	846,000	84,600	761,400
36	**Total Project Implementation [a]**	**13,525,000**	**5,480,000**	**8,045,000**
37	**GRAND TOTAL Demonstration Project [a]**	**67,479,000**	**30,847,000**	**36,634,000**

[a] Rounded values.

Table 5-8: Summary annual O&M cost projections, proposed Demonstration Project.

Item	Description	Total Cost	Cost per 1,000 gallons
1	Power	$960,598	$1.05
2	Burdened Labor & Subcontracted Services	$720,000	$0.79
3	Chemicals	$877,491	$0.96
4	Sinking Fund for Equipment Refurbishment and Replacement	$384,000	$0.42
5	**Total**	**$2,558,000**	**$2.80**

Table 5-9: Annual power cost projections, proposed Demonstration Project.

Item	Description	Total Power (HP)	Total Power (kW)	Hours per Day	kW-hr/Day	Daily Cost[a]	Annual Cost
1	Sea Water Supply Pumps	120	90	24	2,148	$129	$47,052
2	Settled Water Clearwell Transfer Pumps	60	45	24	1,074	$64	$23,526
3	RO Clearwell Transfer Pumps	200	149	24	3,581	$215	$78,420
4	High Pressure SWRO Feed Pumps	1,600	1,194	24	28,646	$1,719	$627,356
6	Rapid Mix	10	7	24	179	$11	$3,921
7	Cleaning Pumps (Only to be used every 3 months)	0	0	2	0	$0	$0
8	Backwash Pumps	60	45	6	269	$16	$5,881
9	Lighting; Interior & Exterior	5	4	12	45	$3	$980
10	Instrumentation System	3	2	24	54	$3	$1,176
11	Filters' Compressor	20	15	6	90	$5	$1,960
12	Intake Screens' Compressor	15	11	2	22	$1	$490
13	Wastewater Pump Station No. 1	5	4	4	15	$1	$327
14	Soda Ash Feed System	2	1	24	36	$2	$784
15	Coagulant Feed Pumps	2	1	24	36	$2	$784
16	Sodium Bisulfate Pumps	2	1	2	3	$0	$65
17	Acid Feed Pumps	2	1	8	12	$1	$261
18	HVAC Compressor; Operations Bldg. Only	20	15	12	179	$11	$3,921
19	Cooling Fans; Membrane, Maintenance and Chemical Bldg.	10	7	18	134	$8	$2,941
20	Backwash Pumps Station	30	22	24	537	$32	$11,763
21	Brine Transfer Pumps	60	45	24	1,074	$64	$23,526
22	Finished Water Transfer Pumps	150	112	24	2,686	$161	$58,815
23	**Subtotal**	**2,376**	**1,772**	------	**40,820**	**$2,449**	**$893,950**
24	Contingency[a]	194	145	------	3,043	$183	$66,648
25	**Total**	**2,570**	**1,917**	------	**40,820**	**$2,449**	**$960,598**

[a] Assumes an energy cost of $0.06 per kWh.
[b] Contingency allows for 25% reserve power for all components with the exception of the High Pressure RO Pumps.

Table 5-10: Annual burdened labor and subcontractor services cost projections, proposed Demonstration Project.

Item	Description	No.	Annual Salary	Annual Burdened Cost
1	Plant General Manager	1	65,000	$130,000
2	Class A Plant Operators	5	35,000	$350,000
3	Instrumentation Specialists	1	45,000	$90,000
4	General Maintenance Personnel	1	25,000	$50,000
5	Electrical Contractor Services	1	25,000	$50,000
6	Analytical Contractor Services	1	25,000	$50,000
7	**Total**	**10**	**-**	**$720,000**

Table 5-11: Annual chemicals cost projections, proposed Demonstration Project.

Item	Description	Dosage (mg/L)	Daily Usage (lbs/day)	Unit Cost ($/lb)	Daily Cost	Annual Cost
1	Ferric Chloride	30.0	2,252	0.40	$901	$328,763
2	Sodium Chlorite (CLO2)	1.0	21	0.11	$2	$837
3	Scale Inhibitor	0.0	0	8.18	$0	$0
4	Sodium Bisulfite	5.0	113	0.56	$63	$23,126
5	Calcium Chloride	25.0	1,629	0.20	$326	$118,910
6	Chlorine	3.0	63	0.28	$18	$6,393
7	LAS	2.0	119	0.25	$30	$10,872
8	Sodium Bicarbonate	30.0	626	1.10	$688	$251,138
9	Caustic Soda	15.0	626	0.36	$225	$82,191
10	Sodium Hypochlorite	10.0	43	0.10	$4	$1,585
11	Citric Acid	15.0	65	0.50	$33	$11,891
12	Sulfuric Acid	0.00	0	1.75	$0	$0
13				**Subtotal**	**$2,290**	**$835,706**
14				5% Contingency	$114	$41,785
15				**Total**	**$2,404**	**$877,491**

Table 5-12: Annual refurbishment and replacement (sinking fund) cost projections, proposed Demonstration Project.

Item	System	Activity	Frequency (Years)	Year 2008 Cost	Annual Equivalent Cost
1	Seawater Intake	Dredge Inlet Channels	5	$150,000	$30,000
2	Pretreatment	Replace MF Membranes	6	$1,500,000	$250,000
3	Primary Treatment	Replace SWRO Membranes	5	$520,000	$104,000
4	**Total Annual Sinking Fund**		-	-	**$384,000**

Table 5-13: Recommended uses and sources of funds, proposed Demonstration Project.

	Total	Biennium	
		2010-2011	2012-2013
Use of Funds			
Design Determination Studies	$2,967,000	$2,967,000	-
Environmental Review and Permitting	$1,079,000	$1,079,000	-
Final Design and Specifications	$5,935,000	$5,935,000	-
Construction Support Services	$2,698,000	-	$2,698,000
Startup Support Services	$846,000	-	$846,000
Construction	$53,954,190	$10,791,000	$43,163,000
Total Uses of Funds	**$67,479,000**	**$20,772,000**	**$46,707,000**
Percent of Total	*100%*	*31%*	*69%*
Sources of Funds			
BPUB Loan From WIF	$20,000,000	$8,300,000	$11,700,000
State Grant	$28,200,000	$12,472,000	$15,728,000
State Participation Program	$19,279,000	-	$19,279,000
Total Sources of Funds	**$67,479,000**	**$20,772,000**	**$46,707,000**

5.3.4 BPUB Rate Analysis

The BPUB currently operates two surface water plants and is a 92% owner of the water supply provided by the Southmost Regional Brackish Desalination Plant. The last fiscal year ending 2007 the BPUB had a combined cost of $2.26 per 1000 gallons for water production. With the addition of the demonstration facility, it is expected to cost $1.26 per kgal for debt service and $2.80 per kgal O&M for a combined cost of $4.06 per kgal. The overall anticipated impact to the cost of water produced in Fiscal Year 2012 is and increase from $2.26 to $2.43 or approximately 8% (Table 5-14).

Table 5-14: Current and projected BPUB costs for all water supply sources.

		Current (FY 2007)	Projected (FY 2012)
Water Production			
	Surface Water Plant 1 (Rio Grande)	3,352	2,738
	Surface Water Plant 2 (Rio Grande)	2,970	2,738
	Southmost (Brackish Desalination)	1,763	2,190
	Seawater Desalination	-	803
	Total YTD	**8,085**	**8,468**
Unit Costs of Water Produced ($ per 1,000 gallons)			
Surface Water Treatment	O&M	$1.75	$1.75
	Debt Service	$0.50	$0.50
	Subtotal Surface	$2.25	$2.25
Brackish Groundwater Desalination	O&M	$1.28	$1.28
	Debt Service	$1.02	$1.02
	Subtotal Brackish	$2.30	$2.30
Proposed Demonstration Project	O&M	$0.00	$2.80
	Debt Service[a]	$0.00	$1.26
	Subtotal Seawater	$0.00	$4.06
Total for All BPUB Water Supply Sources	**O&M**	**$1.65**	**$1.73**
	Debt Service	**$0.61**	**$0.71**
	Total Combined BPUB Cost	**$2.26**	**$2.43**

Source: Current data provided by BPUB Public Finance Division, June 2008.
[a] Assumes grant of $28.2 million, debt service of $20 million by BPUP amortized for 25 years at 3%, and $19.3 million financed under the State Participation Program.

5.4 ADVANTAGES AND CHALLENGES OF THE PROPOSED DEMONSTRATION PROJECT

The proposed Demonstration Project holds several advantages over conventional surface water treatment and brackish desalination facilities. For BPUB, one of the most important advantage is the diversification of its supply. For the State of Texas, the demonstration of the viability of seawater desalination technology in the State is of prime importance. Other key perspectives about the viability of the demonstration project are discussed below:

5.4.1 Advantages

- *Addresses the need for water production for the BPUB* – the 2.5 mgd production capacity of the proposed Demonstration Project will be fully utilized by BPUB. A larger plant at this time would have excess capacity with a much greater investment and risk.

- *Lower near-term investment* – the implementation of the demonstration project has a lower overall initial cost compared to the full-scale plant. A total investment of $67 million compared to $182 million. Nearly 50% of the demonstration cost is for future capacity.
- *Reduction of risk* – A full-scale investment $182 million now incurs some risk in that the Pilot Study yielded good data for a demonstration plant but left some unanswered questions for full production. The Demonstration Project is expected to further refine data in efforts to reduce the overall cost of the full-scale facility.
- *Potential for cost savings in full-scale* – the Pilot Study yielded the need for a higher level of pretreatment and associated costs. The Demonstration Project will be equipped to modify operations to optimize the design data and solicit competition from vendors for the full-scale facility.
- *Development of operational flexibility in demonstration* – the demonstration facility will allow for the testing of a wide variety of conditions such as primary treatment ahead of membrane pretreatment for a portion of the flow to measure cost savings/increases as a result of this flexibility.
- *Provides an opportunity to conditionally permit full-scale facility based on actual demonstration-scale operational data* – the proposed Demonstration Project would provide the opportunity to evaluate the effects of concentrate disposal in the Gulf of Mexico on a smaller scale over a period of years, reducing the environmental risk of full-scale permitting conditions developed solely on artificial modeling results.
- *Operate over a longer term to assure all water qualities* – the Pilot Study operated for a period of 18 months with some short-term successes. The development of the demonstration plant will provide an opportunity for the plant to experience varying conditions over multiple seasons. One potentially complicating phenomenon that did not occur during piloting was the presence of a red tide event.
- *Improvement of intake and its effects on operation and future design parameters* – the pilot was unable to maximize the intake efficiency therefore yielding a highly variable water quality with extreme peaks of turbid water. On the positive side, the pilot yielded good results for poor water conditions. It is anticipated that an improved intake will yield a reduction in cost and improve the reliability of the demonstration and full-scale plants.
- *Demonstrate to the State the effectiveness of seawater desalination along the Texas coast* – the establishment of an inland desalination facility will give confidence to other areas of the state to evaluate this water supply alternative.
- *Developing excess capacity in certain facility components makes full-scale facility more cost effective to build* – major components of the Demonstration Project, such as intake canals and concentrate discharge lines, would be designed and constructed for full-scale (25 mgd) conditions. These capital costs, sunk in present-day dollars, would reduce the expense of future expansion.

As with any project, there are disadvantages to the implementation of a demonstration plant. The following describes disadvantages to the demonstration plant.

5.4.2 Challenges

- *Higher unit cost of water produced* – economies of scale play a large part in the development of a desalination facility. The demonstration plant includes almost 50 percent in extra cost that cannot be fully utilized until future expansion. For the plant to be cost effective, grants and low interest loans must be utilized to complete the Demonstration Project.
- *Less capacity for future needs* – the initial (smaller) desalination plant would provide less capacity for future needs and regional supply possibilities.
- *Perception of not being "big enough"* – the demonstration plant does not have the "big" or large-scale tag and may be perceived as too small.

6.0 References

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7.0 Appendices

7.1 PILOT STUDY CONTRACT SCOPE OF WORK

This appendix includes a detailed list of all TWDB contract work tasks and an executive summary of how they were addressed during the Pilot Study.

1. Prepare funding application

Funding application was prepared and BPUB applied for grant assistance on March 9, 2006. A grant was awarded on April 11, 2006.

2. Prepare pilot operational protocol

2.1. Preliminary Bench Scale Testing
2.2. Pretreatment System Evaluation and Optimization
2.3. SWRO System Evaluation and Optimization
2.4. RO Concentrate Quantity and Quality Evaluation
2.5. Pretreatment Residuals Quantity and Quality Evaluations
2.6. Pretreatment and RO Treatment Cleaning and Chemical Evaluation
2.7. Prepare and Perform 1st Stage TCEQ Testing/Operational Protocols
2.8. Prepare and Perform 2nd Stage TCEQ Testing/Operational Protocols
2.9. Prepare and Perform 3rd Stage TCEQ Testing/Operational Protocols

Pilot operating protocols were submitted to the Texas Commission on Environmental Quality (TCEQ) and approved. The protocols addressed six main subjects: 1) project background, 2) study objectives, 3) seawater reverse osmosis membrane information, 4) pilot facility design, 5) testing protocols and data collection plan, and 6) study schedule. As a permit condition for a facility to provide potable water, the Pilot Study incorporated specific testing components required by TCEQ.

3. Perform raw water characterization

3.1. Ship Channel Preliminary Water Quality Gathering
3.2. Ocean Preliminary Water Quality Data Gathering
3.3. Laboratory sampling and Analysis Program
3.4. Development of Sampling and Monitoring Program
3.5. Perform Ship Channel and Water Quality Sampling and Analysis
3.6. Perform Open Ocean Water Quality Sampling and Analysis
3.7. Investigate Long-term Viability of Ship Channel for Prototype Water Source

A raw water characterization sampling program was developed and implemented for two sources: 1) the Brownsville Ship Channel, and 2) the Gulf of Mexico. In general, water *quality in the ship channel had more variation when compared to that in the Gulf of Mexico mainly due to the presence of shipping traffic in the channel.*

4. **Perform intake siting assessment for pilot**
   - 4.1. Environmental considerations
   - 4.2. Obtain agreements
   - 4.3. Potential for Full-Scale facility

Based largely on infrastructure costs, the pilot facility was located on the Brownsville Ship Channel as opposed to the open Gulf of Mexico at Boca Chica Beach. A lease agreement was obtained from the Port of Brownsville for use of the site during the Pilot Study.

5. **Design pilot treatment process**
   - 5.1. Intake Design
     - 5.1.1. Intake design for port channel water delivery
     - 5.1.2. Intake design for ocean intake delivery
   - 5.2. Pre Treatment
     - 5.2.1. Preliminary Pre Treatment Schemes
     - 5.2.2. Pretreatment Pre-screening and Selection
     - 5.2.3. Final Pretreatment Design
   - 5.3. RO Treatment
     - 5.3.1. Preliminary RO Treatment Scheme
     - 5.3.2. RO Treatment Equipment Selection Criteria
     - 5.3.3. RO Treatment Equipment Pre-Screening and Selection
     - 5.3.4. Final RO Treatment Design
   - 5.4. Post Treatment Evaluation
   - 5.5. QA/QC
     - 5.5.1. Develop a project QA/QC plan and review with Team Members, BPUB and TWDB.
     - 5.5.2. Contact NRS Team members and obtain material per the QA/QC schedule.
     - 5.5.3. Perform QA/QC reviews and provide written comments and marked up plans.
     - 5.5.4. Review final material to insure QA/QC comments have been addressed.
     - 5.5.5. Be available to team for general review and consultation.

Intake Structure – Implementation of the full Feasibility Study design for the intake (stilling well with an excavated channel to the main ship channel) was not possible due to cost and permitting limitations. Therefore, the original raw water intake design was modified for the pilot facility to include only a stilling well.

Pretreatment System – It is generally understood that the most critical component of the seawater desalination is optimizing and evaluating the pretreatment system. The original Pilot Study scope was expanded (and subsequently funded) by the BPUB to include the side-by-side comparison of four different pretreatment technologies (conventional, Zenon Ultrafiltration, Norit Ultrafiltration, and Pall Microfiltration) instead of just two. Based on piloting results, the Pall microfiltration unit proved the capability to operate under worst-case scenarios of high turbidity, suspended solids spikes, and variations in raw water temperature. The Pall *microfiltration system, used with and without a conventional system, is the recommended pretreatment design for the Demonstration Project.*

Primary Treatment (Reverse Osmosis) System – The reverse osmosis (RO) system used at the pilot facility required membrane elements to comply with industry standards so that a larger municipal facility could be designed by scaling up from the pilot results. The final RO *treatment design therefore incorporates a single-stage system operating at a flux of 8.2 gallons per square foot of membrane per day with a recovery of 45%. The permeate water produced from the RO will be treated to provide well stabilized product water to the end user.*

6. **Coordinate activities with the pilot site host**

Frequent discussions and briefings of progress, results, and upcoming events were conducted with the Port of Brownsville throughout the pilot period.

7. **Obtain all permits**
   - 7.1. Pilot Plant Approvals
     - 7.1.1. TCEQ Permission
     - 7.1.2. Port of Brownsville Waste Discharge
     - 7.1.3. Others
   - 7.2. Meetings with TCEQ
   - 7.3. Environmental committee meetings
   - 7.4. Full Scale Plant Permitting and Approvals
     - 7.4.1. USACE Department of the Army Permit
     - 7.4.2. THC Antiquities Permit
     - 7.4.3. TPDES Storm Water Permit
     - 7.4.4. Membrane Washwater Disposal to POTW
     - 7.4.5. Solids Disposal from Filter Backwash to Municipal Landfill
     - 7.4.6. TCEQ Water Use Permit
     - 7.4.7. TPDES Wastewater Discharge Permit

Permits obtained for construction of the pilot facility included Section 404 authorization under the Clean Water Act from the U.S. Army Corps of Engineers and discharge permit from the Texas Commission on Environmental Quality (TCEQ) for the re-combined solids, salts, and water from the pilot process. In addition, quarterly meetings were held with TCEQ to discuss the status of the pilot, including piloting data and full-scale permitting implications.

In anticipate of full-scale project permitting, BPUB has invited numerous regulatory and resource agencies, non-governmental entities, and academic institutions to participate in an environmental advisory group during project formulation. The primary resource concern identified is concentrate disposal. Based on studies of various disposal methods conducted during the Pilot Study, it is recommended that concentrate from the demonstration- and full-scale seawater desalination facilities be disposed of via diffusion into the Gulf of Mexico by diffusion.

8. **Procure pilot plant equipment**
   - 8.1. Develop detail list of equipment
   - 8.2. Obtain breakdown of equipment costs

8.3. Establish subcontract for lease duration with obligations for start-up, operation review and

Prior to commencing piloting, Interviews with potential equipment suppliers were conducted prior to equipment acquisition to allow an informed decision by the design team and project owners. A combination of purchased, leased, and supplier-provided equipment was used to accomplish the Pilot Study objectives.

9. Pilot Plant location – construction

9.1. Prepare site plan for construction of support facilities for treatment system
9.2. Procure construction activities through local contractors and in-kind services

The site design and construction were performed according to the predetermined goals; namely, data acquisition, operational flexibility, and public relations.

10. Perform pilot plant start up, optimization, and operation

10.1. Start up services for plant facilities
10.2. Continuous evaluation of optimization of plant performance
10.3. Collect data in accordance with developed protocol
10.4. Daily operations
10.5. Site visits
10.6. Security

The pilot facility was started and operated according to the approved TCEQ protocols. Optimization of the pilot system and processes took place throughout the Pilot Study. The pilot facility began operation in February 2007 and was decommissioned in July 2008.

11. Mobilization/Demobilization

The design team coordinated closely with the multiple vendors and site owners to ensure a synchronized mobilization and demobilization process.

12. Prepare data collection and monthly updates

12.1. Each month, data will be compiled and summarized with monthly updates to the BPUB and TWDB no later than the 10th of each month.

Monthly updates of project status and results were provided to TWDB throughout the pilot period. These reports included detailed analyses of pretreatment and RO performance, status of project schedule, and any other items or issues that occurred over the course of the month that were related to the pilot project. As necessary or required, these monthly updates were conducted in person or on site.

13. Analyze pilot plant performance

13.1. Remote monitoring during plant operation
13.2. Analyze pilot plant performance and results

Performance of the pilot plant was analyzed on a daily basis. The site was equipped with remote monitoring which allowed for monitoring of pilot performance while absent from the site. Final data analyses are presented in this Pilot Study report.

14. Prepare mid-term report (HB 1370)

14.1. Develop cost update regarding the cost of power when plant is projected to be on line in 2010

14.2. Develop update of capital and O&M cost of full-scale facility and modify according to source water and anticipated location of plant site.

14.2.1. Port Location with port channel intake/ocean discharge

14.2.2. Boca Chica locations with ocean intake/ocean discharge

14.2.3. Developing Alternatives for most cost effective manner to implement the full-scale project.

14.3. Develop a Financial Matrix for full implementation

14.3.1. Examining a range of local and state financing mechanisms.

14.3.2. Exploring Methods for Legislative Appropriations, State Rule Changes and TWDB project funding.

14.3.3. Exploring Federal Legislation and funding support mechanisms.

14.3.4. Exploring inclusion of other users in the LRGV as project water users and financial supporters.

14.3.5. Developing Alternatives for most cost effective manner to implement the full-scale project.

The mid-term report was prepared and submitted to TWDB in August 2006.

15. Prepare final report

15.1. Compilation of and analysis of data

15.2. Preparation of draft Final Report for review

15.3. Modify report based on comments

15.4. Submit appropriate copies of report and electronic format in accordance with TWDB agreement

The final report (the subject work) was prepared and submitted to TWDB in October 2008.

16. Meetings and administration

16.1. Weekly meetings with BPUB

16.2. Monthly meetings with BPUB

16.3. Quarterly Meetings with TWDB

16.4. Monthly Status Report

16.5. Statement confirming submission of monthly reports

16.6. Statement indicating the submission of expense reports

16.7. Quarterly meetings – on site or at TWDB

16.8. Travel and Expenses for review of major sea water desalination facilities

Regular meetings were held between BPUB staff and design team members on site at the pilot facility to discuss data collection and operations. Conference calls were held with the pretreatment vendors weekly to discuss operating conditions and system performance.

17. Public Outreach

17.1. Elements

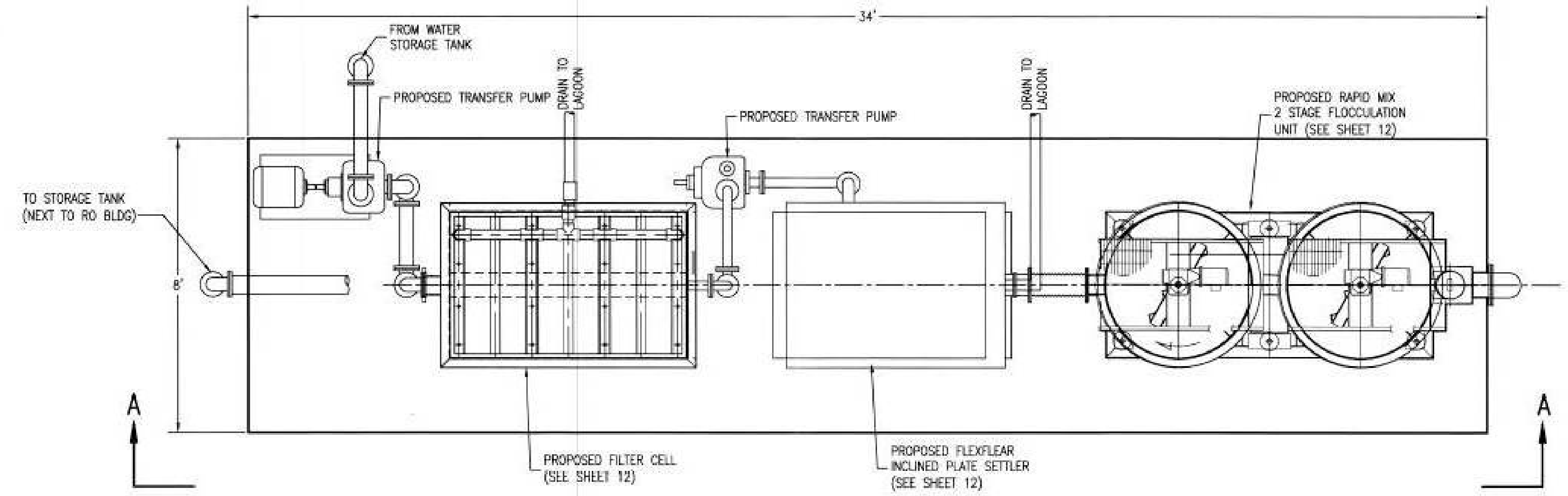
- 17.1.1. Elements of the outreach campaign will include:
- 17.1.2. Written material
- 17.1.3. Website
- 17.1.4. Press releases/conferences
- 17.1.5. Stakeholder meetings
- 17.1.6. Presentations/Tours/open houses
- 17.1.7. Regular media contact/updates

17.2. Tasks

- 17.2.1. Identify outreach targets & opportunities
- 17.2.2. Develop outreach materials
- 17.2.3. Schedule meetings, presentations & media updates

Site tours were held with legislatures, students, employees, and other individuals interested in the technology of seawater desalination. Numerous professional presentations were given throughout the United States detailing the work performed at the Pilot Study facility.

7.2 PROCESS AND INSTRUMENTATION DIAGRAMS FOR THE PILOT STUDY TREATMENT SYSTEMS



CONVENTIONAL TREATMENT UNITS – PLAN VIEW

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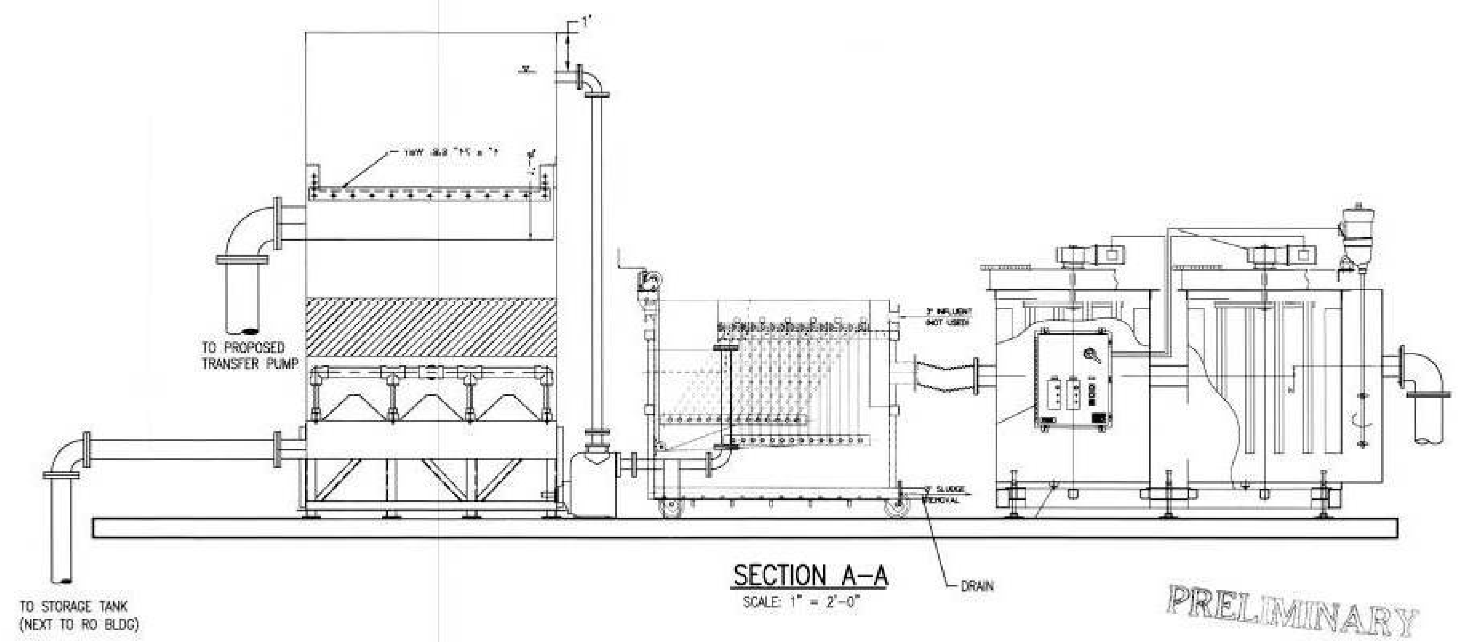


SECTION A–A

SCALE: 1" = 2'-0"

PRELIMINARY

REVISION OR ISSUE			REVISION OR ISSUE		
NO.	DATE	SUBJECT	NO.	DATE	SUBJECT

NRS engineering better communities
1222 E. TYLER, SUITE C
HARLINGEN, TEXAS 78550
(956) 423-7409

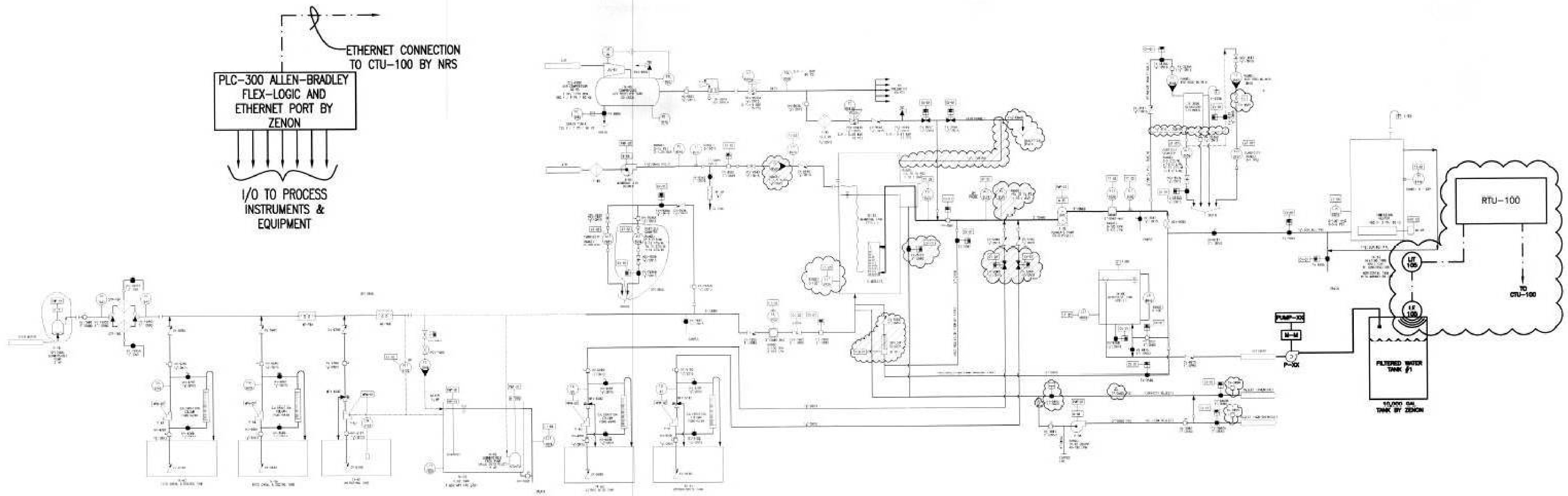
SEAL

BROWNSVILLE PUBLIC UTILITIES BOARD
CAMERON COUNTY, TEXAS
SEAWATER DESALINATION PROJECT

TITLE: CONVENTIONAL TRETAMENT UNIT

SCALE: AS SHOWN DATE: NOVEMBER 2006
DESIGNED BY: J.W.N.
DRAWN BY: R.C.
CHECKED BY: J.L.
APPROVED BY: J.W.N.
PROJECT NO.: BR0602

11 / 31



ZENON Environmental Inc.

ELECTRICAL EXPERTISE, INC.
P. O. Box 9837
Longview, Texas 75608

REVISION OR ISSUE			REVISION OR ISSUE		
NO.	DATE	SUBJECT	NO.	DATE	SUBJECT

NRS
engineering better communities
1222 E. TYLER, SUITE C
HARLINGEN, TEXAS 78550
(956) 423-7409

12/5/06
STATE OF TEXAS
WILLARD W. JORDAN
37135
REGISTERED PROFESSIONAL ENGINEER

BROWNSVILLE PUBLIC UTILITIES BOARD
CAMERON COUNTY, TEXAS

SEAWATER DESALINATION PROJECT

TITLE:
ZENON ENVIRONMENTAL INC.
ULTRAFILTRATION P & ID

SCALE: AS SHOWN	DATE: SEPTEMBER 2003
DESIGNED BY: J.L.	
DRAWN BY: J.M.	
CHECKED BY: J.L.	
APPROVED BY: J.L.	
PROJECT NO.: BR0602	

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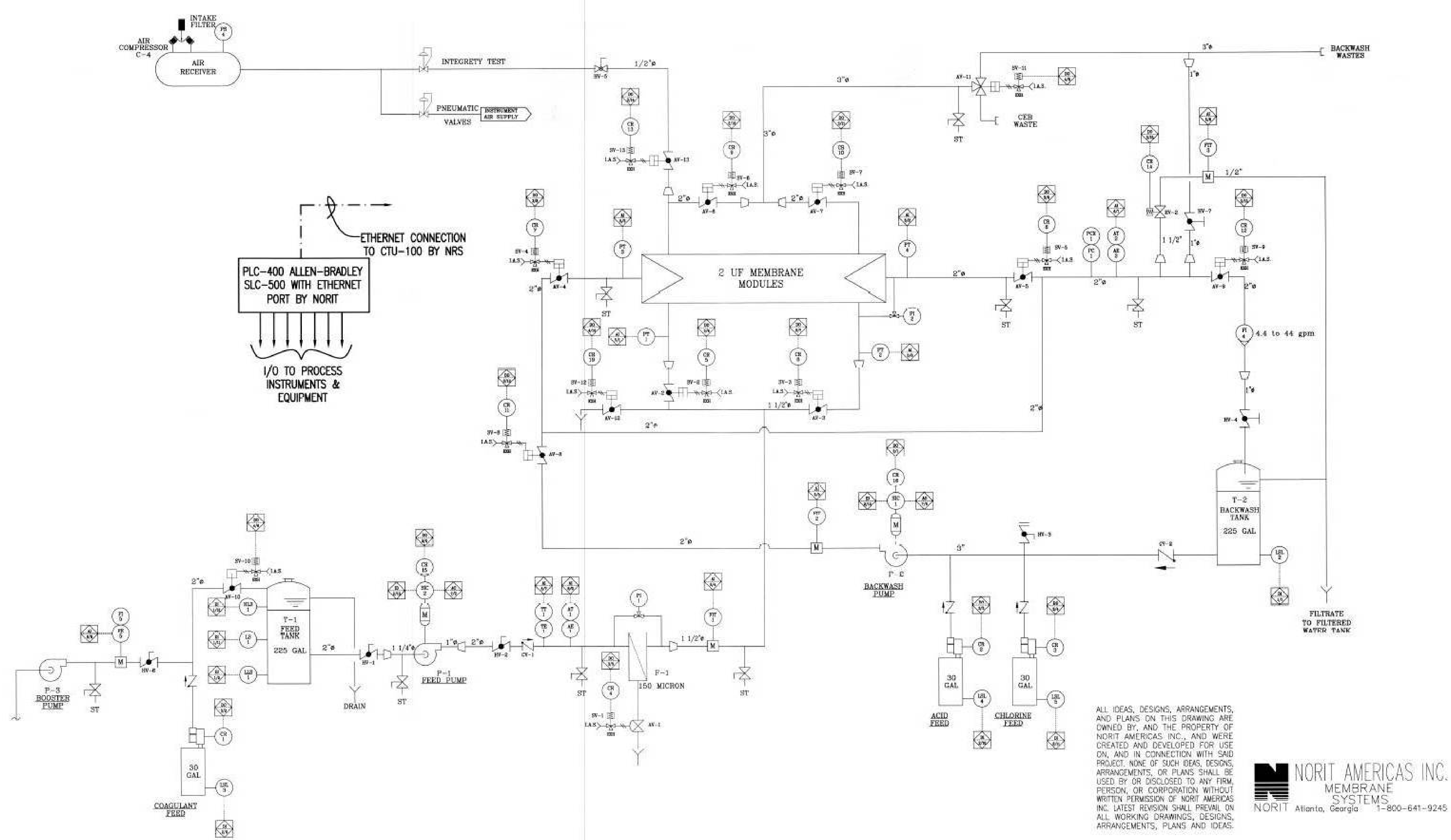
31



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12/5/06
STATE OF TEXAS
WILLARD W. JORDAN
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BROWNSVILLE PUBLIC UTILITIES BOARD
CAMERON COUNTY, TEXAS
SEAWATER DESALINATION PROJECT

TITLE: NORIT AMERICAS INC.
ULTRAFILTRATION P & ID

SCALE: AS SHOWN
DATE: OCTOBER 2006
DESIGNED BY: J.L.
DRAWN BY: R.C.
CHECKED BY: J.L.
APPROVED BY: J.L.
PROJECT NO.: BR0602

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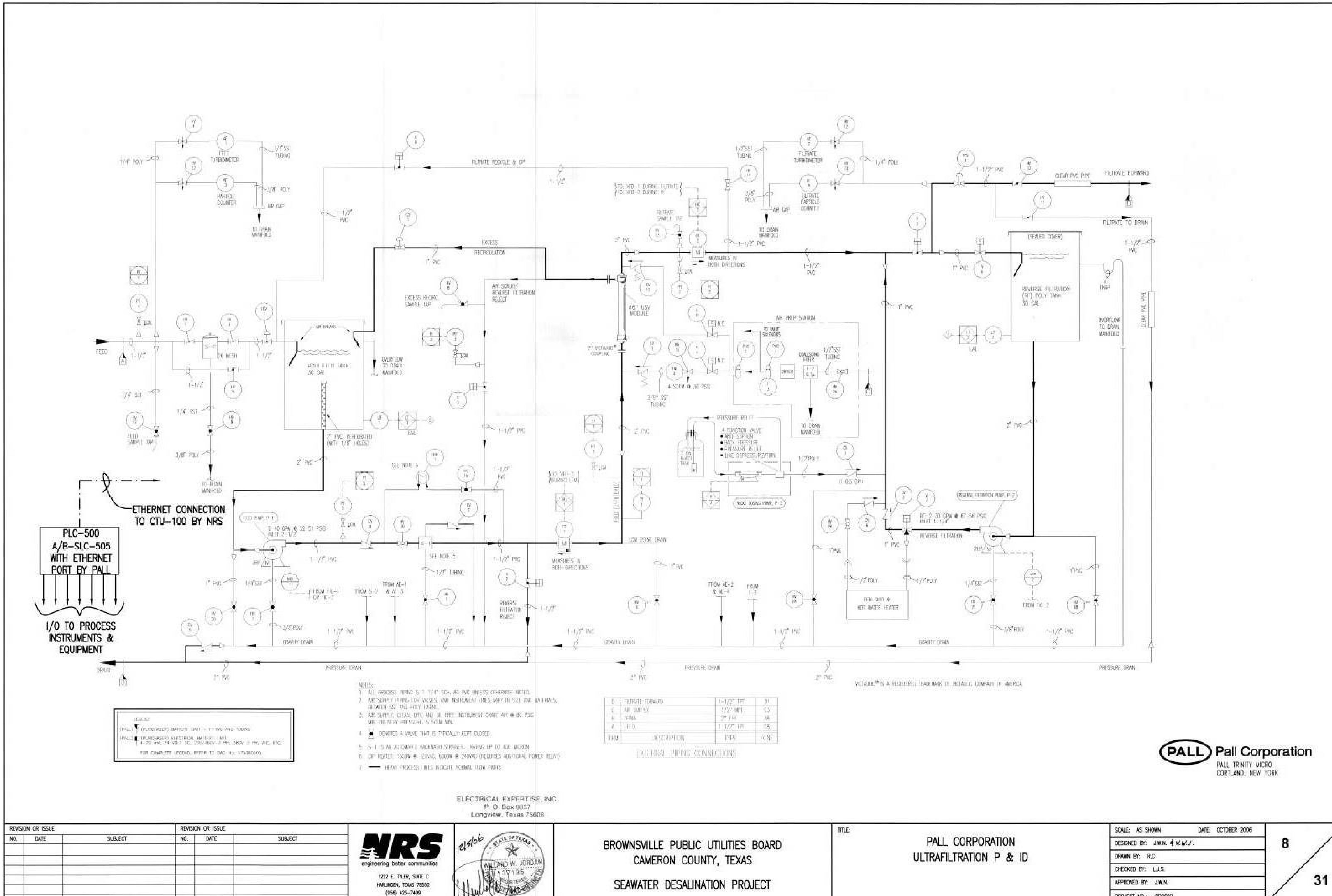

ETHERNET CONNECTION TO CTU-100 BY NRS
PLC-500 A/B-SLC-505 WITH ETHERNET PORT BY PALL
I/O TO PROCESS INSTRUMENTS & EQUIPMENT
FEED
DRAIN
FILTRATE FORWARD
FILTRATE TO DRAIN
GRAVITY DRAIN
PRESSURE DRAIN
ELECTRICAL EXPERTISE, INC.
P. O. Box 9837
Longview, Texas 75608
Pall Corporation
PALL TRINITY MICRO
CORTLAND, NEW YORK
REVISION OR ISSUE
NO. DATE SUBJECT
NRS
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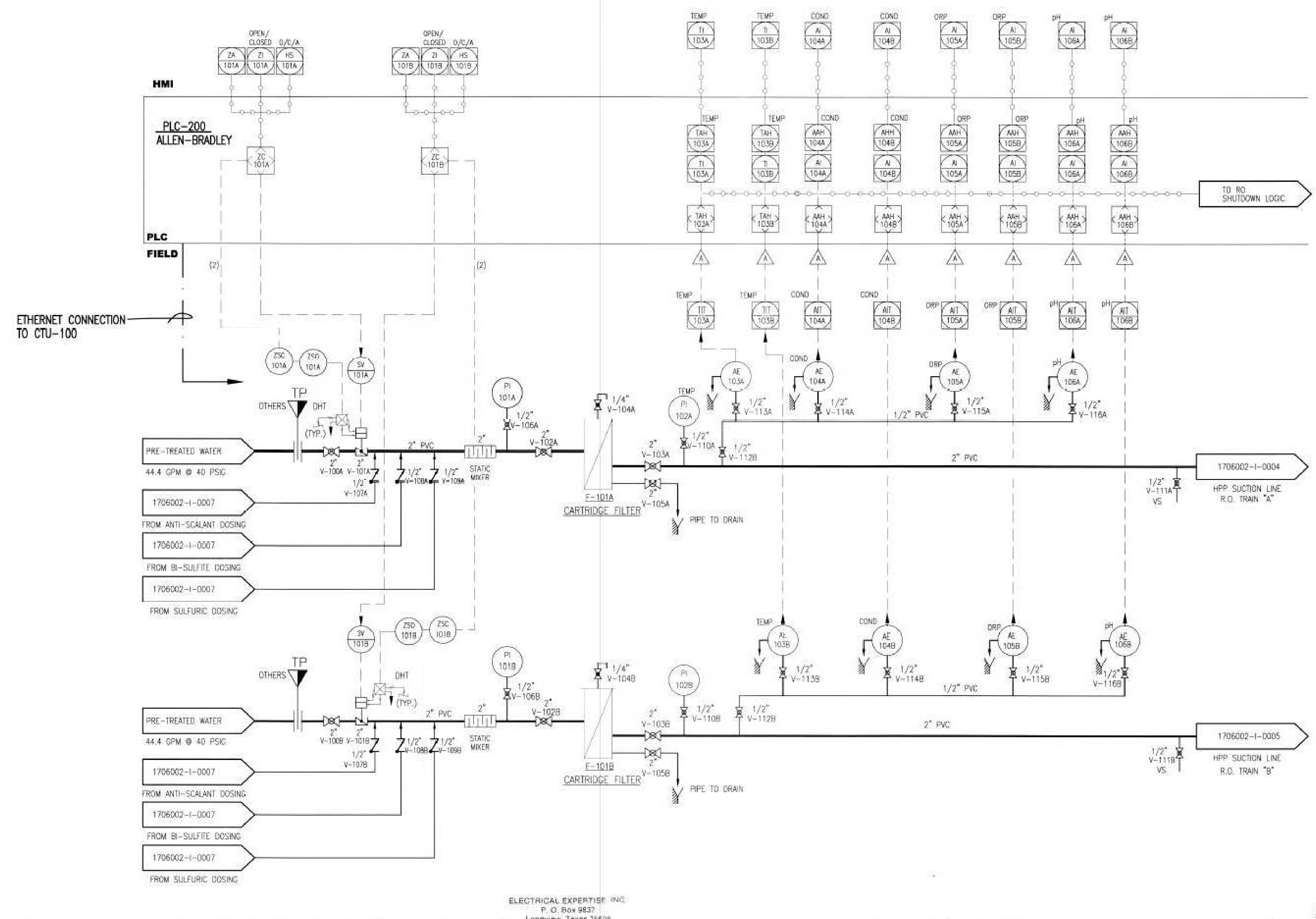
WILLARD W. JORDAN
37135
BROWNSVILLE PUBLIC UTILITIES BOARD
CAMERON COUNTY, TEXAS
SEAWATER DESALINATION PROJECT
TITLE:
PALL CORPORATION
ULTRAFILTRATION P & ID
SCALE: AS SHOWN
DATE: OCTOBER 2006
DESIGNED BY: J.W.N.
DRAWN BY: R.C.
CHECKED BY: L.J.S.
APPROVED BY: J.W.N.
PROJECT NO.: BR0602
8
31



REFERENCE DOOSAN DWG. # 1706002-I-0003

REVISION OR ISSUE			REVISION OR ISSUE		
NO.	DATE	SUBJECT	NO.	DATE	SUBJECT

NRS
engineering better communities
1222 E. TYLER, SUITE C
HARLINGEN, TEXAS 78550
(956) 423-7409

12/5/06
STATE OF TEXAS
WILLARD W. JORDAN
37135

BROWNSVILLE PUBLIC UTILITIES BOARD
CAMERON COUNTY, TEXAS
SEAWATER DESALINATION PROJECT

TITLE:
DOOSAN R.O.
P & I.D. FOR CARTRIDGE FILTER

SCALE: N.T.S. DATE: OCTOBER 2006
DESIGNED BY: J.L.
DRAWN BY: R.C.
CHECKED BY: J.L.
APPROVED BY: J.L.
PROJECT NO.: BR0602

20
31

8.0 List of Digital Attachments

8.1 Engineering plans for the Pilot Study facility
8.2 USACE permit for intake construction
8.3 TCEQ letter for disposal of Pilot Study waste
8.4 Pretreatment proposals
8.5 Public relations materials
8.6 Independent laboratory testing results
8.7 Raw water quality tabular data
8.8 Graphs of the conventional pretreatment unit
8.9 TCEQ pilot testing protocols
8.10 Pretreatment performance tabular data
8.11 CIP processes for RO modules
8.12 RO performance tabular data
8.13 RO membrane autopsy results
8.14 Concentrate diffusion modeling study
8.15 Class I injection well study