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Desalination and Water Purification Research
and Development Program Report No. 137

Pretreatment and Design Considerations for Large-Scale Seawater Facilities

U.S. Department of the Interior
Bureau of Reclamation

February 2008

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
February 2008

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
January 2004 – December 2005

4. TITLE AND SUBTITLE
Pretreatment and Design Considerations for Large-Scale Seawater Facilities

5a. CONTRACT NUMBER
Agreement No. 04-FC-81-1059

5b. GRANT NUMBER
04-FC-81-1059

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER
G

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Reiss Environmental, Inc.
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Orlando FL 32826

8. PERFORMING ORGANIZATION REPORT NUMBER
3802

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of the Interior,
Bureau of Reclamation, Denver Federal Center,
PO Box 25007, Denver CO 80225-0007

10. SPONSOR/MONITOR'S ACRONYM(S)
Reclamation

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
DWPR Report No. 137

12. DISTRIBUTION / AVAILABILITY STATEMENT
Available from the National Technical Information Service (NTIS),
Operations Division, 5285 Port Royal Road, Springfield VA 22161

13. SUPPLEMENTARY NOTES
Also available at: http://www.usbr.gov/pmts/water/publications/reports.html

14. ABSTRACT ***(Maximum 200 words)***

The report addresses key issues of concern regarding the design and operation of seawater desalination facilities in the United States. The use of mixed seawater/surface water results in unique design considerations as evaluated in this study. The objectives of the project were to focus on the following areas:

1. Pretreatment alternatives
2. Impacts of seasonal variations on source water quality and process performance

15. SUBJECT TERMS
desalination, demineralization, reverse osmosis, seawater, seawater pretreatment

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Steve Dundorf
a. REPORT UL	b. ABSTRACT UL	c. THIS PAGE UL	SAR (same as report)	100+ appendices	19b. TELEPHONE NUMBER *(include area code)* (303) 445-2263

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. 239-18

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Prepared for Reclamation Under Agreement No. 04-FC-81-1059

by

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Denver, Colorado

February 2008

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1. Introduction

Within the United States, the continued rise in population, decline in the amount of available natural resources, and increasingly stringent water quality criteria continue to impact the suitability and availability of water supplies. This situation significantly impacts States and regions in varying ways, such as necessitating expanded raw water supply capacity and an increased level of treatment on ground water to reduce analytes that, at one time, met now-outdated drinking water standards. Other impacts include the necessity of coastal regions to investigate seawater as an alternative droughtproof resource. The investigation of seawater sources also aids water suppliers with the ability to diversify their water portfolio because other options are too costly, will take too long to implement, or are simply not available. Seawater represents an alternative supply that can be treated to meet the needs of a population while maintaining all Federal, State, and regional water quality requirements. However, as planners, owners, engineers, and investors look towards the various technical and, in some cases, economic costs of implementing this alternative, a variety of information is simply not available domestically to support the multitude of interrelated components that go into seawater desalination projects.

While use of reverse osmosis (RO) for demineralization of seawater has been practiced on a wide scale for approximately two decades, potable applications within the United States have been limited in number and capacity. Cost has always been the key component in the development of seawater treatment facilities, and many applications have typically been in areas of the world with very low power costs or where there was no other reasonable potable water alternative. As a result, costs were absorbed based on the absence of other alternatives.

However, as costs for RO treatment decrease due to efficiency improvements, and the need for alternative water supplies increases, the level of interest for seawater desalination continues to grow significantly. Over the years, the Bureau of Reclamation (Reclamation) has been involved in a number of projects to further investigate the use of seawater as a source of supply. In addition, numerous other agencies have investigated seawater applications, with the first large-scale seawater facility in the United States commissioned in Tampa, Florida in March 2003.

At this point in the United States, seawater reverse osmosis (SWRO) facilities are being evaluated with a critical focus on optimizing science and technology for the purpose of providing sustainable operation, cost minimization, and compliance with increasingly stringent finished water regulatory requirements. This occurs concurrently with the comparison and consideration of other water supply alternatives such as reuse, brackish ground water desalination, and others.

Key considerations associated with desalination efforts include identification of an optimal intake location and a correspondingly appropriate pretreatment process. These two factors have far-reaching implications and a direct impact on costs and operational sustainability of seawater treatment plants. With most of the domestic projects under consideration, seawaters under the influence of surface water runoff are being considered. These sites are located in bays, estuaries, intracoastal waterways, or at the deltas of rivers. In many cases, seawaters used as once-through cooling water for powerplants are under consideration as the source water for desalination.

The 2001 Desalination Research and Development Workshop, conducted by Reclamation and the National Water Research Institute ranked “Additional Advancement of Membrane Technology” as “Priority 1,” over 18 other issues. Within this category were several issues, including advancement of pretreatment methods. An abundant amount of detailed information and research is available on the membrane treatment process, but there is a significant lack of data regarding the specific influence a particular location or feed water quality may have on the SWRO process design. In some cases, generally accepted design parameters, such as conventional settling/filtration or dual-media two-stage filtration systems, have not met performance expectations when applied to seawater pretreatment.

In light of unanswered questions regarding the application of SWRO technology for large-scale municipal applications and the associated costs, additional research is necessary to further advance the technology and its application to the future water supply needs of the United States.

Pretreatment considerations represent a critical factor in determining project viability and costs. Reclamation has been at the forefront of this effort with a national research and development program. As part of its lab-scale program, in 2002, Reclamation cofunded Reiss Environmental’s Evaluation of Desalination of Seawater Under the Influence of Surface Water Runoff (EDSUISWR) project to provide short-term pilot testing data related to the use of near-shore and inland marine supplies. Such conditions (seawater under the influence of fresh surface water runoff) are the prevailing circumstances under which seawater desalination facilities would likely be developed in the continental United States. While approved by Reclamation through the lab-scale program at associated cofunding levels, the project team successfully developed a short-term pilot-scale program. Reiss Environmental completed the pilot-scale field operations in April 2004 and reported the results in June 2004 (Desalination and Water Purification Research and Development Report No. 113). The short-term pilot operation implemented through the EDSUISWR project has provided a better understanding of the specific weaknesses and areas of improvement needed in membrane filtration (microfiltration [MF] and ultrafiltration [UF]), and sand filtration pretreatment, as well as highlighting the need for further investigations.

This entire seawater desalination investigation program took place from December 2003 through February 2005. A significant portion of the project was funded and sponsored by Tampa Bay Water from December 2003 through December 2004 and developed to evaluate specific operating and process considerations for a planned seawater desalination facility at Progress Energy's Anclote Power Generating Station (APGS) in Holiday, Florida. Reclamation funded an extension of the project for two additional months, and the work scope increased to account for an evaluation of the pilot facility performance as it is applicable to seawater desalination facilities on a national scale. This report is henceforth entitled *Pretreatment and Design Considerations for Large-Scale Seawater Facilities* (PDCLSF).

The team administered and operated the pilot demonstration project to address a number of industry concerns, including:

1. Pretreatment systems alternatives
2. Impacts of seasonal and tidal variations on source water quality and process performance
3. The use of powerplant cooling water discharges versus background seawater at ambient temperatures

The PDCLSF project incorporated differing, parallel pretreatment processes followed by RO treatment. Conventional pretreatment consisted of coagulation, flocculation, sedimentation, two-stage media filtration followed by a high-rejection two-pass SWRO system. This configuration was compared to membrane MF as a pretreatment step, followed by a two-pass high-rejection SWRO system.

2. Project Objectives

The PDCLSF project addresses key issues of concern regarding the design and operation of seawater desalination facilities in the United States. The use of mixed seawater/surface water sources results in unique design considerations as evaluated in this study. The objectives of the project were to focus on the following research areas:

- Pretreatment Alternatives
- Impacts of Seasonal and Tidal Variations on Source Water Quality and Process Performance
- Impacts of Source Water Temperature on Finished Water Quality

2.1 Pretreatment Alternatives

Pretreatment for seawater desalination systems has traditionally consisted of conventional MMF, commonly configured in a two-stage arrangement denoted “roughing filter” and “polishing filter,” operating in series. The type of filtration media typically utilized includes anthracite, sand, garnet, and other traditional media. For challenging source waters, it is a natural extension to add coagulation/sedimentation ahead of MMF. A coagulation-sedimentation-filtration (CSF) system represents a classic surface water treatment plant used throughout the United States to treat surface waters. This process has the potential to provide value relative to seawater desalination pretreatment. In recent years, a significant emphasis has been placed on alternative pretreatment in the form of MF or UF. These membrane filtration systems were designed specifically for turbidity and particle removal and are of particular interest for pretreatment of challenging source waters.

The majority of the ongoing seawater desalination investigations in the United States include the use of a mixed seawater/surface water source, and are dealing with common source water variability and pretreatment challenges. With pretreatment critical to operational sustainability, it is of importance to determine the relative capability of conventional MMF and membrane filtration pretreatment. Although site-specific concerns may modify individual approaches, this information is pertinent to the entire seawater desalination effort in the United States.

The objective of this task was to evaluate a conventional MMF system, a CSF system and a membrane filtration pretreatment system, for an extended period of time using a mixed seawater/surface water source. This effort provided the opportunity to assess the operational sustainability of pretreatment processes themselves, as well as determine the relative rate of SWRO system fouling based on the various pretreatment methods chosen. Note that the term “fouling” is used in this report as a generic term to refer to scaling, particle plugging, biofouling, and organic fouling.

2.2 Seasonal and Tidal Variations

Use of near shore intakes typically reduces the capital and operating costs of supplying raw water to a seawater desalination facility. For projects co-located with a powerplant that employs once-through cooling, the presence of existing intake structures can be of even greater value. Regardless, most proposed seawater desalination facilities in the United States are based on the use of near shore intakes. This results in the potential for mixing seawater with surface water, such as stormwater runoff and river discharges. In addition, the use of near shore intakes can also result in varying water quality associated with tidal exchanges and wind action, and require more robust pretreatment. To this point, little consideration has been given to this variability in the published literature regarding current or proposed United States seawater desalination installations. The objective of this project task is to document the seasonal and tidal variation of the Anclote site source water utilized, as well as assess the impacts on treatment system performance. While this generates site-specific information only, it also provides an assessment of the relative impact of mixed seawater/surface water supplies that has commonality throughout the United States. Furthermore, it compares/contrasts the effectiveness of the pretreatment systems for use with saline source waters.

2.3 Impacts of Source Water Temperature

Two optional sources of supply for many seawater desalination projects are ambient temperature seawater or higher temperature powerplant cooling water discharges. The use of ambient temperature seawater requires use of a seawater intake or a beach well, whether pre-existing or new. The two options consist of either an intake drawing water from the local seawater or drawing water from a powerplant cooling water discharge.

The use of powerplant intake water is not commonly acceptable given the diversion of this water from its originally intended use and, as such, would result in loss of capacity. For powerplants utilizing once-through cooling, large supplies of this higher temperature cooling water discharge can be available for withdrawal and for use as source water for a seawater desalination system.

The benefits of using cooling water discharges over direct use of seawater can be significant and may include reduced permitting requirements, reduced civil infrastructure/piping requirements, pre-existing screening structures, lower operating costs, and other benefits. For this reason, most communities considering seawater desalination facilities evaluate co-location with a powerplant and use of spent cooling water as a source of supply.

It is important that planning and design efforts include assessment of the effects of higher temperature source waters on finished water quality and the ability to meet finished water quality goals. As temperature increases, the passage of inorganic ions through a reverse osmosis membrane increases. Therefore, higher temperatures can result in lower quality finished water.

The objective of this task was to assess, at pilot-scale, the impact of ambient temperature seawater on finished water quality versus utilizing higher temperature cooling water discharges as a source of supply.

3. Pilot Study Approach and Description

The seawater desalination pilot program took place from December 2003 through February 2005. Reclamation partially funded the overall project. The scope of work for the Reclamation portion included the evaluation of pilot facility performance as it may apply to seawater desalination facilities on a broader scale. Prior to beginning, a complete evaluation of the goals and objectives of the pilot operation was conducted. This evaluation included:

- Location
- Process Performance Objectives
- Process Train Selection
- Testing Matrix

3.1 Location

Most of the future seawater facilities in the United States are planning to utilize seawater under the influence of surface water as source water alternative. In order to represent this scenario, the proposed site for this seawater treatment evaluation project was located at the Progress Energy's APGS site in Holiday, Florida (figure 3-1), where seawater under the influence of surface water is readily available from the APGS. This source water is believed to be relatively representative with respect to seawater under the influence of surface water nationwide. In addition, this location was ideal for the evaluation of two of the key design factors: impacts of seasonal and tidal variations of inland seawater supplies, and the use of powerplant cooling water discharge versus seawater at ambient temperatures.

The pilot study was performed on the APGS site, on the opposite side of the discharge canal from the power generating facilities (figure 3-2). The APGS draws 446 to 2,870 million gallons per day (mgd) of raw water from the intake structure for use in cooling the condensers in the power generating station. The cooling water system is operated in once-through fashion, with the heated water exiting via the discharge canal and into the Gulf of Mexico.

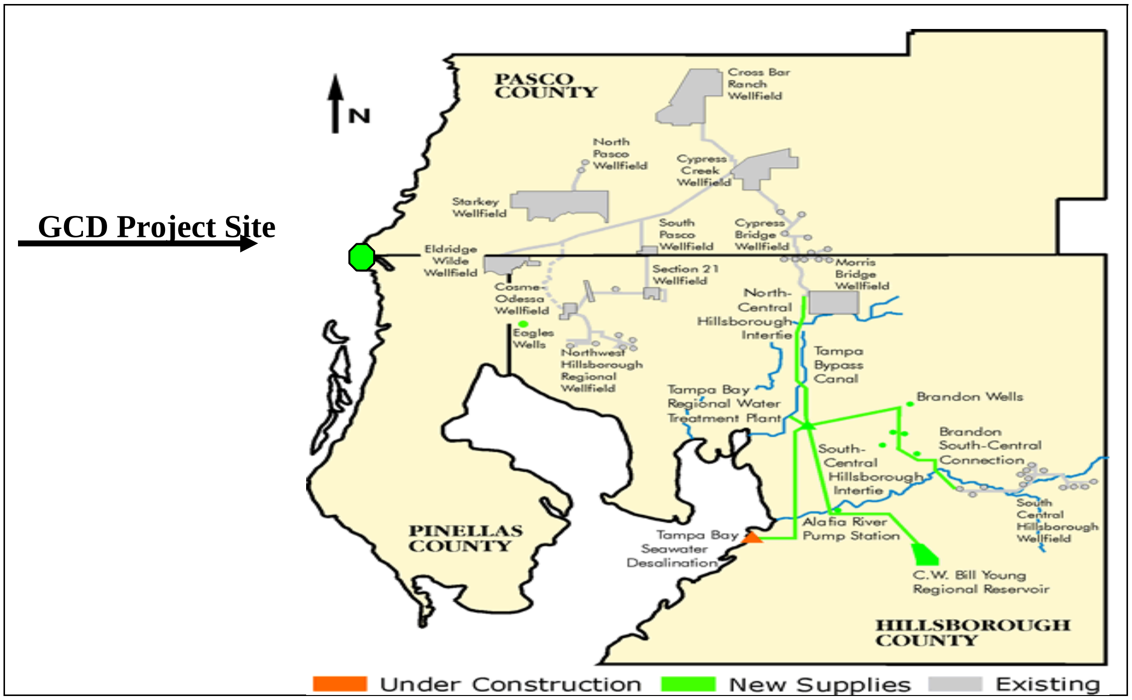


Figure 3-1. Project Site.

Figure 3-2. Aerial of the APGS and Pilot Testing Facility.

3.2 Process Performance Objectives

The overarching objective of the project was to evaluate pretreatment process alternatives (prior to RO) that are capable of providing sustainable production of high-quality finished water. Sustainability is of particular importance in RO systems due to their potential to foul, resulting in excessive chemical cleanings or excessive cartridge filter replacement and associated costs. Finished water quality is of particular importance given the high level of treatment required to convert salt water to a high-quality potable water that would be safe for the customer and compatible with other potential sources of supply. Sustainability and water quality goals were established for this project and were utilized to define acceptable performance of the various process trains tested.

3.2.1 Sustainability Specification

Sustainable operation of a seawater desalination system involves addressing sustainability of all unit processes, including pretreatment and RO treatment. Table 3-1 defines performance targets established for process treatment systems. These represent the maximum acceptable performance levels for the process trains based on typical criteria for similar facilities. Fouling rates and sustainability directly relate to operating costs, as well as the ability to meet water demands.

Table 3-1. Sustainability Specification

Unit Process	Parameter	Units	Limit
Media filtration	Backwash frequency	Hours	No more than once per 8 hours using a 10-psi maximum differential pressure criterion without coagulation/ sedimentation pretreatment. No more than once per day using a 10-psi maximum differential pressure criterion with coagulation/ sedimentation pretreatment.
MF	Chemical cleaning frequency	Days	No more than once per 30 days
RO system feed water quality	Turbidity	NTU	< 0.3
	SDI	Units	< 3.0
RO cartridge filter	Replacement frequency	Days	No more than once per 30 days
RO fouling	Chemical cleaning frequency	Days	No more than once per 90 days

Note: NTU = nephelometric turbidity units, psi = pounds per square inch, SDI = silt density index.

3.2.2 Finished Water Quality Specification

The finished water quality specification developed for this project is shown in table 3-2. This specification is relatively stringent and, therefore, represents a conservative approach. For example, the chloride limit of 35 milligrams per liter (mg/L) is more stringent than the 250-mg/L Federal secondary chloride standard. In addition, this specification has been designed to ensure that bromide levels are low enough that bromide formation (during chlorination disinfection) will not occur and cause unstable disinfectant residuals. In addition, a boron limit was specified to ensure compliance with potential future Federal limits on boron concentration.

Table 3-2. Finished Water Quality Specifications

Parameter	Chemical Name	Limit	Units
pH	- -	7.6 to 8	- -
Alkalinity	As $CaCO_3$	80	mg/L
Ammonia	As N	< 1	mg/L
Arsenic	As As	< 0.01	mg/L
Boron	As B	< 0.5	mg/L
Bromide	As Br	< 0.15	mg/L
Calcium hardness	As $CaCO_3$	50	mg/L
Chloride	As Cl	< 35	mg/L
Conductivity		< 850	µmhos/cm
Fluoride	As F	0.8	mg/L
Total hardness	As $CaCO_3$	< 300	mg/L
Iron	As Fe	< 0.15	mg/L
Nitrate	As N	< 10	mg/L
Nitrite	As N	< 1	mg/L
Odor		< 3	Ton
Ortho phosphorous	As P	< 1	mg/L
Sodium	As Na	< 80	mg/L
Sulfate	As SO_4	< 100	mg/L
TDS		< 500	mg/L
TOC		< 1	mg/L
Phosphorous	As P	< 1	mg/L
Sulfides		< 0.1	mg/L
Turbidity		< 0.3	NTU

Note: TDS = total dissolved solids, µmhos/cm = micro-ohms per centimeter.

3.3 Process Train Selection

Process trains were developed to capture the key variables for consideration at a seawater facility site. These included alternative pretreatment technologies and alternative SWRO design conditions.

The intake location for this project is known to be highly variable due to its proximity to the Anclote River. This location was known for variations due to tidal exchange, as well as seasonal changes with fresher water in the vicinity of the intake during wet summer months. Therefore, it was considered important to evaluate not only conventional two-pass MMF, but also advanced pretreatment options.

Two-pass MMF can consist of various media types, including sand, anthracite, garnet, greensand, or other media. The use of two-pass MMF is a common pretreatment process used ahead of RO systems world-wide. However, it is not as robust as other potential pretreatment technologies. Given its common use worldwide, MMF was considered a “base-line” pretreatment technology for evaluation at this site. A pilot scale system was procured and operated to provide sufficient water to feed a downstream SWRO pilot unit.

Given the variable nature of the source water and the early outcome of pilot testing, MMF pretreatment was upgraded to a CSF system. CSF represents the traditional surface water treatment technology utilized in the United States. This technology offers the opportunity for improved finished water quality and greater ability to absorb potential spikes in raw water quality.

Finally, membrane filtration utilizing MF or UF was considered. MF and UF represent the most promising RO pretreatment technology today and have been utilized for over a decade to treat surface waters for turbidity and particle removal. The application of MF and UF systems as pretreatment to seawater systems is occurring worldwide. However, MF and UF systems can incur their own sustainability problems on certain source waters and typically cost more than MMF. It was considered important to evaluate one MF or UF system for this project for comparison with more conventional technologies.

MF and UF systems vary by vendor and are proprietary. Based on the scope of this project, only one MF or UF system was to be tested. The purpose of this testing was to validate MF/UF technology as a whole due to the common filtrate water quality that can typically be expected from this class of treatment systems. While the fouling rate of the selected MF or UF system would be specific to that vendor, the ability of an MF or UF system to provide adequately pretreated raw water for subsequent use in the RO system could be validated by site-specific testing. The selected system for this project was Pall Corporation’s Microza MF system.

Following selection of the three pretreatment technologies, SWRO options were considered. Seawater reverse osmosis systems utilized RO membranes available from various manufacturers. All RO membranes have common configurations and typically have limited differences relative to fouling potential. However, operating conditions (flux and recovery in particular) can be of importance relative to fouling and can be adjusted to ensure sustainability while minimizing costs. Therefore, a single make and model of membrane (Toray TM-810) was selected for use on this project. Two independent SWRO pilot systems were obtained for testing at this site. These are designated “first-pass” systems due to their treatment of pretreated seawater.

Permeate from first-pass SWRO systems are typically unable to meet stringent finished water quality objectives such as those defined for this project. Therefore, additional treatment is necessary by further treating the permeate from the first-pass RO system. For this project, a 2-1 array brackish RO system was selected to serve as the “second-pass” system.

The associated process trains, including pretreatment and RO treatment processes, are presented in figure 3-3.

3.4 Testing Matrix

The selected process trains were evaluated for sustainability and compliance with the finished water quality goals through approximately 1 year of testing. Operational and design conditions were evaluated as described in the following subsections.

3.4.1 Source Water

The source water quality and its variability were evaluated through collection of grab samples over the course of testing. This allowed for evaluation of both seasonal and tidal variations. Water quality parameters that were analyzed daily are presented below:

- Conductivity
- Turbidity
- Temperature
- pH

In addition, grab samples were collected monthly or biweekly and analyzed for a full range of raw water quality constituents to support an analysis of the variability of the source water, both with season and with tidal exchange, to determine the impact on desalination system design. The water quality parameters associated with the monthly sampling were as presented in table 3-3.

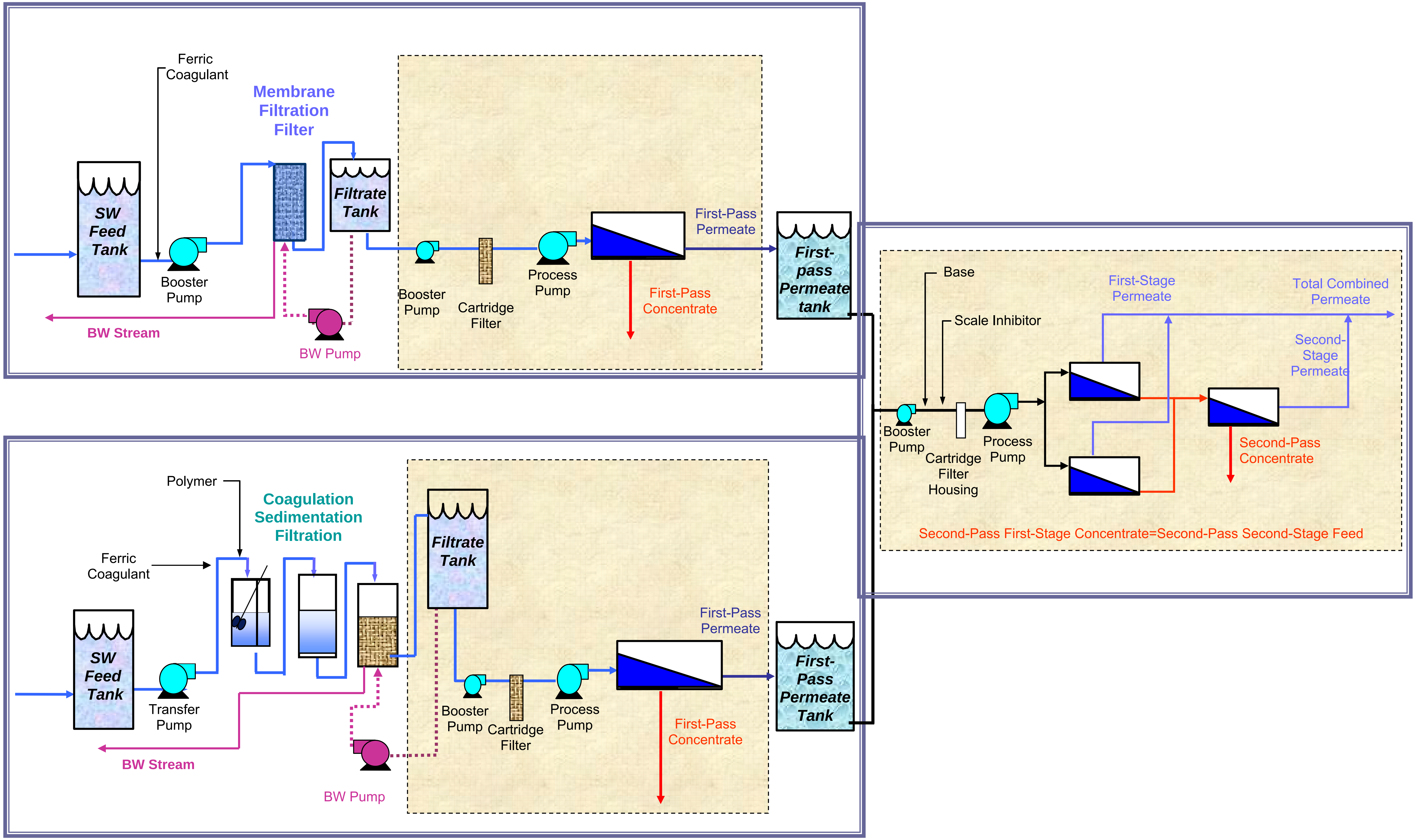


Figure 3-3. Parallel Treatment Process Train.

Table 3-3. Source Water Quality Sampling

Alkalinity[1]	Fluoride	Silica, Dissolved
Ammonia-nitrogen	Heterotrophic plate count (HPC)[1]	Silicon
Aluminum	Iron	Sodium[1]
Barium	Iron, dissolved	Sulfate
Boron1	Lead	Strontium
Bromide[1]	Magnesium	Tin
Calcium[1]	Manganese	TDS[1]
Calcium Hardness[1]	Mercury	Total hardness[1]
Cesium	Nitrate-nitrogen	TOC
Chromium	Phosphorus, ortho	Total phosphorus
Chloride[1]	Phosphorus, total	Total suspended solids
Color	Silica, colloidal	Zinc
Copper		

[1] Biweekly sampling.

Note: TOC = total organic carbon.

3.4.2 Pretreatment

A testing matrix was established for the pretreatment systems to document the effect of a number of design and operational variables. This included assessment of the impact of these variables on system sustainability, as well as ability to meet the filtrate water quality goals necessary to feed the SWRO system. This summary testing matrix is presented in table 3-4.

Table 3-4. Pretreatment System Testing Matrix

Testing Variables	MMF	CSF	Pall MF
Seasonal effects	Operate systems during wet and dry seasons		
Coagulant dose	0.5-15.0 mg/L as Fe	0.5-15.0 mg/L as Fe	0.0 – 3.5 mg/L as Fe
Surface loading rate/flux	2 gpm/square foot roughing - 4 gpm/square foot polishing		40-70 gfd
Polymer type and dose,	0.0 – 4.0	0.0 – 4.0	N/A
pH adjustment	Ambient to 5.8 units	Ambient to 5.8 units	N/A
Media type	Anthracite and anthracite/(sand/ greensand)	Anthracite/sand and greensand/garnet	N/A
Backwash frequency – roughing and polishing filters	As necessary, according to filtrate quality and differential pressure (ΔP) development		N/A
Duration of test runs	Adjustment of operational variables scheduled when finished water quality degraded or pressure/head increased too rapidly and required additional optimization		

Note: gpm = gallons per minute, gfd = gallons per square foot per day

3.4.3 Seawater Reverse Osmosis

A testing matrix was established for the SWRO systems to document the effect of a number of design and operational variables. This included assessment of the impact of these variables on meeting the sustainability and water quality specifications presented previously. The testing matrix is presented below in table 3-5. This represents variables associated with the first-pass system. No variables were adjusted for the second-pass system.

Table 3-5. First-Pass SWRO System Testing Matrix

Testing Variables	
Seasonal effects	Operate systems during wet and dry seasons
Flux	8 and 10 gfd
Recovery	50%, 55%, and 60%
Duration of test runs	Minimum 30 days per experiment
Source water	Warmer condenser discharge water versus ambient temperature intake water

3.5 Pilot Infrastructure and Specifications

The following subsections provide a detailed physical description of the pilot study infrastructure, including photographs, equipment specifications, and more detailed operational specifications.

3.5.1 Source Water

Source water utilized for these pilot tests consisted of cooling water discharge from Progress Energy's Anclote Power Station. Raw water turbidity, total organic carbon (TOC), and total dissolved solids (TDS) vary for this source on not only a seasonal basis, but also a tidal basis.

The pilot facility was fed via a submersible pump, with appropriate measures in place to allow for uninterrupted operation, such as the use of a foot valve, strainer (for impingement of seagrass), and control devices. The flow streams were split at the test site to allow for the subsequent parallel treatment processes.
figures 3-4 and 3-5 show the intake flow diagram and a photograph of the seawater intake location, respectively.

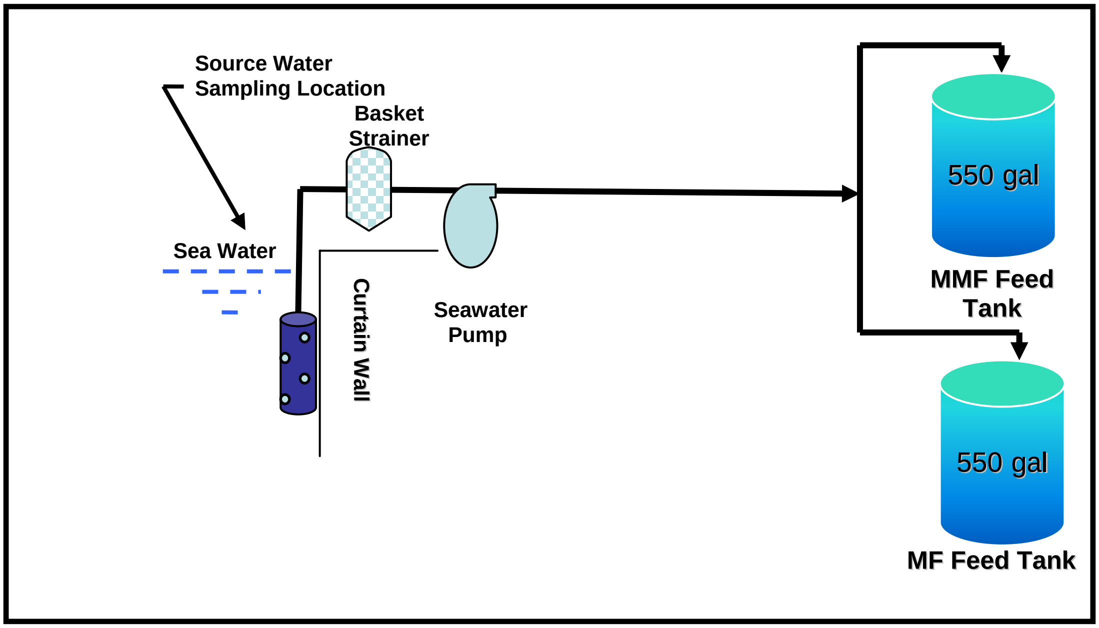


Figure 3-4. Seawater Feed Flow Diagram.

Figure 3-5. Seawater Intake Photograph.

3.5.2 Multi-Media Filtration Pretreatment

A two-pass MMF system was procured for the pilot study. This system was designed to typical engineering standards for MMF systems used for SWRO pretreatment. Also commensurate with the testing program goals, the capability to test various chemical doses was incorporated into the system to allow acid addition, filter-aid polymer, and ferric chloride or ferric sulfate coagulants at various injection site locations throughout the pretreatment process. A process flow diagram of the MMF system with chemical dosing points is presented in figure 3-6. Figure 3-7 shows a photograph of the MMF equipment.

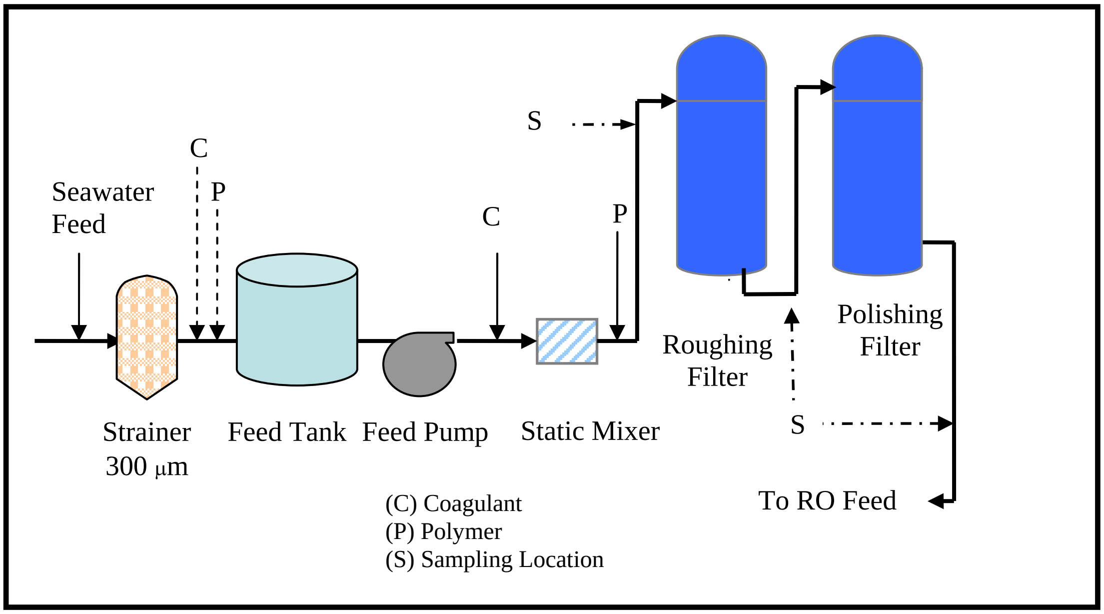


Figure 3-6. MMF Pretreatment Flow Schematic.

Figure 3-7. MMF Pretreatment Equipment Photograph.

MMF pretreatment system design criteria and general operating conditions are presented in table 3-6. Surface loading rates for the MMF pretreatment system were selected based on industry standard design criteria and were fixed for the testing period.

Table 3-6. MMF System Design Criteria

Operating Condition	Value or Range
Strainer	
Mesh size	300 µm
Roughing Filter	
Surface loading rate	2 gpm per square foot
Media type	Anthracite
Media depth	1.12 meters (44 inches)
Effective size	0.8-0.9 mm
Uniformity coefficient	1.3-1.5
Backwash surface loading rate	6.5-10 gpm per square foot
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	10-20 minutes
Filter-to-waste duration	As necessary to achieve steady-state turbidity
Polishing Filter	
Surface loading rate	4 gpm per square foot
Media type	Anthracite/Sand – Phase 1, 2; Anthracite/ Manganese Green Sand – Phase 3
Media depth	24 inches/20 inches - 44 inches total
Effective size	0.8-0.9/0.5-0.6 mm (0.8-0.9/0.3-0.35 mm)
Uniformity coefficient	1.3-1.5
Backwash surface loading rate	12-20 gpm per square foot
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	16 minutes
Filter-to-waste duration	As necessary to achieve steady-state turbidity

Note: mm = millimeters, µm – micrometer.

As part of the pilot study, the following considerations were put into place to gauge the performance of the MMF system:

1. Characterization of filtrate water quality relative to SWRO feed water requirements.

2. Monitoring of MMF system operating performance as measured by:
    a. Feed and filtered water turbidity.
    b. Feed and filtered water Silt Density Index (SDI).
    c. Media hydraulic loading rate.
    d. Feed and filtered water pressure.
    e. Filter run times between backwashes.
    f. Filter to-waste (media rinse) volumes.

3. Development of information necessary to support preliminary design and budgetary cost activities.

The design parameters that were considered for adjustment during pilot testing included acid, polymer, and coagulant dose as other system design criteria were similar to industry standards. This was to support the assurance that an adequate removal of particles through the filtration system would be achieved and, as well, capture the effect that seasonal or tidal variations might have on the performance of the pretreatment system. A pretreatment operation matrix was developed to optimize the operating conditions of the MMF system and to compare finished water quality against overall SWRO system performance. A summary of the operational matrix and testing variables is contained in table 3-7. Data collection efforts during operations centered on measuring conductivity, flow rate, pH, pressure, SDI, TDS, temperature, turbidity, and dissolved oxygen (DO).

Table 3-7. MMF System Operational Variables

Testing Variables	
Seasonal effects	Operate systems during wet and dry seasons
Coagulant dose	0.5-15.0 mg/L as Fe, dose optimized for maximum turbidity/SDI reduction
pH adjustment	Ambient to 5.8 standard units, optimized for maximum turbidity/SDI reduction
Media type	Anthracite/Sand and Anthracite/Greensand
Backwash frequency – roughing and polishing filters	As necessary, according to filtrate quality and differential pressure (ΔP) development
Duration of test runs	Adjustment of operational variables scheduled when finished water quality degrades and requires additional optimization

3.5.3 Coagulation-Sedimentation-Filtration Pretreatment

Particles suspended in water can be sufficiently small that their removal by MMF alone is not practical. To address the need for enhanced particle removal, a coagulation-sedimentation system was integrated with the multi-media filters to form a classic CSF system. This occurred during the latter period of testing.

The most commonly used CSF coagulants are ferric or alum (aluminum sulfate) salts. For this study, ferric sulfate and ferric chloride were utilized in the coagulation step to destabilize particles in the raw feed water. Coagulation was followed by flocculation, a mixing technique promoting the aggregation of the destabilized (coagulated) particles and as an aid to sedimentation and filtration. This process has been practiced for centuries and is, by far, the most widely used process for the removal or reduction of substances producing turbidity in water.

Among a number of similar systems available in the marketplace, Parkson's Lamella® Gravity Settler is a compact inclined plate settler utilized to promote the agglomeration of coagulated, flocculated particulates. This gravity settler process was utilized for this pilot study and is used in a multitude of plants throughout the United States on potable surface water applications. The CSF units are typically capable of:

- Accommodating solids loading rates suitable for large applications in an economical fashion
- Producing greater sludge concentrations than those expected from a conventional sedimentation basin (thereby affecting plant economics)
- Providing sludge storage for flexibility in sludge dewatering equipment operations

The flow schematic for the CSF system is similar to a surface water treatment plant and is shown in figure 3-8.

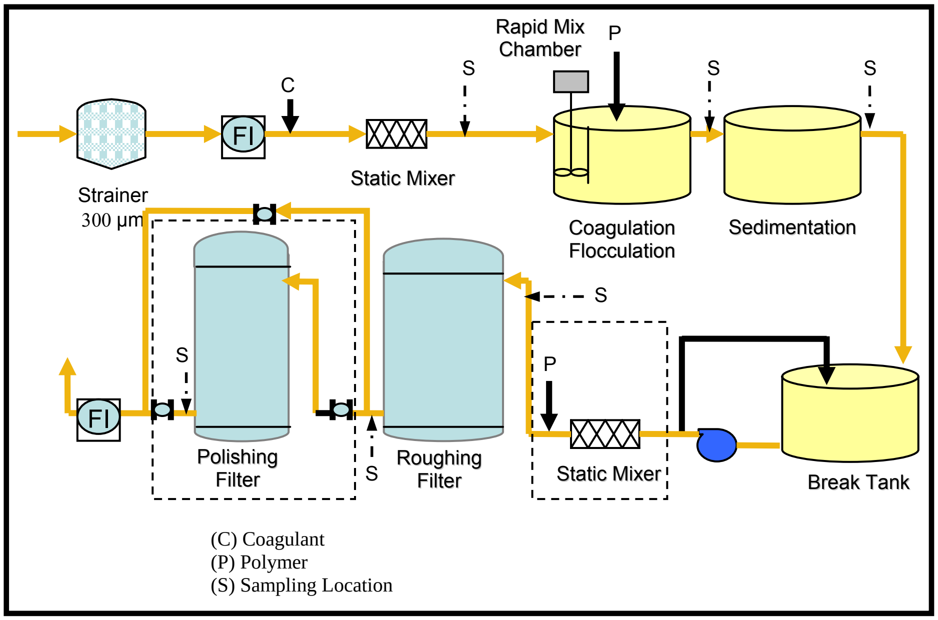


Figure 3-8. CSF-MMF Process Flow Schematic.

Commensurate with the inclusion of CSF into the pretreatment process stream, a concurrent change to an alternative MMF media type and depth was conducted. The CSF and revised MMF design criteria and general operating conditions are contained in table 3-8.

Figure 3-9. CSF - Flash Mixer/Flocculation Tanks and Parkson ™ Lamella Plate Settlers.

Table 3-8. Coagulation Sedimentation with Media Filtration Pretreatment System Design Criteria and General Operating Conditions

Operating Condition	Value or Range
Strainer	300 µm
Mesh size	
Coagulation Sedimentation System	
G-value, range	300-1,100
Detention time	15 to 45 minutes
Flocculator mixing energy	10 sec -1 to 60 sec -1 (first and second stage)
Baffle plates, incline	45 to 60 degrees
Roughing Filter	
Surface loading rate	2 gpm/square foot
Media type	Anthracite/sand
Media depth	24 inches/20 inches
Effective size	0.6-0.8 mm; 0.4-0.5 mm
Uniformity coefficient	1.3-1.5
Specific Gravity	1.4 /2.4
Backwash surface loading rate	6.5-10 gpm/square foot
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	10-20 minutes
Filter-to-waste duration	As necessary to achieve steady-state turbidity
Polishing Filter	
Surface loading rate	4 gpm/square foot
Media type	Manganese Greensand/Fine Garnet
Media depth	20 inches/24 inches-44 inches total
Effective size	0.3-0.35/0.15-0.25 mm
Uniformity coefficient	1.3-1.5
Backwash surface loading rate	12-20 gpm/square foot
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	15 minutes
Filter-to-waste duration	As necessary to achieve steady-state turbidity

Due to the need to ascertain system performance by measuring key parameters, the data collection and analysis effort for the CSF-MMF system was expected to be mostly field-based using field instruments and gauges. This would enable field personnel to receive immediate results and allow on-the-fly operational adjustments as necessary. A summary of the CSF-MMF system testing variables are contained in table 3-9.

Table 3-9. CSF-MMF Pretreatment System Testing Variables

Testing Variables	
CSF mixing energy	Optimized by jar testing
CSF chamber detention time	Optimized by jar testing
CSF coagulant /filter aid dose individual and separately fed	Based on jar testing–best turbidity reduction
CSF acid dose	Based on jar testing for enhanced coagulation–best turbidity reduction
Roughing filter coagulant dose	0.5-15.0 mg/L as Fe, dose optimized for maximum turbidity/SDI reduction
Roughing filter acid dose	pH 6.5, optimized for maximum turbidity/SDI reduction
Backwash frequency – roughing and polishing filters	As necessary, according to filtrate quality and differential pressure (ΔP) development
Duration of test runs	Adjustment of operational variables is scheduled when finished water quality degrades and requires additional optimization

3.5.4 Microfiltration Pretreatment

Microfiltration and UF pretreatment have been presented in recent years as technologies capable of supporting sustainable SWRO operation by providing a feed water of acceptable quality to minimize SWRO fouling. However, there are few full-scale applications, and results are typically site specific.

For this project, a single MF system, the Pall Microza MF system with a pore size of 0.1 µm was tested. The Pall MF system can be used to represent the broader MF/UF technology group, given that filtrate quality from MF and UF systems are generally consistent among manufacturers. While the fouling rate of the Pall MF system itself would clearly be vendor specific, the rate of fouling of the SWRO system would be indicative of the benefits or shortcomings of MF or UF technology as a whole.

The Pall MF process flow diagram is shown in figure 3-10, followed by a photograph of the tested system in figure 3-11.

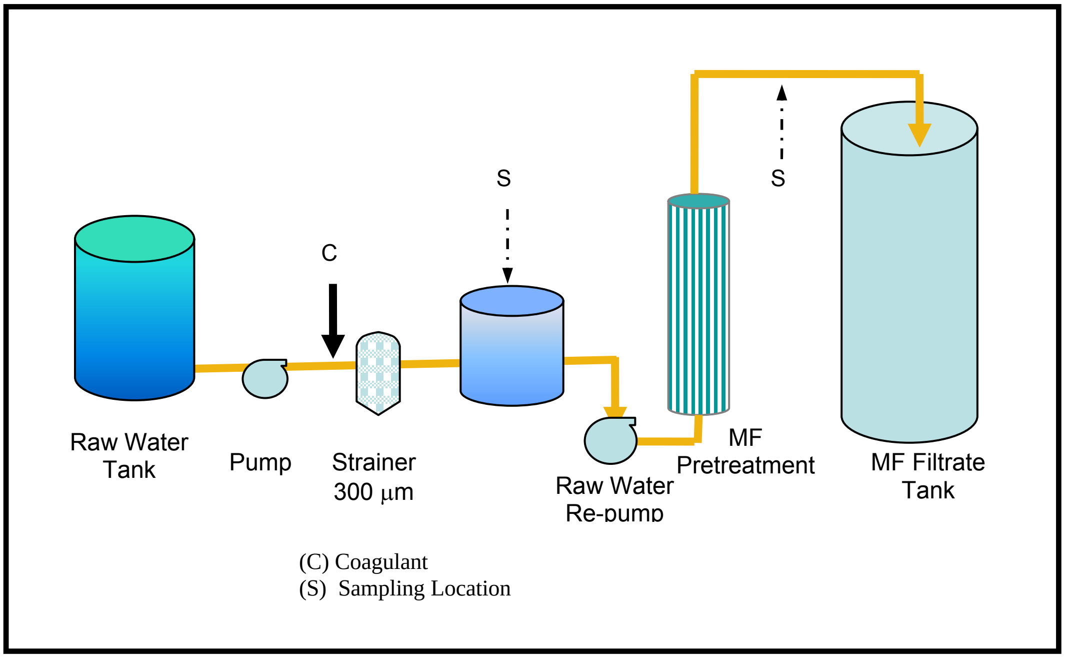


Figure 3-10. Membrane Pretreatment Process Flow Schematic.

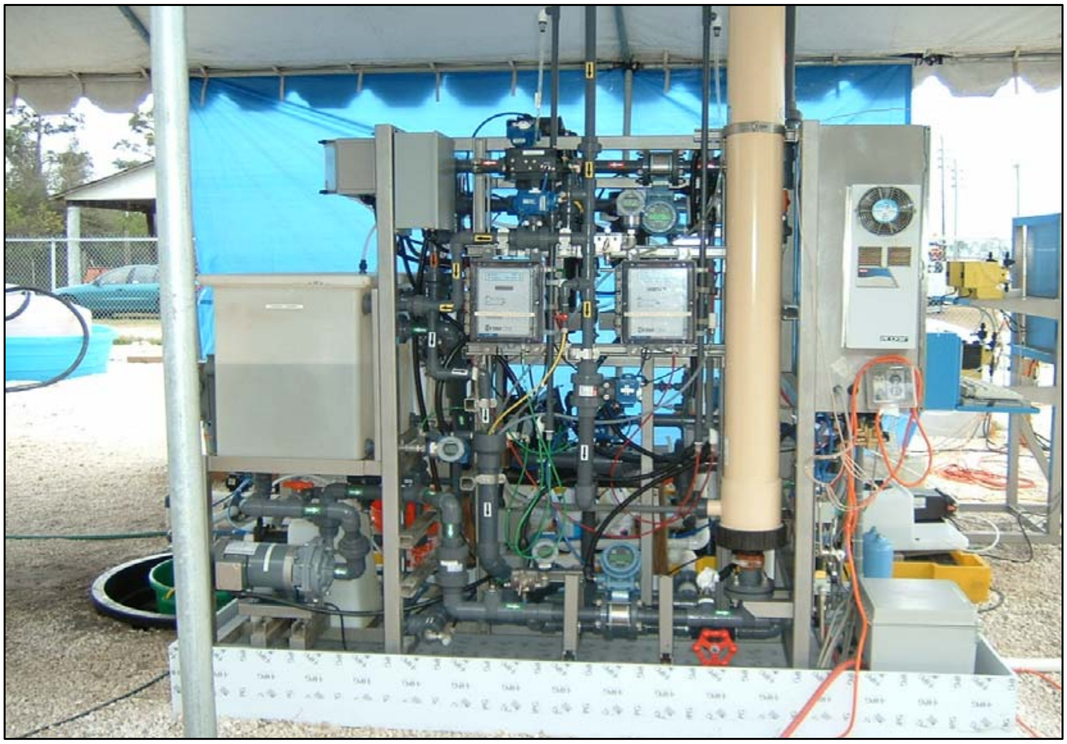


Figure 3-11. Membrane Pretreatment Photograph.

The membrane filtration pretreatment system design criteria and operating conditions are contained in table 3-10.

Table 3-10. MF Pretreatment System Design Criteria and Operating Conditions

Operating Condition	Value or Range
Flux	Sustainable to allow sustainable operation
Recovery	95-97%
SASRF	
Set point frequency	Every 15 minutes
Flow	7 gpm
Duration	60 seconds air/water
RF	
Set point frequency	Every 30 minutes
Flow	15 gpm
Duration	30 seconds
Chemical cleaning frequency	No more than once per 30 days

Note: RF = reverse filtration, SASRF = submerged air scrub and reverse filtration.

The primary design criteria for the MF were fixed since the intent of the work was to generate a representative filtrate quality, allowing sustained operation of the MF, and allowing monitoring of the performance impact and sustainable operation of the SWRO system. A cleaning frequency of no more than once per 30 days was the performance standard for the MF system. This is a common design criterion for MF and UF systems to minimize system downtime and operating costs associated with chemical cleanings.

The secondary objective for the MF pretreatment process was the optimization of the MF system. Optimization was accomplished by making changes to the flux, incorporating the capability to add coagulant, and a recording of the resultant pressure losses (and time to achieve terminal loss to initiate cleaning), chemical/cleaning frequency, and variances, if any, in filtrate water quality.

Therefore, over the course of the pilot study, the following initiatives were put into place to gauge the performance of the MF system:

1. Characterization of MF filtrate water quality relative to SWRO feed water requirements.

2. Monitoring of MF system operating performance as measured by:

   a. Feed and filtered water turbidity.
   b. Feed and filtered water SDI.
   c. Feed water flow rate.
   d. Feed and filtered water pressure.
   e. Filter run times between cleanings.

3. Perform chemical cleanings as required to return performance to acceptable levels needed for SWRO feed water quality.

4. Develop information necessary to support preliminary design and budgetary cost activities.

A summary of the tested variables for the membrane filtration pretreatment system (not including lab sampling events) is contained in table 3-11. Data collection centered around measuring conductivity, flow rate, pH, pressure, SDI, TDS, temperature, and turbidity twice per day, and DO once per day. On weekends, sampling events were scheduled for once per day.

Table 3-11. MF Pretreatment System Testing Variables

Testing Variables	
Seasonal effects	Operate systems during wet and dry seasons
Flux	45 – 70 gfd
Excess recirculation	None (direct flow)
Feed and bleed	None
Coagulant dose	0.0 – 3.5 mg/L as Fe, only as needed
Oxidant dose	None preferable; otherwise, NaOCl as necessary for sustained operation
Duration of test runs	Based on the different flux rates to be tested

3.5.5 Seawater Reverse Osmosis Treatment

SWRO pretreatment is a critical design issue and is particularly important at this facility due to the variable source water quality and possible effects on sustainable SWRO performance. To that end, two parallel RO systems were utilized and monitored to determine how effective the MMF, CSF, and MF pretreatment systems were in generating an acceptable quality, low-fouling filtrate as SWRO feed water. Therefore, the focus of the SWRO operation was to track and observe the performance of the two SWRO systems as measured by cartridge filter differential pressures, and the membrane mass transfer coefficient (MTC); both as impacted by the quality of filtrate from each respective pretreatment system.

MTC is also referred to in the industry as “specific flux,” “permeability,” and “normalized permeate flow” and is the primary measure of the performance or productivity of an RO system. RO systems are typically chemically cleaned when MTC declines by approximately 15 percent.

Over the course of the pilot study, the following initiatives were put into place to assess the performance of the SWRO system:

1. The first-pass SWRO would be operated only during periods when SDI values are less than or equal to 3.0 units and turbidity less than or equal to 0.3 nephelometric turbidity unit (NTU).

2. Characterize RO permeate quality relative to finished water goals.

3. Monitor RO system operating performance as measured by the following:
    a. Feed and permeate conductivity.
    b. Permeate water recovery.
    c. Feed water pressure.

4. Assess changes in RO membrane performance caused by potential fouling of RO membrane elements and chemical oxidation by monitoring:
    a. Normalized permeate flow per American Society for Testing and Materials Standards.
    b. Normalized conductivity passage.

5. Perform chemical cleanings as required when normalized performance parameters change by a predetermined value (15- to 20-percent increase in normalized MTC).

6. Assess the efficiency of one or more chemical cleaning formulations/regimes to restore RO performance losses.

7. Collect information necessary to support a preliminary design and budgetary cost estimate for the project.

With these considerations in mind, the two-pass SWRO system is discussed in the following sections.

3.5.5.1 First-Pass SWRO System

The RO system design was selected to be representative of typical industry designs with capability to accommodate site-specific conditions. The flow schematic for the SWRO system is shown in figure 3-12, followed by a photo in figure 3-13. The SWRO unit is capable of treating up to 25,000 gallons per day (gpd) of raw water producing 12,500 to 20,000 gpd of potable quality water. An integrated two-pass configuration follows the SWRO to treat the permeate stream in order to accommodate stringent overall finished water quality requirements.

Toray RO elements were selected for pilot testing. Suitable alternatives are also available from other major membrane manufacturers around the world.
Table 3-12 shows the first-pass SWRO design criteria and operating conditions. The second pass is discussed in the subsequent section.

In addition to comparing the effect of alternate pretreatment systems on the performance and sustainability of the SWRO systems, flux and recovery were varied because these parameters will impact capital costs and operational costs. On one hand, capital costs will generally decrease with higher flux and recovery; on the other hand, operational costs will increase with higher flux and recovery (more power requirements and more chemical cleanings due to higher fouling rates under higher flux and recovery conditions). That is the reason why optimization of these two parameters is of importance to optimize capital and operational costs.

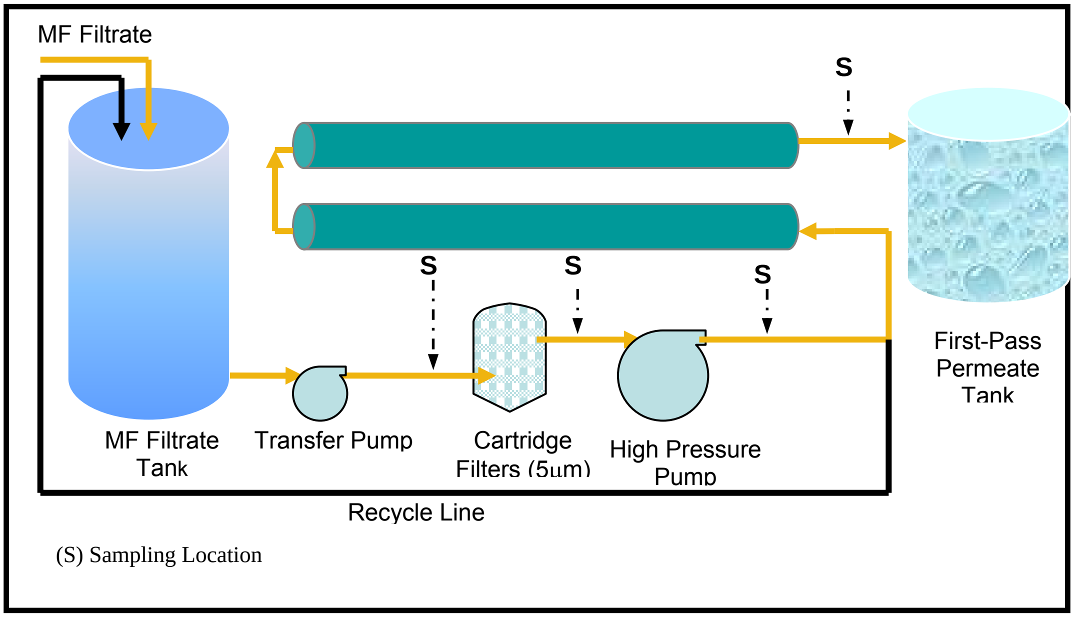


Figure 3-12. First-Pass SWRO Process Flow Schematic.

Figure 3-13. SWRO System Photos.

Therefore, flux rate was varied from 8 gallons per square foot per day (gfd) to a less conservative 10 gfd, and system recovery rates were varied to 50 percent, 55 percent, and 60 percent during wet and dry seasons. The recovery rates represent the range of typically applied recoveries on SWROs similar to this source water. The SWRO systems were to be tested in both wet and dry seasons to quantify the seasonal effects (and expected variations in the feed water composition) on system performance, measured by normalized MTC. In order to accurately assess the MTC trends, each test was to be operated for 30 days.

Table 3-12. First-Pass SWRO Design Criteria and General Operating Conditions

Operating Condition	Value or Range
Manufactured Specified Characteristics a. Membrane type b. Membrane surface area c. Flow rate d. NaCl rejection e. Chlorine/oxidant tolerance	 Cross linked fully aromatic polyamide composite 73 square feet 1,200 gpd 99.75% Zero/none
Array	1:0
No. of membranes per pressure vessel	7
Average flux (gfd)	8-10
Seasonal effects	Operate systems during wet and dry seasons
Feed pressure, maximum, psig	1,000

Note: psig = pounds per square inch gauge.

Assessment of the MTC was performed by recording pressure, flows, temperature, and conductivity two to three times per day onsite and plotting the normalized MTC versus time, the MTC being a function of flow, pressure, temperature, and osmotic pressure. A SWRO membrane would be considered fouled and in need of chemical cleaning when MTC declines by 15 percent or more.

In addition, the expected water quality performance of the first pass of the SWRO applied to the various operating conditions was modeled prior to selecting the pilot configuration. This ensured the pilot, as built, would meet the manufacturer operational criteria for hydraulic loading, concentrate flow rate, and feed water and pressure limitations based on varying temperature, flux, and recovery rates.

Table 3-13 contains a summary of the tested SWRO system variables **and** field data collection requirements.

Table 3-13. SWRO System Tested Variables

Testing Variables[1]	
Seasonal effects	Operate systems during wet and dry seasons
Flux	8 and 10 gfd
Recovery	50%, 55% and 60%
Duration of test runs	Minimum 30 days per experiment

[1] MF optimized prior to testing SWRO system.

Routine data collection for flow rate, pressures, temperature, pH, conductivity, TDS (calculated), turbidity, DO, and SDI were required. During unusual circumstantial events (such as rain events), the protocol allowed for additional sample collection as needed.

3.5.6 Second-Pass SWRO

The finished water quality specified for this project identified a chloride target level of less than or equal to 35 mg/L. Additionally, other selected water quality parameters were also set at levels for this project as presented in table 3-2 (see section 3.2.2). The permeate water quality from the first-pass RO system did not meet these finished water quality standards, as expected, so a second-pass pilot was designed for full-stream treatment of the first-pass permeate stream. Second-pass RO systems are included in SWRO designs throughout the United States and the world for similar reasons.

Table 3-14 presents specific design criteria associated with the second-pass SWRO system.

Table 3-14. Second-Pass SWRO Design Criteria and Operating Conditions

Operating Condition	Value or Range
Manufactured Specified Characteristics a. Membrane type b. Membrane surface area	Cross linked fully aromatic polyamide composite 30 square feet
Array	2:1
No. of membranes per pressure vessel	6
Feed water	Permeate from first-pass SWRO
Testing Variables	
Seasonal effects	Operate systems during wet and dry seasons
Flux	20 gfd
Recovery	90%

Figure 3-14 shows the second-pass seawater system process flow schematic, followed by a photograph in figure 3-15. Routine data collection for flow rate, pressures, temperature, pH, conductivity, TDS (calculated), turbidity, DO, and SDI were required. During unusual circumstantial events (such as rain events), the protocol allowed for additional sample collection as needed.

Note that all the details of the plan of study are presented in appendix A, "Means and Methods."

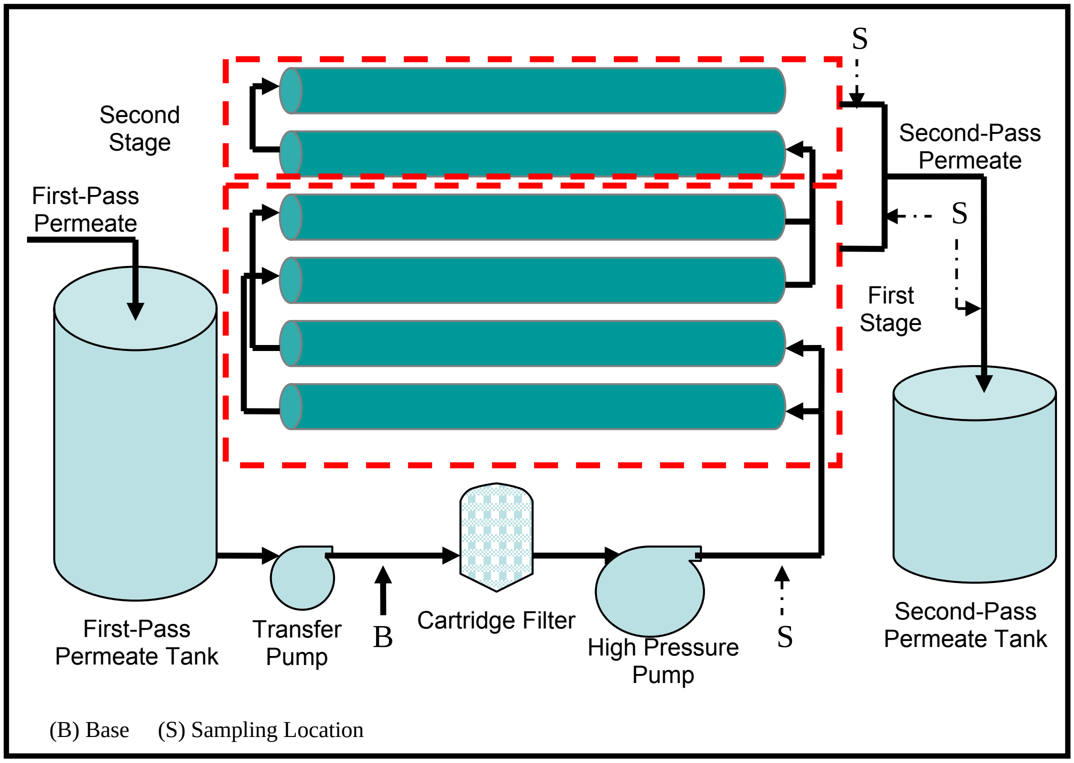


Figure 3-14. Second-Pass SWRO Process Flow Schematic.

Figure 3-15. Second-Pass SWRO Photograph.

4. Source Water Characterization

4.1 Introduction

Source water quality directly affects seawater desalination system design and was extensively analyzed and characterized throughout the course of this 1-year project. The source water characterization was performed through collection of online and grab samples as described previously in Section 3, “Pilot Study Approach and Description.” In addition, streamflow and rainfall data were collected to assist in the interpretation of results. The source water quality of the Anclote site is defined within this chapter as follows:

- Importance of Source Water Quality
- Site and Sampling Locations
- Source Water Quality Results
- Temporal Trends

4.2 Importance of Source Water Quality

Source water quality can affect a number of factors associated with a desalination system including the following:

- Fouling rate
- Operating pressures
- Finished water quality

Source water quality can impact the fouling rate of both the pretreatment and RO system. Fouling of the pretreatment system can include plugging of the system due to particulate material such as decaying organic matter, silt, or biomass. In addition, this particulate material can pass through the pretreatment system and foul the cartridge filters and/or the RO elements. Due to the impact on operational sustainability and efficiency, understanding the variability of the source water quality and its associated impact on fouling rates of the desalination systems was of importance for this project.

As the concentration of TDS or salinity varies, so will the operating pressures, with a higher operating pressure required for a more saline source water. In addition, sources with wide variations in salinity require more flexible pumping and instrumentation and control designs to provide the ability to adjust operating pressures over a wider range. Most importantly, higher operating pressures translate to higher operating costs.

Finished water quality, particularly concentrations of inorganic ions, generally increase as concentration increases in the feed water. Therefore, understanding the highest level of salinity that might be realized is important for ensuring compliance with finished water quality goals. A similar concept applies to concentrate quality, with higher salinity in the concentrate as feed water salinity increases. This can be of importance for permitting concentrate discharge.

4.3 Anclote Site and Sampling Locations

Source water quality was analyzed through online instrumentation and grab samples collected at the discharge of the APGS cooling water discharge system, as well as the intake to the APGS (figure 4-1). Sampling at the intake to the APGS was limited, as this source was primarily evaluated to determine if lower temperature feed water could provide a higher quality finished water and better meet finished water quality goals. The only significant difference expected between APGS intake versus discharge water is temperature, as this water is solely used for cooling the condensers of the power generation station. Unless otherwise noted, all source water quality results presented are for the APGS cooling water discharge stream.

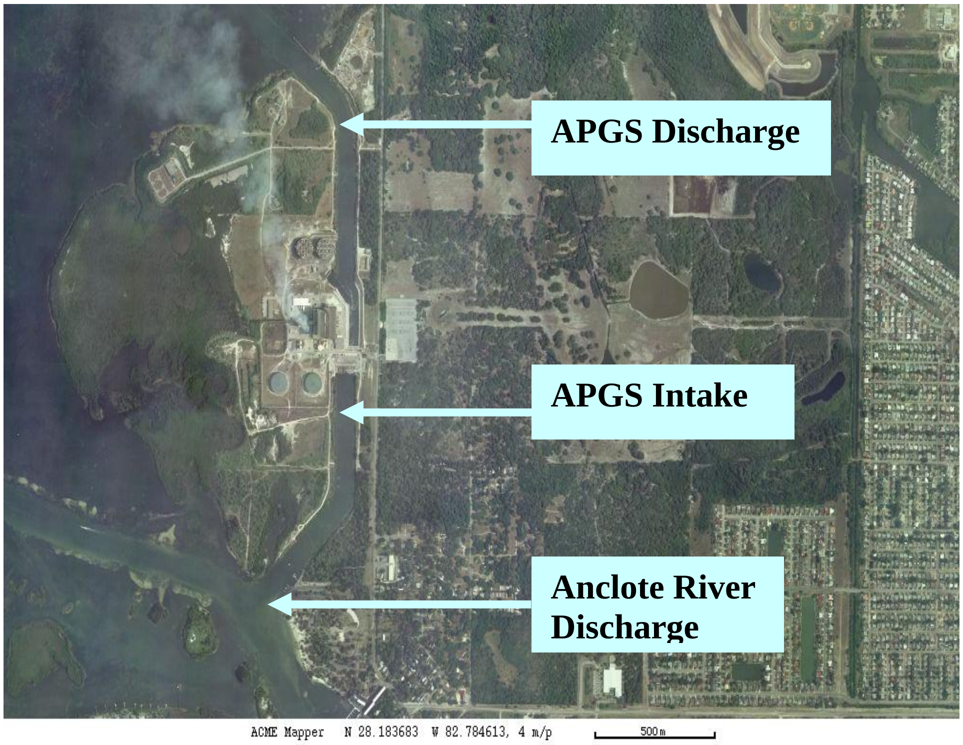


Figure 4-1. Location of Anclote River Discharge, APGS Intake, and Discharge.

In addition, streamflow data for the Anclote River was obtained from an upstream U.S. Geological Survey (USGS) monitoring station near Elfers (USGS station number 02310000; latitude 28°12'50", longitude 82°40'00”) in Pasco County, denoted on figure 4-2. The station is located 16 miles upstream of the mouth of the river. The area of drained watershed represented by this particular gage is 72.5 square miles. Stream flow data have been recorded at this site since May 1946.

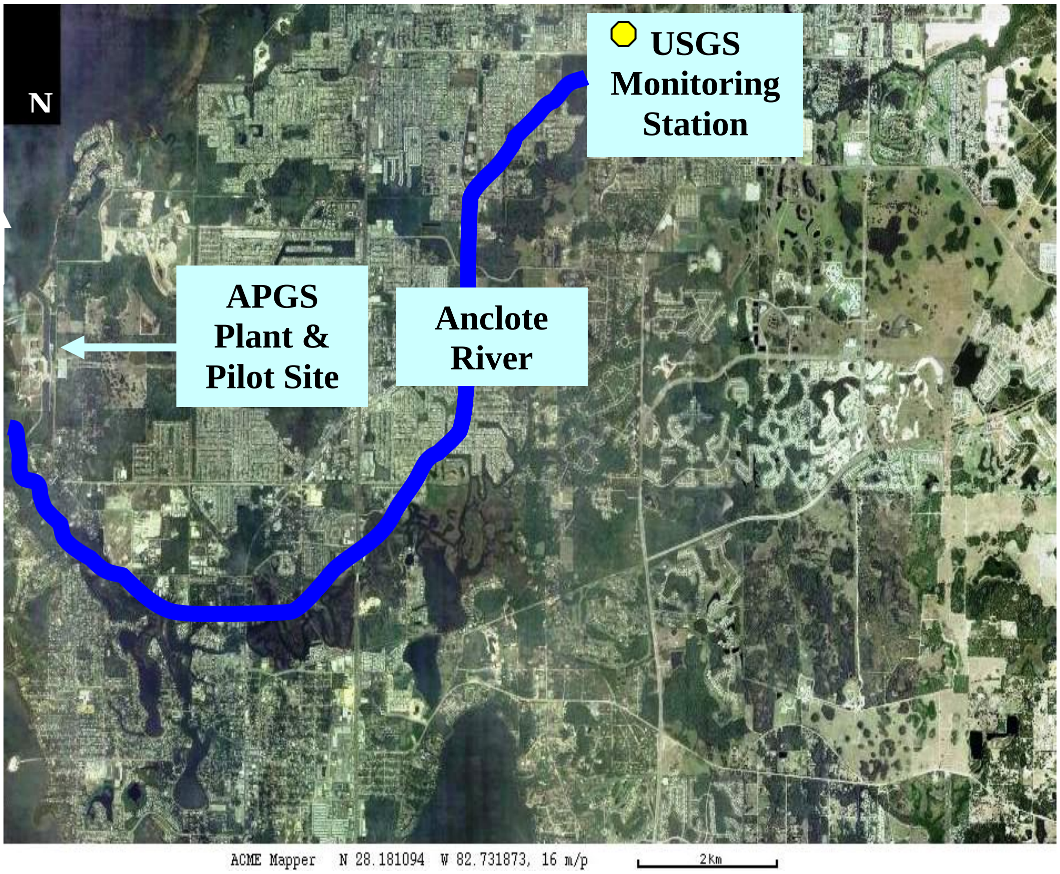


Figure 4-2. Location of Project and USGS Streamflow Monitoring Station.

Area rainfall data were compiled for the Tampa Bay/Anclote River watershed including Pinellas County, southwest Pasco County, northwest Hillsborough County, and the MacDill peninsula. The rainfall data reports were obtained from the Southwest Florida Water Management District.

4.4 Source Water Quality Results

Feed water quality results are summarized in table 4-1.

Table 4-1. Source Water Quality Results

Parameter	Units	Detection Limit	Average	Minimum	Maximum
Daily Sampling					
Conductivity	µS/cm	1	41,295	9,700	53,800
Temperature – APGS discharge	˚C	—	29.4	14.5	40.3
Temperature – APGS intake[1]	˚C	—	27.0	18.2	33.7
Turbidity	NTU	0.1	6.5	1.3	50.2
pH	—	0.0 - 14.0	8.0	7.3	8.6
Biweekly Sampling					
Alkalinity (as CaCO3)	mg/L	5	128	110	146
Calcium	mg/L	0.1	367	301	462
Chloride	mg/L	0.1	15,567	11,000	17,500
Hardness, calcium (as CaCO3)	mg/L	0.03	951	841	1,150
Hardness, total as CaCO3)	mg/L	1.0	5,189	4,250	6,320
HPCs	CFU/ mL	1	683	10	5,700
TDS	mg/L	10	25,706	13,000	36,400
Monthly Sampling					
Aluminum	mg/L	0.1	0.12	0.10	0.23
Barium	mg/L	0.01	BDL	BDL	BDL
Boron	mg/L	0.05	3.7	2.0	4.6
Bromide	mg/L	0.05	53	43	68
Cesium	mg/L	0.001	BDL	BDL	BDL
Color	PCU	1	24	5	50
Copper	mg/L	0.001	0.005	0.001	0.012
Fluoride	mg/L	0.01	0.78	0.15	1.10
Iron, dissolved	mg/L	0.02	0.021	BDL	0.028
Iron, total	mg/L	0.02	0.32	0.032	3.1
Lead	mg/L	0.005	0.0051	BDL	0.0059
Magnesium	mg/L	0.1	1,038	851	1,276
Manganese	mg/L	0.01	BDL	BDL	BDL
Nitrate	mg/L	0.01	0.02	BDL	0.04
Ammonia (as nitrogen)	mg/L	0.01	0.08	BDL	0.14
Phosphorus, Total	mg/L	0.03	0.053	BDL	0.100
Silica dioxide (colloidal)	mg/L	0.02	0.216	0.062	0.530
Silica dioxide (dissolved)	mg/L	0.02	0.64	0.25	1.40
Silicon	mg/L	0.02	0.86	0.45	1.60
Sodium	mg/L	0.1	8,788	7,194	11,430
Sulfate	mg/L	0.1	2,240	2,000	2,580

Table 4-1. Source Water Quality Results (continued)

Parameter	Units	Detection Limit	Average	Minimum	Maximum
Strontium	mg/L	0.01	7.3	5.5	9.2
Tin	mg/L	0.1	BDL	BDL	BDL
TOC	mg/L	1	7.4	4.0	24
Zinc	mg/L	0.005	0.04	BDL	0.15
Quarterly Sampling					
Chromium	mg/L	0.01	BDL	BDL	BDL
Mercury	mg/L	0.0001	BDL	BDL	BDL
Total suspended solids	mg/L	2	13	11	15

[1] Intake sampling was conducted during the day only therefore represents a limited dataset.
Note: µs/cm = microSiemens per centimeter, BDL = below detection limit, CFU/mL = colony forming units per milliliter, PCU = platinum-cobalt units.

Biweekly TDS results showed a variation from 13,000 to 36,400 mg/L. Online conductivity results showed a variation from 9,700 to 53,800 µS/cm. As expected, the freshwater influence of the Anclote River is significant. Therefore, the design of a seawater system treating seawater under the influence of surface water should include consideration of pumping and controls to accommodate up to a four-fold variation in salinity (and maybe more, depending on the site), with associated variations in operating pressures.

For additional characterization, the average values of the seawater feed stream in table 4-1 were compared to select principal ionic constituents in standard seawater as contained in table 4-2. Average analyte values, when compared to the referenced principal constituents in seawater influencing the process design of a seawater desalination facility, show consistently lower dissolved ion content. The major constituents of source water represent 8 percent to 20 percent below the standard seawater constituents, except for fluoride, which is 40 percent below when compared to standard seawater. These differences further demonstrate the influence of the Anclote River on the source water. It should be noted that the ratio of the constituents relative to salinity are similar for the Anclote site source water and standard seawater.

The 95 percentiles were calculated for key water quality parameters. Table 4-3 shows the 95th percentile minimum and maximum for temperature, color, TOC, turbidity, and TDS. A more detailed discussion of temporal trends is presented in Section 4.5, “Temporal Trends.”

Table 4-2. Feed Water vs. Typical Seawater

Parameter	Unit	Project Feed Water Average	Ratio (based on salinity)	Seawater[1]	Ratio (based on salinity)
Salinity	mg/L	27,500		34,700	
Chloride	mg/L	15,567	56.6%	19,162	55.2%
Sodium	mg/L	8,788	32.0%	10,679	30.8%
Magnesium	mg/L	1,038	3.8%	1,280	3.7%
Sulfate	mg/L	2,240	8.1%	2,680	7.7%
Calcium	mg/L	367	1.3%	409	1.2%
Bromide	mg/L	53	0.2%	66	0.2%
Boron	mg/L	3.7	0.013%	4.4	0.013%
Strontium	mg/L	7.3	0.027%	7.9	0.023%
Fluoride	mg/L	0.78	0.003%	1.3	0.004%

[1] Note: *Encyclopedia Britannica,* 2005 deluxe edition.

Table 4-3. Key Parameter 95th Percentile Water Quality

Parameter	Unit	Minimum	Maximum	95th Percentile Minimum	95th Percentile Maximum
Temperature – discharge	˚C	14.5	40.3	18.8	37.9
Temperature – intake	˚C	18.2	33.7	19.7	32.6
Color	PCU	5	50	8	47
TOC	mg/L	4.0	24.0	4.2	18.4
Turbidity	NTU	1.3	50.2	2.2	22.2
TDS	mg/L	13,000	36,400	18,500	33,350
Boron	mg/L	2.0	4.6	2.5	4.4
Bromide	mg/L	43	68	43.3	60.9
Chloride	mg/L	11,000	17,500	12,640	17,180

Organic related results, including TOC and color, confirm the influence of the Anclote River and surface water runoff. Color varied from 5 to 50 PCU, with a 95th-percentile maximum of 47 PCU. TOC levels varied from 4.0 to 24.0 mg/L, with a 95th-percentile maximum of 18.4 mg/L, which is representative of a highly organic source water more consistent with organic Florida fresh surface water sources than the Gulf of Mexico. The high organic levels can contribute to biological fouling due to the increased presence of substrate for biological growth. Based on these results, the seawater/surface water source should be considered more susceptible to biological fouling than a seawater supply. This may differ in other seawater under the influence of surface water conditions nationwide.

Turbidity varied from 1.3 to 50.2 NTU, with an average of 6.5 NTU and a 95th-percentile maximum of 22.2 NTU. The high turbidity level would be difficult for conventional seawater desalination pretreatment systems (MMF) to accommodate. These results are significant and suggest that a desalination facility treating high turbidity seawater may require more advanced pretreatment or may require that the facility operate as a peaking facility, in lieu of a base-load facility, to allow shutdown during adverse turbidity events.

APGS cooling water discharge stream temperatures ranged from 14.5 ˚C to 40.3 ˚C (58.1 ˚F to 104.5 ˚F) with an average of 29 ˚C (84.2 ˚F). The maximum temperature was slightly higher than the RO element manufacturer’s limit of 40 ˚C. It is recommended that a method to further cool the feed water be integrated into a facility treating such a seawater, such as the ability to pump cooler intake water when necessary.

APGS intake water temperature ranged from 18.2 ˚C to 33.7 ˚C. While this is not the primary source of supply proposed for the facility, this water offers the opportunity for reducing the overall temperature into the desalination facility.

Salinity varied significantly, as measured by conductivity and TDS. The TDS of the raw water averaged 25,706 mg/L and was as low as 13,000 mg/L. This exemplifies the impact of surface water runoff at this source and would require less operating pressure for the SWRO system during periods of low salinity.

Boron, bromide, and chloride are three inorganic ions expected to be limiting factors with regard to the level of treatment required to meet finished water quality goals. Based on the data presented, all three parameters approached or equaled the concentration expected in undiluted seawater. Therefore, the treatment capabilities of any SWRO system would have to be sufficient to meet finished water quality goals for these parameters.

4.5 Temporal Trends

An analysis of temporal trends in source water quality was performed, including the effect of rainfall and season. The purpose of this analysis was to determine the frequency and magnitude of possible changes in feed water quality.

4.5.1 River Flow and Rainfall Trends

Stream flow rates for the Anclote River representing the years 2004 and 2005 were obtained from the USGS and are shown as the black data line in figure 4-3. The colored bands in figure 4-3 represent historical percentile ranges for very wet, normal, or very dry conditions. The flow overall falls within the 25 to

75 percentile, or normal flows, with the exception of the period from July to October of 2004, which represented the effects of four hurricanes during the period of study.

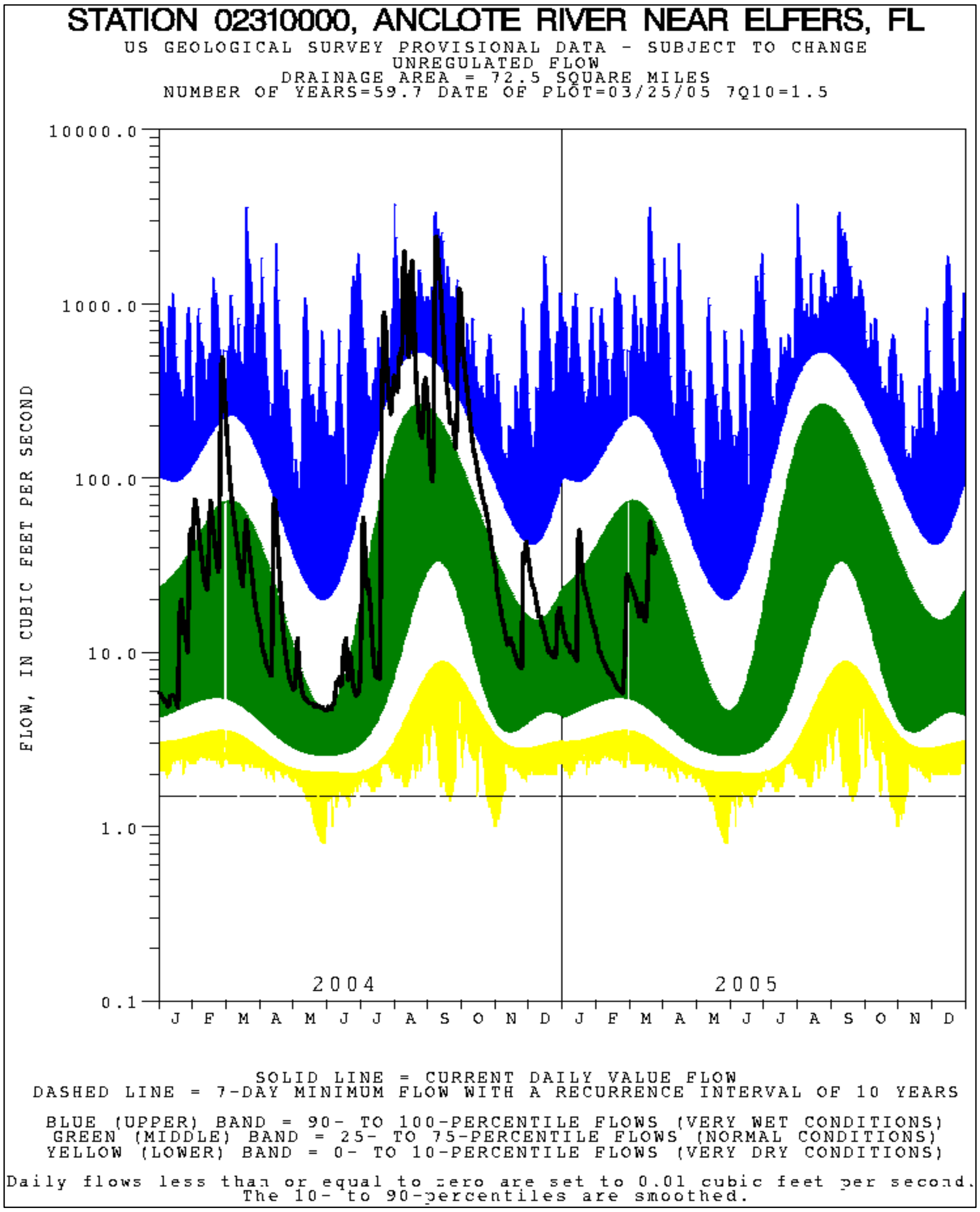


Figure 4-3. Anclote River Stream Flow Data: 2004-2005.

The rainfall during the period of pilot study operation, February 2004 through February 2005, is presented in conjunction with average historical rainfall in figure 4-4. The monthly rainfall from July through September typically ranges from 6 to 8 inches and represents the wet season. The dry season lasts for the remaining 9 months.

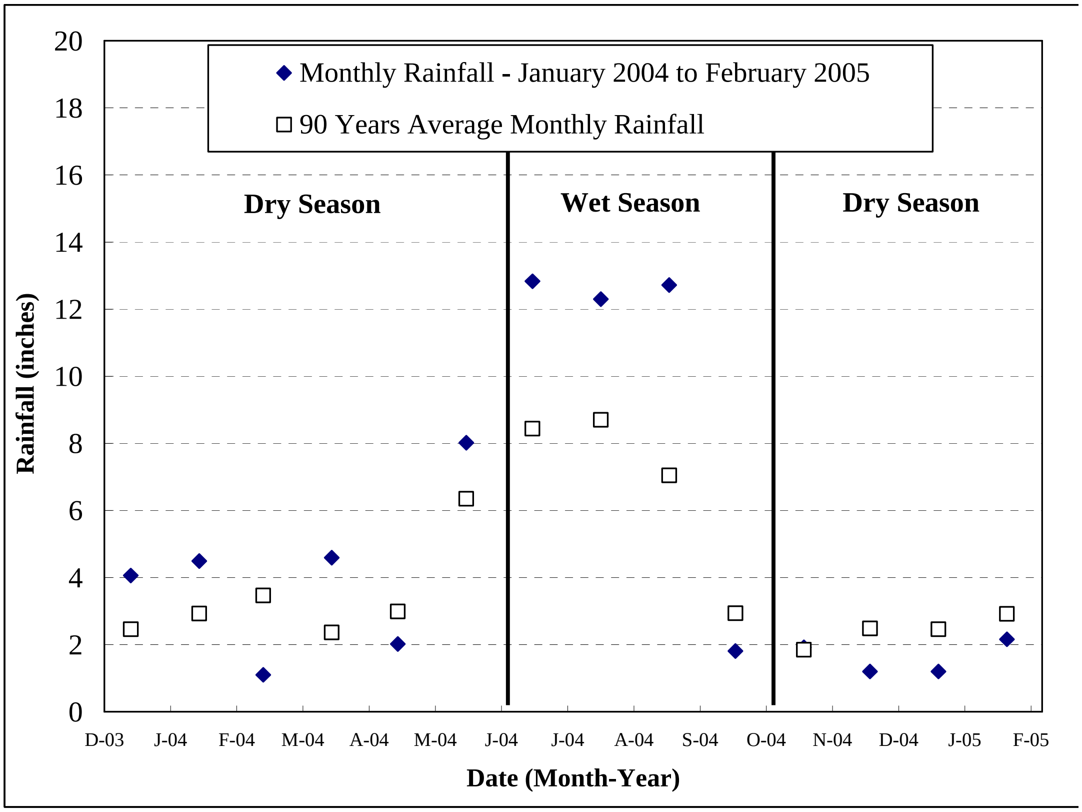


Figure 4-4. Historic Rainfall Data: 2004-2005.

In 2004, rainfall was above the norm, providing an even greater possibility of observing seasonal and freshwater influences on the feed water to the pilot facility. The greater-than-average rainfall was due, in part, to Florida experiencing unprecedented hurricane season activity in 2004. Four hurricanes affected the quality of the raw water in the Anclote area: Charley (from August 10-17, 2004), Frances (from August 25 to September 5, 2004), Ivan (from September 10-17, 2004), and Jeanne (from September 20-28, 2004). During these time periods, the pilot equipment was shut down; and either secured in-place or demobilized to a secure inland location. As a result, some gaps in the field-collected feed water and pilot operating data resulted.

The Anclote River average monthly discharge flow rate does generally track with the average monthly rainfall data for the project duration as shown in figure 4-5.

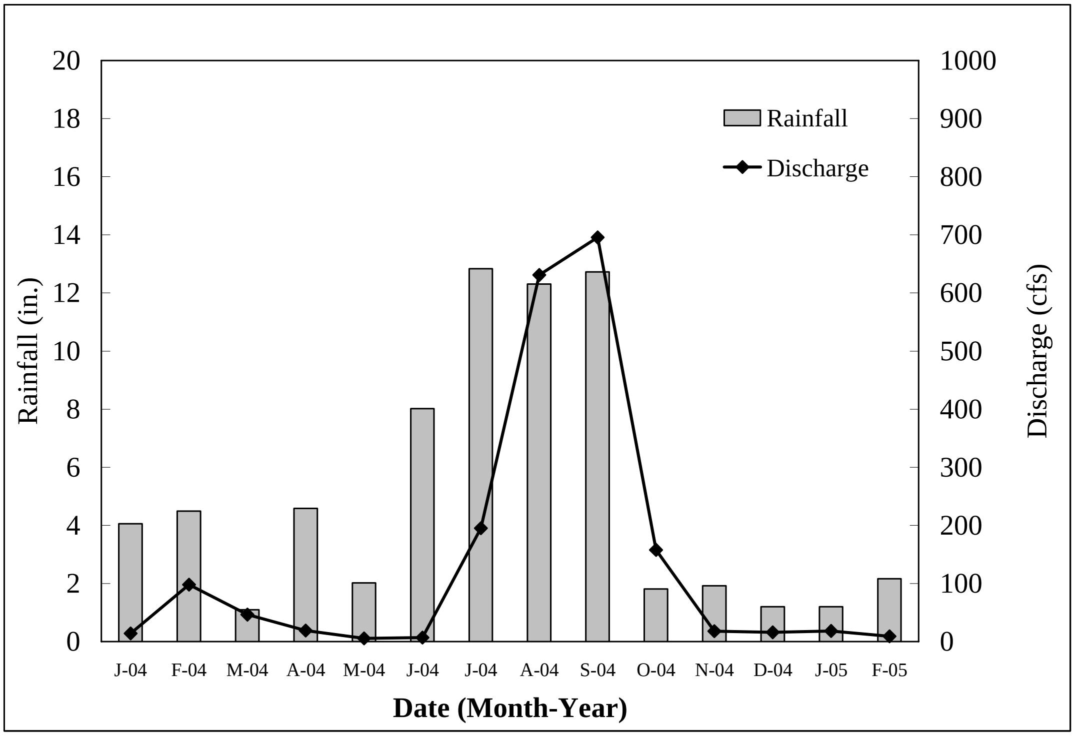


Figure 4-5. Monthly Precipitation and Discharge at the Anclote River.

4.5.2 Source Water Quality Trends

Key water quality parameters were assessed for trends including temperature, TOC, turbidity, and conductivity/TDS. These data are characterized and presented in the following sections. Each of these parameters can have capital or operational impacts on pretreatment performance and/or finished water quality.

4.5.2.1 Temperature

Characterizing seawater feed temperature is a key component of verifying projected analyte rejection on the RO membrane and a key consideration in the development of operating costs.

Feed water temperature ranged from 14.5 ˚C to 40.3 ˚C (58.1 ˚F to 104.5 ˚F), with an average of 29 ˚C (84.2 ˚F). As seen in figure 4-6, the maximum source water temperature of 40.3 ˚C (104.5 ˚F) occurred in August 2004, whereas the minimum source water temperature of 14.5 ˚C (58.1 ˚F) occurred in December 2004.

Based on this single year of temperature data, the 95th-percentile maximum temperature was approximately 38 ˚C (table 4-3). Therefore, it appears that the condenser discharge water at the APGS falls within the RO element manufacturer’s temperature limit of 40 ˚C more than 95 percent of the time.

Based on these results, limited bypass pumping of ambient temperature power station intake water might be needed. As an alternate, the SWRO water treatment plant could be temporarily shut down.

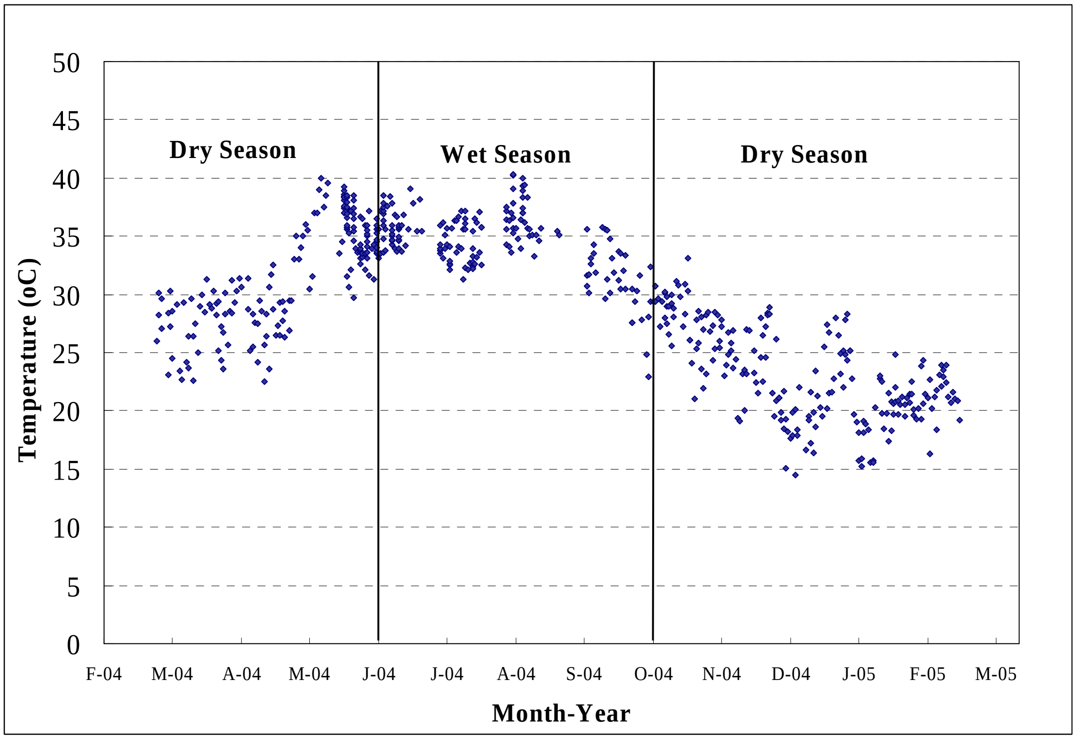


Figure 4-6. Seasonal Feed Water Temperature.

4.5.2.2 TOC

Measurement of organic matter, via TOC, provides guidance regarding the challenge the organic components of seawater will present to any pretreatment system and SWRO system.

Total organic carbon was measured at a mean concentration in the raw water of 7.6 mg/L, with a standard deviation of 5.1 mg/L. Figure 4-7 shows that the maximum feed water TOC of 24 mg/L occurred in October 2004 (immediately after a hurricane), whereas the minimum source water TOC of 4.0 mg/L occurred on November 2004, during the dry season.

The mean concentration of 7.6 mg/L is particularly high for traditional SWRO. In addition, the data show that for a significant portion of the testing period, TOC exceeded 10 mg/L. These results indicate that any SWRO system designed at this site should include the ability to treat for high sustained concentrations of organic matter, similar to Florida surface water.

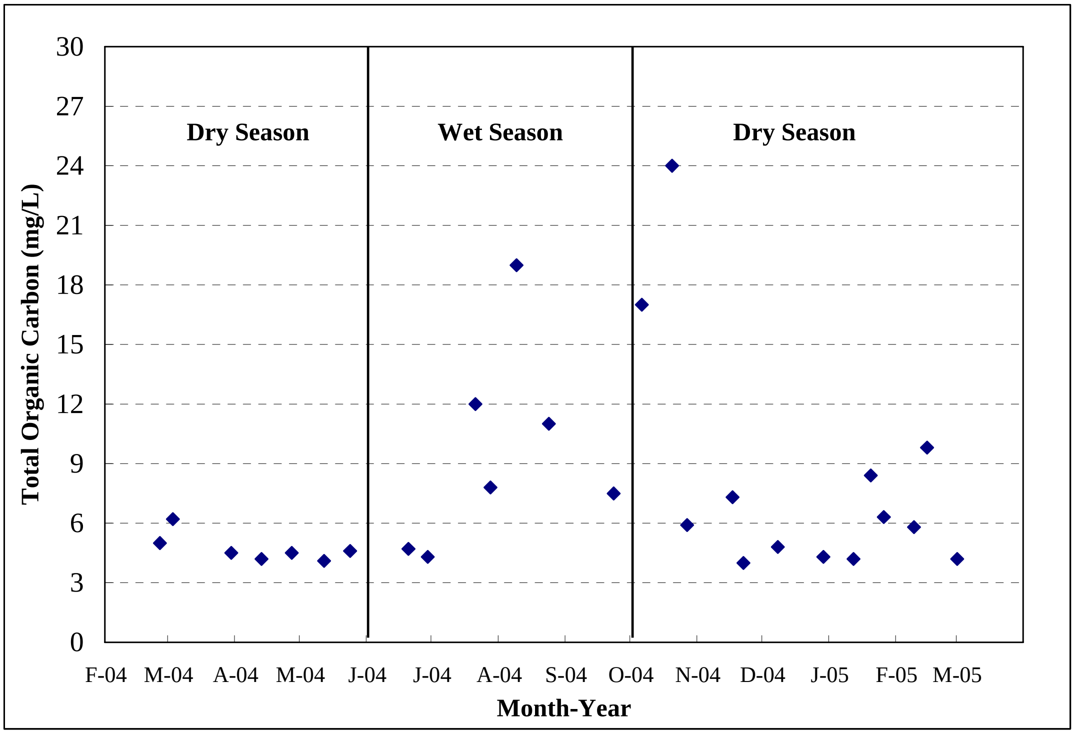


Figure 4-7. Seasonal Feed Water TOC.

4.5.2.3 Turbidity

Turbidity characterization provides guidance regarding the challenge that particulate and suspended matter may present to any pretreatment system and SWRO system.

The daily field turbidity data are presented in figure 4-8 and show that mean turbidity in the raw feed water was 6.4 NTU, with a standard deviation of 6.8 NTU. This indicates that the turbidity varies significantly by season. The average turbidity in the dry season is less than 5.0 NTU, whereas the average turbidity in the wet season is between 10.0 and 15.0 NTU. Field analysis indicated that the maximum source water turbidity of 50.2 NTU occurred in September 2004 (immediately after the third hurricane – wet season), whereas the minimum source water turbidity of 1.4 NTU occurred in May 2004 (dry season). The 95th-percentile maximum was found to be 22.2 NTU (table 4-3).

These turbidity results exemplify the potential for high, sustained turbidity that is expected to be beyond the treatment capabilities of direct filtration or inline coagulation-filtration, the traditional SWRO pretreatment process. Based on review of these turbidity results, it would be expected that advanced pretreatment would be necessary at this site.

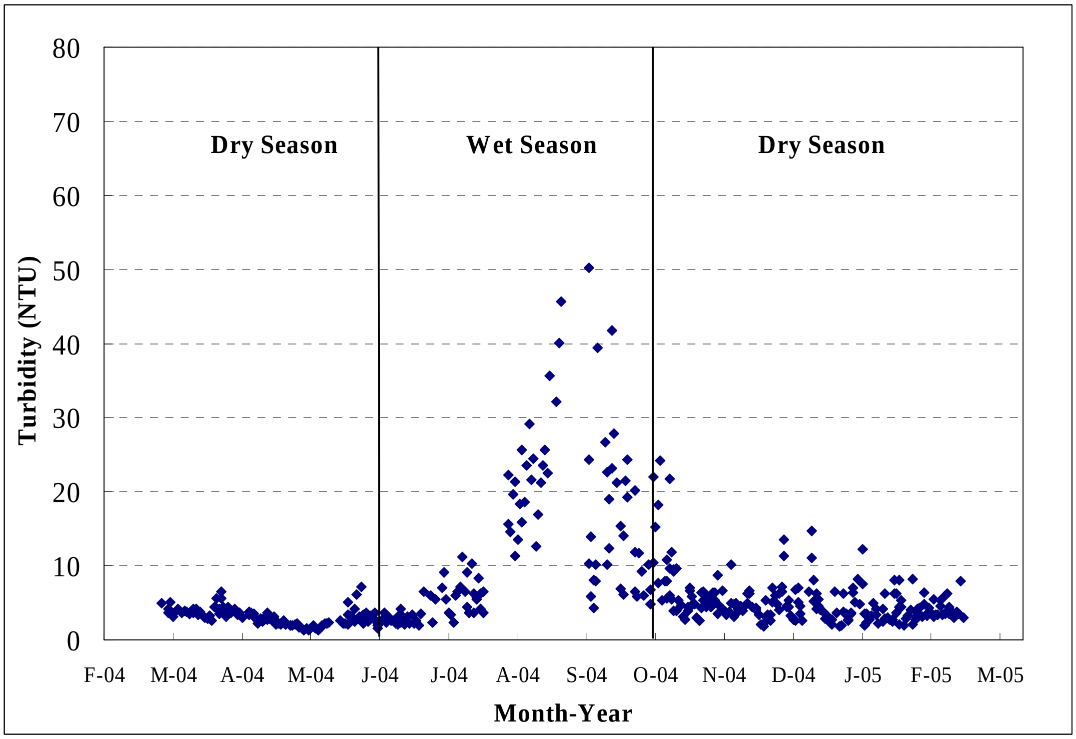


Figure 4-8. Seasonal Feed Water Turbidity.

4.5.2.4 Conductivity/TDS

Conductivity was measured daily for the duration of the project and is presented in figure 4-9. The mean conductivity in the raw water was 41,000 µS/cm, with a standard deviation of 7,800 µS/cm. Conductivity trended downward during the rainy, wet season and reached a low of 13,000 microSiemens per centimeter (µS/cm) on September 30, 2004.

Total dissolved solids is a similar method of determining the aggregate salinity of a sample as conductivity and was measured gravimetrically (filtering, drying, and weighing of the remaining solids) every 2 weeks. Results are presented in figure 4-10. As with conductivity, the TDS level dropped during the wet season, illustrating the impact of a mixed seawater/surface water supply. The TDS was routinely below 25,000 mg/L, compared to 32,000-34,000 mg/L TDS typically found in Gulf of Mexico water. The 95th-percentile maximum was found to be 33,340 mg/L (table 4-3).

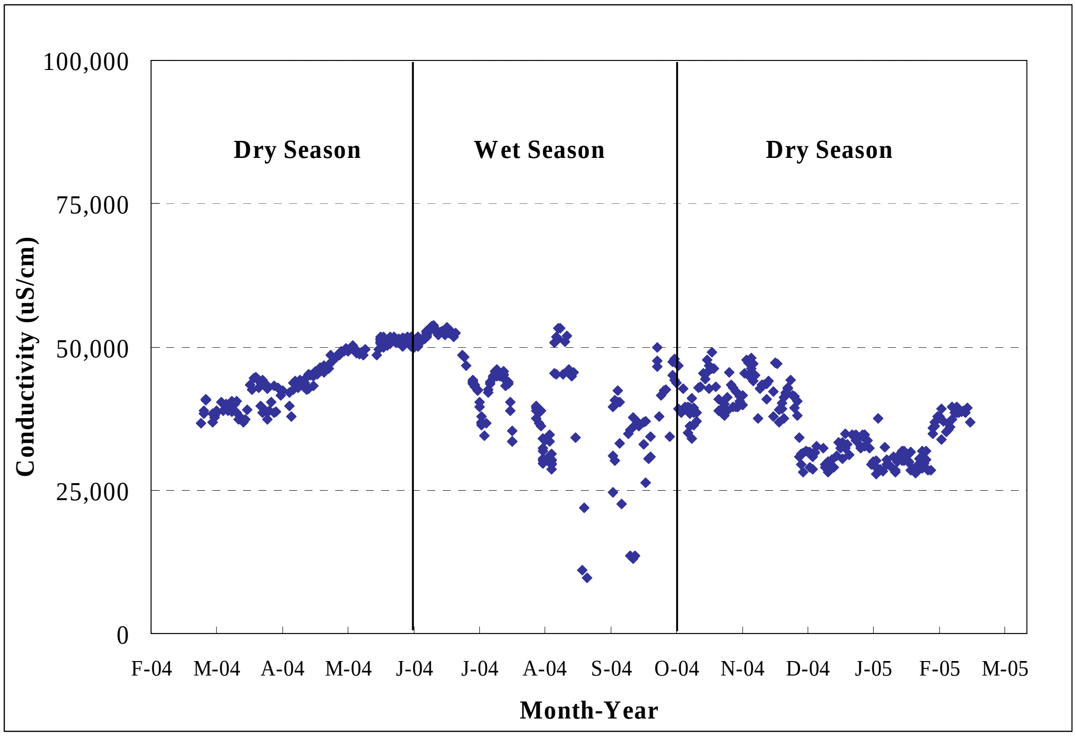


Figure 4-9. Source Water Conductivity.

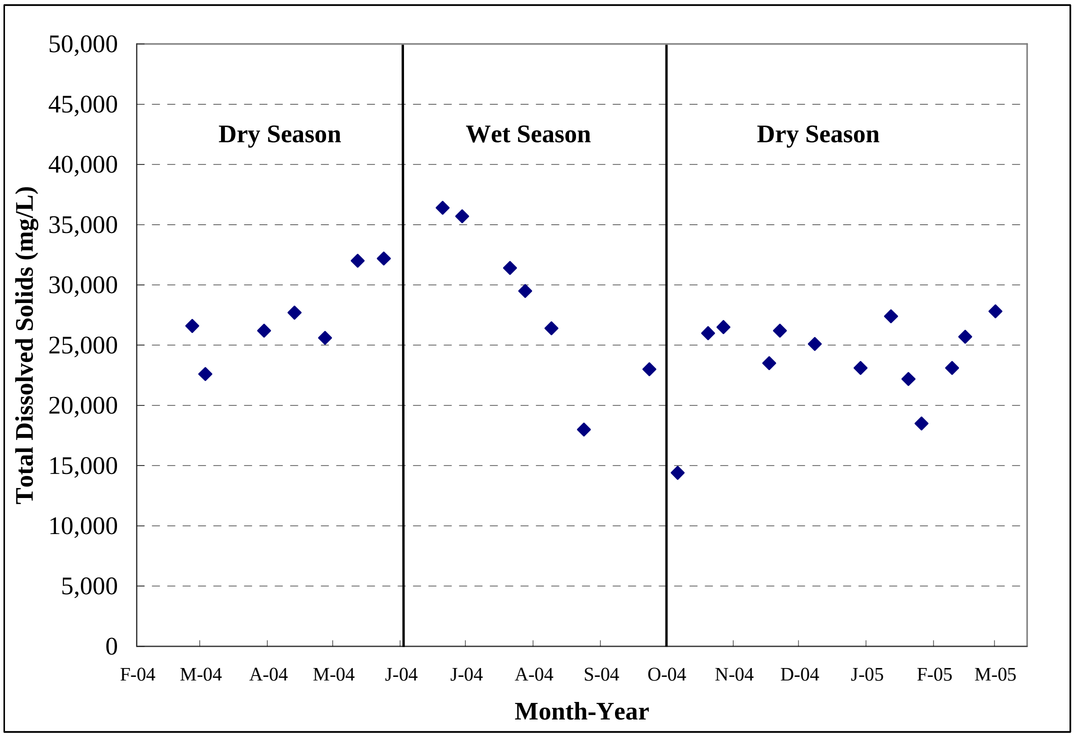


Figure 4-10. Seasonal Feed Water TDS.

Figure 4-11 contains field conductivity measurements versus laboratory TDS measurements and does validate a correlation between the two, with a least squares coefficient of determination (R2) of 0.74. This offers the opportunity, in the future, to measure conductivity in situ during plant operation as a surrogate to determine feed water dissolved salt content as a forecast mechanism during the day to-day operations of a facility. Note that the TDS data presented in this report are not derived from conductivity but are analytical measurements from the laboratory. This TDS/conductivity relationship is provided for information purposes and should be further investigated for site-specific seawater projects.

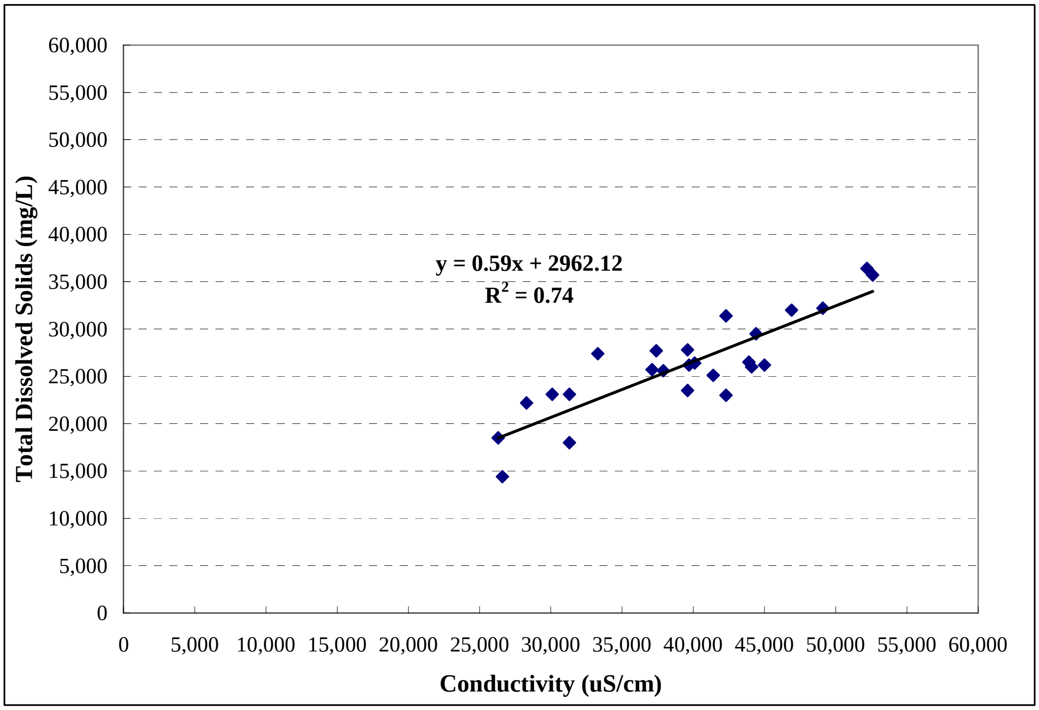


Figure 4-11. Total Feed Water Dissolved Solids Versus Conductivity.

4.6 Source Water Quality Summary

In summary, the source water quality data confirm that the surface water runoff (including the Anclote River) discharge significantly affects the quality of the raw water. This may affect fouling rates, pretreatment requirements, finished water quality, and other factors. Conversely, at times the water quality was equivalent to undiluted seawater, thereby requiring the full capabilities of SWRO treatment.

Temporal trends confirmed the influence of Anclote River streamflow and rainfall on source water quality. Salinity decreased and turbidity and TOC increased concurrent with increases in streamflow and rainfall associated with the wet season. This again illustrates the influence of surface water runoff at this site and is expected to require a higher level of pretreatment than more traditional seawater systems.

5. Treatment Process Evaluation

5.1 Introduction

This chapter presents the pilot study results for each pretreatment alternative and the potential impact on the design of a seawater desalination facility. For each pretreatment system and the SWRO system, water quality and productivity results were assessed and preliminary design criteria were discussed.

Data were collected, recorded, and interpreted with a number of treatment process evaluation objectives, including documentation of the sustainability of SWRO systems when using MMF, CSF, and MF pretreatment; documentation of the relationship between seasonal variations in source water quality to pretreatment and the membrane system performance; and documentation of process efficiency and performance on water of varying temperatures. This section is organized as follows:

- Pretreatment Evaluation
- Cartridge Filter Evaluation
- Seawater Reverse Osmosis Evaluation
- Design Criteria Summary

5.2 Pretreatment Evaluation

Results for the pretreatment systems are presented for each tested configuration in the following subsections. Detailed information on specific test conditions and design parameters is provided in Appendix A, “Means and Methods.”

5.2.1 Multi-Media Filtration

5.2.1.1 Test Conditions

The multi-media filter (MMF) was tested under different operating conditions that can be grouped into three phases as follows:

- Phase 1 consisted of treating seawater using in-line coagulation with ferric sulfate prior to the roughing filter and adjusting the pH for coagulation optimization with sulfuric acid.
- Phase 2 consisted of treating the seawater with in-line coagulation (ferric sulfate) in conjunction with a polymer and adjusting the pH for coagulation optimization.

- Phase 3 consisted of replacement of the sand media with greensand media. Treatment conditions matched that of Phase 1 and consisted of treating seawater using in-line coagulation with ferric sulfate prior to the roughing filter and adjusting the pH for coagulation optimization with sulfuric acid.

For each phase, the coagulant dose and/or the polymer dose was varied, and the variations in doses are presented in table 5-1 for each phase.

Table 5-1. MMF Operating Condition Summary

Phase	Roughing Filter Media	Polishing Filter Media	Coagulant Dose (mg/L as Fe)	Polymer Dose (mg/L)	pH
Phase 1	0.8-0.9 mm anthracite	0.8-0.9 mm anthracite 0.5- 0.6 mm sand	0.0 – 1.5	0.0	6.8 – 8.2
Phase 2	0.8-0.9 mm anthracite	0.8-0.9 mm anthracite 0.5-0.6 mm sand	1.5 – 3.0	1.5 – 3.0	7.0 – 8.2
Phase 3	0.8-0.9 mm anthracite	0.8-0.9 mm anthracite 0.3-0.35 mm greensand	2.0 – 14.0	0.0 – 3.0	8.2

The MMF roughing filter was operated at a surface loading rate of 2.0 gallons per minute (gpm) per square foot and the MMF polishing filter at 4.0 gpm per square foot. All other set points, such as air scour, and filter-to-waste were also kept constant throughout the study phase and are detailed in appendix A. A backwash was performed at the beginning of a different run or when the differential pressure reached 10 psi. Progression to the next run condition was initiated after it was determined that the best possible polishing filter turbidity and SDI had been reached for that set of operating conditions. This was based on the tested conditions and acknowledgement of possible external influences such as rainfall, TOC levels, and whether the system appeared to be producing consistent quality filtrate (regardless of value) from both roughing and polishing filters.

5.2.1.2 Productivity

Productivity of the MMF pretreatment was assessed by monitoring the differential pressure of the roughing and polishing filters. As stated earlier, a manual backwash was performed when the differential pressure reached 10 psi, with a goal of a filter run time of more than 8 hours before this pressure limit was reached. Figure 5-1 presents the differential pressure of the roughing and polishing filters of the MMF pretreatment.

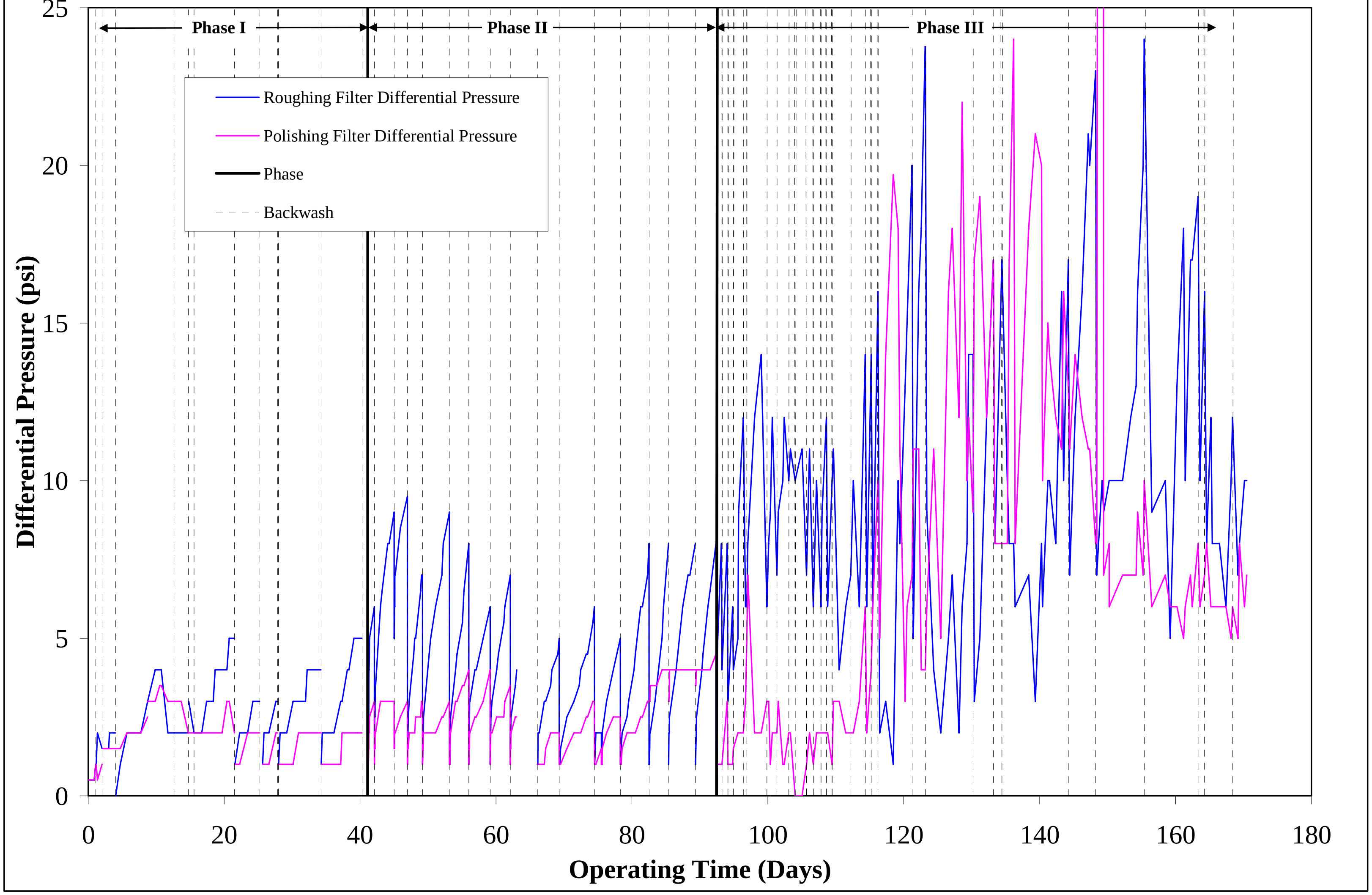


Figure 5-1. MMF Differential Pressure.

The run time between backwashes in the first two phases varied from 1 to 6 days and was not limited by differential pressure (i.e., tests were terminated prior to a 10-psi differential). Therefore, pressure and run time goals were met for Phases 1 and 2.

During Phase 3, manganese greensand was utilized to provide a smaller media size and potentially a higher finished water quality. The greensand had a smaller filtration size (0.3-0.35 mm) than the sand (0.6-0.65 mm). As expected, the run time between backwashes was reduced. In addition, the differential pressure exceeded the 10-psi limit in many cases. Therefore, for Phase 3, run time was calculated based on the duration until a 10-psi differential pressure was reached, and not the total duration of the test. Table 5-2 presents a summary of these results. As shown, the average Phase 3 results meet the run time requirement of at least 8 hours between backwashes.

Table 5-2. Phase 3 MMF Run Time Summary

Condition	Run Time to Reach Differential Pressure Limit (hours)
Average	30
Maximum	64
Minimum	24

5.2.1.3 Water Quality

SDI and turbidity were monitored on the polishing filter filtrate during the study to determine whether MMF pretreatment could meet SDI and turbidity goals of three units and 0.3 NTU, respectively.

Figure 5-2 presents SDI results for the polishing filter filtrate. Note the 15-minute SDI test utilized for this project has a limit of 6.67 units. Therefore, samples with higher levels are simply denoted as having a value of 6.67 units, the limit of the test procedure. The feed water had an SDI of greater than 6.67 units in all cases, as expected for a mixed surface water/seawater supply.

The filtrate results show that addition of polymer, which occurred in Phase 2, significantly reduced SDI values over those achieved in Phase 1. However, regardless of the multi-media filter operating conditions, the SDI goal of three units was never achieved in any phase. SDI is considered important in SWRO design given that RO element warranties are evaluated against influent SDI values. The inability of the MMF system to meet the SDI goal is particularly significant.

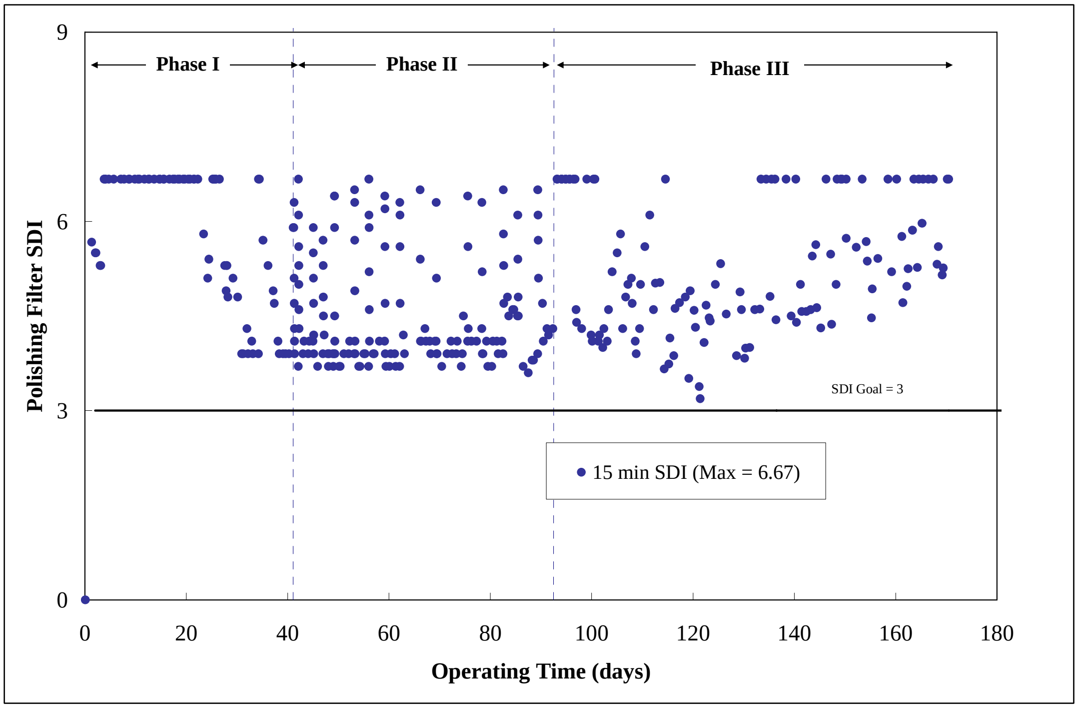


Figure 5-2. MMF Pretreatment Polishing Filter SDI.

Figure 5-3 presents the MMF feed turbidity and polishing filter filtrate turbidity for the three phases of the project. A summary of results is presented in table 5-3. As shown, the filtration turbidity goal of 0.3 NTU was met in Phases 1 and 2, with higher removal of turbidity during Phase 2 when polymer addition was utilized.

An increase in feed turbidity was observed during Phase 3 of the project. Feed turbidity averaged 11.7 NTU and ranged from 2.9 to 74.0 NTU. Feed water turbidity during October and November increased drastically during these months due to surface runoff associated with hurricanes. During Phase 3, the average filtrate turbidity did not meet the 0.3 NTU goal, despite utilizing the finer greensand media. While the average percent removal remained the same using anthracite/greensand instead of traditional anthracite/sand media combinations, the high feed water turbidity of this source of supply was more than MMF alone could treat.

Table 5-3. Multi-Media Filter Turbidity Results Summary

Phase	Feed (NTU)	Filtrate (NTU)	Removal (%)
Phase 1	2.21	0.26	86.1
Phase 2	5.07	0.20	95.6
Phase 3	11.7	0.40	95.1

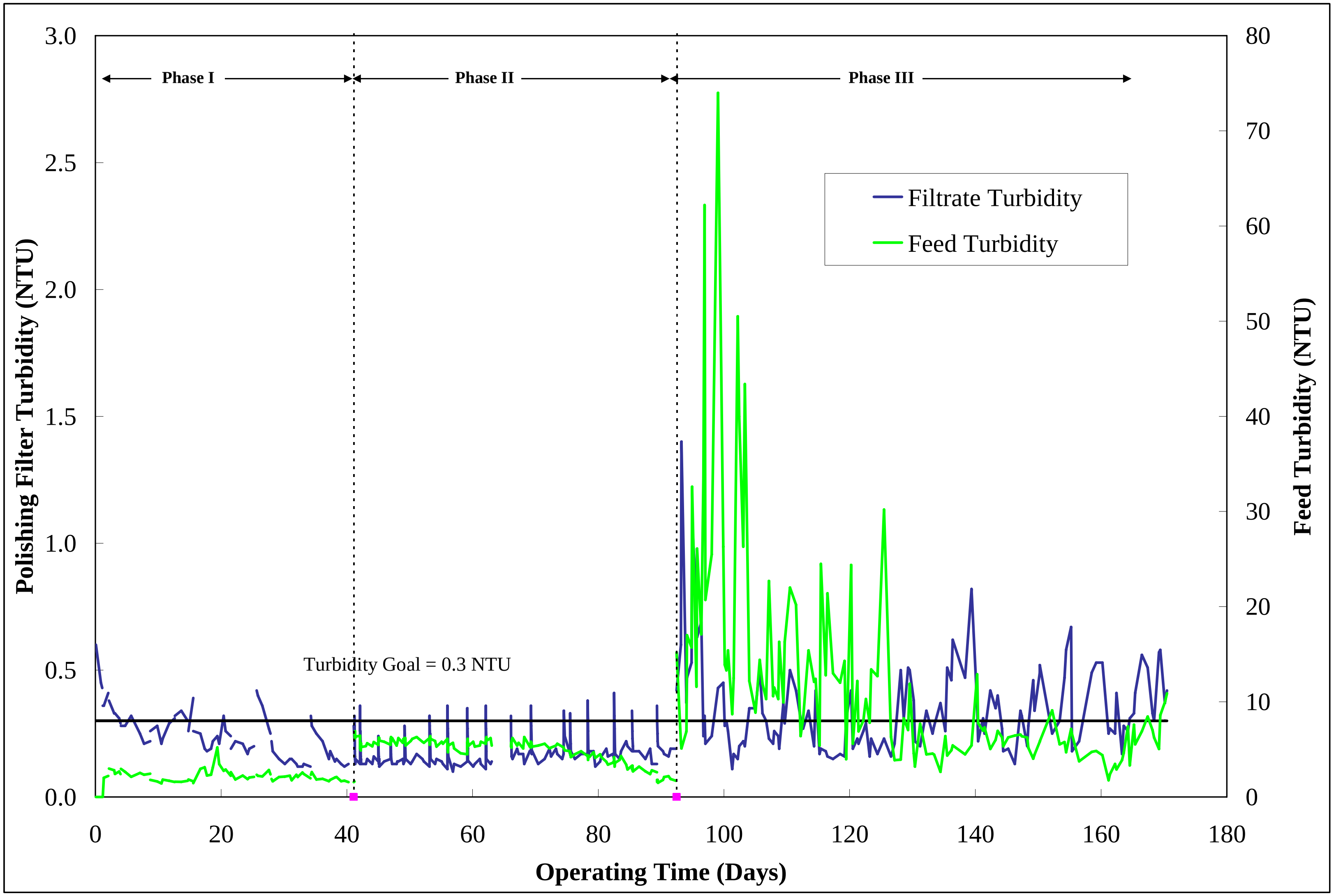


Figure 5-3. MMF Pretreatment Polishing Filter Turbidity.

5.2.1.4 Summary

In summary, the MMF pretreatment process evaluated was unable to meet filtrate water quality objectives relative to proposed operation of a SWRO system for this site. Turbidity goals could not be met during portions of the year, despite utilization of a fine media size. SDI goals could not be met under any operating condition. The SDI levels observed were unacceptable for design of such a system at this site and would likely result in severe fouling and loss of performance for any downstream SWRO system. Based on these results, MMF pretreatment would not be recommended for this site. However, MMF pretreatment could be a feasible option in treating seawater on another site in the United States where the seawater under the influence of surface water has a better water quality than the seawater utilized for this specific study.

5.2.2 Coagulation/Sedimentation/Filtration

5.2.2.1 Test Conditions

A coagulation/sedimentation process was paired with the multi-media filter to improve the water quality of the filtrate in terms of SDI and turbidity. CSF is a common surface water treatment process utilized worldwide. CSF was considered appropriate in this application given the strong influence of surface water at this site. The CSF pretreatment system was tested under different operating conditions that can be grouped into four phases as follows:

- Phase 1 consisted of treating raw water using a polymer in conjunction with the coagulant without pH adjustment. Only the roughing filter was operated.
- Phase 2 consisted of treating raw water using a polymer in conjunction with the coagulant without pH adjustment. The roughing and polishing filters were both operated.
- Phase 3 consisted of treating raw water with a polymer in conjunction with the coagulant. In addition, a free chlorine residual was maintained through the pretreatment system to assist in oxidation of coagulant. The roughing and polishing filters were both operated.
- Phase 4 consisted of treating raw water using a polymer in conjunction with the coagulant, with pH adjustment to 5.8 standard units. The roughing and polishing filters were both operated.

For each phase, the coagulant dose and/or the polymer dose was varied, with the doses presented in table 5-4 for each phase. Detailed operation conditions for each run under each phase are presented in Appendix A, “Means and Methods.”

Table 5-4. CSF Operating Condition Summary

	Filters Online	Coagulant Dose (mg/L as Fe)	Polymer Dose (mg/L)	Chlorine residual (mg/L)	Feed pH
Phase I	Roughing	3.0 – 15.0	2.0	0.0	8.2
Phase II	Roughing + polishing	2.0 – 25.0	0.0 – 4.0	0.0	8.2
Phase III	Roughing + polishing	5.0 – 20.0	0.0 – 2.0	2.0 – 3.0	8.2
Phase IV	Roughing + polishing	5.0 – 15.0	0.0 – 2.0	0.0	5.8 - 6.5

The rapid mix chamber (coagulation) was operated with a mixer achieving a G-value of approximately 630 sec-1, a typical G-value for rapid mixing. The slow mix chambers (flocculation) were operated using a G-value of 65 s-1 and 32 s-1 in the first and second flocculation chambers, respectively, typical of G-values used in flocculation (American Water Works Association *Water Treatment Plant Design*, third edition). The contact time for coagulation was approximately 80 seconds, whereas flocculation was achieved in a two-stage process with a total detention time of 30 minutes. The inclined settling plate was set at 55 degrees to allow for sufficient capture and settling of agglomerated material. NALCO TX12668 polymer was utilized.

The MMF roughing filter was operated at a surface loading rate of 2.0 gpm per square foot and the MMF polishing filter at 4.0 gpm per square foot. The media in the filters was 0.6–0.8 mm/0.4-0.5 mm of anthracite/sand in the roughing filter and 0.3-0.35 mm/ 0.15-0.25 mm of manganese greensand/sand in the polishing filter. All other set points, such as air scour, and filter-to-waste were also kept constant throughout the study phase and are detailed in Appendix A, “Means and Methods.” A backwash was performed at the beginning of a different run or when the differential pressure reached 10 psi. Progression to the next run condition was initiated after it was determined that the polishing filter turbidity and SDI had stabilized to their best possible values.

5.2.2.2 Coagulation/Sedimentation Performance

The purpose of the coagulation/sedimentation system was to reduce the suspended solids loading onto the MMF system, as measured by turbidity. Raw and settled water turbidity results are presented in figure 5-4. As shown, settled water turbidity appears independent of phase or raw water turbidity and averaged 2.4 NTU. From these tests, it appears that using chlorination during coagulation, decreasing the pH to approximately 5.8 units, adjusting coagulant dose, or adding polymer did not improve the turbidity of the settled water. However, these variables had the potential to impact filter performance and filtrate water quality as described in the subsequent subsections.

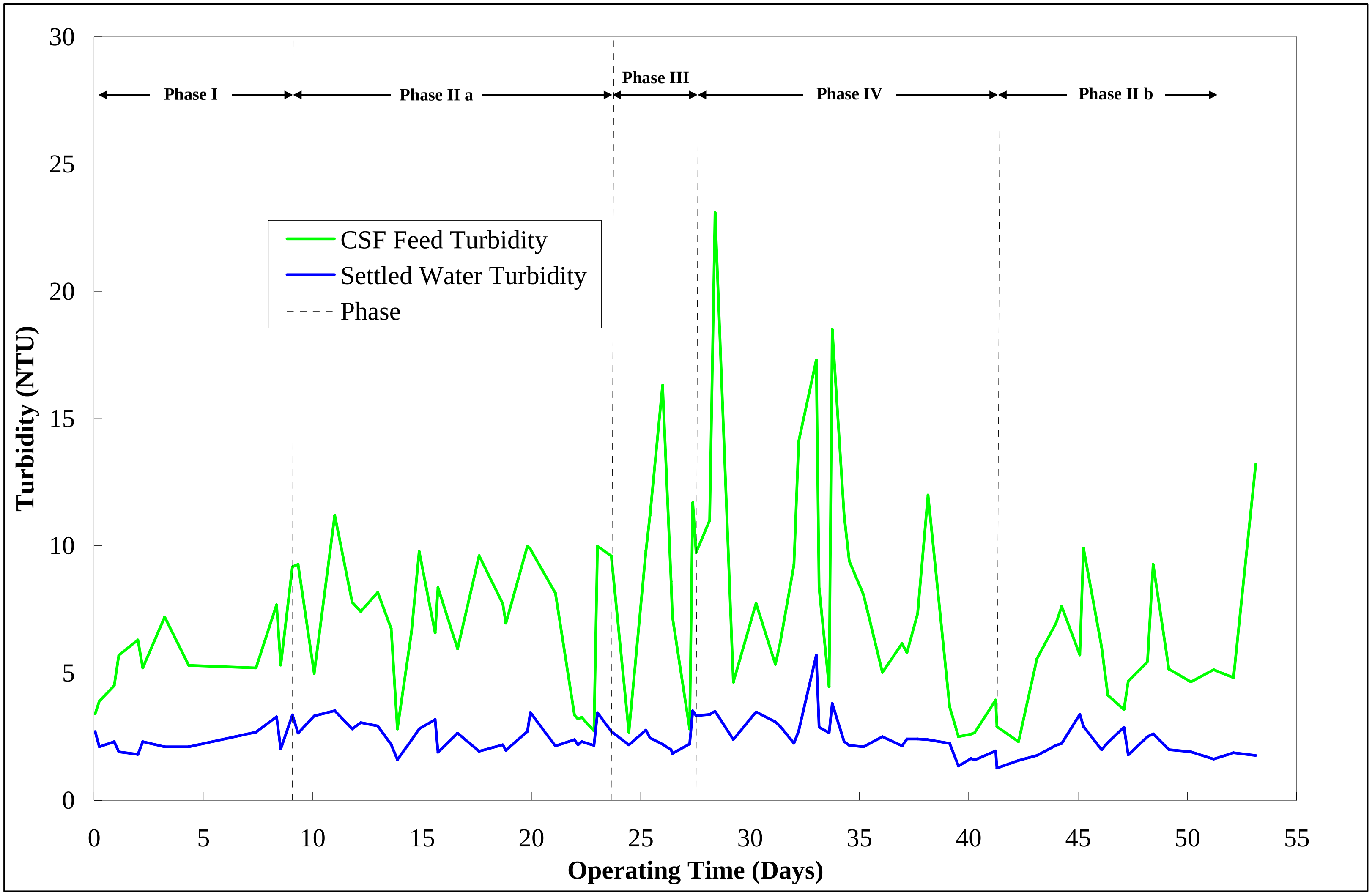


Figure 5-4. Coagulation/Sedimentation Feed and Settled Turbidity.

5.2.2.3 CSF Filter Productivity

Productivity of the CSF filters was assessed by monitoring the differential pressure of the roughing and polishing filters. As stated earlier, a manual backwash was performed when the differential pressure reached 10 psi, with a goal of a filter run time of more than 1 day before this pressure limit was reached. Figure 5-5 presents the differential pressures of the roughing and polishing filters for the CSF pretreatment. Table 5-5 presents a summary of run time to incur the differential pressure limit of 10 psi.

As it can be seen, the run time between backwashes varied from 1 to 6 days and, therefore, met the goals of a minimum run time of 1 day between backwashes. It should be noted that the backwash frequency criterion is 1 day for treating coagulated and settled water (as explained in chapter 3), instead of 8 hours when the filter is operating as a direct filter. It is reasonable to expect a longer filter run time when sedimentation is employed.

Table 5-5. CSF Filter Run Time Summary

Condition	Run Time to Reach Differential Pressure Limit (hours)
Average	42
Maximum	92
Minimum	21

5.2.2.4 MMF Water Quality

CSF filtrate turbidity and SDI were monitored during the study to determine whether the CSF pretreatment system could meet the SDI and turbidity goals of 3 units and 0.3 NTU, respectively.

Figure 5-6 presents the CSF system filtrate turbidity for the four phases. The filtrate turbidity met the goal of 0.3 NTU the majority of the time and averaged approximately 0.2 NTU. However, excursions above 0.3 NTU did occur. Use of a two-pass (roughing/polishing) filtration system did not result in a significant change in filtrate turbidity over the single-pass filter used in Phase 1.

Figure 5-7 presents the CSF system filtrate SDI. The results show that filtrate SDI values averaged slightly more than the goal of 3.0 units. The addition of coagulation-sedimentation significantly improved SDI values in particular. The use of a two-pass filtration system (roughing/polishing) resulted in appreciably lower SDI than single-pass filtration. Six experiments (Phase III) were performed using prechlorination and varying ferric coagulant dose between 5 and 20 mg/L without pH adjustment. Another seven experiments (Phase IV) were performed while adjusting the pH between 5.8 and 6.5 and adjusting the ferric coagulant dose between 5 and 15 mg/L. From these experiments (Phase II and IV), prechlorination and pH adjustment optimization did not appear to provide significant value.

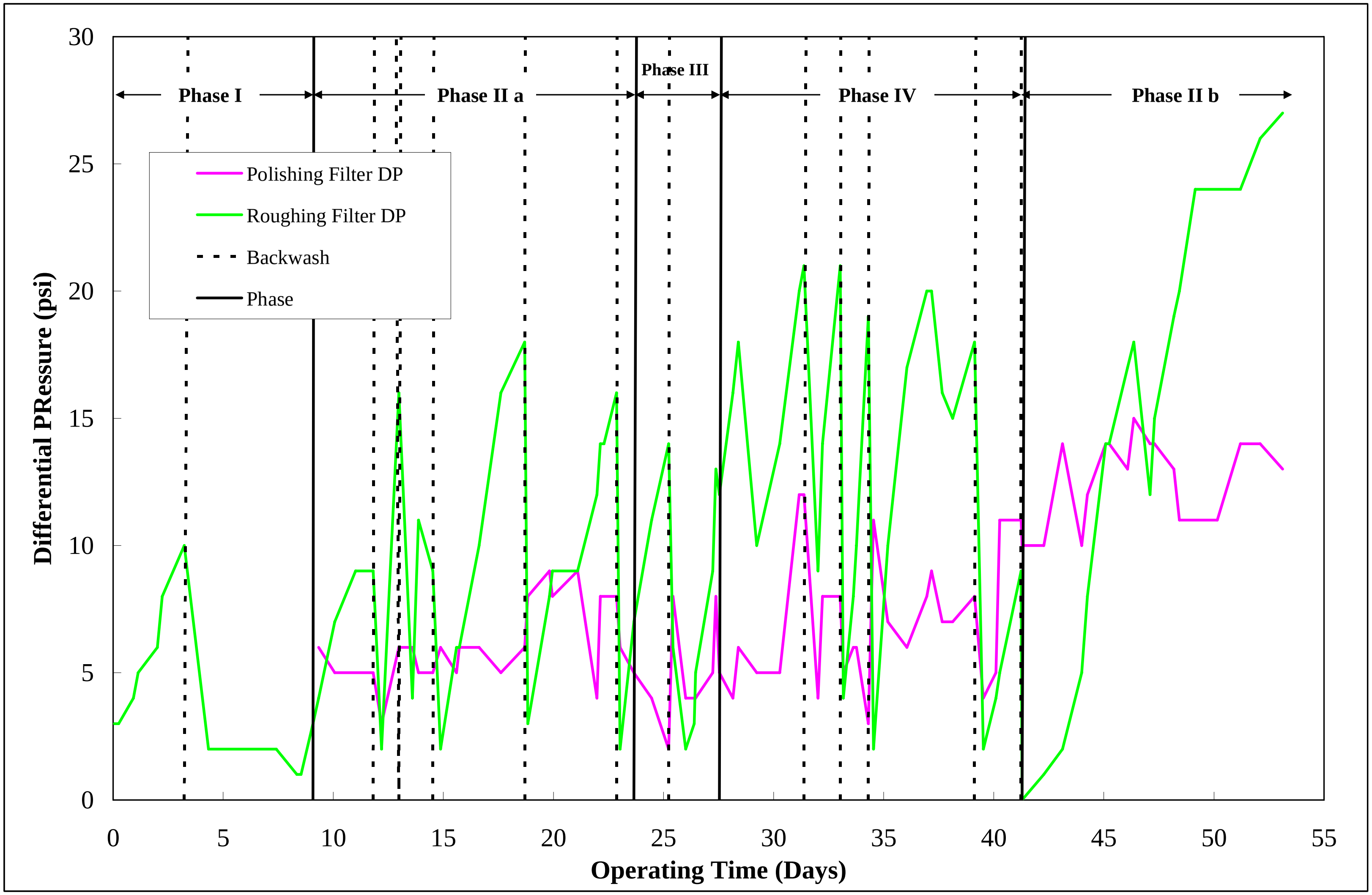


Figure 5-5. CSF Filtration System Differential Pressure.

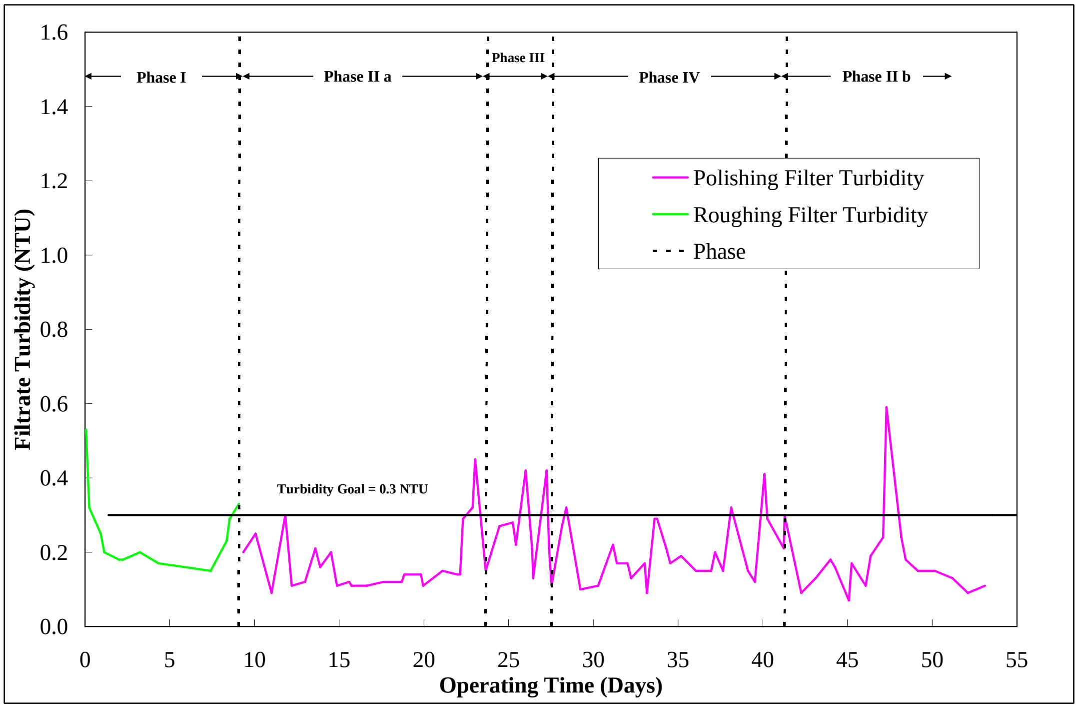


Figure 5-6. CSF Filtrate Turbidity.

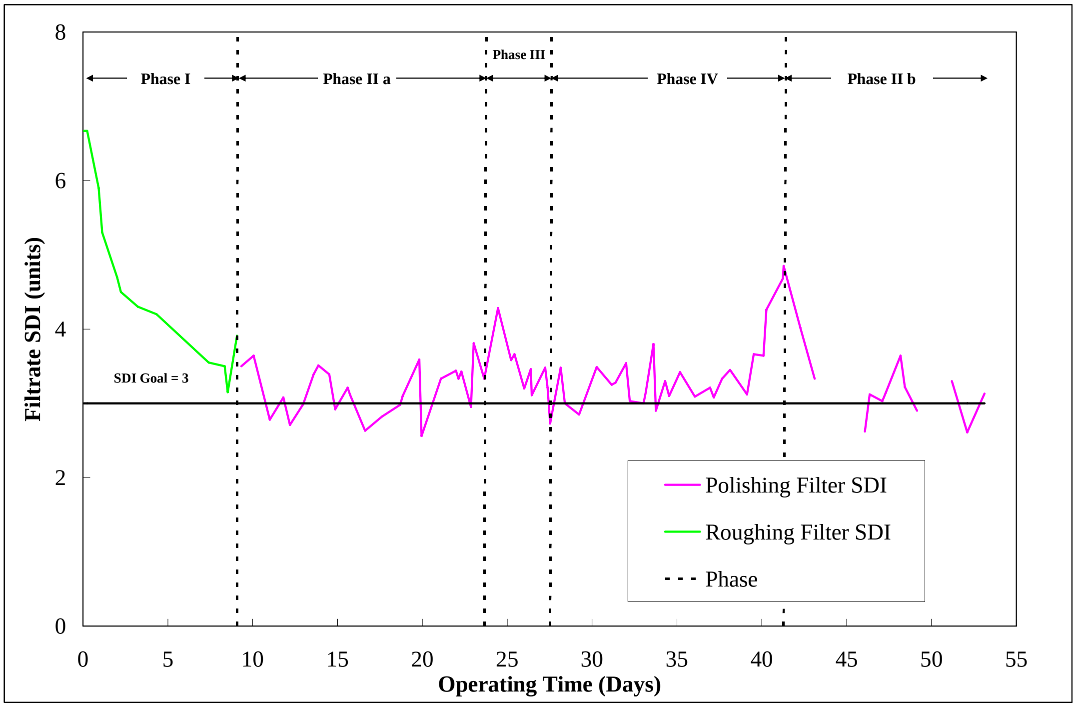


Figure 5-7. CSF Filtrate SDI.

While the results approached and occasionally met the SDI goal, performance of the CSF system is considered inadequate for this site. The SDI goal of 3.0 units is considered a minimum acceptable criterion, and only systems that can reliably and consistently meet this goal should be considered for a seawater desalination project.

5.2.2.5 CSF Summary

In summary, the CSF pretreatment system met the operational goal of run time between backwashes. It did not meet the goals of treated water quality, especially SDI of 3.0 units. CSF is not recommended for further consideration at this site. However, it remains possible that an enhanced CSF system, with utilization of additional unit processes, could potentially be of value. Similar to the MMF pretreatment, the CSF tested on this project site could be a feasible option in treating seawater on another site in the United States, depending on the water quality of the seawater. As such, the MMF and CSF pretreatments could be viable pretreatments where the seawater has an average turbidity and maximum turbidity significantly lower than 6.5 NTU and 75 NTU, respectively. This situation could occur in United States sites where, for example, coastal waters are deep; where there is low ship traffic, and where the seawater is not under the influence of surface water in order to minimize turbidity peaks and to withdraw seawater with consistent water quality in terms of turbidity.

5.2.3 Membrane Filtration

5.2.3.1 Test Conditions

The Pall Microza membrane filtration pretreatment system was tested directly treating raw water and was operated under different conditions that can be grouped into two phases as follows:

- Phase 1 consisted of treating raw water without chemical addition.
- Phase 2 consisted of treating raw water with in-line coagulation

Only the flux and the ferric coagulant dose were varied during the two phases, as shown in table 5-6. All other parameters were kept constant. Detailed operation conditions for each run under each phase are presented in Appendix A, “Means and Methods.” The flux settings and changes were coordinated with Pall representatives to ensure proper operation of the MF unit.

Table 5-6. Pall MF Operating Variables

	Flux (gfd)	Coagulant Dose (mg/L as Fe)
Phase 1	48 – 70	0
Phase 2	42 – 48	1.0 – 3.5

5.2.3.2 Productivity

Productivity of the Pall Microza MF system was evaluated based on temperature corrected transmembrane pressures (TMP). A stable TMP would indicate no fouling of the membranes and, therefore, no need to clean the membranes. An increasing TMP indicates fouling, which ultimately leads to the need for clean-in-place (CIP) when the terminal pressure is reached. For the Pall Microza system, the terminal pressure was 45 psi. The minimum acceptable operational time between chemical cleanings was set at no more than 1 CIP per month, which is a common objective for MF and UF systems.

The flux, temperature-corrected TMP, and temperature trends are provided in figure 5-8. The TMP was corrected to 15 °C to simulate cold water conditions using a correction factor provided by the manufacturer. This temperature was selected as a performance criterion since the temperature during the testing period varied from 15 °C (60 °F) to 41 °C (105 °F) and represents a conservative value. A summary of results is presented in table 5-7.

Table 5-7. Pall MF Filtration Cycle Versus Flux

Flux (gfd)	Duration to Maximum TMP (days)
48	35
60	15
70	10

The experiments at 48 gfd in winter and summer showed that the 30-day cleaning frequency target would be met, since the normalized TMP reached the maximum pressure of 45 psi beyond 30 days of operation. The winter experiments were operated with one enhanced flux maintenance (EFM) per day using chlorine at 500 mg/L. The summer experiments were operated with one EFM per day using chlorine at 500 mg/L and one citric acid EFM every week.

The tests conducted at 60 gfd and 70 gfd showed the normalized TMP reached the maximum pressure of 45 psi after 10 days and after 15 days, respectively. Therefore, these operating conditions do not meet the goal of cleaning frequency.

The operation of the MF system using in-line coagulation (Phase II) as pretreatment to MF did not improve the sustainability of the microfilter, as shown in figure 5-8.

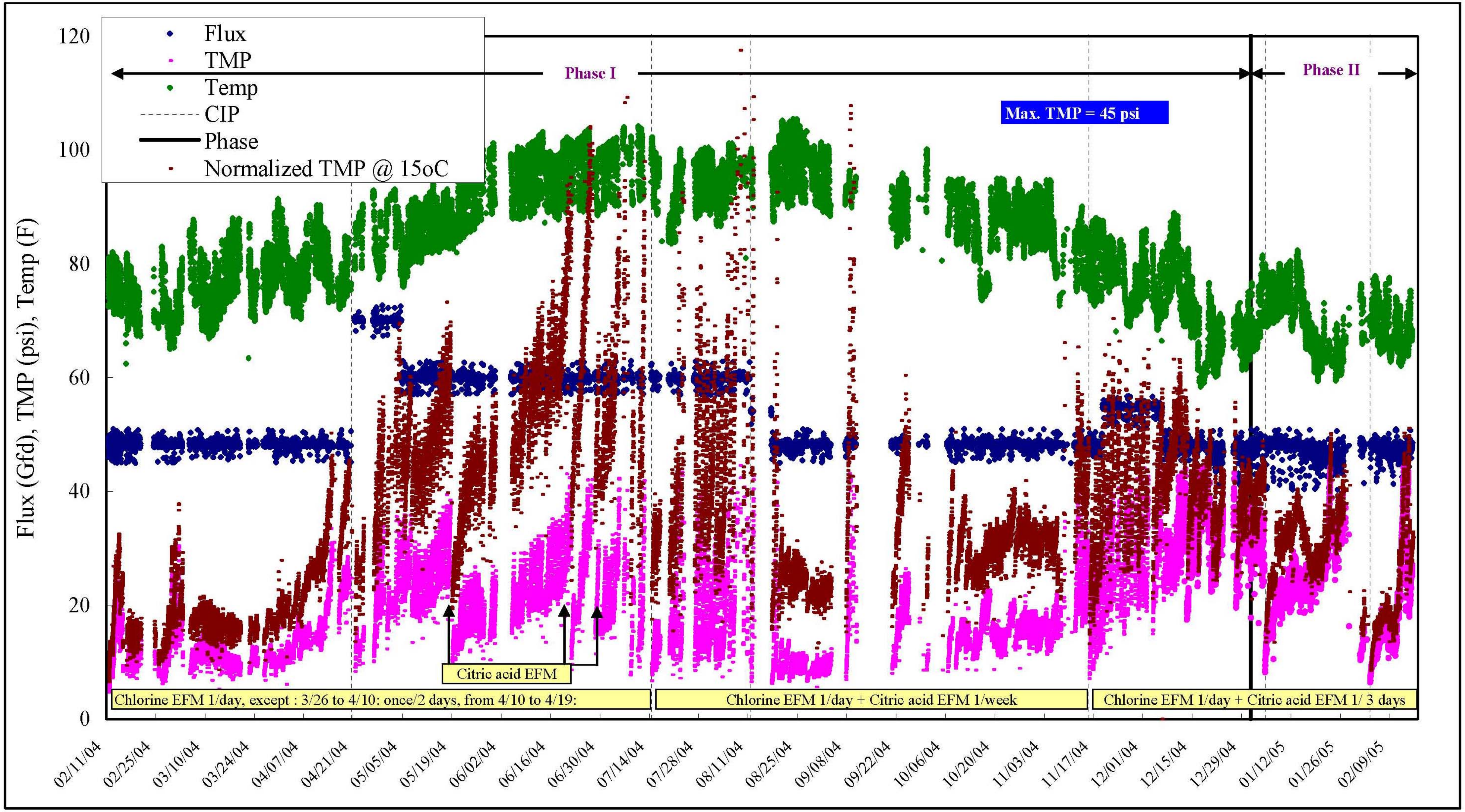


Figure 5-8. MF Pretreatment Productivity.

Based on these results, a maximum flux of 48 gfd would be recommended for this site when using the Pall Microza MF system. Note that the primary purpose of testing the Pall MF system was to generate a filtrate quality considered representative of MF and UF technologies as a whole and evaluate the ability of a SWRO system to engage in sustained operation using this feed water. The Pall Microza MF system was considered appropriate for this purpose. Therefore, a greater emphasis should be placed on the finished water quality associated with the Pall Microza MF system given that it was outside of the scope of this project to perform side-by-side comparisons of multiple proprietary MF and UF systems and their maximum sustainable flux rates.

5.2.3.3 Water Quality

The goal of MF pretreatment was to obtain high water quality in terms of SDI and turbidity to ensure the production sustainability of the SWRO system. Figures 5-9 and 5-10 present the filtrate SDI and the feed and filtrate turbidity, respectively.

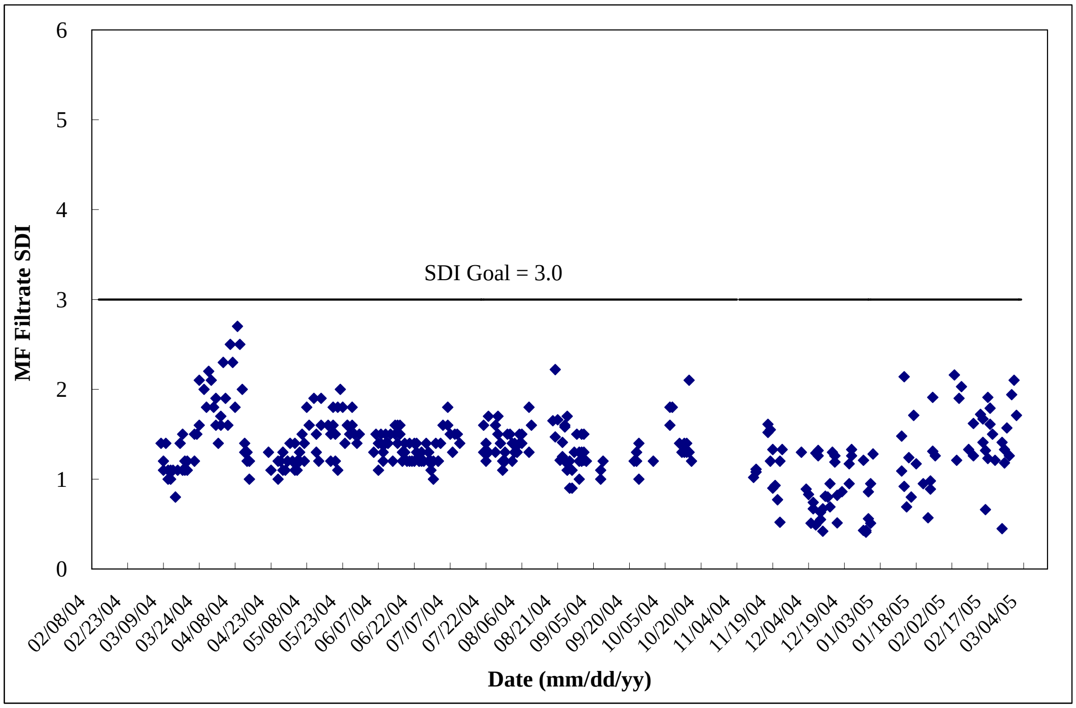


Figure 5-9. Pall MF Pretreatment Filtrate SDI.

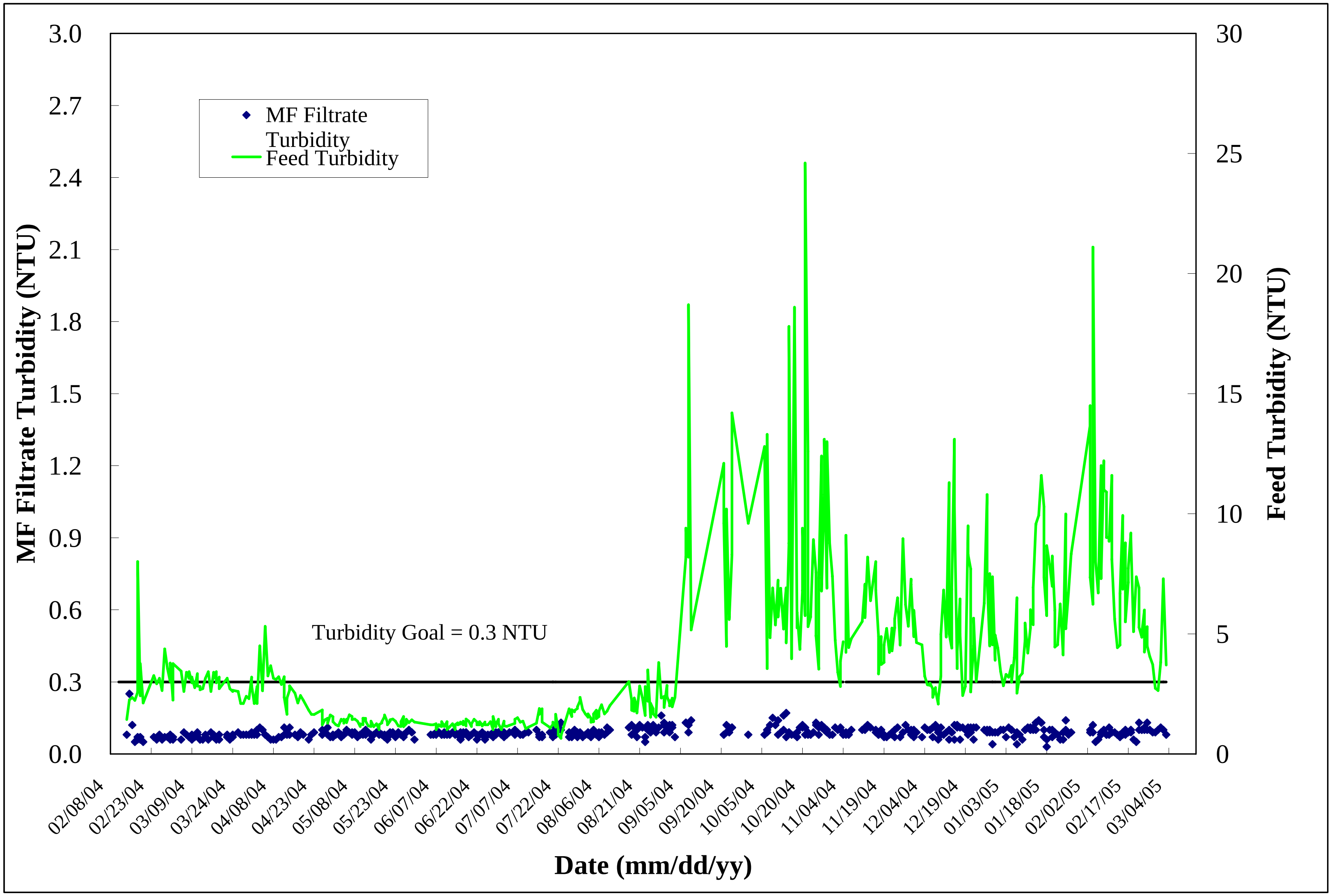


Figure 5-10. Pall MF Pretreatment Filtrate Turbidity.

The MF filtrate SDI was consistently less than the project goal of 3.0 units or less. SDI values typically ranged from 1.5 to 2.5 units. For the test period, feed turbidity averaged 4.2 NTU in the raw water and ranged from 0.7 to 24.6 NTU. The filtrate turbidity was consistently less than 0.1 NTU independent of raw water turbidity and, therefore, readily met the goal of 0.3 NTU. The water quality from the Pall MF system consistently exceeded the water quality criteria for this project and is a viable system for consideration at this site.

5.2.3.4 Summary

The MF system met the goals in terms of water quality under all operating conditions. However, the MF system met the cleaning frequency goal only at a flux of 48 gfd. It is important to note that the design temperature was set at 15 °C. Therefore, the design criteria of the MF system would be 48 gfd with a daily EFM using chlorine for this site. Depending on the water quality of other potential seawater sources in the United States, the design criteria would vary. The design criteria would not only vary with the water quality, but also with the type of UF/MF manufacturer's membranes. Wherever the potential seawater facility is located, the lowest temperature of the source water should be the design temperature, and the TMP should be normalized with this minimum temperature in order to determine the design flux of the MF/UF system.

5.3 Cartridge Filtration Evaluation

Typical SWRO systems include pretreatment-cartridge filtration unit processes. This represents the unit processes evaluated as part of this project. Cartridge filters are utilized as additional protection for the RO membrane elements to capture any final particles or suspended solids that may enter the feed stream. Note that particles that plug the cartridge filter may also plug the RO membranes. The cartridge filters are to capture relatively large particles (> 5 µm) that may plug the membranes. Relatively small particles going through the cartridge filters would likely travel across the RO membrane feed spacer and not clog the membranes. Biofouling of the cartridge filter may or may not be similar to the RO membrane biofouling as explained in section 5.4.

Cartridge filters are replaced when suspended solids plug the filter and increase the differential pressure above a desired level. The maximum differential pressure for the 5-µm cartridge filtration systems used in this project was 20 psi and is considered typical. The maximum acceptable cartridge filter replacement frequency was established to be no more than once every 30 days. While many brackish RO systems operate cartridge filters based on a change out frequency of once every 3 months, the challenging nature of SWRO pretreatment is such that a more frequent replacement criterion was considered.

However, cartridge filters are not intended for systematic and continuous removal of significant quantities of particulate material, which must be addressed in the pretreatment step. Therefore, more frequent replacement or high influent SDI and turbidity levels were considered unacceptable given the costs associated with cartridge filter replacement and the potential for fouling of the RO elements despite the presence of cartridge filters.

Results for the cartridge filter run time and replacement frequency are presented for each pretreatment alternative in the following subsections.

5.3.1 Multi-Media Filtration

Results of the MMF operation indicated that the MMF system could not meet the SDI goal and could not consistently meet the turbidity goal. The SDI and turbidity goals are surrogates that are used to protect against excessive fouling of the cartridge filtration and RO systems. To directly confirm that the quality of the MMF filtrate would result in excessive cartridge filter replacement frequencies, in addition to relying on the surrogates of SDI and turbidity, MMF filtrate was treated through a cartridge filtration system.

The cartridge filters were operated during the third phase of the MMF pretreatment (coagulant and polymer addition and greensand media filter). The SWRO was not operated. The loading rate on the 5 micron melt blown, polypropylene cartridge filters was 3.0 gpm/10-inch equivalent (TIE) and represents a common design setting below the typical maximum recommended value of 5.0 gpm/TIE.

A single experiment was performed using MMF pretreatment. The results are presented in figure 5-11. A melt blown cartridge filter was utilized. As shown, the SDI of the filtered water from the polishing filter ranged from 4 units to greater than 6.67 units and did not meet the goal of 3.0 units. The cartridge filters reached the maximum recommended differential pressure of 20 psi at the end of 210 hours (approximately 9 days) as shown in figure 5-11; therefore, the criterion of a run time of 30 days on the cartridge filter was therefore not met. This result demonstrates that the MMF pretreatment did not provide adequate pretreatment to SWRO to treat the raw water at the Anclote site.

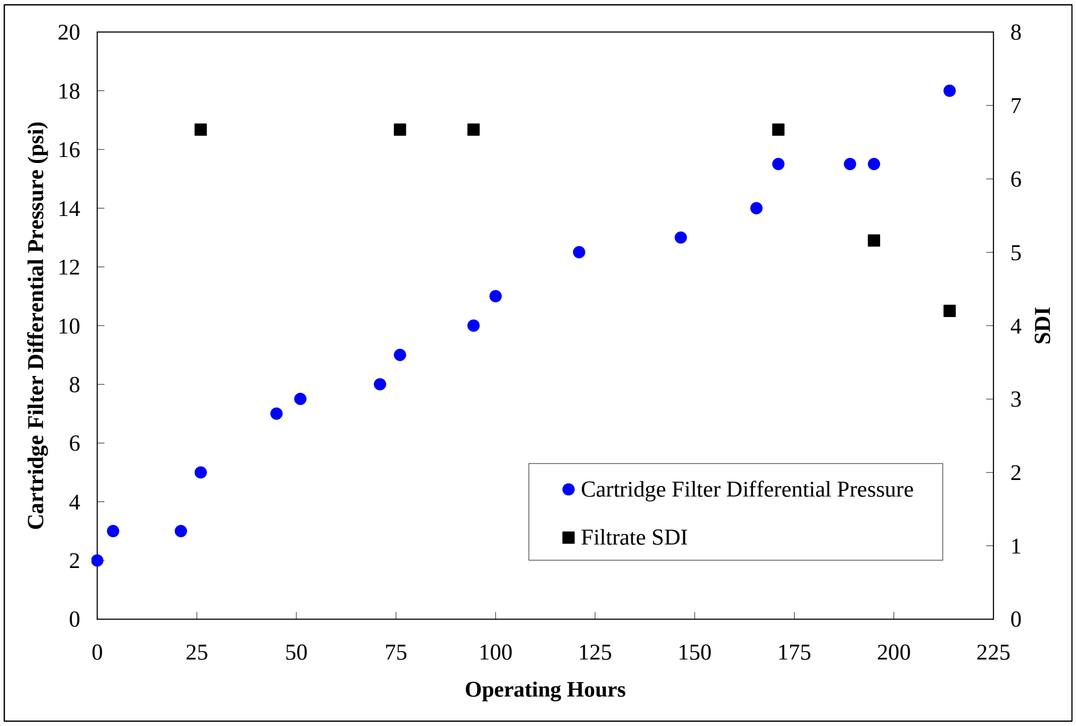


Figure 5-11. Cartridge Filter Differential Pressure with MMF Pretreatment.

5.3.2 Coagulation/Sedimentation/Multi-Media Filtration

During CSF testing, as presented previously, filtrate turbidities and SDIs approached or met the goals only on an intermittent basis. Therefore, it was considered of particular importance to evaluate cartridge filter fouling using CSF filtrate to determine if the SDI and turbidity goals were excessively stringent.

Results of the cartridge filtration tests are presented in figure 5-12. Melt blown cartridge filters were utilized. As shown, four experiments were performed, with a new set of cartridge filters utilized for each experiment. The maximum differential pressure of 20 psi was reached between 8 hours and 5.5 days, as shown in figure 5-12. This result also demonstrates that CSF pretreatment does not provide adequate water quality to prevent the cartridge filters from excessive fouling.

During the operation of the cartridge filter, the SDI of the filtered water from the polishing filter ranged 2.6 units to 3.8 units, as shown in figure 5-12. This lower SDI did not result in run time improvements of the cartridge filter compared to the run time observed when MMF pretreatment was operated. However, biological growth may have occurred in the holding tank between the CSF unit and the cartridge filtration unit and contributed particles that adversely impacted cartridge filter differential pressures.

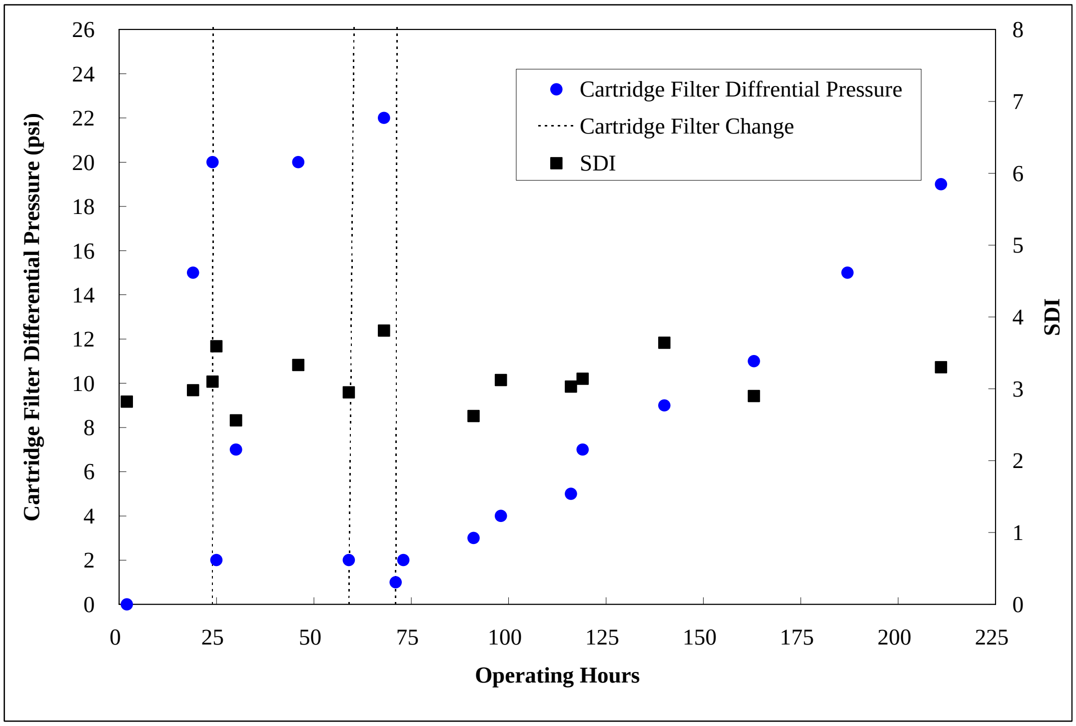


Figure 5-12. Cartridge Filter Differential Pressure with CSF Pretreatment.

5.3.3 Membrane Filtration

Operation of the cartridge filters downstream of the MF pretreatment was divided into three phases as follows:

- Phase 1 consisted of feeding the cartridge filters with MF filtrate without additional treatment.
- Phase 2 consisted of feeding the cartridge filters with MF filtrate with an ultraviolet (UV) disinfection unit installed at the feed inlet of the cartridge filters to inhibit biogrowth and biomass accumulation on the cartridge filter (figure 5-13).
- Phase 3 consisted of feeding the cartridge filters with MF filtrate with UV disinfection on the filtrate pipeline (upstream of the break tank). In addition:
    - The pipeline from the MF system and the cartridge filters, as well as the break tank, were changed.
    - A high-efficiency particulate air (HEPA) filter was placed on the break tank to eliminate airborne particle intrusion.

- Chlorination of the pipeline was performed every day for 30 minutes with a residual of 1 to 2 mg/L of free chlorine.
- The melt blown cartridge filters were replaced with string wound filters.

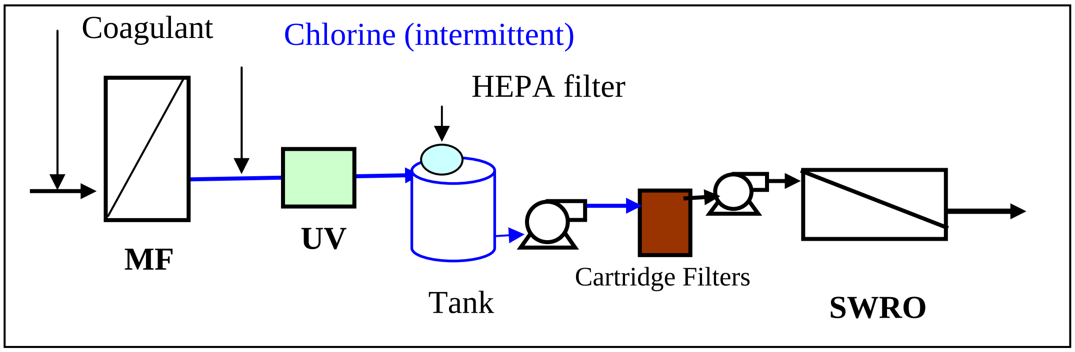


Figure 5-13. Biogrowth Control Measures Schematic.

5.3.3.1 Phase 1

Although MF filtrate quality was consistent and predictable (regardless of feed water quality), the cartridge filters downstream of the MF and just prior to the SWRO system fouled at an unacceptable rate, as shown in table 5-8 and figure 5-14. In the first 2,000 hours of operation, the loading rate on the cartridge filters was 1.5 gpm/TIE, and the changeout frequency averaged 3 weeks. Note that cartridge filters in high rate applications such as ground water RO are commonly operated at loading rates as high as 3.0-5.0 gpm/TIE.

Table 5-8. Cartridge Filter Cycles

Phase	Number of Cartridge Filter Sets	Cartridge Filter Run Time (average)
Phase 1 – MF	8	2 weeks
Phase 2 – MF – UV	3	2 weeks
Phase 3 – MF – multiple biological control methods	1	> 2 weeks

In the next 2,000 hours of operation (2,000 to 4,000 hours), the loading rate was increased to 3.0 gpm/TIE. While a loading rate of 3.0 gpm/TIE was higher than the first experiments, an ongoing assessment of design criteria resulted in selection of 3.0 gpm/TIE as a minimum loading rate for the facility. At these settings, the cartridge filter changeout frequency averaged once every 2 weeks. The goal of changeout every 30 days was, therefore, not met.

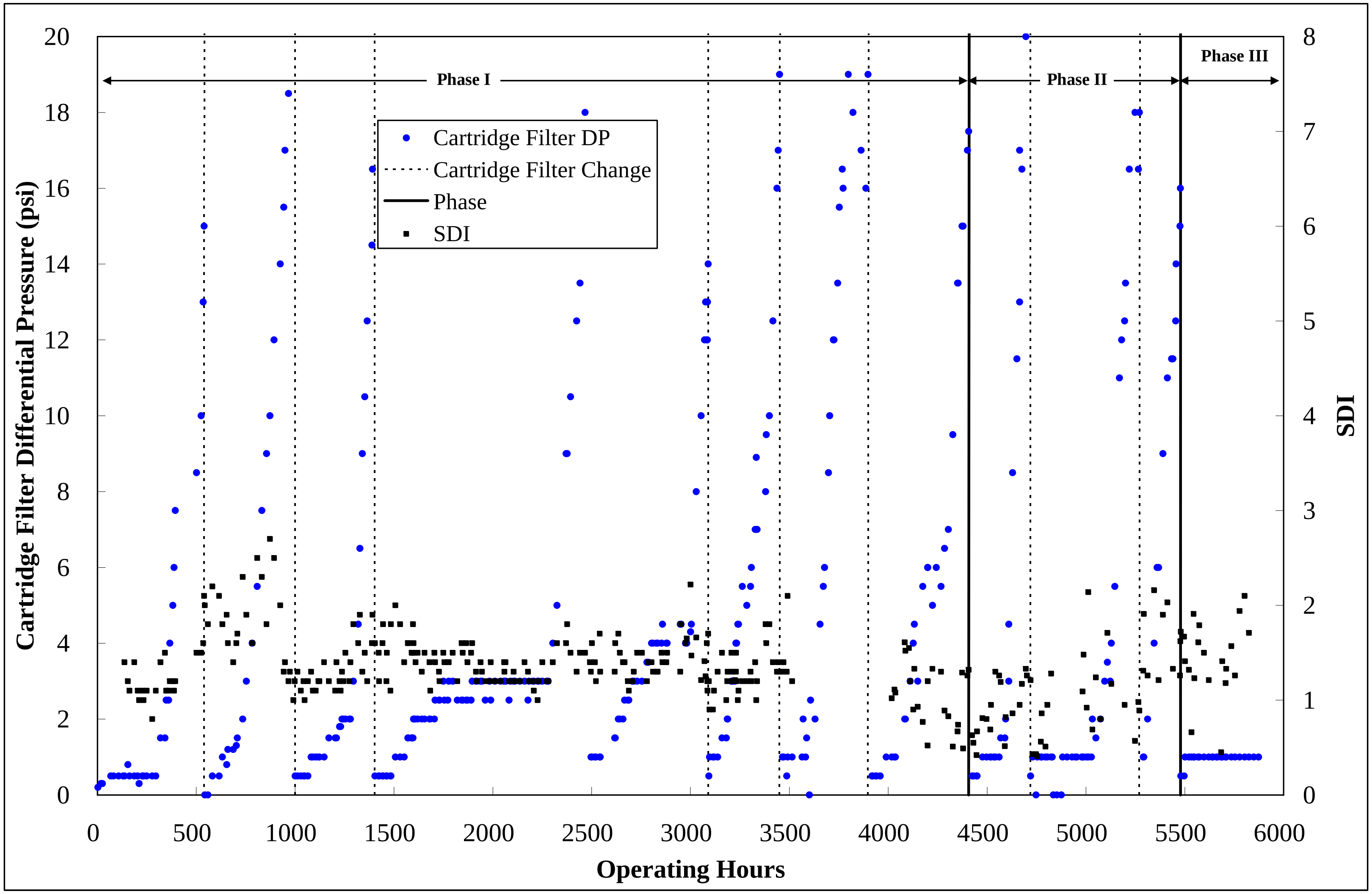


Figure 5-14. Cartridge Filter Differential Pressure with MF Pretreatment.

Even though chlorination of the filtrate tank was performed approximately once every 2 weeks, biological growth was suspected as the cause of the increased cartridge filter replacement frequencies for several reasons. The MF filtrate quality was well below the limits established for this and other similar projects, with SDI consistently below 3 units; therefore, particle plugging was unlikely. In addition, MF was being operated without coagulant addition, which would otherwise remove a portion of substrate for biological growth. Also, visual observations of the break tank between the MF and cartridge filtration systems suggested a biofilm was growing on the tank walls. It was presumed this biofilm could also be growing within the piping network. Lastly, biological growth on cartridge filters themselves has been known to occur and cause cartridge filter fouling. Particle size distribution and autopsy of the cartridge filter are presented in Appendix B, "Cartridge Filter Autopsy Report."

5.3.3.2 Phase 2

In response to the possibility of biological growth, UV disinfection was installed downstream of the break tank and upstream from the cartridge filtration system. The purpose was to sterilize the feed water as it entered the cartridge filters to control any biological growth occurring on the filters themselves. Despite the UV disinfection, the cartridge filters system still fouled at an unacceptable rate, as shown in table 5-8 and figure 5-14. The loading rate on the cartridge filters was 3.0 gpm/TIE and the changeout frequency averaged 2 weeks, showing no improvements from Phase 2. The goal of changeout every 30 days was, therefore, not met.

5.3.3.3 Phase 3

Due to the unacceptable cartridge filter performance during Phases 1 and 2, a comprehensive program of biological control was initiated. The UV system was relocated upstream of the break tank. In addition, the pipeline was replaced and the break tank was cleaned. An air filter was installed on the break tank to eliminate airborne bacteria intrusion, and shock chlorination of the piping and break tank was performed every day. Lastly, the melt blown cartridge filters were changed with string wound cartridge filters. Under these conditions, no increase in the differential pressure of the cartridge filters was observed over a 2-week period of operation (table 5-8 and figure 5-14). These results clearly show the benefit of aggressive biological control methods, confirm the acceptable quality of filtrate from the MF pretreatment system, and confirm the validity of the SDI and turbidity goals for pretreated water. The cartridge filter replacement frequency goal of no more than once every 30 days is expected to be met under these conditions.

5.3.4 Cartridge Filter Summary

Pretreatment systems capable of providing a filtrate with low SDI and turbidity values are of critical importance for SWRO applications. This testing evaluated cartridge filter run times when supplied with filtrate from MMF, CSF, MF, and biologically controlled MF systems. The biologically controlled MF system filtrate resulted in cartridge filter run times of over 2 weeks and was limited by the time available for testing (i.e., no increase in pressure differential was observed).

The MMF, CSF, and MF system filtrates utilized without biological control methods resulted in an increase in cartridge filter differential pressures. This may have been due to suspended solids loading associated with the filtrate or due to biomass released from transfer piping or the holding tank between the pretreatment system and the cartridge filtration system. To better understand the contribution of suspended solids from the filtration to the observed increases in cartridge filter differential pressures, the average run time was summarized as show in table 5-9 below.

Table 5-9. Cartridge Filter Run Time Without Biological Control

Pretreatment	Feed SDI	Cartridge Filter Run Time (average)	Number of Tests
MF	1.5 – 2.5	2 weeks	7
CSF	2.6 – 3.8	< 6 days	4
MMF	4.0 – 6.7	< 9 days	1

As shown, use of MF pretreatment resulted in the longest average cartridge filter run time of 2 weeks and also represented the system with the lowest SDIs, ranging from 1.5 to 2.5 units. The CSF and MMF system cartridge filter run times averaged less than 6 and 9 days, respectively, and had SDIs that ranged from 2.6 to 6.7 units. The correlation between SDI and cartridge filter run time was consistent when comparing MF versus CSF or MMF pretreatment, with lower SDIs and longer run times for the MF. While the correlation did not hold true between the CSF and MMF pretreatment processes, both processes generated SDIs in excess of the goal of 3 units on a regular basis and resulted in lower run times than the MF, which met the SDI goal.

More importantly, this testing showed that generating high water quality filtrate from the pretreatment system does not preclude the potential for cartridge filter fouling due to biological growth in intermediate transmission piping and storage. By adding UV disinfection in addition to intermittent chlorination of the pipeline and preventing intrusion of airborne microorganisms, the fouling of the cartridge filtration system was potentially eliminated. These results are considered a key outcome of this project. It is recommended that any future design for a seawater facility employ robust biological control methods for any intermediate transmission piping and storage between pretreatment system and cartridge filtration system. This should include the ability to chemically, as well as physically, clean these areas as necessary. The use of UV disinfection and/or other biological control method on the MMF and CSF filtrate, as feed water to the cartridge filters, was not studied. However, it is reasonable to expect that the cartridge filter run time would still be less using MMF or CSF pretreatment with biological control methods than using MF pretreatment due to higher load of solids on the cartridge filter.

5.4 Seawater Reverse Osmosis Evaluation

The primary objective of the SWRO system evaluation was to determine the rate of SWRO fouling, the associated cleaning frequencies, and the optimal design that minimized cleaning frequency.

A SWRO system may experience a decline in productivity over time due to deposition of foulants such as particles, precipitates, or biological material. Productivity is defined by the amount of treated water produced for a given pressure. Two methods of evaluating productivity include the water MTC and feed-side pressure differential. Fouling is evidenced by a decline in MTC or an increase in feed-side pressure differential. A decline in productivity requires a chemical cleaning to restore performance. A chemical cleaning is typically performed following a 10- to 20-percent decline in the MTC or a 50-percent increase in feed-side pressure differential. Chemical cleaning frequencies for a seawater source would be typically on the order of once every 3 to 6 months. The cleaning frequency goal for this project was no more than once every 3 months.

During the course of pilot testing, operational variables were adjusted to determine their impact on the rate of RO membrane fouling. These factors included flux and recovery. In addition, the impact of seasonal changes was assessed. The first-pass flux was set at 8 or 10 gfd and the recovery at 50, 55, or 60 percent. Second-pass flux and recovery were maintained at 20 gfd and 90 percent, respectively.

The first-pass RO system utilized TM810 Toray membranes. The second-pass treated water from first pass and used TMA G10 Toray membranes. The first-pass system was operated for a total of 4,800 hours (approximately 6.5 months), whereas the second pass was operated for 1,150 hours (approximately 1.5 months). The second pass was necessary to polish first-pass permeate to meet the finished water quality goals set for the project.

Note that the SWRO system was only operated using MF filtrate due to the inability of the MMF or CSF systems to generate filtrate of acceptable quality to feed a SWRO system. Productivity and water quality data were recorded during this study, and the interpretation of this data is provided in the following subsections.

5.4.1 MF-SWRO First-Pass Productivity

A plot of operational settings is presented in figure 5-15 by season. As shown, system flux of the system remained constant at 8 or 10 gfd, depending on the test. In addition, recovery was maintained at 50 percent, 55 percent, or 60 percent, depending on the test.

Feed-side pressure differential was evaluated as presented in figure 5-16. The feed-side pressure differential did not significantly increase from the beginning to the end of the study and remained within the maximum pressure drop per vessel of 60 psi recommended by the manufacturer. This would indicate that plugging of the feed channel did not occur. While these results are favorable, it should be noted that MTC is typically more sensitive to fouling, as presented in the next paragraph.

The MTC was normalized with osmotic pressure and temperature and is presented in figure 5-17. As shown, the initial MTC varied for each test, as is common when flux or recovery changes. As shown, MTC declined during certain experiments, demonstrating that the membrane experienced a degree of fouling during the period of testing. A single chemical cleaning was performed at approximately 2,100 hours of operation using sodium hydroxide (pH 11.0), which resulted in restoration of performance. In addition, the SWRO membrane elements were replaced at approximately 4,300 hours of operation due to concerns regarding finished water quality, as discussed in more detail in Chapter 6, “Finished Water Quality”. Lastly, UV disinfection was utilized after the MF pretreatment during latter experiments in an attempt to control suspected biological growth before or on the cartridge filters.

To assess the effect of each operating variable, the MTC decline was used to calculate the time between chemical cleanings, based on a linear regression which would predict a percent decline in performance. These results are presented by experiment in table 5-10.

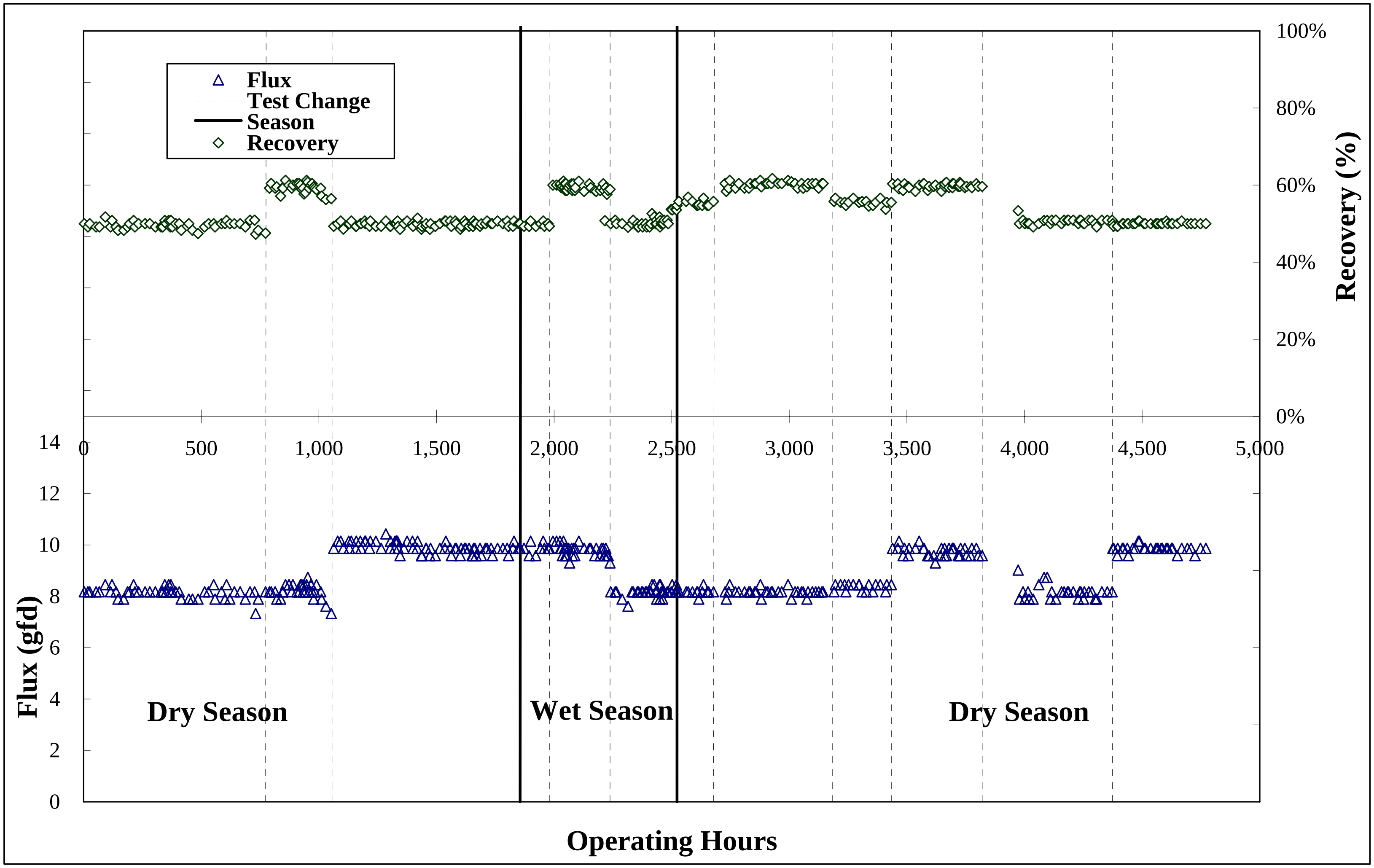


Figure 5-15. SWRO First-Pass Flux and Recovery.

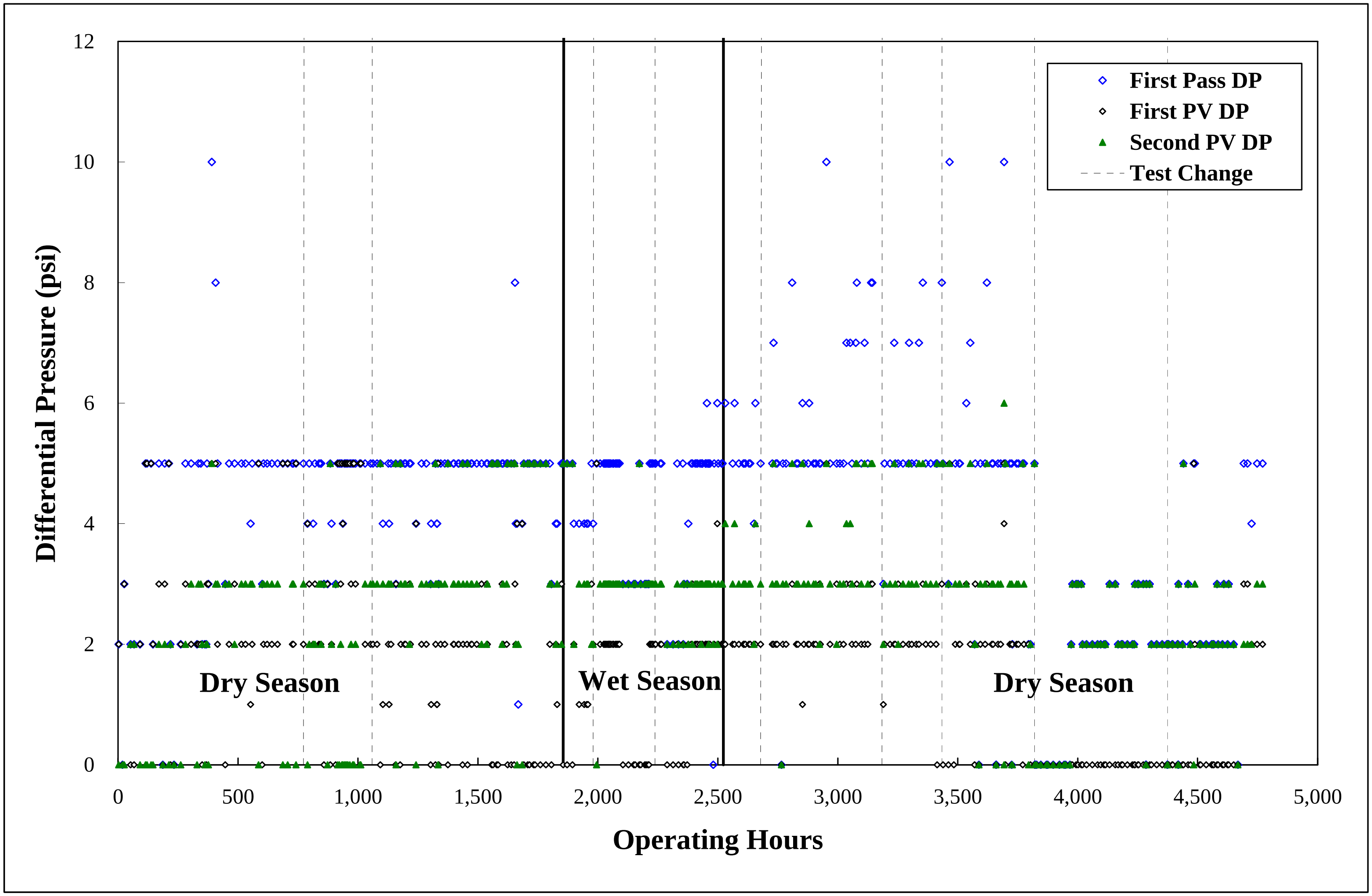


Figure 5-16. SWRO First-Pass Feed Differential Pressure.

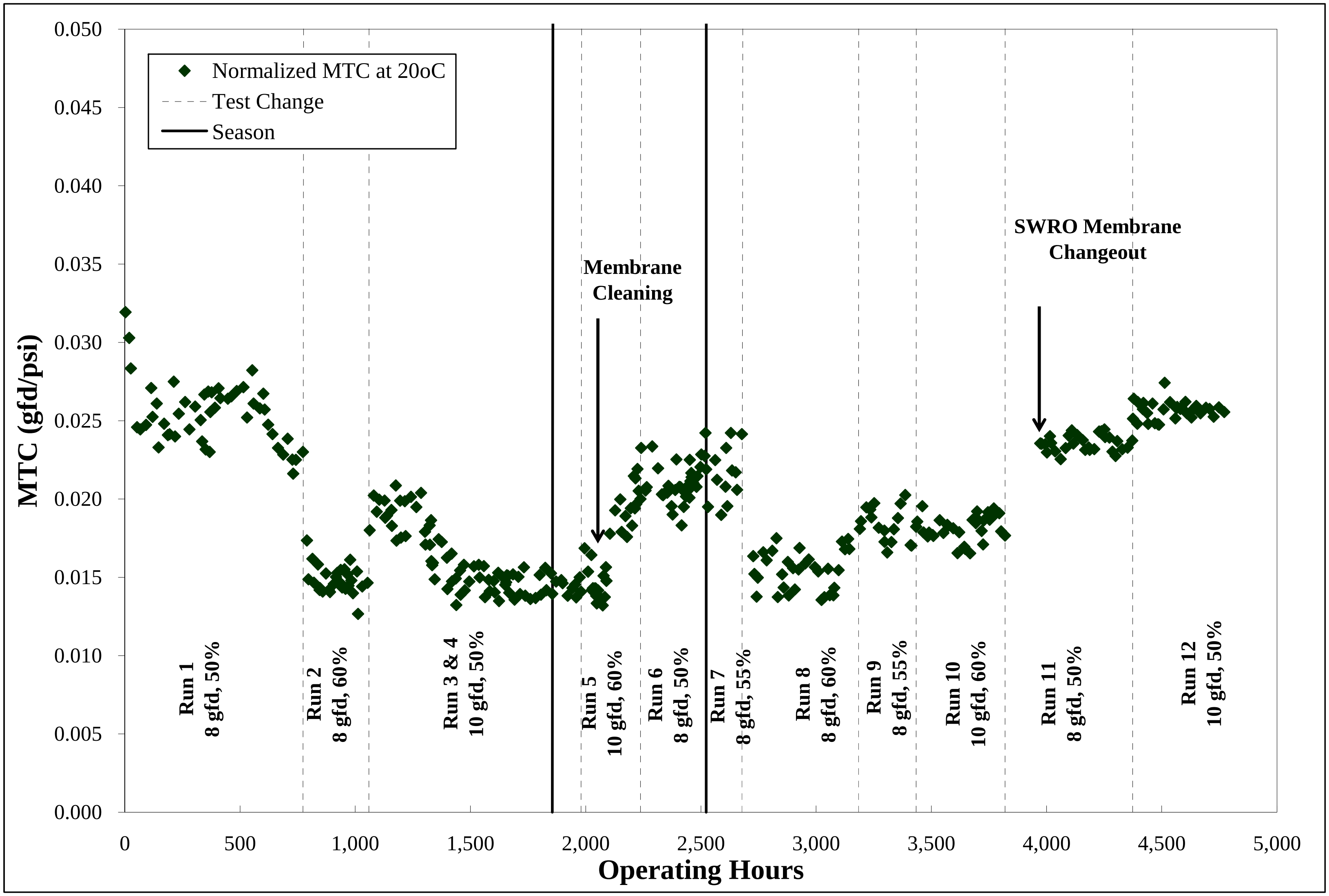


Figure 5-17. SWRO First-Pass Normalized MTC.

Table 5-10. SWRO First-Pass Normalized MTC Decline

SWRO Run	Flux (gfd)	Recovery (%)	Dates (dd/mm/yy)	MTC Decline (%)	Allowable Decline (%)	Operating Days	Projected Cleaning Frequency Months	Season
MF-SWRO								
6	8	50	08/19/04- 09/24/04	1.4	15	12	4.5	Wet
1	8	50	03/01/04- 04/11/04	3.8	15	33	4.5	Dry
7	8	55	09/30/04- 10/16/04	4.5	15	24	2.5	Dry
9	8	55	11/17/04- 12/05/04	5.2	15	11	1.0	Dry
8	8	60	10/16/04- 11/12/04	1.9	15	08	2.0	Dry
2	8	60	04/11/04- 05/10/04	3.4	15	11	1.5	Dry
4	10	50	06/08/04- 07/07/04	5.3	15	11	1.0	Wet
3	10	50	05/10/04- 06/08/04	20.0	15	18	0.25	Dry
5	10	60	07/07/04- 08/10/04	3.4	15	17	2.5	Wet
MF-UV-SWRO								
11	8	50	01/12/05- 02/07/05	0.5	15	15	15.0	Dry
12	10	50	02/07/05- 03/03/05	0.7	15	16	11.5	Dry
10	10	60	12/05/04- 12/31/04	0.8	15	15	9.5	Dry

Without UV pretreatment, the cleaning frequency at 8- and 10-gfd flux averaged 2.5 and 1.3 months, respectively. This is independent of recovery and did not meet the goal of a chemical cleaning no more than once every 3 months. However, an 8-gfd flux approached the target. Therefore, the impact of recovery, for the 8-gfd experiments, was evaluated. The average cleaning frequency at 8-gfd flux and 50-percent recovery was approximately 4.5 months. The average cleaning frequency at 8-gfd flux and 55- or 60-percent recovery averaged approximately 1.75 months. Based on these results, the most conservative flux and recovery settings (8-gfd flux and 50-percent recovery) met the cleaning frequency goal. Under all other operating conditions (flux higher than 8 gfd and/or recovery higher than 50 percent), the run time between chemical cleanings would be less than 3 months and, therefore, not acceptable.

When UV disinfection was used, SWRO fouling was reduced significantly. The run time of the SWRO membranes between chemical cleanings was calculated to be greater than 1 year at 8 gfd and 50-percent recovery and approximately 9 months under the least conservative operating conditions (10 gfd and 60-percent recovery). The improvement in run time between chemical cleanings using UV disinfection suggests that biofouling is a significant fouling mechanism in this system. It should be noted that UV disinfection did not improve run time of the cartridge filters when used just upstream of the cartridge filter, but it did improve run time of the SWRO. This suggests that the fouling of the cartridge filter was due to entrapment of biomass that had sloughed off of the piping and tank upstream of the UV system. The improvement to SWRO fouling could potentially be explained by the UV system's ability to inactivate this biomass, such that any bacteria that passed through the cartridge filter and onto the SWRO membranes had been inactivated.

Evaluation of seasonal impacts to SWRO fouling rate shows a relatively consistent fouling rate independent of season.

It should be noted that each run consisted of 1 to 5 weeks of operation, with an average of 2 weeks. Therefore, linear regressions of MTC data, to determine estimated cleaning frequencies, may not be statistically significant due to the limited number of data points for each run. However, the period of testing for each run was appropriate to estimate the relative differences in cleaning frequencies associated with differing operational variables and provide an approximation of the expected cleaning frequency by operating condition.

Based on these results, a first-pass flux of no more than 8 gfd and recovery of no more than 50 percent are recommended preliminary design criteria when using MF pretreatment. In addition, the use of UV disinfection is recommended. While UV results indicate higher fluxes and recovery could be utilized, the balance between marginal cost savings and the sustainability and reliability of the treatment process should be considered. Given the issues of sustainability and reliability that can occur in SWRO systems, it is strongly recommended that a conservative design approach be employed, despite the associated incremental cost impacts.

5.4.2 MF-SWRO Second-Pass Productivity

Second-pass RO systems utilized to treat first-pass permeate typically experience limited fouling due to the high-quality feed water. During testing, the second-pass flux was maintained at 20 gfd and the recovery at 90 percent, as shown in Figure 5-18. Productivity of the second pass was evaluated by monitoring the MTC of the first and second stages.

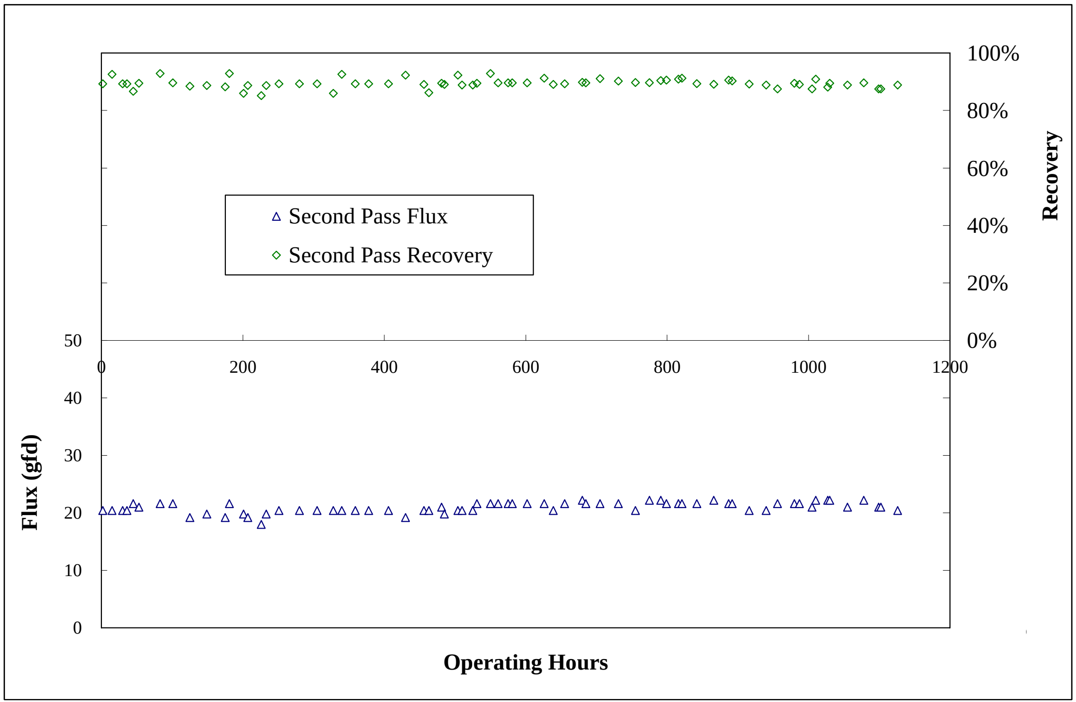


Figure 5-18. Second-Pass Flux and Recovery.

Figure 5-19 shows the MTC for both stages. As can be seen, the normalized MTC remained relatively constant during the 1,200 hours of operation. The fluctuations in the MTC are due to the accuracy of the flowmeters and pressure gauges. Cleaning frequency was calculated based on a linear regression with time and based on a 15-percent decline in MTC. Results indicate that the second-pass system would require chemical cleaning once every 4 months. The cause of this fouling was not determined. Two possibilities include biological fouling in the second-pass break tank and the effects of temperature on the membrane elements. A break tank, which can be susceptible to biogrowth, was installed between the first and the second pass at pilot scale, whereas the second pass will be hard piped from the first pass at full scale. With regard to use of feed waters with high temperature, second-pass membranes have been known to experience temperature-related degradation of the polymeric membrane material, resulting in compaction and increases in pressure requirements. This can occur despite operating within the temperature limit of 40 ˚C, the common temperature limit for warranty compliance. Resolution has included use of alternative polymers that are less susceptible to degradation.

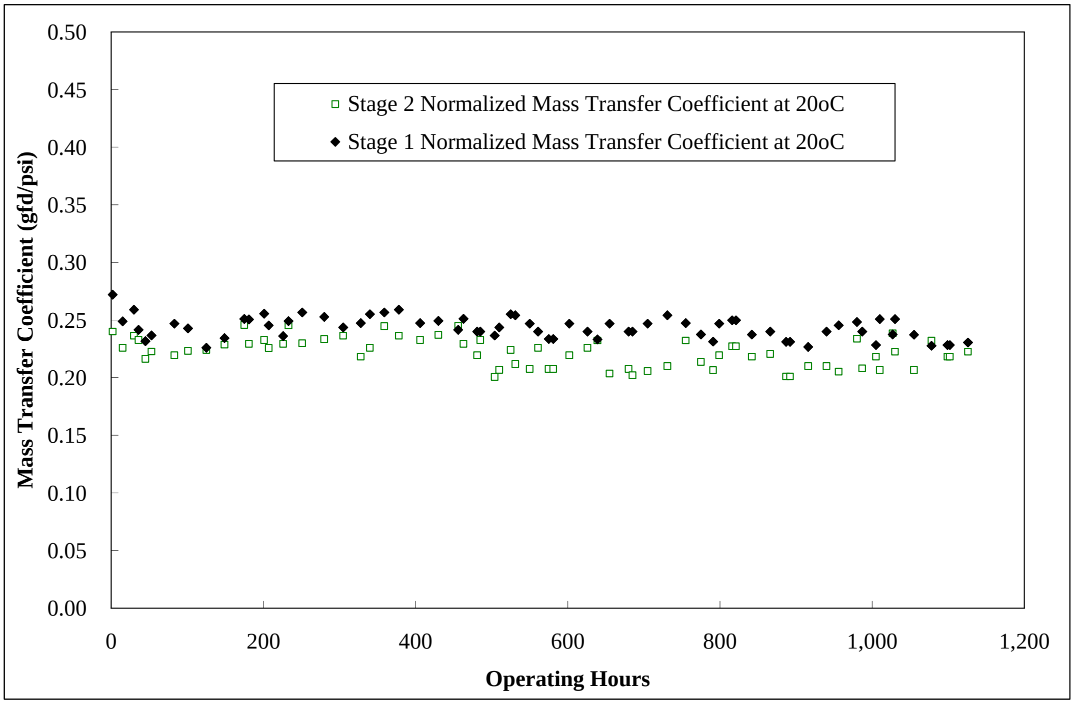


Figure 5-19. Second-Pass Normalized MTC.

Membrane material degradation can be adequately addressed through membrane selection. Any possible biofouling can be minimized through design procedures associated with the full-scale application, primarily related to elimination of a holding tank or biological control methods. Based on this analysis, the design of the second-pass system is still considered adequate to meet project objectives. However, further confirmation of second-pass viability should be performed in conjunction with design and construction of any proposed facility.

5.5 Design Criteria Summary

Table 5-11 presents the recommended design criteria for the seawater treatment process train, based on the results of this pilot study. Note that the design criteria for MF are specific to the Pall Microza system. This system was used to document the capabilities of MF and UF technologies as a whole and demonstrated the operational and performance capabilities of the system, for comparison with MMF and CSF pretreatment systems. In addition, the design criteria are site specific and would vary from one site to another in the United States.

Table 5-11. Design Criteria Summary

Design Criteria	Unit	Design Value
Pall Microza MF Pretreatment		
Flux	gfd	48
Recovery	%	95
SASRF frequency	/hr	4
SASRF duration	sec	60
SASRF flow (air/water)	scfm/gpm	4/7
RF frequency	/hr	4
RF duration	sec	30
RF flow	gpm	17
EFM	/day	1
EFM chemical		Chlorine
EFM chemical dose	mg/L	500
Chemical cleaning	/year	12
UV Disinfection		
Dose	mJs/cm^2	40
Transfer Piping/Clearwells		Chemical and/or physical biological control
Cartridge Filtration		
Loading rate	gpm/TIE	3.0
Filter rating	μm	5
SWRO		
Configuration		Two passes
First pass		
Array configuration		1:0
Flux	gfd	8
Recovery	%	50
Chemical cleaning	/year	4
No. of elements per pressure vessel		7
Second pass		
Array configuration		2:1
Flux	gfd	20
Recovery	%	90
Chemical cleaning	/year	4

Note: scfm = standard cubic feet per minute, mJs/cm^2 = millijoule-second per square centimeter.

The design criteria in table 5-11 for the desalination facility are within the typical ranges used worldwide in the seawater treatment industry. While use of UV disinfection between the pretreatment and the SWRO systems is not common, it has been applied in this manner in other facilities. In addition, even though MF was selected as a pretreatment alternative over MMF and CSF, the later two alternatives could potentially be valid alternatives if further evaluated and optimized.

6. Finished Water Quality

6.1 Introduction

Design of a seawater reverse osmosis system should be based on ensuring compliance with finished water quality objectives. The selected design varies by project based on feed water quality, technology utilized, and finished water quality goals. SWRO technology capable of treating seawater was utilized. The performance of the selected SWRO systems was assessed at various design and operational conditions to determine the optimal configuration for use at this site. This analysis of finished water quality and design considerations is presented as follows:

- General Water Quality Results
- Temperature Impacts
- Flux and Recovery
- SWRO Design

6.2 General Water Quality Results

Warm water from the powerplant cooling water discharge was treated using MF and SWRO for a period of approximately 1 year. The water quality of the first and second-pass permeate of the SWRO treatment is presented in table 6-1. The permeate water quality was then compared to the finished water quality goals established for this project. As can be seen in table 6-1, sodium, chloride, boron, and bromide goals were met when first-pass permeate was further polished using the second-pass RO system.

Note that the boron goal would be met only by adjusting the second-pass feed pH to 9.3 standard units. Therefore, pH adjustment of the second-pass feed is required to meet the boron goal. As can be seen, all water quality goals were achieved using the two-pass RO process.

Table 6-1. Permeate Water Quality and Finished Water Goals

Parameters	Units	Detection Limit	First Pass		Second Pass		Goal
			Average	Maximum	Average	Maximum	
Alkalinity	mg/L as $CaCO_3$	5	7.5	10.7			80
Aluminum	mg/L	0.1	BDL	BDL	BDL	BDL	0.2
Ammonia	mg/L as N	0.01	0.04	0.10			1.0
Barium	mg/L	0.01	BDL	BDL	BDL	BDL	2
Boron without pH adjustment	mg/L	0.05	**1.33**	**2.10**	**1.32**	**1.9**	0.5
Boron with pH adjustment	mg/L	0.05	**1.33**	**2.10**	0.22	0.34	0.5
Bromide	mg/L	0.05	0.65	**1.53**	0.05	0.10	0.15
Calcium hardness	mg/L as $CaCO_3$	0.1	1.25	3.0	0.2	0.2	50
Cesium	mg/L	0.001	BDL	BDL	BDL	BDL	—
Chloride	mg/L	0.1	**193**	**404**	11	23	35
Color	PCU	1	11	25	10	10	15
Copper	mg/L	0.005	BDL	BDL	BDL	BDL	2
Fluoride	mg/L	0.003	0.015	0.04	BDL	BDL	0.8
Hardness, total	mg/L as $CaCO_3$	1.0	9	16	BDL	BDL	300
HPC	CFU/mL	1	102	342			
Iron, dissolved	mg/L	0.02	BDL	BDL	BDL	BDL	0.15
Iron, total	mg/L	0.02	BDL	BDL	BDL	BDL	0.15
Magnesium	mg/L	0.1	2.4	10.3	0.22	0.27	
Manganese	mg/L	0.01	BDL	BDL	BDL	BDl	0.05
Nitrate	mg/L as N	0.01	0.02	0.06	BDL	BDL	1.0
Phosphorus, total	mg/L as P	0.03	BDL	BDL	—	—	1.0
Silica, colloidal	mg/L as SiO_2	0.02	BDL	BDL	BDL	BDL	—
Silica, dissolved	mg/L as SiO_2	0.02	BDL	BDL	BDL	BDL	—
Silicon	mg/L	0.02	BDL	BDL	BDL	BDL	—
Sodium	mg/L	0.1	**100**	**175**	8	9	80
Strontium	mg/L	0.01	BDL	BDL	BDL	BDL	—
Sulfate	mg/L	0.1	5	11	0.20	0.25	100
Tin	mg/L	0.1	BDL	BDL	BDL	BDL	—
TDS	mg/L	10	316	**520**	27	100	500
TOC	mg/L	1.0	BDL	BDL	BDL	BDL	
Zinc	mg/L	0.005	0.006	0.010			5

6.3 Temperature Impacts

When designing a seawater reverse osmosis system that will utilize the cooling water from a power generation facility, the option exists to use the cooler intake water or the warmer condenser discharge water as a source of supply to the SWRO system. The finished water quality of a SWRO system typically improves as temperature decreases. However, there are a number of drivers to use warmer water, including lower operating pressures and avoidance of competing with the power generation facility for source of supply.

For this project, use of warmer, condenser discharge water was selected prior to this pilot study project as the preferred source water. As a design alternative, ambient temperature cooling water was assessed to determine the impact on the finished water quality and, therefore, on the design of the second pass.

To test both sources of supply, a source water intake system was constructed as shown in figure 6-1. On a monthly basis, the source of supply was switched between the two intake options and water quality samples collected.

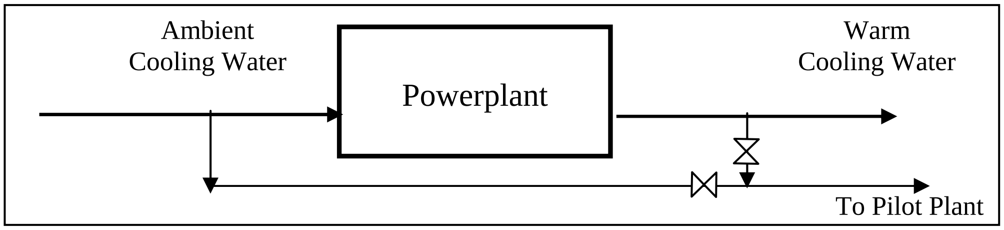


Figure 6-1. Source Water Intake System.

Results of the sampling are presented in table 6-2. Temperature of the cooling water was approximately 3 ˚C lower than the warm cooling water discharge as shown in table 6-2. This difference in temperature is atypical for a powerplant, where the cooling water temperature is usually 5 ˚C to 15 ˚C warmer than the feed water. Note that the data presented for the warm cooling water discharge are only those data collected on the same day as the ambient temperature experiments; therefore, they do not match the summary table presented earlier in this chapter.

Results for chloride, bromide, and boron are presented since those are the constituents that required the highest level of treatment, including use of second pass. As expected, the water quality improved using ambient temperature intake water quality as shown in table 6-2. The concentrations in the permeate decreased approximately by 7 percent on average.

Table 6-2. Water Quality Comparison of First-Pass Permeate

	Ambient Cooling Water Source		Warm Cooling Water Source	
	Average	**Maximum**	**Average**	**Maximum**
Source temperature (˚C)	27.0	33.7	30.6	40.0
First-Pass Permeate	192	287	208	339
Chloride (mg/)	0.81	1.14	0.88	1.23
Bromide (mg/L)	1.33	1.70	1.40	1.80
Boron (mg/L)				
Second-Pass Permeate	8	10	11	23
Chloride (mg/L)	0.04	0.04	0.05	0.10
Bromide (mg/L)	0.22	0.34	0.20	0.28
Boron (mg/L)				

Based on the limited difference in feed water temperature between the two intake options, limited differences in finished water quality were observed. However, further analysis should be performed regarding potential differences in temperature that might be experienced at full scale, given that a wider difference in temperature would materially change permeate concentration. In addition, other factors should be considered relative to use of high temperature water for an overall assessment of which intake location to use. This includes the potential for higher levels of biogrowth using higher temperature water, membrane warrant concerns, potential membrane material degradation, and other issues beyond just finished water quality.

6.4 Flux and Recovery

While Section 6.2, "General Water Quality Results," illustrated the ability of the selected SWRO process to provide an average finished water quality that met the goals of this project, it is important to evaluate differing operational conditions on compliance with goals. Flux and recovery represent key design variables that affect not only costs and sustainability but also water quality. Generally, finished water quality improves as flux increases and recovery decreases.

Based on the sustainability/fouling results presented previously, a flux of 8 gfd and 50 percent is recommended for this project. Therefore, the finished water quality results obtained at these design settings are presented in table 6-3. These parameters are those that required the highest percent removal and would be limiting factors in the design of a seawater reverse osmosis system. As shown, finished water quality goals were met when second-pass RO was utilized. These data are important for sizing of the second-pass system, as presented later in this chapter.

Table 6-3. Finished Water Quality for Recommended Flux and Recovery Setting

Parameters	Units	Detection Limit	First Pass		Second Pass		Goal
			Average	Maximum	Average	Maximum	
Boron with pH adjustment	mg/L	0.05	1.00	1.55	0.20	0.28	0.5
Bromide	mg/L	0.05	0.45	0.65	0.05	0.10	0.15
Chloride	mg/L	0.1	128	179	12	23	35
Sodium	mg/L	0.1	100	175	8	9	80

6.5 Second-Pass Sizing

From the results presented above, the second pass was necessary to meet finished water quality goals. Two scenarios were assessed to determine how much of the first-pass permeate requires treatment by a second pass. The first scenario considered average concentrations of the four parameters in the first and second-pass permeate, and the second scenario considered maximum concentrations. Table 6-4 presents the by-pass percentage for both scenarios. From the results presented in table 6-4, chloride and bromide are the limiting factors under average and maximum conditions. Only 7 percent of the first-pass permeate could be by-passed to meet the chloride and bromide goals under the worst conditions.

Table 6-4. Bypass Percentage

		Chloride	Boron	Bromide	Sodium
First-Pass Concentration					
Average	mg/L	128	1.0	0.45	100
Maximum	mg/L	179	1.5	0.65	175
Second-Pass Concentration					
Average	mg/L	12	0.20	0.05	8
Maximum	mg/L	23	0.28	0.10	9
Goal	mg/L	35	0.50	0.15	80
Bypass Percentage					
Average	%	18	35	23	76
Maximum	%	7	17	8	40

The preliminary design of the seawater plant should consider full treatment of the first-pass permeate in order to meet the chloride goal of 35 mg/L under the worst water quality conditions. In order to produce 25 mgd of finished water from the second pass, the first pass should be designed to treat 55.56 mgd of seawater (after pretreatment) to take into account 50-percent first-pass recovery and 90-percent second-pass recovery.

6.6 Summary

Finished water quality results show that a two-pass system is necessary to meet water quality goals. The design should consider full treatment of the first-pass permeate with a second pass. This design consideration is based on the chloride and bromide goals. Use of pH adjustment is necessary to ensure boron removal. Use of ambient temperature intake water had a limited effect on finished water quality and does not warrant a change in intake location.

Treatment of the seawater using two passes will result in high-quality water and would require post-treatment chemical additions in order to add minerals back in the water and stabilize the water prior to distribution. Addition of calcium and alkalinity are the two main water constituents that could be added to the finished water. In addition, pH would have to be adjusted to reach a positive Langelier Saturation Index to prevent distribution system corrosion.

7. Cost Estimates

7.1 Introduction

This chapter of the report presents an order of conceptual costs for 25 mgd of seawater treatment, based on the data compiled during the pilot study for this project. This conceptual level estimate is based on a preliminary definition of a scope of work reflecting the size and treatment capacity of the piloted process treatment trains. At this predesign report level, the expected accuracy range of the probable costs ranges from +30 percent to -15 percent, according to the American Association of Cost Engineers.

The basis of costs developed and presented in this report was obtained using the WT Cost© Water Treatment Cost Estimation Program Model and comparing those costs with historical cost information from similar facilities. The costs presented are for the treatment processes only and must be further integrated with the overall costs for a full 25-mgd water treatment facility.

7.2 Approach

The pilot study consisted of evaluating several pretreatment options and various operational settings for the SWRO process. The results of the pilot study concluded a single feasible process treatment train with defined operational settings. Capital, operations and maintenance (O&M), and life cycle costs were estimated for this option. As stated above, the costs presented within this section of the report solely represent the costs for the 25-mgd seawater treatment process portion of the overall water treatment plant facility. Specifically, it is assumed that the 25-mgd rating is a final product (finished water) flow rate designed to meet the maximum daily demand requirement set for the facility. Additionally, it is assumed for the purposes of this report that the raw water intake capacity is approximately 55.56 mgd and the concentrate discharge capacity is approximately 30.56 mgd, as shown below in figure 7-1. Second-stage concentrate water is recycled to the MF system and, therefore, reduces the amount of source water required but does not reduce the amount of water treated by the facility.

The costs presented in this section of the report have been specifically developed for the pretreatment and SWRO processes only. These values do not include costs for the other associated civil infrastructure improvements for a complete water treatment plant, such as land acquisition, site work/improvements, yard piping, site utilities, post-treatment, finished product storage, high service pumping, and general administration/operations facilities. These values also do not include costs for any offsite raw water and/or finished product water transmission mains and/or pumping facilities. Additionally, the costs associated with product water delivery, concentrate disposal, sludge disposal, and environmental mitigation; and the financial components including land use or ownership, rights-of-way and easement, legal, fiscal, administration, and interest during construction are not included.

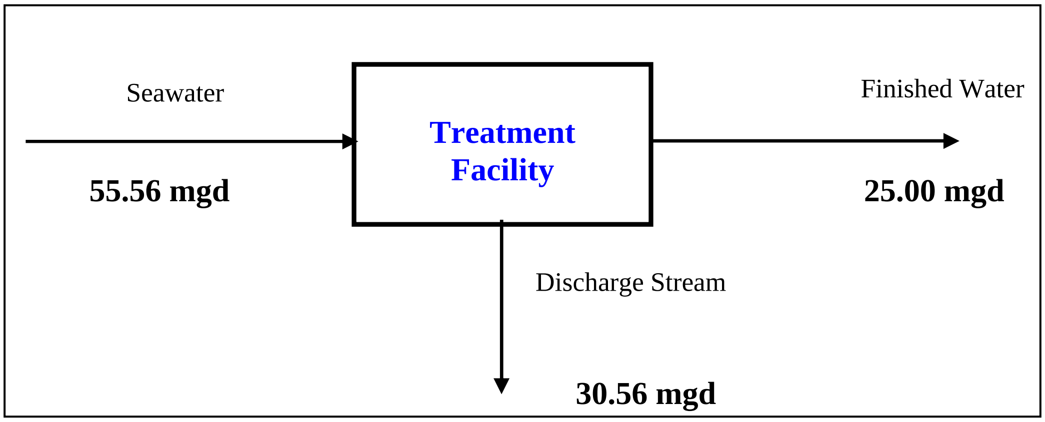


Figure 7-1. Overall SWRO Water Treatment Plant Capacity Assumptions for Cost Estimates.

Specifically, the capital costs presented in this section were estimated for MF pretreatment with in-line coagulation, UV disinfection downstream from the MF unit process, and two-pass SWRO desalination treatment, as shown below in figure 7-2. It is important to note that the capital costs include full treatment of the water through the second pass of the SWRO treatment but do not include any post-treatment capital or O&M costs, nor the capital and O&M costs associated with the remaining facilities for the overall 25-mgd water treatment plant.

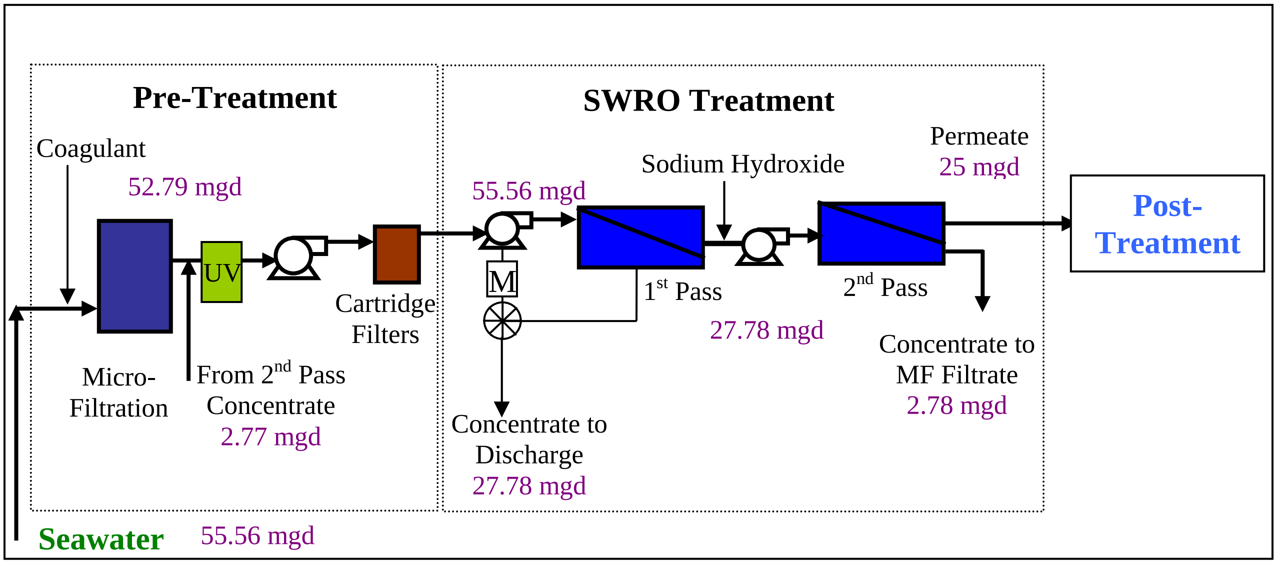


Figure 7-2. Treatment Process Schematic.

The capital costing approach used for this report involved contacting vendors and equipment manufacturers and utilizing cost modeling spreadsheets (WT Cost, Water Treatment Cost Estimation Program, by I. Moch & Associates, Inc., Boulder Research Enterprises, with Reclamation). Appendix C of this report contains the detailed information used to develop the costs presented within this section. Appendix C, "Cost Estimates," also summarizes the basic cost factors utilized and identifies the assumptions and factors used for the various process components of the treatment facility.

The O&M costs considered in the estimate include energy, chemicals, spare parts, and labor costs. Where an optimum set point or operating condition resulted in the best water quality, sustainability, or efficiency as identified through the pilot testing process, these conditions were utilized and identified as such.

7.3 Assumptions

Capital and O&M costs have been specifically developed for the pretreatment and SWRO processes only and do not include costs for the other associated civil infrastructure improvements for a complete water treatment plant. This subsection presents additional detail of the assumptions used in preparation of the cost estimates, and the base assumptions used for the capital and O&M cost estimates are contained in table 7-1. The unit production costs are expressed as $ per 1,000 gallons, which includes the annualized capital recovery costs and the annual O&M costs. The base cost assumptions represent price indexes as of August 2005. No legal bonding or other financial costs are included in this estimate.

Table 7-1. Base Assumptions for Cost Estimates

Labor	$25 per hour
Energy cost	$0.05 per kilowatthour
Interest rate	5.69 percent
Financing period	30 years
Construction cost index[1]	7478.51
Building cost index[1]	4209.7
Skilled labor index[1]	7064.5
Materials index[1]	2465.58
Steel Cost ($/100 lbs)[1]	33.83
Cement Cost ($/ton)[1]	87.82

[1] *Engineering News Record* indices as of August 30, 2005.

7.3.1 Pretreatment Cost Estimate Assumptions

The pretreatment cost estimates presented herein include capital and O&M costs for a ferric chloride feed system, 58-mgd MF treatment, and a 55.5-mgd UV disinfection system, collectively comprising the pretreatment process for the SWRO treatment. The costs include the following items and assumptions for each pretreatment unit process system:

7.3.1.1 Ferric Chloride

Capital Cost Assumptions:

- Dose rate of 5.0 mg/L as Fe
- $455 per dry ton bulk delivery
- Use of dual-head diaphragm metering pumps
- Outdoor storage tank (30 days of storage)
- Full equipment redundancy

O&M Cost Assumptions:

- Electrical requirements include solution mixers, feeder operation, building lights, ventilation, heating, and heating outdoor storage tanks.
- Maintenance materials estimated at 3 percent of the manufactured equipment cost, excluding storage tanks.

7.3.1.2 Microfiltration

Capital Cost Assumptions:

- Treatment capacity is based on 55.5-mgd required feed flow to first-stage RO membranes.
- Design flux is 48 gfd at 27 ˚C.
- Design recovery rate is 95 percent.
- Membrane module costs include membrane modules, backwash manifold piping, integral valves, instruments, support legs, and control panels.
- Air supply system includes air compressors, air dryers, coalescers, air filters, air receiver, air regulator, plant pneumatic control enclosure, solenoid valves, and instruments.
- Clean-in-place system includes concentrate tank, concentrate transfer pump, solution tank, solution tank heater, control panel, recirculation pump, valves, and instruments.
- Control system includes main control panel, master PLC**,** plant I/O**,** and man-machine interface.
- The required prestrainer, post-MF holding tank, and transfer pumps are estimated under “other equipment.”

O&M Cost Assumptions:

- MF membrane life expectancy: 7 years.
- Daily EFM activities include the use of sodium hypochlorite 30 minutes per day.
- Annual module replacement costs are included.
- No waste facilities are included in this cost.

7.3.1.3 Ultraviolet Disinfection

Capital Cost Assumptions:

- Capacity: 55.56 mgd (feed flow requirement to first-pass RO membranes); plus full capacity redundancy
- Number of lamps: 2,844

O&M Cost Assumptions:

- Power requirements are based on 1,202,074 kilowatthours per year.
- Complete UV lamp life is 10 years.
- Lamp replacement cost is $48 each.

The pretreatment costs minus labor are presented in table 7-2. Labor costs are included in the final plant cost estimate.

Table 7-2. Pretreatment Cost Estimates

	Construction	O&M ($/year)
Ferric chloride feed system	$300,000	$200,000
MF system	$22,800,000	$800,000
UV disinfection	$1,400,000	$2,150,000
Other equipment	5,500,000	$150,000
Total pretreatment costs	$30,000,000	$3,300,000

7.3.2 SWRO Cost Estimate Assumptions

The SWRO cost estimates include the capital and annual O&M costs for the first- and second-pass SWRO treatment systems. The costs include the following items/assumptions for each system:

First-Stage RO System

Capital Cost Assumptions:

- Capacity: 55.56-mgd feed water flow
  27.78-mgd permeate water flow
- Treatment process: SWRO
- Elements estimated at: 370 square feet of surface area (8-inch diameter)
- Design flux rate of 8 gfd: 2,960-gpd element flow
- Fouling factor: 0.85
- Feed pressure: 800 psi
- Pressure drop: 15 psi
- Number of elements per pressure vessel: 7
- 28,528-mg/L TDS at 27.4 ˚C
- Seven RO trains; 286 pressure vessels per train
- Recovery: 50 percent
- Membrane cost: $800 per element including installation costs; 14,014 membrane elements
- Pressure vessel cost: $3,000 each (default cost); 2,002 total pressure vessels
- Building cost: $100 per square foot
- Building size: 15,000 square feet

O&M Cost Assumptions:

- Membrane replacement is based on 20 percent per year (total replacement: 5 years)
- Membrane cleaning equipment value of $100,000
- Chemical cost: $2 per element per cleaning cycle
- Estimated cleaning cycles per year: 4
- Seven high-pressure pumps operating, 1 spare pump at 6.6 TDH, 508 discharge psi, 75-percent pump efficiency, 95-percent motor efficiency, 32.8 feet of inlet pipe, inlet pressure 29 psi, 2,248 hp, with Pelton wheel energy recovery turbine with an efficiency of 45 percent
- Oil: $1 per liter
- Maintenance: 0.1 hours per horsepower

Second-Stage RO System

The second-stage system is supplied feed water from the first-stage permeate in order to meet more stringent water quality parameters. These parameters include boron and bromide. In order to obtain finished water quality goals, the feed water pH to the second-stage system must be adjusted to 9.4. The cost for a sodium hydroxide feed water system has been included in this cost estimate. The quantity of second-stage treatment will vary with location and finished water quality goals.

Capital Cost Assumptions:

- Capacity: 25.00-mgd final permeate flow
  (27.78-mgd feed water flow from first-pass permeate
- Treatment process: Brackish RO
- Element surface area: 370 square feet (8-inch diameter)
- Design flux rate: 20 gfd (7,400 element flow per day)
- Fouling factor: 0.85
- Feed pressure: 175 psi
- Pressure drop: 50 psi
- Number of elements per pressure vessel: 7
- TDS at 27 ˚C: 488 mg/L
- Number of trains: 7 RO trains, plus 1 redundant train
- Recovery: 90 percent
- Membrane cost: $800 (including installation costs)
- Pressure vessel cost: $3,000
- Membrane cleaning equipment not included in second stage
- No building costs
- No cartridge filters
- Sodium hydroxide feed system to pH 9.4 for boron removal

O&M Cost Assumptions:

- Membrane replacement is based on 10 percent per year (total replacement: 10 years)
- Seven high-pressure pumps operating, 1 spare pump at 6.6 TDH, 508 discharge psi, 75-percent pump efficiency, 95-percent motor efficiency, 32.8 feet of inlet pipe, inlet pressure 29 psi, 1,136 horsepower, no energy recovery

- Oil: $1 per liter
- Maintenance: 0.1 hours per horsepower

Table 7-3 shows the RO membrane treatment costs minus labor. Labor costs are included in the final plant cost estimate.

Table 7-3. RO Membrane Treatment Cost Estimates

	Construction ($)	**O&M (/year)**
First pass	$45,100,000	$5,900,000
Second pass (with caustic feed system)	$22,300,000	$2,100,000
Total	$67,400,000	$8,000,000

7.4 Summary of Probable Costs

The pilot study consisted of evaluating several pretreatment options and various operational settings for the SWRO process. The results of the pilot study concluded a single feasible process train with defined operational settings. Based on the assumptions summarized above, capital and annual O&M costs were developed for the individual unit processes of the pretreatment system, as well as for the SWRO process. Table 7-4 presents a summary of the pretreatment costs and the SWRO costs, as well as the overall costs for a 25-mgd seawater treatment process.

Table 7-4. Probable Cost Estimates

	Construction ($)	**O&M ($/year)**
Site/land purchase/development	Not included	Not included
Intake structure and pumps	Not included	Not included
Pretreatment	$30,000,000	$3,300,000
SWRO	$67,400,000	$8,000,000
Concentrate disposal	Not included	Not included
Post-treatment	Not included	Not included
Finished water storage and distribution	Not included	Not included
Labor (17 people, 24 hours per day)		$900,000
Total treatment cost	**$97,400,000**	**$12,200,000**
Cost per gallon	**$3.90/gpd**	**$1.34/$1,000 gallons**
Indirect capital cost:		
Contingencies 15%	$14,600,000	
Project management 15%	$14,600,000	
Total construction cost	**$126,600,000**	**0**

Note: (1) Total costs exclude intake system, post-treatment systems, concentrate disposal system, and storage/distribution facilities, as well as other site improvements.
The costs presented above were developed for the recommended feasible unit process as described above for seawater treatment. The capital and annual O&M costs shown above were developed for the pretreatment and SWRO processes only.

8. Conclusions and Recommendations

A conceptual seawater treatment plant design for providing potable water was pilot tested for a period of approximately 1 year at the APGS site. The study was developed to quantify and assess the design and operational considerations necessary to ensure sustainability and compliance with finished water quality goals.

Raw water at the Anclote site was determined to vary in quality based on season, due to the proximity to the Anclote River, a highly organic matter surface water source. Organic matter and particle concentrations were higher than found in seawater and indicated the potential need for advanced pretreatment to ensure sustainable operation of a SWRO system. During dry periods of the year, salinity levels were consistent with undiluted seawater; therefore, any desalination system proposed at the site must be capable of treating undiluted seawater. The raw water quality results were representative of a mixed seawater/surface water supply, including data showing concentrations of constituents that require a higher level of pretreatment while still requiring full seawater desalination capabilities.

Pretreatment systems evaluated included two-pass MMF, CSF and MF. MMF and CSF were unable to provide sufficient quality filtrate for use with a SWRO system. The results clearly indicated the need for robust pretreatment for a seawater reverse osmosis system that would have similar source waters tested at the Anclote site. Based on these results, MMF and CSF would not be recommended for this tested seawater. However, these technologies could be feasible in another site, depending on the quality of the feed water.

Pall Microza MF was selected to generate filtrate of a quality representative of MF and UF technology as a whole. The MF system operated effectively, with identification of design criteria that would be appropriate for the Pall system. This included compliance with a cleaning frequency criterion of no more than once every 30 days. Selection of design criteria for other MF and UF systems would require pilot testing of the equipment under evaluation. Relative to water quality, the MF system generated high-quality water meeting all criteria necessary to feed a seawater reverse osmosis system and showed promise for application to other SWRO sites nationwide.

Intermediate tanks and piping between the MF and SWRO system were found to be susceptible to biological growth. The warmer temperature source water, combined with the higher organic matter levels associated with the surface water influence at the site, may have contributed to biological growth. The biological growth manifested itself as a problem through plugging of the cartridge filtration system located just upstream of the SWRO system. The cartridge filter replacement criterion was no more than once every 30 days.

Cartridge filter plugging was eliminated through use of UV irradiation downstream of the MF system, daily shock chlorination of the transfer tank and piping, and use of a HEPA filtration system on the transfer tank to limit introduction of airborne microorganisms as tank levels varied. Based on these results, significant consideration should be given to chemical and/or physical methods of biological control for the transfer of water from any pretreatment system to the SWRO system. UV irradiation is recommended for use following the pretreatment process.

The sustainability of SWRO was found to be acceptable when operated at conservative loading rates. The cleaning frequency criterion was no more than once every 3 months. Operating at a flux of 8 gfd and 50-percent recovery ensured compliance with this criterion at the Anclote site. Addition of UV pretreatment reduced fouling rates and would allow a higher flux and recovery, though increased SWRO loading rates are not recommended.

Desalinated finished water quality was adequate to meet the finished water quality goals for this project. Chloride represented a parameter requiring the highest level of treatment, based on a finished water quality goal of 35 mg/L. The use of a second-pass RO system is necessary to meet the finished water quality goals. This system would treat permeate from first pass and should be sized to treat 100 percent of first-pass permeate. Less stringent goals for chloride and bromide would result in a decrease of the second-pass size.

The capital cost for a conceptual 25-mgd capacity using the recommended treatment process train of MF-UV-SWRO is an estimated $97 million or $3.9 per gpd. Operating and maintenance costs are an estimated $12.2 million per year or $1.34 per 1,000 gallons. Note that these costs are representative of the treatment train alone and must be integrated into an overall facilities cost estimate to determine the cost of delivered water.

APPENDIX A

MEANS AND METHODS

APPENDIX A
MEANS AND METHODS

A.1 General Approach

In order to demonstrate the effects of (mixed) surface waters, seasonal and tidal variations, and power plant cooling water discharges on varying pretreatment types and seawater reverse osmosis membranes, the appropriate equipment was selected in order to operate, collect, and interpret data in such a fashion that facilitates meaningful results. The pilot treated a mixed seawater/surface water source from the cooling water stream, located in the proximity of the confluence of the Anclote River and the Gulf of Mexico. This is consistent in configuration and approach regarding the supply sources currently used or contemplated for other seawater desalination facility supply sources whether or not the facility is a co-located power plant/seawater desalination project in the United States (US). The approach to piloting, in order to address each of the above concerns, is described in the following Sections.

A.2 Flow Schematics and Sampling Locations

A process train was developed to meet finished water quality compliance for this pilot study. Equipment was specified to allow investigation of all operational and water quality parameters targeted for review in this project.

A.2.1 Source water Intake:

The source water for this project as mentioned earlier was the cooling water discharge from a power generating facility. Water was withdrawn from the discharge structure and fed to the pilot from February 2004 through March 2005. This existing power station employs once-through cooling and draws its cooling water from the delta of the Anclote River as it discharges to the Gulf of Mexico. SWRO pretreatment is a critical design issue and is particularly important at this facility due to the variable source water quality. Raw water turbidity, total organic carbon, and total dissolved solids vary for this source on not only a seasonal but also a tidal basis. Details regarding raw (feed) water quality are presented in Chapter 4 of this report.

The intake structure consisted of a 4 inch diameter foot strainer containing 1.5 inch orifices. These orifices were designed in such a way that it would not let fishes and large debris get into the suction line as well as not small enough that they plug due to biogrowth (barnacles, etc) on it. The foot strainer was followed by a check valve which was then connected to a 4 inch flexible pipe. The intake pipe was designed in such a way that the suction remained at least five feet below sea level at all times.

Initially, 4 inch SCH 80 PVC piping was used for this purpose but due to the effects of water currents and frequent breaks in the pipe joints brought about the change to PVC flexible hose intake pipe. The flexible pipe was then connected to 1/16-inch basket strainer through a 4-inch SCH 80 PVC pipe. The basket strainer would then reject grass and other smaller debris that were not rejected by the foot strainer. A baldor motor pump then followed the basket strainer which pumped the water 1500 ft through 4-inch SCH 80 PVC to supply both pretreatments feed tanks as seen in the Figure 1. The raw water was monitored and analyzed twice daily for pH, turbidity, temperature, conductivity and TDS. The raw water sample for this analysis was taken before the foot strainer.

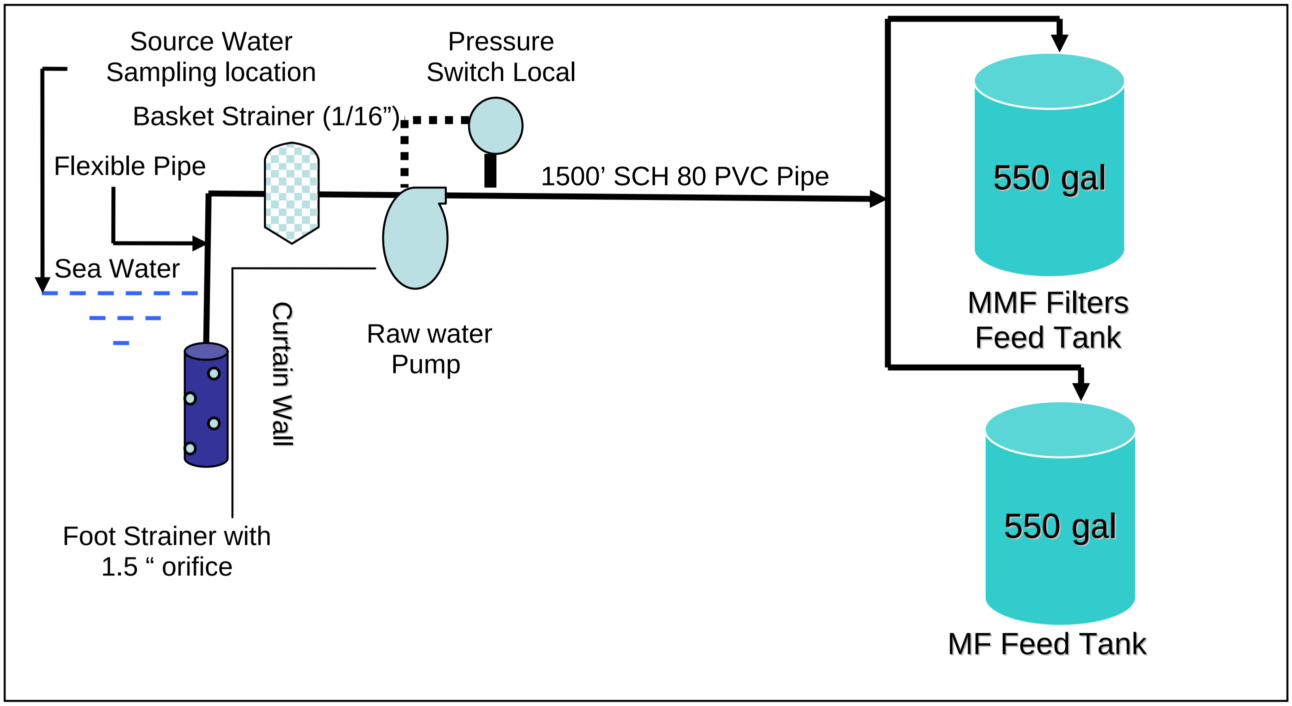


Figure 1 - Raw Water Schematics

A.2.2 Multi-Media Pretreatment

Component selection involved utilizing pretreatment system design criteria that are reasonable and representative of full-scale applications and also provide reasonable backwash frequencies, cleaning chemicals, and other pertinent criteria. The MMF pretreatment process flow diagram is shown in Figure 2.

The MMF flow schematic consisted of the feed seawater passing through a 300 micron strainer into the 550 gallon feed tank. The water was then pumped to feed the multimedia filters. Coagulant and polymer were directly fed in the water line. A static mixer to mix the coagulant was also installed. The roughing filter consisted of anthracite for first phase of testing and consisted of anthracite and sand for the second phase whereas the polishing filter consisted of anthracite and sand/manganese greensand as filtration media for the first phase and consisted of manganese greensand and garnet in the second phase of testing. Table 1 contains the MMF pretreatment system design criteria and general operating conditions.

Commensurate with the testing program goals, the capability to test various chemical doses was incorporated to allow acid addition, filter aid polymer, and ferric chloride or ferric sulfate coagulants, at injection site locations (as well as appropriate in-line mixing) throughout the pretreatment process.

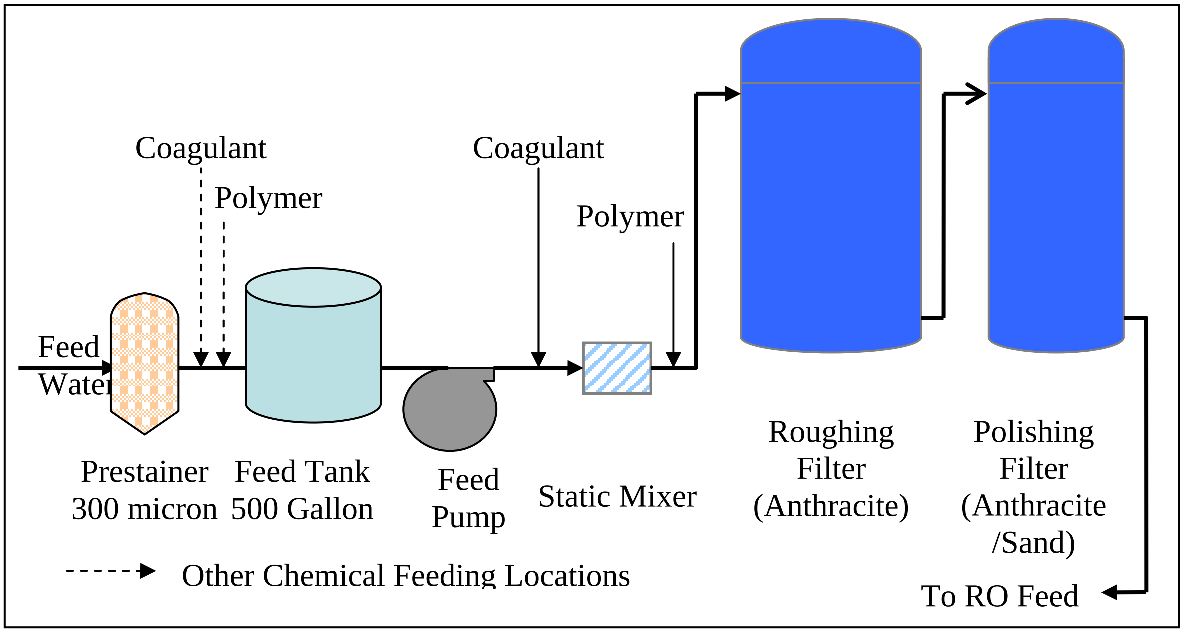


Figure 2 - Flow Schematic For Multimedia Treatment

Table 1
Media Filter Pretreatment System Design Criteria and General Operating Conditions

Operating Condition	**Value or Range**
Operational Duration	12 months (Divided Into Four (4) Phases)
Roughing Filter	
Surface loading rate	2 gpm/sqft
Media type	Anthracite
Media depth	44”
Effective size	0.8-0.9 mm
Uniformity coefficient	1.3-1.5
Acid	Hydrochloric (for Enhanced Coagulation)
Coagulant	Ferric chloride
Backwash surface loading rate	6.5-10 gpm/sqft
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	10-20 minutes
Filter-to-waste duration	32 minutes to achieve steady-state turbidity
Polishing Filter	
Surface loading rate	4 gpm/sqft
Media type	Anthracite/Sand – Phase I Anthracite/Manganese Green Sand – Phase II
Media depth	24”/20”(44 inches total)
Effective size	0.8-0.9/0.5-0.6 mm (0.8-0.9/0.3-0.35 mm)
Uniformity coefficient	1.3-1.5
Backwash surface loading rate	12-20 gpm/sqft
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	15 minutes
Filter-to-waste duration	32 minutes to achieve steady-state turbidity

Additionally, surface loading rates were selected based on industry standard design criteria and were intended to be fixed for the testing period. The design parameters that were planned for adjustment during pilot testing included acid, polymer and coagulant dose, to support the assurance that an adequate removal of particles through the filtration system would be achieved, and as well, capture the effect that seasonal or tidal variations might have on the performance of the pretreatment system.

A pretreatment operation matrix was developed to optimize the operating conditions of the MMF system - to compare the finished water quality within each run condition, and also against overall comparative SWRO system performance. Jar testing data in the field would also assist homing in on the appropriate range of chemical dose rates for the particular water quality (such as rainy season versus dry season); then dose ranges were identified, typically in increments of 0.5 mg/L for any given coagulant or filter aid, applied, and measured, to gauge system performance and possible SWRO impacts. A summary of the operational matrix and testing variables for the runs is contained in Table 2.

Table 2

Media Pretreatment System Testing Variables

Testing Variables	
Seasonal Effects	Operate systems during wet and dry seasons
Roughing Filter Coagulant Dose	0.5-15.0 mg/L as Fe, dose optimized for max. turbidity/SDI reduction
Roughing Filter Acid Dose	pH 6.5, optimized for max. turbidity/SDI Reduction
Backwash Frequency – Roughing and Polishing Filters	As necessary, according to filtrate quality and differential pressure (ΔP) development
Duration of test runs	Adjustment of operational variables is scheduled when finished water quality degrades and requires additional optimization

A.2.2.1 Phase 1 MMF

The Phase 1 component of testing lasted approximately two months. Phase 1 of the MMF tests utilized 0.8-0.9 mm anthracite in the roughing filter followed by 0.8-0.9/0.5-0.6 mm anthracite/sand in the polishing filter. The coagulant utilized for testing purposes was ferric sulfate, and sulfuric acid for pH control. The operational time for each run varied; and soon it became apparent that the MMF filtrate water quality could not be optimized within a reasonable amount of time at a set run condition. So progression to the next run condition was initiated after it was clear that the polishing filter turbidity could not be improved. This was based on the tested conditions and acknowledgement of possible external influences such as rainfall or unusually high TOC; and if the system appeared to be producing consistent quality filtrate (regardless of value) from both roughing and polishing filters. Backwashes were initiated after each run or at a differential pressure of 10 psi; and all set points, including loading rates, air scour, and filter to-waste were kept constant throughout this phase. A summary of the run results for Phase 1 is contained in Table 3.

Table 3
MMF Runs – Summary (Phase 1)

Run No.	Dates (2004)	Coagulant Dose as Fe	Acid Addition	Polishing Turbidity	Polishing SDI	Operation Time
		mg/L		NTU		Hours
1	03/17-03/19	0.0	Ambient pH[1]	0.43	>6.67	26
2	03/19-03/22	1.5	pH 6.8	0.33	6.3	23
3	03/22-03/24	1.5	pH 7.2	0.26	5.3	47
4	03/26-03/31	1.5	pH 7.2	0.28	>6.67	114
5	03/31-04/05	0.8	pH 7.2	0.30	>6.67	93
6	04/05-04/07	0.8	pH 7.2	0.28	>6.67	51
7	04/07-04/09	0.8	pH 7.2	0.32	>6.67	21
8	04/09-04/16	0.8	pH 7.2	0.22	>6.67	143
9	04/16-04/20	0.4	Ambient pH[1]	0.19	5.1	89
10	04/20-04/22	0.6	Ambient pH[1]	0.36	>6.67	4
11	04/22-04/23	0.6	Ambient pH[1]	0.39	>6.67	3
12	04/23-04/26	0.6	Ambient pH[1]	0.35	>6.67	3
13	04/26-04/28	0.6	Ambient pH[1]	0.23	4.9	54
14	04/28-04/30	0.6	Ambient pH[1]	0.25	5.3	3
15	04/30-05/07	0.6	Ambient pH[1]	0.13	3.9	150
16	05/07-05/14	0.6	Ambient pH[1]	0.13	3.9	145
17	05/14-05/15	1.0	Ambient pH[1]	0.25	5.9	23

[1] *Ambient pH: 8.0 – 8.3 units*

A.2.2.2 Phase 2 MMF

The next component of testing, Phase 2, involved addition of a filter aid polymer to aid in the reduction of filtered water turbidity and SDI. Two cationic polymers were procured based on the results of jar testing on the raw water for optimization of the coagulant and polymer doses. As well, the coagulant chemical was changed from ferric sulfate to ferric chloride to measure possible performance improvements. Since the coagulant dose is based on iron (as Fe), the equivalent ferric chloride dose was modified in the field to accommodate the test conditions.

This component of testing lasted approximately three months and a summary of the results for Phase 2 of the MMF pretreatment are contained in Table 4. The operation time, as well as backwash sequence for each run varied in a similar fashion as Phase 1. Once it was clear that the filter performance could not be improved markedly under the tested conditions and through possible external influences (such as rainfall or unusually high TOC); and the system appeared to be producing consistent quality filtrate from both roughing and polishing filters - then the next test run was initiated.

Since goals were not achieved, these operating conditions were deemed unacceptable and the addition of filter aid did not improve water quality, therefore, additional pretreatment is necessary, such as changing the filter media, as explained in the following sub section.

Table 4
MMF Runs – Summary (Phase 2)

Run No.	Date (2004)	Coagulant Dose as Fe	Polymer Dose	Acid Addition	Polishing Turbidity	Polishing SDI	Operation Time
		(mg/L)	(mg/L)	pH	NTU		Hours
1	06/07–06/08	3.0	3.0	Ambient pH[1]	0.14	3.7	21
2	06/08–06/11	1.5	1.5	Ambient pH[1]	0.14	3.9	70
3	06/14-06/16	2.0	1.5	Ambient pH[1]	0.14	3.7	72
4	06/17-06/21	2.0	1.5	7.0	0.14	3.9	96
5	06/21-06/24	3.0	3.0	Ambient pH[1]	0.13	3.7	68
6	06/24-06/27	1.5	1.5	Ambient pH[1]	0.13	3.9	76
7	06/28-07/01	2.0	1.5	Ambient pH[1]	0.13	3.7	71
8	07/01-07/05	2.0	1.5	7.0	0.15	3.9	96
9	07/19-07/22	3.0	3.0	Ambient pH[1]	0.15	3.9	95
10	07/23-07/28	1.5	1.5	Ambient pH[1]	0.13	3.7	144
11	07/30-08/02	2.0	1.5	Ambient pH[1]	0.17	4.1	68
12	08/02-08/06	3.0	1.5	Ambient pH[1]	0.12	3.7	102
13	08/17-08/20	3.0	2.0	Ambient pH[1]	0.13	3.9	96
14	08/20-08/24	2.0	2.0	Ambient pH[1]	0.17	4.1	72

[1] *Ambient pH: 8.0 – 8.3 units*

A.2.2.3 Phase 3 MMF

Although not considered a part of the original testing plan, the determination was made that a smaller effective diameter and deeper bed would provide more advantageous results considering the turbidity and SDI results up to that point. Therefore, the next component of testing was termed Phase 3.

For this Phase, polishing filter media was replaced with manganese greensand; a smaller effective diameter, subangular media that has been used successfully at other seawater desalination facilities in pretreatment service. The polishing filter media was replaced with 0.8-0.9 mm anthracite over 0.3-0.35 mm manganese greensand. The polishing media change took place just after a hurricane shutdown, from September 18 to September 21, 2004.

Addition of a coagulant and filter aid polymer in Phase 2 resulted in marked improvements over turbidity and SDI, compared to Phase 1. Addition of these two chemicals was therefore a component of the testing process and integrated into Phase 3. Table 5 contains the Phase 3 test matrix and performance summary.

This Phase lasted approximately three months, and the operational time between tested conditions was accelerated; though once it became clear that the filter performance could not be improved markedly under the tested conditions, the next run was initiated. Once other component of the operations changed at the mid-point of the phase 3 testing; that is the backwash frequency modification. Previously, backwash events were timed based on completion of a run or reaching maximum acceptable pressure loss of 10 psi; and as well, both roughing and polishing stages were backwashed in accordance with the filter manufacturer's control logic sequence. That logic was disengaged, and the revised protocol based backwash frequency on head loss alone and disconnected the polishing filter from rolling into backwashing sequence following the roughing filter; thereby isolating the polishing backwash to be driven by pressure-loss only.

During and after the advent of four hurricanes, water quality changed drastically. Feed water turbidity increased, as well as TOC and other water quality parameters – with the exception of conductivity/TDS due to the fresh water influence of the Anclote River and storm water runoff. This external influence containing highly variable turbidity and organics substantially influenced the capability of the process to consistently produce low turbidity and SDI.

Although the system was optimized as best as possible, the water proved too challenging for the configuration. Although there were fewer out of-range SDI's (greater than 6.67) compared to earlier Phase runs, the best filtrate SDI was 3.9 with turbidity of 0.15 to 0.17 NTU.

Table 5
MMF Runs – Summary (Phase 3)

Run No.	Dates (2004)	Coagulant Dose as Fe	Polymer Dose	Turbidity	SDI	Operating Time
		(mg/L)	(mg/L)	NTU		(Hours)
1	9/22-9/23	2.0	0.0	0.42	>6.67	17
2	9/23-9/24	4.0	0.0	0.37	>6.67	19
3	9/24-9/25	8.0	0.0	0.47	>6.67	17
4	9/28-9/29	10.0	0.0	0.63	>6.67	19
5	9/29-9/30	10.0	0.5	0.24	5.8	26
6	9/30-10/1	10.0	1.0	0.21	4.6	20
7	10/1-10/2	10.0	1.5	0.23	4.7	14
8	10/2-10/4	8.0	1.5	0.25	4.9	46
9	10/4-10/6	6.0	1.5	0.15	4.0	42
10	10/6-10/8	4.0	1.5	0.17	4.2	44
11	10/8-10/10	6.0	1.0	0.32	6.2	44
12	10/10-10/11	8.0	1.0	0.33	5.8	25
13	10/11-10/12	10.0	1.5	0.23	4.8	23
14	10/12-10-13	10.0	3.0	0.24	4.8	26
15	10/13-10-14	12.0	1.5	0.19	4.1	25
16	10/14-10/15	12.0	3.0	0.23	5.0	23
17	10/15-10/16	14.0	1.5	0.29	5.6	25
18	10/16-10/17	6.0	1.0	0.35	6.3	27
19	10/17-10/18	3.0	2.0	0.27	4.6	24
20	10/18-10/20	2.0	2.0	0.20	4.3	43
21	10/20-10/21	2.5	1.5	0.17	3.9	22
22	10/21-10/24	3.0	2.0	0.15	3.9	69

Table 5

MMF Runs – Summary (Phase 3) – Contd.

Run No.	Dates (2004)	Coagulant Dose as Fe	Polymer Dose	Turbidity	SDI	Operating Time
		(mg/L)	(mg/L)	NTU		(Hours)
23	10/25-11/11	3.0	0.0	0.16	3.9	408
24	11/12-11/14	3.0	1.5	0.47	>6.67	46
25	11/14-11/18	4.0	1.5	0.25	4.6	90
26	11/18-11/23	3.0	2.0	0.18	3.9	104
27	11/23-11/25	2.0	2.0	0.24	4.9	46
28	11/27-11/29	2.0	1.5	0.30	5.7	46
29	11/30-12/4	3.0	2.0	0.18	4.5	110
30	12/5-12/7	3.0	1.5	0.25	4.9	44
31	12/8-12/10	4.0	1.5	0.28	5.6	41
32	12/10-12/12	3.0	2.0	0.42	>6.67	45
33	12/13-12/14	2.0	2.0	0.32	6.2	23
34	12/14-12/15	2.0	1.5	0.46	>6.67	22

Outside of specific analytes that were lab-measured, the data collection and analysis effort was expected to be mostly field-based using local instruments and hand-held devices, due to the need to ascertain MMF system performance by measuring key parameters and receiving immediate results. This approach allows immediate system adjustments to accommodate feedwater quality changes that could influence the performance of the MMF system and also to allow optimization of the pretreatment system on the-fly. A summary of these representative data collection parameters for the MMF system are contained in Table 6.

Table 6
Summary of MMF data collection (in-situ)

Parameter	**Location[1]**			
	Feed Water at source	**Feed Water at pilot site**	**Roughing Filter**	**Polishing Filter**
Conductivity	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Dissolved Oxygen (DO)	Once Daily	Once Daily	Once Daily	Once Daily
Flow Rate	Twice Daily	Twice Daily	Twice Daily	Twice Daily
pH	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Pressure	Twice Daily	Twice Daily	Twice Daily	Twice Daily
SDI	Twice Daily	Twice Daily	Twice Daily	Twice Daily
TDS	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Temperature	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Turbidity	Twice Daily	Twice Daily	Twice Daily	Twice Daily

[1] On weekends the sampling is performed once daily.

A.2.3 Coagulation-Sedimentation-Filtration Pretreatment

A portion of particles suspended in water can be sufficiently small that their removal by sedimentation or filtration is not practicable. Most of these small particles are negatively charged, which is the major cause of the stability of suspended solids. Particles which might otherwise settle are mutually repelled by these charges and remain in suspension. For the fourth phase of the testing (operation in the month of January and February), a coagulation sedimentation system was installed as a pretreatment for multimedia filters, to demonstrate the efficacy of destabilizing and removing these particles.

The most commonly used CSF coagulants are ferric or alum (aluminum sulfate) salts; ferric sulfate and ferric chloride were coagulants utilized in the pretreatment coagulation step to destabilize particles in the raw feedwater. Coagulation was followed by flocculation and Lamella® type gravity plate settler.

The flow schematic for the coagulation sedimentation filtration (CSF) system is similar to a surface water treatment plant and is shown in Figure 3. As seen in the figure, the feed water passed through the 300 micron strainer and a flow meter which would regulate the flow rate of water feeding the

CSF system. The bypass fed the 500 gallon tank finally draining the water back to the canal. Once the water passed through the flow meter coagulant was then added inline followed up by a static mixer which would mix the coagulant well with the feed water. After the coagulant mixes with the water another injection point after the static mixer would inject the polymer in the feed water (only when the polymer was tested for its effectiveness on the feed water in reducing the turbidity and SDI.

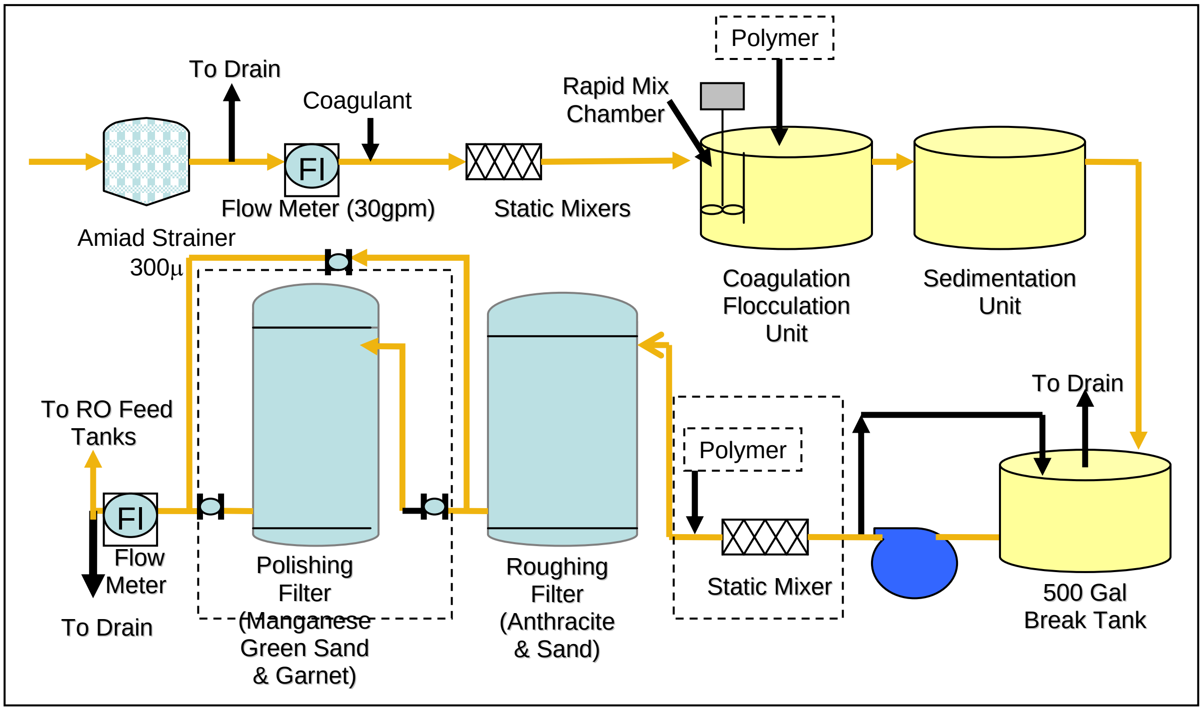


Figure 3 – Flow Schematic for Coagulation, Sedimentation Filtration System

The flash mixer chamber followed next in the flow schematic. The flow exits at the bottom into the first flocculation chamber and then into the second flocculation chamber through a connecting pipe. The water then enters the inclined plate settler via a flexible pipe. The supernatant flowed into a 500 gallon break tank for media filtration.

A.2.3.1 Phase 4 CSF

This treatment component was originally envisioned to be followed by a single stage (polishing) filter, however due to the inability of the 2-stage media filtration system to achieve the filtrate water quality goals, the CSF system was to feed the existing 2 stage roughing/polishing media filters, accompanied by the appropriate media changeout, as the multimedia filters alone could not achieve the project feed water quality target SDI and turbidity objectives. The design and general operating conditions are presented in Table 7.

From December 15th through December 31, 2004, the CSF system was mobilized at the site and existing filter media was changed to 0.6–0.8 mm/0.4-0.5 mm of anthracite/sand in the roughing stage and 0.3-0.35 mm/ 0.15-0.25 mm of manganese greensand/fine garnet in the polishing stage. The total filtered media depth was maintained at 88 inches total (including both roughing and polishing).

Table 7
Coagulation Sedimentation + Media Pretreatment System
Design Criteria and General Operating Conditions

Operating Condition	**Value or Range**
Operational Duration	2 months
Coagulation Sedimentation System	
G-value, range	300-1100
Detention time, min, range	15 to 45 minutes
Flocculator mixing energy	10 sec -1 to 60 sec -1 (1st and 2nd stage)
Baffle plates, incline	45 to 60 degrees
Roughing Filter	
Surface loading rate	2 gpm/sqft
Media type	Anthracite/Sand
Media depth	24"/20"
Effective size	0.6 – 0.8 mm; 0.4 -0.5 mm
Uniformity coefficient	1.3-1.5
Specific Gravity	1.4 / 2.4
Acid	Hydrochloric (for Enhanced Coagulation)
Coagulant	Ferric chloride
Backwash surface loading rate	6.5-10 gpm/sqft
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	10-20 minutes
Filter-to-waste duration	30-60 minutes or as necessary to achieve steady-state turbidity
Polishing Filter	
Surface loading rate	4 gpm/sqft
Media type	Manganese Greensand/Fine Garnet
Media depth	20"/24" (44 inches total)
Effective size	0.3-0.35 / 0.15-0.25 mm
Uniformity coefficient	1.3-1.5
Backwash surface loading rate	12-20 gpm/sqft
Air scour duration	2-5 minutes (at initiation of backwash)
Total backwash duration	15 minutes
Filter-to-waste duration	32 minutes or as necessary to achieve steady-state turbidity

Prior to startup, jar testing directed the need to accommodate conservative mixing energies, and although the rapid mix chamber was capable of achieving G-values up to 1100 sec^{-1}; the system was run at set point of 630 sec^{-1}. Flocculation was achieved in a two-stage process with a total detention time of 30 minutes and mixing energies of 65 sec^{-1} and 32 sec^{-1} for the first and the second flocculation tank respectively. The inclined settling plate was set at 55-degrees to allow for sufficient capture and settling of agglomerated material.

A summary of the CSF-MMF system testing variables is contained in Table 8.

Table 8

CSF-MMF Pretreatment System Testing Variables

Testing Variables	
CSF Mixing Energy	Optimized by jar testing
CSF Chamber Detention Time, min	Optimized by jar testing
CSF Coagulant /Filter aid Dose Individual and separately fed)	Based on jar testing – best turbidity reduction
CSF Acid Dose	Based on jar testing for enhanced coagulation – best turbidity reduction
Roughing Filter Coagulant Dose	0.5-15.0 mg/L as Fe, dose optimized for max. Turbidity/SDI reduction
Roughing Filter Acid Dose	pH 6.5, optimized for max. turbidity/SDI Reduction
Backwash Frequency – Roughing and Polishing Filters	As necessary, according to filtrate quality and differential pressure (ΔP) development
Duration of test runs	Adjustment of operational variables is scheduled when finished water quality degrades and requires additional optimization

In order to gauge the operating efficiency and performance of the CS-MMF system, in-situ direct measurement of operating conditions and analytical measurements were made. The field-measured variables, as discussed in Chapter 3, include feed and filtered water turbidity, feed and filtered water SDI, media hydraulic loading rate, feed and filtered water pressure, filter run times between backwashes, and filter to-waste (media rinse) volumes. The lab analytical results are also presented herein, where applicable.

Field measurement of turbidity in the settled water feeding the roughing filter allowed a real-time assessment of the capability of the coagulation/sedimentation component to reduce suspended material from the raw feedwater. This measurement and performance feedback process allowed for adjustment of chemical dose on the fly if necessary. As a consequence, a much greater number of runs were accomplished during the tested time period of two months.

Results from the runs are contained in Table 9. By removing the roughing filter from direct-filtration duty, and by adding the coagulation-sedimentation component, turbidity and SDI were further reduced. It was also during this time that alternative mechanisms for enhancing filtration efficiency were planned, including chlorination and enhanced coagulation. For the chlorination runs, a minimum residual of 2 mg/L was maintained after the polishing filter, prior to dechlorination via sodium bisulfite. For the enhanced coagulation runs jar testing showed optimum pH of 5.8 for the tested condition.

The effectiveness of the removal of suspended material from the raw feedwater through a typical floc-sed unit can vary based on the frequency and magnitude of turbidity and suspended solids changes that these systems may see on a daily basis. Therefore extra care was necessary in development of the pilot monitoring protocol to ensure the feedwater turbidity, and rain events, for example, were appropriately tracked and effects monitored. As well, multiple chemical injection points were built-in to the design for gauging chemical type and injection location effectiveness, on the feed water towards reducing feedwater turbidity and SDI if one particular injection point location (and resulting chemical contact time) was found to be more effective than another.

Feedwater quality parameters were monitored where there could be impacts to the performance of the CSF system and as well, influence the chemical dose for coagulation/flocculation. Daily data for flow rate, pressures, temperature, pH, conductivity, TDS (calculated), turbidity and SDI were a collection requirement; minimum twice and more as-necessary during unusual circumstantial events (such as rain events). During filter operation, filter backwashing was to be performed as required to return performance to acceptable levels needed for SWRO feed water. Once the system achieved the best possible filtrate water quality the system was run at a different setting of coagulant and pH.

Similarly to the operation and data collection effort for the MMF system, the data collection and analysis effort for the CSF-MMF was expected to be mostly field-based using local instruments and gauges (minus specific lab sample events), due to the need to ascertain system performance by measuring key parameters and receiving immediate results to allow on the-fly operational adjustments as necessary.

Table 9
CSF + MMF Runs – Summary

Run No.	**Dates (2005)**	**Coagulant Dose**	**Polymer Dose**	**Acid / Chlorination**	**Turbidity**	**SDI**	**Operating Time**
		(mg/L as Fe)	**(mg/L)**	**(pH/(mg/L))**	**NTU**		**(Hours)**
01-08	01/06-01/14	3.0-15.0	2.0	-	0.12	2.80	215
9-12	01/15-01/20	15.0-25.0	2.0	-	0.13	3.10	145
13-15	01/21-01/25	3.0-15.0	3.0-4.0	-	0.10	2.30	138
15-19	01/26-01/29	15.0-25.0	3.0-4.0	-	0.12	2.85	110
20-22	01/30-02/01	5.0-20.0	-	2.0–3.0 chlorination followed by dechlorination[1]	0.13	2.95	54
23-25	02/02-02/03	5.0-20.0	1.0 – 2.0	2.0–3.0 chlorination followed by dechlorination[1]	0.11	2.73	42
26-29	02/03-02/07	5.0-15.0	-	Acid pH 5.8	0.12	3.02	95
30-32	02/08-02/10	5.0-15.0	1.0-2.0	Acid pH 5.8	0.10	2.85	65
33-35	02/11-02/23	2.0-25.0	-	-	0.14	3.01	305
36-40	02/24-03/03	2.0-25.0	1.0-2.0	-	0.11	2.62	165

[1] *Feed water to the MMF was chlorinated and the filtrate from the polishing unit was dechlorinated*

Table 10
Summary of CSF Data Collection (in situ)[1]

Parameter	Location						
	Feed Water at source	**Feed Water at pilot site**	**Flocculation Basin**	**Sedimentation Basin**	**Multimedia Feed**	**Roughing Filter**	**Polishing Filter**
Conductivity	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Dissolved Oxygen (DO)	Once Daily	Once Daily	Once Daily	Once Daily	Once Daily	Once Daily	Once Daily
Flow Rate	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
pH	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Pressure	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
SDI	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
TDS	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Temperature	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Turbidity	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily

[1] *On weekends the sampling is performed once daily.*

A.2.4 Membrane Pretreatment

Although MF as a pretreatment to SWRO is generally prescribed in the industry to extend the operation of the RO system between chemical cleanings, it is not known if the increased life cycle costs of the advanced pretreatment will offset the cost savings on the RO system. Therefore the primary purpose for pilot testing of a membrane filtration system was to evaluate the associated rate of fouling on the downstream reverse osmosis system after it meets the project goals for SDI and turbidity, in order to effectively evaluate associated life cycle cost impacts. The question was then in consideration of project goals, what type of membrane pretreatment (and what configuration) would best be suited for the test.

The quality of filtrate produced from different pretreatment MF systems can vary, though within the tolerable range of performance expected for turbidity and SDI reduction. Factors such as filtration cycles, flux settings, and cleaning frequencies can vary among vendors. These differences in performance (and associated costs) can be significant however not considered pertinent given the focus on comparison of the three broad technology groups (multimedia filtration, coagulation sedimentation filtration and membrane filtration) and their effect on reverse osmosis fouling rates. Therefore, a single membrane microfiltration system manufactured by Pall Corporation was evaluated. The membrane pretreatment process flow diagram is shown as Figure 4.

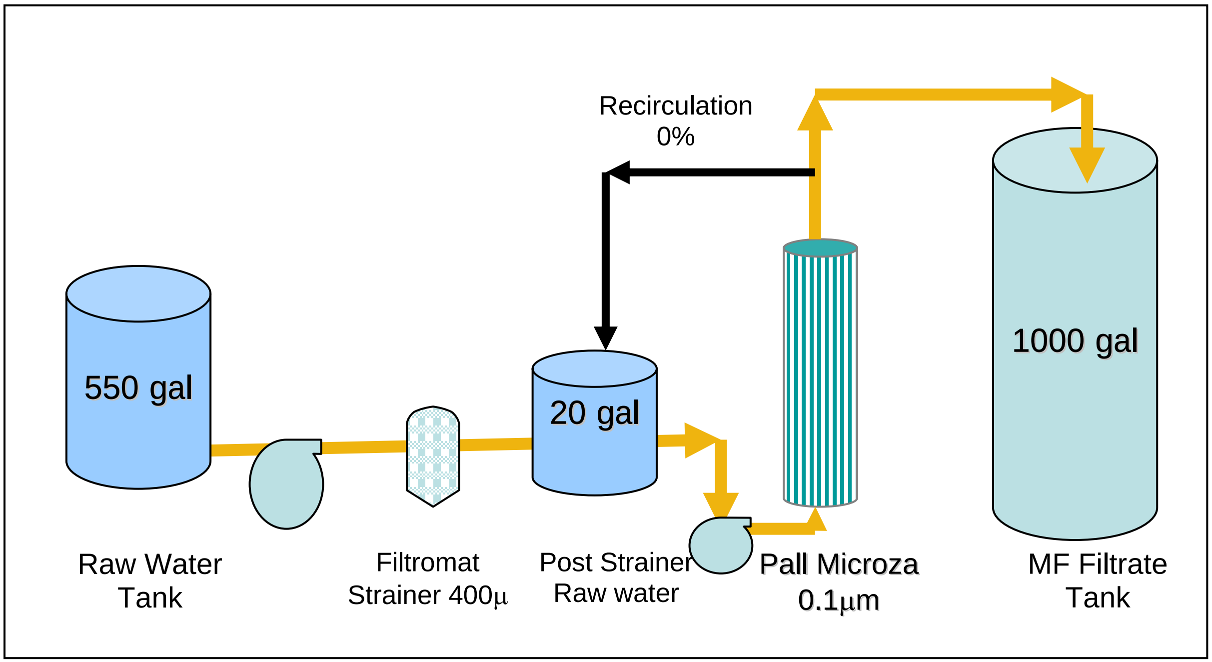


Figure 4 - Flow Schematic For Microfiltration System

The flow schematic for Pall Microfiltration system started off with a raw water feed tank, which was being fed by the raw water pump at the intake. A system controlled feed pump would then pump the feed water through a semi automatic strainer (400 micron) through to the skid mounted feed tank. A skid mounted feed pump would then feed the Pall Microza (0.1 micron rated) microfiltration membrane. The filtrate was collected in a 1000 gallon tank which would then feed the seawater reverse osmosis system for further treatment.

The design criteria for the Pall membrane filtration system were initially fixed since the intent of this task was to generate a representative filtrate quality with sustained operation of the membrane filtration system, and monitoring of the impact/performance of the downstream SWRO system. A cleaning frequency of no more than once per 30 days (vs. more frequent cleaning cycles) was desired since, from a practical standpoint, any off-line membrane deep-cleaning operations that can take up to one to two days, will affect capital and operating costs due to lost production time. The membrane filtration pretreatment system design criteria and operating conditions are contained in Table 11.

The secondary objective of the MF pretreatment process was optimization of the membrane system; accomplished by making changes in the filtrate production hydraulic loading rates, incorporating the capability to add coagulant, and a recording of the resultant pressure losses (and time to achieve terminal loss to initiate cleaning), chemical/cleaning frequency, and variances, if any, in filtrate water quality.

Table 11

MF Pretreatment System Design Criteria and Operating Conditions

Operating Condition	Value or Range
Operating duration	14 months (Two (2) Phases)
Flux	Sustainable to allow continuous operation within the requirements of EFM/shutdown for Chemical Cleaning
Chlorination – feed / RF	As required / (none preferable)
Recovery	95-97%
Coagulant	Ferric chloride (1.0 – 3.5 mg/L as Fe), only as needed
SASRF (Submerged Air Scrub and Reverse Filtration)	
Set_Point Frequency	Every 30 minutes
Flow	4 scfm/7 gpm
Duration	60 seconds air/water
RF (Reverse Filtration)	
Set Point Frequency	Every 30 minutes
Flow	15 gpm
Duration	30 seconds
EFM (Enhanced Flux Maintenance)	NaOCL (daily) up to 500 mg/L; one event per day SBS injection for scavenging after EFM (short duration)
Citric Acid	Weekly; up to 500 mg/L
Chemical cleaning frequency[1]	No more than once per 30 days
Cleaning chemicals	1% caustic soda and chlorine (1000 mg/L) solution
	1% citric acid solution

Therefore, over the course of the pilot study, the following initiatives were put into place:

1. Characterization of microfiltration filtrate water quality relative to SWRO feed water requirements;
2. Monitoring of MF system operating performance as measured by:

    a. feed and filtered water turbidity,
    b. feed and filtered water Silt Density Index (SDI),
    c. feed water flow rate,
    d. feed and filtered water pressure,
    e. filter run times between cleanings;

3. Perform chemical cleanings as required to return performance to acceptable levels needed for SWRO feed water quality; and
4. Develop information necessary to support preliminary design and budgetary cost activities. Design criteria that were developed include:

A summary of the tested variables for the membrane filtration pretreatment system are contained in Table 12.

Table 12

MF Pretreatment System Testing Variables

Testing Variables	
Seasonal effects	Operate systems during wet and dry seasons
Flux	45 – 70 gfd
Excess Recirculation	None (Direct Flow)
Feed and Bleed	None
Coagulant Dose	0.0 – 3.5 mg/L as Fe, only as needed
Duration of test runs	Based on the different flux rates to be tested

Measurements to gauge the performance of the MF system were different than the MMF/CSF system. The performance and monitoring of the MF is measured by feed and filtered water turbidity, feed and filtered water Silt Density Index (SDI), (how is it different from MMF monitoring?) feed water flow rate, feed and filtered water pressure, filter run times between cleanings; and chemical cleanings as required to return performance to acceptable levels. These performance and monitoring components are further detailed in Chapter 3. Lab analytical results are also presented in the Chapter, where applicable.

A.2.4.1 Phase 1

The MF system was started up on February 11, 2004 and operating parameters optimized to minimize fouling and transmembrane pressure during the first 4 weeks of operation. The first MF test run was then initiated at 48 gfd.

Right away, finished water quality met the filtrate water quality goal of a turbidity of less than 0.3 NTU and an SDI of less than 3.0 units, regardless of operational settings. A summary of the runs and the results are presented in Table 13 and 14. The SWRO was operated during this time because MF filtrate water quality goals were achieved.

Run 1 flux was sustainable and the system did not reach the terminal transmembrane pressure (TMP) of 45 psi within the 30 days cleaning frequency as originally predicted. Regardless, the membrane was cleaned with caustic and chlorine following each run during this phase of testing in accordance with Appendix D, Membrane Cleaning.

Adjustments to operational variables for the MF system were not initially contemplated following the initial optimization period, however due to the demonstrated sustained flux with acceptable filtrate quality, further optimization runs were performed to see if additional efficiencies could be realized. Therefore, the runs are divided into Phase 1 (no pretreatment chemical injection) and Phase 2, which employed coagulation.

During this optimization testing period, a Temperature Corrected Flux (TCF) was also determined. TCF represents the predicted, sustainable hydraulic loading rate which can accommodate the range of temperature and seasonal water quality influences with no terminal pressure loss causing shutdown/cleaning.

During winter months, the MF system consistently reached a terminal feed-to-filtrate pressure differential of 45 psi and hence would shut down automatically. By applying the TCF, the system would vary the flux rate automatically, according to the feed water temperature. As the feed water temperature lowered the flux rate lowered, to a minimum of 42 gfd. The operational implication in the field is that there was a trade-off between production capacity and ideal operating flux rate, which was lowered to allow for sustained online production and consistent operating data.

A.2.4.2 Phase 2

The MF system was restarted back on January 4, 2005 and operating parameters optimized to minimize fouling and transmembrane pressure. The MF test run was initiated at 48 gfd with TCF. The runs are contained in Table 13 and 14 and include flux changes, addition of coagulation chemicals to possibly agglomerate organics; and cleaning frequency changes. Ferric was used as the coagulant, and the dosage was varied.

Similarly to the operation and data collection effort for the MMF/CSF system, the data collection and analysis effort for the MF was expected to be mostly field-based using local instruments and gauges (minus specific lab sample events), due to the need to ascertain system performance by measuring key parameters and receiving immediate results to allow on the-fly operational adjustments as necessary.

Table 13

MF Runs – Summary (Phase 1 - Without Coagulation)

Run No.	Date (2004)	Flux	Coagulant Dose	Turbidity[2]	SDI[2]	Operation Time
		(gfd)	(mg/L)	(NTU)		(Hours)
1	02/11- 04/21	48	0.0	0.03	0.8	1,250
2	04/21– 05/03	70	0.0	0.03	0.9	275
3	05/04–07/07	60	0.0	0.03	0.9	1,500
4	07/08–08/10	60	0.0	0.03	0.9	450
5	08/17–11/15	48	0.0	0.03	0.9	1250
6	11/15–11/30	55	0.0	0.03	0.8	350
7	12/01–12/31	48 (TCF[1])	0.0	0.03	0.8	500

Table 14

MF Runs – Summary (Phase 1 - With Coagulation)

Run No.	Date (2005)	Flux	Coagulant Dose	Turbidity[2]	SDI[2]	Operation Time
		(gfd)	(mg/L)	(NTU)		(Hours)
1	01/04–01/12	48 (TCF[1])	0.0	0.03	0.8	200
2	01/12–01/17	48 (TCF[1])	1.5	0.03	0.8	125
3	01/17–01/23	48 (TCF[1])	3.5	0.03	0.8	125
4	01/23–01/27	48 (TCF[1])	2.5	0.03	0.9	100
5	02/03–02/13	48 (TCF[1])	2.0	0.03	0.8	200
6	02/14–03/07	48 (TCF[1])	1.0	0.03	0.8	500

[1] TCF – Temperature Corrected Flux (42 – 48 gfd)

[2] Turbidity and SDI – Best observed numbers

Table 15
Summary of MF data collection (in situ)

Parameter	Location[1]		
	Feed Water at Source	MF Feed Water	MF Filtrate
Conductivity	Twice Daily	Twice Daily	Twice Daily
Dissolved Oxygen (DO)	Once Daily	Once Daily	Once Daily
Flow Rate	Twice Daily	Twice Daily	Twice Daily
pH	Twice Daily	Twice Daily	Twice Daily
Pressure	Twice Daily	Twice Daily	Twice Daily
SDI	Twice Daily	Twice Daily	Twice Daily
TDS	Twice Daily	Twice Daily	Twice Daily
Temperature	Twice Daily	Twice Daily	Twice Daily
Turbidity	Twice Daily	Twice Daily	Twice Daily

[1] On weekends the sampling is performed once daily.

A.2.5 Seawater Reverse Osmosis Treatment

Two parallel reverse osmosis systems were utilized and performance monitored to determine how effective the sedimentation/filtration, media filtration, membrane pretreatment systems were in generating an acceptable quality, low-fouling filtrate as SWRO feedwater. Therefore the focus of the pretreatment task was two-fold; (1) determine the efficacy of the pretreatment systems to produce the best possible filtrate quality based on varying chemical dose rates, hydraulic loading rates, or backwash/cleaning frequency, and (2) track and observe the performance of the two SWRO systems as measured by cartridge filter differential pressures, and the membrane mass transfer coefficient (MTC); MTC is also referred-to in the industry as ‘specific flux’, ‘permeability’ and ‘normalized permeate flow’. The flow schematic for the SWRO system is shown in Figure 5.

The reverse osmosis system design was selected to be representative of typical industry designs with capability to accommodate site-specific conditions. The flow schematic for the SWRO system as seen in Figure 5 consisted of a feed tank which was either filled up with MMF/CSF or MF Filtrate depending on the treatment train. A low pressure transfer pump would then pump water through the cartridge filter housing. The high pressure pump would then pump the water to feed the seven element single array sea water reverse osmosis system. Toray reverse osmosis elements were selected for pilot testing; these elements are utilized throughout the world for seawater desalination.

Cartridge filters protect the elements from damage due to possible gross passage of material that may come through the piping and plug the feed channel, and were utilized prior to both first-pass SWRO systems. The selected cartridge filters were 5-micron nominal, melt blown, polypropylene (PPL) core. The expected filter changeout frequency was once per quarter, generally accepted as representative of industry standard.

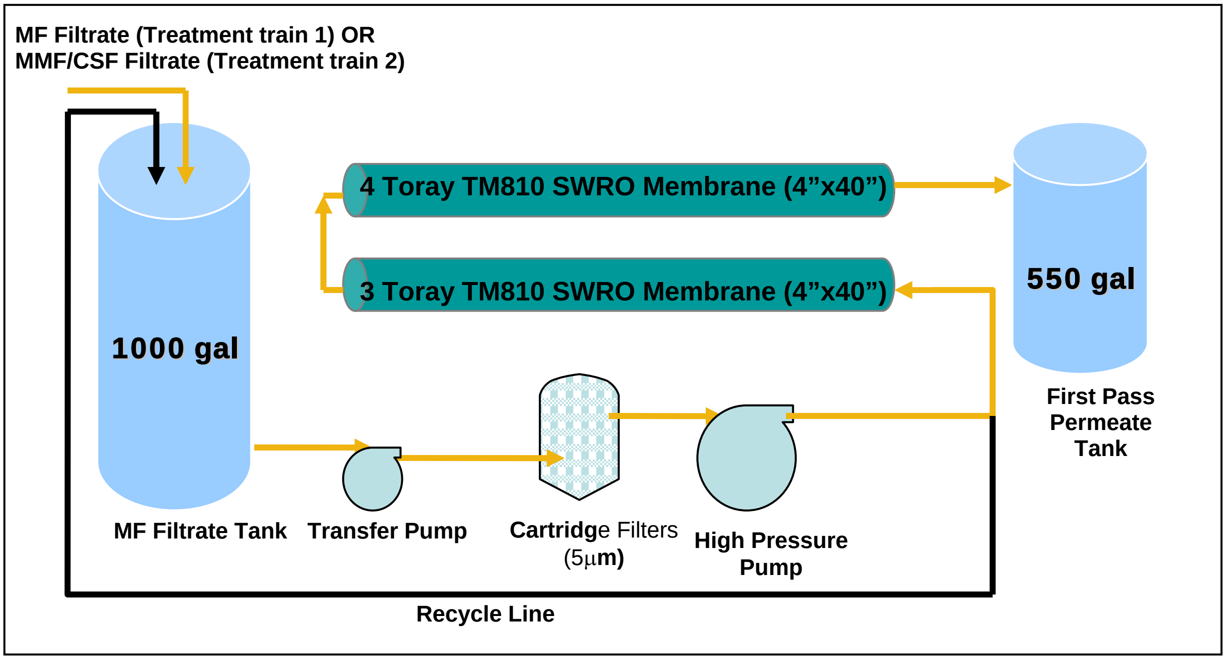


Figure 5 - First Pass Seawater Reverse Osmosis System

Therefore, over the course of the pilot study, the following initiatives were put into place:

1. The first pass SWRO would be operated only during periods when SDI values are below 3.0 units and turbidity less than 0.3 NTU;
2. Characterize RO permeate quality relative to finished water goals;
3. Monitor RO system operating performance as measured by the following:
    a. Feed and permeate conductivity,
    b. Permeate water recovery,
    c. Feed water pressure;
4. Assess changes in RO membrane performance caused by potential fouling of RO membrane elements and chemical oxidation by monitoring:
    a. Normalized permeate flow,
    b. Normalized conductivity passage;
5. Perform chemical cleanings as required when normalized performance parameters change by a pre-determined value (15 to 20-percent increase in normalized MTC) and assess the efficiency of one of more chemical cleaning formulations/regimes to restore RO performance losses;
6. Develop information necessary to develop a preliminary design and budgetary cost estimate.

The first pass SWRO design criteria and operating conditions are contained in Table 16. The second pass is discussed in the subsequent Section.

Table 16
First Pass SWRO Design Criteria and General Operating Conditions

Operating Condition	**First Pass SWRO Value or Range**
Operation Duration	14 months
Membrane Trade Name[1]	TM-810 : Toray
Manufactured Specified Characteristics a. Membrane Type b. Membrane Surface Area c. Flow Rate d. Salt Rejection e. Chlorine/oxidant tolerance	Cross linked fully aromatic polyamide composite 73 ft^2 (7 m^2) 1,200 gpd (5 m^3/day) 99.75 % Zero/none
Array	1:0
No. of membranes per pressure vessel	7m
Average Flux, Gallons per square foot per day (GFD)	8-10
Feed Pressure, max, psig	1,000
Feed water	Pretreated power plant seawater discharge
Chemical addition	Acid/Antiscalent, if needed
Cartridge filter configuration	5 micron absolute, 2.5 gpm per 10-inch equivalent length
Membrane cleaning frequency	No more than once per 6 months
Membrane cleaning chemicals	Per manufacturer instructions

[1] Note: Membrane and equipment manufacturer product line sheets are in Appendix-C.

In addition to comparing the effect of alternate pretreatment systems on the performance and sustainability of the SWRO systems, flux and recovery were varied because these parameters will affect fouling rates, capital cost, and operational costs. Water treatment plant capital costs decrease as flux increases therefore flux can be a significant factor for minimization of costs. However, when flux increases, pressures increase and fouling rates can increase. A similar trend exists with increasing recovery. Therefore variation of these two parameters were expected to provide information on the limits that these parameters can be set at to minimize capital and O&M costs while maintaining sustained operation. As such, the expected performance of the first pass of the SWRO applying the various operating conditions was modeled prior to selecting the pilot configuration. This ensured the pilot, as-built, would meet the manufacturer operational criteria for hydraulic loading, concentrate flow rate, and feedwater and pressure limitations based varying temperature, flux, and recovery rates. Membrane manufacturer system performance projections are contained in Appendix-C.

Thirty days is a suitable time frame to evaluate the possibility of SWRO fouling at a given set of challenge conditions. With that time frame in mind, and based on the expected program duration, a testing matrix consisting of a total of 12 experiments were scheduled, consisting of 30 days duration each. Field (or in-situ) gathered operational data is necessary to gauge and also calculate critical operational parameters for the SWRO system, and assists in troubleshooting. The field and lab measured data also needs to be consistent with analytes necessary to determine fouling effects of the four primary RO fouling mechanisms - plugging, scaling, biological fouling, and organic adsorption.

Therefore the data collection and analysis effort for the SWRO was expected to be daily with intermittent lab sampling events to gauge and evaluate the qualitative performance of the system in terms of rejection (specific ion and general performance) and salt rejection.

Field-based data collection efforts were performed using local process-stream mounted or hand-held instruments, and measured key performance parameters for immediate results. This would allow the field personnel to immediately determine if a problem exists due to site real-time data availability. Table 17 summarizes the run schedule.

Table 17

SWRO Run Schedule - Operational Matrix

	Exp.	CMF	MF	SWRO (First Pass)	
				Flux	**R**
				Gfd	**%**
Dry Season	1	Optimized	Optimized	8	50
	2			8	55
	3			8	60
	4			10	50
	5			10	55
	6			10	60
Wet Season	7			8	50
	8			8	55
	9			8	60
	10			10	50
	11			10	55
	12			10	60

The primary goal for the SWRO system was to demonstrate sustainable operation and the fouling potential as affected by pretreatment type, at operating conditions representative of industry-wide installations; and to gauge the magnitude of these changes on cost and performance. Therefore, flux rate and recovery were varied from 8 GFD to a less conservative 10 gfd; and as well, operating points for system recovery rates were varied to 50%, 55% and 60% during wet and dry seasons.

The recovery rates represent the range of typically applied recoveries on seawater similar to this Project. The systems were to be tested in both wet and dry seasons to quantify the seasonal effects (and expected variations in the feedwater composition) on system performance, measured by normalized MTC.

A summary of the SWRO system testing variables and commensurate field data collection requirements are contained in Table 18 and Table 19, respectively.

Table 18

SWRO System Testing Variables

Testing Variables[1]	
Seasonal effects	Operate systems during wet and dry seasons
Flux	8 and 10 gfd
Recovery	50%, 55% and 60%
Duration of test runs	Minimum 30 days per experiment

1 Note: MMF/MF optimized prior to testing SWRO system

Table 19

Summary of SWRO data collection (in-situ)

Parameter	**Location**[1]			
	SWRO Feed Water (Pre Cartridge Filter)	**SWRO Feed Water (Post Cartridge Filter)**	**SWRO Permeate**	**SWRO Concentrate**
Conductivity	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Dissolved Oxygen	Once Daily	Once Daily	Once Daily	Once Daily
Flow Rate	Twice Daily	Twice Daily	Twice Daily	Twice Daily
pH	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Pressure	Twice Daily	Twice Daily	Twice Daily	Twice Daily
SDI	Twice Daily	Twice Daily	Twice Daily	Twice Daily
TDS	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Temperature	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Turbidity	Twice Daily	Twice Daily	Twice Daily	Twice Daily

[1] On weekends the sampling is performed once daily.

A.2.6 Second Pass BWRO Systems Operations

The finished water quality for this project required the chloride levels of equal to and less than 35 mg/L. Additionally, other selected water quality parameters were also set at aggressive levels for this project. The permeate water quality from the first pass reverse osmosis system did not meet these more aggressive standards, as expected, and so a second pass pilot was designed for full-stream treatment of the first-pass permeate stream.

Permeate water quality characteristics between the MMF and MF-fed SWRO systems were not expected to vary by any appreciable degree, and as such the second pass was fed by mixing the filtrate water from both the MF and MMF. The second pass seawater system consisted of two stage system with 6 – 2540 membrane elements contained in four membrane vessels as seen in Figure 6. Specific design criteria associated with the second pass BWRO system is presented in Table 20.

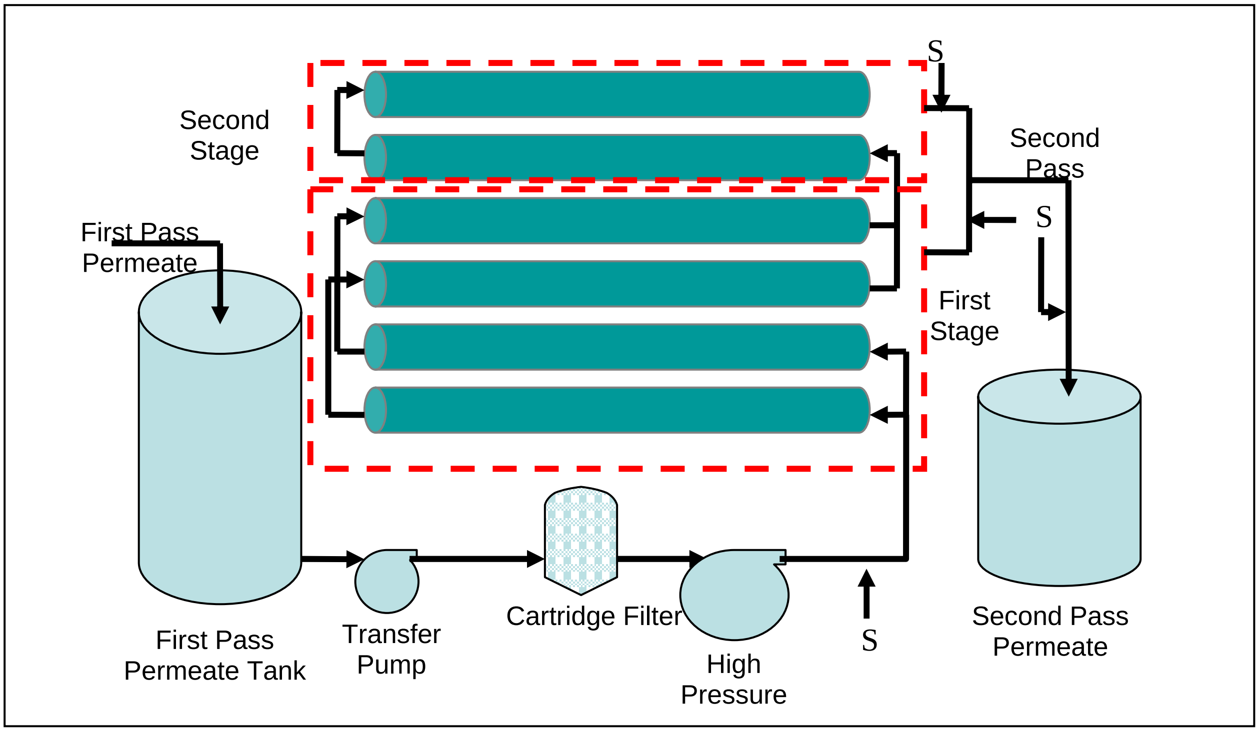


Figure 6 - Second Pass BWRO system

The flow schematic for this system consisted of a feed tank that then fed the transfer pump. Before the water was fed to the transfer pump, sodium hydroxide was injected in the feed stream and the pH was raised to 9.4 units. The water was pump through the cartridge filter housing (no cartridge filter present) to the high pressure pump which would then feed the water to a two stage second pass brackish water reverse osmosis system. The permeate from first and second stage was collected in a tank. The second pass BWRO design criteria and operating conditions are summarized in Table 20.

Similarly to the operation and data collection effort for the pretreatment and first pass SWRO system, the data collection and analysis effort for the BWRO was expected to be mostly field-based using local instruments and gauges (minus specific lab sample events), due to the need to ascertain system performance by measuring key parameters and receiving immediate results to allow on the-fly operational adjustments as necessary.

Table 20
Second Pass BWRO Design Criteria and Operating Conditions

Operating Condition	**Second Pass SWRO** **Value or Range**
Operation Duration	10 months
Membrane Trade Name	TMA G10: Toray
Manufactured Specified Characteristics a. Membrane Type b. Membrane Surface Area	 Cross linked fully aromatic polyamide composite 30 ft^2 (2.8 m^2)
Array	2:1
No. of membranes per pressure vessel	2m
Feed water	Permeate from First Pass SWRO
Chemical Addition	Base & Antiscalent
Cleaning Frequency	No greater than once per 6-month interval
Cleaning chemicals	Per manufacturer instructions
Testing Variables	
Seasonal effects	Operate systems during wet and dry seasons
Flux	20 gfd
Recovery	90%

Table 21
BWRO Second Pass System – Selected, Measured Parameters

Parameter	**Location[1]**					
	2nd Pass Feed	**2nd Pass Feed after pH adj.**	**1st Stage – 2nd Pass Permeate**	**2nd Stage - 2nd Pass Permeate**	**2nd Pass Concentrate**	**Combined Permeate**
Conductivity	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Dissolved Oxygen	Once Daily	Once Daily	Once Daily	Once Daily	Once Daily	Once Daily
Flow Rate	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
pH	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Pressure	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
SDI	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
TDS	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Temperature	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily
Turbidity	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily	Twice Daily

[1] On weekends the sampling is performed once daily.

A.2.7 Sampling Collection Events and Analytical Methods

The laboratory measured analytes were collected in order to coincide with the wet and dry seasons, and to capture each flux and recovery rates and are contained in Table 22. The analysis methods used for these analytes are contained in Table 23.

A.2.8 Instrument Calibration, Maintenance and Logbook

All field instruments were calibrated on a weekly basis. A pilot study logbook was maintained on-site to report the following:

- Field instruments calibration
- The date and time of membrane cleaning and a detailed description of the cleaning procedure (i.e. cleaning agent, volume of cleaning solution, duration of cleaning, etc.),
- Process upsets that could affect performance (e.g. pretreatment failure, a major change in water quality, operator error, etc.),
- Replacement and specification of cartridge filters and membrane elements or any other system components,
- Any change in the system's operating parameters, and
- Any time that the system is offline

Operations personnel entered all activities in this logbook that might be considered of importance in interpretation of pilot results.

Table 22 - Laboratory Sampling

	Raw (Feed Water)	Coagulation Filtrate	Sedimentation Filtrate	MMF Filtrate	MF Filtrate	MMF BW	MF BW	SWRO Feed (CSF)	SWRO Feed (MF)	SWRO Permeate (CSF)	SWRO Permeate (MF)	SWRO Concentrate (MMF)	SWRO Concentrate (MF)	Feed to 2nd Pass RO	2nd Pass RO Feed after pH adj.	1st stage – 2nd Pass RO Permeate	2nd stage – 2nd Pass RO Permeate	2nd Pass RO Concentrate	Combined 2nd Pass Permeate
Alkalinity, Total (as $CaCO_3$)	M	M	M					M	M	M	M	M	M	M	M	M	M		M
Aluminum	M	M	M					M	M	M	M	M	M						M
Barium	M	M	M					M	M	M	M	M	M						M
Boron	B	B	B					B	B	B	B	B	B	B	B	B	B	B	B
Bromide	B	B	B					B	B	B	B	B	B	B	B	B	B	B	B
Calcium	M	M	M					M	M	M	M	M	M						M
Cesium	M	M	M					M	M	M	M	M	M						M
Chloride	B	B	B	B	B	M	M	B	B	B	B	B	B	B	B	B	B	B	B
Chromium	M	M	M					M	M	M	M	M	M						M
Color	M	M	M					M	M	M	M	M	M						M
Copper	M	M	M					M	M	M	M	M	M						M
Fluoride	M	M	M					M	M	M	M	M	M						M
Hardness, Total (as $CaCO_3$)	M	M	M					M	M	M	M	M	M						M
Heterotrophic Plate count	B	B	B	B	B	B	B	B	B	B	B	B	B						B
Iron (total)	M	M	M	M	M	M	M	M	M	M	M	M	M						M
Iron (dissolved)	M	M	M	M	M	M	M	M	M	M	M	M	M						M

	Raw (Feed Water)	Coagulation Filtrate	Sedimentation Filtrate	MMF Filtrate	MF Filtrate	MMF BW	MF BW	SWRO Feed (CSF)	SWRO Feed (MF)	SWRO Permeate (CSF)	SWRO Permeate (MF)	SWRO Concentrate (MMF)	SWRO Concentrate (MF)	Feed to 2^{nd} Pass RO	2^{nd} Pass RO Feed after pH adj.	1^{st} stage – 2^{nd} Pass RO Permeate	2^{nd} stage – 2^{nd} Pass RO Permeate	2^{nd} Pass RO Concentrate	Combined 2^{nd} Pass Permeate
Lead	M	M	M					M	M	M	M	M	M						M
Magnesium	M	M	M					M	M	M	M	M	M	B					M
Manganese	M	M	M					M	M	M	M	M	M						M
Nitrate (as N)	M	M	M					M	M	M	M	M	M						M
Nitrogen (as Ammonia)	M	M	M					M	M	M	M	M	M						M
Silica Dioxide	M	M	M					M	M	M	M	M	M						M
Silica Dioxide (Colloidal)	M	M	M					M	M	M	M	M	M						M
Sodium	M	M	M					M	M	M	M	M	M						M
Strontium	M							M	M	M	M	M	M						M
Sulfate	M	M	M					M	M	M	M	M	M						M
Tin	M	M	M					M	M	M	M	M	M						M
Total Dissolved Solids (gravimetric)	B	B	B	M	M			B	B	B	B	B	B	B	B	B	B		B
Total Organic Carbon	B	B	B	M	M			M	M	M	M	M	M						M
Zinc	M	M	M					M	M	M	M	M	M						M

M- Monthly(M)/Biweekly(B)

Table 23
List of parameters analyzed for water characterization

Parameter	Analytical Method
Alkalinity, Total (as $CaCO_3$)	EPA 310.1
Aluminum	SM3111D (EPA 202.1)
Barium	SM3111D (EPA 208.1)
Boron	SM4500B
Bromide	SM 4500-BR^-
Calcium	EPA 215.1
Cesium	EPA 258.1
Chloride	EPA 300.0
Chromium	SM 3111 B
Color	SM 2120 C
Copper	SM 3111 B
Dissolved Oxygen (DO)	SM 4500-O G
Field pH	SM4500-H+B
Fluoride	EPA 300.0
Hardness, Total (as $CaCO_3$)	SM 2340 C
Heterotrophic Plate Count (HPC)	SM 9215 D
Iron (dissolved)	SM3111B (EPA 236.1)
Iron (total)	SM 3111 B
Lead	SM 3111 B
Magnesium	EPA 242.1
Manganese	SM3111B (EPA 243.1)
Mercury	SM 3112 B
Nitrate (as N)	EPA 300.0
Nitrogen (as Ammonia)	EPA 350.1
Phosphorus, Total	EPA 365.4
Silica Dioxide	EPA 370.1
Silica Dioxide (Colloidal)	EPA 370.1
Silt Density Index (SDI)	ASTM D4189-95
Sodium	SM3111B (EPA 273.1)
Strontium	SM303A
Specific Conductivity	SM2510B
Sulfate	EPA 300.0
Tin	SM 3111 B
Total Dissolved Solids (gravimetric)	SM2540C (EPA 160.1)
Total Organic Carbon	SM 5310B
Turbidity	SM2130
Zinc	SM3111B (EPA 289.1)

Abbreviations: SM – According Standard Methods for Examination of Water and Wastewater.
EPA – According to U.S. Environmental Protection Agency published methods

A.3 Impact of Seasonal and Tidal Variations

Facility siting is primarily driven by a number of factors, including proximity to the raw water source, transmission pipeline costs, easement and space availability, power (operational and other) costs due to lower TDS levels, and any number of other site-specific reasons. Therefore, selection of a site which raw water supply is under the influence becomes an inadvertent by-product of the selection process and not always a controlled variable. Then by definition, source waters in the majority of existing and planned SWRO installations in North and South America are not purely open ocean intakes, but in embayments, estuaries, or under the influence of a nearby surface water runoff. The result of this is often a highly variable salinity (depending on season and tidal cycle), and turbidity, sediment and dissolved organic loads, of which all can spike daily and/or seasonally. With this contribution of fresh water from rivers and surface water/treated wastewater runoff related to seasonal and tidal variations, these raw water sources have a higher potential for fouling of an RO system.

These seasonal and tidal variations are expected to have a significant impact on SWRO plant process design, capital, and operation and maintenance (O&M) costs. Therefore, awareness of the variability of these influential parameters, whether duration or occurrence-specific, played a role in the consideration of the pilot equipment to be tested at the PDCLSF Project. Because the level of organics or suspended material challenging a pretreatment system can vary by 10x or greater based on seasonal changes or a site-specifically influenced storm event, the testing plan as outlined in the next section allowed for data collection and operation searching for a balance between both MF and CSF/MMF operational sustainability. The data and record-keeping for each SWRO system is commensurate to allow the capability to observe the influence-on and sustainability of these membrane systems.

A.3.1 Impact of Seasonal and Tidal Variations - Testing Plan

For mixed seawater/surface water supplies, an inverse relationship is thought to exist between pressure requirements and fouling potential. As surface water runoff increases and during outgoing tides, TDS decreases and the concentration of foulants such as turbidity and total organic carbon (TOC) increases. As such, maximum concentrations for foulants will govern pretreatment system design; and while average annual values for TDS may suggest a significant operational cost savings, maximum TDS values govern RO plant design and pump design in particular. With this consideration and knowledge of the variability of water quality due to surface water influence, a testing and sampling plan was developed to in consideration of this possible relationship and as well to measure the impact of seasonal and tidal changes on the performance of the systems during the operation of the pilot.

The testing plan includes selected data points and analytical parameters needed to interpret and calculate system performance in consideration of possible seasonal or tidal influence. These tables are presented throughout the aforementioned sections (as field and lab collected data) and include parameters such as conductivity, dissolved oxygen, flow, pH, pressure, SDI, TDS, temperature, TOC, and turbidity.

Collection of rainfall data and tidal information is a component of the data assimilation process in order to correlate the possible influence of surface runoff on MF, CSF-MMF, and

SWRO membrane sustainability. In addition, the seasons were defined as a group of two (2), six-month time periods. Wet season was defined as the period of the year from the month of May to the month of October whereas the dry season was defined as the period between November to April. There was a bit of an overlap with seasons since the project time span during pilot operations was February 2004 through March 2005.

Therefore, rainfall and tidal data would be gathered and seasons overlayed against the following operational field-gathered operational parameters:

- Pretreatment:
    - Filtered water turbidity
    - SDI
    - Backwash frequency
    - Differential pressures
    - Chemical dose
- SWRO:
    - Cartridge filter replacement frequency
    - Normalized mass transfer coefficient (MTC)
    - Salt passage

A.4 Source Water Temperature and Cost-Effectiveness

A common consideration in SWRO planning efforts in the US is the potential use of warmer discharge waters from once-through cooling systems associated with certain power plants. Warmer discharge water may be desired due to the decreased pressure requirements associated with warmer, less viscous water. However, this must be balanced with the increased salt passage that occurs at higher temperatures. Concerns regarding distribution system stability, boron, bromide, chloride and other constituents are such that many communities are requiring a finished water quality that exceeds USEPA requirements. Tampa Bay Water, for example, has selected a finished water chloride limit of 35 mg/L for the proposed GCD project, and it is not known if facilities such as this and others on the planning horizon, with higher water quality standards (such as chloride of less than 35 mg/L) actually benefit from the intended outcome of using warmer water.

Warm-water discharges could be a more cost-effective source of supply for facilities that have more traditional finished water quality standards (such as a TDS of less than 500 mg/L). However there is no published information, to the knowledge of this team, that presents the factors and conditions in which warmer cooling water discharge is more favorable over ambient temperature intake water. Experiences of Reiss Environmental suggest that the increased salt passage of warmer water could readily be correlated to a finished water quality goal for an inorganic ion such as chloride. A correlation between finished water quality goals and source water selection would be of significant value to the industry and is addressed in this Program.

A.4.1 Source Water Temperature and Cost-Effectiveness – Testing Plan

The PDCLSF Project incorporated measurements to account for and determine the net benefit of warmer power plant cooling water versus ambient temperature source water in terms of energy costs and compliance with finished water quality specifications. Since the pilot would be fed from the warm-water discharge of the powerplant, ambient-temperature intake water for the power plant will be used periodically for comparison purposes and to assist in the assessment of the value of warmer cooling water versus ambient cooling water.

Overall there was no specific change in the monitoring protocol during the switch between warm and cold-water events, as the everyday monitoring and collection of field-data used to assess normalized mass transfer coefficient (MTC) and salt passage were ongoing. However, there were certain lab-measured parameters that were scheduled for collection during changeovers. This was accomplished in order to allow a performance comparison among specific analytes that cannot practically be measured in the field.

APPENDIX B

CARTRIDGE FILTER AUTOPSY REPORT

Technical Services Laboratory Report

Distributor:	Gil Turner – H.C. Warner	TSP Number:	04 -1697
Customer:	Reiss Environmental	Date:	01-Sep-04
Project Title:	PSD, TSS, and Autopsy – Water Samples		
Author:	Stacci McVay		

Background

Two samples, labeled “inlet” and “outlet” were submitted by Gil Turner (H.C. Warner) on behalf of Reiss Environmental for laboratory services. The existing filter system includes a AVS5M20. The requested testing will determine the particle characterization of the sample so a proper filtration solution can be selected.

Procedures/Instrumentation

1.) Total suspended solids (TSS) were determined by using the Standard Method 2540D. A 0.45 µm glass patch disk was dried in an oven at 130^{O}F for at least 2 hours and cooled in a desiccator for one hour. A known volume of sample was then filtered through the disk. The disk was then dried for 24 hours at 130^{O} F and cooled in a desiccator for one hour. The disk was then re-weighed. The level of suspended solids is calculated using the following equation.

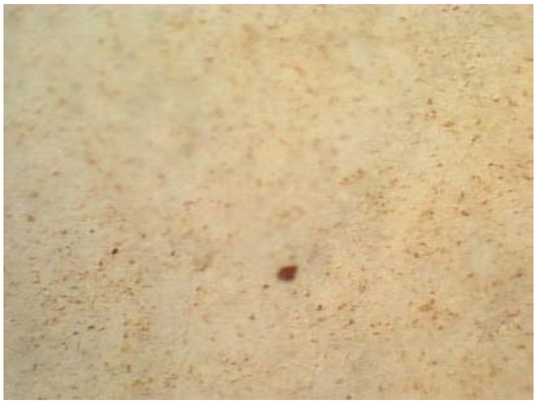
$$\frac{(\text{Wt. Of Filter and Residue, mg} - \text{Wt. of filter, mg})}{\text{Sample volume, mL}}$$

The total suspended solids for the inlet sample are 1.035 ± 0.09 mg/L.

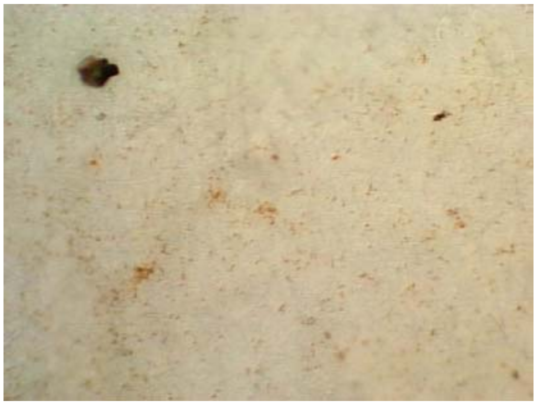
The total suspended solids for the outlet sample are 0.745 ± 0.18 mg/L.

2.) Microscopy: The TSS patch disks were viewed with a Sony CCD-IRIS/RGB Color Video Camera with Carl Zeiss Optics. The TSS patch disks were viewed at 25x and 50x magnification to show the level of contaminants that were isolated.


Inlet Sample @ 25x Magnification


Inlet Sample @ 50x Magnification


Outlet Sample @ 25x Magnification


Outlet Sample @ 50x Magnification

3.) Particle Distribution: The Particle Count Distribution (PCD) of the sample was analyzed with a Beckman-Coulter® MultiSizer. The total volume analyzed was 75-µL.

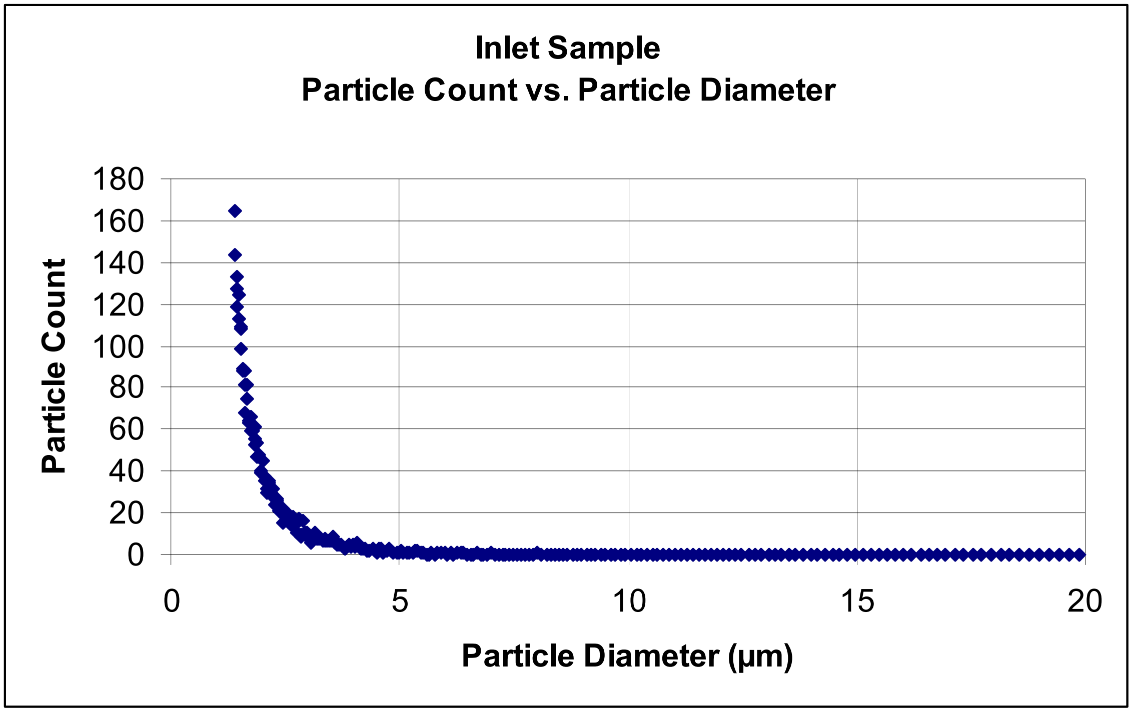


Figure 1: Particle count versus particle diameter for the inlet sample.

Figure 1 represents the number of particles counted at a particular micron range. The results of the particle distribution analysis are as follows:

- 71.9% of the particles counted are below 2 µm
- 93.4% of the particles counted are below 3 µm
- 99.2% of the particles counted are below 5 µm
- Only 29 particles were detected between 5 µm and the detectors limit of 42 µm.

Although only a few particles were detected are above 5 µm, these few particles contribute 34.6% of the total volume of solid material present in this sample. Assuming the particles present in this sample have a uniform density, these few particles represent an equal percentage of the total mass.

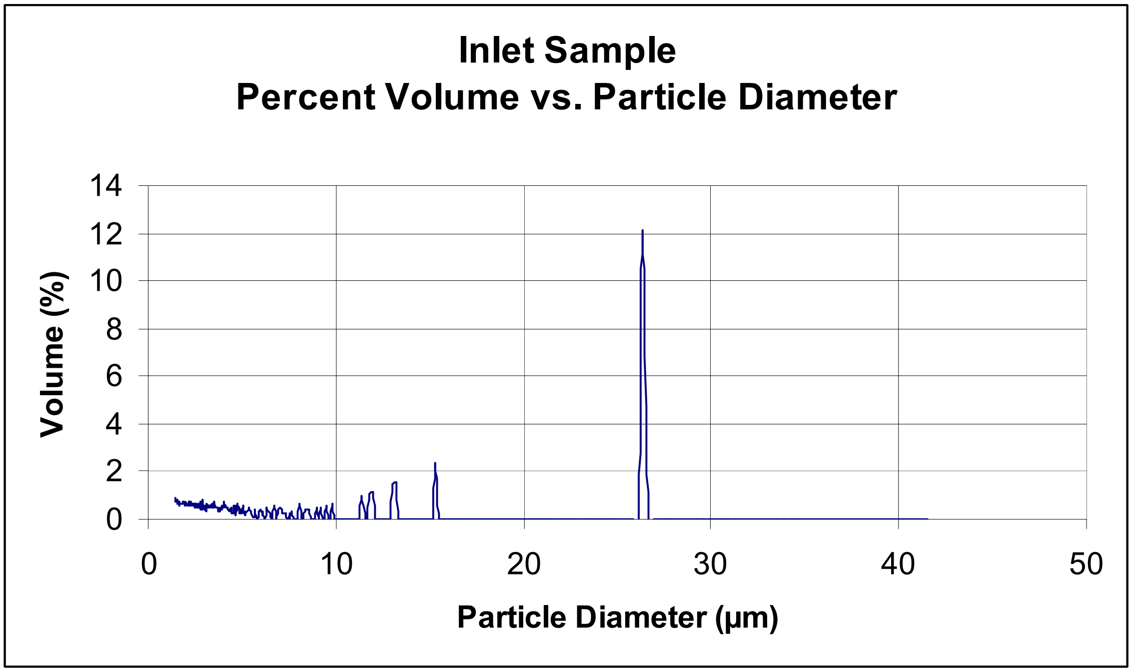


Figure 2: Percent volume versus particle diameter for the inlet sample.

Figure 2 represents the percent volume of particulate at a specific micron range. The results for the sample are as follows:

- 77.4% of the total volume of particles are above 2 µm.
- 56.1% of the total volume of particles are above 3 µm.
- 34.6% of the total volume of particles are above 5 µm.
- 12.2% of the total volume of particles are above 20 µm and the detector's limit of 42 µm.

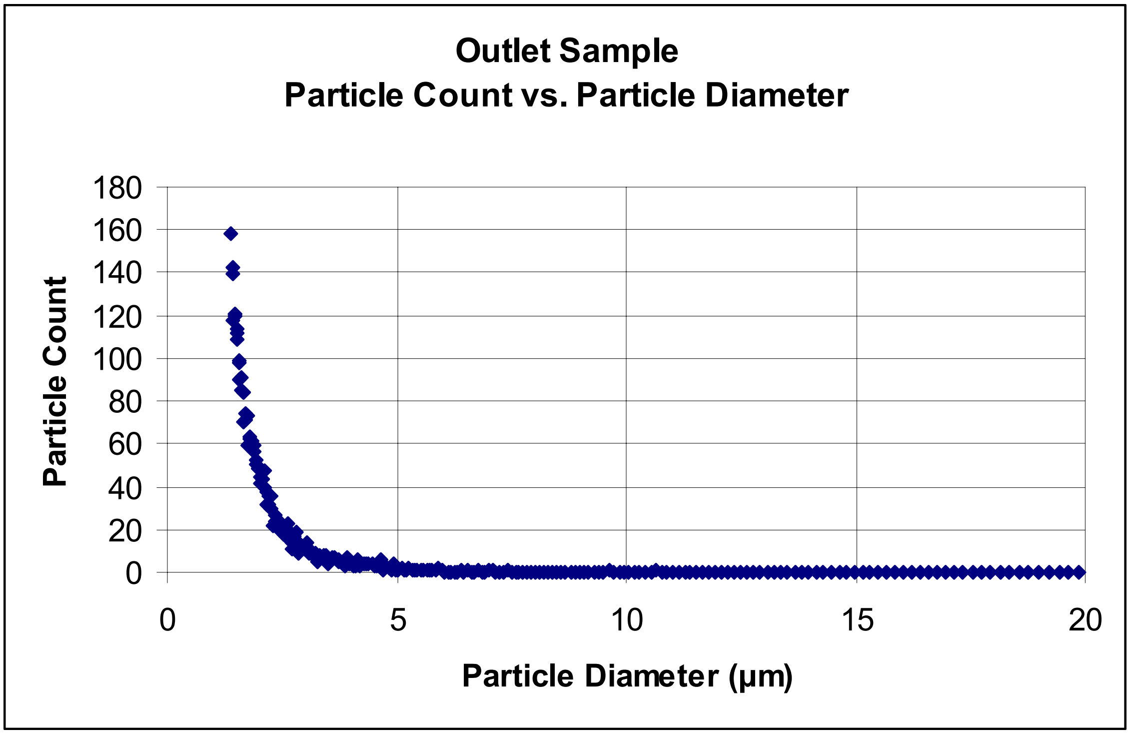


Figure 3: Particle count versus particle diameter for the outlet sample.

Figure 3 represents the number of particles counted at a particular micron range. The results of the particle distribution analysis are as follows:

- 69.0% of the particles counted are below 2 µm
- 92.6% of the particles counted are below 3 µm
- 99.1% of the particles counted are below 5 µm
- Only 33 particles were detected between 5 µm and the detectors limit of 42 µm.

Although only a few particles were detected are above 5 µm, these few particles contribute 41.4% of the total volume of solid material present in this sample. Assuming the particles present in this sample have a uniform density, these few particles represent an equal percentage of the total mass.

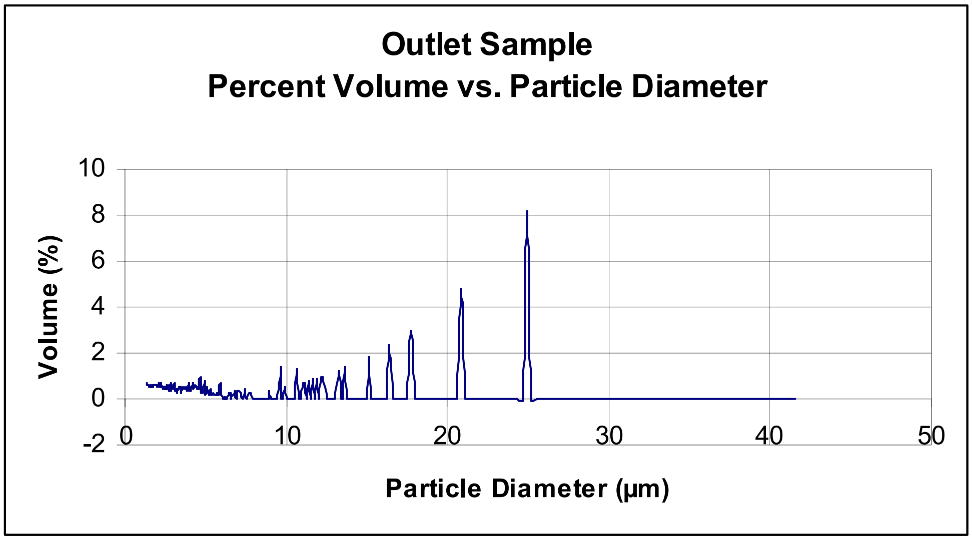


Figure 4: Percent volume versus particle diameter for the inlet sample.

Figure 4 represents the percent volume of particulate at a specific micron range. The results for the sample are as follows:

- 80.9% of the total volume of particles are above 2 µm.
- 62.1% of the total volume of particles are above 3 µm.
- 41.4% of the total volume of particles are above 5 µm.
- 13.0% of the total volume of particles are above 20 µm and the detector's limit of 42 µm.

Conclusions and Recommendations

The AVS5M20 cartridge has removed about 27.2% of the total solids. The particle size distribution did not shift noticeably downward when the inlet and outlet are compared to each other. This could be related to a poor sealing mechanism.

Value Added Service

The cost of this service if provided by an independent laboratory would have been $1040.00.

Technical Services Laboratory Report

Distributor:	Gil Turner – H.C. Warner, Inc.	TSP Number:	04 -1726
Customer:	Reiss Environmental	Date:	11-Nov-2004
Project Title:	Particle Size Distribution and Filter Autopsy – Water Sample		
Author:	Stacci McVay		

Background

Two water samples, labeled “Pre-Filter” and “Post-Filter”, and a fouled AVS5M20 cartridge were submitted by Gil Turner (H.C. Warner) on behalf of Reiss Environmental for laboratory services. The requested testing will determine the particle characterization of the sample so a proper filtration solution can be determined.

Procedures/Instrumentation

1.) Particle Distribution: The Particle Size Distribution (PSD) of the sample was analyzed with a Beckman-Coulter® MultiSizer. The total volume analyzed was 75-μL.

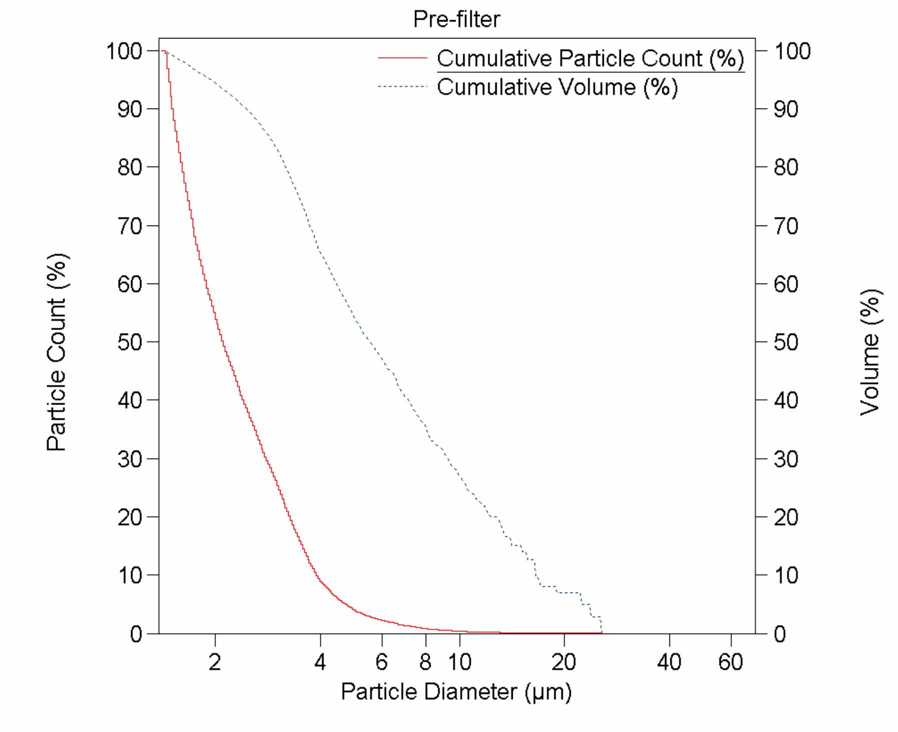


Figure 1: The cumulative percent count and cumulative volume versus the particle diameter for the Pre-Filter sample.

The results of the particle distribution analysis are as follows:

- 12.0% of the particles counted are below 1.5 µm.
- 46.9% of the particles counted are below 2 µm.
- 75.4% of the particles counted are below 3 µm.
- 96.2% of the particles counted are below 5 µm.
- 99.6% of the particles counted are below 10 µm.
- Only 11 particles were detected between 10 µm and the detectors limit of 42 µm.

Although only a few particles were detected are above 10 µm, these few particles contribute 26.7% of the total volume of solid material present in this sample. Assuming the particles present in this sample have a uniform density, these few particles represent an equal percentage of the total mass.

- 94.2% of the total volume of particles are above 2 µm.
- 82.6% of the total volume of particles are above 3 µm.
- 53.8% of the total volume of particles are above 5 µm.
- 26.7% of the total volume of particles are above 10 µm.
- 14.0% of the total volume of particles are above 15 µm.
- 6.9% of the total volume of particles are between 20 µm and the detector's limit of 42 µm.

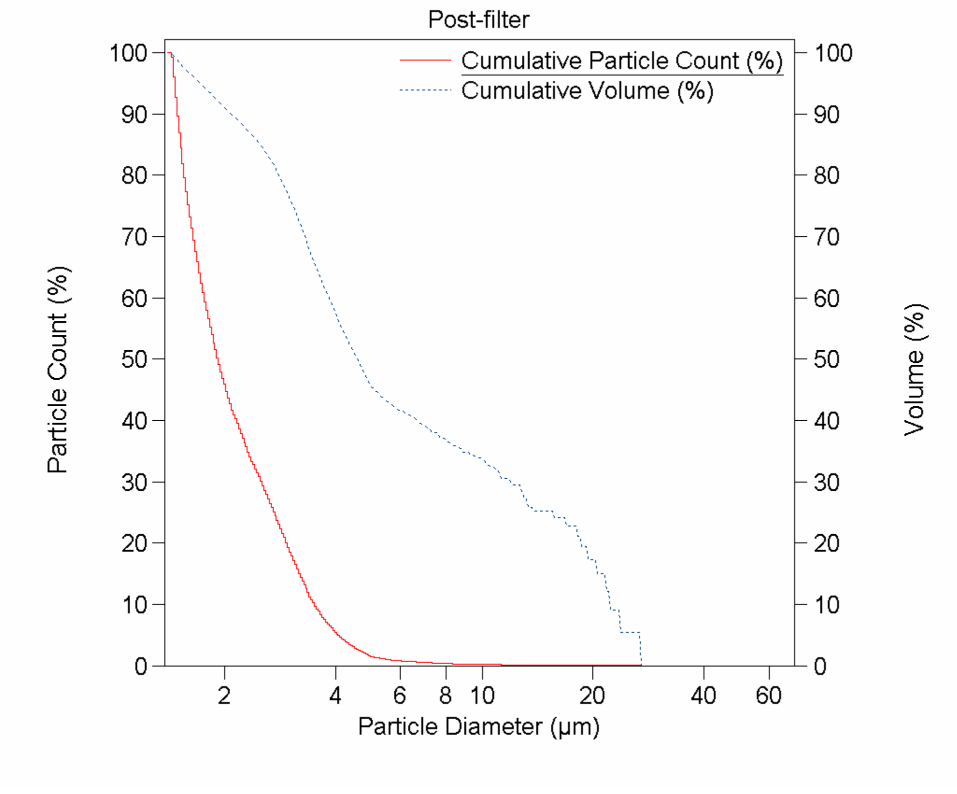


Figure 2: The cumulative percent count and cumulative volume versus the particle diameter for the Post-Filter sample.

The results of the particle distribution analysis are as follows:

- 15.5% of the particles counted are below 1.5 µm.
- 55.2% of the particles counted are below 2 µm.
- 82.2% of the particles counted are below 3 µm.
- 98.5% of the particles counted are below 5 µm.
- 99.8% of the particles counted are below 10 µm.
- Only 6 particles were detected between 10 µm and the detectors limit of 42 µm.

Although only a few particles were detected are above 10 µm, these few particles contribute 33.6% of the total volume of solid material present in this sample. Assuming the particles present in this sample have a uniform density, these few particles represent an equal percentage of the total mass.

- 90.9% of the total volume of particles are above 2 µm.
- 75.7% of the total volume of particles are above 3 µm.
- 45.4% of the total volume of particles are above 5 µm.
- 33.6% of the total volume of particles are above 10 µm.
- 25.2% of the total volume of particles are above 15 µm.
- 17.3% of the total volume of particles are between 20 µm and the detector's limit of 42 µm.

2.) Filter Autopsy:

Conclusions and Recommendations

There is not a significant difference between the particle size distribution of the inlet and the outlet.

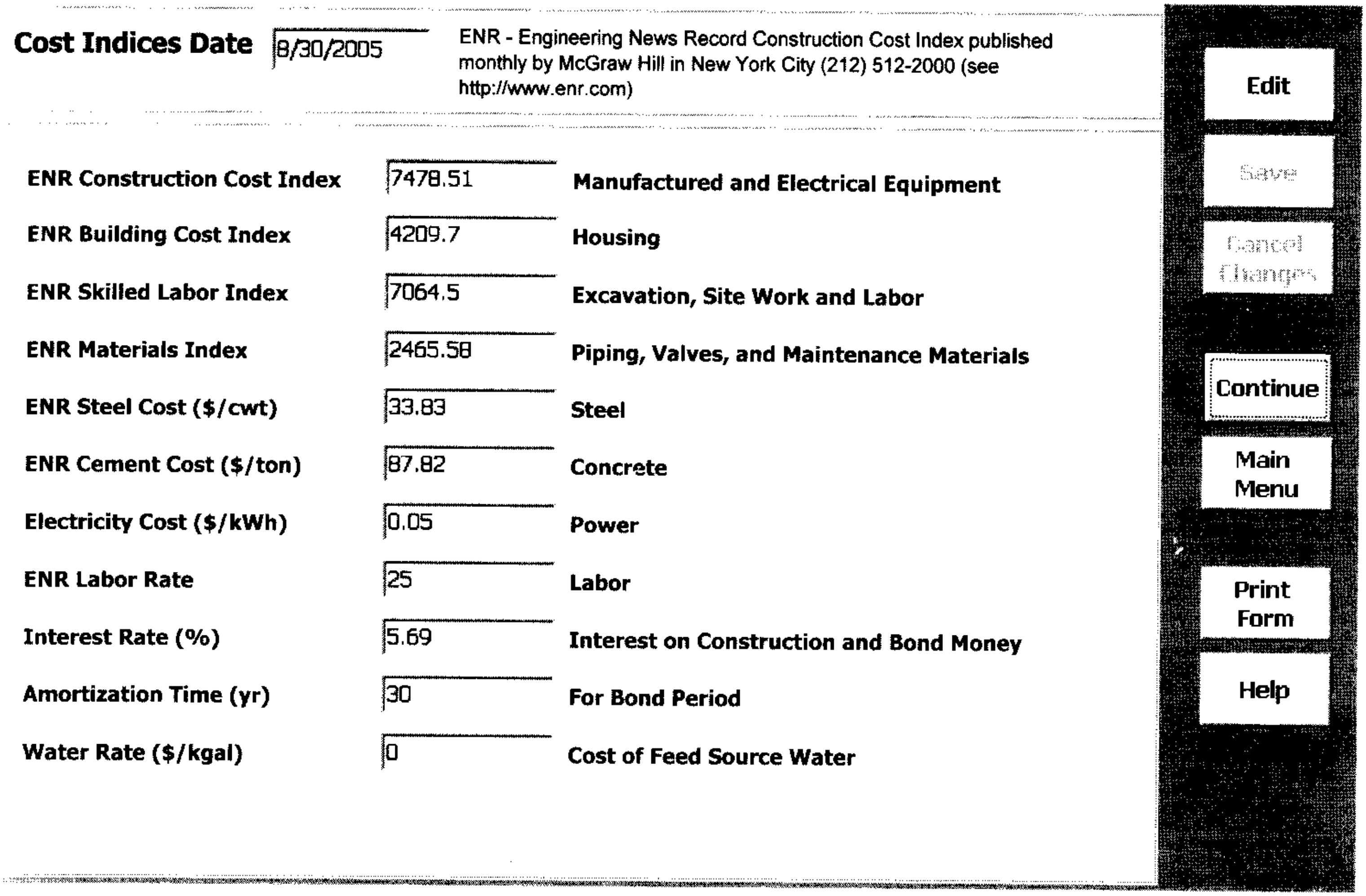
The Filter Autopsy showed that the element had a good seal as evidenced by the dark/light media color difference at the knife edge seal interface. The outside surface of the filter is darkened by contamination and most of the contaminant has been trapped in the outer third of the media.

Value Added Service

The cost of this service if provided by an independent laboratory would have been $500.00.

APPENDIX C

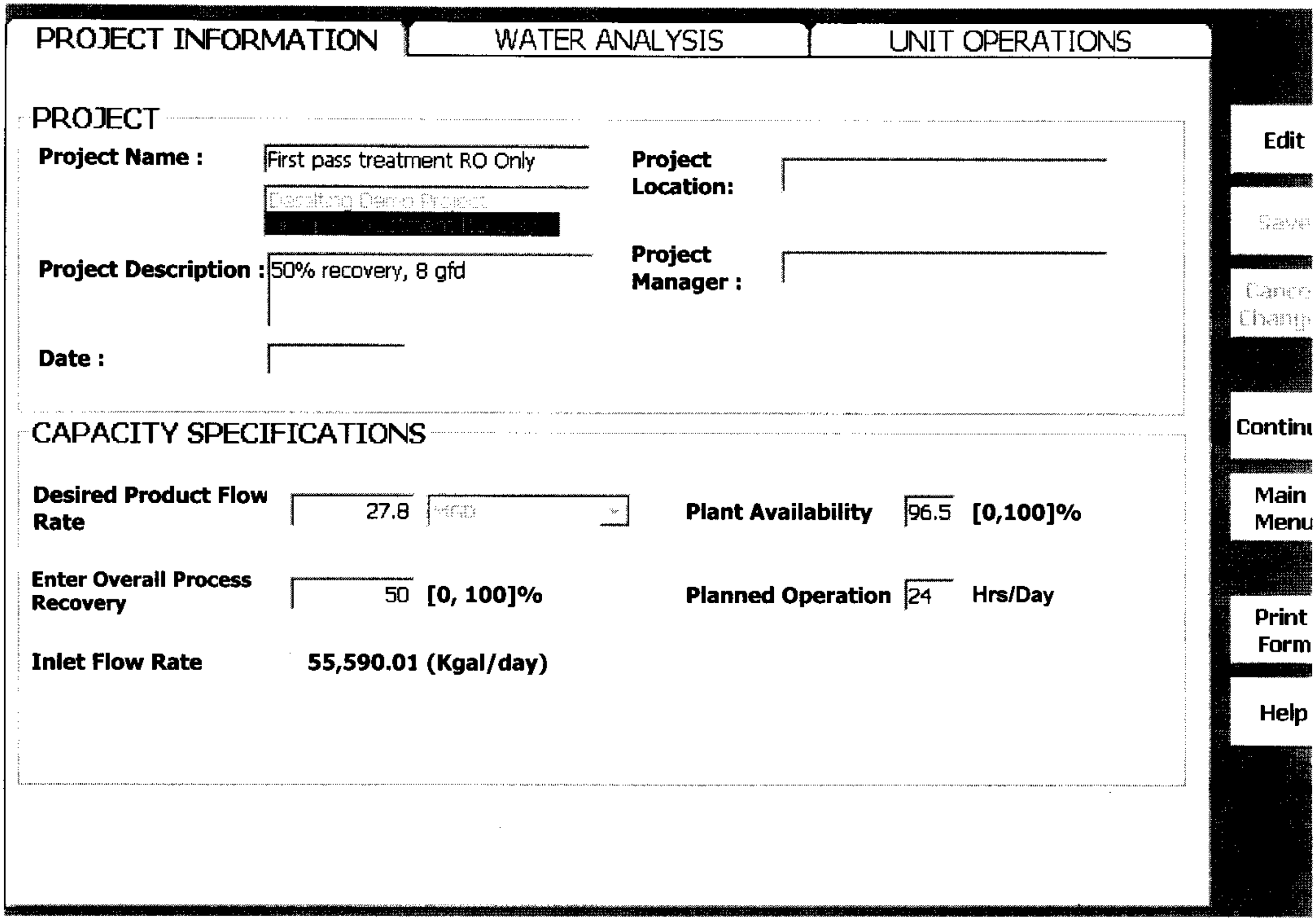
COST ESTIMATES



Cost Indices Date 8/30/2005

ENR - Engineering News Record Construction Cost Index published monthly by McGraw Hill in New York City (212) 512-2000 (see http://www.enr.com)

ENR Construction Cost Index	7478.51	**Manufactured and Electrical Equipment**
ENR Building Cost Index	4209.7	**Housing**
ENR Skilled Labor Index	7064.5	**Excavation, Site Work and Labor**
ENR Materials Index	2465.58	**Piping, Valves, and Maintenance Materials**
ENR Steel Cost ($/cwt)	33.83	**Steel**
ENR Cement Cost ($/ton)	87.82	**Concrete**
Electricity Cost ($/kWh)	0.05	**Power**
ENR Labor Rate	25	**Labor**
Interest Rate (%)	5.69	**Interest on Construction and Bond Money**
Amortization Time (yr)	30	**For Bond Period**
Water Rate ($/kgal)	0	**Cost of Feed Source Water**



PROJECT

Project Name : First pass treatment RO Only

Desalting Demo Project

[illegible]

Project Description : 50% recovery, 8 gfd

Date :

Project Location:

Project Manager :

CAPACITY SPECIFICATIONS

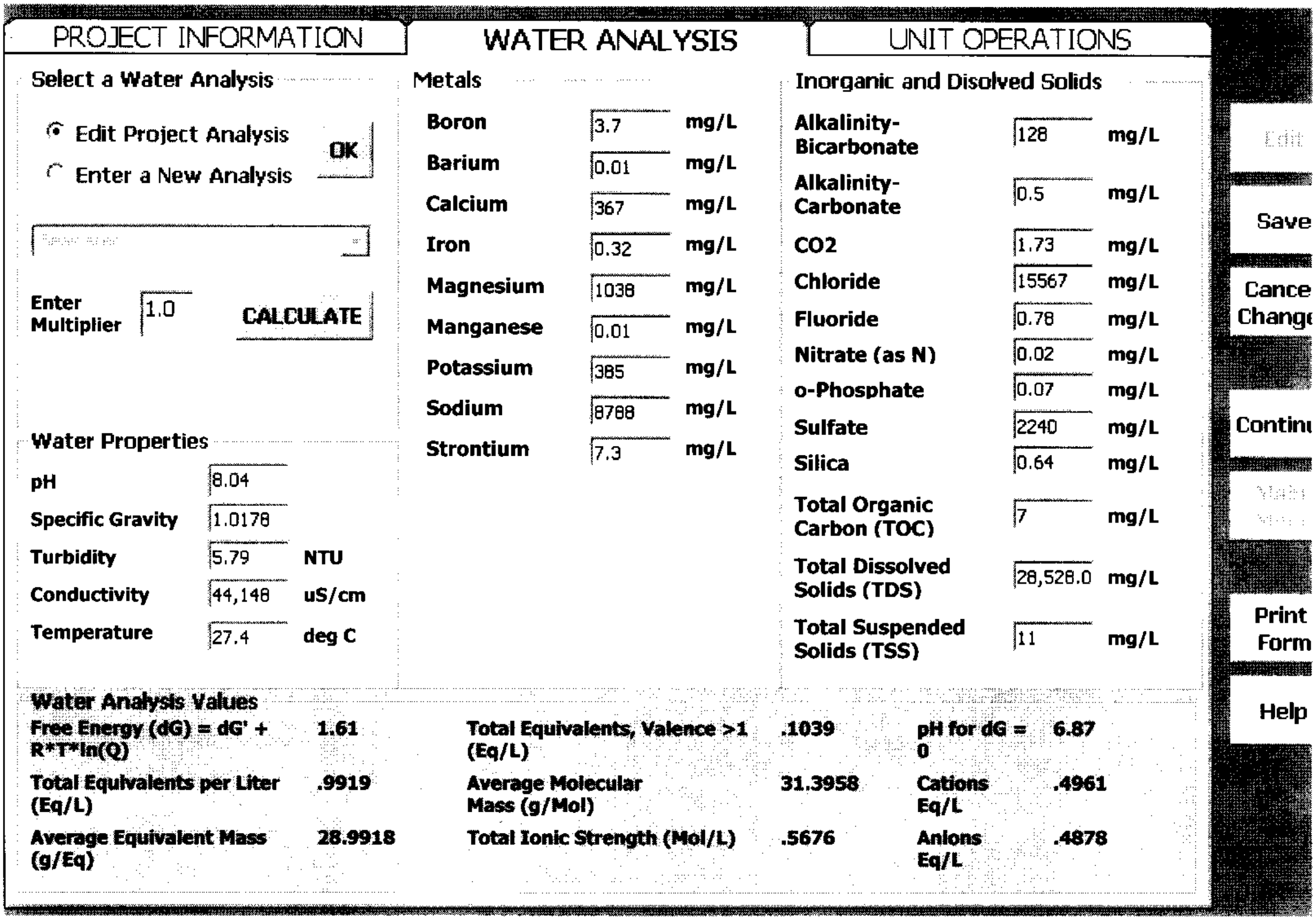
Desired Product Flow Rate 27.8 MGD

Enter Overall Process Recovery 50 **[0, 100]%**

Inlet Flow Rate **55,590.01 (Kgal/day)**

Plant Availability 96.5 **[0,100]%**

Planned Operation 24 **Hrs/Day**



Select a Water Analysis

● Edit Project Analysis
○ Enter a New Analysis

Enter Multiplier: 1.0

Water Properties

pH	8.04	
Specific Gravity	1.0178	
Turbidity	5.79	NTU
Conductivity	44,148	uS/cm
Temperature	27.4	deg C

Metals

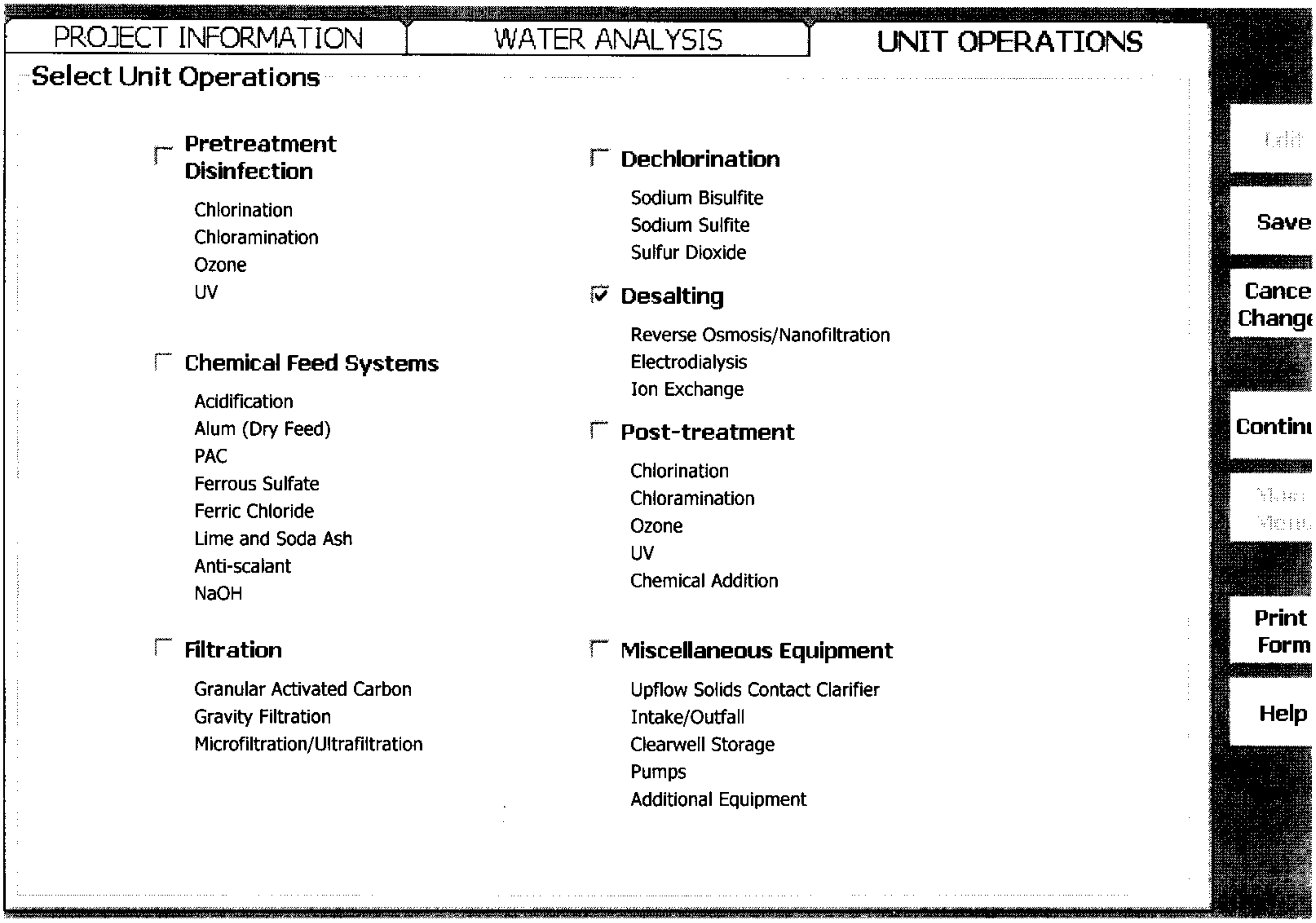
Boron	3.7	mg/L
Barium	0.01	mg/L
Calcium	367	mg/L
Iron	0.32	mg/L
Magnesium	1038	mg/L
Manganese	0.01	mg/L
Potassium	385	mg/L
Sodium	8788	mg/L
Strontium	7.3	mg/L

Inorganic and Disolved Solids

Alkalinity-Bicarbonate	128	mg/L
Alkalinity-Carbonate	0.5	mg/L
CO2	1.73	mg/L
Chloride	15567	mg/L
Fluoride	0.78	mg/L
Nitrate (as N)	0.02	mg/L
o-Phosphate	0.07	mg/L
Sulfate	2240	mg/L
Silica	0.64	mg/L
Total Organic Carbon (TOC)	7	mg/L
Total Dissolved Solids (TDS)	28,528.0	mg/L
Total Suspended Solids (TSS)	11	mg/L

Water Analysis Values

Free Energy (dG) = dG' + R*T*ln(Q)	1.61	Total Equivalents, Valence >1 (Eq/L)	.1039	pH for dG = 0	6.87
Total Equivalents per Liter (Eq/L)	.9919	Average Molecular Mass (g/Mol)	31.3958	Cations Eq/L	.4961
Average Equivalent Mass (g/Eq)	28.9918	Total Ionic Strength (Mol/L)	.5676	Anions Eq/L	.4878



Select Unit Operations

☐ **Pretreatment Disinfection**
- Chlorination
- Chloramination
- Ozone
- UV

☐ **Chemical Feed Systems**
- Acidification
- Alum (Dry Feed)
- PAC
- Ferrous Sulfate
- Ferric Chloride
- Lime and Soda Ash
- Anti-scalant
- NaOH

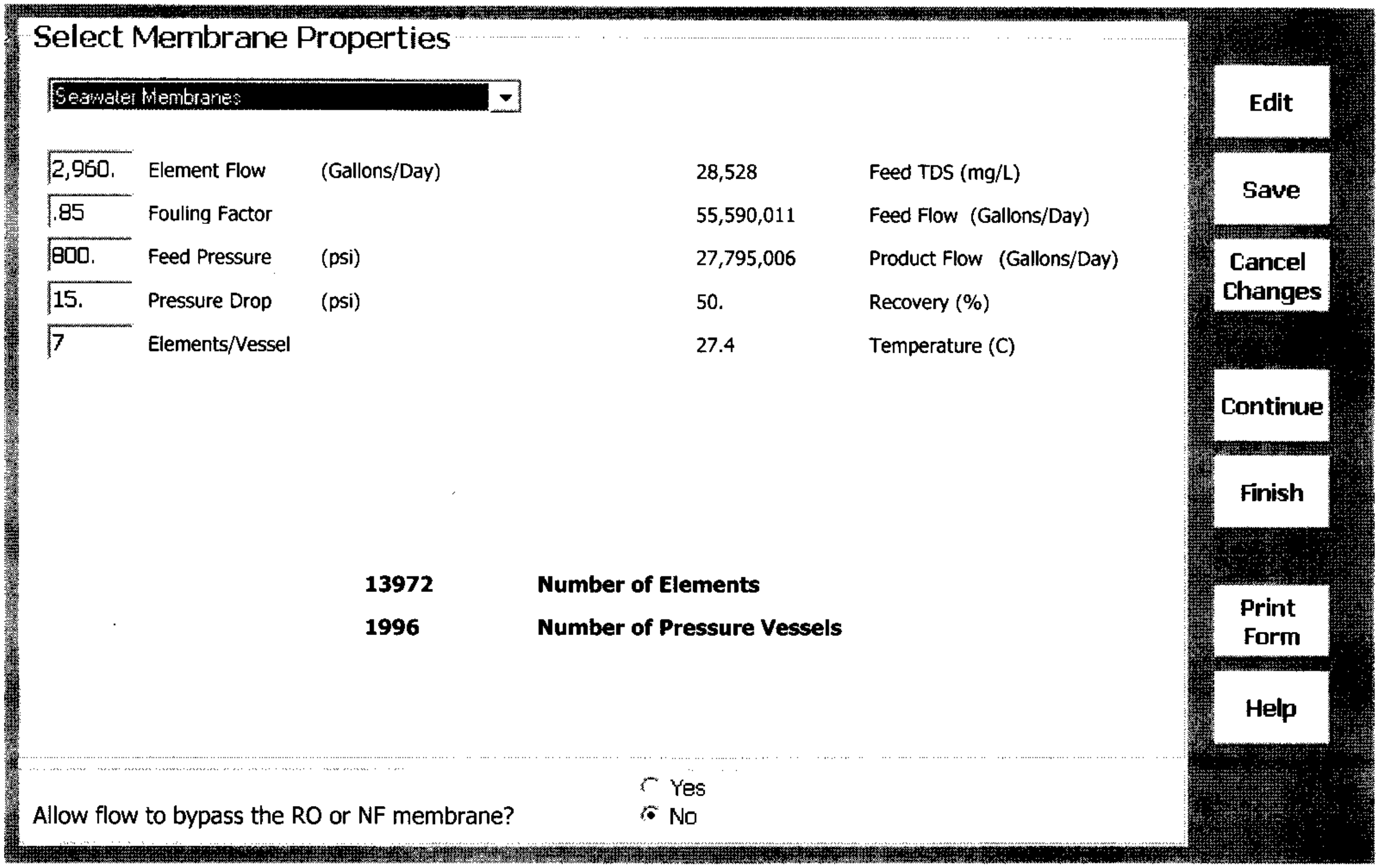
☐ **Filtration**
- Granular Activated Carbon
- Gravity Filtration
- Microfiltration/Ultrafiltration

☐ **Dechlorination**
- Sodium Bisulfite
- Sodium Sulfite
- Sulfur Dioxide

☑ **Desalting**
- Reverse Osmosis/Nanofiltration
- Electrodialysis
- Ion Exchange

☐ **Post-treatment**
- Chlorination
- Chloramination
- Ozone
- UV
- Chemical Addition

☐ **Miscellaneous Equipment**
- Upflow Solids Contact Clarifier
- Intake/Outfall
- Clearwell Storage
- Pumps
- Additional Equipment



Select Membrane Properties

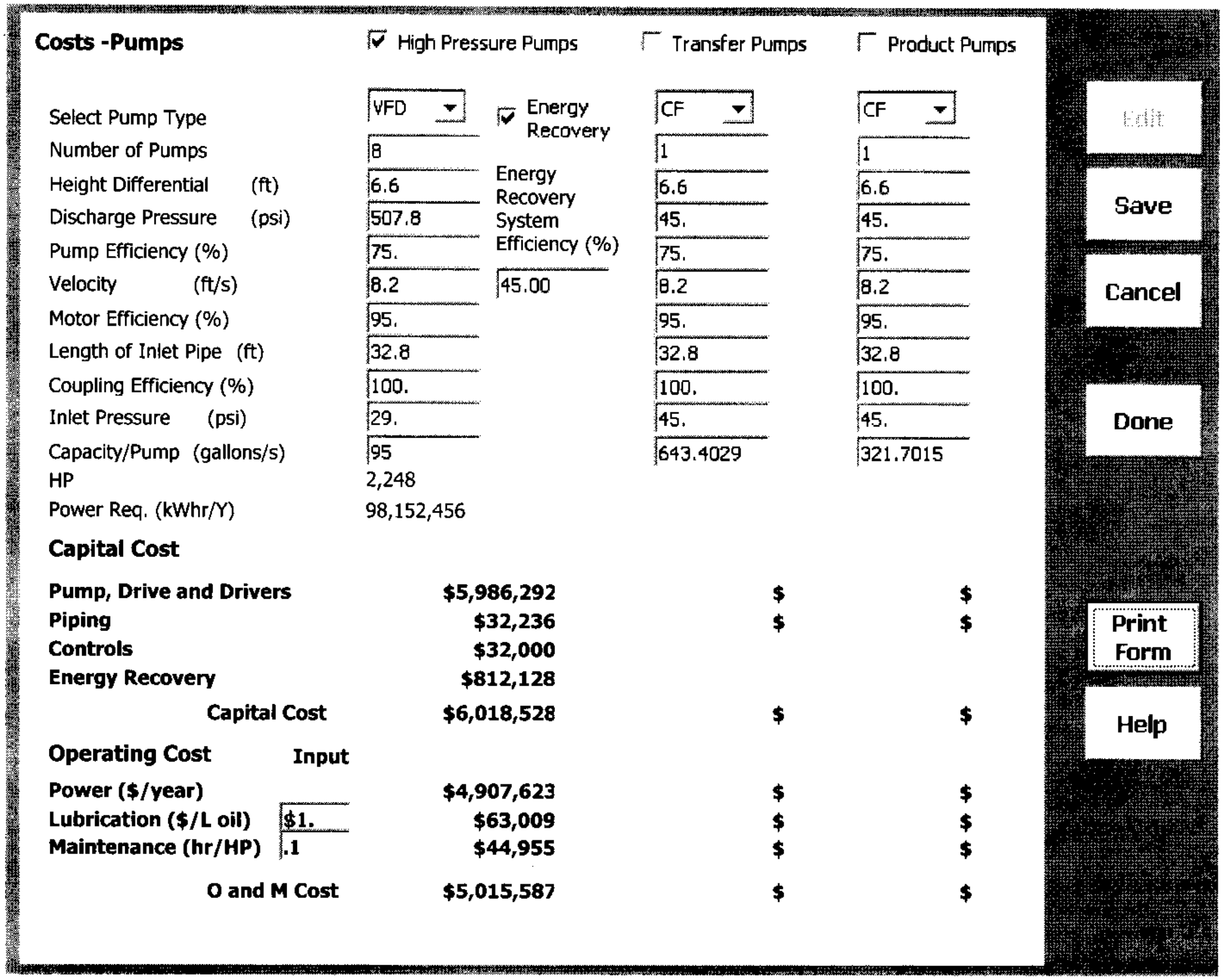
Seawater Membranes

2,960.	Element Flow (Gallons/Day)		28,528	Feed TDS (mg/L)
.85	Fouling Factor		55,590,011	Feed Flow (Gallons/Day)
800.	Feed Pressure	(psi)	27,795,006	Product Flow (Gallons/Day)
15.	Pressure Drop	(psi)	50.	Recovery (%)
7	Elements/Vessel		27.4	Temperature (C)

13972 **Number of Elements**

1996 **Number of Pressure Vessels**

Allow flow to bypass the RO or NF membrane? ○ Yes ● No



Costs -Pumps

☑ High Pressure Pumps ☐ Transfer Pumps ☐ Product Pumps

	High Pressure Pumps	Transfer Pumps	Product Pumps
Select Pump Type	VFD	CF	CF
Number of Pumps	8	1	1
Height Differential (ft)	6.6	6.6	6.6
Discharge Pressure (psi)	507.8	45.	45.
Pump Efficiency (%)	75.	75.	75.
Velocity (ft/s)	8.2	8.2	8.2
Motor Efficiency (%)	95.	95.	95.
Length of Inlet Pipe (ft)	32.8	32.8	32.8
Coupling Efficiency (%)	100.	100.	100.
Inlet Pressure (psi)	29.	45.	45.
Capacity/Pump (gallons/s)	95	643.4029	321.7015
HP	2,248		
Power Req. (kWhr/Y)	98,152,456		

☑ Energy Recovery

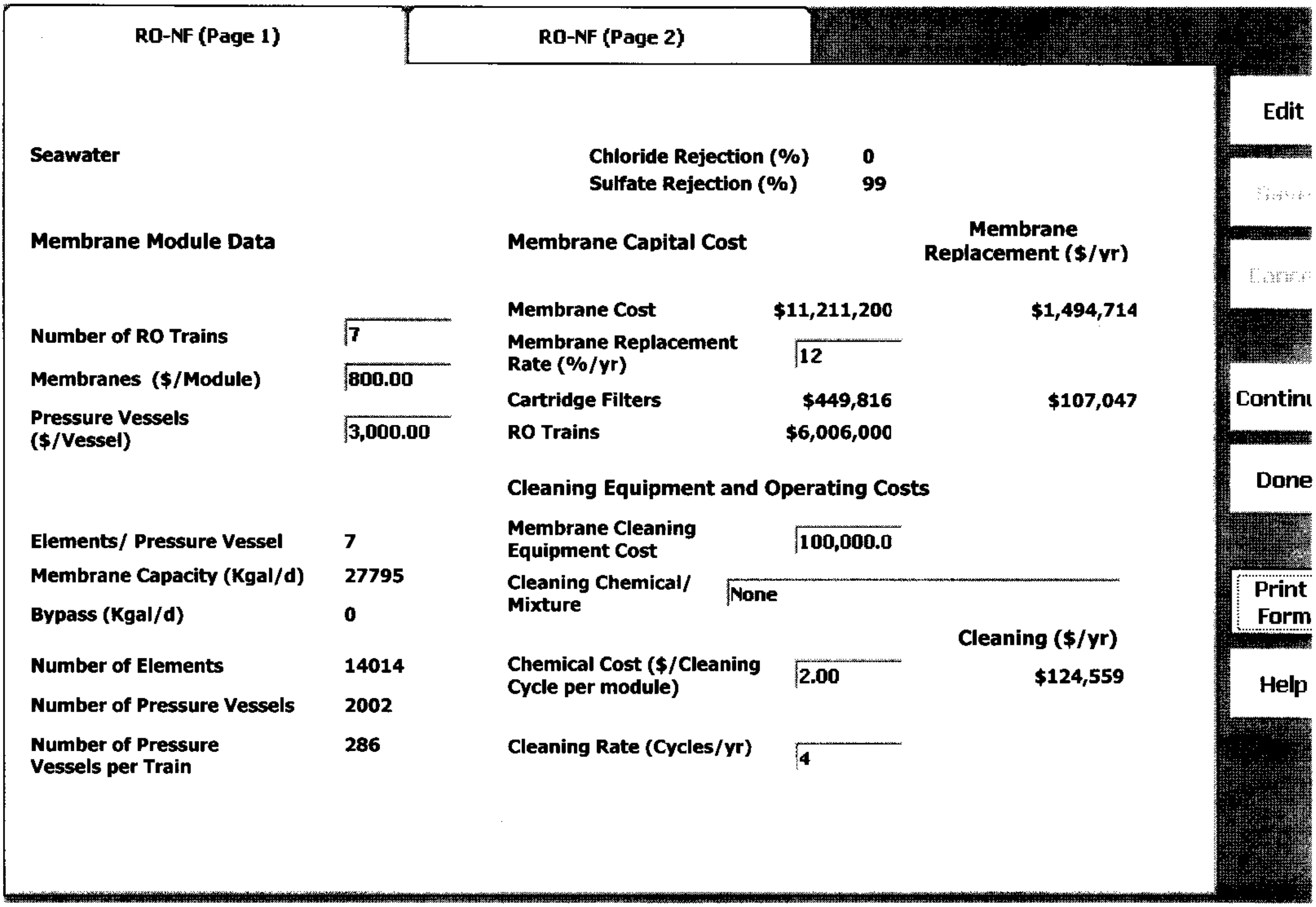
Energy Recovery System Efficiency (%): 45.00

Capital Cost

Pump, Drive and Drivers	**$5,986,292**	**$**	**$**
Piping	**$32,236**	**$**	**$**
Controls	**$32,000**		
Energy Recovery	**$812,128**		
Capital Cost	**$6,018,528**	**$**	**$**

Operating Cost

	Input			
Power ($/year)		**$4,907,623**	**$**	**$**
Lubrication ($/L oil)	$1.	**$63,009**	**$**	**$**
Maintenance (hr/HP)	.1	**$44,955**	**$**	**$**
O and M Cost		**$5,015,587**	**$**	**$**



Seawater

Chloride Rejection (%)	0
Sulfate Rejection (%)	99

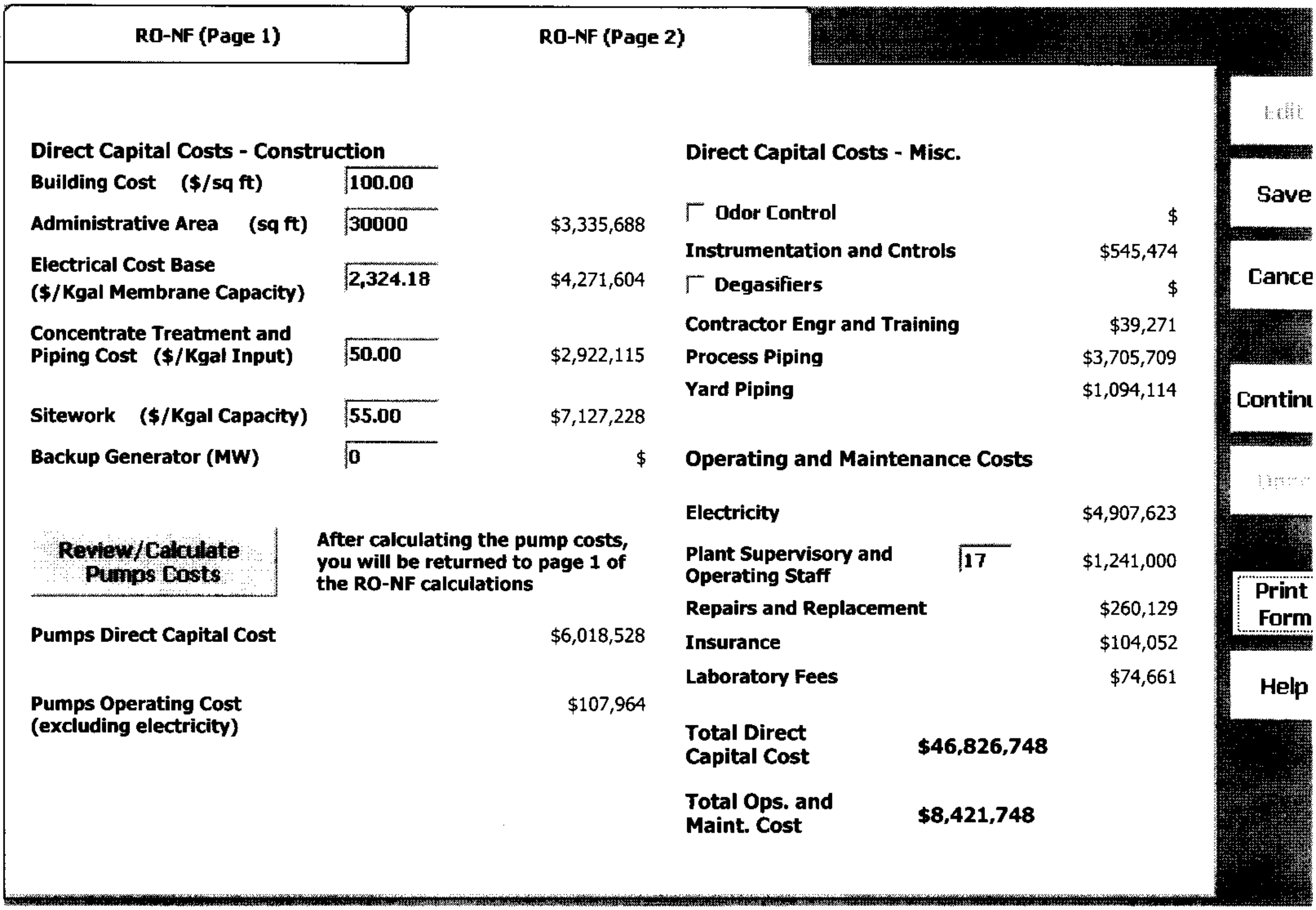
Membrane Module Data

Number of RO Trains	7
Membranes ($/Module)	800.00
Pressure Vessels ($/Vessel)	3,000.00
Elements/ Pressure Vessel	7
Membrane Capacity (Kgal/d)	27795
Bypass (Kgal/d)	0
Number of Elements	14014
Number of Pressure Vessels	2002
Number of Pressure Vessels per Train	286

Membrane Capital Cost		Membrane Replacement ($/yr)
Membrane Cost	$11,211,200	$1,494,714
Membrane Replacement Rate (%/yr)	12	
Cartridge Filters	$449,816	$107,047
RO Trains	$6,006,000	

Cleaning Equipment and Operating Costs

		Cleaning ($/yr)
Membrane Cleaning Equipment Cost	100,000.0	
Cleaning Chemical/ Mixture	None	
Chemical Cost ($/Cleaning Cycle per module)	2.00	$124,559
Cleaning Rate (Cycles/yr)	4	



Direct Capital Costs - Construction

Building Cost ($/sq ft)	100.00	
Administrative Area (sq ft)	30000	$3,335,688
Electrical Cost Base ($/Kgal Membrane Capacity)	2,324.18	$4,271,604
Concentrate Treatment and Piping Cost ($/Kgal Input)	50.00	$2,922,115
Sitework ($/Kgal Capacity)	55.00	$7,127,228
Backup Generator (MW)	0	$

After calculating the pump costs, you will be returned to page 1 of the RO-NF calculations

Pumps Direct Capital Cost	$6,018,528
Pumps Operating Cost (excluding electricity)	$107,964

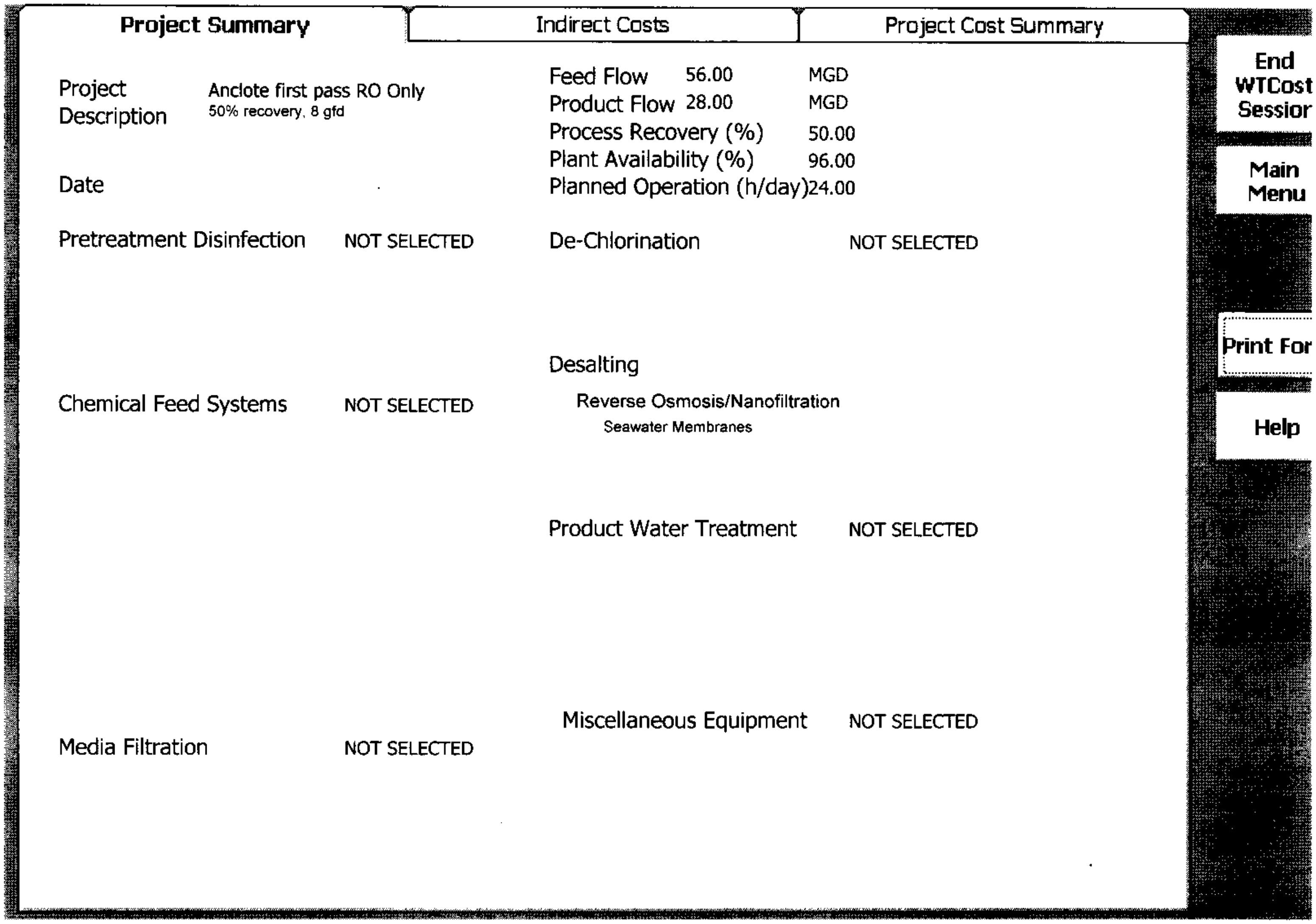
Direct Capital Costs - Misc.

☐ Odor Control	$
Instrumentation and Cntrols	$545,474
☐ Degasifiers	$
Contractor Engr and Training	$39,271
Process Piping	$3,705,709
Yard Piping	$1,094,114

Operating and Maintenance Costs

Electricity		$4,907,623
Plant Supervisory and Operating Staff	17	$1,241,000
Repairs and Replacement		$260,129
Insurance		$104,052
Laboratory Fees		$74,661

Total Direct Capital Cost	**$46,826,748**
Total Ops. and Maint. Cost	**$8,421,748**



Project Description: Anclote first pass RO Only
50% recovery, 8 gfd

Date

Feed Flow 56.00 MGD
Product Flow 28.00 MGD
Process Recovery (%) 50.00
Plant Availability (%) 96.00
Planned Operation (h/day) 24.00

Pretreatment Disinfection NOT SELECTED

De-Chlorination NOT SELECTED

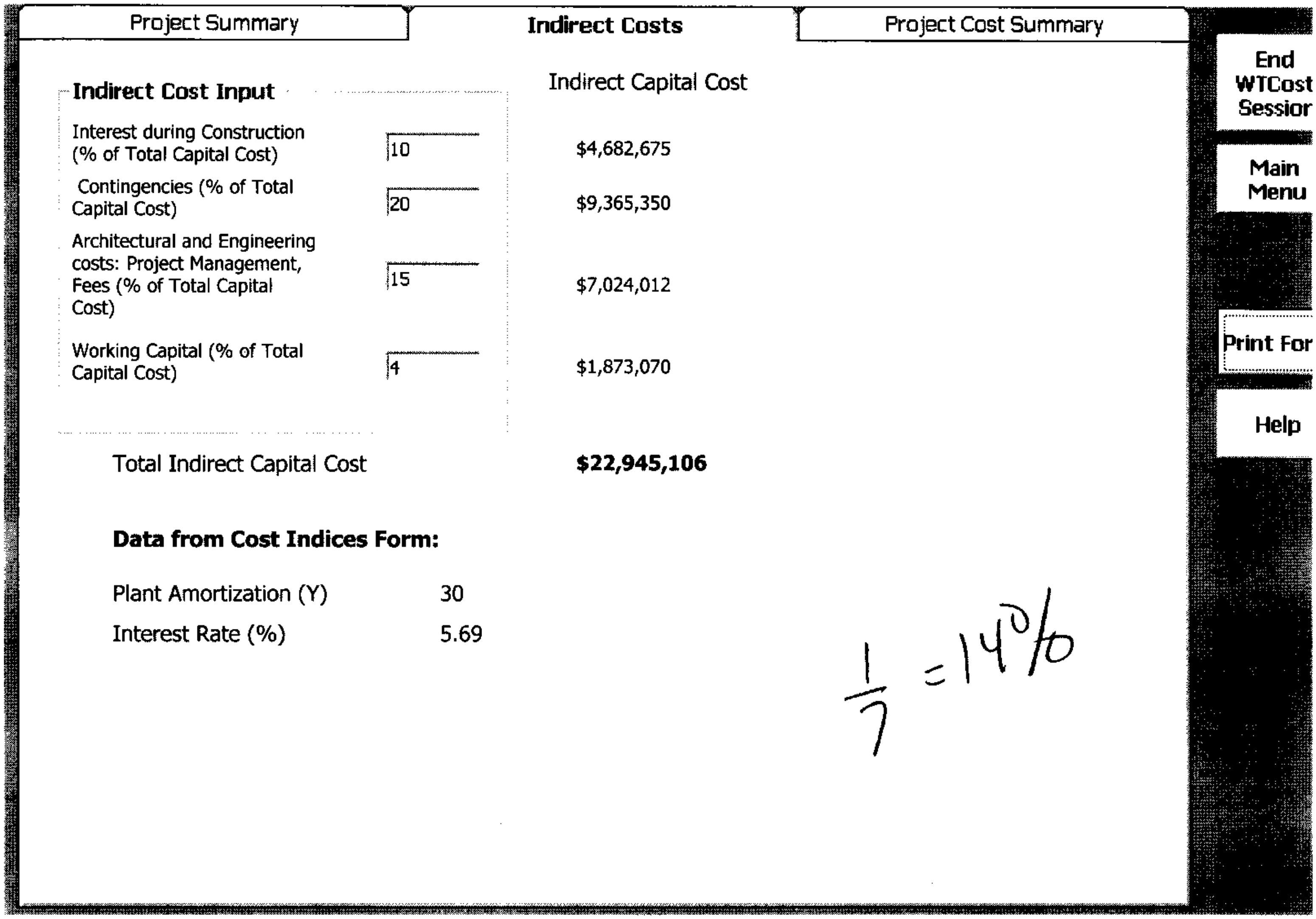
Desalting
Reverse Osmosis/Nanofiltration
Seawater Membranes

Chemical Feed Systems NOT SELECTED

Product Water Treatment NOT SELECTED

Miscellaneous Equipment NOT SELECTED

Media Filtration NOT SELECTED



Indirect Cost Input

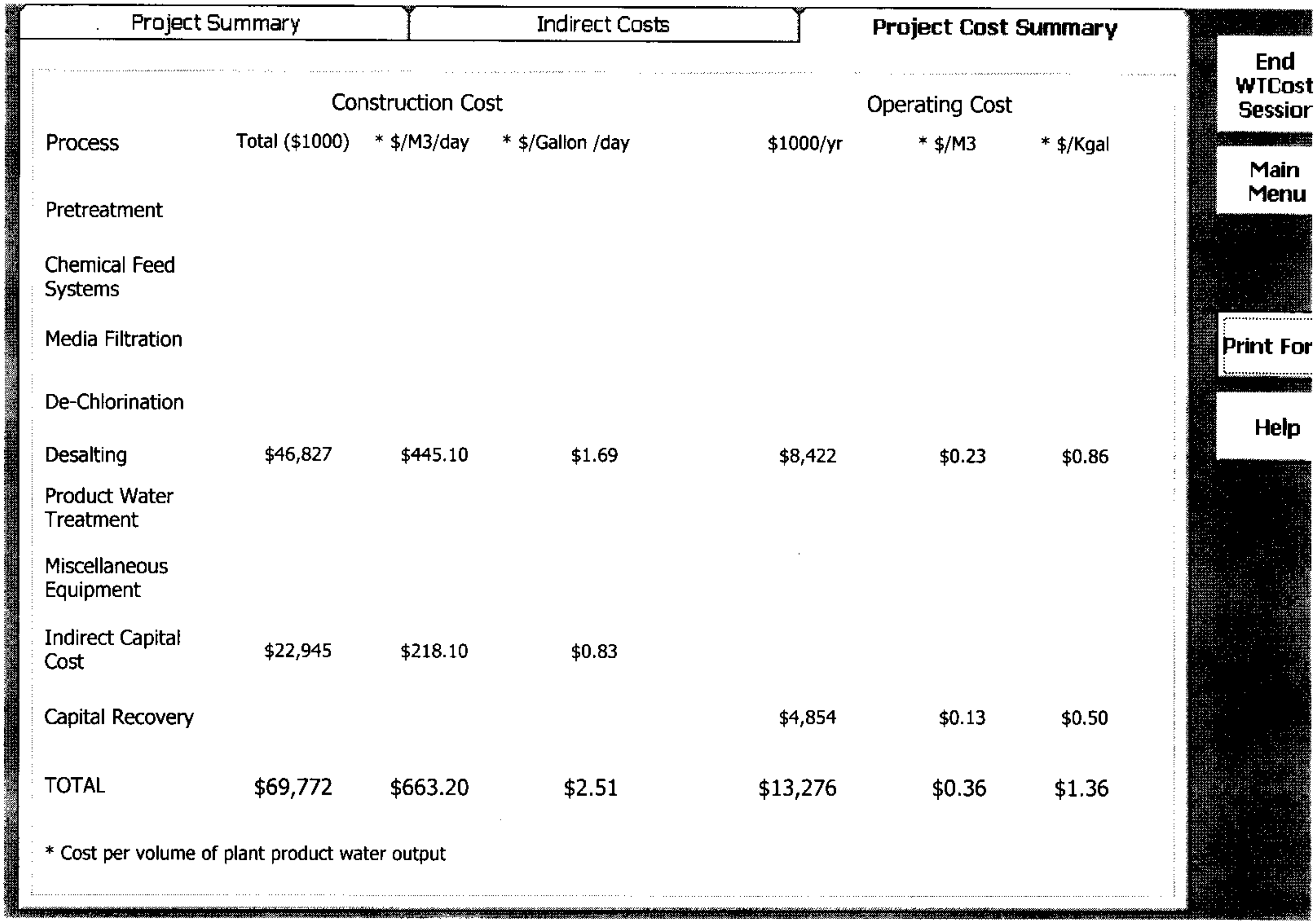
		Indirect Capital Cost
Interest during Construction (% of Total Capital Cost)	10	$4,682,675
Contingencies (% of Total Capital Cost)	20	$9,365,350
Architectural and Engineering costs: Project Management, Fees (% of Total Capital Cost)	15	$7,024,012
Working Capital (% of Total Capital Cost)	4	$1,873,070

Total Indirect Capital Cost **$22,945,106**

Data from Cost Indices Form:

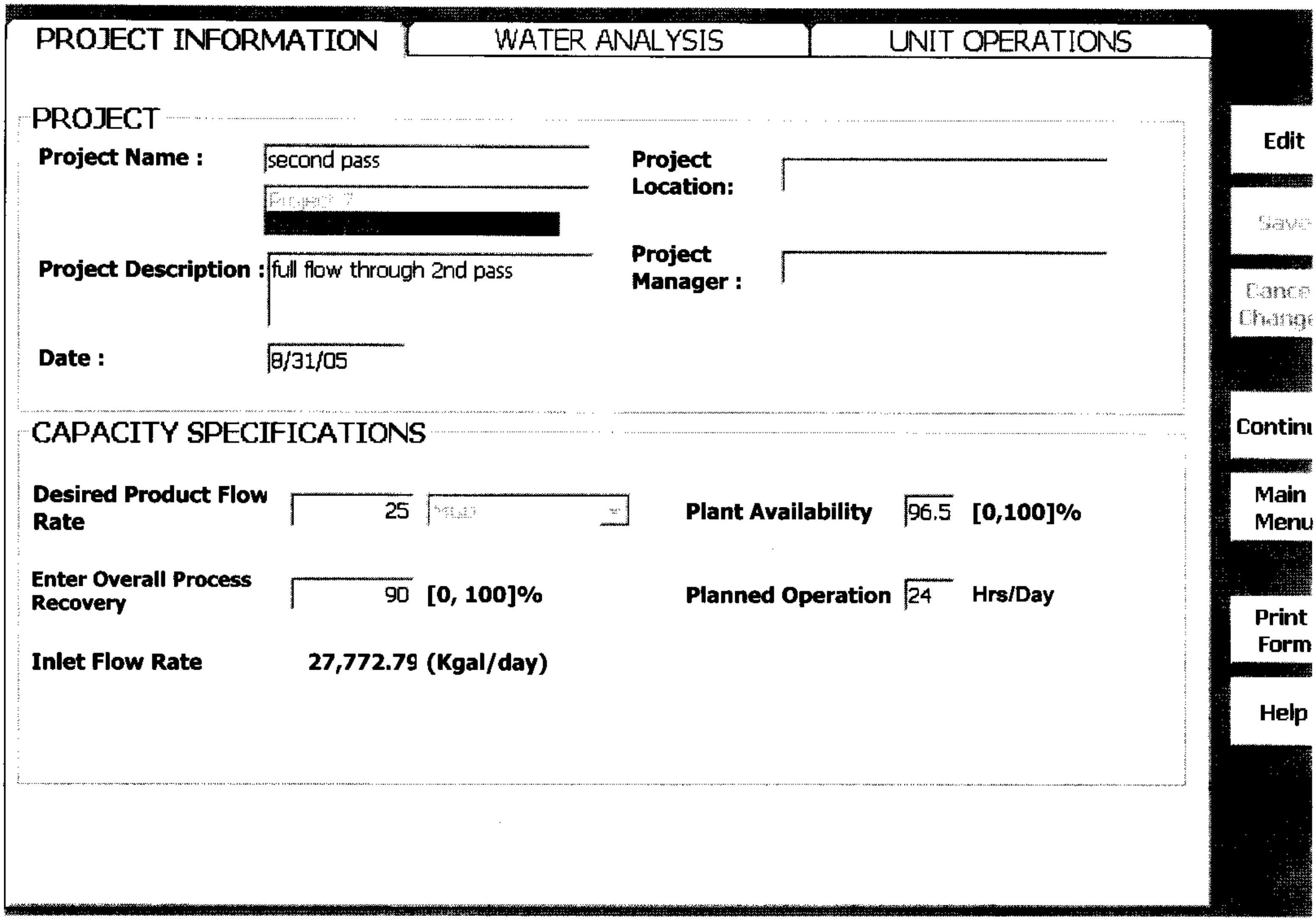
Plant Amortization (Y)	30
Interest Rate (%)	5.69

$\frac{1}{7} = 14\%$



Process	Construction Cost			Operating Cost		
	Total ($1000)	* $/M3/day	* $/Gallon /day	$1000/yr	* $/M3	* $/Kgal
Pretreatment						
Chemical Feed Systems						
Media Filtration						
De-Chlorination						
Desalting	$46,827	$445.10	$1.69	$8,422	$0.23	$0.86
Product Water Treatment						
Miscellaneous Equipment						
Indirect Capital Cost	$22,945	$218.10	$0.83			
Capital Recovery				$4,854	$0.13	$0.50
TOTAL	$69,772	$663.20	$2.51	$13,276	$0.36	$1.36

* Cost per volume of plant product water output



PROJECT

Project Name : second pass

Project 7

[redacted]

Project Location:

Project Description : full flow through 2nd pass

Project Manager :

Date : 8/31/05

CAPACITY SPECIFICATIONS

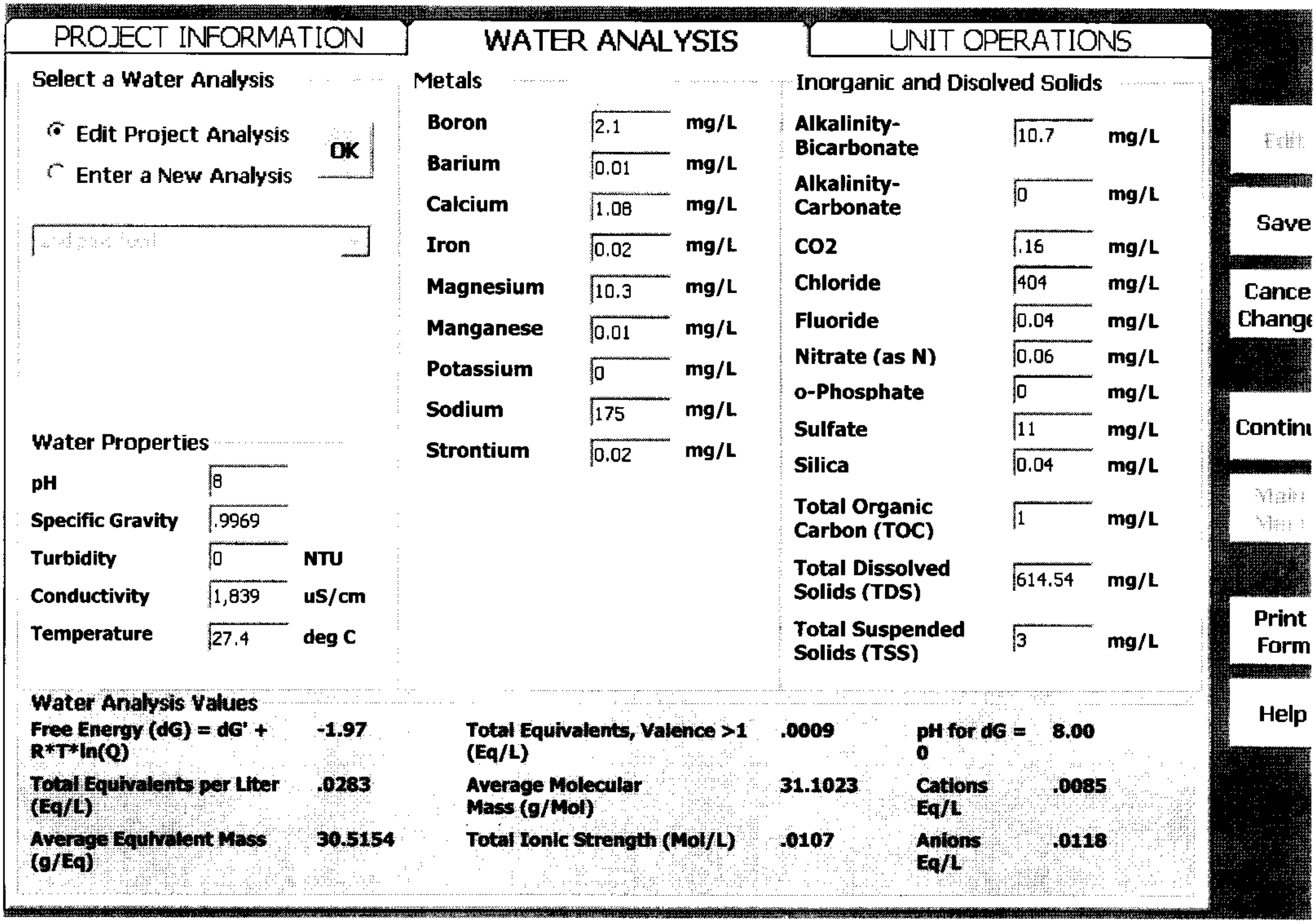
Desired Product Flow Rate 25 MGD

Plant Availability 96.5 **[0,100]%**

Enter Overall Process Recovery 90 **[0, 100]%**

Planned Operation 24 **Hrs/Day**

Inlet Flow Rate **27,772.79 (Kgal/day)**



Select a Water Analysis

● Edit Project Analysis

○ Enter a New Analysis

Water Properties

pH	8	
Specific Gravity	.9969	
Turbidity	0	NTU
Conductivity	1,839	uS/cm
Temperature	27.4	deg C

Metals

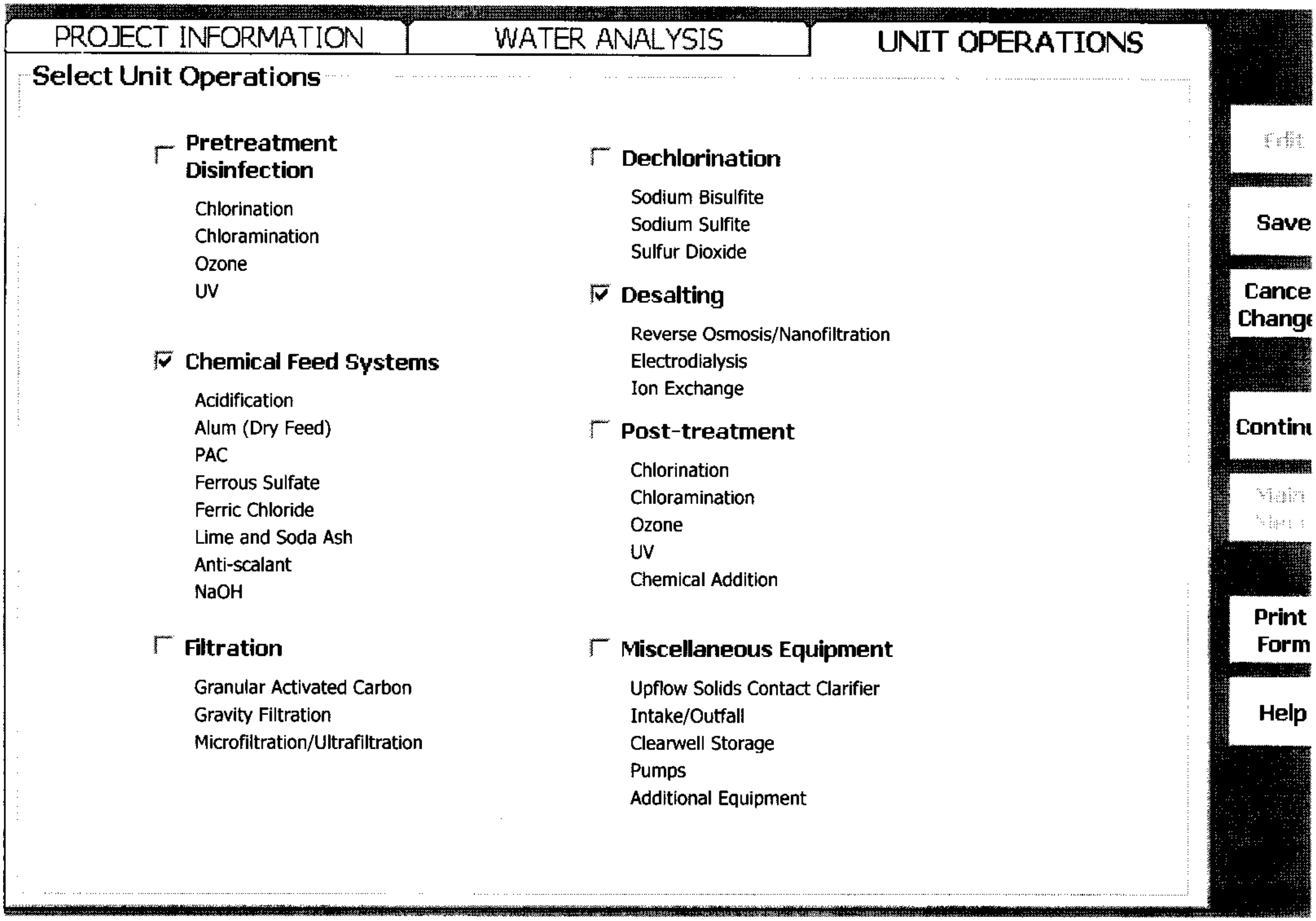
Boron	2.1	mg/L
Barium	0.01	mg/L
Calcium	1.08	mg/L
Iron	0.02	mg/L
Magnesium	10.3	mg/L
Manganese	0.01	mg/L
Potassium	0	mg/L
Sodium	175	mg/L
Strontium	0.02	mg/L

Inorganic and Disolved Solids

Alkalinity-Bicarbonate	10.7	mg/L
Alkalinity-Carbonate	0	mg/L
CO2	.16	mg/L
Chloride	404	mg/L
Fluoride	0.04	mg/L
Nitrate (as N)	0.06	mg/L
o-Phosphate	0	mg/L
Sulfate	11	mg/L
Silica	0.04	mg/L
Total Organic Carbon (TOC)	1	mg/L
Total Dissolved Solids (TDS)	614.54	mg/L
Total Suspended Solids (TSS)	3	mg/L

Water Analysis Values

Free Energy (dG) = dG' + R*T*ln(Q)	-1.97	Total Equivalents, Valence >1 (Eq/L)	.0009	pH for dG = 0	8.00
Total Equivalents per Liter (Eq/L)	.0283	Average Molecular Mass (g/Mol)	31.1023	Cations Eq/L	.0085
Average Equivalent Mass (g/Eq)	30.5154	Total Ionic Strength (Mol/L)	.0107	Anions Eq/L	.0118



Select Unit Operations

☐ **Pretreatment Disinfection**
- Chlorination
- Chloramination
- Ozone
- UV

☑ **Chemical Feed Systems**
- Acidification
- Alum (Dry Feed)
- PAC
- Ferrous Sulfate
- Ferric Chloride
- Lime and Soda Ash
- Anti-scalant
- NaOH

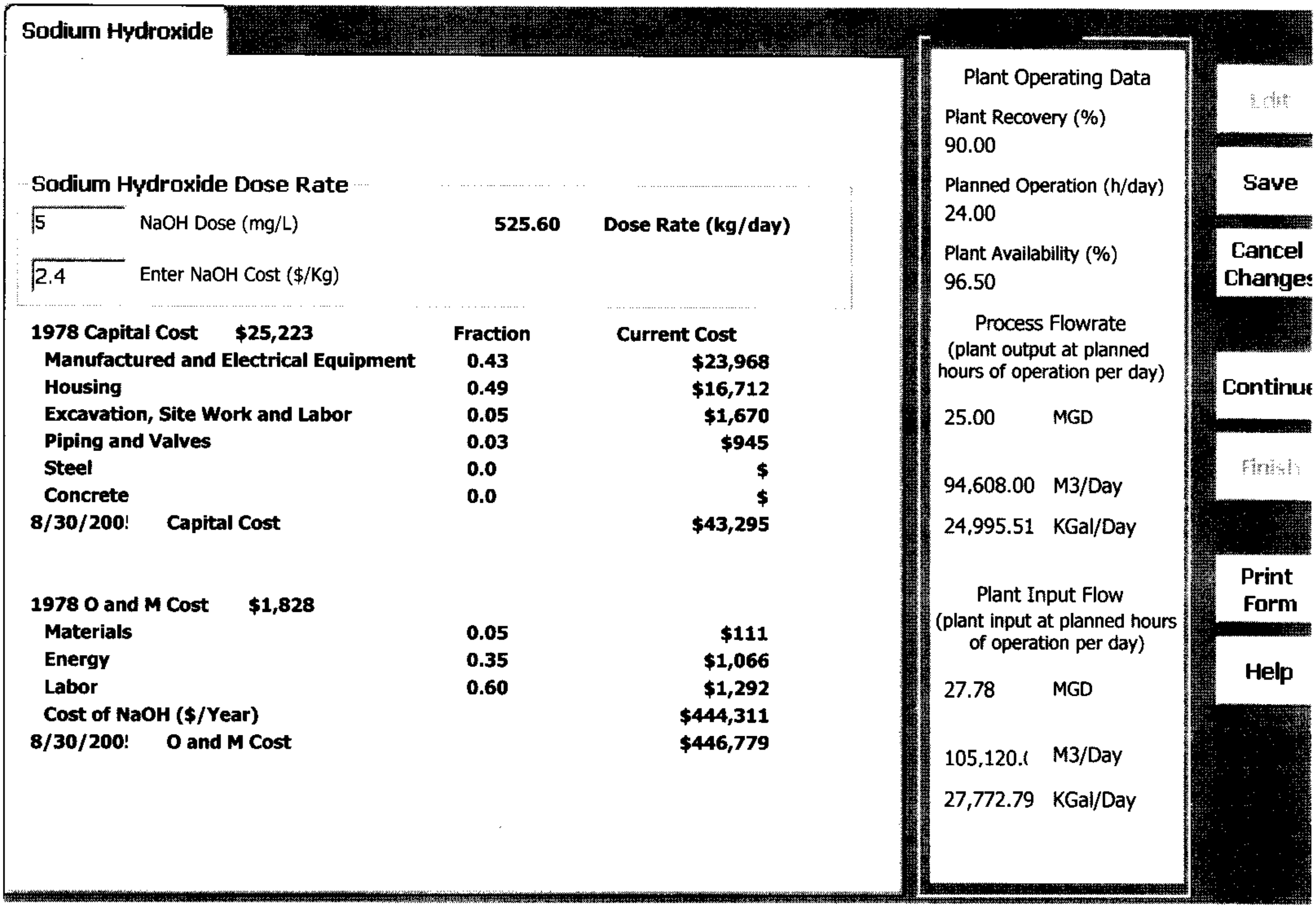
☐ **Filtration**
- Granular Activated Carbon
- Gravity Filtration
- Microfiltration/Ultrafiltration

☐ **Dechlorination**
- Sodium Bisulfite
- Sodium Sulfite
- Sulfur Dioxide

☑ **Desalting**
- Reverse Osmosis/Nanofiltration
- Electrodialysis
- Ion Exchange

☐ **Post-treatment**
- Chlorination
- Chloramination
- Ozone
- UV
- Chemical Addition

☐ **Miscellaneous Equipment**
- Upflow Solids Contact Clarifier
- Intake/Outfall
- Clearwell Storage
- Pumps
- Additional Equipment



Sodium Hydroxide Dose Rate

5 NaOH Dose (mg/L) **525.60** **Dose Rate (kg/day)**

2.4 Enter NaOH Cost ($/Kg)

1978 Capital Cost	**$25,223**	**Fraction**	**Current Cost**
Manufactured and Electrical Equipment		**0.43**	**$23,968**
Housing		**0.49**	**$16,712**
Excavation, Site Work and Labor		**0.05**	**$1,670**
Piping and Valves		**0.03**	**$945**
Steel		**0.0**	**$**
Concrete		**0.0**	**$**
8/30/200!	**Capital Cost**		**$43,295**
1978 O and M Cost	**$1,828**		
Materials		**0.05**	**$111**
Energy		**0.35**	**$1,066**
Labor		**0.60**	**$1,292**
Cost of NaOH ($/Year)			**$444,311**
8/30/200!	**O and M Cost**		**$446,779**

Plant Operating Data

Plant Recovery (%)
90.00

Planned Operation (h/day)
24.00

Plant Availability (%)
96.50

Process Flowrate
(plant output at planned hours of operation per day)

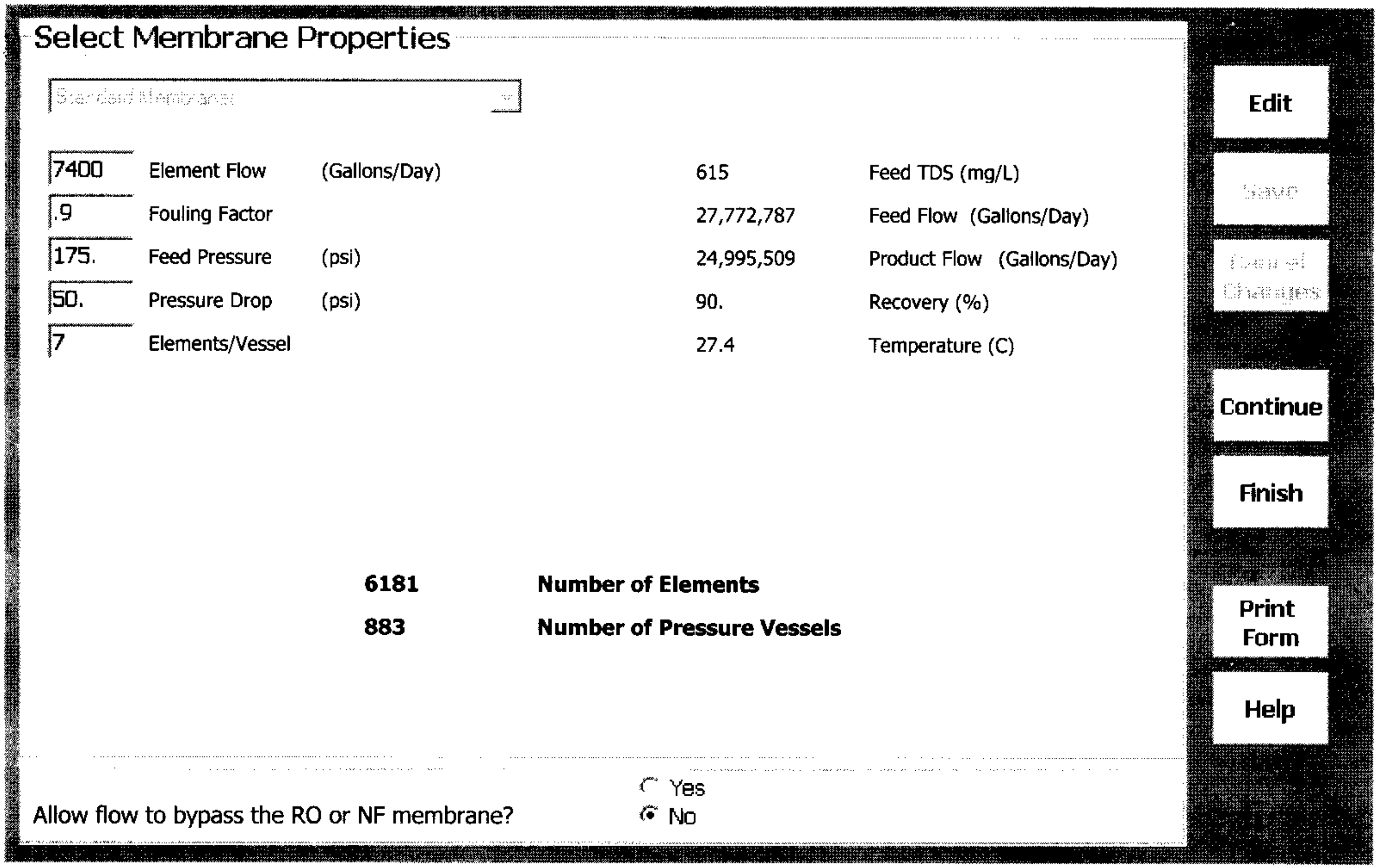
25.00 MGD

94,608.00 M3/Day
24,995.51 KGal/Day

Plant Input Flow
(plant input at planned hours of operation per day)

27.78 MGD

105,120.(M3/Day
27,772.79 KGal/Day



Select Membrane Properties

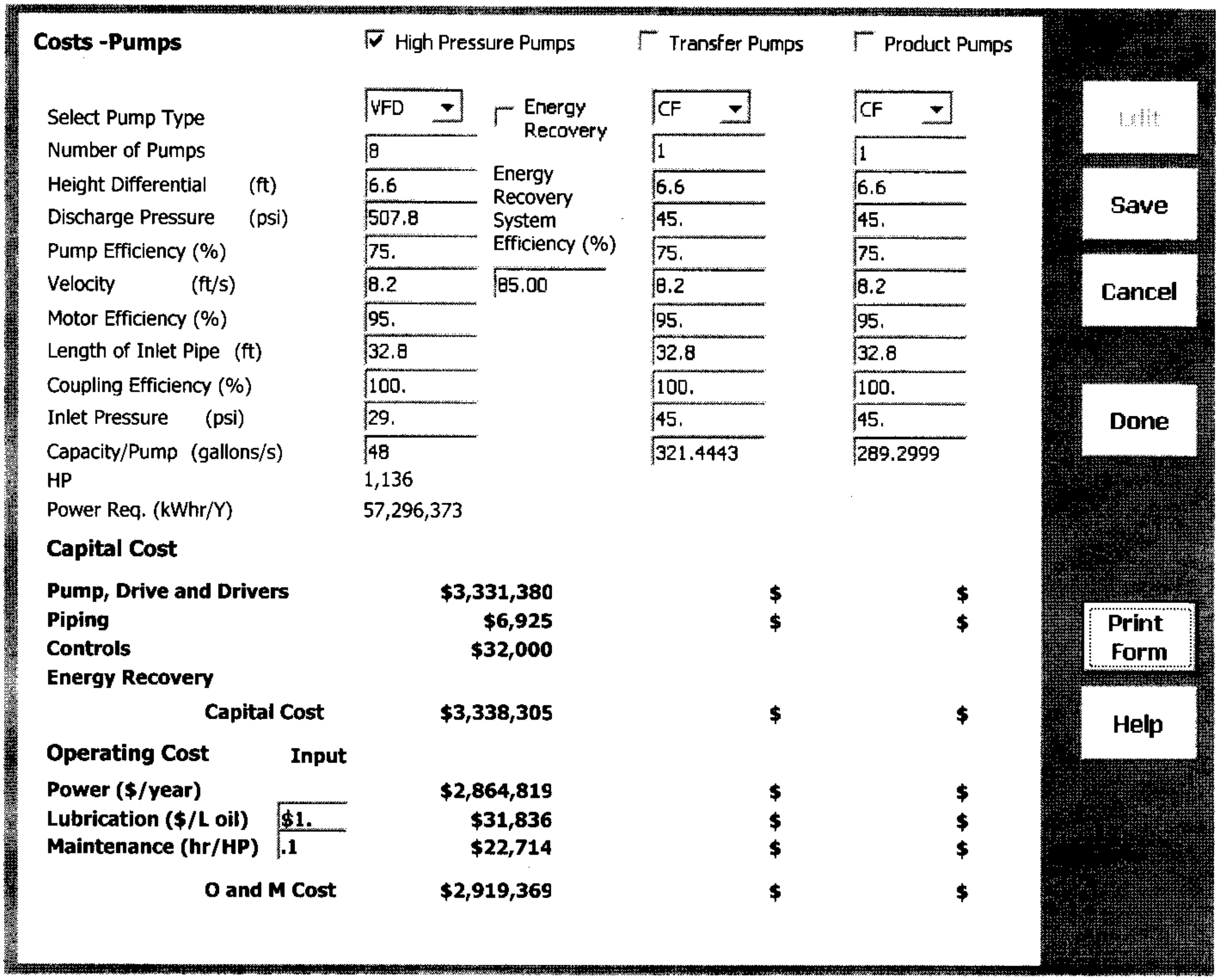
Standard Membranes

7400	Element Flow (Gallons/Day)		615	Feed TDS (mg/L)
.9	Fouling Factor		27,772,787	Feed Flow (Gallons/Day)
175.	Feed Pressure (psi)		24,995,509	Product Flow (Gallons/Day)
50.	Pressure Drop (psi)		90.	Recovery (%)
7	Elements/Vessel		27.4	Temperature (C)

6181 Number of Elements

883 Number of Pressure Vessels

Allow flow to bypass the RO or NF membrane? ○ Yes ● No



Costs -Pumps

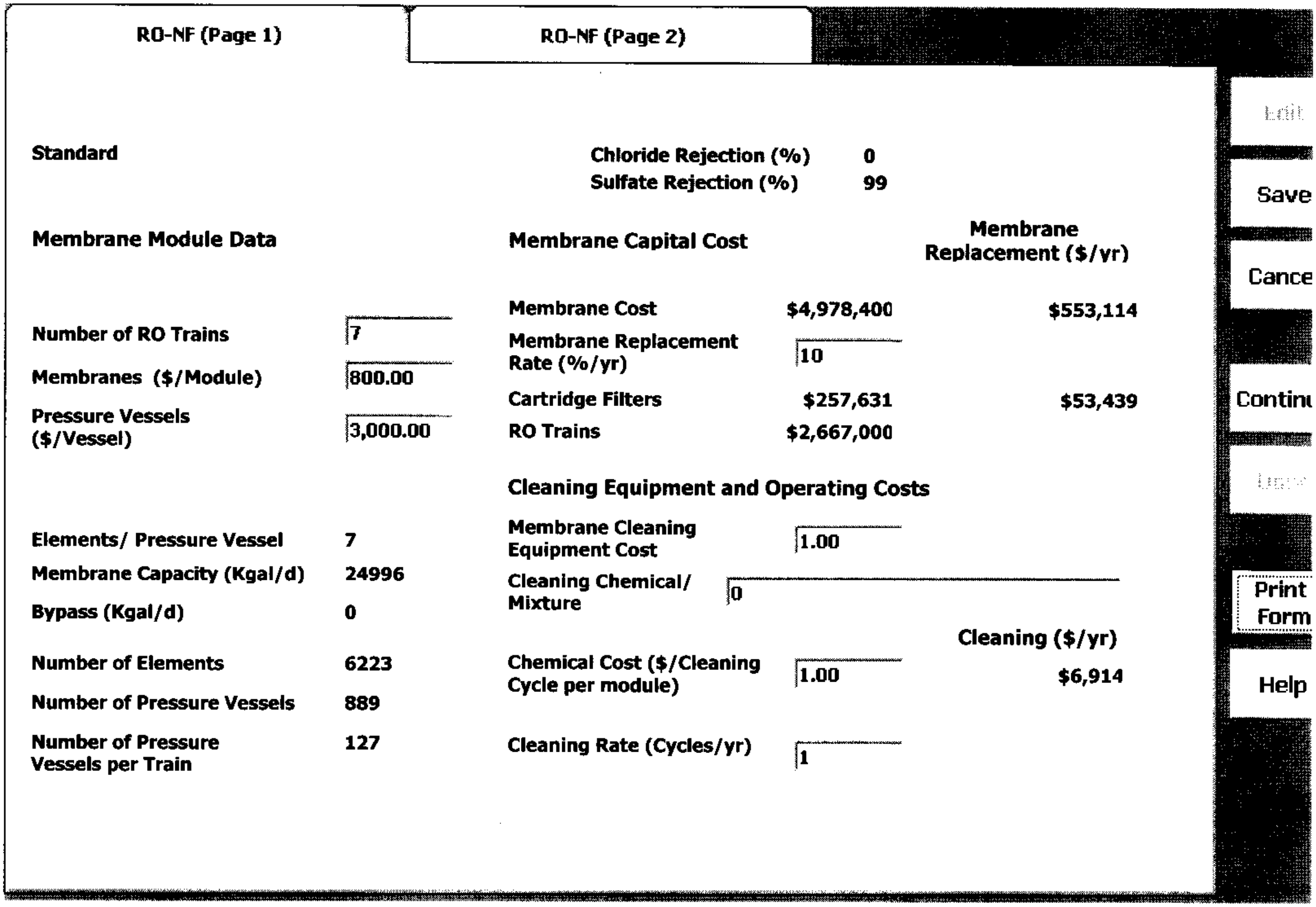
☑ High Pressure Pumps ☐ Transfer Pumps ☐ Product Pumps

	High Pressure Pumps		Transfer Pumps	Product Pumps
Select Pump Type	VFD	☐ Energy Recovery	CF	CF
Number of Pumps	8		1	1
Height Differential (ft)	6.6	Energy Recovery System Efficiency (%)	6.6	6.6
Discharge Pressure (psi)	507.8		45.	45.
Pump Efficiency (%)	75.		75.	75.
Velocity (ft/s)	8.2	85.00	8.2	8.2
Motor Efficiency (%)	95.		95.	95.
Length of Inlet Pipe (ft)	32.8		32.8	32.8
Coupling Efficiency (%)	100.		100.	100.
Inlet Pressure (psi)	29.		45.	45.
Capacity/Pump (gallons/s)	48		321.4443	289.2999
HP	1,136			
Power Req. (kWhr/Y)	57,296,373			

Capital Cost

Pump, Drive and Drivers	**$3,331,380**	**$**	**$**
Piping	**$6,925**	**$**	**$**
Controls	**$32,000**		
Energy Recovery			
Capital Cost	**$3,338,305**	**$**	**$**

Operating Cost	**Input**			
Power ($/year)		**$2,864,819**	**$**	**$**
Lubrication ($/L oil)	$1.	**$31,836**	**$**	**$**
Maintenance (hr/HP)	.1	**$22,714**	**$**	**$**
O and M Cost		**$2,919,369**	**$**	**$**



Standard

Chloride Rejection (%) 0
Sulfate Rejection (%) 99

Membrane Module Data

Number of RO Trains 7
Membranes ($/Module) 800.00
Pressure Vessels ($/Vessel) 3,000.00

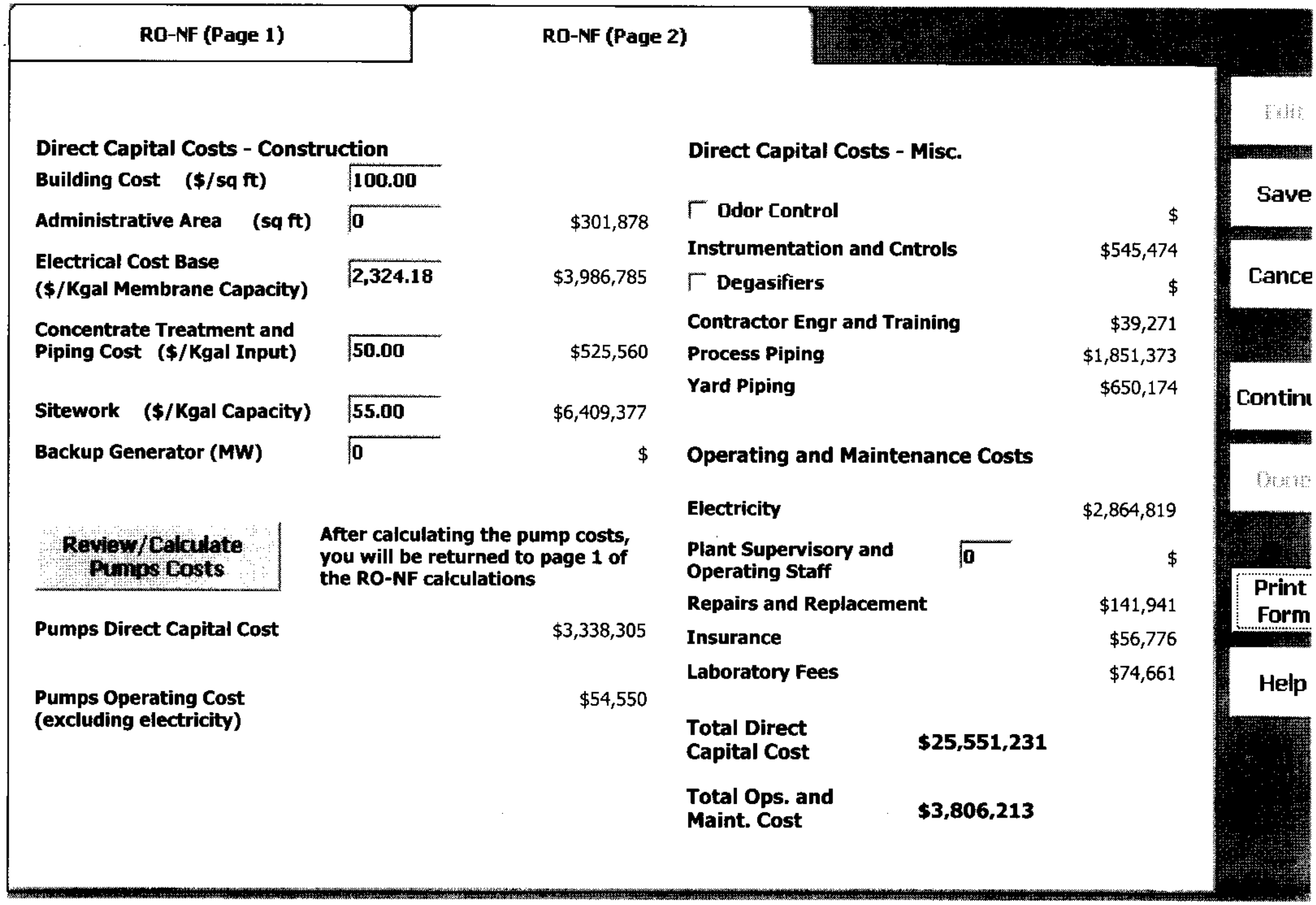
Elements/ Pressure Vessel 7
Membrane Capacity (Kgal/d) 24996
Bypass (Kgal/d) 0
Number of Elements 6223
Number of Pressure Vessels 889
Number of Pressure Vessels per Train 127

Membrane Capital Cost		**Membrane Replacement ($/yr)**
Membrane Cost	$4,978,400	$553,114
Membrane Replacement Rate (%/yr)	10	
Cartridge Filters	$257,631	$53,439
RO Trains	$2,667,000	

Cleaning Equipment and Operating Costs

Membrane Cleaning Equipment Cost 1.00
Cleaning Chemical/ Mixture 0

		Cleaning ($/yr)
Chemical Cost ($/Cleaning Cycle per module)	1.00	$6,914
Cleaning Rate (Cycles/yr)	1	



Direct Capital Costs - Construction

Building Cost ($/sq ft)	100.00	
Administrative Area (sq ft)	0	$301,878
Electrical Cost Base ($/Kgal Membrane Capacity)	2,324.18	$3,986,785
Concentrate Treatment and Piping Cost ($/Kgal Input)	50.00	$525,560
Sitework ($/Kgal Capacity)	55.00	$6,409,377
Backup Generator (MW)	0	$

After calculating the pump costs, you will be returned to page 1 of the RO-NF calculations

Pumps Direct Capital Cost	$3,338,305
Pumps Operating Cost (excluding electricity)	$54,550

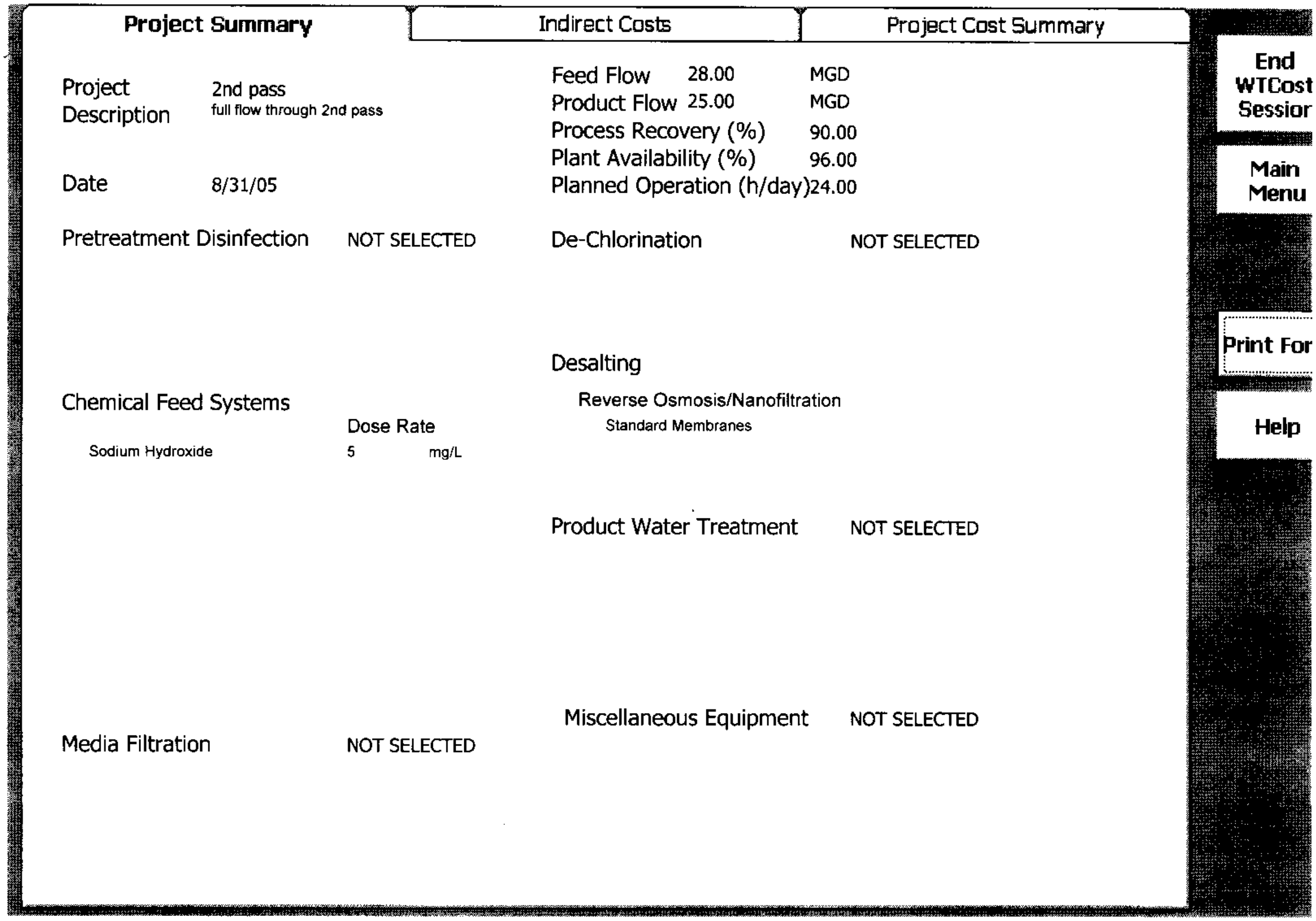
Direct Capital Costs - Misc.

☐ Odor Control	$
Instrumentation and Cntrols	$545,474
☐ Degasifiers	$
Contractor Engr and Training	$39,271
Process Piping	$1,851,373
Yard Piping	$650,174

Operating and Maintenance Costs

Electricity		$2,864,819
Plant Supervisory and Operating Staff	0	$
Repairs and Replacement		$141,941
Insurance		$56,776
Laboratory Fees		$74,661

Total Direct Capital Cost	**$25,551,231**
Total Ops. and Maint. Cost	**$3,806,213**



Project Description 2nd pass
full flow through 2nd pass

Date 8/31/05

Feed Flow 28.00 MGD
Product Flow 25.00 MGD
Process Recovery (%) 90.00
Plant Availability (%) 96.00
Planned Operation (h/day) 24.00

Pretreatment Disinfection NOT SELECTED

De-Chlorination NOT SELECTED

Chemical Feed Systems

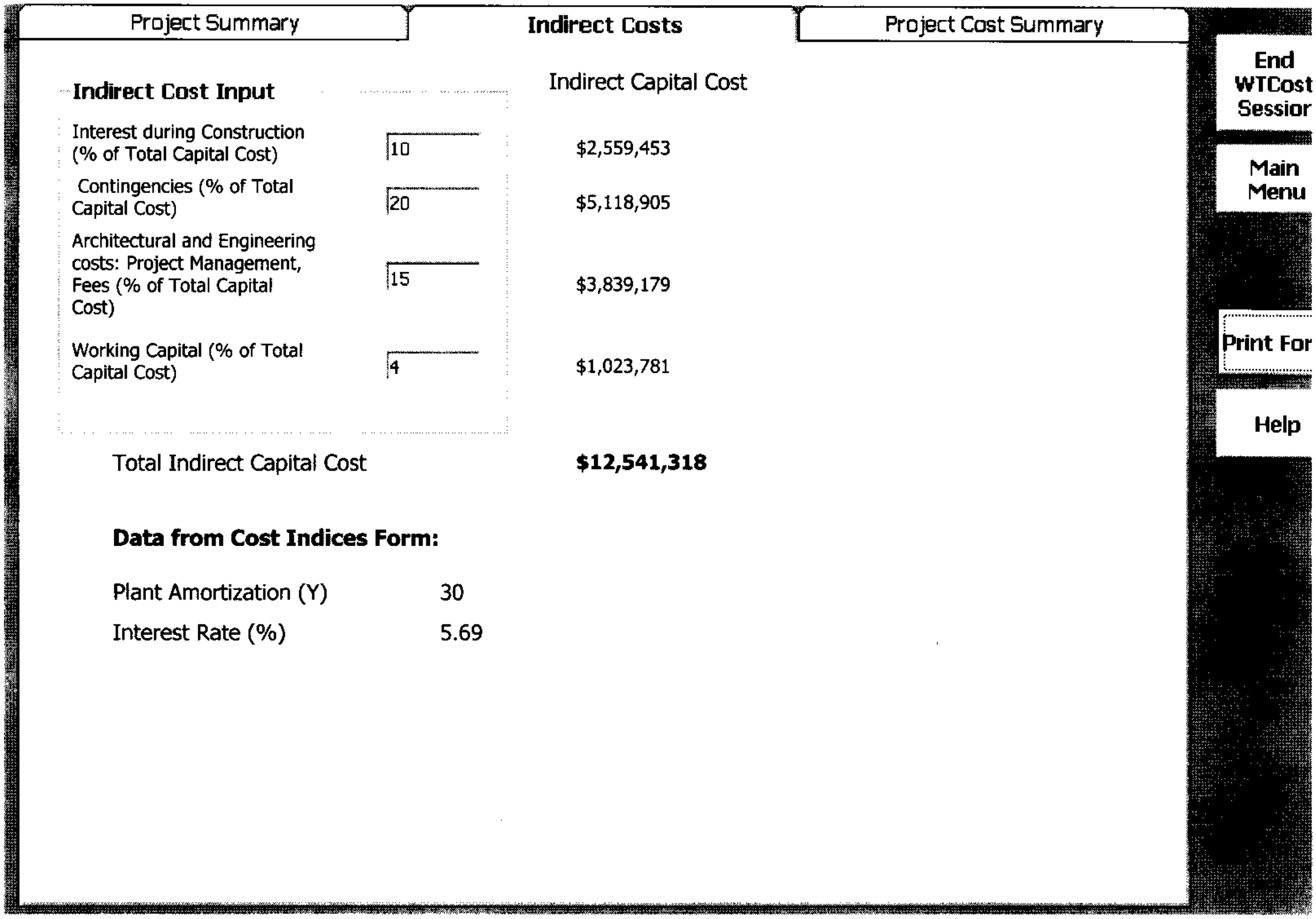
	Dose Rate	
Sodium Hydroxide	5	mg/L

Desalting
Reverse Osmosis/Nanofiltration
Standard Membranes

Product Water Treatment NOT SELECTED

Miscellaneous Equipment NOT SELECTED

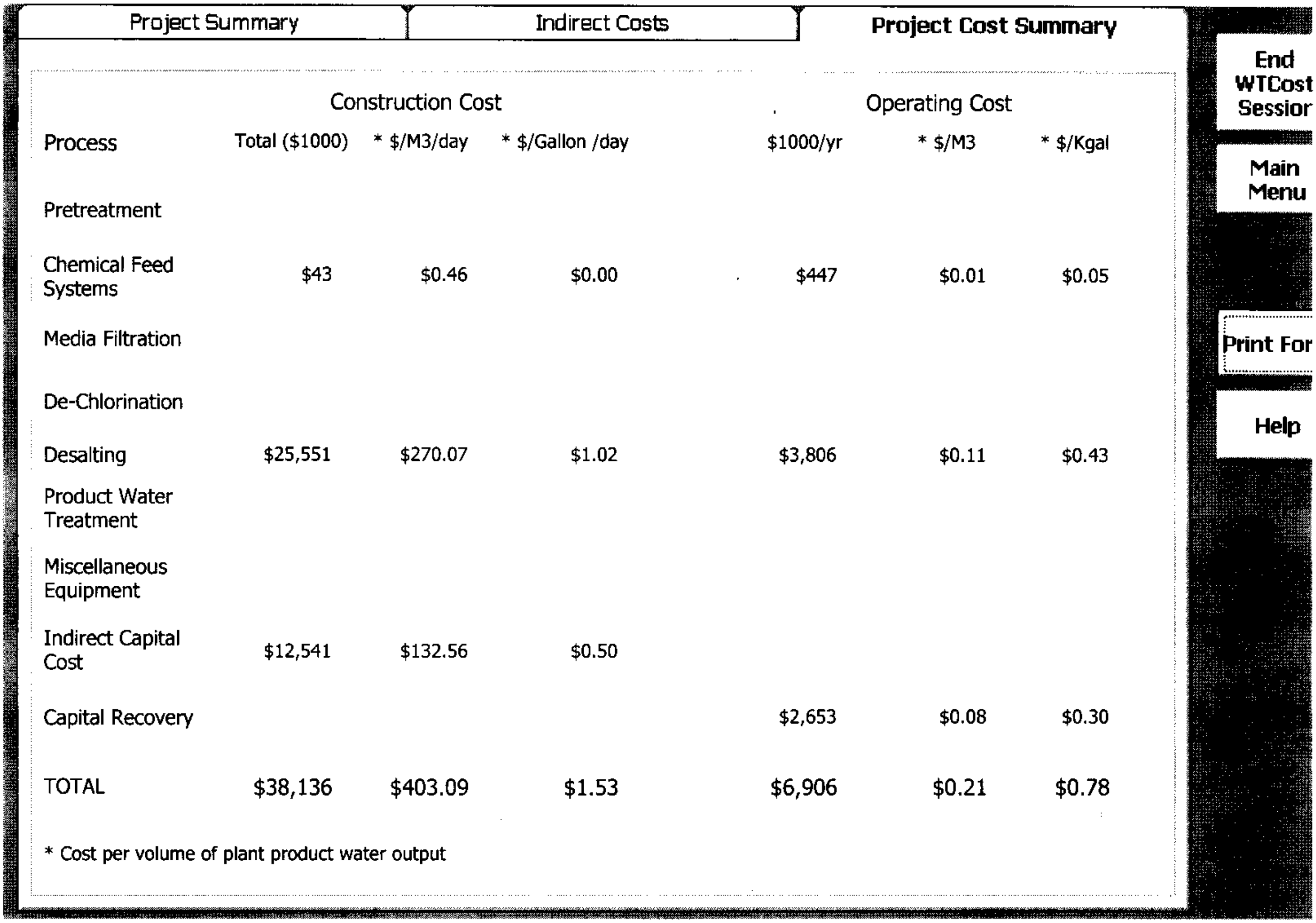
Media Filtration NOT SELECTED



Indirect Cost Input		Indirect Capital Cost
Interest during Construction (% of Total Capital Cost)	10	$2,559,453
Contingencies (% of Total Capital Cost)	20	$5,118,905
Architectural and Engineering costs: Project Management, Fees (% of Total Capital Cost)	15	$3,839,179
Working Capital (% of Total Capital Cost)	4	$1,023,781
Total Indirect Capital Cost		**$12,541,318**

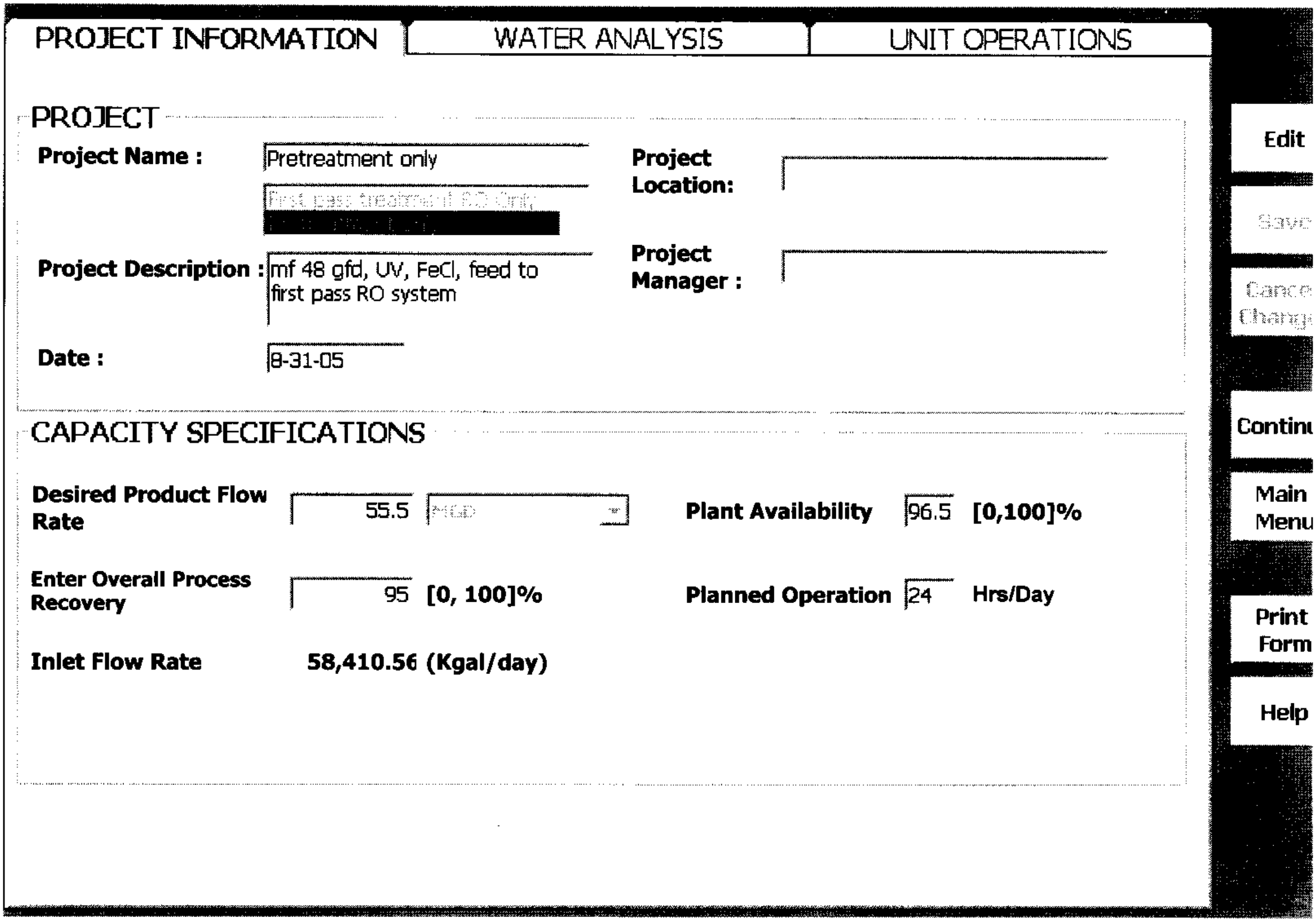
Data from Cost Indices Form:

Plant Amortization (Y)	30
Interest Rate (%)	5.69



	Construction Cost			Operating Cost		
Process	Total ($1000)	* $/M3/day	* $/Gallon /day	$1000/yr	* $/M3	* $/Kgal
Pretreatment						
Chemical Feed Systems	$43	$0.46	$0.00	$447	$0.01	$0.05
Media Filtration						
De-Chlorination						
Desalting	$25,551	$270.07	$1.02	$3,806	$0.11	$0.43
Product Water Treatment						
Miscellaneous Equipment						
Indirect Capital Cost	$12,541	$132.56	$0.50			
Capital Recovery				$2,653	$0.08	$0.30
TOTAL	$38,136	$403.09	$1.53	$6,906	$0.21	$0.78

* Cost per volume of plant product water output



PROJECT

Project Name : Pretreatment only

First pass treatment RO Only

[redacted]

Project Location:

Project Description : mf 48 gfd, UV, FeCl, feed to first pass RO system

Project Manager :

Date : 8-31-05

CAPACITY SPECIFICATIONS

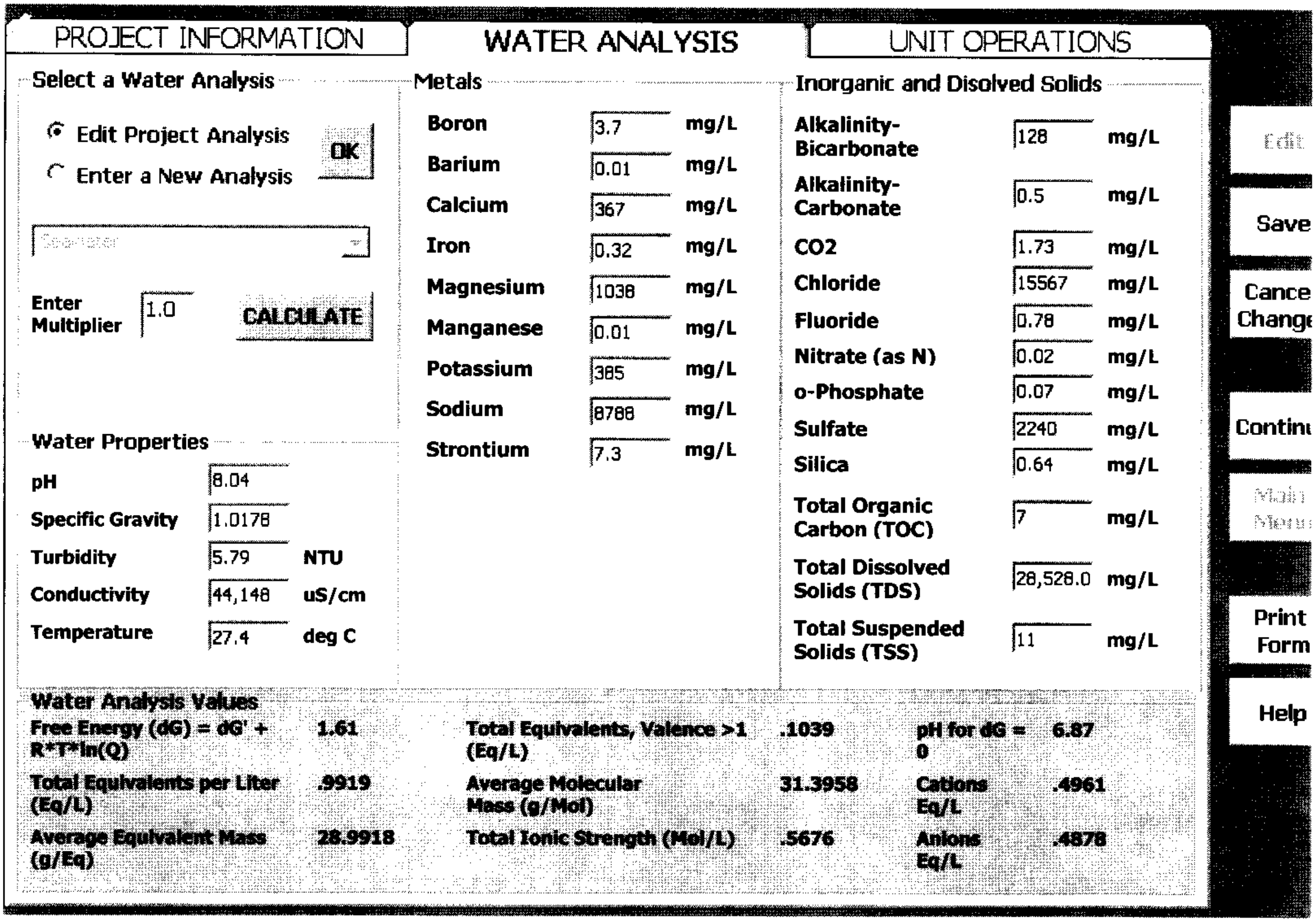
Desired Product Flow Rate 55.5 MGD

Plant Availability 96.5 **[0,100]%**

Enter Overall Process Recovery 95 **[0, 100]%**

Planned Operation 24 **Hrs/Day**

Inlet Flow Rate **58,410.56 (Kgal/day)**



Select a Water Analysis

● Edit Project Analysis
○ Enter a New Analysis

Seawater

Enter Multiplier: 1.0

Water Properties

pH	8.04	
Specific Gravity	1.0178	
Turbidity	5.79	NTU
Conductivity	44,148	uS/cm
Temperature	27.4	deg C

Metals

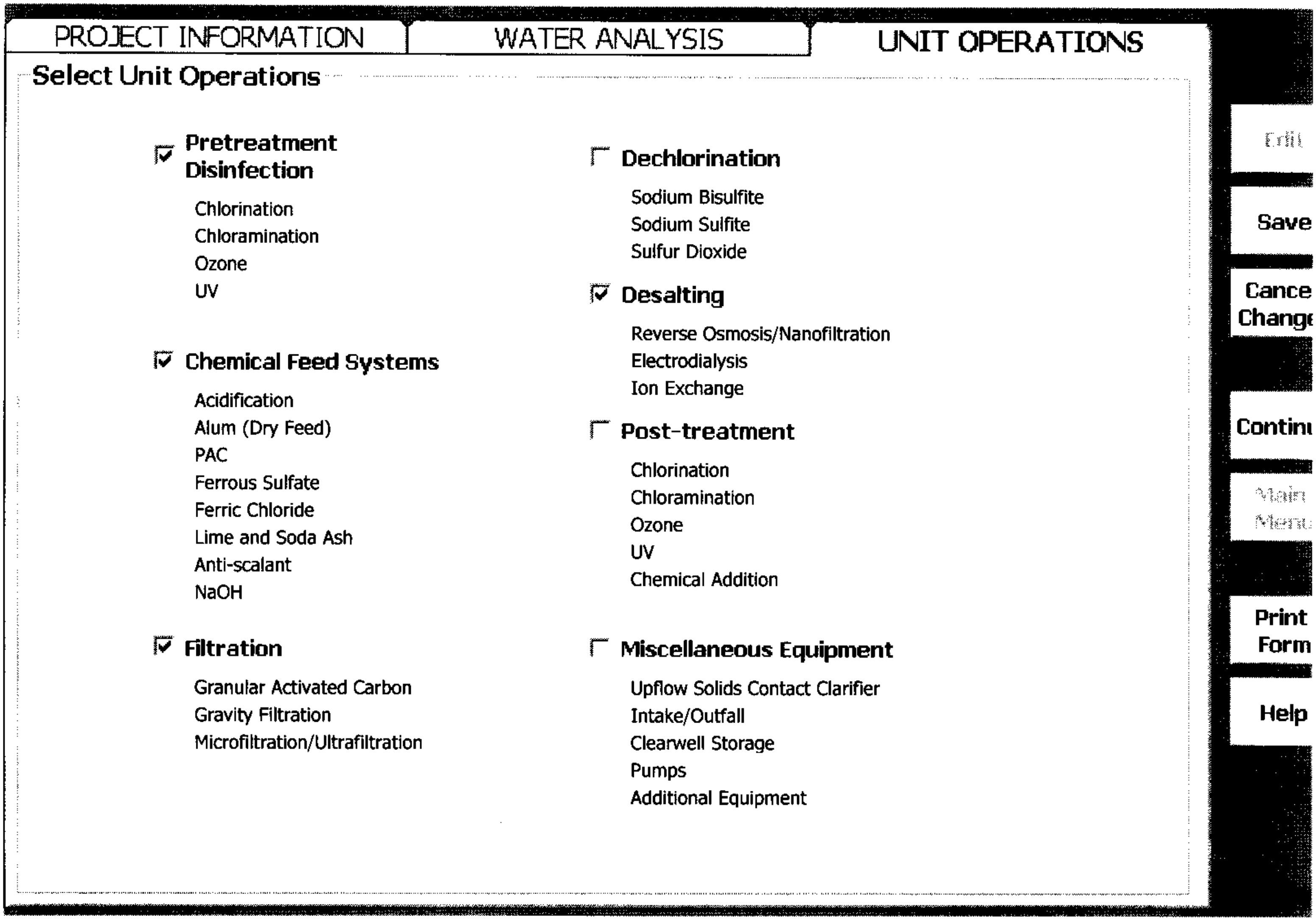
Boron	3.7	mg/L
Barium	0.01	mg/L
Calcium	367	mg/L
Iron	0.32	mg/L
Magnesium	1038	mg/L
Manganese	0.01	mg/L
Potassium	385	mg/L
Sodium	8788	mg/L
Strontium	7.3	mg/L

Inorganic and Disolved Solids

Alkalinity-Bicarbonate	128	mg/L
Alkalinity-Carbonate	0.5	mg/L
CO2	1.73	mg/L
Chloride	15567	mg/L
Fluoride	0.78	mg/L
Nitrate (as N)	0.02	mg/L
o-Phosphate	0.07	mg/L
Sulfate	2240	mg/L
Silica	0.64	mg/L
Total Organic Carbon (TOC)	7	mg/L
Total Dissolved Solids (TDS)	28,528.0	mg/L
Total Suspended Solids (TSS)	11	mg/L

Water Analysis Values

Free Energy (dG) = dG' + R*T*ln(Q)	1.61	Total Equivalents, Valence >1 (Eq/L)	.1039	pH for dG = 0	6.87
Total Equivalents per Liter (Eq/L)	.9919	Average Molecular Mass (g/Mol)	31.3958	Cations Eq/L	.4961
Average Equivalent Mass (g/Eq)	28.9918	Total Ionic Strength (Mol/L)	.5676	Anions Eq/L	.4878



Select Unit Operations

☑ **Pretreatment Disinfection**
Chlorination
Chloramination
Ozone
UV

☑ **Chemical Feed Systems**
Acidification
Alum (Dry Feed)
PAC
Ferrous Sulfate
Ferric Chloride
Lime and Soda Ash
Anti-scalant
NaOH

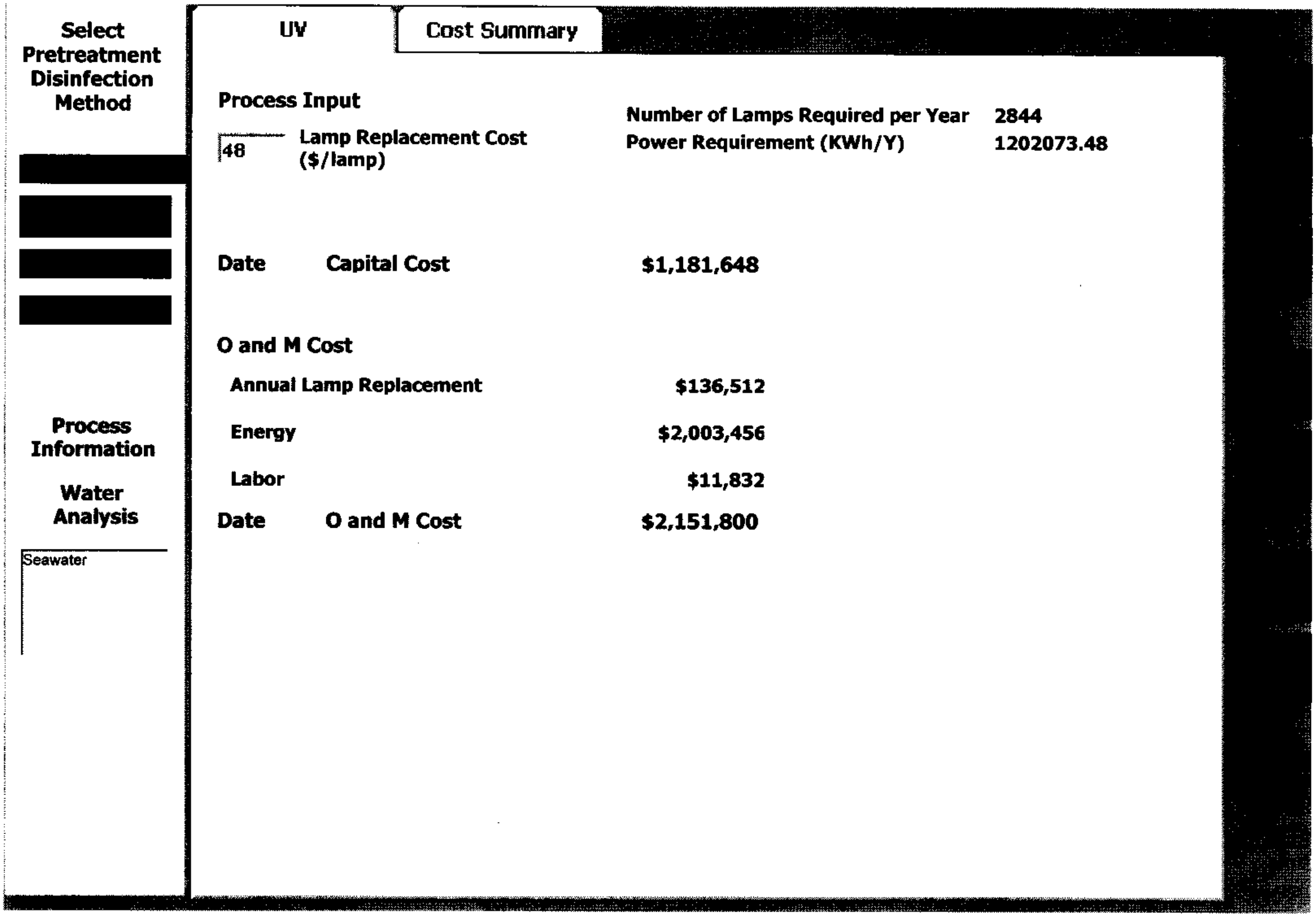
☑ **Filtration**
Granular Activated Carbon
Gravity Filtration
Microfiltration/Ultrafiltration

☐ **Dechlorination**
Sodium Bisulfite
Sodium Sulfite
Sulfur Dioxide

☑ **Desalting**
Reverse Osmosis/Nanofiltration
Electrodialysis
Ion Exchange

☐ **Post-treatment**
Chlorination
Chloramination
Ozone
UV
Chemical Addition

☐ **Miscellaneous Equipment**
Upflow Solids Contact Clarifier
Intake/Outfall
Clearwell Storage
Pumps
Additional Equipment



Seawater

Process Input

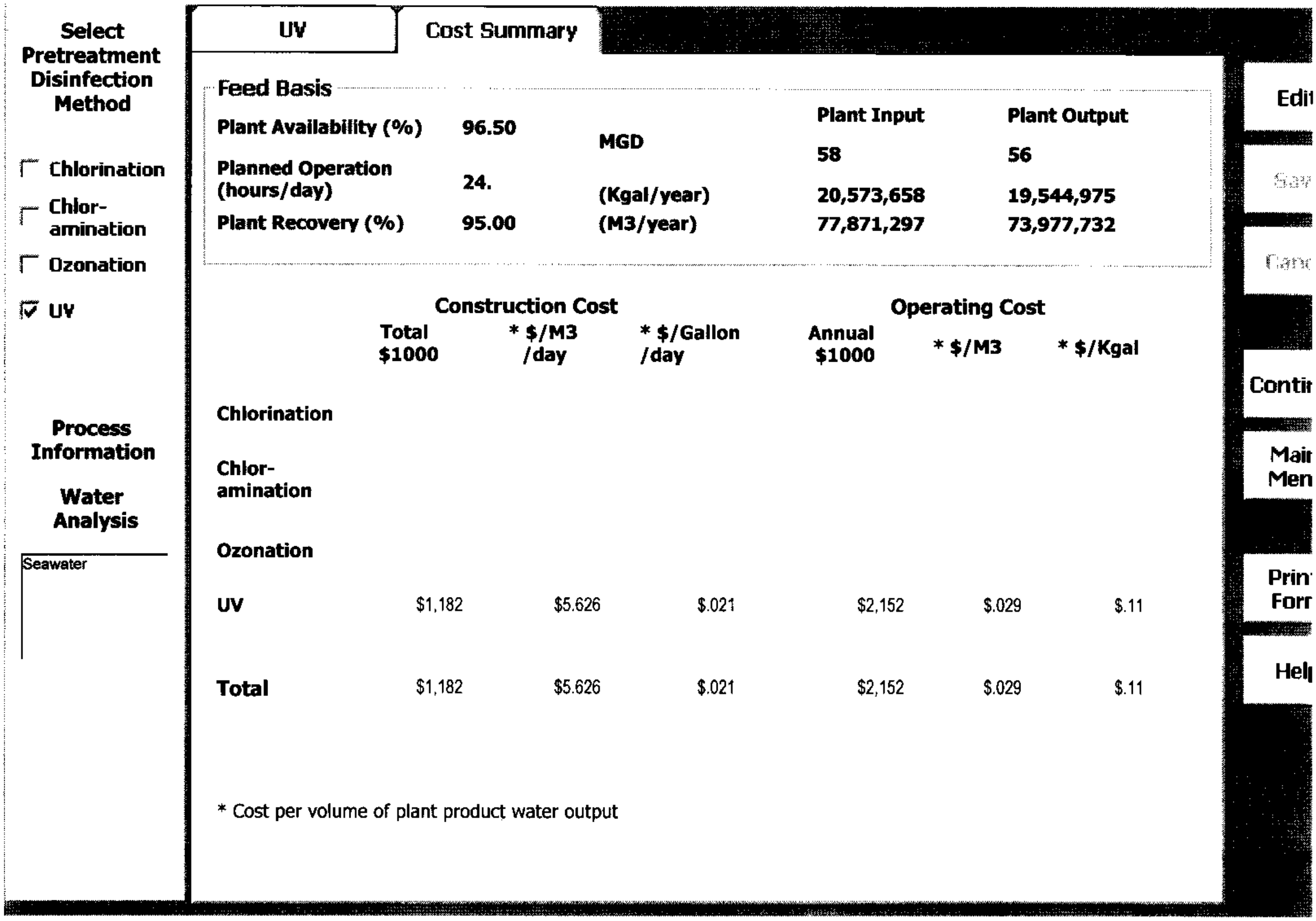
Lamp Replacement Cost ($/lamp)	48
Number of Lamps Required per Year	2844
Power Requirement (KWh/Y)	1202073.48

Date	**Capital Cost**	**$1,181,648**

O and M Cost

Annual Lamp Replacement	$136,512
Energy	$2,003,456
Labor	$11,832

Date	**O and M Cost**	**$2,151,800**



Select Pretreatment Disinfection Method

☐ Chlorination
☐ Chlor-amination
☐ Ozonation
☑ UV

Process Information

Water Analysis

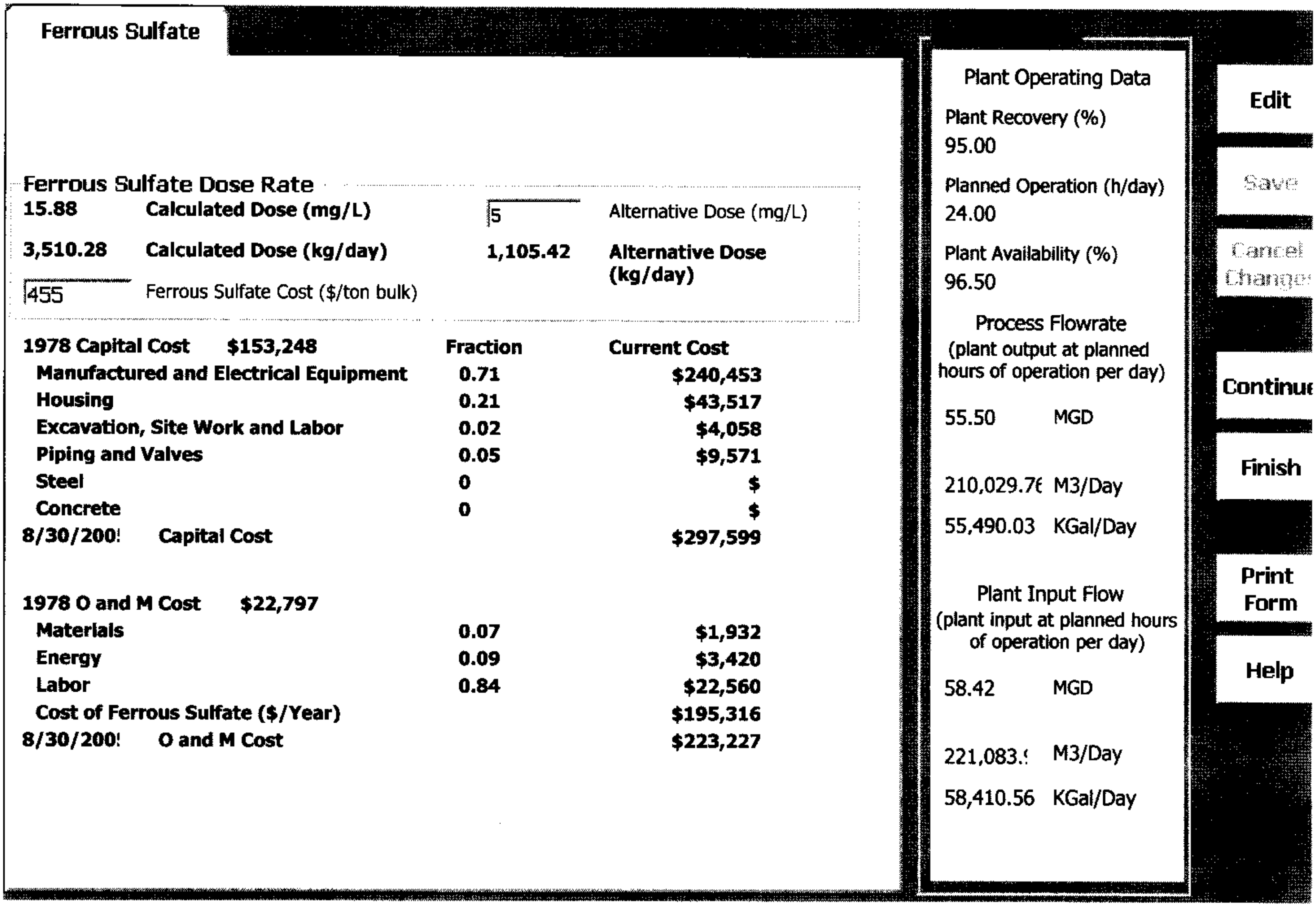
Seawater

Feed Basis

			Plant Input	Plant Output
Plant Availability (%)	96.50	MGD	58	56
Planned Operation (hours/day)	24.	(Kgal/year)	20,573,658	19,544,975
Plant Recovery (%)	95.00	(M3/year)	77,871,297	73,977,732

	Construction Cost			Operating Cost		
	Total $1000	* $/M3 /day	* $/Gallon /day	Annual $1000	* $/M3	* $/Kgal
Chlorination						
Chlor-amination						
Ozonation						
UV	$1,182	$5.626	$.021	$2,152	$.029	$.11
Total	$1,182	$5.626	$.021	$2,152	$.029	$.11

* Cost per volume of plant product water output



Ferrous Sulfate Dose Rate

15.88	**Calculated Dose (mg/L)**	5	Alternative Dose (mg/L)
3,510.28	**Calculated Dose (kg/day)**	1,105.42	**Alternative Dose (kg/day)**
455	Ferrous Sulfate Cost ($/ton bulk)		

1978 Capital Cost	**$153,248**	**Fraction**	**Current Cost**
Manufactured and Electrical Equipment		**0.71**	**$240,453**
Housing		**0.21**	**$43,517**
Excavation, Site Work and Labor		**0.02**	**$4,058**
Piping and Valves		**0.05**	**$9,571**
Steel		**0**	**$**
Concrete		**0**	**$**
8/30/200	**Capital Cost**		**$297,599**

1978 O and M Cost	**$22,797**		
Materials		**0.07**	**$1,932**
Energy		**0.09**	**$3,420**
Labor		**0.84**	**$22,560**
Cost of Ferrous Sulfate ($/Year)			**$195,316**
8/30/200	**O and M Cost**		**$223,227**

Plant Operating Data

Plant Recovery (%)
95.00

Planned Operation (h/day)
24.00

Plant Availability (%)
96.50

Process Flowrate
(plant output at planned hours of operation per day)

55.50 MGD

210,029.7 M3/Day

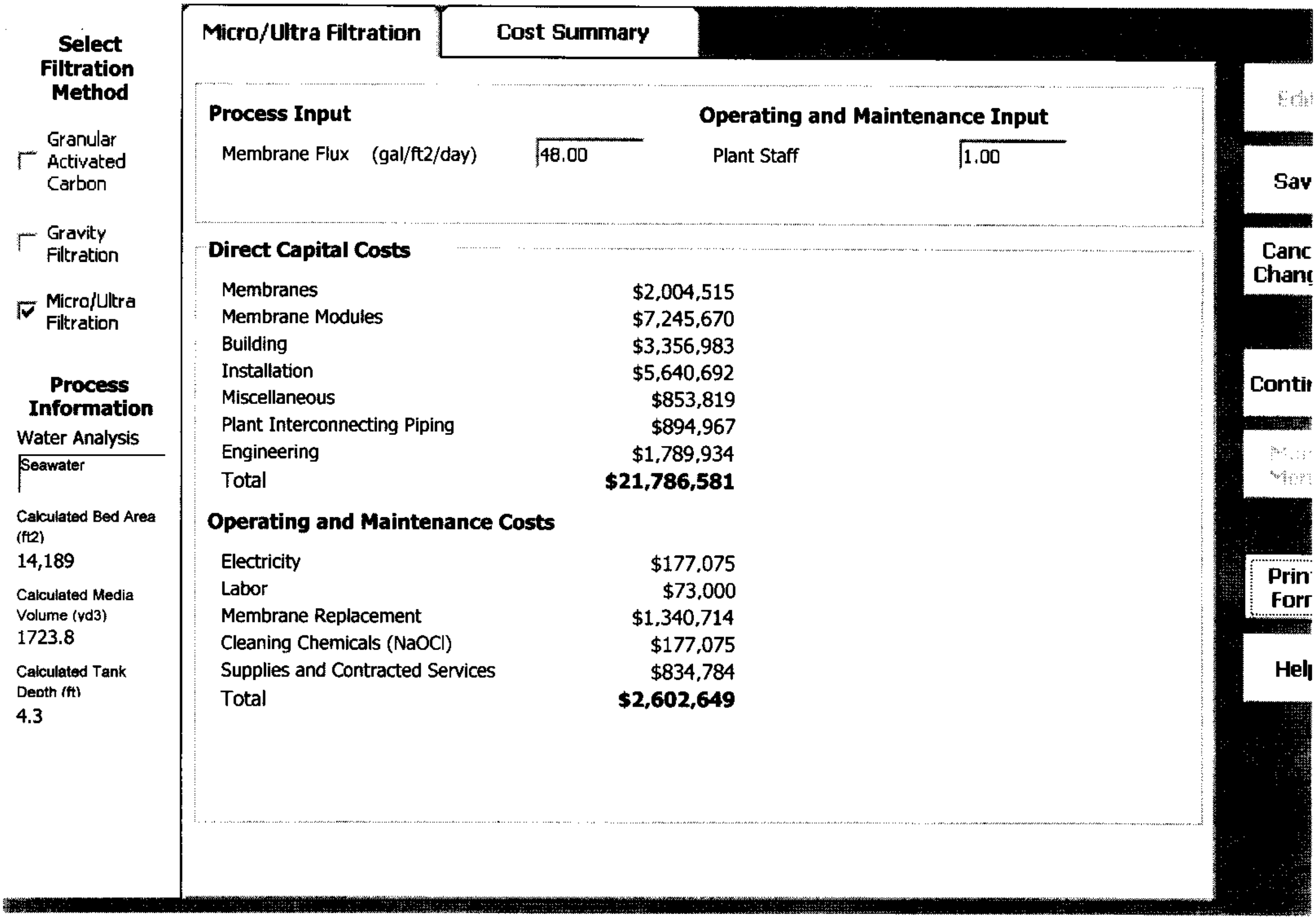
55,490.03 KGal/Day

Plant Input Flow
(plant input at planned hours of operation per day)

58.42 MGD

221,083. M3/Day

58,410.56 KGal/Day



Select Filtration Method

☐ Granular Activated Carbon
☐ Gravity Filtration
☑ Micro/Ultra Filtration

Process Information

Water Analysis: Seawater

Calculated Bed Area (ft2): 14,189

Calculated Media Volume (yd3): 1723.8

Calculated Tank Depth (ft): 4.3

Process Input

Membrane Flux (gal/ft2/day): 48.00

Operating and Maintenance Input

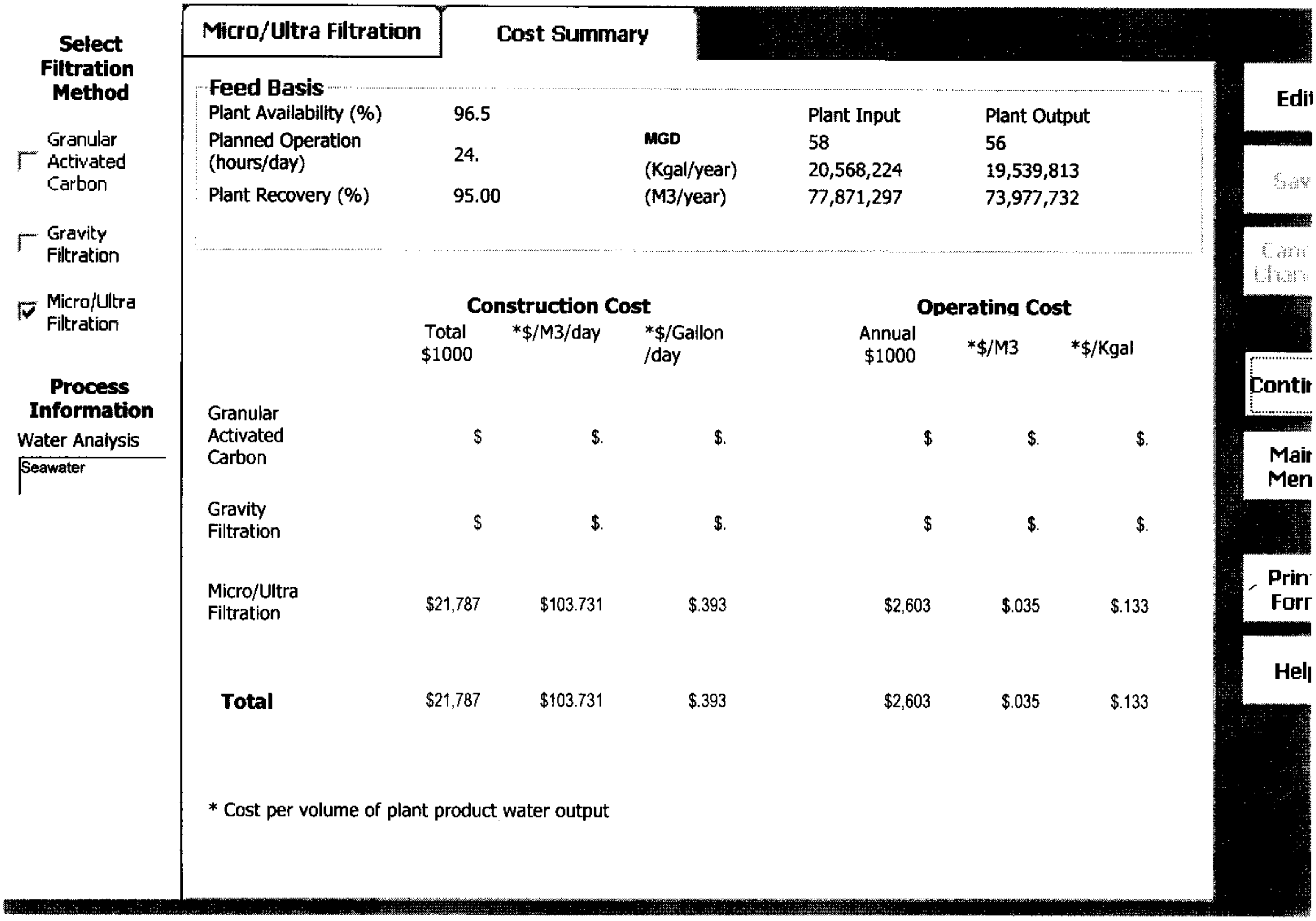
Plant Staff: 1.00

Direct Capital Costs

Membranes	$2,004,515
Membrane Modules	$7,245,670
Building	$3,356,983
Installation	$5,640,692
Miscellaneous	$853,819
Plant Interconnecting Piping	$894,967
Engineering	$1,789,934
Total	**$21,786,581**

Operating and Maintenance Costs

Electricity	$177,075
Labor	$73,000
Membrane Replacement	$1,340,714
Cleaning Chemicals (NaOCl)	$177,075
Supplies and Contracted Services	$834,784
Total	**$2,602,649**



Select Filtration Method

☐ Granular Activated Carbon
☐ Gravity Filtration
☑ Micro/Ultra Filtration

Process Information

Water Analysis: Seawater

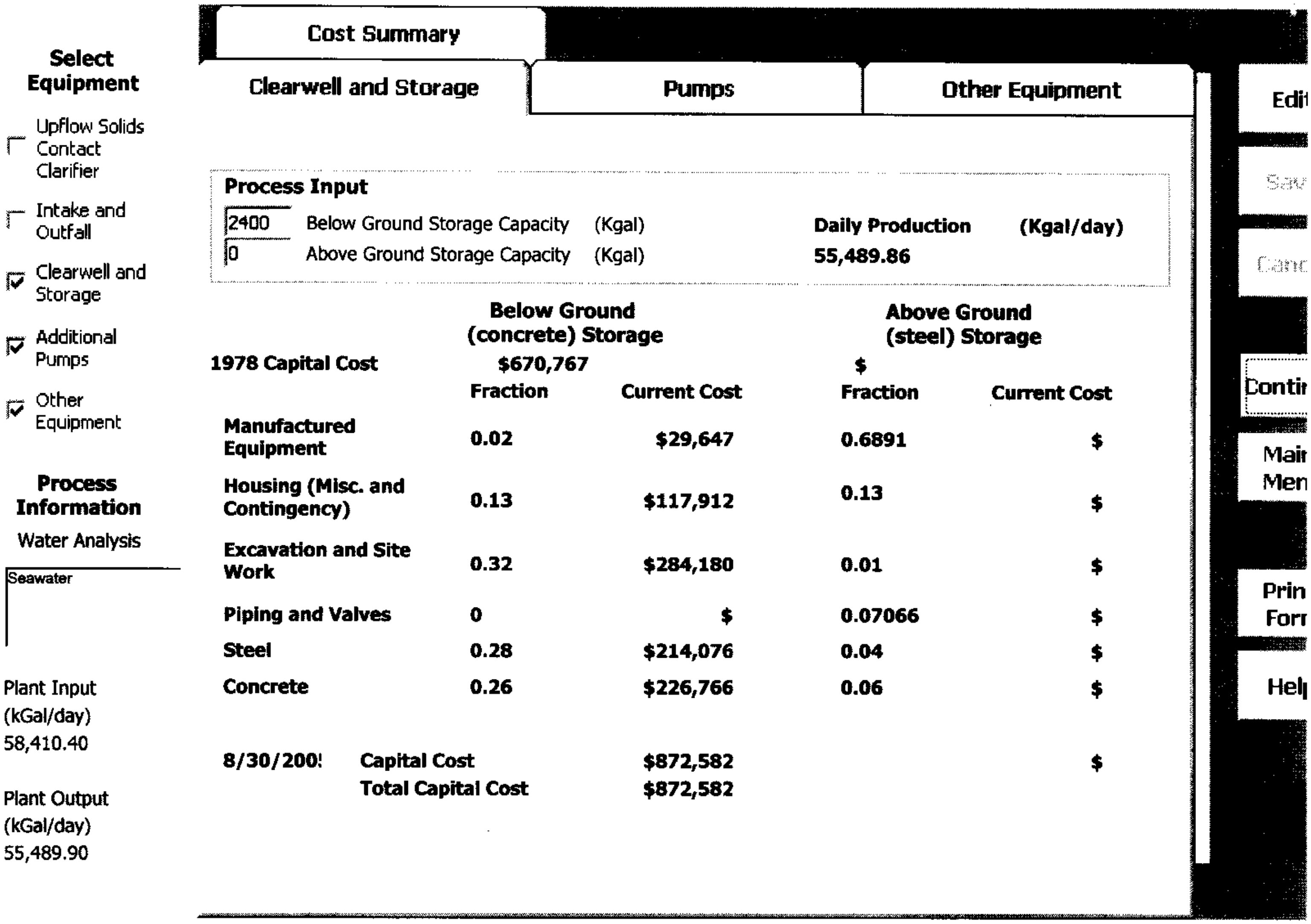
Feed Basis

Plant Availability (%): 96.5
Planned Operation (hours/day): 24.
Plant Recovery (%): 95.00

	Plant Input	Plant Output
MGD	58	56
(Kgal/year)	20,568,224	19,539,813
(M3/year)	77,871,297	73,977,732

	Construction Cost			Operating Cost		
	Total $1000	*$/M3/day	*$/Gallon /day	Annual $1000	*$/M3	*$/Kgal
Granular Activated Carbon	$	$.	$.	$	$.	$.
Gravity Filtration	$	$.	$.	$	$.	$.
Micro/Ultra Filtration	$21,787	$103.731	$.393	$2,603	$.035	$.133
Total	$21,787	$103.731	$.393	$2,603	$.035	$.133

* Cost per volume of plant product water output



Select Equipment

☐ Upflow Solids Contact Clarifier

☐ Intake and Outfall

☑ Clearwell and Storage

☑ Additional Pumps

☑ Other Equipment

Process Information

Water Analysis

Seawater

Plant Input (kGal/day) 58,410.40

Plant Output (kGal/day) 55,489.90

Process Input

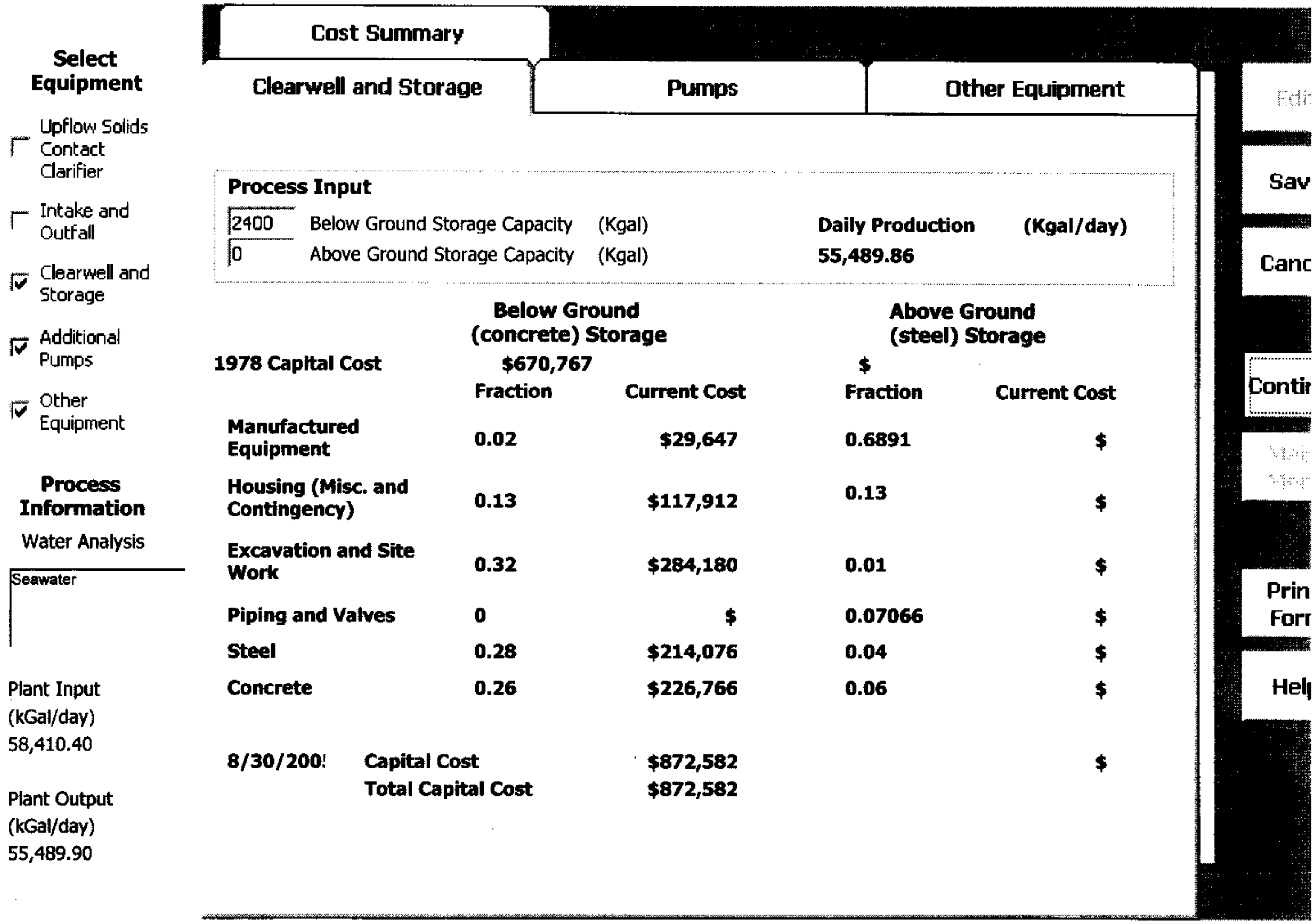
2400 Below Ground Storage Capacity (Kgal)

0 Above Ground Storage Capacity (Kgal)

Daily Production (Kgal/day) 55,489.86

	Below Ground (concrete) Storage		**Above Ground (steel) Storage**	
1978 Capital Cost	**$670,767**		**$**	
	Fraction	**Current Cost**	**Fraction**	**Current Cost**
Manufactured Equipment	0.02	$29,647	0.6891	$
Housing (Misc. and Contingency)	0.13	$117,912	0.13	$
Excavation and Site Work	0.32	$284,180	0.01	$
Piping and Valves	0	$	0.07066	$
Steel	0.28	$214,076	0.04	$
Concrete	0.26	$226,766	0.06	$
8/30/200! **Capital Cost**		$872,582		$
Total Capital Cost		$872,582		

2 Storage tanks
Between MF & RO
each tank
Capable of 30 min
flow to RO



Select Equipment

☐ Upflow Solids Contact Clarifier
☐ Intake and Outfall
☑ Clearwell and Storage
☑ Additional Pumps
☑ Other Equipment

Process Information

Water Analysis

Seawater

Plant Input (kGal/day) 58,410.40

Plant Output (kGal/day) 55,489.90

Process Input

2400 Below Ground Storage Capacity (Kgal)
0 Above Ground Storage Capacity (Kgal)

Daily Production **(Kgal/day)**
55,489.86

	Below Ground (concrete) Storage		**Above Ground (steel) Storage**	
1978 Capital Cost	**$670,767**		**$**	
	Fraction	**Current Cost**	**Fraction**	**Current Cost**
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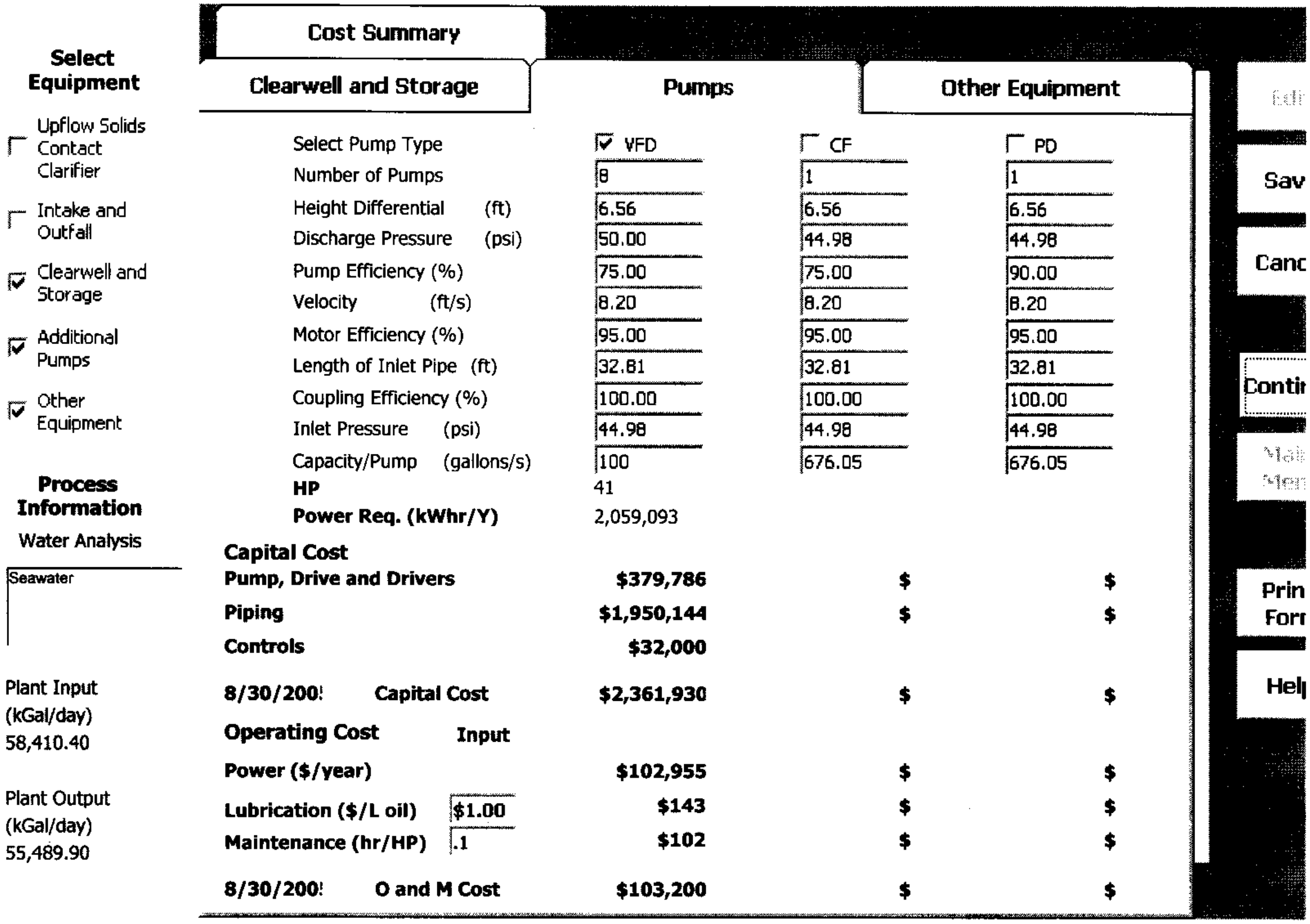
Excavation and Site Work	**0.32**	**$284,180**	**0.01**	**$**
Piping and Valves	**0**	**$**	**0.07066**	**$**
Steel	**0.28**	**$214,076**	**0.04**	**$**
Concrete	**0.26**	**$226,766**	**0.06**	**$**
8/30/200 **Capital Cost**		**$872,582**		**$**
Total Capital Cost		**$872,582**		



Select Equipment

☐ Upflow Solids Contact Clarifier

☐ Intake and Outfall

☑ Clearwell and Storage

☑ Additional Pumps

☑ Other Equipment

Process Information

Water Analysis

Seawater

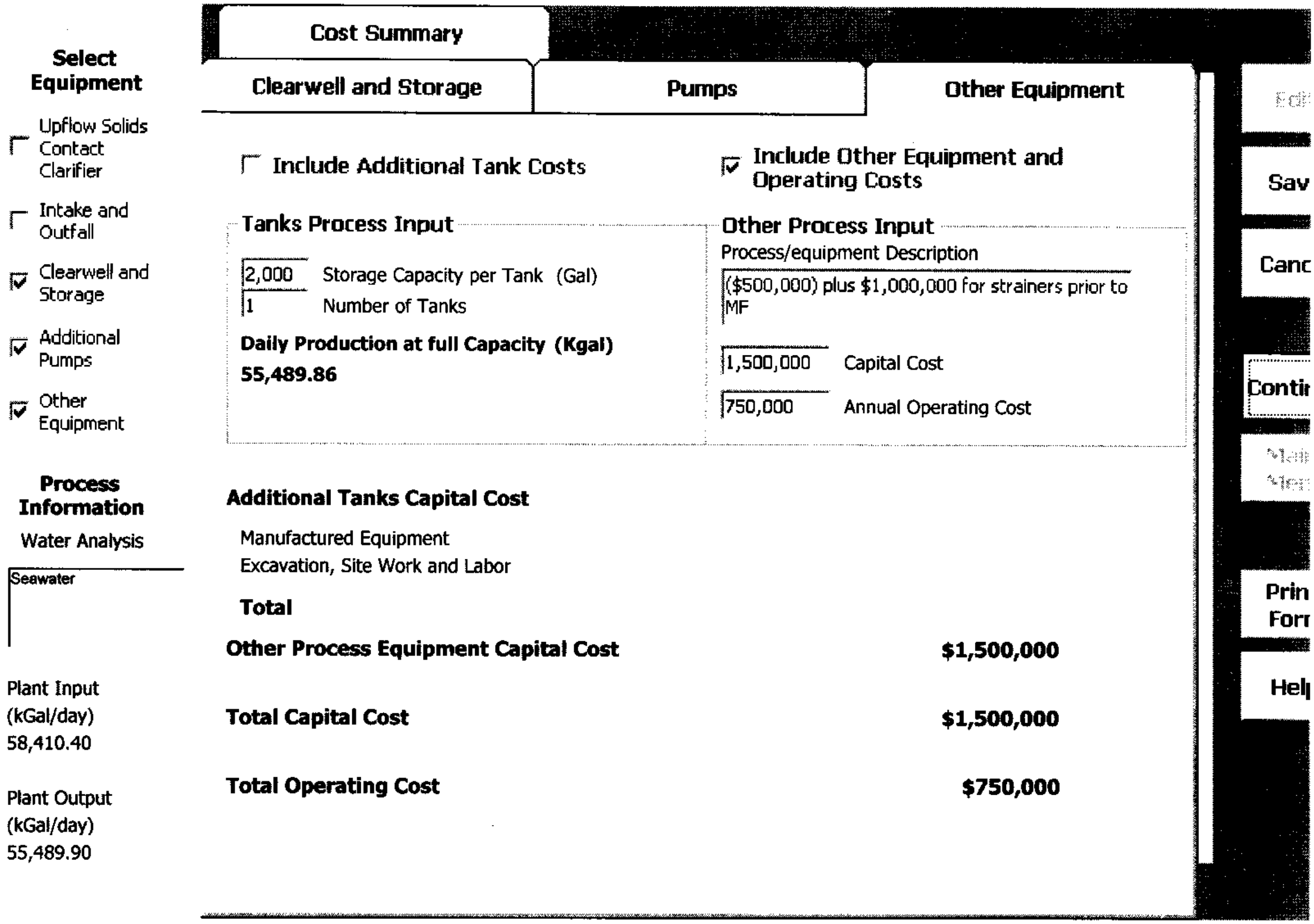
Plant Input (kGal/day)
58,410.40

Plant Output (kGal/day)
55,489.90

Select Pump Type	☑ VFD	☐ CF	☐ PD
Number of Pumps	8	1	1
Height Differential (ft)	6.56	6.56	6.56
Discharge Pressure (psi)	50.00	44.98	44.98
Pump Efficiency (%)	75.00	75.00	90.00
Velocity (ft/s)	8.20	8.20	8.20
Motor Efficiency (%)	95.00	95.00	95.00
Length of Inlet Pipe (ft)	32.81	32.81	32.81
Coupling Efficiency (%)	100.00	100.00	100.00
Inlet Pressure (psi)	44.98	44.98	44.98
Capacity/Pump (gallons/s)	100	676.05	676.05
HP	41		
Power Req. (kWhr/Y)	2,059,093		

Capital Cost			
Pump, Drive and Drivers	**$379,786**	**$**	**$**
Piping	**$1,950,144**	**$**	**$**
Controls	**$32,000**		
8/30/200! Capital Cost	**$2,361,930**	**$**	**$**

Operating Cost	**Input**			
Power ($/year)		**$102,955**	**$**	**$**
Lubrication ($/L oil)	**$1.00**	**$143**	**$**	**$**
Maintenance (hr/HP)	.1	**$102**	**$**	**$**
8/30/200! O and M Cost		**$103,200**	**$**	**$**



Select Equipment

☐ Upflow Solids Contact Clarifier
☐ Intake and Outfall
☑ Clearwell and Storage
☑ Additional Pumps
☑ Other Equipment

Process Information

Water Analysis

Seawater

Plant Input (kGal/day) 58,410.40

Plant Output (kGal/day) 55,489.90

☐ Include Additional Tank Costs

☑ Include Other Equipment and Operating Costs

Tanks Process Input

2,000 Storage Capacity per Tank (Gal)
1 Number of Tanks

Daily Production at full Capacity (Kgal)
55,489.86

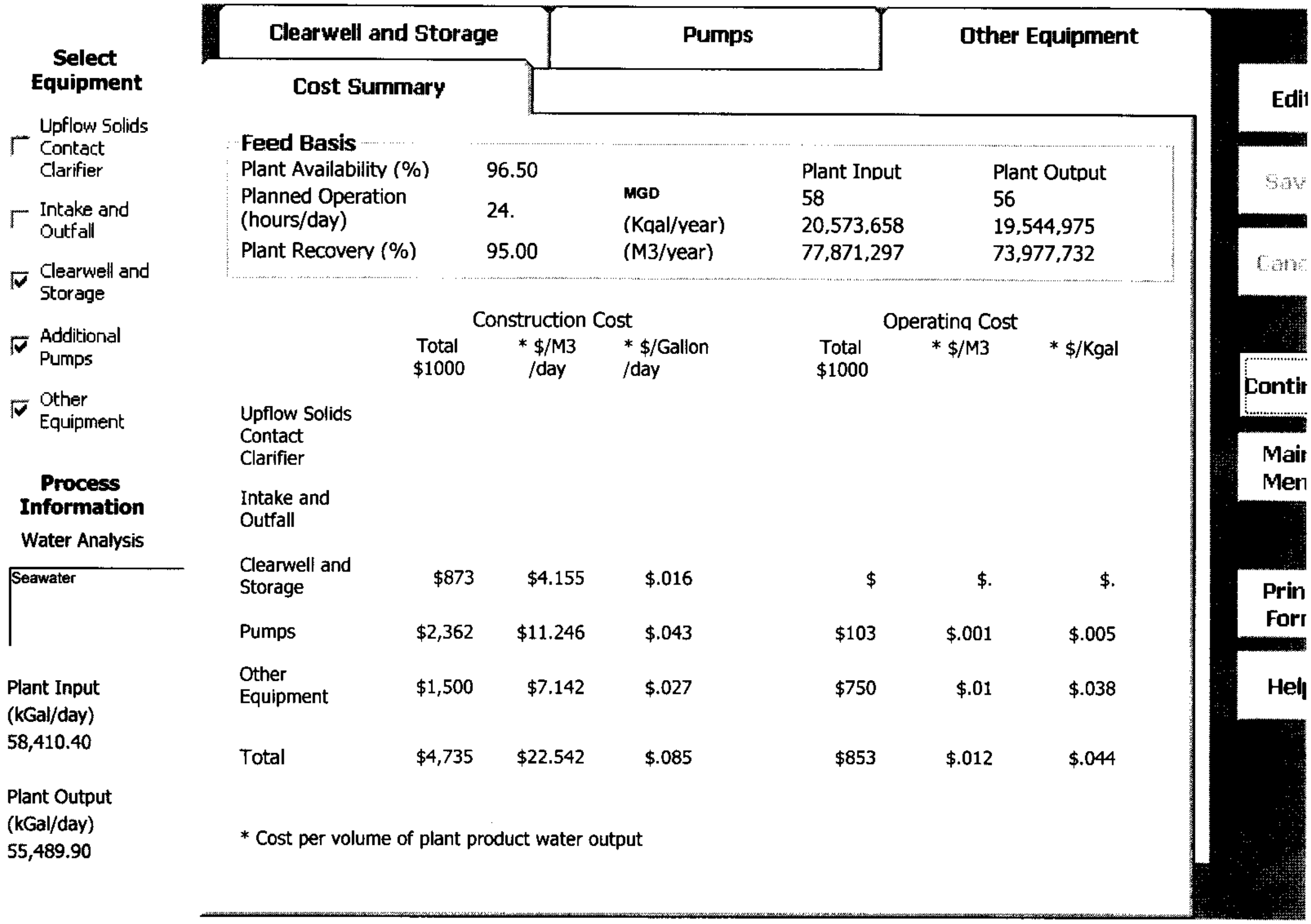
Other Process Input

Process/equipment Description
($500,000) plus $1,000,000 for strainers prior to MF

1,500,000 Capital Cost
750,000 Annual Operating Cost

Additional Tanks Capital Cost

Manufactured Equipment	
Excavation, Site Work and Labor	
Total	
Other Process Equipment Capital Cost	**$1,500,000**
Total Capital Cost	**$1,500,000**
Total Operating Cost	**$750,000**



Select Equipment

☐ Upflow Solids Contact Clarifier

☐ Intake and Outfall

☑ Clearwell and Storage

☑ Additional Pumps

☑ Other Equipment

Process Information

Water Analysis

Seawater

Plant Input (kGal/day) 58,410.40

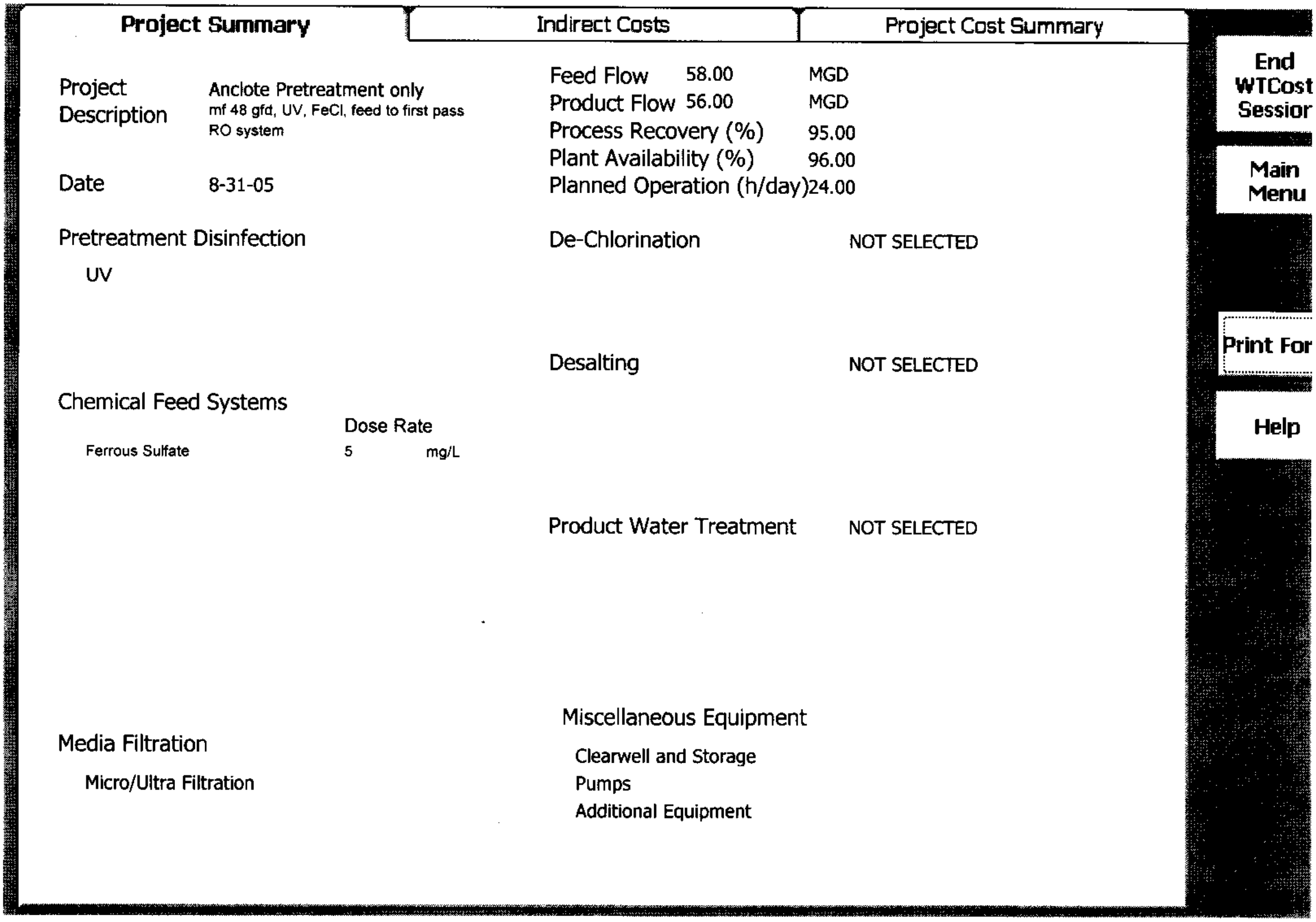
Plant Output (kGal/day) 55,489.90

Feed Basis

			Plant Input	Plant Output
Plant Availability (%)	96.50			
Planned Operation (hours/day)	24.	MGD	58	56
		(Kgal/year)	20,573,658	19,544,975
Plant Recovery (%)	95.00	(M3/year)	77,871,297	73,977,732

	Construction Cost			Operating Cost		
	Total $1000	* $/M3 /day	* $/Gallon /day	Total $1000	* $/M3	* $/Kgal
Upflow Solids Contact Clarifier						
Intake and Outfall						
Clearwell and Storage	$873	$4.155	$.016	$	$.	$.
Pumps	$2,362	$11.246	$.043	$103	$.001	$.005
Other Equipment	$1,500	$7.142	$.027	$750	$.01	$.038
Total	$4,735	$22.542	$.085	$853	$.012	$.044

* Cost per volume of plant product water output



Project Description	Anclote Pretreatment only mf 48 gfd, UV, FeCl, feed to first pass RO system
Date	8-31-05

Feed Flow	58.00	MGD
Product Flow	56.00	MGD
Process Recovery (%)	95.00	
Plant Availability (%)	96.00	
Planned Operation (h/day)	24.00	

Pretreatment Disinfection

UV

De-Chlorination NOT SELECTED

Desalting NOT SELECTED

Chemical Feed Systems

	Dose Rate	
Ferrous Sulfate	5	mg/L

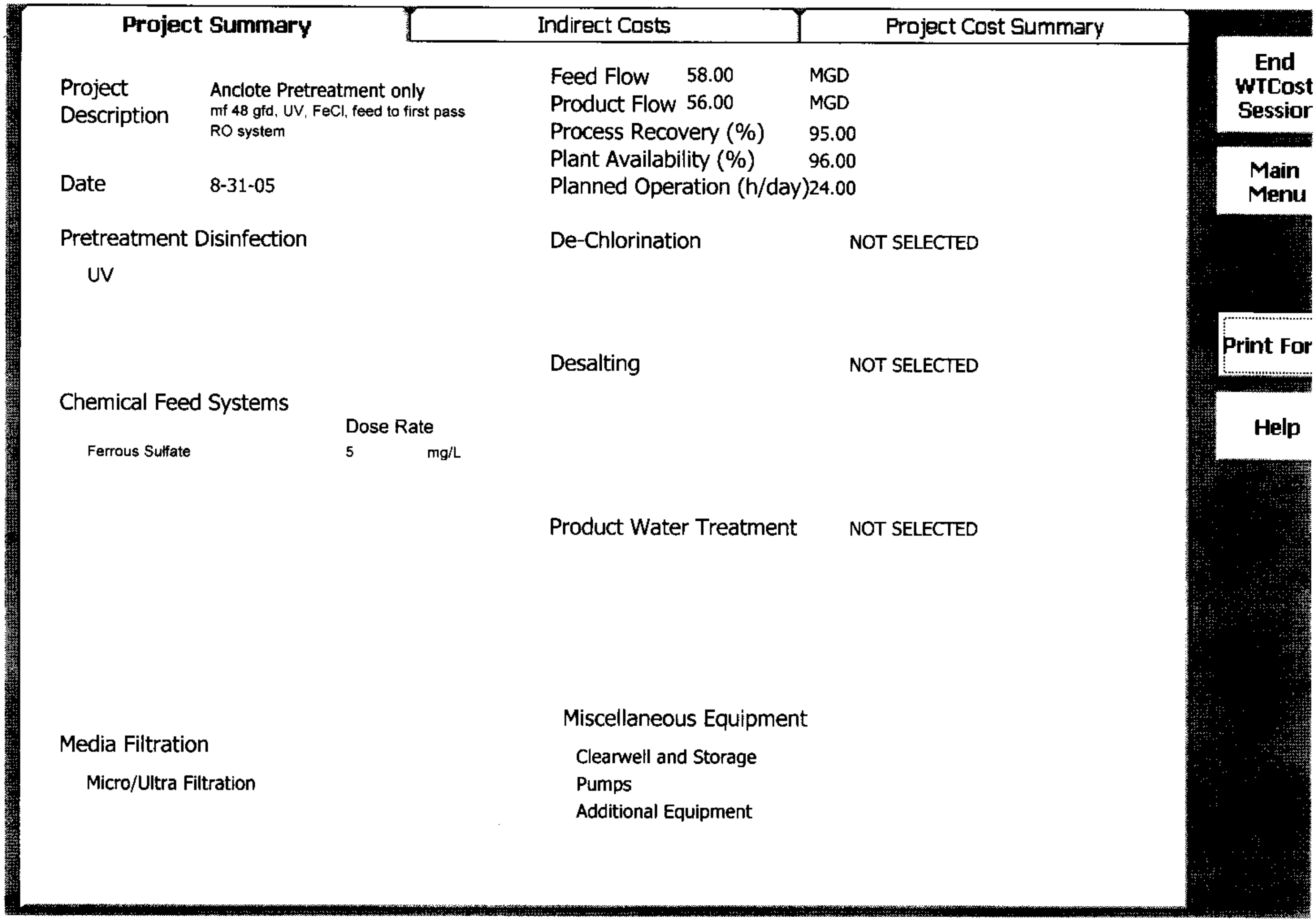
Product Water Treatment NOT SELECTED

Miscellaneous Equipment

Clearwell and Storage
Pumps
Additional Equipment

Media Filtration

Micro/Ultra Filtration



Project Description	Anclote Pretreatment only mf 48 gfd, UV, FeCl, feed to first pass RO system
Date	8-31-05

Feed Flow	58.00	MGD
Product Flow	56.00	MGD
Process Recovery (%)	95.00	
Plant Availability (%)	96.00	
Planned Operation (h/day)	24.00	

Pretreatment Disinfection

UV

De-Chlorination NOT SELECTED

Desalting NOT SELECTED

Chemical Feed Systems

	Dose Rate	
Ferrous Sulfate	5	mg/L

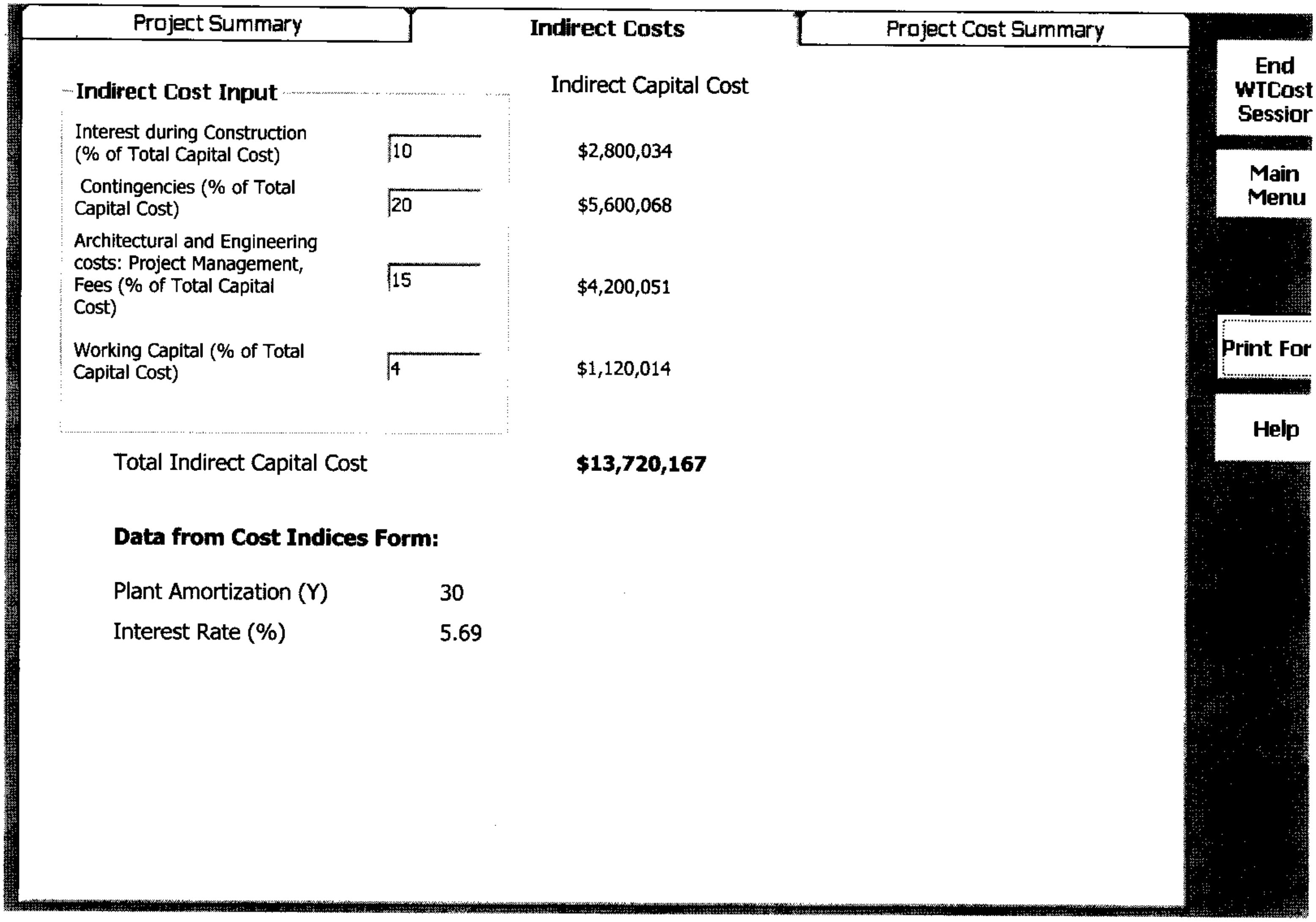
Product Water Treatment NOT SELECTED

Media Filtration

Micro/Ultra Filtration

Miscellaneous Equipment

Clearwell and Storage
Pumps
Additional Equipment

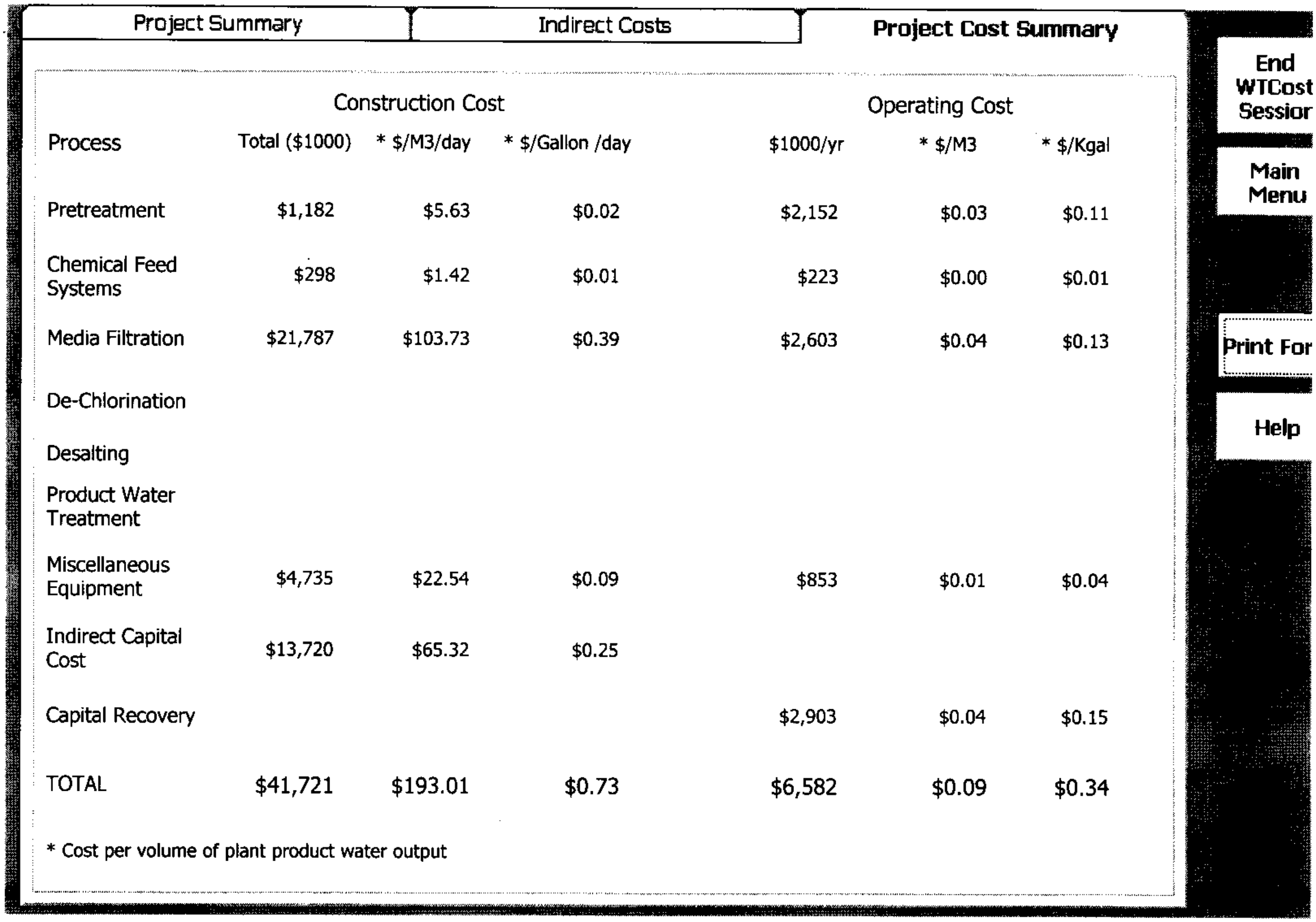


Indirect Cost Input

Indirect Cost Input		Indirect Capital Cost
Interest during Construction (% of Total Capital Cost)	10	$2,800,034
Contingencies (% of Total Capital Cost)	20	$5,600,068
Architectural and Engineering costs: Project Management, Fees (% of Total Capital Cost)	15	$4,200,051
Working Capital (% of Total Capital Cost)	4	$1,120,014
Total Indirect Capital Cost		**$13,720,167**

Data from Cost Indices Form:

Plant Amortization (Y)	30
Interest Rate (%)	5.69



	Construction Cost			Operating Cost		
Process	Total ($1000)	* $/M3/day	* $/Gallon /day	$1000/yr	* $/M3	* $/Kgal
Pretreatment	$1,182	$5.63	$0.02	$2,152	$0.03	$0.11
Chemical Feed Systems	$298	$1.42	$0.01	$223	$0.00	$0.01
Media Filtration	$21,787	$103.73	$0.39	$2,603	$0.04	$0.13
De-Chlorination						
Desalting						
Product Water Treatment						
Miscellaneous Equipment	$4,735	$22.54	$0.09	$853	$0.01	$0.04
Indirect Capital Cost	$13,720	$65.32	$0.25			
Capital Recovery				$2,903	$0.04	$0.15
TOTAL	$41,721	$193.01	$0.73	$6,582	$0.09	$0.34

* Cost per volume of plant product water output