Marco Island Water System
Integrated Membrane Systems Evaluation

Pilot Protocol and Work Plan for Phases II and III

Prepared For:

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- **Bulk Rejection** - Percent solute concentration retained by the membrane relative to the bulk stream concentration.
- **Bulk Solution** - The solution on the high pressure side of the membrane that has a water quality between that of the influent and concentrate streams.
- **Concentrate** - One of the membrane output streams that has a more concentrated water quality than the feed stream.
- **Conventional RO/NF Process** - A treatment system consisting of acid and/or scale inhibitor addition for scale control, cartridge filtration, RO/NF membrane filtration, aeration, chlorination and corrosion control.
- **Feed** - Input stream to the membrane process after pretreatment.
- **Flux** - Mass (lb/ft^2-day) or volume (gal/ft2-day, gsfd, gfd) rate of transfer through membrane surface.
- **Fouling** - Reduction of productivity measured by a decrease in the temperature normalized water MTC.
- **Influent** - Input stream to the membrane array after the recycle stream has been blended with the feed stream. If there is no concentrate recycle then the feed and influent streams are identical.
- **Integrated Membrane System (IMS)** – A water system utilizing a membrane system proceeded by a form of pretreatment such as microfiltration, ultrafiltration, lime softening or coagulation.
- **Mass Transfer Coefficient (MTC)** - Mass or volume unit transfer through membrane based on driving force (gfd/psi).
- **Membrane element** - A single membrane unit containing a bound group of spiral wound or hollow-fiber membranes to provide a nominal surface area for treatment.
- **Membrane system** – An operating water system using membrane elements as the media for process.
- **Permeate** - The membrane output stream that has convected through the membrane.

List of Definitions

- **Pressure Vessel** - A single tube or housing that contains several membrane elements in series.
- **Productivity** - The efficiency with which a membrane system produces permeate over time.
- **Raw** - Input stream to the membrane process prior to any pretreatment.
- **Recovery** - The ratio of permeate flow to feed flow.
- **Rejection (mass)** – The mass of a specific solute entering a membrane system that does not pass through the membrane.
- **Scaling** - Precipitation of solids onto the membrane surface due to solute concentrations on the concentrate side of the membrane exceeding solubility and precipitating onto membrane surface.
- **Solute** - The dissolved constituent in a solution or process stream.
- **Solvent** - A substance, usually a liquid such as water, capable of dissolving other substances.
- **Staging** – Parallel configuration of pressure vessels
- **Total Organic Carbon (TOC)** – A measure of the organic matter in a water in terms of the organic carbon content.

1.0 Introduction

1.1 Background

Florida Water Services (Florida Water) is proceeding with a project known as the Marco Island Water System Integrated Membrane System (IMS) Pilot Plant Evaluation. The existing Marco Lakes raw water supply will be evaluated using an IMS pilot treatment process. This evaluation is divided into three different phases.

Phase I involves screening nanofiltration (NF) membrane elements on Marco Lakes water supply that have been pretreated with cartridge filtration, acid addition and scale inhibitor. Phase I also includes those activities required to start-up and perform initial screening of microfiltration (MF) and ultrafiltration (UF) systems (Zenon Environmental Systems, Pall Advanced Separation Systems, and Aquasource, North America, L.L.C.). The primary purpose for Phase II is to evaluate various MF and UF membrane technologies, and include a re-evaluation of NF single-element screenings but using a MF or UF pretreatment approach that would result in an IMS configuration. Phase III consists of an extended period of evaluating the IMS treatment process comprised of the selected MF or UF technology in conjunction with a full-scale pilot using NF membrane elements.

The current treatment process at the Marco Island Lime Softening Water Treatment Plant (LSWTP) is shown in Figure 1.1. At the LSWTP, raw water is withdrawn from the Marco Lakes surface water supply, which is located approximately nine miles away. The chemical treatment includes quick lime (CaO), alum, chlorine, and ammonia addition. Filtration is accomplished through one four-cell unit. A phosphate-based inhibitor is added after filtration to provide control corrosion in the distribution system. The finished water then proceeds to ground storage where it is mixed and blended with water that has been treated at a separate reverse osmosis (RO) desalting water treatment plant on the island prior to being pumped into the distribution system.

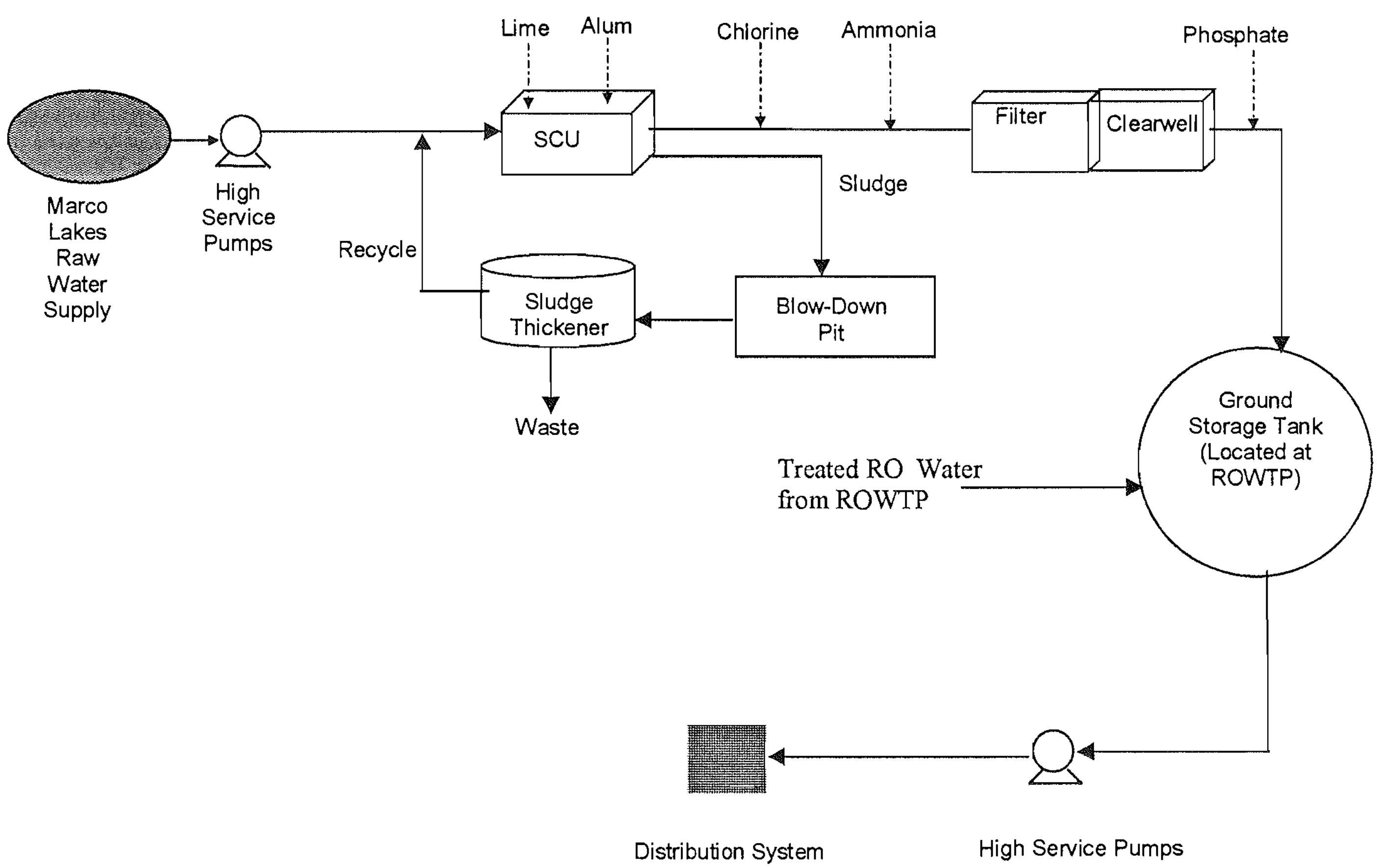
In December 1997, Boyle Engineering Corporation (Boyle) completed a report for the Florida Water entitled "*Marco Island Water System Conceptual Treatment Alternatives and SWTR Planning Study*". This report recommended that pilot evaluations be performed in support of the expansion of the Marco Island Water System. The pilot evaluation was intended to study particulate removal, hardness reduction, and disinfectant by-product (DBP) precursor removal followed by disinfection. Integrated membrane systems (IMSs) utilizing MF or UF followed by NF would accomplish particle, hardness and total dissolved solids (TDS), and DBP precursor removal, and was to be evaluated in the pilot testing.

This document serves as a Pilot-Scale Test Plan for Phases II and III of the Marco Island IMS Evaluation. This pilot test document was prepared to provide general guidance for the operation of the pilot test program. Conditions and variables may change prior to or during the operation of the pilot test and hence affect the utilization of this document. The test plan and protocol for Phase I was previously

1.0 Introduction

Figure 1.1

Marco Island Water System Lime Softening Water Treatment Process Flow Diagram



presented in the report titled *"Marco Island Water System Integrated Membrane System Pilot Plant Evaluation, Test Plan and Protocol – Phase I."*

1.2 Objectives

The primary objective of the Marco Island IMS Evaluation is to evaluate the feasibility of IMS treatment relative to primary drinking water quality standards and sustainable potable water production. Specific objectives are listed as follows:

- IMS compliance with the Surface Water Treatment Rule (SWTR);
- Reduction of disinfection by-products (DBP);
- Removal of hardness and TDS from the supply water;
- Projected MF/UF and NF required cleaning frequency;
- IMS disinfection capability integrity via microbial challenge testing;
- Evaluate membrane performance under varying operating conditions using IMS combinations of MF or UF with NF to determine the effectiveness in achieving existing and future regulatory requirements; and,
- Generate operating data and reports that will be transferred to Florida Water concerning costs and environmental impact of IMS treatment.

1.3 Purpose

In order to meet the objectives stated above, this pilot plant test plan has been created to describe the procedures, methods, and protocol for implementing an IMS for the treatment of the Marco Lakes Water Supply. The pilot plants used to evaluate the IMS will be located at the Marco Island LSWTP. The pilot test plan described in this document consists of the following items:

- Pilot test conditions and variables;
- Descriptions of pilot test scenarios;
- Procedures for evaluating membrane performance including: productivity, finished water quality, and cleaning efficiency;
- Microbial challenge test protocol;
- Procedure for providing Quality Assurance / Quality Control (QA/QC); and

1.0 Introduction

- Pilot test capital and operations and maintenance (O & M) cost considerations that may be utilized for cost comparisons of full scale IMS systems.

Pilot test data, collected at the Marco Island LSWTP, will be utilized for the planning and design of an IMS to be constructed to treat the Marco Lakes Surface Water Supply.

2.0 Pilot Test Conditions, Variables, and Standard Procedures

2.1 Introduction

This section addresses the testing condition, variables and standard procedures for Phases II and III only. Information concerning testing conditions, variables and standard procedures for Phase I can be found in the report titled "*Marco Island Water System Integrated Membrane System Pilot Plant Evaluation, Test Plan and Protocol Phase I.*" The pilot test program for these two phases includes evaluation of MF/UF technologies (Phase II), and operation of a full-scale pilot IMS system (Phase III). Results from these two phases of testing are intended to provide equipment testing information for membrane process performance under a range of operational conditions. During each of the pilot testing phases, evaluation of cleaning efficiency and finished water quality will be performed concurrent with the flux and recovery testing procedures.

2.2 Phase I - Preliminary Screening

Initially in Phase I of the IMS Evaluation, several NF membrane elements will be used for preliminary screening of identified membranes from various manufacturers along with preliminary screening of various MF and UF technologies. The configuration for this phase involves screening each unit (NF, UF and MF) independently for optimum operating conditions established by the manufacture. An IMS configuration will not be used in this phase. Each NF membrane that is selected for inclusion into this project will be screened using bench-scale testing procedures with a minimum of two-week testing runs. The primary purpose of this phase is to evaluate flux decline, TOC, TDS and hardness removal from each NF membrane element tested and solute (total suspended solids, microbiological, and turbidity) removal from each MF and UF pilot unit. In the Phase III of the integrated membrane study, a full-scale pilot plant will be used to evaluate the selected NF elements that provide greater performance as identified in the single-stage initial testing component of this evaluation.

2.3 Phase II - Evaluation of MF/UF Technologies- Operating Conditions

Phase II of the IMS pilot test program shall be performed within a 3 to 4 –month period at the Marco Island Lime Softening Water Treatment Plant (LSWTP). Each phase of the IMS pilot study will use the surface water supplied from Marco Lakes as the water source to the pilot plants. In this phase, the MF/UF pilot unit will be configured for pretreatment to the single element bench scale test (SEBST) unit in addition to the feedwater chemical pretreatment applied in Phase I of the IMS pilot study. Figure 2.1 shows the flow diagram for Phase II of the IMS pilot study. Figure 2.2 presents the proposed process test matrix using various manufacturer membrane systems. As indicated in this figure, the UF membrane technology identified as UF_B will be supplied as a single 4-inch x 40-inch spiral wound element. This

Figure 2.1

Flow Diagram for Phase II

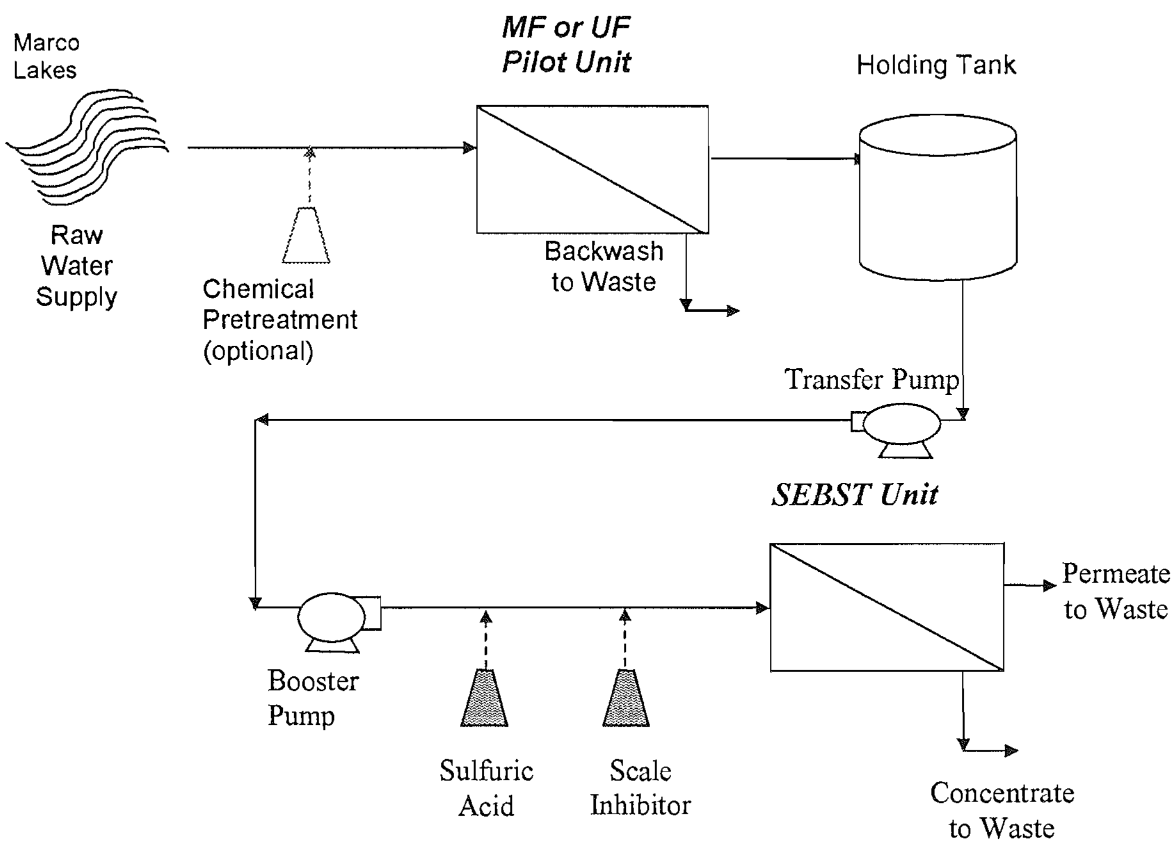
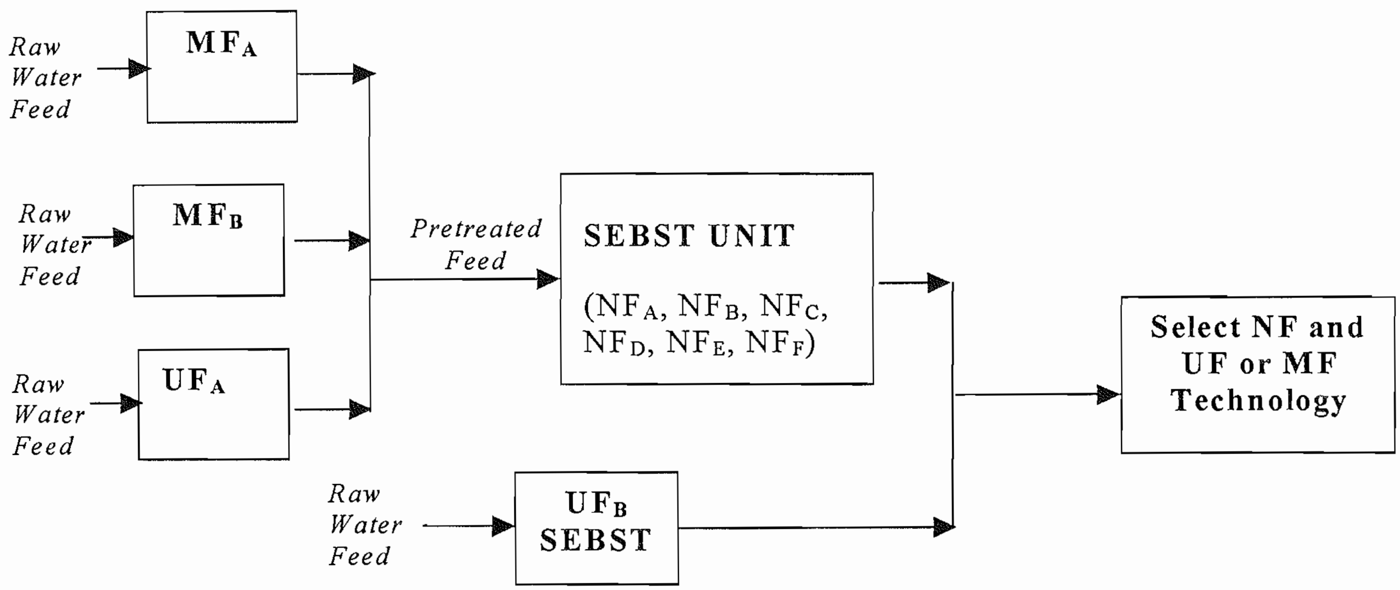


Figure 2.2

Proposed Membrane Process Test Matrix – Phase II



MF_A = Zenon Environmental Systems (Zenon)
845 Harrington Court
Burlington, Ontario, Canada L7N 3P3

MF_B = Pall Advanced Separation Systems (Pall)
2200 Northern Boulevard
East Hills, New York 11548

UF_A^* = Aquasource, North America, L.L.C. (AquaSource)
292 Emerywood Parkway
Richmond, Virginia 23294

UF_B = Osmonics DeSal (DeSal)
760 Shadowridge Drive
Vista, California 92083

NF_A = Hydranautics (Model 4040-TFV-7410)

NF_B = Hydranautics (Model ESNA1-4040)

NF_C = Fluid Systems (Model TFCS 4921S)

NF_D = TriSep (Model TS80-TSA)

NF_E = FilmTec (Model 200B-4040)

NF_F = DeSal (Model PW4040F)

* *Phase I testing only.*

element will use the SEBST pilot unit to evaluate the pretreated water supplied from the spiral wound technology.

Operating conditions for the MF and UF units to be established includes the flux, recovery, backwash frequency, operational pressures/vacuum and bleed rate of each unit. These conditions will be monitored throughout the IMS pilot study. In addition, a high and low operational flux rate for the MF/UF units will be established in step one. The maximum/moderate recovery and high/low operational flux rate for the SEBST unit will be established in step two. Each rate will be used in the remaining portion of the IMS pilot study. An evaluation of particulate removal and solute removal for the established optimum conditions will also be included in both steps of this phase.

The operational variables for Phase II are listed in Table 2.1. Table 2.2 summarizes the MF/UF parameters that will be used to evaluate the effects of the operational variables and provide design data for a full-scale IMS plant.

2.3.1 Phase III - IMS Extended Evaluation – Operating Conditions

The MF/UF system(s) and NF membranes selected from the screening process will be used to configure the IMS for Phase III. The testing for this phase will be conducted for a minimum of 24-weeks. This extended test period will be used for verification of the recommended MF/UF pretreatment systems. The extended test period will also serve to verify performance from the screening run of the selected NFs.

Figure 2.3 lists the test matrix for the IMS for this phase of testing. The test conditions to be used for the extended testing period will provide information relative to fouling potential. A range of run conditions will be considered for each membrane process during this extended test period. Table 2.3 summarizes the test conditions to be implemented during the extended testing period. This operating scenario allows for 3 weeks of operation under each test combination for a total of 12 weeks of operation.

Figure 2.4 illustrated the flow diagram for this phase of testing. As shown in Figure 2.4, an additional chloramine injection for disinfection will be used in this phase. The extended operating scenario is intended to offer information regarding long-term productivity decline for both the MF/UF and NF membrane systems in addition to the effect of varied operating condition upon productivity decline.

2.4 Standard Sampling Methods

The analytical methods utilized in this study for on-site monitoring of raw water, feed water, concentrate and permeate water quality will follow methods described in *Standard Methods for the Examination of Water and Wastewater (Standard Methods)*, 18th edition (1992). Use of either bench-top or on-line field analytical equipment will be acceptable for the IMS Evaluation. Tables 2.4 through 2.6 summarize water quality analyses to be performed and the standard method of analysis during the Phases II and III of the

Table 2.1

Phase II Operational Variables

Variable	**Units**
MF/UF membranes	MF_A = Zenon MF_B = Pall UF_A = Aquasource UF_B = DeSal
NF membranes	NF_A = Hydranautics (Model 4040-TFV-7410) NF_B = Hydranautics (Model ESNA1-4040) NF_C = Fluid Systems (Model TFCS 4921S) NF_D = TriSep (Model TS80-TSA) NF_E = FilmTec (Model 200B-4040) NF_F = DeSal (Model PW4040F)
Water flux (gal-ft^{-2} day^{-1})	Specified by manufacturer
Operating time	Screening tests: 0 to 12 weeks

Note: Other MF and UF equipment may also be tested.

Table 2.2

MF and UF Assessment Parameters

Water Quality:
1. Filtrate particle counts in seven bin sizes reported as particles/mL greater than 0.5, 1, 3, 5, 7, 10 and 15 microns.
2. Heterotrophic plate count (HPC), counts/mL.
3. Filtrate turbidity, NTU.
4. Microbial disinfection
5. Feed and filtrate TOC. On a limited basis, DBPs and specific DBP precursors may also be analyzed (see Table 2.5).
Process:
5. Flux Rate (gal-ft^{-2} day^{-1}) (gfd).
6. Filtrate run time; time during which the MF/UF unit is producing filtrate at the above flux rate (nonfiltrate process periods include backwash and cleaning periods).
7. Water recovery, percent.
8. filtrate silt density index (SDI).
9. Fouling rate of downstream NF elements.
10. Cleaning frequency, hrs^{-1}.
11. Ability to operate with and without chemical pretreated feed water.
Cost:
12. Chemical consumption.
13. Power cost
14. Feed and backwash pressures and volumes.
15. Operator and maintenance time required. (approximate estimates)

Figure 2.3

Proposed Membrane Process Test Matrix – Phase III

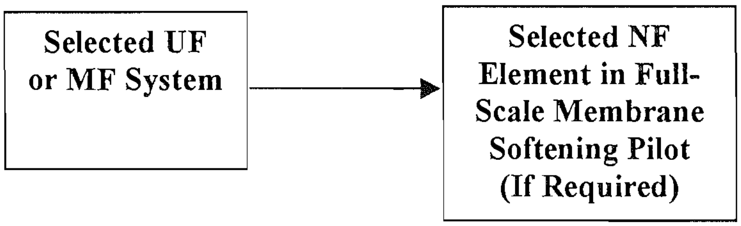


Table 2.3

Twelve-Week Operating Scenario for IMS Extended Testing

Time Interval (week)	System	
	MF/UF Operating Scenario	NF Operating Scenario
1-6	low flux	low flux, moderate recovery
6-12	high flux	low flux, moderate recovery
12-18	low flux	high flux, moderate recovery
18-24	high flux	high flux, moderate recovery

Figure 2.4

Flow Diagram for Phase III

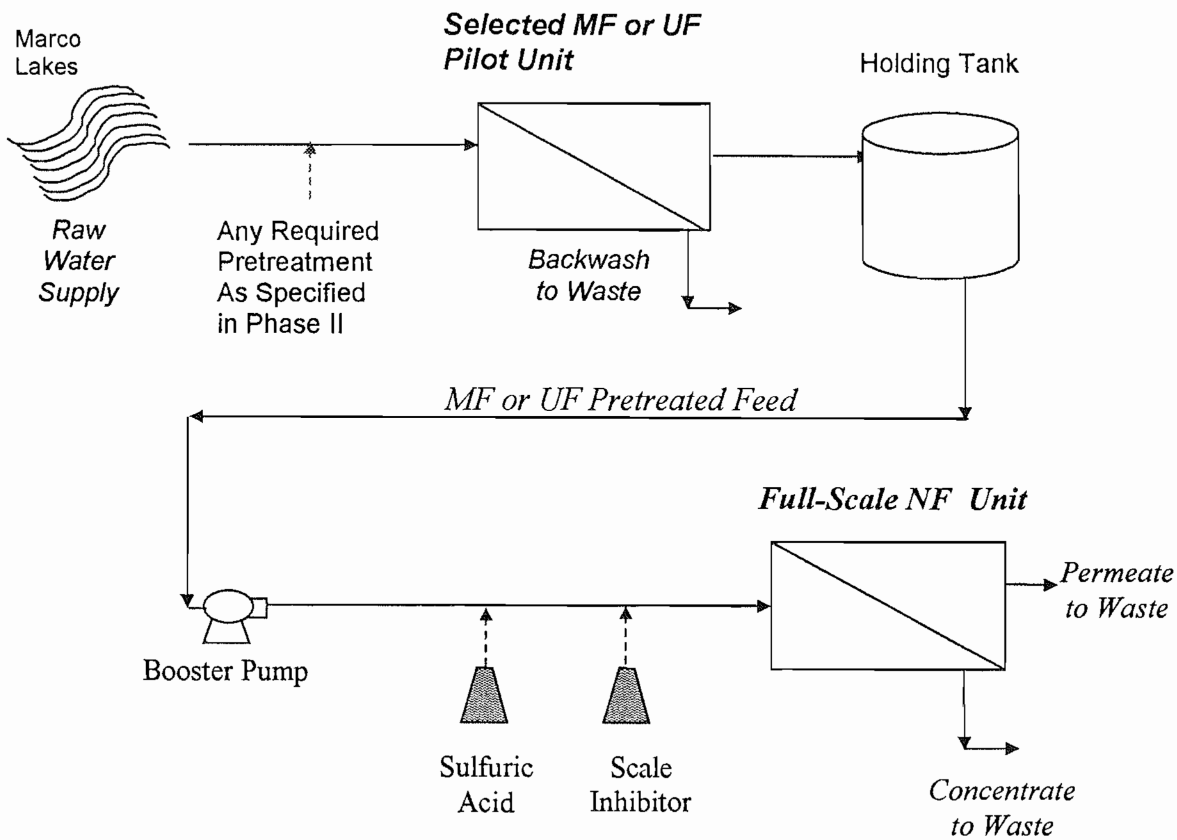


Table 2.4

Inorganic Analyses

Analysis Parameter	Suggested Method
TDS @ 180 °C	SM 2540C
Total Alkalinity	SM 2320
Total Hardness	SM 2340
Calcium Hardness	SM 3500-Ca-D
Sodium	SM 3120B
Iron, dissolved and total	SM 3120B
Aluminum, dissolved and total	SM 3120B
Manganese	SM 3120B
Potassium	SM 3120B
Strontium	SM 3500-Sr-C
Barium	SM 3120B
Silica (SiO_2)	SM 3120B
Fluoride	SM 4500-F-C
Phosphate	SM 4500-P-F
Nitrate	SM 4500-NO_3-C
Chloride	SM 4500-Cl^--F
Sulfate	EPA 300
Ammonia	SM 4500-NH_3-G
Lead	SM 3120B
Copper	SM 3120B
Bromide	EPA 300

[1] ICP analyses for SM 3120B will utilize 0.45 m filtered samples from NF feed and reject and unfiltered samples from the NF product.

Table 2.5
Organic Analyses

Analysis Parameters	Suggested Method
Total organic carbon (TOC)	SM 5310B
UV absorbance at 254 nm (UV-254)	SM 5910B
Chloral hydrate chloropicrin	EPA 551.1
Chloral hydrate chloropicrin FP	SM 5710D
Haloketones	EPA 551.1
Haloketones FP	SM 5710D
Haloacetonitrile	EPA 551.1
Haloacetonitrile FP	SM 5710D
THM	EPA 502.2
THMFP	SM 552.1
HAA	SM 6251B
HAAFP	SM 5710D
TOX	SM 5320B
TOXFP	SM 5710D

Table 2.6

Other Laboratory Analyses

Analysis Parameter	Suggested Method
Temperature	SM 2550B
pH	SM 4500-H^+-B
Total Suspended Solids (TSS)	SM 2540D
Specific Conductance	SM 2510
Turbidity	EPA 180.1
True Color	SM 2120 C
Total Coliform	SM 9222B
Heterotrophic Plate Count (HPC)	SM 9215B

IMS Evaluation. Trihalomethane and haloacetic formation potential (THMFP and HAAFP) parameters will be analysed on a limited basis during Phase III of the IMS pilot study.

Sample preservation shall be done in accordance with *Standard Methods*. Strict adherence to the protocol set forth in *Standard Methods* is essential for obtaining accurate, meaningful results. In addition, the sample ports shall be rinsed with 70% diluted bleach solution and afterwards, distilled water, prior to any bacteriological sampling. Bacteriological samples should be the last type of sample collected during each sampling event.

The necessary sampling and monitoring instruments shall be calibrated prior to each day's use. Only fresh pH buffers shall be used for calibration of the pH meter. The pH meter calibration should include two points that represent the range of measurements that will be made (i.e., pH of 4 to a pH of 10). A chain-of-custody form shall accompany each group of samples. The chain-of-custody form can be obtained from the laboratory performing the analytical services should be filled out on this form. This form should include the temperature and pH of the sample at the time of collection and note any variance from typical operations of the pilot plant.

Each sample container shall have the following information inscripted on it:

- sample location,
- sample identification, number, if appropriate,
- date,
- time of collection,
- type of preservative, if any,
- initials of sample collector and
- special notes, comments or deviations.

The sample collector should use proper fitting, protective eyewear and rubber latex gloves dedicated only to this purpose, primarily for safety and contamination avoidance. Use of latex rubber gloves can help prevent sample contamination.

For the water quality parameters requiring analysis at a Department of Heath (DOH)-certified laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the DOH-certified, off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab. Whenever possible, a large wide-mouthed container should be used to collect the bulk sample with the exception of total coliform or volatile organic carbon analysis requirements. An aliquot should be poured into the appropriate smaller container for the field measurement of pH, temperature, conductivity, and TDS. **Do not insert the pH, or conductivity probes directly into the bulk sample container. Doing so could contaminate the bulk sample.** Only calibrated instruments shall be used for the field measurements. The instruments should be calibrated prior to each use. The balance of the bulk sample shall be poured into the appropriate container for laboratory analysis of the remaining water quality parameters.

Organic Parameters: Total Organic Carbon, UV_{254} *Absorbance*

Samples for analysis of TOC shall be collected in glass bottles supplied by the DOH-certified laboratory and shipped with an internal cooler temperature of approximately 2 – 8 °C to the analytical laboratory. Samples shall be processed for analysis by the DOH-certified laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2 – 8 °C until initiation of analysis.

Turbidity and Conductivity Analysis

Turbidity analyses shall be performed according to EPA 180.1 with either an in-line or bench-top turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the permeate waters, and either an on-line or bench-top turbidimeter may be used for measurement of the feedwater (and concentrate where applicable). Conductivity analysis will conform to Standard Methods.

Florida Water personnel shall be required to document any problems experienced with the turbidity monitoring instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Optional Monitoring: Microbial Challenge Study

Clostridium and *Bacillus* (C&B) will be utilized (if required) as the model parasites for the microbial challenge studies. One C&B seeding will be initially conducted on each MF/UF permeate and NF membrane system. If the membrane system rejected these parasites to below detection level of the assay, no additional seeding will be conducted on that system. However, if C&B is recovered in the permeate of the membrane system a second seeding may be conducted after repeating the quality control procedures on that membrane system. Provisions should be made to repeat a maximum of two C&B seeding experiments for the MF/UF pretreatment membrane systems and two experiments for the NF membrane system. A stock solution of the *Clostridium* and *Bacillus* will be initially prepared and may be injected into the feed stream of treatment units or applied in a batch test mode using the constant feed tank volumes between 50 to 200 gallons. Prior to the microbial challenge study, a tracer study will be conducted in order to establish the hydraulic stabilization (contaminant level in = contaminant level out). A protocol for the tracer study and challenge experiments is provided in the Appendix. Sodium chloride (table salt) may be used as the injected contaminant thereby allowing conductivity to be measured as an indicator of the hydraulic stabilization. After a stabilization period, samples will be collected by the filter-concentration method and analyzed by the fluorescent antibody procedure.

Samples for analysis of parasite challenge experiments shall be collected in bottles supplied by a qualified laboratory and shipped with an internal cooler temperature of approximately 2 - 8°C to the analytical laboratory. Samples shall be processed for analysis by the laboratory within 24 hours of collection.

Optional: Disinfection Screening

The objective of the disinfection screening is to determine the impacts of sodium hypochlorite (bleach) on the finished water quality. This screening will include water quality analysis, titration curves, and jar tests. In addition, the screening evaluation will provide information on the comparison of sulfuric acid and carbon dioxide addition to suppress the pH after disinfection using bleach. Chlorite, chlorate, hardness, alkalinity, and chloride will be the primary water quality parameters of concern.

2.5 Data Management

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that sufficient and reliable operational data is collected for evaluation purposes. The data management system used in the Pilot Test Program shall involve the use of computer spreadsheets characterizing membranes and recording of operational parameters for the membrane equipment on a daily basis.

The database for the project will be set up in custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each of the monitored water quality and operational parameters from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheets. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Any corrections will be noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out.

Hand written data shall be recorded three times a day, (once every 8-hour shift) on the provided daily log sheet as illustrated in Tables 2.7 and 2.8. The original copy of these sheets should be maintained in a notebook at the Lime Softening Plant; however, a copy of the data sheets shall be forwarded to Boyle weekly. All data from the daily log sheets shall be entered into the appropriate spreadsheets provided to Florida Water personnel. Data entry shall be conducted on-site by the designated field testing operators and checked at this time.

Following data entry, the spreadsheet shall be printed and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard copies and corrected in the database. The corrected-recorded calculations shall also be checked at this time. The final spreadsheet shall be forwarded to the Boyle electronically. In spreadsheet form, Boyle will manipulate this data into a convenient framework to allow analysis of membrane equipment operation.

Table 2.7

SEBST Field Data Collection Sheet

Daily Readings for : ____________________ **RO Feed Temperature:** ____________________

Time and Hour Meter Reading	Location	Parameters					
		Flow (gpm)	Pressure (psi)	pH (units)	Conductivity (µmhos/cm)	Calcium (mg/L)	Total Hardness (mg/L as $CaCO_3$)
	Raw Feed (Inlet)						
	Pretreated Feed						
Initials:	RO Feed						
	Permeate						
RO Feed Pump Speed = ________	Recycle						
	Concentrate						
	Comments:						

Time and Hour Meter Reading	Location	Parameters					
		Flow (gpm)	Pressure (psi)	pH (units)	Conductivity (µmhos/cm)	Calcium (mg/L)	Total Hardness (mg/L as $CaCO_3$)
	Raw Feed (Inlet)						
	Pretreated Feed						
Initials:	RO Feed						
	Permeate						
RO Feed Pump Speed = ________	Recycle						
	Concentrate						
	Comments:						

Time and Hour Meter Reading	Location	Parameters					
		Flow (gpm)	Pressure (psi)	pH (units)	Conductivity (µmhos/cm)	Calcium (mg/L)	Total Hardness (mg/L as $CaCO_3$)
	Raw Feed (Inlet)						
	Pretreated Feed						
Initials:	RO Feed						
	Permeate						
RO Feed Pump Speed = ________	Recycle						
	Concentrate						
	Comments:						

Table 2.8

Example MF/UF Daily Operational Data Collection Sheet

Parameter	Shift 1	Shift 2	Shift 3
Time			
Initials			
Feed			
Q_{feed} (gpm)			
P_{feed} (psi)			
T_{feed} (°C)			
pH_{feed}			
$Turbidity_{Feed}$ (NTU)			
Particle $Counts_{Feed}$ (counts)			
Concentrate			
Q_{conc} (gpm)			
P_{conc} (psi)			
T_{conc} (°C)			
pH_{conc}			
$Turbidity_{conc}$ (NTU)			
Particle $Counts_{conc}$ (counts)			
Finished			
Q_{fin} (gpm)			
TDS_{fin} (mg/L)			
$Turbidity_{fin}$ (NTU)			
Particle $Counts_{fin}$ (counts)			
Recovery (Q_{fin}/Q_f) (%)			

Each experiment (e.g. each membrane test run) shall be assigned a run number that will then be cross-referenced to the data from that experiment through each step of data entry and analysis. As samples are collected and analyzed by certified laboratories, the data shall be tracked by use of the same system of run numbers. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

Power costs for operation of the membrane equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by Florida Water personnel during each of the testing periods. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements: pumping requirements, size of pumps, name-plate, voltage, current draw, power factor, peak usage, etc.). In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

3.0 Pilot Test Description

The section provides a road map for pilot testing to obtain information that can be used in the planning of a full-scale facility. The procedures described in this section are intended only to supplement the project with information on available vendors, and are not intended to serve as data for design considerations.

3.1 Schedule

After the initial raw water preliminary screening, a 10 week MF/UF screening and an extended 18-week minimum IMS operations testing will be performed. The MF/UF systems that will be used include Pall, Zenon, Aquasource, and Desal. The selected MF membranes and UF membranes will be configured as pretreatment with the NF membrane(s) selected from preliminary screening. Any other membrane technologies submitted for testing will be tested for 2 to 4-week short-screens during the extended 12-week testing because of time and budget constraints. Figure 3.1 presents the schedule for Phases II and III of the IMS pilot test program.

3.2 Phase II - MF/UF Evaluation Tests

MF/UF membrane technologies will be evaluated using pilot-scale testing procedures. All tests will be performed using the surface water supplied from Marco Lakes. Optimum operational parameters for each MF/UF units will be identified during the raw screening in Phase I.

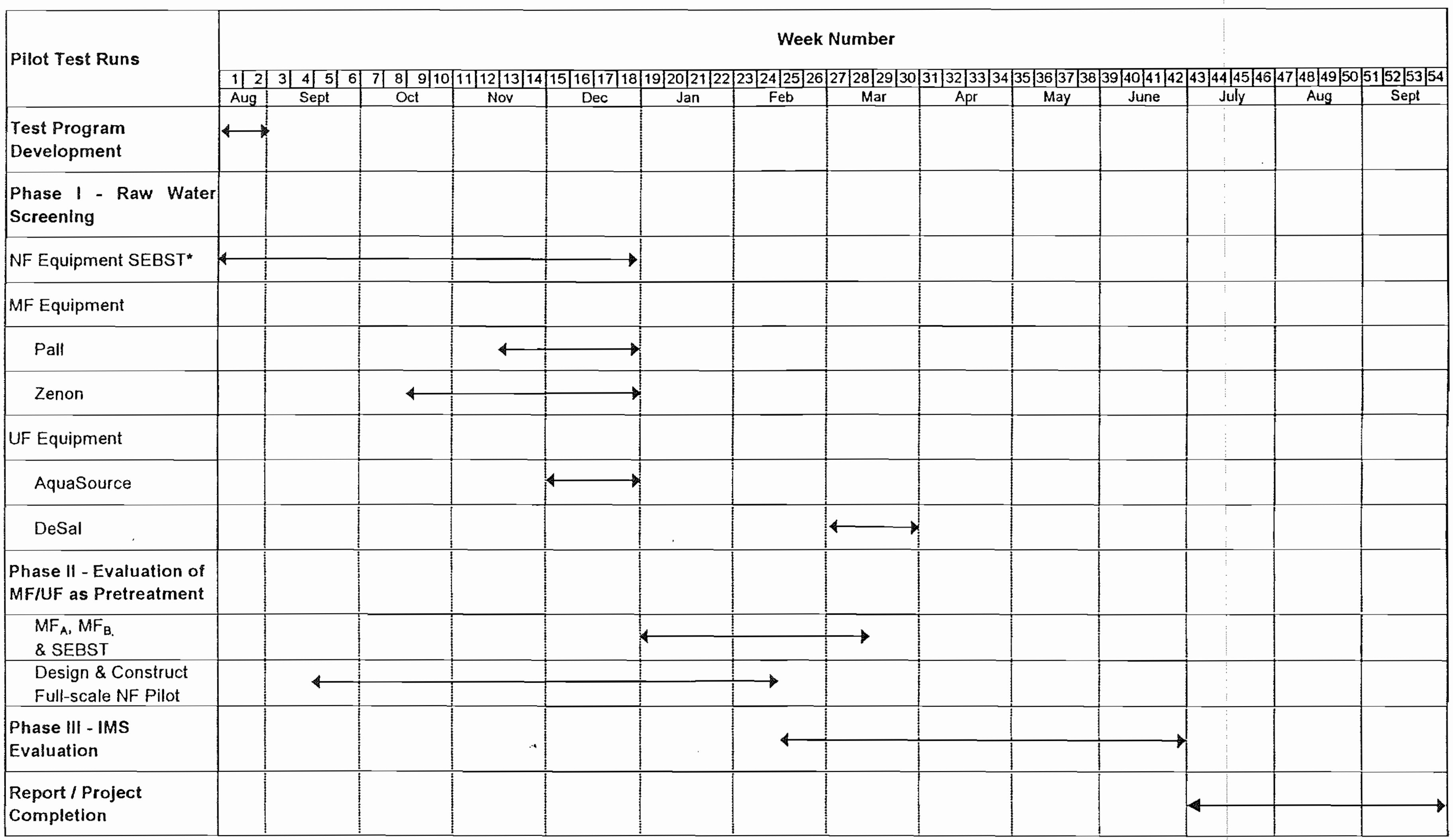
3.2.1 General Requirements

Each of the MF/UF pilot units will be monitored individually in Phase I. Subsequently, in Phase II; each MF/UF unit will be connected as pretreatment to the SEBST unit as shown in Figure 2.2. Each MF/UF unit will be operated at the manufacture recommended flux and recovery established in Phase I. The MF/UF pilot descriptions and set-up requirements are listed in Table 3.1.

The objectives of the test conditions for this phase of testing are based upon expected fouling potential of the NF membranes. In addition to the data obtained in Phase I, the evaluation test in this phase is intended to offer information regarding productivity decline as it relates to the effects of MF/UF pretreatment for the NF membrane systems tested.

Figure 3.1

Weekly Schedule for IMS Testing for Florida Water Marco Island Project



*Hydranautics, Fluid Systems, DeSal, and FilmTec

Table 3.1

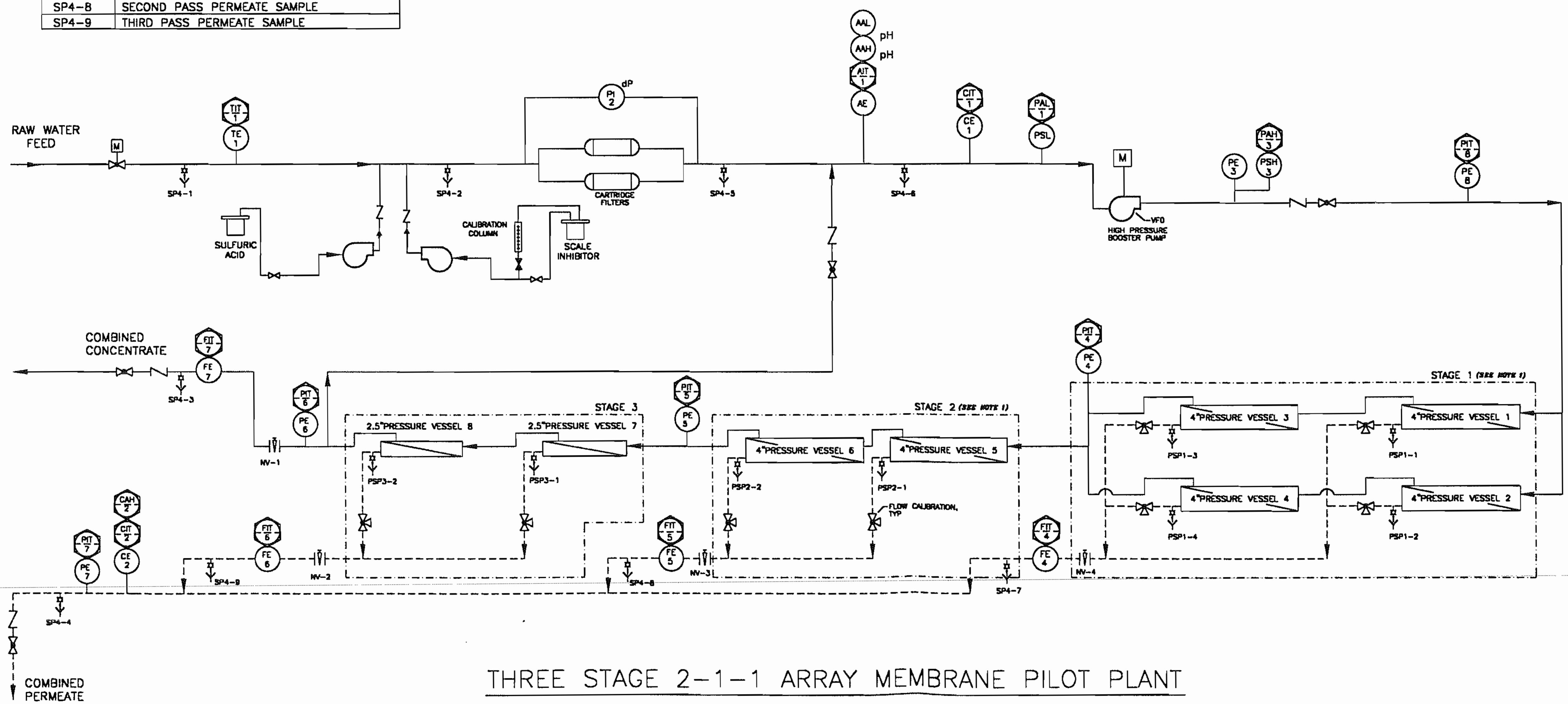
MF/UF Pilot Unit Description

Parameter	Zenon	Pall Corporation	AquaSource*
Unit	ZeeWeed Drinking Water Unit	WPM – 1 Microza™ Pilot Unit	UF Pilot
Modules included with system	Zeeweed 500	One 3" and 5" diameter Microza™ microfilter	2 modules in parallel configuration
Nominal Membrane Pore Size	0.1 microns	0.1 micron (microfilter)	Not provided
Nominal Surface Area	460 ft^2	3" - 40.9 ft^2 (ID) 5" - 214 ft^2 (ID)	77.5 ft^2/module
Raw Water Feed Min. (gpm)	17 gpm	Not provided	10 gpm
Raw Water Feed Max. (gpm)	20 gpm	10 gpm	Approximately 15 gpm
Permeate Flow Min. (gpm)	0 gpm	1 gpm	0 gpm
Permeate Flow Max. (gpm)	16 gpm	15 gpm (nominal 10 gpm)	10 gpm
Process Tank Size	185 gal	75 gal	N/A
Compressed Air Supply (psi)	Min 80 psi	90 psi, avg. < 10 SCFM, instrument grade air	N/A
Process Chemicals	Cleaning Chemicals	Citric Acid, NaOH, NaOCl	Ultrasil 43, Ultrasil 59

** Participation in Phase I only.*

SAMPLE POINT SCHEDULE

SAMPLE POINT	DESCRIPTION
PSP1-1	STAGE 1/VESSEL 1 PERMEATE SAMPLE
PSP1-2	STAGE 1/VESSEL 2 PERMEATE SAMPLE
PSP1-3	STAGE 1/VESSEL 3 PERMEATE SAMPLE
PSP1-4	STAGE 1/VESSEL 4 PERMEATE SAMPLE
PSP2-1	STAGE 2/VESSEL 1 PERMEATE SAMPLE
PSP2-2	STAGE 2/VESSEL 2 PERMEATE SAMPLE
PSP3-1	STAGE 3/VESSEL 1 PERMEATE SAMPLE
PSP3-2	STAGE 3/VESSEL 2 PERMEATE SAMPLE
SP4-1	RAW WATER SAMPLE/SDI POINT
SP4-2	FEED WATER SAMPLE/SDI POINT
SP4-3	COMBINED CONCENTRATE SAMPLE
SP4-4	COMBINED PERMEATE SAMPLE
SP4-5	FILTERED FEED SAMPLE
SP4-6	RO FEED SAMPLE
SP4-7	FIRST PASS PERMEATE SAMPLE
SP4-8	SECOND PASS PERMEATE SAMPLE
SP4-9	THIRD PASS PERMEATE SAMPLE



THREE STAGE 2-1-1 ARRAY MEMBRANE PILOT PLANT

NOTES:

1. EACH PRESSURE VESSEL SHALL CONTAIN NANOFILTRATION MEMBRANE ELEMENTS.
2. PIPING MATERIALS: FROM RAW WATER SUPPLY TO SUCTION SIDE OF HIGH PRESSURE BOOSTER PUMPS SHALL BE SCHEDULE 80 PVC; HIGH PRESSURE PIPING DOWNSTREAM OF BOOSTER PUMPS INCLUDING CONCENTRATE AND RECYCLE STREAMS UP TO CONTROL VALVES SHALL BE 316 SS HIGH PRESSURE TUBING; PERMEATE PIPING SHALL BE SCHEDULE 80 PVC.

DATE | REVISIONS | NO.

PROJECT MANAGER STEVEN J. DURANCEAU, PhD,PE
REG. NO. 46583

BOYLE ENGINEERING CORPORATION

PILOT PLANT PROCESS FLOW DIAGRAM
P & I DIAGRAM

FLORIDA WATER SERVICES
MEMBRANE SOFTENING WATER TREATMENT PILOT PLANT

SHEET 1 OF 1
EXHIBIT A

3.2.2 IMS Evaluation Using SEBST

The single element bench scale test (SEBST) unit in series with the MF/UF pilot units will demonstrate the ability of an IMS process to reduce particles and TDS from the feed water and identify appropriate pretreatment for the NF process. Each of the 4-inch x 40-inch membrane elements screened in Phase I will be used in the SEBST unit for this evaluation.

3.2.3 Data Collection and Analyses

Monitoring data that is anticipated to be collected by the operators daily, laboratory data, and chemical analyses performed during Phase II of the IMS pilot testing program evaluation process are presented in this section. Tables 3.2 and 3.3 outline the MF/UF and the SEBST NF monitoring data. Tables 3.4 and 3.5 outline the Weekly MF/UF and SEBST NF laboratory data. Table 3.6 summarizes the proposed chemical analyses to be performed in Phase II.

3.3 Phase III - IMS Operation Tests

The IMS configuration selected from the evaluation process will be conducted for approximately 24-week testing period. This extended test period will be used for operation of the recommended MF/UF system(s), and the Phase III test period will also serve to verify performance of IMS using of the selected NF membrane. The approximately 24-week operation will enable the evaluation of the selected MF/UF - NF combinations.

3.3.1 Operating Conditions

Exhibit A illustrates the full-scale NF pilot system to be used in this phase of the IMS pilot testing program. A selected MF/UF system will feed the full scale NF pilot unit.

The NF pilot membrane system is designed as a staged array of elements similar to the design of the full scale membrane plants. Staging will be used to increase the system recovery by feeding the concentrate from previous stages to downstream stages. The NF pilot plant design criteria is as follows:

- Pressure available at the suction flange of the raw water feed pumps: (30 to 50 psig)
- Permeate backpressure as required to achieve hydraulic balance across membrane stages.
- A variable frequency drive will control the RO feed pump.
- Number of stages: 3
- Pressure vessel array: 2:2:1:1:1:1
- Number of 40" elements per pressure vessel: 3

Table 3.2

Phase II - MF/UF Operator Data Collection Items

Frequency: Continuous if automatic; 3 times a day if manual			
Stream Properties	Process Streams		
	Raw Water Feed	Filtrate	Backwash Waste
Temperature, C	X		
Pressure, psi	X	X	
Flow, L/min[1]	X	X	X(if instrumented)
Turbidity, NTU	X	X	
SDI or plugging factor[2]		X	
Particles/mL sizes[3]:			
> 0.5 µm[4]		X	
> 1.0 µm		X	
> 3.0 µm		X	
> 5.0 µm		X	
> 7.0 µm		X	
> 10.0 µm		X	
> 15.0 µm		X	

[1]For intermittent flows, totalizer flowmeters are required to calculate average flows and water recoveries.
[2]SDI analysis should be provided weekly
[3]When available, a light blocking or a light-scattering instrument may be used.
[4]The 0.5 mm range is only on the light-scattering particle counter.

Table 3.3

Phase II - SEBST Unit Operator Data Collection Items

Frequency: 3 times a day			
Stream Properties	Process Streams		
	Transfer Tank Feed	Concentrate	Permeate
Operation Time	X		
Temperature, C	X		
Pressure, psi	X	X	
Flow, L/min		X	X
Conductivity, μm/cm	X	X	X
pH	X	X	X
Calcium Hardness	X	X	X
Total Hardness	X	X	X
SDI (weekly measurement)	X		

Table 3.4

Phase II - Weekly MF/UF Laboratory Data

Frequency: Once a week			
Stream Properties	Process Streams		
	Raw Water Feed	Filtrate	Backwash Waste
Operation Time	X		
Temperature, C	X		
pH	X		
TSS, mg/L	X		X
Turbidity, NTU	X	X	
HPC, no./mL	X	X	
Dissolved Oxygen, mg/L	X		

Table 3.5

Phase II - Weekly SEBST Unit Laboratory Data Collection

Frequency: Once a week			
Stream Properties	Process Streams		
	Transfer Tank Feed	Concentrate	Permeate
Operational Time	X		
Temperature, C	X		
pH	X		
HPC, no/mL		X	X
Conductivity, µm/cm	X	X	X
UV-254	X		X

Table 3.6

Phase II - Chemical Analyses

Frequency: Every 2 weeks					
Stream Properties	Process Streams				
	MF/UF		NF in SEBST Unit		
	Raw Water Feed	Backwash Waste	Transfer Tank Feed	Concentrate	Permeate
Time	X		X		
Temperature, C	X		X		
pH	X		X		
Organic/Inorganic Analyses (see Tables 2.4 and 2.5)	X			X[1]	X

[1] *Inorganic analysis only from the concentrate stream.*

- ➢ Total number of 4-inch membrane elements: 18
- ➢ Total number of 2.5-inch membrane elements: 6

- Minimum Recovery: 75%
  Maximum Recovery: 90%
- Hydraulic design includes:
  - ➢ Nominal Permeate Production Rate: 14 gpm
  - ➢ System Feed Flow Rate: 16 to 26 gpm
  - ➢ Minimum Feed Flow Rate for 4-inch elements: 3 to 6 gpm
  - ➢ Minimum Feed Flow Rate for 2.5-inch elements: 0.75 to 1.5 gpm

The maximum recommended recoveries are based on projections from membrane manufacturers and antiscalant companies. The minimum recommended reject flows are determined based on results from Phase II and discussions with the membrane manufacturers. The product water flux selected is based on the recovery, recommended minimum reject flows, and rates of NF fouling observed during the Phase II screening tests.

3.3.2 Data Collection and Analyses

Daily operator data collection, laboratory data, and chemical analyses will also be required during the Phase III extended testing period. For MF/UF operator data refer to Table 3.2 presented earlier in this section. Table 3.7 outlines the membrane unit consisting of MF or UF pilot unit in conjunction with the NF pilot unit (MU/NF) Operator Data. Table 3.8 outlines Weekly MF/UF Laboratory data. Tables 3.9 and 3.10 summarize the proposed chemical analyses to be performed in Phase III testing.

Table 3.7

Phase III - MU/NF Operation Data Collection

Frequency: Continuous if automatic; 3 times a day if manual									
Stream Properties	Process Streams								
	Raw Water Feed	Transfer Tank Feed	Concentrate			Permeate			
			Instg. 1	Instg. 2	Combined	Stage 1	Stage 2	Stage 3	Total
Operation Time		X							
Temperature, °C		X							
pH	X	X							
SDI[1]		X							
Turbidity	X	X							
Pressure, psi	X	X	X	X	X				
Flow, gal/min		X	X	X	X	X	X	X	X
Conductivity, µS/cm	X	X	X	X	X	X	X	X	X
Calcium Hardness, mg/L as $CaCO_3$	X		X	X	X	X	X	X	X
Total Hardness, mg/L as $CaCO_3$	X		X	X	X	X	X	X	X

[1]*SDI analysis should be measured weekly.*

Table 3.8

Phase III - Weekly MU/NF Laboratory Data Collection

Frequency: Once a week			
Stream Properties	Process Streams		
	Raw Water Feed	Transfer Tank Feed	Concentrate
Operation Time	X		
Field Temperature, C	X		
Field pH	X		
TSS, mg/L	X		X
Turbidity, NTU	X	X	
HPC, no./mL	X	X	
Dissolved Oxygen, mg/L	X		

Table 3.9

Phase III - Biweekly Laboratory Data Analyses

Frequency: Every 2 weeks					
Stream Properties	Process Streams				
	MF/UF		NF		
	Raw Feed	Backwash Waste	Transfer Tank Feed	Concentrate	Permeate
Time			X		
Temperature, C			X		
pH			X	X	X
HPC, no./mL			X	X	X
Conductivity, µm/cm			X	X	X
Inorganic Analyses			X	X	X
TOC, mg/L	X	X	X	X	X

Table 3.10

Phase III - DBP Laboratory Analyses

Frequency: Contingent on available funding, twice during the 12-week test as a minimum				
Stream Properties	Process Streams			
	MF/UF	NF in MU		
	Feed	Feed	Concentrate	Permeate
Time	X	X		
Temperature, C	X	X		
pH	X	X	X	X
DBP Organic Analyses	X	X	X	X

4.0 Membrane Performance

4.1 MF/UF Pretreatment

Conceptually, MF and UF membranes utilize sieved control (physical size exclusion) as the primary mechanism for particle removal. However, they do not have a low enough molecular weight cut-off (MWCO) range to reject ionic species. As a result of this, MF/UF processes do not significantly affect TDS removal. Consequently, MF/UF applied as pretreatment to a NF process may protect the NF membranes from performance decline due to a number of factors including colloidal fouling and biofouling.

4.2 Filtrate Water Quality

4.2.1 Filtrate Water Experimental Objectives

The objective of this task is to verify membrane performance for particulate and microbial contaminant removal.

4.2.1.1 Particulate Removal

The 1989 SWTR requires that treatment plants using surface water as a source must meet a 0.5 NTU finished water turbidity level 95 percent of the time, with no single measurement exceeding 5 NTU. The Enhanced SWTR will require even lower turbidity limits. Under the proposed ESWTR, a finished water turbidity of 0.3 NTU (95 percent of the time) and no single measured turbidity level exceeding 1 NTU in more than 2 consecutive samples will be required. The IMS pilot configuration will be evaluated for particulate removal to meet and/or exceed turbidity of 0.3 NTU (95 percent of the time).

4.1.1.2 Microbial Contaminant Removal

One of the primary applications of MF and UF processes is removal of microorganisms. The protozoa *Giaradia* and *Cryptosporidium* have been the principle organisms controlling disinfection regulations in the US over the past decade. The SWTR was promulgated in 1986 to address the control of *Giardia* in surface water supplies. In addition, *Cryptosporidium* is particularly resistant to traditional water treatment disinfectants such as chlorine and chloramines. The ESWTR may ultimately require specified levels of *Cryptosporidium*, as the current SWTR does for Giardia.

It is desired to achieve a 5 to 6-log removal of *Cryptosporidium* and *Giardia*. *Clostridium* and *Bacillus* will be used as surrogate spores for this evaluation because they have spore size of less than 3 um. *Cryptosporidium* has a spore size of approximately 4 – 6 um and *Giaridia* a spore size of approximately

10 – 12 um. It is desired to achieve a 5 to 6-log removal of *Clostridium* and *Bacillus* spores for this evaluation.

4.1.2 Filtrate Water Work Plan

Turbidity and in-line particle count testing is an indirect method of evaluating the membrane integrity by using these parameters as surrogate parameters for assessing the membrane's condition. When available, on-line turbidimeters and particle counters connected to the feed and/or filtrate stream will be used to monitor the performance of the membrane system. Each meter will be installed and calibrated by membrane system manufacturer.

When collecting water quality data, the system flow meters will be periodically calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the feed, filtrate and backwash waste (concentrate) flow rates by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stop watch. This will allow for a direct check on the system flow measuring devices and overall recovery.

4.3 Productivity

Productivity from the IMS will be assessed by the rate of specific flux decline over time of operation. Flux decline is generally a function of water quality, membrane type and operational conditions. In establishing the range of operation for the NF membrane performance evaluations, limiting salt information should be used to define the recoveries of the elements. The operating conditions shall include MF/UF pretreatment scenarios that approach and exceed the projected recovery limits for each NF element. Subsequent water quality analysis will allow for assessment of the degree of saturation of the sparingly soluble salts in the final concentrate. The degree of saturation of the salts shall then be compared to the resulting membrane productivity decline.

4.3.1 Membrane Productivity Experimental Objectives and Work Plan

The objectives of this task are to demonstrate:

- appropriate operational conditions for the membrane equipment;
- permeate water recovery achieved by the membrane equipment; and
- rate of flux decline observed over extended membrane process operation.

Raw water quality shall be measured prior to system operation and then monitored regularly during the testing period. This will track limiting salts that may cause flux decline.

4.3.2 Feedwater Quality Limitations

The characteristics of the feed water used during the testing period shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feedwater characteristics as temperature, TOC, UV-254, turbidity, total suspended solids (TSS), pH, alkalinity and hardness is critical for the Test Program, as these parameters can substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions.

4.4 Finished Water Quality

Water quality goals and target removal goals for the membrane equipment are provided in previous sections of this report. Finished water sampling shall be simultaneously with feed water samples. If permeate samples have previously showed to be below detection for a particular parameter then values from the concentrate samples collected will be used in the calculation of mass balances to estimate the permeate concentration.

4.4.1 Finished Water Experimental Objectives and Work Plan

The objective of this task is to verify membrane performance. When collecting water quality data, the system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the final permeate and concentrate flow rates by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stop watch. This will allow for a direct check on the system flow measuring devices and overall permeate recovery.

Boyle and Florida Water personnel shall measure many of the water quality parameters described in this task on-site. A qualified analytical laboratory shall perform analysis of the remaining water quality parameters. The methods to be used for measurement of water quality parameters in the field have been described in the Analytical Methods section. The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are described in the Quality Assurance/ Quality Control (QA/QC) section. Suggested standard methods reference numbers and EPA method numbers for water quality parameters have been provided for both the field and laboratory analytical procedures.

Mass balances will be performed on the system for water quality parameters measured in the feed, permeate and concentrate streams. This will enable an additional quality control check on the accuracy and reliability of the analyzed data. Mass balances may provide insight into the mechanism for rejection of individual solutes. For example, mass balances showing incomplete recovery for a particular solute may suggest possible adsorption onto the membrane surface.

4.5 Cleaning Efficiency

There are certain types of scale that pose an immediate threat to the operational integrity of a membrane process. Key examples include calcium carbonate scale and barium or sulfate scale. The following guidelines can be used with the normalized performance data to determine the maximum fouling prior to cleaning the system:

a. 10 to 15 percent decrease in the normalized permeate flow rate, or 10 to 15 percent increase in feed pressure.

b. 1 to 15 percent increase in the normalized System Differential Pressure.

c. Decrease in salt rejection.

Should scaling or fouling occur during or following the test runs, the membranes will require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the fouling frequency of the membrane during each specified test period. In the case where the membrane does not fully reach the operational criteria for fouling as specified by the Manufacturer, chemical cleaning shall be performed, with a record made of the operational conditions before and after cleaning.

Productivity goals should include cleaning frequencies once per 12-week period for no more than 10 percent productivity decline. Productivity decline will be determined by either normalized flux decline or specific flux reduction. Therefore, conditions of constant system pressure where solvent flux remains greater than 90 percent of its original value would be desired. The use of the normalized specific flux for productivity decline would eliminate the need for constant system pressure for productivity decline determination.

Chemical cleaning of the membranes will be performed when required for the removal of foulants per manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solutions should also be analyzed to determine which constituents may have adsorbed or precipitated onto the membrane surface.

4.5.1 Cleaning Efficiency Experimental Objectives and Work Plan

The objective of this task is to evaluate the effectiveness of chemical cleaning to the membrane systems. The intent of this task is to confirm that standard Manufacturer recommended cleaning practices are sufficient to restore membrane productivity for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the Manufacturer recommendations. The ability of the membrane to be cleaned as prescribed by the manufacturer when required is considered a "proof of concept" effort.

The membrane systems may become fouled during the membrane test runs. These fouled membranes shall be utilized for the cleaning assessments herein. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the returned to the flux condition being tested. The Manufacturer shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- hydraulic conditions of cleaning
- duration of each cleaning step
- chemical cleaning solution

4.5.2 Analytical Schedule and Evaluation Criteria

The pH of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure. Conductivity and turbidity should also be used to monitor flush periods. Flow and pressure data shall be collected before system shutdown due to membrane fouling. Flow and pressure data shall also be collected after chemical cleaning.

At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure shall be recorded and the specific flux calculated. The efficiency of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficiency achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible fouling.

4.5.3 Evaluation Criteria and Minimum Reporting Requirements

At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure shall be recorded and the specific flux calculated. The efficiency of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficiency achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible fouling.

5.0 Quality Assurance/ Quality Control

Quality assurance and quality control (QA/QC) of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the Test Program. Strict QA/QC methods and procedures should be maintained during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

5.1 System Calibration and Verification

Equipment flow rates and associated signals should be calibrated and verified on a routine basis. Calibration of equipment was discussed in Section 2 of this plan. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate into a flow stream that is operating at the expected flow rate. In-line monitoring equipment such as flow meters, etc. shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The following items listed are in addition to any specified checks outlined in the analytical methods.

Daily QA/QC verifications will include the following:

- Chemical feed pump flow rates (verify volumetrically over a specific time period)
- On-line conductivity meters (check and verify components)
- On-line turbidimeter flow rates (verify volumetrically, if employed).

Weekly QA/QC verifications will include the following:

- On-line conductivity meters (recalibrate)
- In-line flow meters/rotometers (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

Monthly QA/QC verifications will include the following:

- On-line turbidimeters (clean out reservoirs and recalibrate, if employed)
- On-line conductivity meters (recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signals)

Tubing (verify good condition of all tubing and connections, replace if necessary)

5.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

5.3 QA/QC Work Plan

Equipment flow rates and associated signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that any chemicals are being fed at the defined flow rate into a flow stream that is operating at the expected flow rate, such that the chemical concentrations are correct. In-line monitoring equipment such as flow meters, etc. shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

6.0 Cost Evaluation

The purpose of a pilot test is to determine the system that provides the best results at the lowest cost. Therefore, a pilot test cost evaluation is integral to choosing an IMS system for Marco Island Water System for full scale design. Capital and O & M costs realized in the pilot test can be utilized for calculating full scale cost estimates. Full scale design parameters are summarized in Table 6.1. These parameters will be used with the pilot test costs to prepare full scale IMS cost comparisons. Further definition of these membrane process design parameters are located in the Appendix .

The pilot test costs that will be determined will include capital and O & M costs. Full scale capital costs will include land, building, and equipment costs. Land and building costs will be based on estimated land and building area required. This will vary between systems as the different process equipment will have different area requirements. The equipment costs will vary based on the cost of the membrane elements. To simplify the capital cost comparisons the cost of other WTP equipment would be assumed equal. The pilot plant capital costs will only include membrane equipment and building space requirements. These costs are located in Table 6.2. In addition, a summary of capital costs for full scale design is outlined in Table 6.2.

The O & M costs that will be recorded and compared during the pilot test include labor, electricity, chemical dosage, and membrane replacement frequency. These items are listed in Table 6.3. Full scale O & M costs will incorporate similar items as those listed in this table.

Capital and O & M costs should be provided for each membrane system that is tested. In order to receive the full benefit of the pilot test program, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the pilot tests.

Table 6.1
Design Parameters for Cost Analysis

Design Parameter	Specific Utility Values
Total required plant production (mgd)	
By-pass flow rate (mgd)	
Required membrane train capacity (mgd)	
High/Low plant feed water temperature (°C)	
Average Flux (gsfd/psi)	
Maximum Flux (gsfd/psi)	
Average cleaning frequency (days)	
High/Low feed TDS (mg/L)	

Table 6.2
Pilot and Full-scale Capital Cost Criteria

Pilot Capitol Cost Parameter	Specific Utility Values
Membrane process equipment area (ft^2 per mgd)	
Building costs ($\$/ft^2$)	
Area of a standard 8" x 40" membrane element (ft^2)	
Cost of a standard 8" x 40" membrane element ($)	
Capital Cost Design Parameter	
Building area requirements (ft^2)	
Membrane process equipment (ft^2 per mgd)	
Electrical room (ft^2 per mgd)	
Chemical rooms (ft^2 per mgd)	
Control room (ft^2)	
Generator (ft^2)	
Transformer vault (ft^2)	
Building costs ($\$/ft^2$)	

Table 6.2 (cont)
Pilot and Full-scale Capital Cost Criteria

Pilot Capitol Cost Parameter	**Specific Utility Values**
Land area requirements (ft^2)	
Land costs ($\$/ft^2$)	
Cost of a standard 8" x 40" membrane element ($)	
Area of a standard 8" x 40" membrane element (ft^2)	
Capital recovery interest rate (%)	
Capital recovery period (years)	
Overhead and profit factor (% of construction cost)	
Special site-work factor (% of construction cost)	
Construction contingencies (% of construction cost)	
Engineering fee factor (% of construction cost)	
Contract mobilization, insurance and bonds (% of construction cost)	
ENR construction cost index (CCI base year 1978) (date)	
Producers price index (PPI base year 1967 = 100) (date)	

Table 6.3

Operations and Maintenance Cost

Cost Parameter	**Specific Utility Values**	
Labor rate + fringe ($/personnel-hour)		
Labor overhead factor (% of labor)		
Number of O&M personnel hours per week		
Electric rate ($/kWh)		
Membrane replacement frequency (%/year)		
Chemical Dosage (per week)		
	Dose	Bulk Chemical Cost
Chlorine (Disinfectant)		
Sulfuric acid (Pretreatment)		
Alum (Pretreatment)		
Hydrochloric acid (Pretreatment)		
Scale inhibitor [2](Pretreatment)		
Caustic (Post-treatment)		
Sodium hydroxide (Membrane cleaning)		
Phosphoric acid (Membrane cleaning)		

[1]Information for cleaning chemicals and pretreatment chemicals (such as alum) should also be provided in this table. For cleaning agents, the concentration of the cleaning solution used to clean the membranes should be reported as the chemicals dose.

[2]Report the product name and manufacturer of the specific scale inhibitor used.

7.0 References

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Appendix

Appendix A - Membrane Processes: Mathematical Considerations

This section provides an overview for MF/UF and NF membrane system designs and performance characterization. These items will assist in recognizing the required considerations associated with membrane design and performance. Mechanisms that will help in qualifying and quantifying the removal efficiency of the membrane processes will be described.

Membrane System Design

Flux decline indicated by a reduction in membrane process productivity can be a result of scaling, colloidal fouling, biological fouling, chemical fouling or a combination of two or more reasons. These mechanisms should be recognized and understood in order to develop strategies to control flux decline. Scaling can be approximated by chemical analysis and equilibrium calculations (limiting salt). Similar to MF/UF, NF colloidal fouling can be approximated by fouling indices (SDI, MFI, MPFI and cross-flow fouling). Biological and chemical fouling can only be approximated at this time by pilot testing. However chemical fouling may only occur in the treatment of organic surface waters.

NF Scaling Control

Controlling precipitation or scaling within the membrane element requires identification of a limiting salt, acid addition for prevention of $CaCO_3$ and/or addition of an scale inhibitor. The amount of scale inhibitor or acid addition is determined by the limiting salt. A diffusion controlled membrane process will concentrate salts on the feed side of the membrane. If excessive water is passed through the membrane, this concentration process will continue until a salt precipitates and scaling occurs. Scaling will reduce membrane productivity and consequently recovery is limited by the allowable recovery just before the limiting salt precipitates. The limiting salt can be determined from the solubility products of potential limiting salts and the actual feed stream water quality. Ionic strength must also be considered in these calculations as the natural concentration of the feed stream during the membrane process increases the ionic strength, allowable solubility and recovery. Calcium carbonate scaling is commonly controlled by sulfuric acid addition however sulfate salts are often the limiting salt. Commercially available scale inhibitors can be used to control scaling by complexing the metal ions in the feed stream and preventing precipitation. Equilibrium constants for these scale inhibitors are not available which prevents direct calculation. However some manufacturers provide computer programs for estimating the required scale inhibitor dose for a given recovery, water quality and membrane.

NF Pretreatment

The purpose of pretreatment is to protect the membranes from performance decline due to a number of factors (mineral scaling, colloidal fouling, biofouling and chemical fouling). The conventional pretreatment process consists of scale inhibitor and/or acid addition and pre-filters. These pretreatment process are used to control scaling, to protect the membrane elements and are required for conventional NF systems. Scaling is caused by the precipitation of a salt within the membrane because of feed stream concentration. Scaling is controlled by scale inhibitor and/or acid addition. Fouling is caused by materials such as colloids that are present in the raw water and that will reduce the productivity of the membrane. If a raw water is excessively fouling the membranes, additional or advanced pretreatment may be required.

Fouling is caused by biological growth or materials such as colloids that are present in the raw water and that will reduce the productivity of the membrane. If a raw water is excessively fouling the membranes, additional or advanced pretreatment may be required.

Flux decline indicated by a reduction in membrane process productivity can be a result of, colloidal fouling, biological fouling or a combination of two or more reasons. These mechanisms should be recognized and understood in order to develop strategies to control flux decline. Colloidal fouling can be approximated by fouling indices (SDI, MFI, MPFI and cross-flow fouling). Biological can only be approximated at this time by pilot testing.

Fouling indices are simple measurements that provide a estimate of the required pretreatment for membrane processes. Fouling indices are determined from membrane tests and are similar to specific fluxes for membranes used to produce drinking water. Fouling indices can be quickly developed from simple filtration tests, are used to qualitatively estimate pretreatment requirements and possibly could be used to predict membrane fouling. The silt-density index (SDI), modified fouling index (MFI) and mini plugging factor index (MPFI) are the most common fouling indices. The SDI, MFI and the MPFI are defined using the basic resistance model, and are quantitatively related to water quality and membrane fouling.

MF/UF Advanced Pretreatment

By definition, unit operations that precede conventional pretreatment would be advanced pretreatment. Advanced pretreatment for MF/UF processes would be unit operations that precede the membrane system. Examples of MF/ UF advanced pretreatment would be chloramines, powdered activated carbon (PAC) addition, or coagulant addition.

NF Advanced Pretreatment

By definition, unit operations that precede conventional pretreatment would be advanced pretreatment. Advanced pretreatment for NF processes would be unit operations that precede scaling control. Examples of NF advanced pretreatment would be MF, UF, conventional coagulation-flocculation-sedimentation-filtration, oxidation followed by greensand filtration, lime softening (LS), ion exchange (IX) or GAC filtration.

MF/UF Membrane Processes

The MF/UF membrane process follows pretreatment. This is where the majority of water quality constituents are removed. If the membrane fouls then the productivity of the membrane system declines and eventually the membranes must be chemically cleaned to restore productivity.

NF Membrane Processes

The membrane process follows pretreatment. This is where the majority of water quality constituents are removed. If the membrane scales or fouls then the productivity of the membrane system declines and eventually the membranes must be chemically cleaned to restore productivity. Cleaning frequencies for NF systems average about 3 to 4 years when using ground waters and 1 to 2 years when using surface water IMSs.

NF Membrane Productivity

Membrane productivity will be assessed by the rate of specific flux decline over time of operation. As flux declines, a constant product is achieved by increasing pressure to maintain a constant flux. The procedure for determining fouling rates and recoveries are presented within this section. The specific flux is calculated by using the permeate flow and membrane surface area as shown in Equation A.12.

$$F_w = \frac{Q_p}{A} = K_w * NDP \quad \textbf{(Equation A.12)}$$

From this the specific flux (K_w) can be calculated. However, given the relationship between temperature and the viscosity of water, flux should be normalized to a standard temperature condition (25°C). These relationships should be provided by the membrane manufacturer and used to normalize the flux data set as shown is Equation A.13.

$$K_w = \frac{F_{w,\,25\,°C}}{NDP} \qquad \textbf{(Equation A.13)}$$

If manufacturer does not specify a temperature correction factor (TCF) of 1.03 may be used so that water production can be compared on an equivalent basis (Equation A.14).

$$F_{w,\,25\,°C} \cdot F_{w,\,T\,°C} * 1.03^{(25\,°C \cdot T\,°C)} \quad \textbf{(Equation A.14)}$$

The net driving pressure (NDP) is calculated using the influent, concentrate and permeate pressure as shown in Equation A.15.

$$NDP = \left[\frac{(P_i + P_c)}{2}\right] - P_p - \Delta\Pi \qquad \textbf{(Equation A.15)}$$

In order to determine the NDP, the osmotic pressure gradient must be estimated from the influent, concentrate and permeate TDS as shown in Equation A.16 assuming that 1 psi = 100 mg/L of TDS.

$$\Delta\Pi = \left(\left[\frac{(TDS_i + TDS_c)}{2}\right] - TDS_p\right) * \left(\frac{1\ psi}{100\frac{mg}{L}}\right) \qquad \textbf{(Equation A.16)}$$

Recovery should also be calculated using the permeate and influent flow (Equation A.17).

$$R = \frac{Q_p}{Q_i} \qquad \textbf{(Equation A.17)}$$

Using the above equations the normalized flux and recovery for each stage and the system can be calculated for each set of operational data and plotted as a function of cumulative operating time.

NF Membrane Model Theory

The homogeneous solution diffusion (HSD) model is the basic model for describing the performance of a membrane system (Weber 1972, Taylor 1990). It is generally accepted that the HSD theory accurately describes mass transfer through polymeric membranes (Merten 1966; Lonsdale 1967). The equations for the water mass transfer flux are proportional to the pressure differential across the membrane (Kedem and Katchalsky 1958). The flux of water passing through the membrane can be predicted from a global solvent mass transfer coefficient (MTC), the differential pressure and the osmotic pressure, as shown in Equation A.18.

$$T_w hi\ \ hs_w h\Delta eh c h\Delta\Pi thi\ \ h\frac{O_p}{n} \qquad \textbf{(Equation A.18)}$$

where:

- F_w = water flux $(M/L^2 \cdot t)$
- K_w = global water mass transfer coefficient (t^{-1})
- ΔP = transmembranic pressure gradient (M/L^2)
- $\Delta\Pi$ = osmotic pressure gradient (M/L^2)
- Q_p = permeate flow (L^T/t)

A = membrane surface area (L^2)

The osmotic pressure gradient through the membrane can be estimated from an adaptation of the natural gas law to the total dissolved solids (TDS) in an aqueous system, which develops a ratio of 1 psi per 100 mg/L TDS (Weber 1972).

In HSD theory, the movement (flux) of solute through the membrane can be predicted by the solute concentration differential between the membrane surface and the permeate stream as shown in Equation A.19:

$$F_s = K_s [C_m - C_p] = K_s \left[\left[\frac{C_f + C_c}{2} \right] - C_p \right] = \frac{Q_p C_p}{A} \quad \textbf{(Equation A.19)}$$

where:

F_s = solute flux ($M/L^2 \cdot t$)

K_s = global solute mass transfer coefficient (L/t)

C_m = concentration at the membrane surface (M/L^3)

C_f = concentration of the feed (M/L^3)

C_p = concentration of the permeate (M/L^3)

C_c = concentration of the concentrate (M/L^3)

The solvent (K_w) and solute (K_s) specific fluxes are typically determined experimentally using permeate flow, concentration and membrane surface area. There are different types of membranes and each manufacturer should supply these values. The MTCs K_w and K_s can be predicted by the HSD model using Equations A.20 and A.21, if the membrane thickness and diffusivity are known (Weber 1972). However, many of the variables shown in Equations A.20 and A.21 are not available in the literature or easily determined in the laboratory or field. Consequently, global MTCs as shown in Equation A.18 and A.19 are normally reported.

$$K_w = \frac{D_w C_w V_w}{RTd_m} \quad \textbf{(EQUATION A.20)}$$

$$K_s = \frac{D_s K_d}{d_m} \quad \textbf{(EQUATION A.21)}$$

where:

D_w = diffusivity of water through membrane (L^2/t)

D_s = diffusivity of solute through membrane (L^2/t)

C_w = concentration of solvent or water (M/L^3)

V_w = molar volume of water (L^3)

d_m = membrane thickness (L)

K_d = distribution coefficient

R = gas constant

T = temperature

Equations A.22 and A.23 describe the water and solute mass balance around a membrane with both permeate and concentrate stream outputs as follows:

$$Q_f = Q_p + Q_c \qquad \textbf{(Equation A.22)}$$

$$Q_f C_f = Q_p C_p + Q_c C_c \qquad \textbf{(Equation A.23)}$$

where:

Q_f = feed hydraulic flow (L^3/t)

Q_p = permeate hydraulic flow (L^3/t)

Q_c = concentrate hydraulic flow (L^3/t)

Equation A.24 describes the fraction water recovery (R) for a membrane system as follows:

$$R = \frac{Q_p}{Q_f} \qquad \textbf{(Equation A.24)}$$

Equation A.25 presents the recycle ratio (r) for a membrane system as follows:

$$r = \frac{Q_r}{Q_f} \qquad \textbf{(Equation A.25)}$$

where:

Q_r = recycle hydraulic flow (L^3/t)

Equation A.26 presents the backdiffusion constant as follows:

$$\left[\frac{C_m - C_p}{C_b - C_p}\right] = e^{\frac{F_w}{k}} \qquad \textbf{(Equation A.26)}$$

where:

C_b = solute concentration in membrane bulk (M/L^2)

k = diffusion coefficient from the surface to the bulk (L^3/L^2t)

Equation A.27 can be derived from Equations A.18, A.19, A.22, A.23, A.24, A.25 and A.26. This is the modified linear model to describe film theory diffusion (Taylor et. al. 1989). It predicts the solute concentration exponentially increases from the center of the feed stream toward the surface of the membrane and diffuses back into the bulk stream. Solutes back diffuse from the membrane surface to the feed stream, solute mass transport is diffusion controlled and solvent flow is pressure (convection) controlled. Taking the derivative of C_p with respect to each of the five independent variables in Equation A.27 shows that permeate concentration decreases with increasing ΔP or K_w; on the other hand, C_p increases with increasing R, C_f or K_s.

$$C_p = \frac{K_s C_f e^{\frac{F_w}{k}}}{\left[K_w(\Delta P - \Delta\Pi)\left(\frac{(1-r)(2-2R)}{2+2r-R}\right) + K_s e^{\frac{F_w}{k}}\right]} \qquad \textbf{(Equation A.27)}$$

Equation A.28 is used to describe sieving controlled mass transfer in membranes, and is applicable to MF, UF and organics rejection in RO and NF systems.

$$C_p = \Phi C_f \qquad \textbf{(Equation A.28)}$$

where:

ϕ = sieving pass coefficient

NF Post-Treatment

Typical post-treatment unit operations can consist of disinfection, aeration, followed by stabilization and storage. Aeration may be required to strip dissolved gases (Duranceau 1993). Stabilization may be required to produce a non-corrosive finished water since membrane permeate is corrosive. Alkalinity recovery is an effective process for recovering dissolved inorganic carbon (DIC) in the permeate. Alkalinity can be recovered by lowering the pH prior to membrane filtration converting the alkalinity to CO_2, and then raising the pH of the permeate in a closed system to recover dissolved CO_2 as alkalinity. By-passing feed water and blending it with membrane permeate is another way of stabilizing the finished water, however blending would negate the benefit of membrane treatment system to act as a barrier against contaminants.

In addition to post treatment, the concentrate stream from the membrane processes must be disposed. Effective concentrate disposal methods depend on the concentrate water quality, local regulations and site specific factors. Information regarding concentrate disposal options can be found in Membrane Concentrate Disposal (AWWARF 1993).

Cleaning Frequency

Membrane productivity is measured by the loss or decrease of the specific flux for water over time of production. Membranes foul during operation. Constant production is achieved in membrane plants by increasing pressure. Cleaning is done when the pressure increases by 10 to 15 percent. Cleaning frequency (CF) and a measurement of productivity can be approximated from the specific flux decline. However, membrane area is changing as the lead elements foul. Equation A.29 assumes that the rate of specific flux decline maintains a constant area.

$$CF = \frac{\Omega K_w}{\frac{dK_w}{dt}} \quad \textbf{(Equation A.29)}$$

where:

CF = cleaning frequency (days)

Ω = acceptable fractional loss of specific flux prior to cleaning

dK_w/dt = rate of specific flux decline (gsfd/psi-d)

Determination of Permeate Backwash Requirement and Feed Water Recovery

The parameters "permeate backwash requirement" (PBR) and "feed water recovery" (FWR) are utilized to evaluate the operational performance of the membranes under different operating conditions. PBR represents the permeate water used for backwashing MF/UF UF membranes. FWR is a function of the pilot-plant design. FWR represents the percent recovery of feed water and accounts for:

1. the volume of permeate used to backwash the membrane;
2. the raw water used for flushing the pilot plant (hollow fiber type only); and
3. the concentrate water bleed.

The two terms are calculated according to Equations A.10 and A.11.

$$\%PBR = \left[\frac{\text{volume of permeate used for backwashing}}{\text{total volume of permeate produced}}\right]*100\% \qquad \textbf{(Equation A.10)}$$

$$\%FWR = \left[1 - \frac{\text{volume of water wasted}}{\text{volume of raw water used}}\right]*100\% \qquad \textbf{(Equation A.11)}$$

Appendix B - Challenge Testing Protocol

Introduction

Challenge testing procedures have been developed for the Marco Island IMS evaluation should Florida Water wish to pursue challenge testing. The objective of these procedures is to evaluate the efficacy of the integrated treatment processes used for the removal of microbial and microbial surrogate contaminants. Naturally, direct injection of such contaminants and subsequent measurement in treated water offers the most conservative approach for quantifying membrane disinfection capability and integrity. Furthermore, the surrogate parameters turbidity and particle counts will be measured for comparison to the microbial challenge test data.

Study Objectives

The objective of the challenge testing is to evaluate the removal of *Cryptosporidium*, and *Giardia* by each component of the membrane process units using surrogate spores of *Clostridium* and *Bacillus.*

Methods and Materials

It is desired to allow *6 to 8* log assessment of *Clostridium* and *Bacillus*. A separate challenge testing will be performed on the MF, UF and NF pilot systems.

Boyle Engineering along with Florida Water will coordinate and supervise the laboratory requirements of the challenge tests in cooperation with a qualified laboratory. The qualified laboratory personnel may be required to be on-site for delivery, sample collection and transport of samples to the laboratory for microbial analysis.

For any given challenge test event, each of the systems to be challenged separately. However, the frequency of challenge testing will vary by contaminant depending upon the resources of the qualified laboratory has available. At a minimum, one challenge event should be performed.

Spiking Procedure

It is desired to evaluate each treatment unit under steady state conditions. This can be accomplished via continuous addition of all spiking materials at a uniform rate up to and during sample collection. Depending upon the system, continuous addition is possible by injection into a batch feed tank or in-line with a calibrated precision chemical injection pump.

Sample Collection

Each sampling location will be sampled for of *Clostridium, Bacillus* (or equivalent*)*, turbidity and particle counts. The qualified laboratory will specify the required sample volume; container type and preparation along with sample collection procedures. Turbidity samples will be collected in a beaker or bottle. Particle count samples will be collected in 250 ml glass bottles. Turbidity and particle count samples should be analyzed upon collection.

Samples will be obtained at times and locations as specified in Tables 1 and 4. Unique sample IDs have been developed for each process train. Note: the sampling times for each system in Table 1 are estimates. Actual times will be based upon tracer tests that will be performed with NaCl spiking prior to challenge testing.

Spiking Solution Concentrations and Volumes

The selected qualified laboratory will provide concentration estimates of each microbial specie. This information was used to develop Tables 2a, 2b, 3a and 3b, which can be used to estimate the required volumes of spiking solution for each challenge event.

Table B-1
Challenge Testing Sampling Locations and Sampling Times

Unit Process	Sample ID	Sample Name	Sample Location	Time
Zenon MF Membrane Unit	MF-1	MF Feed	MF feed tank	After feed tank spike and approximately 5 minutes mixing in MF feed tank
	MF-2	MF Filtrate	Filtrate sample port	Approximately 10 minutes after feed tank spike and restart of MF unit
	MF-3	MF Feed	MF feed tank	Approximately 10 minutes after feed tank spike and restart of MF unit
	MF-4	MF Feed	Filtrate sample port	Approximately 20 minutes after feed tank spike and restart of MF unit
	MF-5	MF Filtrate	Filtrate sample port	Approximately 20 minutes after feed tank spike and restart of MF unit
Pall MF Membrane Unit	MF-6	MF Feed	MF feed tank	After feed tank spike and approximately 5 minutes mixing in MF feed tank
	MF-7	MF Feed	Filtrate sample port	Approximately 10 minutes after feed tank spike and restart of MF unit
	MF-8	MF Filtrate	Filtrate sample port	Approximately 10 minutes after feed tank spike and restart of MF unit

Table B-1 (cont)
Challenge Testing Sampling Locations and Sampling Times

Unit Process	Sample ID	Sample Name	Sample Location	Time
Pall MF Membrane Unit	MF-9	MF Feed	Filtrate sample port	Approximately 18 minutes after feed tank spike and restart of MF unit
	MF-10	MF Filtrate	Filtrate sample port	Approximately 18 minutes after feed tank spike and restart of MF unit

Table B-2

Challenge Material Quantity Estimates for Clostridium and Bacillus Spiked at 10^6/ml

Treatment Unit	Method of Spike Introduction	Tank Spiking Volume (gallons)	In-line Spiking Water Flow (gpm)	Duration of Spiking Event (minutes)	# of Organisms per Challenge Event[2]
Pall MF	Spiked Batch	15	---	18	$5.7x10^{10}$
Zenon MF	Spiked Batch	185		20	$7.0x10^{11}$

[1] Flow varies with test condition.
[2] Spiked concentration of 10^6/ml assumed.

Zenon Microfiltration Pilot System

The MF unit draws water from a 185 gallon feed tank that is filled with raw water via a float valve. The unit will shutdown if the level in this tank falls below approximately 3 inches. The unit draws from 12 to 17 gpm of raw water depending upon operational conditions and enters a 30-second automatic backwash every 15 minutes.

It is proposed that spiking of the 185 gallon feed tank be conducted as follows:

1. Prepare data collection sheet and record all data specified.
2. Collect raw and filtrate sample for particles and turbidity.
3. Shutdown the MF unit and close the raw water influent valve.
4. Drain the MF filtrate tank. Enable clean water feed until tank is full.
5. Direct permeate and concentrate lines to waste container for temporary storage and disinfection.
6. Add the aliquot of the challenge material suspension to the tank and allow blower to run approximately 5 minutes for mixing.
7. Drain CIP tank and refill using clean water. Do not add chlorine puck. Measure chlorine residual and add additional clean water if level is not zero.
8. Obtain feed sample from the feed tank.
9. Restart the MF unit.
10. Collect feed and filtrate samples at the times indicated in Table B-1 after the unit has been restarted.
11. Continue to collect sufficient volume of filtrate and backwash waste in order to flush microbials from the NF systems. Properly disinfect and dispose of MF spiked filtrate and backwash water.

Note: Be sure to return the chlorine puck to the CIP tank once the challenge test has been completed.

Pall Microfilter Pilot System

The MF unit draws water from a 75 gallon feed tank that is filled with raw water via a float valve. The unit will shutdown if the level in this tank falls below approximately 15 gallons. The unit draws from 2 to 6 gpm of raw water depending upon operational conditions and enters a 30-second automatic backwash every 15 minutes.

It is proposed that spiking of the 75 gallon feed tank be conducted as follows:

1. Prepare data collection sheet and record all data specified.
2. Collect raw and filtrate sample for particles and turbidity.
3. Once the feed tank is full shutdown the MF unit and close the raw water influent valve.
4. Direct filtrate and backwash waste lines to waste container for temporary storage and disinfection.
5. Add the aliquot of the challenge material suspension to the tank and mix for approximately 5 minutes.
6. Drain CIP tank and refill using clean water. Do not add chlorine puck. Measure chlorine residual and add additional clean water if level is not zero.
7. Obtain feed sample from the feed tank.
8. Restart the MF unit.
9. Collect feed and filtrate samples at the times indicated in Table B-1 after the unit has been restarted.
10. Continue to collect sufficient volume of filtrate and backwash waste in order to flush microbials from the MF systems. Properly disinfect and dispose of MF spiked filtrate and backwash water.

Note: Be sure to return the chlorine puck to the CIP tank once the challenge test has been completed.