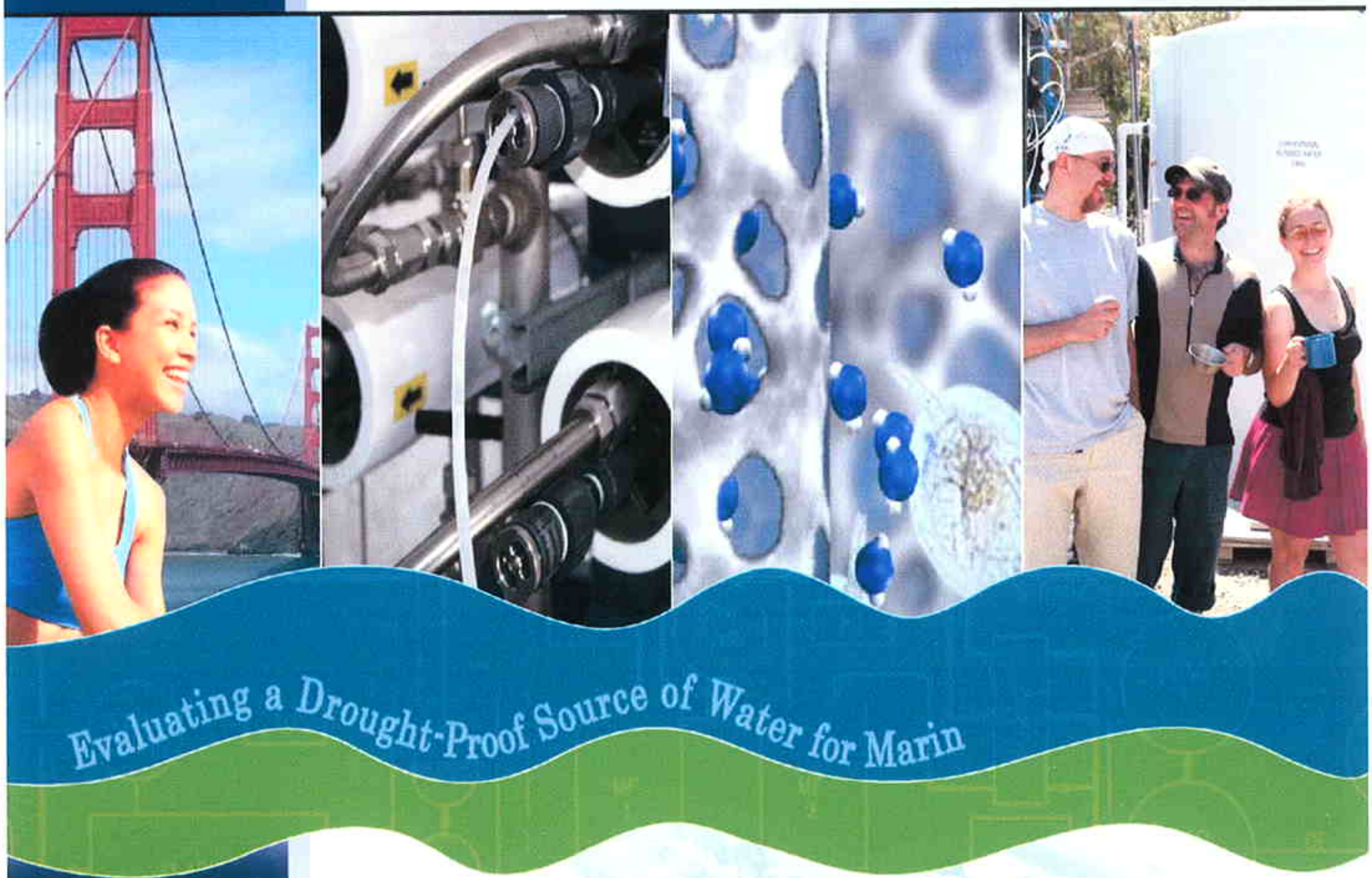
MARIN MUNICIPAL WATER DISTRICT

Engineering Report
Seawater Desalination Pilot Program



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MMWD Seawater Desalination Pilot Program

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Evaluating a Drought-Proof Water Source for Marin

> "But there were dry years too, and they put a terror on the (Salinas) valley. The water came in a thirty-year cycle…And it never failed that during the dry years, the people forgot about the wet years, and during the wet years they lost all memory of the dry years. It was always that way."
>
> \- John Steinbeck, *East of Eden*

Marin Municipal Water District has not forgotten the hardships of the droughts of the mid-1970s or the early 1990s. To ensure a sufficient and reliable water supply in dry years, Marin Municipal Water District (MMWD) is evaluating broadening its water supply portfolio to include a seawater desalination plant to treat Northern San Francisco Bay (Bay) water. Pilot tests conducted in 1990 demonstrated that desalination could produce a drinking water that was both safe and palatable. Since that time treatment technologies have improved and there are new environmental and regulatory requirements that could impact permitting and operation of a full-scale desalination facility.

MMWD conducted a year-long Seawater Desalination Pilot Program to test more advanced treatment technologies and to update the previous desalination pilot work performed in 1990. This pilot program addressed treating the challenging Bay source water, tested new treatment technologies, and performed environmental studies to supplement the Environmental Impact Report (EIR) and to facilitate the application of permits for a full-scale facility. The outcome of this pilot program provides MMWD with the data necessary for a comprehensive evaluation of a full-scale desalination facility.

This report describes a few of the many environmental studies conducted to evaluate the proposed desalination project as part of the pilot program. However, this report is not intended to be a substitute for the EIR which will address all of the environmental issues involved with the proposed project. The EIR is scheduled for release in Spring 2007.

Summary of Pilot Study Results

The MMWD Seawater Desalination Pilot Program was a successful year-long desalination pilot study and public outreach program that met the program objectives. Based on the favorable outcome of the pilot program, seawater desalination can be a viable, reliable and drought-proof drinking water source for Marin.

The major pilot program objectives and findings are presented in Table ES.1. The Executive Summary provides a brief discussion of these findings. Additional technical discussion is provided in the body of the report and more detailed engineering data developed during the study is provided in the appendices.

Table ES.1: Pilot Program Objectives and Findings

MMWD Seawater Desalination Pilot Program Key Objectives	Pilot Program Findings
Demonstrate that the desalinated water meets state and federal drinking water standards. Demonstrate that the desalinated water meets MMWD's more stringent water quality goals and is compatible with MMWD current water sources.	*The desalinated water is safe.* *Over 650 regulated and voluntary constituents were tested. Results showed the desalinated water either meets or is better than all state and federal drinking water standards.* *Water quality and corrosion testing demonstrated the stability and compatibility of the desalination water with MMWD's other supplies.*
Conduct environmental studies to demonstrate that the desalination facility will not negatively impact the Bay environment and to support the EIR and permitting process for the full-scale facility.	*Desalination does not adversely impact the health of the Bay.* *The brine blended with existing wastewater effluent discharge from the Central Marin Sanitation Agency did not show significant effects during bioassay testing.* *Solids from the plant are not toxic and are acceptable to Redwood Landfill in Novato, CA.*
Conduct a public outreach program to inform the public and media about desalination processes and the high quality of the desalinated water.	*MMWD customers became more familiar with desalination technology through tours, education seminars, media coverage, and presentations to community groups.* *MMWD customers who compared desalinated water with the existing supplies liked the taste of the desalinated water.*
Demonstrate advanced microfiltration and ultrafiltration (MF/UF) membrane treatment in parallel with conventional treatment to determine the best-suited pretreatment process for Bay water.	*The MF/UF pretreatment is the best suited pretreatment process for Bay water because it provides better water quality at lower cost.*
Develop design criteria and preliminary cost estimates for a full-scale desalination facility.	*Recommended design criteria and their associated costs are presented for full-scale 5 and 10 MGD capacity desalination facilities with various expansion options.*

Finding #1: Desalinated Water is Safe

The Northern San Francisco Bay is a complex estuarine water body with influences from the Pacific Ocean, fresh water flow from the Sacramento Delta, local rivers, and Bay discharges. These influences affect water quality on a daily as well as a seasonal basis. Desalination treats this source water through pretreatment filtration, first-pass seawater reverse osmosis (SWRO) and, as an option, may include second-pass reverse osmosis (RO). Minerals are then added to match the composition of MMWD's current water sources.

To determine the safety of the desalinated water, the pilot program included a Sampling and Analysis Program (SAP). This program studied the characteristics of the Bay water (the source water) and the desalinated water. This process tracks the contaminants found in Bay water and evaluates their presence (or absence) in the desalinated water. The SAP also verified that:

- Desalinated water met state and federal drinking water regulatory requirements.
- Pilot plant processes were operating properly.

Because some compounds are known to be in the Bay water at very low levels, MMWD identified over 290 compounds that had high potential for low-level presence in Bay water and tested for these components in both source and desalinated water. These included:

- 209 types of polychlorinated biphenyls (PCBs).
- 44 types of flame retardants [polybrominated diphenyl ethers (PBDEs)].
- 40 pharmaceutical and personal care product compounds.

To detect these compounds, MMWD used analyses with minimum reporting limits (MRLs) that are 1,000 to 1,000,000 times lower than typically performed for regulatory compliance.

In total, the SAP analyzed a comprehensive list of 126 Regulated and 538 Voluntary (Non-Regulated) constituents over a 12-month period from March 2005 to March 2006.

The test program also included the E-Screen Assay, a unique test that uses a human breast cancer cell culture to screen for endocrine disrupting chemicals. Unlike traditional chemical testing that detects one chemical at a time, the E-Screen detects estrogenic activity regardless of what is causing that effect. It can also measure the effect of multiple estrogenic chemicals perhaps acting in combination or ones that are still unknown. These unique abilities make this new test a very important and powerful screening tool. The E-Screen Assay was used on both the source and desalinated water. The results of the E-Screen Assay testing were all non-detect.

Table ES.2 below presents the water quality results for regulated constituents that were detected in either the source or the desalinated water. The average water quality of MMWD's Reservoir and Sonoma County water supplies is provided for comparison. The results are also briefly described in the text that follows. For more in-depth information about the SAP and its results, see Sections 3, 4, and 5 and Appendix 1.

Table ES.2: Bay Source Water, Desalinated Water, and MMWD Drinking Water Quality

Drinking Water Quality Parameters			SF Bay Source Water[A]			Desalinated Water[A, B]			MMWD Reservoir			Sonoma County Water		
Analyte	**Unit**	**Regulatory Limit**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
Regulated Constituents														
Turbidity	NTU	5	2.7	300	15	0.05	0.1	0.07	0.05	0.24	0.08	0.06	0.28	0.11
Primary Drinking Water Regulated Constituents														
Inorganics with MCLs		--												
Arsenic	ppm	0.01	ND	0.024	0.004		ND			ND			ND	
Barium	ppm	2	ND	0.051	0.019		ND			ND			ND	
Beryllium	ppm	0.004	ND	0.0033	0.0005		ND			ND			ND	
Chromium	ppm	0.1	ND	0.042	0.0087		ND			ND			ND	
Mercury	ppm	0.002		ND		ND	0.0003[C]	ND		ND			ND	
Nickel	ppm	0.1	ND	0.057	0.022		ND			ND			ND	
Nitrate	ppm	44	ND	0.38	0.23		ND			ND		--	--	0.52
Nitrite	ppm	3.3	ND	0.017	0.013	ND	0.01[C]	ND		ND			ND	
Selenium	ppm	0.05	ND	0.091	0.01		ND			ND			ND	
Total Organic Carbon (TOC)	ppm	2	ND	6.98	1.41		ND		0.8	2.6	1.7	ND	1.4	0.8
Organics with MCLs		--												
Ethylene dibromide	ppm	0.00005	ND	0.00002[C]	0.00001		ND			ND			ND	
Radionuclides		--												
Gross Alpha	± 2.1 pCi/L	15	4.4	6.4	5.4		ND			2			1.6	
Gross Beta	± 33 pCi/L	50	144	236	190		ND			ND			ND	
Federal and State Monitoring Requirements		--												
CA UCMR		--												
Boron	ppm	1	1.5	3.3	2.3	0.1	0.4	0.2		ND		--	--	0.19
Manganese	ppm	0.05	ND	0.044	0.02		ND			ND			ND	
Secondary Drinking Water Regulated Constituents[D]														
Aluminum	ppm	0.05-0.2	ND	1.60	0.44		ND			ND			ND	
Chloride	ppm	250	3,100	15,000	11,000	15	34	20	10	37	21	7	10	8
Color (Apparent)	Pt/Co units	15	10	10	10		ND			ND			ND	
Copper	ppm	1.0	ND	0.01	0.003		ND			ND			ND	
Fluoride[E]	ppm	4	0.24	0.85	0.64		ND		0.7	1.1	0.8	0.7	1.1	0.8
Foaming Agents (MBAS)	ppm	0.5	0.10	0.44	0.29		ND			ND		ND	0.06	ND
Iron	ppm	0.3	0.18	0.75	0.34		ND			ND			ND	
Silver	ppm	0.1	ND	0.013	0.0029		ND			ND			ND	
Sulfate	ppm	500	440	2,100	1,500		ND		5	25	12	11	14	13
Solids, Dissolved	ppm	500	2,500	29,000	21,000	60	142	95	97	136	120	160	187	174
Zinc[E]	ppm	5	ND	0.010	0.004		ND		0.29	0.59	0.43	0.27	0.34	0.31

Abbreviations

MCL - Federal and/or State Maximum Contaminant Level. The level of a contaminant that is allowed in drinking water.

ND - not detected

ppm (parts per million) = mg/l (milligrams of constituent per liter of water)

pCi/L - picocuries per liter

Pt/Co units - Color units

CA UCMR - California Unregulated Contaminant Monitoring Regulation

Notes

(A) SF Bay source water and RO permeate data from 19 sampling events between March 2005 and March 2006

(B) Desalinated water is composed of RO permeate water plus minerals added to match current MMWD drinking water quality

(C) One sample out of 8 had a result above the detection limit.

(D) National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

(E) Small amounts of this constituent are added to MMWD drinking water for health benefit

SAP Results: Source Water Characterization

The SAP characterized the Bay source and found that over 95 percent of the analyses resulted in non-detect levels. The SAP also found that the Bay water contains ultra-low levels of non-regulated constituents. Most of the constituents that were detected in the source water were inorganic salts and minerals typical of the Pacific Ocean and the Bay, which the desalination process is specifically designed to remove.

SAP Results: Desalinated Water

Over 98 percent of the SAP analyses of the desalinated water resulted in non-detect levels. All detected constituents in the desalinated water were well below the regulatory limits.

The desalination process removed ultra-low level non-regulated constituents found in the source water. For these constituents, results of desalinated water testing were comparable to tests of the ultra-pure water blanks provided by analytical laboratories for quality control purposes.

Compatibility with MMWD's Existing Sources

Water quality and corrosion testing showed that the desalinated water is stable and compatible with MMWD's current water supplies. Section 7 of the report describes the corrosion testing in more detail.

Finding #2: Desalination Does Not Adversely Impact the Health of the Bay

Desalination plants have two separate byproducts. One is a salty, liquid stream (brine) comprised of filtered water and concentrated minerals from the Bay water. The brine discharge is approximately twice as salty as the Bay source water. The other byproduct is comprised of the solids removed from the source water by the pretreatment processes. The solids include silts and sediments from the Bay and the coagulant used in the pretreatment process. To ensure that a full-scale desalination plant would not adversely impact the Bay ecosystems, MMWD developed plans for the disposal of the brine and solids and conducted testing to address environmental and regulatory concerns during the pilot program.

The plan calls for the brine produced by a full-scale MMWD desalination facility to be mixed with the relatively low-salt wastewater effluent that is discharged by the Central Marin Sanitation Agency (CMSA). The mixture of brine from the desalination plant and CMSA effluent would have a salinity level nearer to that of the Bay than the current CMSA effluent. The mixture would be discharged to the Bay through an existing deep-water outfall.

To ensure that the brine disposal process would meet the requirements of the San Francisco Bay Area Regional Water Quality Control Board (RWQCB), MMWD conducted acute and chronic bioassay testing with the pilot plant brine of the proposed desalination facility's whole effluent discharge. Whole effluent (WE) is defined as the blend of brine and CMSA effluent that would be discharged into the Bay. Acute bioassay tests expose sensitive marine organisms to the WE for short periods of time to test for survivability, while chronic bioassay tests expose organisms to the WE for longer periods of time to identify possible reproductive and developmental impacts on the organisms.

Based on the expert opinion of biologists at the Romberg Tiburon Center for Environmental Studies, RWQCB staff, and staff from the consultant preparing the project EIR, the following aquatic species were selected for acute bioassay testing:

- Mysid shrimp (*Mysidopsis bahia)*
- Topsmelt (*Atherinops affinis*)
- Marine algae (*Thallasiosira pseudonanna*)



The following aquatic species were selected for the chronic bioassay testing:

- Marine Giant Kelp, (*Macrocystis pyrifera*), germination and growth test
- Bay Mussel, (*Mytilus edulis*), larval development and percent survival test
- Inland Silverside, (*Menidia beryllina*), survival and growth test
- Opossum Shrimp, (*Mysidopsis bahia*), survival and growth test
- Marine Diatom, (*Thalassiosira pseudonana*), growth test

The pilot plant produced a brine that is representative of the brine that would come from a full-scale desalination facility. This brine was used to conduct the required bioassay testing. The acute and chronic bioassay testing demonstrated that the blends of desalination brine and CMSA effluent discharged from a full-scale MMWD desalination facility should not adversely impact the Bay environment and the facility should meet NPDES permit requirements.

CMSA also conducted chronic bioassay testing of their current effluent concurrent with the pilot program WE testing. The results of pilot program WE testing were similar to the results of the current CMSA effluent testing, further showing that the addition of brine to CMSA effluent should not adversely impact the Bay environment. Section 7 of the report provides a more detailed discussion of the bioassay testing and the laboratory reports for the acute and chronic bioassay testing are included in Appendix 6.

Acute Bioassay Results

No significant effects on survival were observed among the acute bioassays conducted with shrimp, topsmelt or marine algae during any of the three episodes of testing. Consequently, no distinction in species sensitivity to the SWRO brine/CMSA discharge was detected.

Chronic Bioassay Results

The chronic bioassay testing provided the following results:

- Exposure to the WE blends did not cause statistically significant mortality to any of the five species tested.
- The WE blend did not elicit any statistically significant growth or developmental effects in three of the five species tested. Minor growth and development effects were observed on Giant Kelp and Bay Mussel. These observed effects are expected to be eliminated with minimal receiving-water dilution. The growth and development effects of the WE blend were similar to that of the current CMSA effluent without the addition of desalination brine.
- The results of the chronic bioassay testing using the WE blends were similar to the results of the chronic bioassay testing using the current CMSA effluent alone.

Solids Testing Results

For disposal of the pretreatment solids, the plan calls for sending the solids to the Redwood Landfill located in Novato, CA. This is typical of the disposal methods used for solids removed by other drinking water treatment and wastewater treatment plants in the region. The pilot program conducted testing on the pretreatment solids and demonstrated that they are not toxic and meet Redwood Landfill's acceptability requirements. Additional information and laboratory testing results are included in Appendix 1.

Finding #3: MMWD Customers Learned about Desalination and Liked the Water

The MMWD Seawater Desalination Pilot Program informed consumers about desalination technology and the high quality of water produced by membrane processes. The public outreach program included development of informational and educational materials and events including:

- Pilot plant layout and educational signs
- Desalination Explorer, an interactive computer animation that shows how all of the desalination and pretreatment processes work
- MMWD website content
- Media outreach
- Pilot plant grand opening
- 15 pilot plant tours and water tasting sessions
- Three public information seminars

Desalination technology was explained using handouts, signs and an interactive computer program


Marin Independent Journal

MONDAY

H₂O taste test

MMWD's desalinated bay water beats Marin competition

PIPE: Extension is sought

TASTE: Desalinated water wins

Tastings dispel desal's bad reputation

Which water tastes best?

Pipeline project could soon die

MMWD's customers liked the taste of the desalinated water

The pilot plant tours and seminars provided excellent forums to inform and communicate with the public. During these events, desalinated water from the pilot plant and MMWD's local tap water were available for the public to taste and to compare. An overwhelming majority of the pilot plant visitors judged that the desalinated water tasted as good as, if not better than, the MMWD tap water.

Informing the Public about Energy Use

One of the public's significant concerns about desalination is energy use. In the March 8 public information seminar, Desalination: Understanding and Managing Energy Use, MMWD and the consultant team presented information on:

- Why MMWD is considering desalination
- An overview of desalination and energy use
- Advances in desalination energy efficiency

- Estimated energy use by an MMWD desalination facility
- Possible renewable energy sources for an MMWD desalination facility

All of the presentations from the three desalination seminars may be found on the MMWD website www.marinwater.org.

Energy Requirements for Desalination are Decreasing

The public presentations included important information regarding the significant reduction in energy requirements for seawater desalination facilities over the past few decades. These energy savings are primarily due to improvements in membrane technology and advances in energy recovery systems. A copy of the presentation is in Appendix 5 and on the MMWD website.

The energy required to desalinate water is a function of the temperature and salinity of the water. Higher salinity and colder water requires more energy to desalinate than lower salinity and warmer water. In the Bay, the highest salinity occurs in late summer and peaks in droughts when temperatures are the highest. The lowest temperatures occur in winter when salinity drops due to local precipitation and snowmelt from the Sierra.

Production from the proposed desalination plant would be low in wet and normal years and would be at the maximum during droughts. During average weather, a proposed desalination plant would operate only at partial capacity, with an average of 5 million gallons per day (MGD) and require 10 kilowatt-hours (kWhr) per 1000 gallons to desalinate water from the Bay and deliver it to customers. During droughts, the plant would operate at full capacity (up to 10 MGD) and require 14 kWhrs per 1000 gallons. Taking this energy use and spreading it among the 60,000 service connections in the MMWD service area, average operation would be equivalent to a compact fluorescent light bulb (34 watts) operating continuously in each service connection; and in droughts would be equivalent to a 100-watt light bulb operating continuously in each service connection.

MMWD plans to explore the use of alternative renewable energy sources to power the desalination facility. MMWD could purchase alternative energy from various suppliers including Pacific Gas and Electric. Alternative renewable energy sources could include:

- Solar energy
- Wind energy
- Wave/tidal energy
- Landfill gas energy

To help minimize the energy requirements for the MMWD Desalination facility, the plant design would incorporate high efficiency pumps and the most advanced energy recovery systems available. The desalination facility would also be designed with the flexibility to permit adjusting system operations to minimize energy use depending on the salinity and temperature of the Bay water.

Finding #4: MF/UF is the Best Suited Pretreatment Process for Northern San Francisco Bay Water

Bay water requires pretreatment prior to the seawater reverse osmosis (SWRO) process to remove particulate matter and other contaminants that could foul the spiral-wound, reverse-osmosis membranes. Two skid-mounted SWRO pilot units were used to compare the performance and efficiency of the two pretreatment systems in controlling SWRO membrane fouling. One SWRO pilot unit received feedwater filtered by the MF/UF pretreatment system (MF/UF SWRO), and the second SWRO pilot unit received feedwater filtered by the conventional pretreatment system (Conventional SWRO).

The MF/UF pretreatment system is best suited for the MMWD desalination facility because it provides:

- Better filtered water quality
- More consistent filtered water quality
- Less fouling of the SWRO units.

In addition, MF/UF pretreatment requires:

- Fewer process chemicals
- Smaller area
- Lower capital costs
- Lower operational costs.

State-of-the-art UF and MF pilot units

Sections 8 and 10 of the report provide a detailed evaluation of the performance and costs of the conventional and MF/UF pretreatment systems.

Finding #5: Various Implementation Options Balance Capital Expenditures and Flexibility

The recommended treatment processes for a full-scale MMWD seawater desalination facility are based on the performance of the pilot systems over the period of the MMWD pilot study as well as information from other published studies and operating seawater desalination systems. Our approach was to reliably meet water quality and production requirements and minimize the capital and operating costs of the facility.

Recommended Desalination Process and Project Plan

Figure ES.1 presents a simplified flow diagram of the recommended treatment processes for the MMWD desalination facility. The second-pass RO process is shown as an option to meet more stringent sodium, chloride and boron water quality criteria, if desired, during a drought. The second-pass RO is not required to meet state and federal water quality requirements.

Figure ES.1: Desalination Facility Simplified Process Flow Schematic

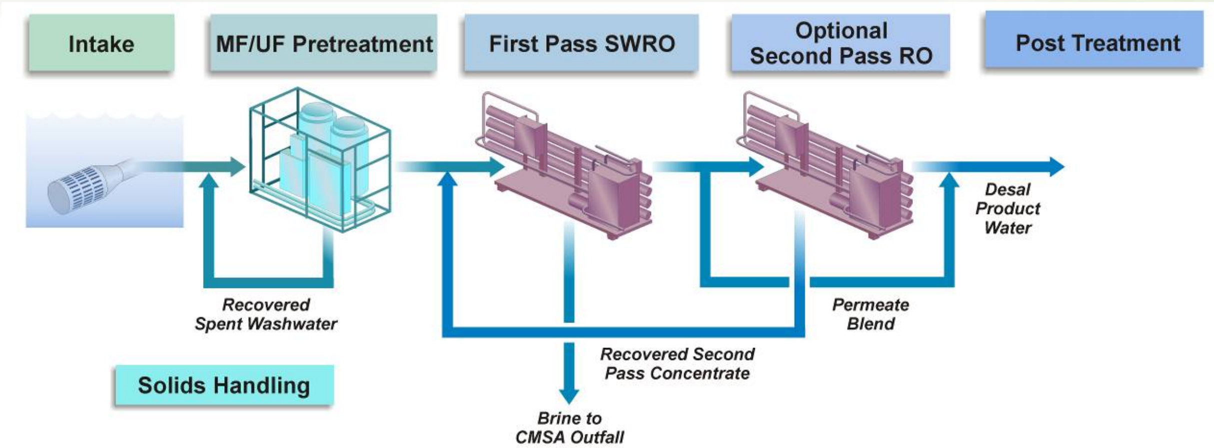
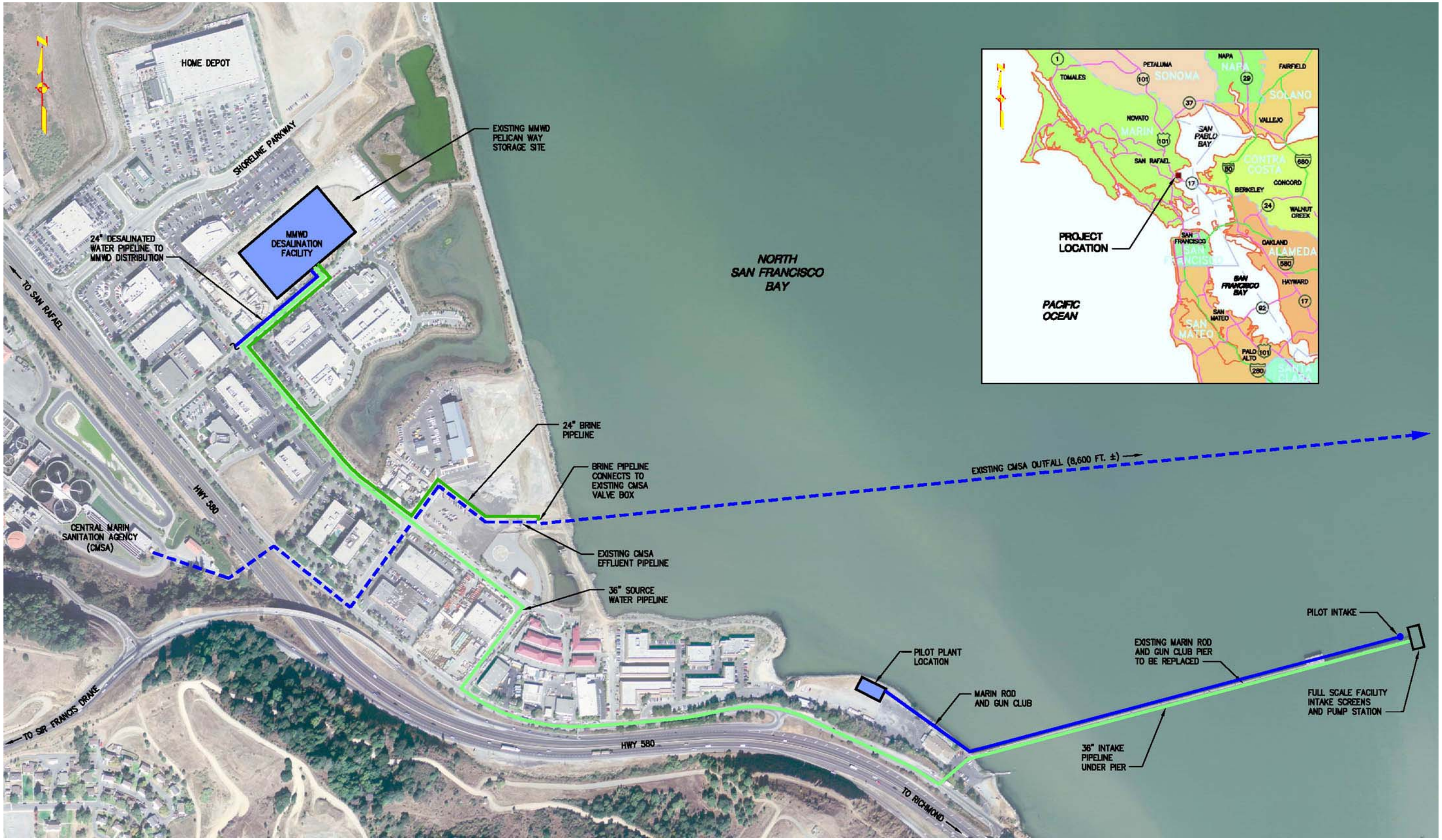


Figure ES.2 shows the overall project plan for the proposed desalination facility. The intake would be located at the end of a new concrete pier that is proposed to replace the existing Marin Rod and Gun Club pier. This approach minimizes new structures in the Bay and provides for access to the intake screens and equipment from the pier. A new pipeline would connect the pier intake facilities to the desalination facility site at MMWD's existing Pelican Way Storage Yard.

The brine from the desalination facility is proposed to be blended with effluent from the CMSA facility and returned to the Bay via CMSA's existing outfall. The spent washwater from the pretreatment systems would be captured, treated and recycled within the facility. Dewatered solids from the facility would be trucked to the Redwood Landfill. Desalinated drinking water produced by the facility would be delivered into the MMWD distribution system.

The treatment processes and ancillary support systems for a full-scale desalination facility as well as the operating parameters are described in more detail in Sections 8 and 9.

Figure ES.2: Overall Project Plan



The MMWD Desalination Facility at the District's existing Pelican Way Storage Yard would include the following major buildings or process areas:

- Control and electrical building
- Pretreatment process area/basins
- First-pass SWRO building
- Post-treatment process area and finished water disinfection tanks
- Chemical Storage Area
- Solids residuals handling basins and dewatering building

Desalination Facility Capacity and Construction Alternatives

MMWD staff projected potential future system water demands through the year 2025 to estimate the amount of desalinated water that would be needed to meet those demands. The demand model projections incorporated use and supply factors based on normal rainfall years, low rainfall (dry) years and drought years. Based on these projections, in normal and dry years, the desalination plant would operate at lower production levels during the wet season (approximately December through April) and operate at increased production in the dry, summer season (approximately May through November). During droughts, the desalination plant would operate at full production levels all year or as required to meet water demands.

Based on MMWD staff projections, the potential operations scenarios for a full-scale desalination facility could be as follows:

- Initial operation:
  - In normal rainfall years: 4 MGD during the period May through November, 1 MGD during the period December through April.
  - In dry years: 10 MGD during the period April through Nov, 4 MGD during the period December through March.
  - In drought years: 10 MGD year-round.

- Approximately 10 years later:
  - In normal rainfall years: 8 MGD during the period May through November, 1 MGD during the period December through April.
  - In dry years: 12 MGD during the period April through November, 8 MGD during the period December through March.
  - In drought years: 15 MGD year round.

- Approximately Year 2025 and beyond:
  - In normal rainfall years: 12 MGD during the period May through November, 2 MGD during the period December through April.
  - In dry years: 15 MGD during the period April thru November, 12 MGD during the period December through March.
  - In drought years: 15 MGD year-round.

To meet some or all of the water demands described in the operations assumptions above, MMWD is considering several different approaches to designing and constructing a full-scale desalination facility. Cost estimates were developed for the initial construction phase of each of these approaches as described below:

Case A: A 5-MGD facility that is not designed for expansion.

Case B: A 5-MGD facility that is designed for typical expansion. This facility could be expanded to 10 or 15 MGD in later phases.

Case C: A 5-MGD facility that is designed for a rapid expansion to 10 MGD in a second phase. It could be expanded to 15 MGD using a typical approach in a third phase.

Case D: A10-MGD facility that is designed for typical expansion to 15 MGD.

In Cases A-C, the first phase results in construction of a 5-MGD facility, while in Case D, the first phase results in construction of a 10-MGD facility. The differences in the approach and features of the three facilities are presented in Table ES.3 below.

Table ES.3: Comparison of Construction Approaches

Comparison of Key Components	Case A: 5 MGD non-expandable	Case B: 5 MGD typical future expansion	Case C: 5 MGD rapid future expansion	Case D: 10 MGD typical future expansion
Site layout capacity	5 MGD	Allows for 15 MGD	Allows for 15 MGD	Allows for 15 MGD
Intake, raw water, and brine pipelines capacity	5 MGD	15 MGD	15 MGD	15 MGD
Buildings, tanks capacity	5 MGD	5 MGD	10 MGD	10 MGD
Piping stub-outs for future connections	None	Available	Available	Available
Installed process equipment capacity	5 MGD	5 MGD	5 MGD	10 MGD

Full-Scale Desalination Facility Cost Estimates

The capital and operating cost estimates for the MMWD Seawater Desalination Facility were developed using an in-depth parametric cost estimating model developed by CH2M HILL. A parametric model uses specific unit quantities and costs, derived from the quantities of materials required to construct similar facilities and current material costs. The model, called CPES (CH2M HILL's Parametric Cost Estimating System), includes individual cost modules for each water treatment unit operation. Operating and maintenance (O&M) cost estimates are calculated based on quantities and usage of chemicals, power and consumable equipment (e.g., membranes and cartridge filters) defined in each module in combination with user-defined input units for electrical, chemical, consumable and labor costs.

CPES used specific design criteria defined through the pilot testing and unit costs for power, chemicals and labor representative of the Bay area. The cost model parameters were also evaluated and adjusted for MMWD project specific aspects.

Table ES.3 below presents a summary of standard cost estimating level descriptions, accuracy and recommended contingencies based on the level of the project. This data was complied from the Association for the Advancement of Cost Engineering (AACE).

Table ES.3: Standard AACE Cost Estimating Guidelines[(a)]

Cost Estimate Class[(a)]	Project Level Description	Estimate Accuracy Range	Recommended Estimate Contingency
Class 5	Planning	-30 to +50%	30 to 50%
Class 4	Conceptual (1 to 5% Design)	-15 to +30%	25 to 30%
Class 3	Preliminary (10 to 30% Design)	-10 to +20%	15 to 20%
Class 2	Detailed (40 to 70% Design)	-5 to +15%	10 to 15%
Class 1	Final (90 to 100% Design)	-5 to +10%	5 to 10%

Notes:
(a) Association for the Advancement of Cost Engineering, 1997. International Recommended Practices and Standards.

Although no design has been formally conducted in association with the development of the CPES cost estimates, preliminary design criteria have been developed through the conduct of the pilot study (as presented in Sections 8 and 9 of the report) and a basic understanding of site conditions and environmental issues has been developed through project specific studies. Consequently, a contingency of 25%, reflecting that used with a Class 4 estimate, has been applied to the cost estimates presented in this report.

The cost estimate tables also include a factor for escalation to the mid-point of construction, assumed to be approximately three years, based on approximately 5% cost inflation per year. This is based on the recent trend of the San Francisco Engineering News Record Construction Cost Index which has been higher than in years past due to more rapid increases seen in materials and construction costs since 2004.

In addition to the escalation to the mid-point of construction, Kennedy/Jenks-CH2M HILL recommend including a market uncertainty factor of 15%. This factor accounts for cost variation due to the recent tight construction market and reduced number of contractors bidding projects. This factor would be re-evaluated as the project moves closer to the bidding phase to account for the actual construction and bidding climate observed at the time.

Conceptual-level capital cost estimates are presented for the four capacity and implementation alternatives described above. Table ES.4 presents conceptual-level capital cost estimates for a full-scale MMWD Desalination Facility with MF/UF pretreatment as described in Sections 8 and 9 of the report. Section 10 of this report includes a comparison of the cost estimates of the conventional pretreatment SWRO facility with a MF/UF pretreatment SWRO facility and provides greater detail for the cost estimates of the SWRO facility components.

Table ES.4: Desalination Facility Conceptual Capital Cost Estimates

MMWD Desalination Facility				
Project Cost Component	**Case A: 5 MGD Not Expandable**	**Case B: 5 MGD "Typical" Expansion**	**Case C: 5 MGD "Rapid" Expansion**	**Case D: 10 MGD "Typical" Expansion**
Basic Facility and Intake Costs	**$47,275,000**	**$49,656,000**	**$62,570,000**	**$70,265,000**
Construction Markup @ 18% of Basic Cost	$8,511,000	$8,940,000	$11,265,000	$12,648,000
Contingency @ 25% of Basic Cost	$11,819,000	$12,414,000	$15,643,000	$17,567,000
Escalation to Mid-Point of Construction @ 15% of Basic Cost	$7,092,000	$7,449,000	$9,386,000	$10,540,000
Construction Market Uncertainty for SWRO Facility @ 15% of Basic Cost	$7,092,000	$7,449,000	$9,386,000	$10,540,000
Total Desalination Facility Construction Cost	**$81,789,000**	**$85,908,000**	**$108,250,000**	**$121,560,000**
Desalination Facility Cost per Gallon of Capacity, $	**$16**	**$17**	**$22**	**$12**
Non-Construction Costs @ 14% of Basic Cost (Permitting, Engineering, Construction Management)	$6,846,000	$7,156,000	$8,835,000	$9,836,000
MMWD Distribution System Improvements Cost	$22,600,000	$22,6000,000	$42,000,000	$42,000,000
Total Project Cost w/ Distribution System Improvements	**$111,235,000**	**$115,664,000**	**$159,085,000**	**$173,396,000**

Case A, would provide a 5-MGD facility and the facility would not be designed with any features to facilitate future expansion. The Case B approach provides the lowest initial capital cost for the 5-MGD facility while still providing the ability to expand in the future. The cost estimate difference between Case A and Case B represents a relatively minor capital cost (3%).

The Case C approach would require a greater initial capital investment by MMWD compared to a typically expandable 5-MGD facility, but would provide the ability to rapidly expand from 5 MGD to 10 MGD in a period of approximately 12 months if increased desalinated water production is required in a drought. The typical expansion time could be approximately 24 to 36 months. The cost difference between the first phase of Case B and C is approximately 21%. The Case D approach provides 10 MGD of production capacity initially with the ability expand to 15 MGD. While this has a higher initial capital cost, the unit cost of the water for this approach is lowest.

Table ES.5 presents the conceptual operating and maintenance costs for a full-scale 5- and 10-MGD desalination facility presented for average and drought conditions as described in Section 10. This presents the typical range of annual operating costs for the MMWD desalination facility based on production and source water salinity variations.

Table ES.5: Desalination Facility Conceptual Operating Cost Estimates

MMWD MF/UF SWRO Desalination Facility				
O&M Cost Category	**5 MGD Average Conditions**	**5 MGD Drought Conditions**	**10 MGD Average Conditions**	**10 MGD Drought Conditions**
Chemicals	$628,000	$1,399,000	$1,140,000	$2,797,000
Power	$1,408,000	$3,289,000	$2,724,000	$7,042,000
Membrane Replacement	$215,000	$213,000	$424,000	$424,000
Solids Disposal	$27,000	$87,000	$45,000	$173,000
Maintenance	$795,000	$795,000	$1,228,000	$1,228,000
Labor	$1,650,000	$1,650,000	$1,065,000	$1,650,000
Total Annual O&M Cost	**$4,138,000**	**$6,848,000**	**$6,626,000**	**$12,729,000**

Under drought conditions the power use increases due to the increased salinity of the Bay source water and the increased plant production. The cost of chemicals and solids disposal also increase in a drought due to the increased plant production.

Table ES.6 presents the conceptual total water cost estimates (annualized capital and operating costs) for a proposed MMWD desalination facility with capacities and construction approaches as described above. The capital costs are converted into annual costs assuming financing over a 30-year period at an interest rate of 5 percent. The 30-year period is typical for financing SWRO facilities. To permit comparing the current project total water cost to total water costs in previous reports, the annual operations and maintenance costs are based on average Bay water salinity conditions and operations to produce 5,300 and 10,600 acre-feet (AF) of water per year as shown in the table.

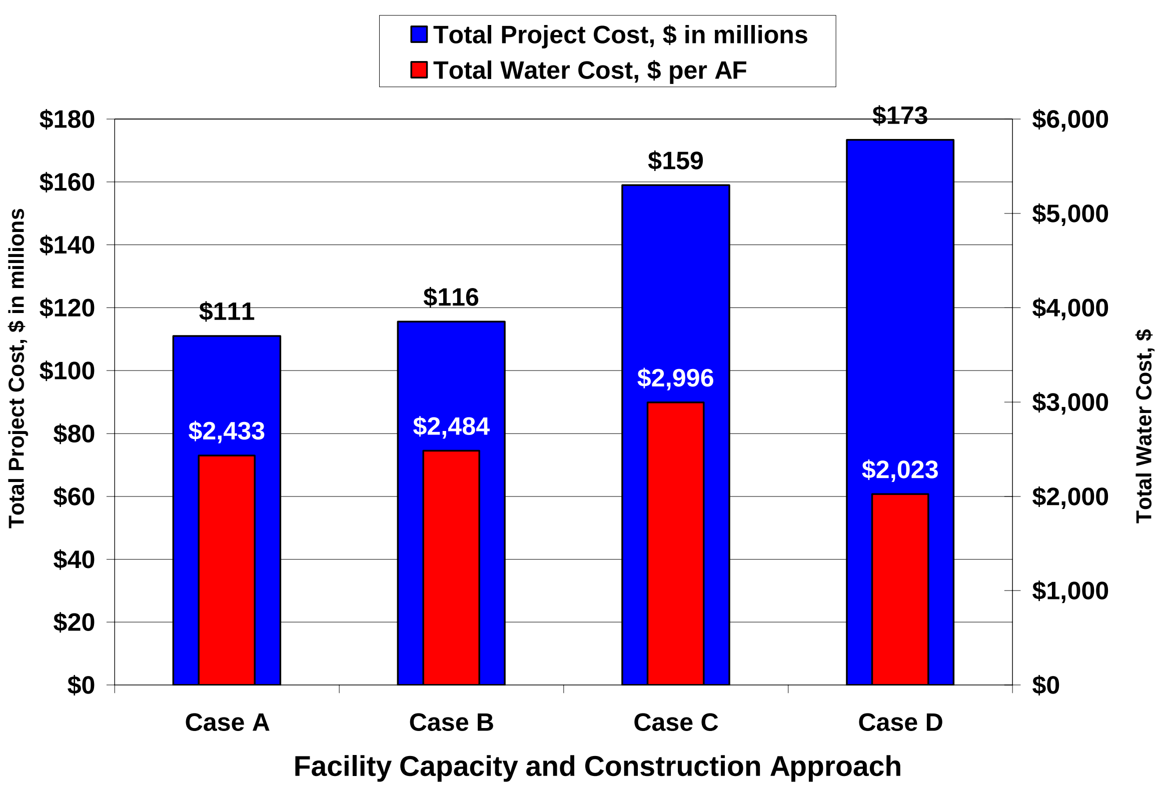
Table ES.6: Desalination Facility Total Water Cost Estimates

MMWD Desalination Facility Total Water Costs				
SWRO Facility Capacity	**Case A: 5 MGD Not Expandable**	**Case B: 5 MGD "Regular" Expansion**	**Case C: 5 MGD "Rapid" Expansion**	**Case D: 10 MGD "Regular" Expansion**
Annual Production in AF	5,300	5,300	5,300	10,600
Estimated Desalination Facility and Intake Capital Cost	$81,789,000	$85,908,000	$108,250,000	$121,560,000
Annualized Capital Cost	$5,324,464	$5,592,611	$7,047,075	$7,913,556
Annual Operating Cost	$6,100,000	$6,100,000	$6,100,000	$10,800,000
Total Desalination Facility Annual Costs	**$11,424,464**	**$11,692,611**	**$13,147,075**	**$18,713,556**

MMWD Desalination Facility Total Water Costs				
SWRO Facility Capacity	Case A: 5 MGD Not Expandable	Case B: 5 MGD "Regular" Expansion	Case C: 5 MGD "Rapid" Expansion	Case D: 10 MGD "Regular" Expansion
Desalination Facility Water Cost, $ per AF	**$2,156**	**$2,206**	**$2,481**	**$1,765**
Estimated Distribution System Improvements Capital Cost	$22,600,000	$22,600,000	$42,000,000	$42,000,000
Annualized Capital Cost	$1,471,260	$1,471,260	$2,734,200	$2,734,200
Total Project Annual Costs	**$12,895,724**	**$13,163,871**	**$15,881,275**	**$21,447,756**
Total Water Cost, $ per AF	**$2,433**	**$2,484**	**$2,996**	**$2,023**

While the Case D approach (initial 10 MGD of production capacity with the ability expand to 15 MGD) has a higher initial capital cost, the total unit cost of the water for this approach is lowest.

Figure ES.3: Desalination Project Estimated Capital and Total Water Cost



Conclusion

The MMWD Seawater Desalination Pilot Program was a successful year-long desalination pilot study and public outreach program that met the program objectives. Based on the favorable outcome of the pilot program, seawater desalination can be a reliable drought-proof source of drinking water supply for Marin. The pilot program:

- Demonstrated that the desalinated water is safe and meets all state and federal requirements.
- Informed MMWD's customers about desalination and demonstrated that the water tastes good.
- Demonstrated that the brine discharge blended with CMSA effluent will not adversely impact the San Francisco Bay environment.
- Determined that MF/UF filtration is the best pretreatment process for North San Francisco Bay water.
- Developed preliminary design criteria and conceptual costs for a full scale desalination facility with capacities of 5 and 10 MGD, with varying expansion options.

MMWD has not forgotten the hardships of the droughts of the mid-1970s or the early 1990s. Desalination of San Francisco Bay water is a drought-proof, local, independent and effective approach to ensure a sufficient and reliable water supply for Marin through dry years and in the next drought.

Acknowledgements

We would like to acknowledge and thank the project team for their dedication and hard work on this successful project.

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Section 1: Pilot Program Objectives and Pilot Facilities

Marin Municipal Water District's (MMWD) current water-supply components include local surface water, imported groundwater from the Russian River, water from conservation programs, and recycled water. MMWD is evaluating increasing its water supply portfolio to include a seawater desalination plant with a potential ultimate capacity of 15 million gallons per day (MGD). The most suitable site for a desalination facility appears to be at District-owned Pelican Way site in San Rafael. Pilot tests conducted in 1990 demonstrated that desalination could produce a drinking water that was both safe and palatable. Since that time, treatment technologies have improved and new regulatory requirements exist today that could impact permitting and operation of a full-scale desalination facility.

MMWD therefore conducted an approximately one-year-long Seawater Desalination Pilot Program using more advanced seawater reverse osmosis (SWRO) technologies to update the pilot work done in 1990. This report described the results of the Pilot Program. The outcome of this Pilot Program provides MMWD with the current data necessary for a comprehensive evaluation of a full-scale desalination drinking-water facility to treat Northern San Francisco Bay (Bay) water.

This report describes a few of the many environmental studies conducted to evaluate the proposed desalination project as part of the Seawater Desalination Pilot Plant Program. However, this report it is not intended to be a substitute for the Environmental Impact Report (EIR) which will address all of the environmental issues involved with the proposed project. The EIR is scheduled for release in Spring 2007.

1.1 Organization of Engineering Report

This Seawater Desalination Pilot Program Engineering Report describes the construction and operation of the pilot plant; summarizes the San Francisco Bay source water quality and the treatment objectives; summarizes the public outreach program; summarizes the results of the pilot plant operations; describes the finished drinking water quality from the desalination process; summarizes the results of various environmental studies; and provides preliminary design and operating criteria and costs for a full scale Desalination facility.

The Seawater Desalination Pilot Program Engineering Report is separated into four sections:

- Executive Summary
- Pilot Program Summary
- Full Scale Facility Recommendations
- Appendix

The Executive Summary presents the overall big picture results of the pilot program and is intended for a general audience. The Pilot Program Summary section summarizes the construction, operation and results of the pilot program. The Full Scale Facility

Recommendations section provides preliminary design and operating criteria and preliminary level costs for a full scale seawater reverse osmosis (SWRO) desalination facility. The Pilot Program Summary and the Full Scale Facility Recommendations sections have more technical detail but could also be read by a general audience. The Appendix Section includes more in-depth and detailed technical back-up information that is important to the project but has too much detail for the main body of the report. The Appendix has a significant amount of information and to keep the report to a reasonable size, the Appendix has been provided on a CD attached to the back cover of the report.

1.2 Overall Pilot Program Objectives

The MMWD Seawater Desalination Pilot Program was a successful, desalination pilot study and public outreach program. The overall objectives of the MMWD Seawater Desalination Pilot Program are listed in Table ES.1 below along with confirmation that the project objective was met. The overall objectives of the MMWD Seawater Desalination Pilot Program were to:

Table 1.1: Pilot Program Objectives

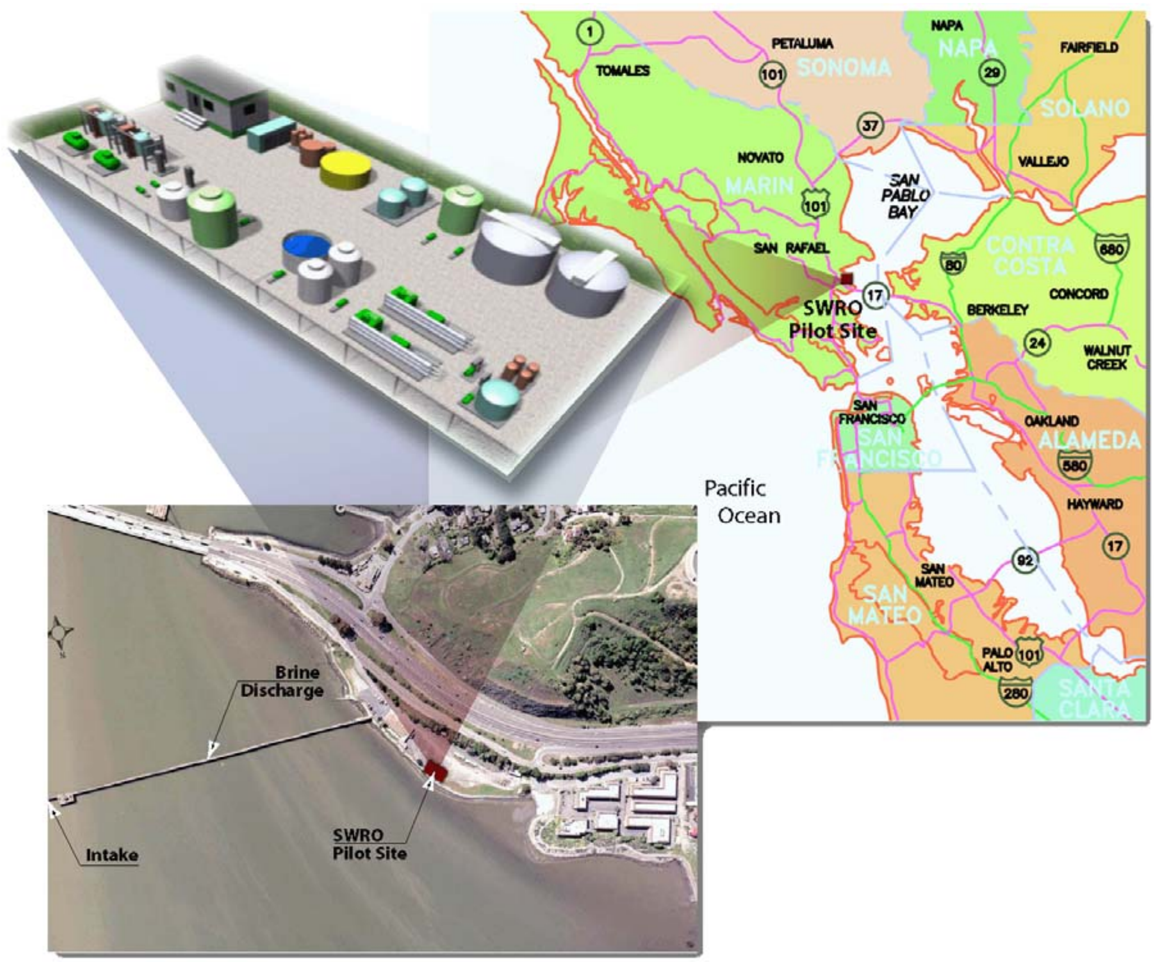
MMWD Seawater Desalination Pilot Program Objectives	Pilot Program Objectives Were Met
Demonstrate advanced low-pressure microfiltration/ultrafiltration (MF/UF) membrane filtration in parallel operation with a conventional treatment system to determine the best-suited pretreatment process for Northern San Francisco Bay water.	*The Siemens/Memcor MF and Zenon UF systems were operated in parallel with conventional pretreatment and comparable performance data was collected.* *The MF/UF pretreatment is the best-suited pretreatment process for Northern San Francisco Bay water.*
Establish optimum operating conditions for both conventional and membrane pretreatment.	*The pretreatment pilot equipment was operated over a range of loading/flux rates with and without coagulation addition and under varying source water conditions to provide the data necessary to establish optimum operating conditions for a full-scale facility.*
Demonstrate that the SWRO process can reliably desalinate Northern San Francisco Bay water.	*Pilot plant performance data and water quality test results demonstrate that the SWRO process can reliably desalinate Bay water.*

MMWD Seawater Desalination Pilot Program Objectives	Pilot Program Objectives Were Met
Demonstrate that the desalinated water has high water quality, equal to or better than state and federal drinking water standards.	*The desalinated water is safe.* *The drinking water (regulated) and voluntary (non-regulated) test results collected over the study and presented to the public indicate the desalinated water is of high quality and meets state and federal drinking water standards.*
Demonstrate the efficacy of the SWRO process in removing trace and emerging contaminants of concern including, but not limited to, pesticides, endocrine disruptors, herbicides and pharmaceutically active components.	*Some non-regulated trace and emerging contaminants were detected at very low levels in the source water and were removed with the SWRO process.*
Develop design criteria and preliminary cost estimates, and establish operating parameters for a full-scale SWRO desalination facility with an ultimate capacity of 15 MGD of drinking water production.	*Pilot performance data and water quality test results collected have provided the information necessary to develop design criteria for a full-scale facility.*
Demonstrate that the SWRO product water meets regulatory standards and MMWD's water quality goals. Determine the best method for controlling corrosion in MMWD's distribution system and perform testing to determine the compatibility of the desalinated water with MMWD's other water sources and to meet Lead-Copper Rule regulations.	*The Desalinated water tastes good and matches MMWD water.* *Pilot performance data and water quality test results indicate the SWRO water meets regulatory standards and MMWD's stringent water quality goals. Corrosion testing demonstrated the stability and compatibility of the finished desalination water with MMWD's other supplies.*
Conduct testing of pretreatment residuals and develop design criteria for full-scale plant residuals handling to ensure acceptance of these residuals by a common landfill.	*Residual solids from the pretreatment processes were collected and bench scale tests were conducted on thickening of the solids. The data provided information for developing design criteria for residuals handling in a full-scale plant. Samples were analyzed for acceptance at Redwood Landfill. Solids test results indicated the solids meet the requirements for acceptance at Redwood Landfill.*

MMWD Seawater Desalination Pilot Program Objectives	Pilot Program Objectives Were Met
Conduct a public outreach program to educate the public and media on the SWRO process technology and the high quality of the desalinated water through tours, presentations, educational materials, and taste tests.	*The program provided effective outreach on the desalination technology and the high quality of desalinated water through educational materials and public tours, water tastings and public education seminars.*

1.3 Pilot Plant Location

The MMWD Desalination Seawater Pilot Plant (pilot plant) was located in the rear parking lot at the Marin Rod and Gun Club in San Rafael, California. This location enabled the pilot plant intake to be located on the Marin Rod and Gun Club pier, as is proposed for the full-scale facility.



MMWD Seawater Desalination Pilot Plant in San Rafael, California

The pilot plant consisted of the pilot desalination process equipment, an electrical motor control center, and a small, furnished office trailer to store parts and equipment and to house a computer and phone to assist in data collection and evaluation. The pilot site was enclosed by a temporary security fence and high-quality canopy covers were provided over the MF/UF pretreatment and SWRO equipment for rain protection. The pilot site was laid out to permit public tours and to inform the public about the desalination process. It had gravel ground cover to keep the site functional and accessible for tours through the rainy season. Drawings of the pilot site are included in Appendix 3.

1.4 Pilot Plant Systems and Objectives

The pilot plant included the following treatment processes and pilot components:

- A Bay water intake system
- Two feed strainer systems
- One microfiltration (MF) membrane filtration pretreatment train
- One ultrafiltration (UF) membrane filtration pretreatment train
- One conventional filtration pretreatment train
- Two independent SWRO trains to test pretreatment
- A bench-top second-pass reverse osmosis system
- A solids handling system
- A return-water system to return test water to the Bay

Each treatment process system, and its objectives, is described below. A more detailed description of the pilot plant treatment process systems is presented in the Technical Memoranda included in Appendix 1.

1.4.1 Intake Water System

The pilot plant intake water system is described briefly below, and in more detail in Technical Memorandum No. 1 in Appendix 1.

The intake system for the pilot plant withdrew approximately 125 gallons per minute (gpm) of source water from the Bay at the end of the approximately 2,000-foot-long Marin Rod and Gun Club pier and delivered it to the pilot plant site. The intake system included:

- Passive intake screen with a manual air-burst self-cleaning system
- Intake pump and priming pump
- Intake piping
- Seawater holding tank

The overall objectives for the pilot plant intake system are listed below:

- Evaluate, via pilot testing, intake components and design concepts most likely to be required for a full-scale facility.
- Design and operate the intake screen to meet state and federal requirements to minimize impingement and entrainment of marine organisms (i.e. 3/32 inch slotted screen openings and <0.3 ft/sec flow velocity).
- Evaluate periodic shock chlorination for control of biological growth, if necessary.
- Determine appropriate materials and design and operating parameters for a full-scale intake system.

Wedge-wire intake strainer to protect fish and remove large debris (screen dimensions 12-inch diameter by 12 inches long)

Pilot intake was located on the end of the Rod and Gun Club pier

1.4.2 Feed Strainer System

The pilot plant tested a Bollfilter strainer and an Arkal strainer, to remove large particles ahead of the pretreatment processes. Both strainer systems were rated at a nominal particle removal size of 100 microns. The Bollfilter strainer used stainless-steel wedge wire strainer elements and was operated ahead of the conventional pretreatment process for a period of several months. The Arkal strainer used compressed plastic disks for straining and was operated to strain feedwater to the MF and UF systems throughout the entire study.

The strainer systems included:

- Bollfilter wedge wire 100-micron strainer
- Arkal disk 100-micron strainer
- Compressed air for backwash
- Strainer backwash pump

Bollfilter strainer on the left and Arkal Strainer on the right

1.4.3 MF and UF Pretreatment System

The Bay water requires pretreatment prior to the SWRO process to remove particulate matter and other contaminants that could foul the spiral wound reverse-osmosis membranes. While conventional pretreatment has been traditionally used in the past, recent advances and cost reductions in MF and UF technologies provide the opportunity for improved pretreatment. The MMWD pilot program tested both MF/UF and conventional pretreatment systems in parallel to determine which process is best suited for pretreatment of Northern San Francisco Bay water.

The pilot plant MF and UF filtration pretreatment systems are described briefly below and in more detail in Technical Memorandum No. 2 in Appendix 1.

The MF/UF pretreatment system included:

- Coagulant contact tank and coagulant dosing system
- U.S. Filter/Memcor CMF-S MF system (The current designation for this product is MEMCOR CS manufactured by Siemens. The MF system will be referred to by the new name henceforth.)
- Zenon Zeeweed-1000 UF system
- MF/UF spent washwater capture system
- MF/UF filtrate tank

As part of the pilot testing program, MMWD requested that two immersed MF/UF systems with an "outside-in" flow configuration be evaluated. At the time of the testing, the only two immersed products commercially available for use in the municipal drinking water market were manufactured by ZENON Environmental, Inc. and U.S. Filter/Memcor (now Siemens/Memcor). Consequently, the ZENON Zeeweed 1000 UF system and the MEMCOR CS system were piloted as part of the program. The systems were operated in parallel during the study so the performance of each could be directly compared (identical feedwater conditions). Each manufacturer was allowed to optimize the operating conditions of their system for the source water-quality conditions prior to long-term testing. The filtered water from the MF/UF units was combined together in a common filtrate tank to serve as the feed to one of the two SWRO units.

UF and MF pilot units

The overall performance objective for each of the MF and UF systems during the pilot study was to determine the most economical combination of operating parameters while producing a filtrate that met the SWRO feedwater requirements. Generally, this would be a balance between maximizing flux and system recovery while minimizing the cost associated with chemical cleaning. The flux at which a membrane system can operate depends on source water quality, temperature, and membrane cleaning strategy. Typically, the higher the flux and recovery, the greater the rate of fouling and the more frequent the required cleanings to maintain production. The performance objectives included:

- Optimize flux for water quality conditions
- Minimize cleaning frequency
- Optimize recovery (to a target of 95%)
- Produce a filtrate having a turbidity <0.1 NTU 5% of the time and an average silt density index (SDI) <3.0

1.4.4 Conventional Pretreatment System

The pilot plant conventional pretreatment system is described briefly below and in more detail in Technical Memorandum No. 3 in Appendix 1. The conventional pilot system consisted of rapid mix, flocculation, and sedimentation followed by two-stage granular media filtration.

The conventional pretreatment system included:

- Flocculation tank
- Lamella-type tubular clarifier
- Two-stage granular media filtration (GMF)
- GMF filtrate tank
- Backwash supply tank
- Chemicals (coagulant, flocculant aid)

Conventional pretreatment system filters

The performance objectives for the conventional treatment system included:

- Producing a filtered water having a turbidity <0.2 NTU 95% of the time and an average SDI of <4.0
- Optimize chemical types and doses for clarification and filtration
- Optimize clarification and GMF filtration (loading) rates
- Optimize backwash frequency, duration, and flow rates

1.4.5 Seawater Reverse Osmosis Systems

The pilot plant seawater reverse osmosis (SWRO) systems are described briefly below and in more detail in Technical Memorandum No. 4 in Appendix 1.

Two skid-mounted SWRO pilot units were used to compare the performance and efficiency of the two pretreatment systems in controlling SWRO membrane fouling and to demonstrate the viability and reliability of SWRO desalting for San Francisco Bay water. One SWRO pilot unit received feedwater provided by the MF/UF pretreatment system (MF/UF SWRO), and the second SWRO pilot unit received feedwater provided by the conventional pretreatment system (Conventional SWRO). This provided a means to directly compare the differences in SWRO performance based on difference in pretreated water quality over the course of the pilot study.

To minimize pilot capital costs and water demand, the SWRO systems used 4-inch diameter by 40” long membrane elements. The performance of the 4-inch elements can be used to accurately predict the performance of standard 8-inch diameter by 40- (or 60-) inch long or larger elements. Also, each SWRO system skid was configured to permit testing three different manufacturer’s membrane elements in parallel. The SWRO membranes tested were those available from major manufacturers that have had full-size SWRO systems in commercial operation for at least one-year and included: (1) Dow/Filmtec; (2) Hydranautics; (3) Toray; and (4) Koch.

The SWRO systems included the following components:

- SWRO booster pumps
- Chemical injection and cartridge filters
- Two SWRO units, each with three parallel membrane vessel trains
- Common RO permeate/flush tank
- SWRO Clean-In-Place (CIP) system
- Common bench-scale second-pass RO system

The product water from the SWRO pilot units (first pass) was then treated, on a limited batch basis, with a second RO unit (second pass) to further reduce the levels of salts in the treated water. The second pass RO unit was a small bench scale system.

First Pass SWRO pilot units and second pass RO unit

The general water treatment objectives for the first-pass SWRO system are described in Section 3. The overall SWRO system performance objectives include:

- Compare performance of different membrane types.
- Compare performance of each membrane type on different pretreated feedwater (MF/UF and conventional pretreatment).
- Determine need for feedwater chemical conditioning and dose requirements of pretreatment chemicals.
- Compare differences in rate of cartridge filter fouling (between MF/UF and conventional pretreated water).
- Optimize SWRO flux, recovery and cleaning frequency.

1.4.6 Solids Handling System

The pilot plant solids handling system is described briefly below and in more detail in Technical Memorandum No. 5 in Appendix 1.

The pilot plant solids handling system was used to collect all waste residuals from the pilot plant (strainer backwash water, clarifier underflow, spent filter washwater and spent cleaning (CIP) solutions from the MF/UF and RO systems) except for the SWRO brine. These residuals, which could not be returned to the Bay, were then pumped to the sanitary sewer at a controlled rate. The solids handling system included:

- Spent washwater tank
- Sludge sump and pump
- Spent washwater return pump

- Miscellaneous equipment and instrumentation

The overall objectives for the solids handling system include:

- Capture and discharge pilot plant suspended solids to the sanitary sewer.
- Capture and discharge neutralized cleaning solutions to the sanitary sewer.
- Evaluate physical and chemical characteristics of the solids produced by the different processes.
- Evaluate the suitability of solids for disposal at a municipal landfill (Redwood Landfill).

1.4.7 Return Water System

The pilot plant return-water system is described below and in more detail in Technical Memorandum No. 1 in Appendix 1. The return-water system for the pilot plant collected filtrates and permeates from the pretreatment and RO systems, and RO concentrate and miscellaneous overflows from the pilot plant, and returned the combined flows back to the San Francisco Bay approximately 500-feet out along the Marin Rod and Gun Club pier. The return-water system included:

- Return-water tank
- Return-water pump
- Return-water piping

Section 2: Public Outreach Program

The MMWD Seawater Desalination Pilot Plant Program was successful in informing consumers about the desalination technology and helping to forge an effective partnership between local citizens of the County and MMWD. The project team's approach to public outreach was to foster open communication and project understanding.

The pilot plant program made an early commitment to use the best approaches in technology, public relations, and education to give the District's customers a chance to learn about desalinated water as a new source of water supply for Marin. An analysis of print and broadcast media coverage showed that people understood both the purpose and the capabilities of the pilot plant program. They understood that the desalination pilot plant could produce fresh water as good as if not better tasting than MMWD's local tap water. Furthermore, the response by the media and the public to the desalination pilot program was positive.

The public outreach program included the following main components:

- Development of informational and educational materials and MMWD website content
- Pilot plant layout and educational signs
- Pilot plant grand opening and media outreach
- Pilot plant tours and water-tasting sessions
- Public information seminars

These main components are summarized below.

2.1 Development of Pilot Program Materials

The theme "Evaluating a Drought-proof Source of Water for Marin" and its sub-messages were consistently communicated verbally and visually in all pilot program communications. The following materials were used to communicate these messages:

- Pilot program brochure
- Pilot plant educational signs
- Interactive "Desal" explorer
- Media press releases and fact sheets
- Educational presentations

A consistent theme and messages were presented using handouts and signs

The informational and educational materials also supported and provided content for MMWD's presentation materials, public outreach mailings, website, and handouts to the media.

2.2 Interactive "Desal" Explorer

The project team developed the Desal Pilot Plant Explorer interactive tool, which lets the public view the desalination process at magnification levels beyond even those of the electron microscope. Through 3-D modeling the viewer is provided a virtual tour of the pilot plant and the internal workings of its technology. The Explorer was a part of all the pilot plant tours. It also was on display at the MMWD office as well as in other locations around the community. Feedback on the Desal Explorer from the public was extremely positive.

Screen from the Interactive Desal Explorer

2.3 Pilot Plant Layout and Educational Signs

The pilot plant site was laid out to facilitate public tours and to educate the public on the desalination technology being tested. The plant layout had four key elements:

- Access to the process units
- Signs describing the function of each process unit
- A kiosk where the public could use the Desal Explorer
- A water-tasting area where the public could compare desalinated water with MMWD's current tap water

The central area of the pilot plant site allowed easy access to the process units. The MF/UF pretreatment and SWRO equipment was protected by high-quality canopies with sides that were rolled up during public tours so that the public could view the equipment. Canopies also protected the water-tasting area and an educational kiosk where visitors could view the Desal Explorer. The pilot site also had gravel ground cover to provide a suitable surface for public tours as well as to keep the site functional through the rainy season.

Educational kiosk at the pilot plant site

Working closely with MMWD staff, the project team provided ten 4-foot by 6-foot full-color educational display signs that were mounted at the pilot site. These educational signs described the “Four Steps to Fresh Water” treatment process. The signs were mounted in front of the process equipment so that the public could relate the functions described in the signs to the physical equipment. The signs were weather-resistant and transportable, with graphics big enough so that they were suitable for large group tours. Individuals at the public tours made positive comments on the educational signs. The graphics and text communicated both simple and more complex messages. The signage, displays, and a brochure helped to stimulate interest and provided understandable, effective, and accurate information to the public.

2.4 Pilot Plant Grand Opening

The MMWD Seawater Desalination Pilot Plant ribbon-cutting event publicized MMWD’s efforts to evaluate Bay water as a supplemental, drought-proof source of water. The event also served as a celebration, as the plant was opened to the public and stakeholders for the first time. Some statistics on circulation and audience for the event are given below:

- Almost 100 people tasted desalinated water at the grand opening, including elected officials and key stakeholders.
- 800,000 television viewers tuned in during the news hours when coverage of the pilot grand opening occurred.
- 1.6 million radio-listeners tuned in during the week when three stories aired about the pilot program.
- The total circulation audience for newspapers with articles on the pilot program reached over 1 million readers.

These numbers do not include "hits" on MMWD's website by those seeking information on the pilot program.

Our project team and MMWD staff developed outreach materials to communicate to the media in advance of the ribbon-cutting event and during the event. These materials included:

- Press release
- Media alert
- Bios on the event speakers
- General fact sheet
- Technical fact sheet
- Explorer fact sheet

Our team worked with MMWD staff to identify and prepare spokespeople from MMWD and the community to present materials at the ribbon-cutting ceremony and to participate in media interviews. The ribbon-cutting ceremony was a great success, with effective spokespeople speaking and conducting interviews with the local media.

We communicated with and encouraged numerous Bay Area newspaper, television, and radio outlets to attend the ribbon-cutting ceremony and to announce and report on the public open house tours.

Grand opening ceremony for the pilot plant

2.5 Pilot Plant Tours and Water Tasting

MMWD staff and the project team conducted more than 18 pilot plant tours and water-tasting events to foster open communication and create and enhance program understanding. The pilot plant tour and water-tasting events for key stakeholder groups and the public were spread out over the nearly year-long study, including the following events:

- Ribbon-cutting ceremony (9 June 2005)
- American Water Works Association National Conference Tour (15 June 2005)
- Central Marin Sanitation Agency Staff (20 July 2005)
- Marin County League of Women Voters (22 July 2005)
- Rod and Gun Club Oyster Restoration Project Kickoff (25 July 2005)
- Rod and Gun Club Annual Picnic (31 July 2005)
- Public Open House (6 August 2005)
- Public Open House (20 August 2005)
- Public Open House (10 September 2005)
- Central Marin Sanitation Agency Board of Directors (13 September 2005)
- Public Open House (24 September 2005)
- Public Open House (8 October 2005)
- Public Open House (15 October 2005)
- Public Open House (22 October 2005)
- Environmental Forum of Marin (1 November 2005)
- Public Tour before Information Seminar (9 November 2005)
- Public Tour before Information Seminar (25 January 2006)
- Public Tour before Information Seminar (8 March 2006)

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H$_2$O taste test

MMWD's desalinated bay water beats Marin competition

IJ photo/Jeff Vendsel

GULP: Stephanie Taubert of San Rafael tries one of the three samples of Marin Municipal Water District tap water, desalinated water and North Marin Water District tap water during a blind taste test at the IJ on Friday afternoon.

Tastings dispel desal's bad reputation

By Mark Prado
IJ reporter

Maybe drinking bay water is not such a bad idea after all.

Desalinated water scored on par and even better than Marin tap water, according an unscientific blind taste test conducted Friday outside the Independent Journal's Novato office building.

Unmarked samples of Marin Municipal Water District's desalinated water, Marin Municipal tap water and North Marin Water District's tap water were offered and testers were asked to rank the three water samples on a 1 to 3 scale, with 1 being the best, 3 the worst.

Fifty people, many of them Independent Journal employees, stopped by the test table and sipped from paper cups.

Of the 50 who sampled, 20 ranked the desalinated water as their top choice, with 18 preferring North Marin water and 12 indicating Marin Municipal tap as the best. Overall, desalinated water and North Marin water tallied 98 points, and Marin Municipal tap 103. The lower the score, the better taste of the water.

Stephanie Taubert pulled a wry face when told one of the three waters was cleaned San Pablo Bay water. After carefully tasting all three, she indicated the water marked with a yellow sticker was her favorite: the desalinated bay water.

"You're kidding! That's weird," she said, before her

See Taste, page A7

Which water tastes best?

At an unscientific blind taste test conducted at the front doors of the Marin IJ on Friday, random visitors and employees compared water samples from three Marin sources. Here are the results:

	A. North Marin Water District tap water from the IJ in Novato	B. Desalinated water from MMWD's pilot plant in San Rafael	C. MMWD tap water from a Terra Linda home
First place votes:	18	20	12
Total points*:	98	98	103
Comments:	"... tasted like nothing."	"It is smooth, it didn't have any lingering flavor."	"A metallic, unpleasant taste."

*Participants were asked to rate three samples 1-3 in order of preference. Lowest number indicates the winner.

IJ graphic

Pipeline project could soon die

By Mark Prado
IJ reporter

Plans for a pipeline to move water from Sonoma County to Marin could die if the Marin Municipal Water District does not renew a contract that expires at the end of the month.

The MMWD has a series of contracts with the Sonoma County Water Agency to provide it with water. Two contracts are locked in and provide Marin with up to 9,300 acre-feet annually. MMWD's demand for that water is 8,000 acre-feet annually.

A third contract provides MMWD with 5,000 acre-feet on an "as available" basis. MMWD now must decide if it wants to lock in those water rights at a cost of $6 million.

The 5,000 acre-feet would be used for a pipeline to tap water from the Russian River.

See Pipe, page A7

PIPE: Extension is sought

From page A1

But the project has been put on the back burner as the water district pursues desalination.

If MMWD does not renew the contract, the pipeline project is essentially dead.

"We would like an extension for at least two years," said Jared Huffman, president of the Marin Municipal Water District board of directors.

It would cost the district $200,000 for each year of an extension, officials said.

There will be a series of meetings to determine the issue. The Sonoma County Water Advisory Committee will meet next Monday, then the water agency's board meets Tuesday.

"Ideally everyone will agree on this, but we will have to wait and see what they say," said Elizabeth Emmett, spokeswoman for the Sonoma water district.

The Marin water district board will then hold a special meeting June 29.

Simply renewing the contract wouldn't mean the water from the Russian River would be available overnight, Huffman noted.

First, Marin would have to build a pipeline, and then Sonoma County would need facilities in place to deliver the water. The Sonoma facilities haven't been built and could take another 10 years to materialize.

"That is one reason we are asking for an extension," Huffman said. "Sonoma doesn't have everything together on their side. That's not our fault. We'd hate to commit $6 million to something that is under a huge cloud."

Beyond the physical issue of getting water from Sonoma, there are several legal ones as well. Environmental groups have sued, trying to halt water pulled from the Russian and Eel rivers because of concern about fish protection. Water from the Eel River is diverted into the Russian River.

The amount of water flowing from the rivers could be limited by the courts, preventing Marin from seeing an extra drop of water through the pipeline, Huffman noted.

"Whatever happens has to happen soon, because the curtain is coming down soon," Huffman said.

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TASTE: Desalinated water wins

From page A1

mouth went agape. "It just tasted a little sweeter; that's frightening. I'm very surprised."

Despite choosing bay water as the best tasting, she still wasn't sold on drinking desalinated water, an issue Marin Municipal officials realize they must overcome.

"It's not good news that I liked it. Do you know what is in the bay? Toxics and contaminants," she said. "I think I'll start buying bottled water."

David Giambastiani also liked the desalinated brew.

"It is smooth; it didn't have any lingering flavor. It just tasted like bottled water," he said.

Giambastiani described MMWD tap as having a "metallic, unpleasant taste" and North Marin's as having a "tap water taste."

But sampler Fred Conner thought the desalinated water had a "chemical and chlorine taste" and favored North Marin's "neutral" flavor.

Flora Mavrak favored the desalinated water because it was the only one to have a taste.

"There was a flavor; the other two tasted like nothing," she said.

The desalinated water was some of the first to come from the Marin Municipal Water District's $1.2 million pilot desalination plant at the Marin Rod and Gun Club site near the west end of the Richmond-San Rafael Bridge.

The pilot plant cleans water through a reverse osmosis process and microfilters.

Testing for the next nine months will determine if desalting bay water and pumping it to Marin homes is feasible. That could lead to construction of a $77 million, full-scale facility capable of producing at least 5 million gallons of water daily.

Although officials plan to arrange for the public to weigh in on the taste of desalinated water, they haven't yet formally organized taste testing.

Friday's informal Independent Journal test indicated desalinated water is off to a decent start.

"They are all good," said taster Ruth Mendoza. "The (desalinated water) had an interesting flavor that I liked."

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MMWD's customers liked the taste of the desal water

The open houses at the pilot plant often had more than 100 visitors over a period of one to four hours and provided clear information to inform consumers and stakeholders about desalination technology and the pilot project. The open houses and the tours also provided finished water from the pilot plant along with MMWD's local tap water for comparison. An overwhelming majority of the pilot plant visitors judged that the desalinated water tasted as good as, if not better than, the MMWD tap water.

2.6 Seminars Focused on Customer's Interests

The project team worked with MMWD staff to prepare and present public information seminars at the Rod and Gun Club facility. The seminars were a successful way to inform and communicate with the public about the three areas of greatest customer interest. The seminars were announced as Board of Directors' meetings, enabling all the MMWD Board members to attend. The MMWD General Manager hosted the seminars. The format consisted of a presentation followed by a question-and-answer period with subject-matter experts on the topic of the seminar. The three information seminars were:

- "**Desalination: Understanding Bay Environmental Issues**." This seminar was held on Wednesday, 9 November 2005. It covered the following topics: Why MMWD is considering desalination; an overview of desalination; an overview of the project environmental studies; a discussion in the intake and fish entrainment study; a discussion of the brine discharge issues; and discussion of the acute and chronic bioassay study for the project.

- "**Desalination: High Quality of Drinking Water from San Francisco Bay**." This seminar was held on Wednesday, 25 January 2006. It covered the following topics: Why MMWD is considering desalination; MMWD current water quality; characteristics of San Francisco Bay; a discussion of the rigorous water-sampling approach; a discussion of the water-quality results; and a statewide perspective on water quality and testing.

- "**Desalination: Understanding and Managing Energy Use**." This seminar was held on Wednesday, 8 March 2006 and covered the following topics: Why MMWD is considering desalination; an overview of desalination and energy use; advances in desalination energy efficiency; estimated energy use by an MMWD desalination facility; and possible energy sources for an MMWD desalination facility.

Copies of the public outreach program materials are available on the District's website www.marinwater.org and are included in Appendix 5.

Section 3: Source Water Quality and Treatment Objectives

This section describes the San Francisco Bay source water quality data and the recommended treatment objectives for a future full-scale Seawater Desalination Plant. This section also summarizes current and anticipated Federal and California Department of Health Services (DHS) water-quality regulations.

3.1 San Francisco Bay Source Water

The source water for the MMWD Seawater Desalination Pilot Plant was the Northern San Francisco Bay water drawn from a screened intake located at the end of the pier at the Marin Rod and Gun Club. The Northern San Francisco Bay is a complex estuarine water body with influences from the Pacific Ocean, fresh water flow from the Sacramento Delta, local rivers, and bay discharges that affect water quality on a daily as well as a seasonal basis.

The United States Geological Survey (USGS) and the Romberg Tiburon Center (RTC) collect basic water-quality data at select locations in San Francisco Bay. The San Francisco Estuary Institute (SFEI) also collects water-quality data and its research of the occurrence of select non-regulated compounds within the San Francisco Bay provides historical data on these compounds. Technical Memorandum No. 6 in Appendix 1 summarizes collected historical source water quality for key parameters that could affect the operation of a full-scale desalination plant or the quality of the finished water quality produced by such a plant.

The general San Francisco Bay source water quality data and treatment objectives pertaining to the operation of the desalination treatment processes are described below. Section 5 discusses in more detail the occurrence of regulated and non-regulated drinking water constituents and their removal through the desalination treatment process.

3.1.1 Historical and Pilot Plant Source Water Quality

Table 3.1 below presents general and mineralogical water-quality data for typical Pacific Ocean water, historical maximum levels of constituents in Northern San Francisco Bay (Bay) water, and the water-quality of the Bay water that served as the source water to the pilot plant during the study period. As expected, the pilot plant source water parameters were lower than, but consistent with, Pacific Ocean water-quality parameters. A full-scale SWRO facility must be able to treat the worst-case (highest-salinity) San Francisco Bay water quality that would occur during a prolonged drought, and as represented by the historical maximum values in the table.

Table 3.1: Historical and Pilot Study Source Water Quality

Parameter	units	Typical Pacific Ocean Seawater[a]	Historical North San Francisco Bay Water Quality[b] Max.	Pilot Study Source Water (Bay Water) Quality[c] Avg.	Max.	Min.
TDS	mg/l	34,465	32,000	21,700	29,000	2,500
Conductivity	umhos/cm	–	48,000	39,200	43,500	5,000
Calcium	mg/l	400	371[d]	210	310	71
Magnesium	mg/l	1272	1,181[d]	755	910	580
Sodium	mg/l	10,560	9,805[d]	6,700	8,100	3,300
Potassium	mg/l	380	353[d]	262	350	190
Ammonia	mg/l	0.4	0.4	ND	ND	ND
Barium	mg/l	5	3	5.0	27	0.011
Strontium	mg/l	13	12[d]	2.63	5.9	.004
Bromide	mg/l	–	–	6.9	8.1	6.0
Bicarbonate	mg/l	142	110[d]	101	110	94
Temperature	°C	10	21.7	17	21	10
pH	units	8.2	8.19	7.9	8.3	7.6
Sulfate	mg/l	2,560	2,377[d]	1,533	1,900	1,000
Chloride	mg/l	18,980	17,620	11,000	15,000	2,100
Fluoride	mg/l	1.4	1.3[d]	0.682	0.79	0.5
Boron	mg/l	4.6	4.3[d]	2.3	3.3	1.7

Notes:
(a) From Van der Leeden, et al., 1990, The Water Encyclopedia.
(b) Historical North San Francisco Bay Water Quality Data: 1990 MMWD Pilot Study and USGS data.
(c) On-line and grab samples from March 2005 to April 2006.
(d) Value calculated by taking the ratio of analyte concentration to TDS concentration in typical seawater and multiplying it by the San Francisco Bay TDS historical maximum value for that analyte.

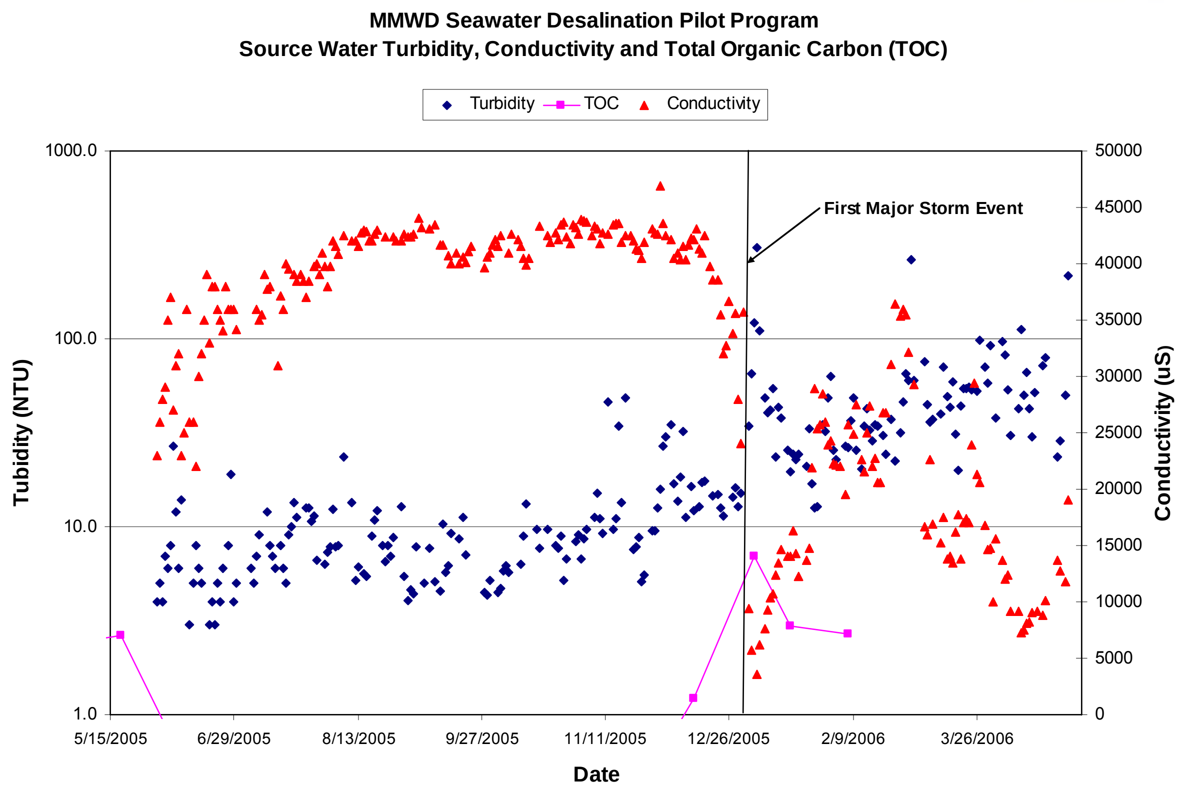
In addition to the source-water samples taken approximately every two weeks and analyzed at a laboratory, daily measurements of source water conductivity, pH, temperature and turbidity were made.

Figure 3.1 below shows the variability of turbidity, conductivity, and total organic carbon over the course of the study. The source water quality can be categorized according to two generally distinct periods: (1) a dry season characterized by higher salinity and lower levels of suspended solids and organics, and (2) a wet season characterized by lower salinity and higher levels of suspended solids and organics. Although not shown on the figure, the source water TOC levels from May to November 2005 were less than 0.5 mg/l.

Table 3.2 below presents the average, 10th percentile, and 95th percentile values of the daily source water quality parameters during the dry period of the pilot study, from May 2005 through November 2005. Several light to moderate rainfall events occurred in December 2005, and significant rainfall events occurred in January through mid April 2006.

Table 3.3 below presents the average, 10th percentile and 95th percentile values of the daily source water quality parameters during the wet period of the pilot study, from December 2005 through April 2006.

Figure 3.1: Source Water Turbidity, Conductivity and Total Organic Carbon



Note: TOC values in Figure 3.1 from June 2005 to December 2005 were approximately 0.5 mg/l.

Table 3.2: Dry Season (May to November 2005) Pilot Program Source Water Quality

Daily Parameters	Units	Average	10%	95%
Turbidity	NTU	8.9	4.5	14.9
pH	pH	7.9	7.7	8.1
Temperature	°C	17.9	15.2	21.4
Conductivity	uS	39,200	32,000	43,500
TDS	mg/l	21,800	17,800	24,200

Table 3.3: Wet Season (December 2005 to April 2006) Pilot Program Source Water Quality

Daily Parameters	Units	Average	10%	95%
Turbidity	NTU	42.2	14.4	93.8
pH	pH	7.5	7.2	7.8
Temperature	°C	12.1	10.8	13.5
Conductivity	uS	24,900	12,500	42,300
TDS	mg/l	13,800	6,900	23,500

Pilot data Figures 1.1 through 1.4 in Appendix 2 present the source water quality variation over the course of the pilot study for turbidity, conductivity, temperature, pH, boron, and TOC. These data are briefly described below.

3.1.1.1 Turbidity

The pilot operators measured source water turbidity using daily grab samples of the source water before the inlet tank and strainers. These measurements were compared with the readings from the on-line turbidimeters installed on the MF and UF units, which provided continuous monitoring of the source-water turbidity following screening. The daily grab samples were consistent with and used to confirm the on-line readings.

During the dry season, source water turbidity averaged approximately 9 NTU, with short-lived spikes up to 30 NTU due to windy and shallow conditions in the Bay. The source-water turbidity increased considerably with the rainy season as more solids were washed into the Bay from the Sacramento Delta as well as from local runoff. The storm conditions also stirred up Bay sediments. During the wet season, turbidity averaged approximately 42 NTU with short-lived spikes up over 200 NTU due to storm runoff conditions in the Bay.

3.1.1.2 Conductivity and TDS

Conductivity of the SWRO feedwater was measured with on-line instruments on the SWRO pilot units and recorded daily over the pilot study. Source-water conductivity was also measured on an hourly basis during several periods of the pilot program to evaluate variation with tides. The conductivity showed the most tidal variability in the periods when there was significant runoff out of the Delta. The tidal variation decreased through the summer dry period. Conductivity ranged from a low of 5 milliSiemens (mS) to 45 mS. The source water TDS was measured every two weeks in the lab and correlated to conductivity. The measured conductivity value was divided by the corresponding measured TDS value to determine a ratio between the two for calculation of daily source water TDS. The conductivity and TDS were fairly constant from August 2005 to early December 2005 and then dropped sharply with the first major storm of the wet season.

3.1.1.3 Temperature and pH

The pilot plant operators measured source water temperature and pH using daily grab samples of the source water before the inlet tank and strainers. Pilot data Figure 1.2 in Appendix 2 presents source-water temperature and pH during the pilot study. The source water temperature ranged from a minimum of approximately 10 degrees Celsius (°C) in December to a maximum of approximately 20°C in early August and showed typical daily variability, with the high temperatures occurring in the late afternoon and the low temperatures occurring just after midnight. The diurnal temperature variation was approximately 5 to 8°C. This temperature variation is partly due to the exposed piping of the pilot plant and would not be as pronounced in a full-scale facility. Source water pH ranged from near 7.0 to 8.1, with dry and wet season averages as shown above.

3.1.1.4 Boron

Boron in the Bay source water ranged from 1.5 to 3.3 mg/l. Pilot data Figure 1.3 in Appendix 2, shows that the boron levels generally track the source water TDS levels as expected. The source-water boron concentration is approximately 0.013% of the TDS concentration. This is slightly less than the 0.014% for typical seawater (Handbook of Chemistry and Physics, 61st edition). The highest boron concentration measured in the source water during the pilot study was 1.0 mg/l less than the maximum historical Bay water value (Table 3.1).

3.1.1.5 Organics

Pilot data Figure 1.4 in Appendix 2 presents source-water total organic carbon (TOC) during the pilot study. TOC in the source water decreased from 2.6 mg/l in May 2005 to approximately 0.5 mg/l to 0.6 mg/l through December 2005. TOC levels increased significantly to approximately 7 mg/l with the first major storm of the wet season, as high solids and organics were flushed into the Bay from local storm runoff as well as water coming from the Sacramento Delta. The TOC levels dropped after the main storm event and approached levels measured during the previous spring. Source water UV-254 measurements had a similar pattern to the source water TOC measurements.

The pilot plant did not experience any algae blooms that would cause an increase in source water TOC during the summer dry period; however, data from the Carlsbad, California, SWRO pilot study indicate that the levels of organics associated with an algae bloom could be similar to the period of high organics levels that occurred during the first large storm flush – between 5 and 10 mg/l. The Carlsbad study experienced a red tide event that caused high source-water TOC levels. It then later also experienced a similar large storm event, which flushed a large amount of suspended solids and organics into the source water for that pilot plant. The Carlsbad pilot operator reported that the measured TOC and the response of the Carlsbad pilot systems for the two events were similar. The impact of high organics levels and methods to address this are covered in Section 8 and 9 of the report.

3.2 Characterization of San Francisco Bay Source Water Bacteriological Quality and Log Removal Requirements

The project team met with DHS to discuss the potential treatment requirements for a full-scale desalination facility treating water from Northern San Francisco Bay. The DHS requested an evaluation of the Total Coliform levels in the Bay source water to determine the level of treatment that would be required for the Bay to be an approved source. This section reviews the DHS coliform requirements, and summarizes the Total Coliform data obtained during the pilot study.

The California DHS Office of Drinking Water, Surface Water Treatment Staff Guidance Manual, Appendix B, provides guidelines for determining when surface waters will require more than the typical minimum levels of treatment defined in the surface water treatment regulations. Table 3.4 shows the treatment requirements based on the Total Coliform concentrations in the source water. Total Coliform, though not specifically a pathogen, can be easily measured and is thus used as an indicator to quantify the potential for microbiological contamination.

Table 3.4: DHS Treatment Requirements for Surface Waters

Total Coliform Concentration in Source Water[a] (Median Monthly MPN/100 ml)	*Giardia* Cyst Treatment Requirement (Log removal / inactivation)	Virus Treatment Requirement (Log removal / inactivation)
< 1,000	3	4
> 1,000 – 10,000	4	5
> 10,000 – 100,000	5	6

Notes:
(a) Most probable number (MPN), per Standard Method #9221.
(b) From DHS Surface Water Treatment Staff Guidance Manual, Appendix B, Tables 1 and 2.

The minimum treatment requirements of the Surface Water Treatment Rule are 3-log *Giardia* removal/inactivation and 4-log virus removal/inactivation. If the median Total Coliform concentration in the source water is greater than 1,000 MPN/100 ml, this indicates an increased risk for the presence of significantly more pathogenic organisms in the source water than water treatment facilities are typically designed to remove. Therefore, the poor-quality source water would require greater levels of treatment than would be required for higher-quality source water.

3.2.1 San Francisco Bay Source Coliform Data

MMWD Staff measured Total Coliform in the Bay source water to the pilot plant as directed by DHS, approximately every two weeks over the course of the pilot study. As shown in Table 3.5 below, the overall bacteriological quality of the Bay water with respect to Total Coliform was low, with the source median monthly Total Coliform levels consistently in the range of less than 1,000 MPN/100 ml. Therefore, it is anticipated that DHS will only require treatment of the Bay water to achieve are 3-log *Giardia* and 4-log virus removal/inactivation. The desalination plant treatment processes, including disinfection, are expected to readily meet the DHS required log removal /inactivation criteria.

Table 3.5: SF Bay Monthly Median Coliform Levels

Month	Total Coliform Concentration in Source Water (Median Monthly MPN/100 ml)
July, 2005	2
August, 2005	2
September, 2005	2
October, 2005	2
November, 2005	5
December, 2005	60
January, 2006	160
February, 2006	30

3.2.2 San Francisco Bay Source VBNC Bacteria Data

In seawater, a percentage of bacteria may be viable but not culturable on standard marine agar (marine heterotrophic plate counting) (Bogosian, 2001). These “non-culturable” bacteria, called “viable but non culturable” (VBNC), can potentially cause fouling of cartridge filters and seawater RO systems when they are activated by changing hydrodynamic conditions within these two processes (Winters, 2006). VBNC bacteria, which can be as small as 0.2-um in diameter, are measured and enumerated through epifluorescence microscopy (EFM) analysis with DAPI (cell staining).

Samples of the Bay source water, along with samples at critical points in each pilot train were collected on 14 February 2006 and analyzed by epifluorescence microscopy (EFM) and heterotrophic plate counts (HPC) techniques at EMSL Analytical, Westmont, New Jersey. A second set of samples were taken on 20 April 2006 and analyzed by EFM and HPC techniques at BioVir Laboratories, Benicia, California. There was concern that the time for shipping the samples to New Jersey led to increased bacterial counts over what was actually present in the water at sample time.

Table 3.6 presents the results of the VBNC bacteria analysis for the source water and for a number of locations through the treatment process. Table 3.7 presents VBNC bacteria size enumeration in the sample after the 5 micron cartridge filters of the SWRO pilot units.

Table 3.6: VBNC Bacteria Data

Sample Point	HPC (CFU/ml)		Viable Bacteria (#/ml)		Nonviable Bacteria (#/ml)		Total (#/ml)	
Laboratory	EMSL	BioVir	EMSL	BioVir	EMSL	BioVir	EMSL	BioVir
Source water	>30,000	6000	1.02E+06	5.50E+05	7.70E+05	1.30E+06	1.79E+06	1.85E+06
MF Filtrate	>30,000	2.00E+05	8.70E+05	5.50E+03	1.24E+06	<450 (ND)	2.11E+06	5.50E+03
UF Filtrate	Speaders	1400	1.19E+06	1.20E+06	9.40E+05	<4.5E+03 (ND)	2.13E+06	1.20E+06
Conventional Filtrate	5400	420	1.15E+06	6.90E+05	1.02E+06	4.60E+04	2.17E+06	7.36E+05
Before MF/UF SWRO Cartridge	3000	~1 E+06 (Spreaders)	1.34E+06	1.20E+06	1.14E+06	9.20E+04	2.48E+06	1.29E+06
Before Conv. SWRO Cartridge	>30,000	1000	1.24E+06	1.60E+06	1.13E+06	<4.5E+04 (ND)	2.37E+06	1.60E+06
After MF/UF SWRO Cartridge	Spreaders	3.90E+04	7.80E+05	6.40E+05	9.00E+05	<4.5E+04 (ND)	1.68E+06	6.40E+05
After Conv. SWRO Cartridge	200	390	8.30E+05	3.30E+04	9.30E+05	1.40E+03	1.76E+06	3.44E+04

Table 3.7: VBNC Bacteria Size Data After Cartridge Filtration

Sample Point	EMSL Sizing (um)	BioVir Sizing (um)			
		<0.5	0.5< and <1.0	1.0< and <3.0	>3.0
After MF/UF SWRO Cartridge	Ave 1.5-2.0	27.5	69.6	3.9	0
After Conv. SWRO Cartridge	Ave 1.5-2.0	46.4	48.2	5.4	0

The project team communicated with Dr. Harvey Winters, a Professor Emeritus of Biological Sciences at Fairleigh Dickenson University on the results of the VBNC sampling and the impact to operations of the pilot. In discussions with Dr. Winters, the levels of VBNC bacteria in the Bay source water are higher than are generally seen in a typical seawater. This could be due to the fact that the Bay is an estuary with a mix of seawater, fresh water from the Sacramento Delta and fresh water from local runoff. The sample periods also coincided with periods of lower salinity and higher organics and suspended solids in the Bay. The levels of VBNC bacteria also are not consistent and do not appear to change throughout the treatment process as would be expected. Since the pilot treatment processes were not (and the full scale processes will not be) sterile, this could indicate that bacteria have colonized in the treatment process tanks and piping. The size range of the VBNC after the cartridge filters are consistent with the nominal level of removal of the 5 micron cartridge filters. The measured VBNC did not adversely impact the operations of the pilot treatment processes in terms of system fouling as discussed in Section 6 of this report and in the Appendix.

3.3 Overall Finished Water Objectives

The overall finished water quality objectives for a future, full-scale Seawater Desalination Plant are to provide water that:

- Meets or exceeds state and federal water-quality requirements.
- Meets or exceeds MMWD's additional and more stringent water-quality objectives.
- Tastes as good as or better than MMWD's current water supplies.
- Is stable and similar to MMWD's current water supplies in terms of corrosivity.

3.3.1 Proposed Finished Water Quality Objectives

The proposed water-quality objectives for the MMWD pilot plant program and full-scale desalination facility finished water are shown in Table 3.8 below. Table 3.8 also lists important water quality parameters of MMWD's current water sources and the objectives of the MMWD Desalination Plant finished water. These values were used to evaluate the performance of the first-pass SWRO system and to determine the extent of first-pass permeate that would need to be treated by a second-pass brackish water RO (BWRO) system. The table also lists corrosion control parameter objectives for the finished water; these were used to evaluate post-treatment processes for water stabilization. Finished water-quality objectives are discussed further in Technical Memorandum No. 7 in Appendix 1.

Table 3.8: Proposed Finished Water Quality Objectives for the MMWD Desalination Plant

		MMWD Treated Reservoir			Sonoma County Water			Desalination Plant Finished Water Quality Objectives		
Parameter	**units**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**
TDS	mg/l	119	136	86	171	186	148	120	180	60
Hardness	mg/l	62	74	52	105	112	96	60	110	50
Alkalinity	mg/l	61	70	49	119	125	110	60	110	50
pH	units	7.8	7.9	7.8	8.1	8.4	7.8	7.9	8.4	7.8
Color	CU	<3	<3	<3	<3	<3	<3	<3	<3	–
TOC	mg/l	1.6	2.4	1.1	0.9	1.2	0.7	<1	1	–
Sodium	mg/l	16	25	11	20	23	16	30	50	10
Chloride	mg/l	27	37	22	8	10	7	50	70	10
Boron	mg/l	<0.05	<0.05	<0.05	0.28	0.26	0.16	0.5	1	–
LSI	–	-0.94	-0.64	-1.29	0.11	0.42	-0.14	0	0.5	-0.5
RI	–	–	–	–	–	–	–	7	8	6
AI	–	11	11.3	10.8	12	12.2	11.8	11.5	12	11
LNI	–	–	–	–	–	–	–	0.3	0.4	0.25

Notes:

(a) Corrosion quarterly data from 2000-2004 (pH, LSI, AI).
(b) WQ Parameter quarterly data from 2000-2004 for treated reservoir (n=32).
(c) WQ Parameter quarterly data from 2002-2004 for SCWA (n=6).
(d) Chloride and TOC values from post ferric chloride changeover.
(e) Langlier Saturation Index (LSI); Ryzner Index (RI).
(f) Aggressiveness Index (AI); Larsen Index (LNI).

The proposed general water-quality objectives for the pilot plant program and full-scale Desalination Plant finished water fall within the range of the water quality parameters for MMWD's current treated reservoir water supply and the imported water from Sonoma County. The total dissolved solids, hardness, alkalinity, color, pH, and corrosion index parameter objectives are based on the goal of providing finished water similar to MMWD's current water supplies with respect to these aesthetic and corrosivity indices.

3.3.1.1 Sodium and Boron Objectives

The finished water objectives for sodium of less than 50 mg/l is based on the goal of providing finished water with sodium values close to that of MMWD's current water supply and which conforms to the characteristics of what is typically called "low-sodium water."

The present California Drinking Water Action Level for boron is 1 mg/l. Because of the interest in seawater as a potential new drinking water source, legislation is pending that would allow the California DHS to start the process of establishing a public health goal (PHG) and/or maximum contaminant level (MCL) for boron in drinking water. The World Health Organization

(WHO) recommended a guideline level of 0.5 mg/l for boron in 1998 but is currently evaluating raising the level to 1 mg/l.

The finished water boron objective shown in Table 3.5, although higher than that for MMWD's current supplies, is well below the DHS action level goal of 1 mg/l during average conditions and meets DHS goals in a drought. This boron objective is based on the District's desire to provide a finished water that meets or exceeds anticipated DHS regulations and that is close to the quality of existing sources. The first pass SWRO system would typically meet the lower boron objectives under average SF Bay water conditions. In drought conditions, the pH of the source water could be adjusted with caustic soda to increase the boron removal of the first pass SWRO process. This is described in more detail in Section 4.

3.3.2 Federal and State Treatment Objectives

Table 3.9 summarizes current and upcoming drinking-water regulations that would be applicable to a full-scale desalination plant. It is anticipated that the finished water from a future full-scale SWRO desalination plant using either MF/UF or conventional pretreatment, followed by SWRO, would fully comply with these regulations.

Table 3.9: Overview of Federal and State Drinking Water Requirements

Regulation	Promulgation Date	Compliance Date	Requirements/Comments	
Surface Water Treatment Rule (SWTR)	1989	Effective	3-log (99.9%) removal/inactivation of *Giardia*;	
			4-log (99.99%) removal/inactivation of virus.	
			0.5 NTU CFE 95% of the time.	
			CA DHS 0.2 NTU CFE 95% of the time (1994)	
			At no time exceed 5 NTU.	
Long-term 1 Enhanced Surface Water Treatment Rule (LT1 ESWTR)	Jan. 2002	Effective	2-log (99%) removal goal for *Cryptosporidium* oocysts.	
			TTHM and HAA5 monitoring, or Disinfection Profile.	
			Conventional & Direct Filtration	0.3 NTU CFE 95% of the time.
				At no time exceed 1 NTU.
			Contact Clarification Filtration	CA DHS requires 0.2 NTU individual filter effluent and CFE 95% of the time.
			Membrane Filtration	CA DHS requires 0.1 NTU individual filter effluent and CFE 95% of the time.
Long-term 2 Enhanced Surface Water Treatment Rule (L2 ESWTR)	Dec. 2005	2012	Source Water *Cryptosporidium* Sampling Program Source Water Specific Risk Bins Microbial Tool Box Requirements	
			CA DHS possible 0.1 NTU CFE 95% of the time	
			Unfiltered Systems must provide 2-log Crypto inactivation	

Regulation	Promulgation Date	Compliance Date	Requirements/Comments
Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR)	Dec. 1998	Effective	MCLs: TTHM = 0.080 mg/l (RAA); HAA5 = 0.060 mg/l (RAA); Bromate = 0.010 mg/l MRDLs: Chlorine & Chloramines = 4.0 mg/l For conventional systems only, Enhanced Coagulation for TOC removal (DBP precursor) depending on TOC and alkalinity.
Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 D/DBPR)	Dec. 2005	2012	MCLs: TTHM = 0.080 mg/l; HAA5 = 0.060 mg/l MRDLs: Chlorine & Chloramines = 4.0 mg/l TOC reduction applies to all Systems. THM and HHA5 values are for specific locations (LRAA), as well as averaged over whole system (SRAA).
Total Coliform Rule (TCR)	1989	Effective	Distribution system monitoring; 0.05 mg/l distribution system disinfectant residual in 95% of samples
Lead and Copper Rule (LCR)	1991	Effective	ALs for Copper = 1.3 mg/l; Lead = 0.015 mg/l.
Filter Backwash Rule (FBR)	Jun. 2001	Effective	Spent washwater that is recycled must be returned to the head of the plant (prior to the point of coagulation).
Arsenic Rule	Jan. 2001	Effective	MCL = 10 ppb
Fluoridation Rule	1995	Effective	Optimal Level of Fluoride = 0.7 - 1.3 mg/l
Radionuclides Rule	Dec. 2000	Effective	MCLs for Gross Alpha Particle = 15 pCi/L; Combined radium 226/228 = 5 pCi/L; Uranium = 30 ug/L; Beta/Photon emitters = 4 mrem/yr.

References:

Bogosian, Gregg, Bourneuf, Edward, 2001, *A Matter of Bacterial Life and Death,* EMBO Reports, 2,9,770.

Winters, Harvey, 2006, *Use of a Novel Flow Distributor and EMF in Seawater Reverse Osmosis to Prevent Membrane Fouling,* EUROMED Conference Proceedings.

Section 4: Finished Water Quality from Desalination Pilot Program

This section describes the predicted finished water quality from a full-scale MMWD desalination facility based on the results of the pilot program. This section also describes the results of water corrosivity studies performed on the pilot plant desalinated water, MMWD's treated reservoir water, and MMWD's imported treated water.

4.1 First-Pass SWRO Water Quality Results

The measured and predicted general water quality of the permeate from the first-pass SWRO system and a potential second-pass RO system are described in detail in Technical Memorandum No. 7 in Appendix 1. This section summarizes the information developed and presented in the Memorandum for the first-pass system. Section 4.2 summarizes the information in the Memorandum for the second-pass system. Section 5 also describes the quality of the SWRO permeate, in terms of regulated and non-regulated constituents that were measured during the pilot program.

Table 4.1 presents the predicted quality of first pass SWRO permeate from a full-scale facility operating with the San Francisco Bay water at the historical maximum water-quality levels and with the average dry-period Bay water quality during the pilot program. The permeate quality is an average of the predicted water quality from the three different first-pass SWRO membranes elements tested at the pilot plant. The respective manufacturers' membrane performance models were used to predict permeate quality for a full-scale system. The following worst-case parameters were used in the membrane performance models:

- 50% recovery
- 10 gallons per square foot per day (gfd) flux
- Single pass
- 8-inch SWRO elements
- Single-stage system, six elements per vessel
- End of membrane life (5-year life assumed)
- Maximum water temperature (21°C)

Based on the predicted single-pass SWRO permeate water quality described in Table 4.1, the membrane performance models indicated that a full-scale desalination facility may need partial second-pass RO treatment of the first pass permeate to reduce TDS, sodium and chloride levels to meet the water-quality objectives (maximum values) during a severe drought period. See Section 3 for a discussion on the finished water quality objectives. However, since the TDS, sodium and chloride levels in a drought would still be within state and federal drinking water requirements, the second pass RO would be optional.

Table 4.1: Full-Scale System Predicted Permeate Quality – Single-Pass SWRO Treatment

		Finished Water Objectives		Drought Conditions Permeate Quality[(a)]	Average Conditions Permeate Quality[(b)]
Parameter	**units**	**Avg.**	**Max.**		
TDS	mg/l	120	180	170	100
Conductivity	umhos/cm	–	–	NA	NA
Calcium	mg/l	20	30	0.43	0.25
Magnesium	mg/l	–	–	1.4	0.87
Sodium	mg/l	30	50	60	35
Potassium	mg/l	–	–	2.2	1.5
Bicarbonate	mg/l	60	110	1.2	0.86
Temperature	°C	–	–	NA	NA
pH	units	8	8.2	6.4	6.0
Sulfate	mg/l	–	–	1.11	0.7
Chloride	mg/l	50	70	100	56
Fluoride	mg/l	–	–	0.01	0.00
Boron	mg/l	0.5	1	1	0.5

Notes:

(a) Predicted first pass permeate quality based historical maximum drought water-quality levels for Bay source water shown in Table 3.1.

(b) Predicted first pass permeate quality based on average pilot program water-quality levels for feed water shown in Table 3.1.

4.2 Second-Pass RO Water-Quality Results

During wet season and average dry season Bay water conditions, the MMWD desalination facility would not need to operate a second-pass RO system to meet the water-quality objectives. MMWD could elect to provide optional second-pass RO treatment of the first-pass SWRO permeate during a drought period to meet the more stringent treated water-quality objectives for TDS, sodium, chloride.

The feed water to the first pass SWRO or second-pass RO could also be conditioned to raise the pH and provide additional removal of boron. Table 4.2 presents the projected boron removal for a second-pass RO system treating first-pass SWRO permeate given the historical maximum levels of San Francisco Bay water quality with a pH of 9.0, 9.5, and 10.0. The following worst-case parameters were used in the second-pass membrane performance model:

- 90% recovery
- 16 gfd flux
- 8-inch BWRO elements
- Three-stage system with six elements per vessel
- End of membrane life (5-year life assumed)
- Maximum water temperature (21°C)

Table 4.2: Projected Boron Removal by Optional Second-Pass RO system

Feed Water pH	Estimated Sodium Hydroxide Dose (mg/l)	Predicted Average Second-pass RO Boron Removal
9.0	1.5	50%
9.5	2.4	70%
10.0	4.9	80%

The approach to providing lower boron levels in the finished water, if needed, with average and worst-case maximum water-quality levels could be to combine pH adjustment and blending of second-pass and first-pass permeate. For example, with a 2:1 ratio of second-pass permeate to first-pass permeate, during average water-quality conditions, the boron objective could be met with minimal pH adjustment. As the feed water boron levels increase, the feed water pH to the second-pass RO could be increased up to 10 to maintain boron levels in the finished water below the target. To meet more stringent MMWD finished water quality goals during drought conditions, a 2:1 blending ratio of second-pass permeate to first-pass permeate could be used along with pH adjustment for the second-pass RO. Table 4.3 below presents the predicted finished water quality with the optional second pass RO permeate blending.

As advances are made in the ability of first-pass SWRO membrane elements to reject boron, the first pass SWRO system may provide better water quality than demonstrated during the pilot. Also, ongoing research (Lozier, et al, 2006) is studying pH adjustment of the feed water to first-pass SWRO systems to improve boron removal without long-term scaling of the SWRO membranes. These potential advances are discussed with regard to a full-scale facility in Section 9 of this report. The design of an optional second pass RO system is provided in Section 9 in case MMWD elects to include this in the overall project.

4.3 Post-Treatment Stabilization

The permeate from the SWRO system (treated by either single-pass or both first-pass and second-pass) will need to be stabilized by increasing the hardness, alkalinity, and pH of the finished water to match those of the current MMWD water sources.

Table 4.3 presents the predicted water-quality parameters of the MMWD Desalination Facility water stabilized with the addition of calcite or lime and carbon dioxide (CO_2). This approach adds hardness and alkalinity to the permeate to increase the pH of the finished water while minimizing the addition of sodium and other ions that would increase TDS and contribute to corrosivity. The water quality was modeled using the American Water Works Association (AWWA) Rothenberg, Tamburini & Windsor (RTW) Model for Corrosion Control and Process Chemistry. To ensure corrosion control for the “worst-case” desalinated product water, the model assumed a blend of approximately 33% first-pass permeate and 67% second-pass permeate. The second-pass RO was modeled as operating with a source water pH of 10, for enhanced boron removal during maximum drought conditions. The modeled permeate quality is based on the averaged water quality from Hydranautics and Dow/Filmtec first-pass and second-pass membrane elements.

Table 4.3: Predicted Full-Scale System Finished Water Quality

		Desal Finished Water Objectives			Stabilized First- Pass and Optional Second-pass RO Permeate Blend Quality	
Parameter	**units**	**Avg.**	**Max.**	**Min.**	**During a Drought**	**During Average Conditions**
Carbon Dioxide added	*mg/l*				*87*[(a)]	*59*[(a)]
Lime (slaked) added	*mg/l*				*73*[(a)]	*50*[(a)]
TDS	mg/l	120	180	60	142	95
Hardness	mg/l, as $CaCO_3$	60	110	50	96	68
Alkalinity	mg/l, as $CaCO_3$	60	110	50	94	67
pH	units	7.9	8.2	7.8	7.8	8.1
Color	CU	<3	<3	–	<1	<1
TOC	mg/l	<1	1	–	<1	<1
Sodium	mg/l	30	50	10	21	13
Chloride	mg/l	50	70	10	34	20
Boron	mg/l	0.5	1	–	0.5	0.2
LSI	–	0	0.5	-0.5	0.4	0.2
RI	–	7	8	6	7.4	7.9
AI	–	11.5	12	11	12.2	11.9
LNI	–	0.3	0.4	0.25	0.35	0.31

Notes
(a) Dose

The modeled finished water quality meets the finished water quality objectives and is relatively close to the water quality of MMWD's existing sources. The modeled finished water quality was based on the following assumptions:

- First-pass SWRO at end of membrane life (5 years)
- Second-pass RO with increased pH to enhance boron removal (pH 9 to 10)
- 2:1 blend of second-pass RO permeate with first-pass SWRO permeate
- Addition of approximately 50 to 75 mg/l of calcite/lime
- Addition of approximately 60 to 85 mg/l of carbon dioxide (CO_2)

MMWD currently adds a corrosion inhibitor to its reservoir water supply. It is recommended that MMWD add a corrosion inhibitor to the desalination plant water also.

4.4 Comparative Corrosion Testing

This section summarizes the protocol and results of a laboratory study conducted to assess the relative corrosivity of chemically conditioned desalinated water, MMWD treated reservoir water, and imported Sonoma water, conducted as part of the pilot program. Technical Memorandum No. 14 in Appendix 1 discusses the corrosivity testing protocol and results in more detail.

Corrosion control is an important element in the design of a SWRO facility. The desalination process significantly lowers the mineral content in the permeate and can produce water corrosive to both metals and cementatious materials in the distribution system if the water is not properly stabilized. Proper stabilization and corrosion control are important for the following reasons:

- Health effects – Compliance with the Lead and Copper Rule (LCR) of the Federal and State Safe Drinking Water Act Regulations
- Aesthetic – Prevention of discoloration of distributed water primarily related to leaching of iron from distribution pipes, causing red water, or of copper laterals and consumer plumbing systems, causing blue water and sometimes a metallic taste to the water
- Economic – Prevention of accelerated corrosion and pitting of iron and steel distribution pipes or storage tanks, and pitting of copper piping of consumer systems, and increased interior roughness, causing capacity loss or higher pumping costs
- Environmental – Minimization of metals in wastewater discharged to Marin wastewater treatment plants, with subsequent discharge to the San Francisco Bay, from corrosion and leaching of copper, lead, nickel, chromium, etc., primarily from consumer plumbing systems

MMWD has had an ongoing and effective corrosion control program for many years addressing internal and external corrosion of distribution piping, tanks, etc., as well as consumer plumbing systems. This is achieved by both pH adjustment and addition of a zinc orthophosphate corrosion inhibitor to the treated or delivered water.

4.4.1 Linear Polarization Corrosion Testing

The three source waters were all tested for corrosivity to steel, copper, and lead by a linear polarization pipe loop test assembly beginning in April 2006 and extending into June 2006. The testing consisted of circulating a 20-gallon water sample of each supply through a pipe loop. The pipe loop had linear polarization electrode assemblies of steel, lead, and copper. Each electrode assembly had three probes for increased accuracy. The electrodes were arranged in this order: first, steel, copper, and then lead, as would be typical of sequential exposure in distribution and plumbing systems.

The water was circulated for a week to provide an initial passivation of the test loop. Then linear polarization readings of cathodic and anodic corrosion rates were taken at intervals during the second week of testing. The linear polarization readings provide a relative degree of corrosivity of the desalinated water compared to the current MMWD water sources. This method of real-time corrosion assessment is now extensively used in water system corrosion evaluations.

Table 4.4 below presents the measured water quality and calculated corrosion indexes for the desalinated water, treated reservoir water and Sonoma water samples used for corrosion testing. The quality of the chemically conditioned desalinated water from the pilot plant was in the range expected for a full-scale facility. The Langlier Saturation Index was slightly below -0.5 but in the range of MMWD's current water supplies.

Table 4.4: Characteristics of Water Samples for Linear Polarization Corrosion Testing

Characteristic	Units	Desal Water[(a)]	MMWD Reservoir Water[(b)]	Sonoma Water[(c)]
General				
Temperature	°C	10	10	10
pH	units	7.70	7.81	8.24
Total Dissolved Solids	mg/l	140	120	180
Total Hardness	mg/l $CaCO_3$	55	62	59
Total Alkalinity	mg/l $CaCO_3$	65	59	148
Cations				
Calcium	mg/l	22	9.3	24
Magnesium	mg/l	< 0.1	9.4	-
Sodium	mg/l	35	22	25
Anions				
Bicarbonate	mg/l	79	72	180
Chloride	mg/l	36	28	8.3
Sulfate	mg/l	8.2	7.5	13
Corrosion Indices				
pH $CaCO_3$ Saturation	pHs	8.46	8.87	8.07
Langelier Saturation Index	LSI	-0.51	-1.06	+0.17
Ryznar Index	RI	8.72	9.93	8.10
Aggressive Index	AI	11.12	10.95	12.13
Larson Index	LI	0.91	0.80	0.17
SO_4/CL Ratio	Ratio	0.16	0.20	1.17
Copper Pitting Propensity[(6)]	CPP	0	+2	-1
Sampled		4/19/06	5/12/06	6/7/06

Notes:
(a) Conditioned RO permeate from the MMWD desalination pilot plant.
(b) Reservoir water treated at San Geronimo WTP.
(c) Ignacio Pump Station treated water.
(d) Before corrosion pipe loop testing.
(e) After 14 days of corrosion pipe loop testing.
(f) (Cruse 1985).

The results of the linear polarization corrosion testing are presented in Table 4.5 below. For each finished water, the table presents the overall corrosion rate for the three electrodes at 7, 10, and 14 days, as well as the less accurate but comparative two-electrode pitting rate and pitting index at 14 days. The 14-day testing was of sufficient duration for this comparative analysis given the relatively stable corrosion rates for the metals after 14 days. The table also describes the corrosion type and relative corrosion rating.

Table 4.5: Water Corrosivity Evaluation by Linear Polarization Analysis

	Corrosion Rate[b] – mils per year (mpy)						
Material	**7 days**	**10 days**	**14 days**	**Pitting Rate[c] (mpy)**	**Pitting Index[d]**	**Probe Appearance**	**Corrosivity Type[e] and Rating[f]**
1. Test 1: Desalinated Water							
Steel	11.25	9.90	9.70	44.85	1.1	Orange red with dark brown tubercles	Low – pitting and tubercles
Copper	0.04	0.01	0.01	0.45	0.8	Slight tan burnish (Cu_2O)	Very low – uniform
Lead	0.44	0.20	0.56	13.0	2.2	Grey adherent scale	Moderate- pitting
2. Test 2: Reservoir Source							
Steel	6.52	7.12	7.26	30.6	1.1	Brown scale with tubercles	Low – pitting and tubercles
Copper	0.015	0.075	0.05	0.085	0.8	Tan burnish	Low – uniform
Lead	0.67	0.55	0.75	7.00	1.3	Grey adherent scale	Moderate – pitting
3. Test 3: Russian River Source							
Steel	9.55	10.70	9.87	42.85	1.1	Orange brown scale with tubercles	Low – pitting and tubercles
Copper	0.05	0.01	0.015	0.10	0.4	Tan burnish	Very low – uniform
Lead	1.31	1.07	1.10	11.75	0.9	Dark grey adherent scale	Moderately high pitting

Notes:
(a) Metal Products, Inc. MS1500L LPR Data Logger
(b) Average of cathodic and anodic LPR of 3rd and last reading
(c) Pitting rate 2-electrode probe after 1 minute – 14 days exposure
(d) Pitting index of 2-electrode probe analysis – 14 days exposure
(e) Corrosivity Type – Uniform or pitting basins on pitting index <1 uniform and >1 increasingly pitting
(f) Corrosivity Rating – Steel: 5 to 10 mpy loop, 10 to 20 mpy moderate, > 20 mpy, heavy; copper: very low <0.1 mpy, low 0.1 – 0.2 mpy; lead: low 0.1 – 0.5 mpy, moderate 0.5 – 1 mpy, heavy >1 mpy; (Bradford 2002)

Observations on the comparative corrosion of the three finished waters based on the linear polarization corrosion testing include the following:

1. The steel corrosion rates were all relatively uniform and relatively low for the three water sources. The corrosion rates for the desalinated and Sonoma Water sources were nearly the same, while that for the MMWD Reservoir was somewhat less.

2. The corrosion iron rust deposits were orange-colored geothite (FeOOH) with darker tubercles of magnetite (Fe_3O_4).

3. The predominant type of corrosion of steel was pitting and tubercle formation. Photographs are included in Technical Memorandum 14 in Appendix 1.

4. The copper corrosion rates resulting from all three water sources were very low. Corrosion tended to be uniform, producing a slight burnish of cuprite scale (Cu_2O).

5. The measured 14-day copper corrosion rate of the desalinated water was lower than that produced by the other water sources. The 14-day pitting index for the desalinated water was similar to the Reservoir Water. While the two-probe pitting rate was higher, this is a less accurate measure of pitting. The appearance of all of the copper probes was approximately the same for all three waters

6. Lead corrosion rates for desalinated water were significantly lower than for the MMWD Reservoir or Sonoma Water source waters, although the desalinated water had the highest pitting rate and pitting index.

7. There was an adherent gray scale, which is probably a complex combination of lead carbonate, lead oxicle, and possibly lead phosphate. The fact that it is an adherent scale, however, would tend to lessen the concern about lead particulate sloughing from lead soldered pipes or brass fixtures.

8. The appearance of all of the lead probes was approximately the same for all three waters.

4.4.2 Conclusions from Comparative Corrosion Testing

The overall conclusions about the comparative corrosion of the three finished waters based on the linear polarization corrosion testing include:

1. The linear polarization corrosion pipe loop testing for steel, copper, and lead indicated that properly conditioned desalinated water would likely be no more corrosive than existing MMWD sources or Sonoma water supplies.

2. Copper corrosion was very low and uniform with all water sources.

3. Lead corrosion was also low, and adherent protective films developed with all sources.

4. Steel corrosion was moderately low. The conditioned desalinated water appears no worse than the current supplies and should not aggravate existing corrosion rates or pipe scales; however, on start up of a full scale facility, it is recommended to slowly introduce the desalinated water source into the distribution system to minimize any adverse effects.

In summary, the conditioned desalinated water appears no worse than the current water supplies and is unlikely to aggravate existing corrosion rates or pipes scales; however, on startup of a full-scale facility, it is recommended that the desalinated water source be slowly introduced into the distribution system to minimize any adverse effects.

References:

Lozier, J., Huehmer, R., 2006, *Optimizing Boron Rejection of Seawater Reverse Osmosis Membranes through Feedwater pH Adjustment,* AMTA Conference Proceedings, 2006.

Section 5: Drinking Water Quality Analysis

This section briefly describes the design, implementation and results of the Water Quality Sampling and Analysis Program (SAP) that was conducted as part of the MMWD Seawater Desalination Pilot Program. The SAP is described in detail in Technical Memorandum No. 6 and the results are presented below and in Technical Memorandum No. 12. Both technical memoranda are located in Appendix 1. This section focuses on regulated and non-regulated drinking water related analyses. Additional process related water analysis and finished water quality analyses are summarized and discussed in Sections 3 and 4.

5.1 Sampling and Analysis Program (SAP)

The SAP was designed to obtain the most thorough and accurate water quality characterization of the source and treated water possible, within the analytical budget of the project. To this end, a comprehensive list of Regulated and Voluntary (Non-Regulated) constituents was monitored over a 12-month period. Sampling began in March 2005 on the source water before the pilot was fully operational and was completed in March 2006 shortly before shut down of the pilot plant.

The primary goals of the SAP were to:

1. Characterize the source water quality;

2. Verify that the Pilot Plant was operating as designed; and

3. Determine if the water quality of the product water (RO permeate) met the District's stringent water quality goals.

Additional goals included permit compliance of liquid and solids waste streams, monitoring post-treatment stabilization, and design and review of bioassay studies performed on the brine generated during treatment. The results of this work are described in Section 7 of the report.

The SAP was modeled after the extensive drinking water characterization program performed by the District on their current source and treated waters. The District has very stringent water quality goals and they routinely, voluntarily monitor approximately 220 non-regulated constituents in addition to the mandatory regulated constituents and the non-regulated constituents that require monitoring by State or Federal agencies. The SAP included these constituents and also included more voluntary non-regulated constituents that were chosen due to the historical water quality of Northern San Francisco Bay (Bay). In addition, the SAP included ultra low-level analyses to test the efficacy of desalination treatment to remove contaminants in the Bay source water.

The SAP Constituents Requiring Monitoring included:

- Organic compounds with federally mandated maximum contaminant levels (MCLs)
- Inorganic ions or compounds with MCLs
- Disinfection-By-Products (DBPs)

- Radionuclides
- Non-Regulated Compounds Requiring Monitoring by Federal or California agencies

The SAP Voluntary (Non-Regulated) Constituents included:

- Organic pesticides, herbicides, and industrial chemicals
- Synthetic or natural hormones
- Phenolics
- Pharmaceuticals and Personal Care Products
- Flame Retardants - Polybrominated diphenyl ethers (PBDEs)
- Polychlorinated biphenyls (PCBs)
- E-Screen Assay estrogenicity test

Analytical laboratories were selected to perform the analyses described in the SAP based upon the following criteria:

1. Current State certification was necessary for laboratories performing regulated constituents or non-regulated constituents requiring monitoring.

2. Standard or EPA approved analytical methods were performed, if available.

3. Lowest possible minimum reporting limits while maintaining a rigorous quality assurance program.

4. Approval of the analytical laboratory by the District.

Six laboratories were chosen to perform the SAP analyses:

- Environmental Health Laboratories/Underwriters Laboratories (EHL)
- Caltest Analytical Laboratory (Caltest)
- Sequoia Analytical (Sequoia)
- Axys Analytical Services (Axys)
- Southern Nevada Water Authority (SNWA)
- Wisconsin State Laboratory of Hygiene (WSLH)

EHL performed the majority of the regulated analyses and Caltest and Sequoia performed a small amount of analyses that EHL was not equipped to perform. Axys performed the ultra low-level analysis of PCBs and PBDEs and SNWA performed the ultra low-level analyses of personal care product compounds. The analyses performed by SNWA were part of an American Water Works Association Research Foundation (AwwaRF) Research Project entitled, "*Toxicological Relevance of Endocrine Disruptors and Pharmaceuticals in Drinking Water #3085*". Finally, the WSLH performed the E-screen assay that looks at the combined estrogenicity of numerous compounds to determine overall sample quality. The analyses are further described in the sections below.

A total of 19 sampling events over the 12-month pilot program yielded over 6,500 data points to evaluate the performance of the pilot plant and the quality of the water. The SAP was separated into Process-Related Water Quality Analyses (PRWQA) and Drinking Water Related Analyses (DWRA). Select PRWQA were performed every two weeks during the operation of the Pilot Plant. Select DWRA were performed monthly. The PRWQA samples were obtaining from various points within the treatment process, whereas the DWRA focused on the source water, first pass SWRO and the second pass RO permeates.

Technical Memorandum No. 12 in Appendix 1 provides a more detailed discussion and listing of the complete SAP list of 126 regulated constituents and non-regulated constituents required to be monitored by State and Federal drinking water regulations and the 538 voluntary non-regulated constituents, the laboratory that performed each analyses, and the minimum reporting limits for each analysis.

5.2 Constituents Requiring Monitoring

The majority of analyses performed during the SAP resulted in non-detect levels of the constituents in the source water and RO permeate. Table 5.1 below presents the results for Constituents Requiring Monitoring, that were detected in either the source or the desalinated water. The desalinated water is a blend of one-third first pass SWRO water and two-thirds second pass RO permeate that had minerals added to match current MMWD drinking water quality. All detected constituents in the desalinated water were well below the regulatory limits. The majority of regulated constituents that were detected were inorganic salts and minerals typical of Pacific Ocean and San Francisco Bay water.

Table 5.1: Results of Detected Constituents Requiring Monitoring

Drinking Water Quality Parameters			SF Bay Source Water[A]			Desalinated Water[A, B]			MMWD Reservoir			Sonoma Water		
Analyte	**Unit**	**Regulatory Limit**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
Regulated Constituents														
Turbidity	NTU	5	2.7	300	15	0.05	0.1	0.07	0.05	0.24	0.08	0.06	0.28	0.11
Primary Drinking Water Regulated Constituents														
Inorganics with MCLs		--												
Arsenic	ppm	0.01	ND	0.024	0.004		ND			ND			ND	
Barium	ppm	2	ND	0.051	0.019		ND			ND			ND	
Beryllium	ppm	0.004	ND	0.0033	0.0005		ND			ND			ND	
Chromium	ppm	0.1	ND	0.042	0.0087		ND			ND			ND	
Mercury	ppm	0.002		ND		ND	0.0003[C]	ND		ND			ND	
Nickel	ppm	0.1	ND	0.057	0.022		ND			ND			ND	
Nitrate	ppm	44	ND	0.38	0.23		ND			ND		--	--	0.52
Nitrite	ppm	3.3	ND	0.017	0.013	ND	0.01[C]	ND		ND			ND	
Selenium	ppm	0.05	ND	0.091	0.01		ND			ND			ND	
Total Organic Carbon (TOC)	ppm	2	ND	6.98	1.41		ND		0.8	2.6	1.7	ND	1.4	0.8
Organics with MCLs		--												
Ethylene dibromide	ppm	0.00005	ND	0.00002[C]	0.00001		ND			ND			ND	
Radionuclides		--												
Gross Alpha	± 2.1 pCi/L	15	4.4	6.4	5.4		ND			2			1.6	
Gross Beta	± 33 pCi/L	50	144	236	190		ND			ND			ND	
Federal and State Monitoring Requirements		--												
CA UCMR		--												
Boron	ppm	1	1.5	3.3	2.3	0.1	0.4	0.2		ND		--	--	0.19
Manganese	ppm	0.05	ND	0.044	0.02		ND			ND			ND	
Secondary Drinking Water Regulated Constituents[D]														
Aluminum	ppm	0.05-0.2	ND	1.60	0.44		ND			ND			ND	
Chloride	ppm	250	3,100	15,000	11,000	15	34	20	10	37	21	7	10	8
Color (Apparent)	Pt/Co units	15	10	10	10		ND			ND			ND	
Copper	ppm	1.0	ND	0.01	0.003		ND			ND			ND	
Fluoride[E]	ppm	4	0.24	0.85	0.64		ND		0.7	1.1	0.8	0.7	1.1	0.8
Foaming Agents (MBAS)	ppm	0.5	0.10	0.44	0.29		ND			ND		ND	0.06	ND
Iron	ppm	0.3	0.18	0.75	0.34		ND			ND			ND	
Silver	ppm	0.1	ND	0.013	0.0029		ND			ND			ND	
Sulfate	ppm	500	440	2,100	1,500		ND		5	25	12	11	14	13
Solids, Dissolved	ppm	500	2,500	29,000	21,000	60	142	95	97	136	120	160	187	174
Zinc[E]	ppm	5	ND	0.010	0.004		ND		0.29	0.59	0.43	0.27	0.34	0.31

Abbreviations

MCL - Federal and/or State Maximum Contaminant Level. The level of a contaminant that is allowed in drinking water.

ND - not detected

ppm (parts per million) = mg/l (milligrams of constituent per liter of water)

pCi/L - picocuries per liter

Pt/Co units - Color units

CA UCMR - California Unregulated Contaminant Monitoring Regulation

Notes

(A) SF Bay source water and RO permeate data from 19 sampling events between March 2005 and March 2006

(B) Desalinated water is composed of RO permeate water plus minerals added to match current MMWD drinking water quality

(C) One sample out of 8 had a result above the detection limit.

(D) National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

(E) Small amounts of this constituent are added to MMWD drinking water for health benefit

The first pass SWRO process removed the majority of the constituents that were detected in source water. The second pass RO removed additional constituents from the first pass permeate. Low to non-detectable levels of inorganic ions were measured in the desalinated water well below State or Federal regulatory levels and below DHS Public Health Goals, where applicable.

Mercury was detected once (out of 8 sampling events) at 0.0003 mg/l after the first pass SWRO treatment but was not detected in the source water samples nor in the second pass RO permeate. The concentration is close to the minimum reporting limit (MRL) of 0.0001 mg/l and well below Federal drinking water regulations (i.e., 0.002 mg/l). This result does not appear plausible due to known maximum dissolved mercury concentration in Northern San Francisco Bay (0.000003 mg/l). This one data point is suspect and mercury levels in the first pass SWRO permeate of a full scale facility are expected to be non-detect.

Ethylene Dibromide (EDB) was detected in the source water at near minimum reporting limit (MRL) level once. EDB was not detected in 6 of the 7 source water samples analyzed for EDB.

Table 5.2 below presents the results for constituents that were analyzed for in the source water and the desalinated water over the 12-month period from March 2005 to March 2006, but that were not detected using standard EPA methods. Table 5.2 lists the constituent analyzed, the minimum reporting limit (MRL) in accordance with standard EPA analysis methods and the results. Additional ultra-low level analyses of some constituents are described later in this section.

Table 5.2: Constituents Not Detected in SF Bay or Desalinated Water

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Process Related Water Quality Parameters				
FOGs				
Oil & Grease, Hydrocarbons	ppm	5	ND	ND
Oil & Grease, Total	ppm	5	ND	ND
Other inorganics				
Nitrogen, Ammonia	ppm	0.1	ND	ND
Drinking Water Quality Parameters				
Regulated Constituents				
Organics with MCLs				
Alachlor (Alanex)	ppm	0.0001	ND	ND
Atrazine	ppm	0.0001	ND	ND
Bentazon (Basagran)	ppm	0.0005	ND	ND
Benzene	ppm	0.0005	ND	ND
Benzo[a]pyrene	ppm	0.00002	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Carbofuran (Furadan)	ppm	0.0009	ND	ND
Carbon Tetrachloride	ppm	0.0005	ND	ND
Chlordane	ppm	0.0001	ND	ND
alpha-Chlordane	ppm	0.0001	ND	ND
gamma-Chlordane	ppm	0.0001	ND	ND
2,4-D	ppm	0.0001	ND	ND
Dalapon	ppm	0.001	ND	ND
Di(2-ethylhexyl)adipate	ppm	0.0006	ND	ND
Di(2-ethylhexyl)phthalate (DEHP)	ppm	0.0006	ND	ND
1,2-Dibromo-3-Chloropropane (DBCP)	ppm	0.00001	ND	ND
1,2-Dichlorobenzene (o-Dichlorobenzene)	ppm	0.0005	ND	ND
1,4-Dichlorobenzene (p-DCB)	ppm	0.0005	ND	ND
1,1-Dichloroethane (1,1-DCA)	ppm	0.0005	ND	ND
1,2-Dichloroethane (1,2-DCA)	ppm	0.0005	ND	ND
1,1-Dichloroethylene (1,1-DCE)	ppm	0.0005	ND	ND
cis-1,2-Dichloroethylene	ppm	0.0005	ND	ND
trans-1,2-Dichloroethylene	ppm	0.0005	ND	ND
Dichloromethane (Methylene Chloride)	ppm	0.0005	ND	ND
1,2-Dichloropropane (Propylene Dichloride)	ppm	0.0005	ND	ND
1,3-Dichloropropylene, cis & trans	ppm	0.0005	ND	ND
Dinoseb (DNBP)	ppm	0.0001	ND	ND
Diquat	ppm	0.0004	ND	ND
Endothall	ppm	0.009	ND	ND
Endrin	ppm	0.00001	ND	ND
Ethylbenzene (Phenylethane)	ppm	0.0005	ND	ND
Ethyl tert-butyl ether	ppm	0.003	ND	ND
Glyphosate	ppm	0.006	ND	ND
Heptachlor	ppm	0.00004	ND	ND
Heptachlor Epoxide	ppm	0.00002	ND	ND
Hexachlorobenzene	ppm	0.0001	ND	ND
Hexachlorocyclopentadiene	ppm	0.0001	ND	ND
gamma-BHC (Lindane)	ppm	0.00002	ND	ND
Methoxychlor	ppm	0.0001	ND	ND
Methyl-t-butyl ether (MTBE)	ppm	0.0005	ND	ND
Molinate (Ordam)	ppm	0.0001	ND	ND
Monochlorobenzene (Chlorobenzene)	ppm	0.0005	ND	ND
Oxamyl	ppm	0.001	ND	ND
Pentachlorophenol	ppm	0.00004	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Picloram	ppm	0.0001	ND	ND
Polychlorinated Biphenyls - Aroclor 1016	ppm	0.00008	ND	ND
Polychlorinated Biphenyls - Aroclor 1221	ppm	0.002	ND	ND
Polychlorinated Biphenyls -Aroclor 1232	ppm	0.0005	ND	ND
Polychlorinated Biphenyls -Aroclor 1242	ppm	0.0003	ND	ND
Polychlorinated Biphenyls- Aroclor 1248	ppm	0.0001	ND	ND
Polychlorinated Biphenyls -Aroclor 1254	ppm	0.0001	ND	ND
Polychlorinated Biphenyls -Aroclor 1260	ppm	0.0002	ND	ND
PCBs, Total	ppm	0.00008	ND	ND
Simazine (Princep)	ppm	0.00007	ND	ND
Styrene (Vinylbenzene)	ppm	0.0005	ND	ND
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	ppm	0.0005	ND	ND
1,1,2,2-Tetrachloroethane	ppm	0.0005	ND	ND
Tetrachloroethylene	ppm	0.0005	ND	ND
Thiobencarb (Bolero)	ppm	0.0001	ND	ND
Toluene (Methylbenzene)	ppm	0.0005	ND	ND
Toxaphene	ppm	0.001	ND	ND
2,4,5-TP (Silvex)	ppm	0.0001	ND	ND
1,2,4-Trichlorobenzene (Unsym-Trichlorobenzene)	ppm	0.0005	ND	ND
1,1,1-Trichloroethane (1,1,1-TCA)	ppm	0.0005	ND	ND
1,1,2-Trichloroethane (1,1,2-TCA)	ppm	0.0005	ND	ND
Trichloroethylene (TCE)	ppm	0.0005	ND	ND
Trichloroflouromethane (Freon 11)	ppm	0.0005	ND	ND
1,1,2-Trichloro-1,2,2-trifluoroethane	ppm	0.0005	ND	ND
Trifluralin	ppm	0.0001	ND	ND
Vinyl Chloride	ppm	0.0002	ND	ND
Xylenes (single isomer or sum of isomers)	ppm			
1,3 + 1,4-Xylene	ppm	0.0005	ND	ND
1,2-Xylene	ppm	0.0005	ND	ND
Xylenes, Total	ppm	0.0005	ND	ND
Inorganics with MCLs				
Antimony	ppm	0.001	ND	ND
Asbestos	< mf/L	0.194	ND	ND
Cadmium	ppm	0.001	ND	ND
Cyanide, Total	ppm	0.02	ND	ND
Lead	ppm	0.001	ND	ND
Odor-Threshold	TON	1	ND	ND
Thallium	ppm	0.0004	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
DBPs				
THMs				
Bromodichloromethane	ppm	0.0005	ND	ND
Bromoform	ppm	0.0005	ND	ND
Chloroform	ppm	0.0005	ND	ND
Dibromochloromethane	ppm	0.0005	ND	ND
Total Trihalomethanes	ppm	0.0005	ND	ND
HAA5				
Dibromoacetic acid	ppm	0.001	ND	ND
Dichloroacetic acid	ppm	0.001	ND	ND
Monobromoacetic acid	ppm	0.001	ND	ND
Monochloroacetic acid	ppm	0.002	ND	ND
Trichloroacetic acid	ppm	0.001	ND	ND
Total HAA5	ppm	0.002	ND	ND
Bromate	ppm	0.005	ND	ND
Radionuclides				
Tritium	< pCi/L	265	ND	ND
Federal and State Monitoring Requirements				
UCMR List 1				
Acetochlor	ppm	0.0001	ND	ND
DCPA	ppm	0.0001	ND	ND
DCPA mono-acid degradate (Dacthal)	ppm	0.0005	ND	ND
DCPA di-acid degradate (Chlorthal)	ppm	0.0005	ND	ND
4,4'-DDE	ppm	0.0001	ND	ND
2,4-Dinitrotoluene	ppm	0.0005	ND	ND
2,6-Dinitrotoluene	ppm	0.0005	ND	ND
EPTC	ppm	0.0001	ND	ND
Methyl-t-butyl ether (MTBE)	ppm	0.0005	ND	ND
Molinate (Ordam)	ppm	0.0001	ND	ND
Nitrobenzene	ppm	0.005	ND	ND
Terbacil	ppm	0.0001	ND	ND
Perchlorate	ppm	0.004	ND	ND
CA UCMR	ppm			
Dichlorodifluoromethane (Freon 12)	ppm	0.0005	ND	ND
Ethyl tert-butyl ether	ppm	0.003	ND	ND
tert-Amyl Methyl ether	ppm	0.003	ND	ND
Tertiary Butyl Alcohol (TBA)	ppm	0.002	ND	ND
1,2,3-Trichloropropane (1,2,3-TCP)	ppm	0.000005	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Nitrosoamine	ppm			
N-Nitropyrrolidine	ppm	0.000002	ND	ND
N-Nitrosodiethylamine	ppm	0.000002	ND	ND
N-Nitrosodimethylamine	ppm	0.000002	ND	ND
N-Nitrosodi-N-butylamine	ppm	0.000005	ND	ND
N-Nitrosodi-N-propylamine	ppm	0.000002	ND	ND
N-Nitrosomethylethylamine	ppm	0.000002	ND	ND
N-Nitrosopiperidine	ppm	0.000002	ND	ND
1,4-Dioxane	ppm	0.005	ND	ND
4-Methyl-2-Pentanone (MIBK)	ppm	0.002	ND	ND
Naphthalene	ppm	0.0001	ND	ND
n-Propylbenzene	ppm	0.0005	ND	ND
1,2,3-Trimethylbenzene	ppm	0.0005	ND	ND
1,2,4-Trimethylbenzene (Pseudocumene)	ppm	0.0005	ND	ND
n-Butylbenzene (1-Butlypropane,1-Phenylbutane)	ppm	0.0005	ND	ND
sec-Butylbenzene	ppm	0.0005	ND	ND
tert-Butylbenzene	ppm	0.0005	ND	ND
2-Chlorotoluene (o-Chlorotoluene)	ppm	0.0005	ND	ND
4-Chlorotoluene (p-Chlorotoluene)	ppm	0.0005	ND	ND
Formaldehyde	ppm	0.005	ND	ND
Isopropylbenzene (Cumene)	ppm	0.0005	ND	ND
Chlorate	ppm	0.01	ND	ND
Carbon Disulfide	ppm	0.005	ND	ND
Non-regulated Constituents				
"Extended" EPA 525.2				
Acenaphthylene	ppm	0.0001	ND	ND
Acenaphthene	ppm	0.0001	ND	ND
Acetochlor	ppm	0.0001	ND	ND
Acifluorfen	ppm	0.001	ND	ND
Aldicarb (Temik)	ppm	0.0005	ND	ND
Aldicarb Sulfone	ppm	0.0007	ND	ND
Aldicarb Sulfoxide	ppm	0.0005	ND	ND
Aldrin	ppm	0.0001	ND	ND
Ametryn	ppm	0.0001	ND	ND
Anilazine	ppm	0.001	ND	ND
Anthracene	ppm	0.0001	ND	ND
Aspon	ppm	0.0001	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Azinphos-ethyl	ppm	0.0005	ND	ND
Azinphos-methyl	ppm	0.0005	ND	ND
Baygon	ppm	0.0005	ND	ND
Bendiocarb	ppm	0.0005	ND	ND
Benfluralin	ppm	0.0001	ND	ND
Benzo[a]anthracene	ppm	0.0001	ND	ND
Benzo[b]fluoranthene	ppm	0.0001	ND	ND
Benzo[g,h,i]perylene	ppm	0.0001	ND	ND
Benzo[k]fluoranthene	ppm	0.0001	ND	ND
Alpha-BHC	ppm	0.0001	ND	ND
Beta-BHC	ppm	0.0001	ND	ND
Delta-BHC	ppm	0.0001	ND	ND
Bolstar	ppm	0.0001	ND	ND
Bromacil (Hyvar X, Hyvar XL)	ppm	0.0001	ND	ND
Bromobenzene (Monobromobenzene)	ppm	0.0005	ND	ND
Bromochloromethane (Chlorobromomethane)	ppm	0.0005	ND	ND
Bromomethane (Methyl Bromide)	ppm	0.0005	ND	ND
Butachlor (Butanex,Lambast,Machete)	ppm	0.0001	ND	ND
Butylate	ppm	0.0001	ND	ND
n-Butylbenzene (1-Butlypropane,1-Phenylbutane)	ppm	0.0005	ND	ND
sec-Butylbenzene	ppm	0.0005	ND	ND
Butylbenzylphthalate	ppm	0.001	ND	ND
Carbaryl (Sevin)	ppm	0.0005	ND	ND
Carbophenothion	ppm	0.0005	ND	ND
Carboxin	ppm	0.0001	ND	ND
Chlorfenvinphos	ppm	0.005	ND	ND
Chlorobenzilate	ppm	0.0001	ND	ND
2-Chlorobiphenyl	ppm	0.0001	ND	ND
Chloroethane (Ethyl Chloride)	ppm	0.0005	ND	ND
Chloromethane (Methyl Chloride)	ppm	0.0005	ND	ND
Chloroneb	ppm	0.0001	ND	ND
Chloropropylate	ppm	0.0001	ND	ND
Chlorothalonil	ppm	0.0001	ND	ND
2-Chlorotoluene (o-Chlorotoluene)	ppm	0.0005	ND	ND
4-Chlorotoluene (p-Chlorotoluene)	ppm	0.0005	ND	ND
Chlorpropham	ppm	0.0001	ND	ND
Chlorpyrifos (Dursban, Lorsban)	ppm	0.0001	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Chlorpyrifos methyl	ppm	0.0005	ND	ND
Chrysene	ppm	0.0001	ND	ND
cis-1,3-Dichloropropylene	ppm	0.0005	ND	ND
cis-Permethrin	ppm	0.0001	ND	ND
Clomazone	ppm	0.0001	ND	ND
Clopyralid	ppm	0.01	ND	ND
Coumaphos	ppm	0.0001	ND	ND
Crotoxyphos	ppm	0.0005	ND	ND
Cycloate	ppm	0.0001	ND	ND
2,4-DB	ppm	0.002	ND	ND
4,4'-DDD	ppm	0.0001	ND	ND
4,4'-DDE	ppm	0.0001	ND	ND
4,4'-DDT	ppm	0.0001	ND	ND
Demeton O	ppm	0.0005	ND	ND
Demeton S	ppm	0.0005	ND	ND
Desethylatrazine	ppm	0.001	ND	ND
Desisopropylatrazine	ppm	0.001	ND	ND
Diazinon	ppm	0.0001	ND	ND
Dibenzo[a,h]anthracene	ppm	0.0001	ND	ND
Dibromomethane (Methylene Bromide)	ppm	0.0005	ND	ND
Dicamba (Banax, Banvel, Dianat)	ppm	0.0001	ND	ND
Dichlobenil	ppm	0.0001	ND	ND
Dichlofenthion	ppm	0.0001	ND	ND
1,3-Dichlorobenzene (m-Dichlorobenzene)	ppm	0.0005	ND	ND
2,3-Dichlorobiphenyl	ppm	0.0001	ND	ND
Dichlorprop	ppm	0.002	ND	ND
1,3-Dichloropropane	ppm	0.0005	ND	ND
2,2-Dichloropropane	ppm	0.0005	ND	ND
1,1-Dichloropropylene	ppm	0.0005	ND	ND
Dichlorvos (DDVP)	ppm	0.0001	ND	ND
Dicrotophos	ppm	0.0005	ND	ND
Dieldrin	ppm	0.0001	ND	ND
Diethylphthalate	ppm	0.001	ND	ND
Dimethoate (Cygon)	ppm	0.0005	ND	ND
Dimethylphthalate	ppm	0.001	ND	ND
Di-n-Butylphthalate	ppm	0.002	ND	ND
Di-n-octylphthalate	ppm	0.002	ND	ND
Dioxathion	ppm	0.0005	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Diphenamid	ppm	0.0001	ND	ND
Disulfoton	ppm	0.0001	ND	ND
Disulfoton sulfone	ppm	0.0001	ND	ND
Disulfoton sulfoxide	ppm	0.01	ND	ND
Endosulfan I (alpha)	ppm	0.0001	ND	ND
Endosulfan II (beta)	ppm	0.0001	ND	ND
Endosulfan sulfate	ppm	0.0001	ND	ND
Endrin Aldehyde	ppm	0.0005	ND	ND
EPN	ppm	0.0005	ND	ND
EPTC	ppm	0.0001	ND	ND
Erucylamide	ppm	0.005	ND	ND
Esfenvalerate	ppm	0.0005	ND	ND
Ethalfluralin	ppm	0.0001	ND	ND
Ethion	ppm	0.005	ND	ND
Ethofumesate	ppm	0.0005	ND	ND
Ethoprop	ppm	0.0001	ND	ND
Etridiazole	ppm	0.0001	ND	ND
Famphur	ppm	0.0001	ND	ND
Fenamiphos	ppm	0.0001	ND	ND
Fenarimol	ppm	0.001	ND	ND
Fenitrothion	ppm	0.0005	ND	ND
Fenoxaprop-ethyl	ppm	0.001	ND	ND
Fensulfothion	ppm	0.0005	ND	ND
Fenthion	ppm	0.0001	ND	ND
Fluorene	ppm	0.0001	ND	ND
Fluazifop-butyl	ppm	0.0001	ND	ND
Fluchloralin	ppm	0.0001	ND	ND
Fluometuron	ppm	0.0005	ND	ND
Fluoranthene	ppm	0.0001	ND	ND
Fluridone	ppm	0.001	ND	ND
Fonofos	ppm	0.0001	ND	ND
2,2',3,3',4,4',6-Heptachlorobiphenyl	ppm	0.0005	ND	ND
2,2',4,4',5',6-Hexachlorobiphenyl	ppm	0.0001	ND	ND
Hexazinone	ppm	0.0001	ND	ND
3-Hydroxycarbofuran	ppm	0.0005	ND	ND
Indeno[1,2,3-cd]pyrene	ppm	0.0001	ND	ND
Iprodione	ppm	0.0005	ND	ND
Isofenphos	ppm	0.0005	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Isophorone	ppm	0.0001	ND	ND
Isopropylbenzene (Cumene)	ppm	0.0005	ND	ND
4-Isopropyltoluene	ppm	0.0005	ND	ND
Leptophos	ppm	0.0005	ND	ND
Malathion	ppm	0.0001	ND	ND
Metalaxyl	ppm	0.0005	ND	ND
Methiocarb	ppm	0.001	ND	ND
Methomyl (Lannate)	ppm	0.0005	ND	ND
2-Butanone (MEK)	ppm	0.005	ND	ND
1-Methylnaphthalene	ppm	0.0001	ND	ND
2-Methylnaphthalene	ppm	0.0001	ND	ND
Methyl parathion	ppm	0.0005	ND	ND
Methyl paraoxon	ppm	0.0005	ND	ND
4-Methyl-2-Pentanone (MIBK)	ppm	0.002	ND	ND
Metolachlor	ppm	0.0001	ND	ND
Metribuzin (Lexone, Sencor, Sencoral)	ppm	0.0001	ND	ND
Metsulfuron-methyl	ppm	0.01	ND	ND
Mevinphos	ppm	0.0001	ND	ND
MGK 264 isomer a	ppm	0.0001	ND	ND
MGK 264 isomer b	ppm	0.0001	ND	ND
MGK 326	ppm	0.0001	ND	ND
Mirex	ppm	0.0005	ND	ND
Monocrotophos	ppm	0.0005	ND	ND
Naphthalene	ppm	0.0005	ND	ND
Napropamide	ppm	0.0001	ND	ND
Nitrobenzene	ppm	0.005	ND	ND
Norflurazon	ppm	0.001	ND	ND
2,2',3,3',4,5',6,6'-Octachlorobiphenyl	ppm	0.0005	ND	ND
Oryzalin	ppm	0.01	ND	ND
Oxadiazon	ppm	0.0001	ND	ND
Oxyfluorfen	ppm	0.0005	ND	ND
Paraquat	ppm	0.0004	ND	ND
Parathion	ppm	0.0005	ND	ND
Pebulate	ppm	0.0001	ND	ND
Pendimethalin	ppm	0.0001	ND	ND
Pentachlorobenzene	ppm	0.0005	ND	ND
2,2',3',4,6-Pentachlorobiphenyl	ppm	0.0001	ND	ND
Pentachloronitrobenzene	ppm	0.0005	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Pentachlorophenol	ppm	0.001	ND	ND
Phenanthrene	ppm	0.0001	ND	ND
n-Propylbenzene	ppm	0.0005	ND	ND
Phorate	ppm	0.0001	ND	ND
Phosmet	ppm	0.0005	ND	ND
Phosphamidon	ppm	0.0005	ND	ND
Profluralin	ppm	0.0001	ND	ND
Prometryn (Caparol)	ppm	0.0001	ND	ND
Pronamide	ppm	0.0001	ND	ND
Propachlor (Albrass,Ramrod)	ppm	0.0001	ND	ND
Propanil	ppm	0.0005	ND	ND
Propazine	ppm	0.0001	ND	ND
Propiconazole isomer a	ppm	0.005	ND	ND
Propiconazole isomer b	ppm	0.005	ND	ND
Prothiofos	ppm	0.0005	ND	ND
Pyrene	ppm	0.0001	ND	ND
Simetryn	ppm	0.0001	ND	ND
Stirofos	ppm	0.0001	ND	ND
Sulfotep	ppm	0.0005	ND	ND
2,4,5-T	ppm	0.0005	ND	ND
Tebuthiuron	ppm	0.01	ND	ND
TEPP	ppm	0.001	ND	ND
Terbacil	ppm	0.0001	ND	ND
Terbufos	ppm	0.0005	ND	ND
Terbutryn	ppm	0.0001	ND	ND
tert-Butylbenzene	ppm	0.0005	ND	ND
1,2,4,5-Tetrachlorobenzene	ppm	0.0005	ND	ND
2,2',4,4'-Tetrachlorobiphenyl	ppm	0.0001	ND	ND
1,1,1,2-Tetrachloroethane	ppm	0.0005	ND	ND
Thiabendazole	ppm	0.01	ND	ND
Thionazin	ppm	0.0005	ND	ND
trans-1,3-Dichloropropylene	ppm	0.0005	ND	ND
trans-Nonachlor	ppm	0.0001	ND	ND
trans-Permethrin	ppm	0.0001	ND	ND
Triadimefon	ppm	0.0005	ND	ND
Tribufos	ppm	0.0001	ND	ND
Trichlorfon	ppm	0.01	ND	ND
2,4,5-Trichlorobiphenyl	ppm	0.0001	ND	ND

Constituent	Unit	MRL	SF Bay Source Water	Desalinated Water
Trichloronate	ppm	0.0005	ND	ND
2,4,6-Trichlorophenol	ppm	0.0001	ND	ND
Tricyclazole	ppm	0.001	ND	ND
Trifluralin	ppm	0.0001	ND	ND
1,2,3-Trimethylbenzene	ppm	0.0005	ND	ND
1,2,4-Trimethylbenzene (Pseudocumene)	ppm	0.0005	ND	ND
1,3,5-Trimethylbenzene (Mesitylene)	ppm	0.0005	ND	ND
Vernolate	ppm	0.0001	ND	ND
Vinclozolin	ppm	0.0005	ND	ND
Hormones				
17alpha-Ethynyl estradiol	ppm	0.0000005	ND	ND
17alpha-Estradiol	ppm	0.0000005	ND	ND
17beta-Estradiol	ppm	0.0000005	ND	ND
cis-Testosterone	ppm	0.0000001	ND	ND
trans-Testosterone	ppm	0.0000001	ND	ND
Diethylstilbestrol (DES)	ppm	0.0000005	ND	ND
Estriol	ppm	0.0000005	ND	ND
Estrone	ppm	0.0000005	ND	ND
Phenolics				
2,4,6-Trichlorophenol	ppm	0.0001	ND	ND
4-n-Octylphenol	ppm	0.0005	ND	ND
4-tert-Octylphenol	ppm	0.0005	ND	ND
Bisphenol A	ppm	0.0001	ND	ND
Nonylphenol, isomer mix	ppm	0.0005	ND	ND
Pentachlorophenol	ppm	0.0001	ND	ND
Phenylphenol, total	ppm	0.0001	ND	ND
Tetrabromobisphenol A	ppm	0.0001	ND	ND
E-Screen Assay	ppm	0.00008	ND	ND

Notes:

SF Bay source water and RO permeate data from sampling events between March 2005 and March 2006.
MRL – minimum reporting limit based on standard EPA test
ND – not detected
ppm (parts per million) – mg/l (milligrams of constituent per liter of water)

5.3 Voluntary Constituents

The list of voluntary (non-regulated) constituents monitored as part of the pilot program can be separated into four subsets, each of which is described below:

1. Process and other non-regulated constituents measured at EPA standard low level analysis levels

2. Non-Regulated constituents measured ultra low-level analyses levels by research or specialty laboratories

3. Algal Toxins

4. E-Screen Assay

A total of 538 voluntary non-regulated constituents were monitored. 244 voluntary non-regulated constituents were measured down to EPA standard low level analysis. 294 voluntary non-regulated constituents were measured with the Ultra Low-Level Analyses, Algal Toxin Program, or E-Screen Assay subsets. Of these constituents, only a common detergent metabolite (nonylphenol monoethoxylate) was detected once in the source water near its MRL. The remainder of the analyses on these constituents yielded non-detect values for the source water. None of these constituents were detected in the desalinated water samples.

Table 5.3 presents the results of voluntary non-regulated process water quality parameters in the source water, the desalinated water and in MMWD current water supplies.

Table 5.3: Voluntary Constituents Detected in SF Bay and Desalinated Water

Process Related Parameters			SF Bay Source Water(A)			Desalinated Water(A. B)			MMWD Reservoir			Sonoma Water		
Analyte	**Unit**	**MCL**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
UV absorbance at 254nm	cm^{-1}	-	0.016	0.170	0.051	ND	0.016	0.007	0.04	0.032	0.024	0.009	0.024	0.017
Inorganic Constituents		-												
Conductivity	umho/cm	-	4,700	68,000	41,000	77	250	190	165	250	206	262	296	281
Hardness, Calcium	ppm as $CaCO_3$	-	290	770	600	50	96	68	20	32	26	52	64	56
pH	pH units	-	7.85	7.94	7.90	7.8	8.2	7.9	7.5	8.0	7.8	8.0	8.4	8.2
Saturation (Langlier) Index	N/A	-	0.10	0.64	0.43	-0.5	0.4	0.2	-0.98	-0.6	-0.86	0.0	0.67	0.30
Alkalinity	ppm as $CaCO_3$	-	58	110	96	50	94	67	47	70	58	110	129	118
Other inorganics		-												
Bromide	ppm	-	10	55	39	0.01	0.15	0.08	0.01	0.01	0.01	0.01	0.01	0.01
Calcium	ppm	-	71	310	210	10	20	15	7.2	15	10	19	51	23
Magnesium	ppm	-	430	970	770	ND	0.26	0.1	8.3	13	10	11	16	14
Phosphate, ortho(C)	ppm as P	-	0.08	0.12	0.10		ND		0.14	0.34	0.23	0.27	0.4	0.32
Potassium	ppm	-	140	350	260	0.13	0.9	0.4	--	--	--	--	--	--
Silica, Total	ppm	-	5.1	12.0	7.1		ND		--	--	--	--	--	--
Silica, Dissolved	ppm	-	ND	15.0	8.4	ND	0.16	ND	--	--	--	--	--	--
Sodium	ppm	-	3,300	8,100	6,700	10	21	13	12	25	18	19	23	20
Strontium	ppm	-	2.5	5.9	4.6	ND	0.006	ND		ND			ND	
Phenolics														
Nonylphenol monoethoxylate, isomer mix	ppm		ND	0.015	0.010		ND			--			--	

Abbreviations
MCL - Federal and/or State Maximum Contaminant Level. The level of a contaminant that is allowed in drinking water.
ND - not detected
ppm (parts per million) = mg/l (milligrams of constituent per liter of water)
NTU - nephelometric turbidity units
umho/cm - micromhos per centimeter
mg P/L - milligrams of phosporus per liter
cm-1 - inverse centimeters

Notes
(A) SF Bay source water and RO permeate data from 19 sampling events between March 2005 and March 2006
(B) Desalinated water is composed of RO permeate water plus minerals added to match current MMWD drinking water quality
(C) Small amounts of this constituent are added to MMWD drinking water for health benefit

5.3.1 Ultra-Low Level Analyses

Analyses of ultra low-level constituents were added to SAP based on potential occurrence in the Bay source water. These include 209 types of polychlorinated biphenyls (PCBs) and 44 types of flame retardants [polybrominated diphenyl ethers (PBDEs)] analyses performed by Axys Analytical Services. The analyses of ultra low-level constituents also included a suite of 40 pharmaceutical and personal care product compounds analyzed by the Southern Nevada Water Authority analytical laboratory. Typical low-level drinking water analysis MRLs are in microgram (0.001 mg) per liter (µg/L) range. Ultra low-level non-regulated analyses MRLs range from nanogram (0.000001 mg) per liter (ng/L) to picogram (0.000000001 mg) per liter (pg/L).

"Blanks" are commonly sampled and analyzed when monitoring constituents using ultra low-level analyses. Two types of blanks were used in the SAP:

1. Laboratory blanks, which are ultra pure water used by the analytical laboratory to test their instrumentation, and

2. Sample blanks, which are ultra pure water provided by the analytical laboratory placed in sample jars and shipped to the pilot plant. Samplers transfer that water to another clean sample jar while sampling. Sample blanks are used in an effort to capture any possible contamination that occurs during sampling.

Blanks typically contained ultra low-levels of monitored constituents and a statistical approach of blank correction was performed to try to obtain valid results in pilot plant samples. This approach is further described in Technical Memorandum No. 12.

Table 5.4 presents the results of ultra-low level analysis for PCBs in the San Francisco Bay water and in the desalinated water. Trace amounts of PCBs, approximately 350 pg/l (0.00000035 mg/l), were found in source water samples. This is similar to previous studies performed with San Francisco Bay water (McFarland and Clarke, 1989). The drinking water regulatory level (i.e., MCL) for total PCBs in a finished water is 0.5 µg/l (0.0005 mg/l). No ultra-low level PCBs were detected above reportable limits in the desalinated water.

Table 5.4: Results of Ultra Low-Level Analysis for PCBs

		SF Bay Source Water		Desalinated Water	
COMPOUND	**Units**	**Results**	**MRL**	**Result**	**MRL**
Total Monochloro Biphenyls	ppm	ND	0.000000001	ND	0.000000001
Total Dichloro Biphenyls	ppm	ND	0.000000002	ND	0.000000002
Total Trichloro Biphenyls	ppm	0.000000005	0.000000001	ND	0.000000001
Total Tetrachloro Biphenyls	ppm	0.000000033	0.000000001	ND	0.000000001
Total Pentachloro Biphenyls	ppm	0.000000095	0.000000001	ND	0.000000001

		SF Bay Source Water		Desalinated Water	
COMPOUND	**Units**	**Results**	**MRL**	**Result**	**MRL**
Total Hexachloro Biphenyls	ppm	0.000000119	0.000000001	ND	0.000000001
Total Heptachloro Biphenyls	ppm	0.000000065	0.000000001	ND	0.000000001
Total Octachloro Biphenyls	ppm	0.000000019	0.000000001	ND	0.000000001
Total Nonachloro Biphenyls	ppm	0.000000005	0.000000003	ND	0.000000003
Decachloro Biphenyl	ppm	0.000000004	0.000000001	ND	0.000000001
TOTAL PCBs	ppm	0.000000347		ND	

ppm (parts per million) = mg/l (milligrams of constituent per liter of water)

Table 5.5 below presents the results of ultra-low level analysis for flame retardants in the San Francisco Bay water and in the desalinated water. Forty four flame retardants (polybrominated diphenyl ethers (PBDEs)) were analyzed. Thirteen specific PBDE's were detected in Bay water at levels of a few pg/l to a few µg/l. This is similar to other studies of Bay water (Lacorte et al., 2003, Oros et al., 2005). These compounds were not detected in the finished desalinated water.

Table 5.5: Results of Ultra Low-Level Analysis for Flame Retardants

		SF Bay Source Water		Desalinated Water	
Analyte	**Unit**	**Result**	**MRL**	**Result**	**MRL**
2,2',3,3',4,4',5,5',6,6'-DeBDE	ppm	ND	0.000000594	ND	0.000000475
2,2',3,3',4,4',5,5',6-NoBDE	ppm	ND	0.000000064	ND	0.000000058
2,2',3,3',4,4',5,6,6'-NoBDE	ppm	ND	0.000000034	ND	0.000000033
2,2',3,3',4,4'-HxBDE	ppm	ND	0.000000039	ND	0.000000035
2,2',3,3',4,5,5',6,6'-NoBDE	ppm	ND	0.000000048	ND	0.000000046
2,2',3,4,4',5,5',6-OcBDE	ppm	ND	0.000000017	ND	0.000000013
2,2',3,4,4',5',6-HpBDE	ppm	ND	0.000000013	ND	0.000000011
2,2',3,4,4',5,6-HpBDE	ppm	ND	0.000000019	ND	0.000000013
2,2',3,4,4',5'-HxBDE/2,3,4,4',5,6-HxBDE	ppm	0.000000030	0.000000019	ND	0.000000016
2,2',3,4,4',6'-HxBDE	ppm	ND	0.000000013	ND	0.000000010
2,2',3,4,4'-PeBDE	ppm	0.000000081	0.000000024	ND	0.000000007
2,2',4,4',5,5'-HxBDE	ppm	0.000000169	0.000000015	ND	0.000000013
2,2',4,4',5,6'-HxBDE	ppm	0.000000128	0.000000009	ND	0.000000008
2,2',4,4',5-PeBDE	ppm	0.000001415	0.000000015	ND	0.000000005
2,2',4,4',6,6'-HxBDE	ppm	0.000000009	0.000000008	ND	0.000000007
2,2',4,4',6-PeBDE	ppm	0.000000291	0.000000011	ND	0.000000004
2,2',4,4'-TeBDE	ppm	0.000004732	0.000000006	ND	0.000000006
2,2',4,5'-TeBDE	ppm	0.000000035	0.000000008	ND	0.000000007
2,2',4,6'-TeBDE	ppm	ND	0.000000006	ND	0.000000005
2,2',4-TriBDE/2,3',4-TriBDE	ppm	0.000000013	0.000000005	ND	0.000000004
2,3,3',4,4',5,6-HpBDE	ppm	ND	0.000000029	ND	0.000000023
2,3,3',4,4'-PeBDE	ppm	ND	0.000000030	ND	0.000000009

		SF Bay Source Water		Desalinated Water	
Analyte	Unit	Result	MRL	Result	MRL
2,3',4,4',6-PeBDE/2,3',4,5,5'-PeBDE	ppm	ND	0.000000024	ND	0.000000007
2,3',4,4'-TeBDE	ppm	0.000000032	0.000000009	ND	0.000000007
2,3,4,5,6-PeBDE	ppm	ND	0.000000039	ND	0.000000012
2,3',4',6-TeBDE	ppm	0.000000008	0.000000008	ND	0.000000007
2,4,4',6-TeBDE	ppm	ND	0.000000007	ND	0.000000006
2,4,4'-TriBDE/2',3,4-TriBDE	ppm	0.000000013	0.000000005	ND	0.000000003
2,4',6-TriBDE	ppm	ND	0.000000005	ND	0.000000003
2,4,6-TriBDE	ppm	ND	0.000000005	ND	0.000000004
2,4'-DiBDE	ppm	NQ	0.000000002	ND	0.000000003
2,4-DiBDE	ppm	NQ	0.000000002	ND	0.000000003
2,6-DiBDE	ppm	NQ	0.000000002	ND	0.000000003
3,3',4,4',5-PeBDE	ppm	ND	0.000000016	ND	0.000000005
3,3',4,4'-TeBDE	ppm	ND	0.000000006	ND	0.000000005
3,3',4,5'-TeBDE	ppm	ND	0.000000007	ND	0.000000006
3,3',4-TriBDE	ppm	ND	0.000000004	ND	0.000000003
3,4,4'-TriBDE	ppm	ND	0.000000004	ND	0.000000003
3,4-DiBDE	ppm	NQ	0.000000002	ND	0.000000002
4,4'-DiBDE	ppm	NQ	0.000000002	ND	0.000000002

ppm (parts per million) = mg/l (milligrams of constituent per liter of water)

Table 5.6 presents the results of ultra-low level analysis for pharmaceutical and personal care product compounds in the San Francisco Bay water and in the desalinated water. Trace levels (i.e., low ng/l) of several pharmaceutical and personal care product compound constituents were detected in Bay water. These compounds have been found in surface and groundwaters and SAP results are comparable to previous studies (Snyder et al., 2003, Gross et al., 2004). These compounds were not detected in the finished desalinated water.

Table 5.6: Results of Ultra Low-Level Analysis for Pharmaceuticals and Personal Care Products

		SF Bay Source Water		Desalinated Water	
Constituent	Units	Result	MRL	Result	MRL
Acetaminophen	ppm	ND	0.000000001	ND	0.000000001
Androstenedione	ppm	ND	0.000000001	ND	0.000000001
Atenolol	ppm	0.000000005	0.000000001	ND	0.000000001
Atorvastatin	ppm	ND	0.000000001	ND	0.000000001
Atrazine	ppm	ND	0.000000001	ND	0.000000001
Bisphenol A	ppm	ND	0.000000001	ND	0.000000001
Caffeine	ppm	0.000000008	0.000000010	ND	0.000000010
Carbamazepine	ppm	0.000000002	0.000000001	ND	0.000000001
DEET	ppm	0.000000005	0.000000001	ND	0.000000001
Diazepam	ppm	ND	0.000000001	ND	0.000000001
Diclofenac	ppm	ND	0.000000001	ND	0.000000001
Dilantin	ppm	0.000000002	0.000000001	ND	0.000000001
Enalapril	ppm	ND	0.000000001	ND	0.000000001

Constituent	Units	SF Bay Source Water Result	SF Bay Source Water MRL	Desalinated Water Result	Desalinated Water MRL
Erythromycin-H2O	ppm	0.000000001	0.000000001	ND	0.000000001
Estradiol	ppm	ND	0.000000001	ND	0.000000001
Estriol	ppm	ND	0.000000005	ND	0.000000005
Estrone	ppm	0.000000001	0.000000001	ND	0.000000001
Ethynylestradiol	ppm	ND	0.000000001	ND	0.000000001
Fluoxetine	ppm	ND	0.000000001	ND	0.000000001
Gemfibrozil	ppm	0.000000010	0.000000001	ND	0.000000001
Hydrocodone	ppm	ND	0.000000001	ND	0.000000001
o-Hydroxy atorvastatin	ppm	ND	0.000000001	ND	0.000000001
p-Hydroxy atorvastatin	ppm	ND	0.000000001	ND	0.000000001
Ibuprofen	ppm	0.000000003	0.000000001	ND	0.000000001
Iopromide	ppm	0.000000008	0.000000001	ND	0.000000001
Linuron	ppm	ND	0.000000001	ND	0.000000001
Meprobamate	ppm	0.000000004	0.000000001	ND	0.000000001
Naproxen	ppm	0.000000002	0.000000001	ND	0.000000001
Norfluoxetine	ppm	ND	0.000000001	ND	0.000000001
Oxybenzone	ppm	ND	0.000000001	ND	0.000000001
Pentoxifylline	ppm	ND	0.000000001	ND	0.000000001
Progesterone	ppm	ND	0.000000001	ND	0.000000001
Risperidone	ppm	ND	0.000000001	ND	0.000000001
Simvastatin	ppm	ND	0.000000001	ND	0.000000001
Simvastatin hydroxy acid	ppm	ND	0.000000001	ND	0.000000001
Sulfamethoxazole	ppm	0.000000007	0.000000001	ND	0.000000001
TCEP	ppm	ND	0.000000010	ND	0.000000010
Testosterone	ppm	ND	0.000000001	ND	0.000000001
Triclosan	ppm	ND	0.000000001	ND	0.000000001
Trimethoprim	ppm	ND	0.000000001	ND	0.000000001

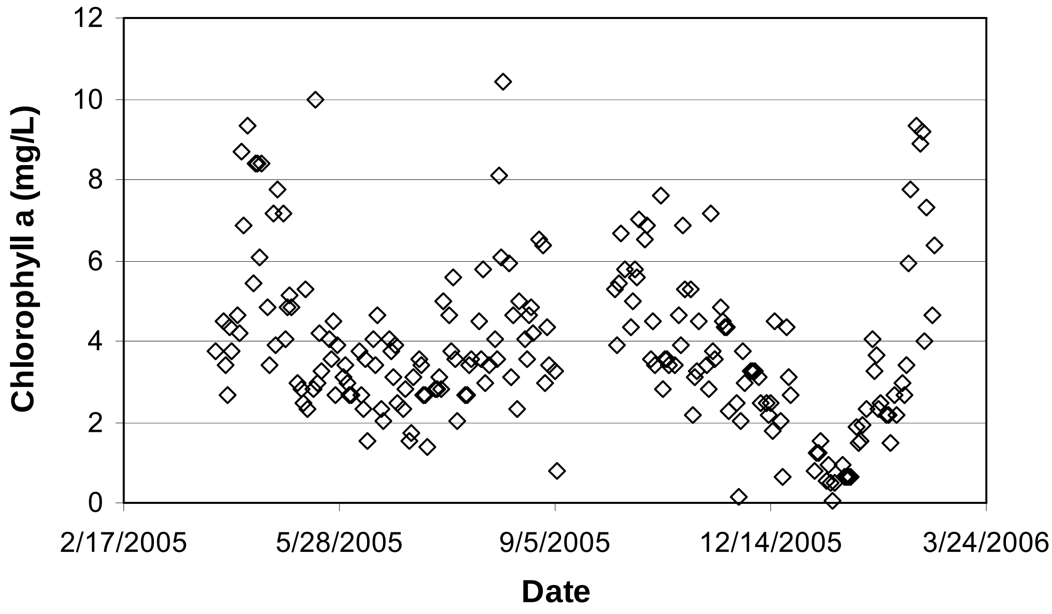
ppm (parts per million) = mg/l (milligrams of constituent per liter of water)

In general, for the ultra-low level constituents, the desalinated water (first pass SWRO and second pass RO permeate) samples had results comparable to results in the ultra pure blanks provided by the analytical laboratories. Most blanks and treated waters contained several constituents at, or near, the ultra-low detection limits (low pg/l levels). These results indicate that either the laboratory instrumentation is limited at ultra low-levels or detection limits are approaching background levels in the general environment.

5.3.2 Algal Toxins

An algal toxin protocol for the pilot program is described in Technical Memorandum No. 6 in Appendix 1. As the source water is influenced by fresh and saline water, this protocol considered algae from fresh and saline sources. Using World Health Organization guidelines, when the compound “Chlorophyll a” is below 10 mg/l, there is no threat to human health by algal toxins. Chlorophyll a levels were monitored daily at the Romberg Tiburon Center during the pilot study and are presented in Figure 5.1 below. Chlorophyll a levels remained low, indicating no algal blooms in the vicinity of the pilot plant intake during pilot plant operation. Consequently, algal toxin analyses were not performed.

Figure 5.1: Source Water Chlorophyll a Concentrations



Although algal toxins were not present at high enough levels to sample during the pilot program, due to the physical and chemical characteristics of potential local algal toxins, removal through the multi-barrier, pretreatment, first pass SWRO and second pass RO desalination treatment process is expected to be excellent (Drewes et al., 2006).

5.3.3 E-Screen Assay

The E-Screen Assay is a test that measures a chemical, or a group of chemicals, that act like estrogenic hormones. An assay technique was incorporated into the SAP at the request of the District to capture a possible health effect caused by pollutants that were not monitored or by an additive effect of numerous pollutants. The E-Screen assay is very sensitive yielding a very low MRL (0.00008 mg/l).

Three samples of the source water and three samples of the first pass SWRO permeate were taken for E-Screen assay analysis. None of the results indicted activity above the MRL.

5.4 Conclusions

While the Bay water contains very low levels of regulated and non-regulated constituents, this source water can be treated to meet or exceed State, Federal and MMWD's stringent water quality objectives with the pilot tested seawater desalination process.

The first pass SWRO process removed the majority of the constituents that were detected in source water. Low to non-reportable levels of inorganic ions (salts and minerals) were measured in the treated water well below state or federal regulatory levels and below California Public Health Goals (PHGs). PHGs are non-mandatory advisory criteria. They are defined as "the level of a contaminant in drinking water below which there is no known or expected risk to health." Water quality constituents that were present in the desalinated water were typical salts and minerals expected due to predicted membrane performance.

Overall, first pass SWRO and second pass RO have demonstrated the capacity to remove ultra-low level non-regulated constituents found in the source water. In general, with regard to the comprehensive list of pollutants monitored, desalinated water (first pass SWRO and second pass RO permeate) had results comparable to results in the ultra pure blanks provided by analytical laboratories.

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Section 6: Desalination Pilot Systems Operations and Performance

The section describes the operating characteristics and summarizes the performance of the different processes at the MMWD Seawater Desalination Pilot Plant. Photos and tabular information are also provided below. Pilot system performance graphs are included in Appendix 2.

6.1 Intake System

The intake system at the pilot plant was in operation for one year, from 29 April 2005 through 28 April 2006. MMWD staff continued to operate the intake system for a concurrent fish entrainment study through June 2006.

6.1.1 Intake Screen

The intake screen was a Hendrick wedge wire drum screen. The screen area was 10-3/4-inches long and 10-3/4-inches in diameter. The screen material was a copper-nickel alloy and the other parts of the intake were 316 SS. The screen was equipped for air-burst self-cleaning. The screen slot width was 3/32-inches and the approach velocity at 150 gpm was approximately 0.24 feet per second (fps) (below the maximum limit of 0.33 fps).

Intake Screen after manual cleaning 8 August 2005

There was moderate marine growth on the stainless steel portions of the screen during the summer months and less growth during the winter months, as would be expected. The barnacles, marine plants, and other organisms on the exterior of the screen were removed by moderate physical scraping with a metal scraper and washing; however, there was significant marine plant growth inside the intake screen that could not be washed out – the plant material was growing on the stainless steel screen support pieces and other internal stainless steel components.

The intake screen was air-burst-cleaned in the water once per week and raised, inspected, and cleaned approximately every 4 to 6 weeks over the course of the pilot program.

Intake screen after manual cleaning 3 April 2006

The intake screen worked well in terms of producing the required flow rates even when it was covered in marine growth. A fish entrainment study under a separate contract will provide information on the screen's passage of marine life. The stainless steel has held up well in terms of corrosion. Zinc anodes were attached to the intake to provide sacrificial anode protection. The zinc anodes successfully protected the stainless steel components of the screen from corrosion. The copper-nickel components also resisted corrosion well. One spot of the intake did experience corrosion that led to a half-dollar size hole in the screen. The corrosion was due to a dissimilar metal from the supports that came in contact with the screen. The screen hole was successfully repaired with copper wire.

The copper-nickel material also worked well in preventing tenacious bio-growth. The slime that covered the copper-nickel screen appears to be easily removed by periodic air-burst-cleaning and by washing; however, barnacles and marine plants were able to attach to the stainless steel components inside of the screen and grow. The intake was left in operation for two months following the end of the pilot study without monthly cleaning. The photo below shows the intake after approximately three months without cleaning. There is significant bio-growth on the non-copper components.

Intake after three months with no cleaning from April to June 2006

The inside of the intake suction hose for the pilot plant also had considerable bio-growth, silts, and mud near the intake screen after the year of operation. This is likely due to silts being trapped in bio-growth near the intake screen and the fact that the intake hose had a low spot at this location. The small amount of light in this area permitted growth. The internal pipes further downstream did not experience significant bio-growth.

6.1.2 Intake Pump and Pipeline

In August 2005, after approximately three and a half months of operation, a section of the intake and return water pipelines on the pier was removed to investigate potential biological growth in the pipelines that could lead to reduced flows. The intake and return water pipe had a relatively thin bio-slime layer estimated to be less than 0.5 millimeters thick. There was no indication of barnacle growth inside the two pipes. The intake pipe had been shock-chlorinated in mid July 2005 after approximately three months of operation. The return water pipeline had no biological control treatment through August 2005.

Thin bio-film on intake pipe after three months operation

The return water pipeline and the approximately 2,500-foot-long length of the intake pipeline were shock-chlorinated in September 2005. After the shock-chlorination, the flow rate from the intake and return pumps increased to near where it had previously been under the same discharge pressure. The project team surmised that the reduction in flow for the intake and return water system was caused by the increased head loss from the bio-growth on the inside of the pipes. An approximately 1,000-foot-long portion of the intake pipeline between the pilot site and the return water discharge point was shock-chlorinated approximately every 6 to 8 weeks over the remainder of the pilot study to maintain system flow rates. Visual inspection of the intake pipe after the intake pumps at the end of the year-long study showed no significant additional bio-growth beyond that observed at three months.

6.1.3 Intake Screen and Pipeline Wastes

The intake screen could have an automatic air-burst cleaning system to regularly remove built-up debris on the screen; however, organisms such as barnacles and plant life will grow on any stainless steel components of the screen and, to a much lesser degree, on the copper-nickel components as well. This plant life growing on the inside of the screen will make air-bursting less effective.

6.2 Strainer System

The pilot plant operated two intake strainers in parallel to remove particles greater than 100 microns and microorganisms, such as mussel larva, ahead of the pretreatment processes whose presence in the MF/UF units might cause performance degradation. Both strainer systems were rated at a nominal particle removal size of 100 microns. The Bollfilter strainer uses stainless steel wedge wire strainer elements and was operated ahead of the conventional pretreatment process for a period of several months. The Arkal strainer uses compressed plastic disks for straining and was operated ahead of the membrane pretreatment processes for the entire study.

The general performance of the intake strainers was compared by evaluation of turbidity removal and by measurement of the clogging capacity of the strainers. Daily grab samples of turbidity from the water before and after the strainers showed that the strainers did not significantly affect the feed water turbidity. The turbidity levels in flows after the strainers are typically equal to or 1 to 2 NTU less than the feed water. This is expected, since the 100-micron strainers should have minimal ability to remove the smaller particles that primarily contribute to turbidity.

Clogging capacity was measured with a Clogging Capacity Meter (CCM) provided by Arkal. The CCM is used to simulate the performance of a strainer on the process water. The CCM is a flow-through device operated on a small portion of the flow and uses a standard screen (in this case 100-micron) to simulate the strainer.

CCM testing was performed on the feed water and on the strained water from the Arkal Spinklin and Bollfilter strainers in July 2005. The photo below shows the strained water CCM screens for the Arkal strainer (on the right) and for the Bollfiter (on the left) and shows the difference in the solids that pass through each filter. The CCM units ran for a period of 110 minutes on the effluent of each strainer. After 110 minutes, the differential pressure (DP) across the 100-micron test screen for the Bollfilter effluent was 5 psi, while the Arkal strained water test screen DP showed no increase.

CCM test screens on Bollfilter and Arkal Strainer effluent (Arkal on the right)

Although both strainers are rated at 100-micron nominal removal, the side by side CCM testing indicated that the compressed disk-type strainer provided greater reduction in solids than the wedge-wire type strainer. This could be due to the fact that the compressed disk-type strainer has approximately 1/2-inch of depth between the source and strained water, and formation of a solids layer at the surface could be aiding in the trapping and retention of solids.

An inspection of the MF and UF systems at the end of the pilot plant study showed no barnacle or mussel growth in the systems and no invertebrate shells or other debris in the tanks. The MF and UF systems did not experience any damage to the fibers over the 11 months of operation. The Arkal 100-micron strainer was effective in protecting the MF/UF systems.

A strainer is not required for the conventional pretreatment system but still may be advantageous to minimize mussel and barnacle growth in the process piping and tanks of a full-scale system. The pilot system conventional flocculation tank and clarifier showed some indication of barnacle growth in the tanks.

6.2.1 Strainer System Wastes

The intake strainer backwashes using compressed air and strained source water. For a full-scale system, the spent washwater volume would be less than 1% of the source water flow and would contain an elevated concentration of suspended solids relative to the source water. The solids and washwater would be collected and treated by a solids handling system for treatment and recovery of the water.

The intake strainer could be periodically shocked with chlorine to control biological growth in the strainer. The strainer manufacturer also recommends freshwater shocks as an effective in controlling bio-growth in the strainers and the small volume of the strainer housings limits the amount of fresh water required.

6.3 Conventional Pretreatment System

The conventional pretreatment system consisted of rapid mix, flocculation, and sedimentation followed by two-stage granular media filtration. The conventional pretreatment system provided feed water to a dedicated seawater RO pilot unit (Conventional SWRO) and operated from June 2005 through April 2006.

6.3.1 Conventional Pretreatment Operations

The conventional pilot systems were operated and optimized in accordance with the pilot plant testing protocol. Adjustments were made based on source-water conditions during the pilot program using jar tests. The conventional pretreatment system operations and optimization testing included the following variations:

- Jar-tested ferric coagulant and a ferric/polymer blended coagulant.
- Jar-tested and operated system at various coagulant doses (5 to 25 mg/l).
- Operated system with coagulant only and no polymer.
- Jar-tested different polymers.
- Operated system at polymer dose of 0.5 mg/l.
- Jar-tested acid addition to lower pH.
- Operated system with and without feed water strainer.
- Operated system with varying filter loading rates (2.5 to 4 gpm/ft^2).
- Operated system with varying filter backwash frequencies.

Table 6.1 presents the conventional system characteristics and operating parameters for the pilot program.

Table 6.1: Conventional Pretreatment System Characteristics and Operational Parameters

Process	Characteristics	Flow Rate (gpm)	Loading Rate (gpm/ft^2)	HDT (min.)/ Dose (mg/l)
Flocculator	4-foot diameter tank, center flocculation paddle mixer, 5-foot water depth.	30 to 40	N/A	20 to 15
Clarifier	7.5-foot-diameter circular tank, cone bottom clarifier with tube settlers 2-feet deep. 5 feet between distribution inlet and distribution outlet. Internal baffle wall.	30 to 40	0.45 to 0.6	80 to 60
Filter No. 1	36-inches of anthracite with an effective size of 1.0 - 1.1 mm, a specific gravity of 1.55 - 1.65, and a uniformity coefficient <1.7.	28 to 38	3 to 4	N/A
Filter No. 2	24-inches of silica sand with an effective size of 0.45-0.65 mm, a specific gravity of 2.6, and a uniformity coefficient of <1.5. 12-inches of garnet having an effective size of 0.18 - 0.28 mm, a specific gravity of 4.0 - 4.2, and a uniformity coefficient of <2.2.	28 to 38	3 to 4	N/A
Filter Backwash	Source was freshwater. Filtered seawater could also be used. Backwash was set for 5 minutes with filter to waste for 5 minutes.	170	17.7	N/A
Coagulant	Ferric chloride	N/A	N/A	12 to 25
Polymer	PolyFloc from King Lee Technologies	N/A	N/A	0.5

6.3.2 Conventional Pretreatment System Performance

The conventional system performed well overall and generally produced filtered water that was suitable as feed to the SWRO system. An analysis of the conventional pretreatment filtered water turbidity and silt density index (SDI) is presented below. During summer dry period source-water conditions, a ferric coagulant dose of 10 to 12 mg/l and a polymer dose of 0.5 mg/l were required to produce an acceptable filtered water quality. In the winter wet period source-water conditions, the coagulant dose was increased to as much as 25 mg/l to address high source-water turbidities. The filtration rate was also reduced and the backwash frequency increased to handle the increased solids loading on the system.

Initially, the conventional pretreatment system was operated with single-stage (anthracite media) filtration because of an internal bypass problem in the second filter. The filtered water turbidities during this period were near 1 NTU and elevated SDI values for the Conventional SWRO feed water reflect the poor performance of the single-stage filtration. The bypass problem was identified and corrected and filtered water quality immediately improved. This event demonstrated the need for multimedia, deep-bed filtration for this source water.

Also, while the pilot plant conventional pretreatment system was not automated, nor did it have full time operations staff that a full-scale facility would have, the performance of the pilot plant conventional pretreatment system was similar to performance of a similar full-scale conventional pretreatment system for the SWRO facility at Pt. Lisas, Tinidad. The Pt. Lisas SWRO facility has operated for 4 years on a variable bay source water with a similar coagulation, clarification, dual media filtration pretreatment system. The reported average filtrate SDI values for the Pt. Lisas facility ranged from 3.4 to 3.9 – similar to the average SDI values for the MMWD conventional pilot (Thompson, 2006). Therefore, the MMWD pilot plant conventional pretreatment system is fairly representative of a more automated and more closely operated full-scale facility.

The paragraphs below provide more detail on the conventional system filtered water performance with respect to turbidity, SDI, TOC reduction, and system performance. Recommended design criteria for the conventional system are presented in Section 8 of this report.

6.3.2.1 Turbidity and SDI

The conventional pretreatment system average, standard deviation, and 95th percentile clarified and filtered water turbidities, and filtered water and SWRO feed water SDI values are shown in Table 6.2. Table 6.2 does not include data from when the conventional pretreatment system operated with single-stage filtration. Pilot data Figure 3.1 in Appendix 2 shows the source, clarified, and filtered water turbidities over the pilot program, and pilot data Figure 4.1 in this appendix presents the conventional system SDI values.

Table 6.2: Conventional Pretreatment Performance Values

	Clarified Water Turbidity, NTU	Conventional Filtrate Turbidity, NTU	Conventional Filtrate SDI	Conventional SWRO Feed SDI
Average	3.94	0.1	3.89	4.04
Standard Deviation	3.96	0.05	0.53	0.61
95 Percentile Value	12.6	0.16	4.84	4.79

The average conventional pretreatment system's filtrate turbidity and SDI values met the pretreatment system performance objectives. Although the conventional system required careful attention to produce the target water-quality in terms of proper coagulant dose, flocculation time, and clarification and filtration rates, the standard deviation and 95th percentile values show that the performance was relatively consistent. During initial pilot operations, the conventional filtrate tank experienced significant bio-fouling. The tank was painted to block sunlight, and the tank and associated piping were shock-chlorinated approximately every 6 weeks to control bio-growth in the tank. Although not statistically significant, the slightly higher average SDI values in the feed water to the SWRO pilot unit could be due to minor bio-growth in the filtrate tank during the pilot program.

During the relatively low-turbidity dry-season conditions, the clarifier primarily provided additional flocculation contact time for the ferric coagulant to react and form floc particles. During the high-turbidity wet season, the clarifier made a more significant contribution to solids reduction by reducing the turbidity of the feed to the filters. Pilot data Figure 3.1 in Appendix 2 shows the source, clarified, and filtered water turbidities over the pilot program.

The pilot program confirmed the benefit of a coagulation polymer for the conventional process. Table 6.3 shows the impact of polymer on improving the SDI values from the conventional pretreatment system by indicating the difference in values when the polymer was not used for approximately one month.

Table 6.3: Conventional Pretreatment SDI Values with Polymer Addition

Conventional Pretreatment Operating Conditions filtration rate, polymer feed	Average SDI During Operations Period
3.5 gpm/ft^2, 0.5 mg/l polymer addition	3.89
4 gpm/ft^2, no polymer addition	4.32
4 gpm/ft^2, 0.5 mg/l polymer addition	3.66

6.3.2.2 Total Organic Carbon Reduction

As described in Section 3, the source-water total organic carbon (TOC) levels ranged from less than 0.5 mg/l in the dry summer period and spiked up to approximately 7 mg/l in the first major storm flush event. During the spring and winter periods, when source water TOC was above 0.5 mg/l, the conventional system reduced TOC levels by an average of 35%. The coagulant used by the conventional system to create filterable floc particles also acts to coagulate and adsorb dissolved organics in the source water.

6.3.2.3 Conventional System Filtration Rates and Backwash Frequency

During the dry-season source-water conditions, the conventional filters were operated at a rate as high as 4 gallons per minute per square foot (gpm/ft^2) and the filters were backwashed every 48 hours. The clarifier overflow rate was relatively low at 0.6 gpm/ft^2 and was limited by the volume of the flocculation basin. The project team believes that higher overflow rates would be feasible in a full-scale facility if sufficient hydraulic residence time is provided in the flocculation basin ahead of the clarification zone.

During the extremely high-turbidity wet-season source-water conditions, the conventional filtration rate was reduced to 3 gpm/ft^2 and the filters were backwashed every 24 hours. The reduced filtration rates and increased backwash frequency were required to handle the high solids loading while maintaining appropriate filtered water quality.

6.3.3 Conventional Pretreatment System Wastes

The primary wastes from the conventional pretreatment system include spent washwater and suspended solids from filter backwashes and solids from the clarification process. The conventional pretreatment wastes were characterized during the pilot study and Table 6.4 summarizes the estimated general waste stream characteristics of the spent washwater from a conventional system process. The volumes presented in Table 6.4 are approximate volumes for a 15-MGD facility. Technical Memorandum 8 in Appendix 1 describes and characterizes the conventional pretreatment system wastes in more detail.

Table 6.4: General Characteristics Conventional Pretreatment System Spent Washwater

Process Waste	Constituents	Approx. TDS (mg/l)	Approx. TSS (mg/l)	Approx. Volume (gal/day)	Approx. Frequency	Treatment/ Disposal
Clarifier Sludge	Dissolved solids; suspended solids; coagulant, polymer	10,000 to 30,000	17,000	130,000 to 275,000	Periodic blow-down	Remove solids; return supernatant to head of plant
Conventional Filter BW and Filter to Waste	Dissolved solids; suspended solids; coagulant, polymer	10,000 to 30,000	50 to 3,100	1,200,000 to 2,000,000	1 every 18 to 48 hrs	Remove solids; return supernatant to head of plant

The spent washwater for the conventional system equipment contains coagulants, polymers, and solids filtered out of the raw water as well as the dissolved solids present in the water. The spent washwater from the conventional filters systems has a relatively large volume on a per-wash basis but occur with a relatively low frequency. The treatment proposed for this type of waste would be to send it to a Solids Handling System Equalization Basin and then to a clarification system. The clarifier supernatant would be returned to the head of the desalination plant and the clarifier underflow would be treated and dewatered for disposal to a landfill as described in Sections 8 and 9 of this report.

6.4 MF/UF Pretreatment System

The pilot program tested both MF and UF hollow-fiber, immersed membrane systems in parallel. The two systems were the MEMCOR CS microfiltration (MF) system and the Zenon Zeeweed-1000 ultrafiltration (UF) system. The filtered water from the two MF/UF pretreatment systems was combined to provide feed water to a dedicated seawater RO pilot unit (MF/UF SWRO). The MF/UF system operated from mid-May 2005 through April 2006.

6.4.1 MF/UF Operations

The MF/UF pilot systems were operated and optimized in accordance with the pilot plant testing protocol, and adjustments were made based on source-water conditions during the pilot program. The MF/UF pretreatment system operations and testing included the following variations:

- Variable flux rates (22 to 40 gfd)
- Variable system recovery (90 to 95%)
- Variable backwash frequency (25 to 30 minutes)
- With and without daily chemical wash
- With and without ferric coagulation

Table 6.5 below presents the MF/UF system characteristics and operating parameters for the program.

Table 6.5: MF/UF Pretreatment System Characteristics and Operational Parameters

Parameter	Units	Siemens/Memcor	Zenon
Membrane Configuration	--	Submerged	Submerged
Membrane Flow Path	--	Outside-In	Outside-In
Membrane Type	MF/UF	MF	UF
Membrane Model	--	V10S	Z-1000 V3.0/V3.1
Membrane Nominal Pore Size	microns	0.1	0.02
Membrane Material	--	PVDF	PVDF
Active Membrane area of One Membrane Element	ft^2/element	272	450 / 600
Number of Membrane Elements in Pilot Unit	number	4	3
Instantaneous Flux	gfd	25 to 40	25 to 40
Recovery	%	93 to 95	93 to 95
FOULING MANAGEMENT			
Backwash	Frequency	25-30 minutes	25-30 minutes
Chemical Wash (CW)	Frequency	Daily	Daily
CW Duration	minutes	30	25
CW Chemical	Chemical / Dose (mg/l)	NaOCl/ 200	NaOCl/ 100 - 200 Extended aeration used during wet season
Cleaning-in-Place (CIP)	Frequency	30 to 60 days	30 to 60 days
CIP Duration	hrs	2 each chemical	2 each chemical
CIP Chemical #1	Chemical / Dose	Citric Acid / 2% pH2	Citric Acid / 2% pH2
CIP Chemical #2	Chemical / Dose (mg/l)	NaOCl/500	NaOCl/500

6.4.2 MF/UF Pretreatment System Performance

The MF and UF systems performed well overall. They consistently produced filtered water that was suitable for feed to the SWRO system. An analysis of the MF and UF pretreatment filtered water turbidity and silt density index (SDI) is presented below. A coagulant was not required to produce an acceptable filtered water quality. During the wet-period source-water conditions or algal bloom conditions where TOC levels are elevated, a coagulant could be used to reduce dissolved organic concentration, as described below. As was done for the conventional pretreatment system, the MF/UF system filtration rate was reduced and the backwash frequency was increased to handle the increased solids loading on the MF/UF systems during the extremely high-turbidity events in the wet season. The MF and UF membrane systems did not experience any fiber breakage over the 11 months of pilot operation. Visual inspection of the membrane basins showed no mussel or barnacle growth, indicating that the feed water strainer and daily maintenance washes prevented growth of large organisms in the membrane basin.

The MEMCOR CS pilot unit experienced a significant mechanical failure of the permeate pump, which kept the unit from operating for more than two months in August and September

2005. Equipment failures on pilot units do occur, and this failure was unrelated to – and did not adversely impact – the MF membrane system performance. The pilot unit was repaired, and the MF system resumed operation with only minor stoppages for the remainder of the pilot study.

The paragraphs below provide more detail on the MF and UF pretreatment systems' filtered water performance with respect to turbidity, SDI, TOC reduction, and overall system performance. Recommended MF and UF system design criteria are presented in Section 8 of this report.

6.4.2.1 Turbidity and SDI

The MF and UF pretreatment systems average, standard deviation, and 95th percentile filtered water turbidities, and filtered water and SWRO feed water SDI values, are shown in Table 6.6. Pilot data Figures 2.1 and 2.3 in Appendix 2 shows the source and filtered water turbidities for the UF and MF systems, respectively, over the pilot program. Pilot data Figure 4.1 in Appendix 2 presents the MF and UF filtrate SDI values.

Table 6.6: MF/UF Pretreatment Performance Values

	MF Filtrate Turbidity, NTU	UF Filtrate Turbidity, NTU	MF Filtrate SDI	UF Filtrate SDI	MF/UF SWRO Feed SDI
Average	0.06	0.05	2.61	2.56	2.71
Standard Deviation	0.04	0.04	0.51	0.48	0.72
95th Percentile Value	0.08	0.09	3.39	3.32	3.67

The average MEMCOR CS MF system and Zenon UF system filtrate turbidity and SDI values consistently met the pretreatment system performance objectives. While the UF system had lower average turbidity and SDI values than the MF does, the differences are not considered to be statistically significant. During initial pilot operations, the MF/UF filtrate tank experienced significant bio-fouling. The tank was painted to limit light penetration and the tank and piping were shock-chlorinated approximately every 6 weeks to control bio-growth. The slightly higher average SDI values in the feed water to the SWRO pilot unit could be due to minor bio-growth in the filtrate tank during the pilot study; however a statistical analysis of the SDI has not been performed to determine if the difference is significant.

6.4.2.2 TOC Reduction

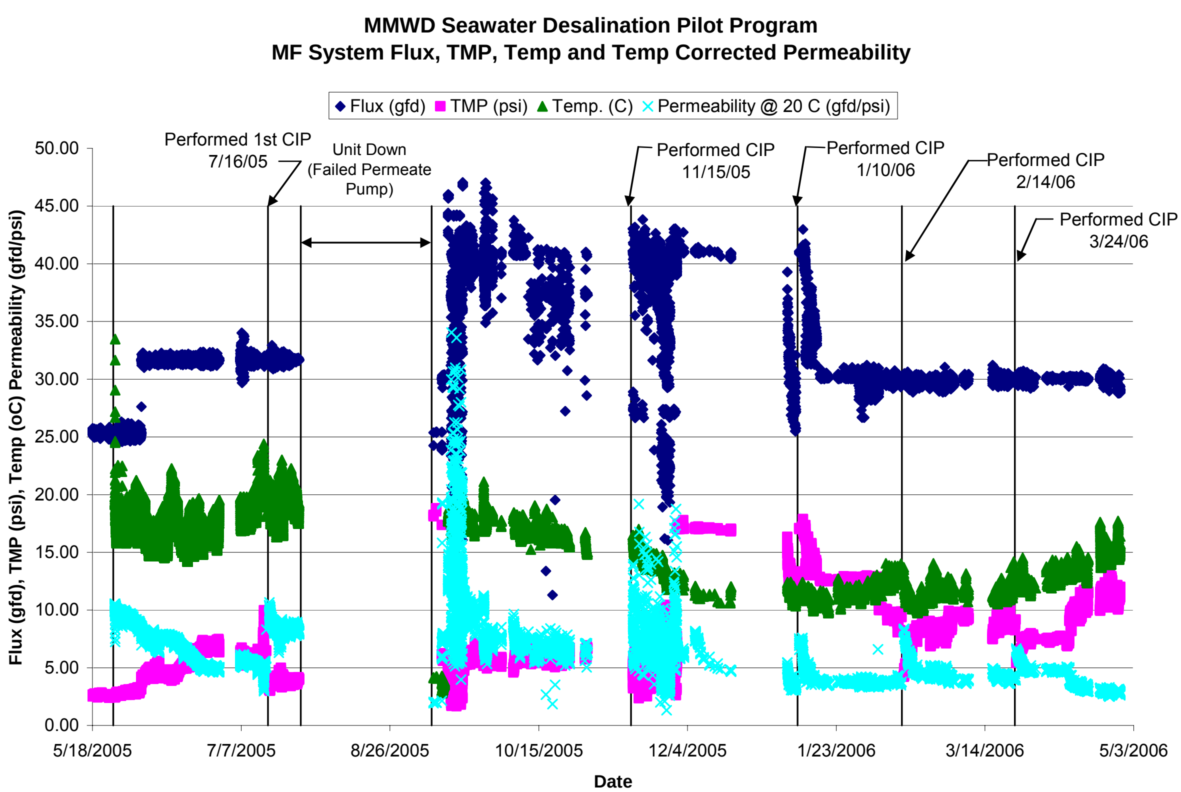
As described in Section 3, the source water TOC levels ranged from less than 0.5 mg/l in the dry summer period and spiked up to approximately 7 mg/l in the first major storm flush event. During the spring and winter periods, when source water TOC was above 0.5 mg/l, the MF and UF systems reduced TOC levels by an average of 16%. This is less than achieved by the conventional system and is attributable to the lack of coagulation/flocculation prior to the MF/UF units. The coagulant used by the conventional system to create filterable floc particles also acted to coagulate and adsorb dissolved organics in the source water.

Ferric coagulant was tested ahead of the MF and UF filters for approximately two weeks in March 2006 to evaluate TOC reduction. The source water TOC during this period was approximately 2 mg/l. The coagulant was dosed at 10 mg/l and rapidly mixed, and the coagulated water had approximately 10 minutes of contact time before filtration. Pre-coagulation reduced the TOC levels by approximately 50% during the testing period. Based on this result, it can be assumed, therefore, that coagulation ahead of MF/UF filters in a full-scale seawater desalination facility would reduce TOC levels to a degree equal to or better than conventional pretreatment.

6.4.2.3 MF/UF System Flux, Permeability, and Cleaning Frequency

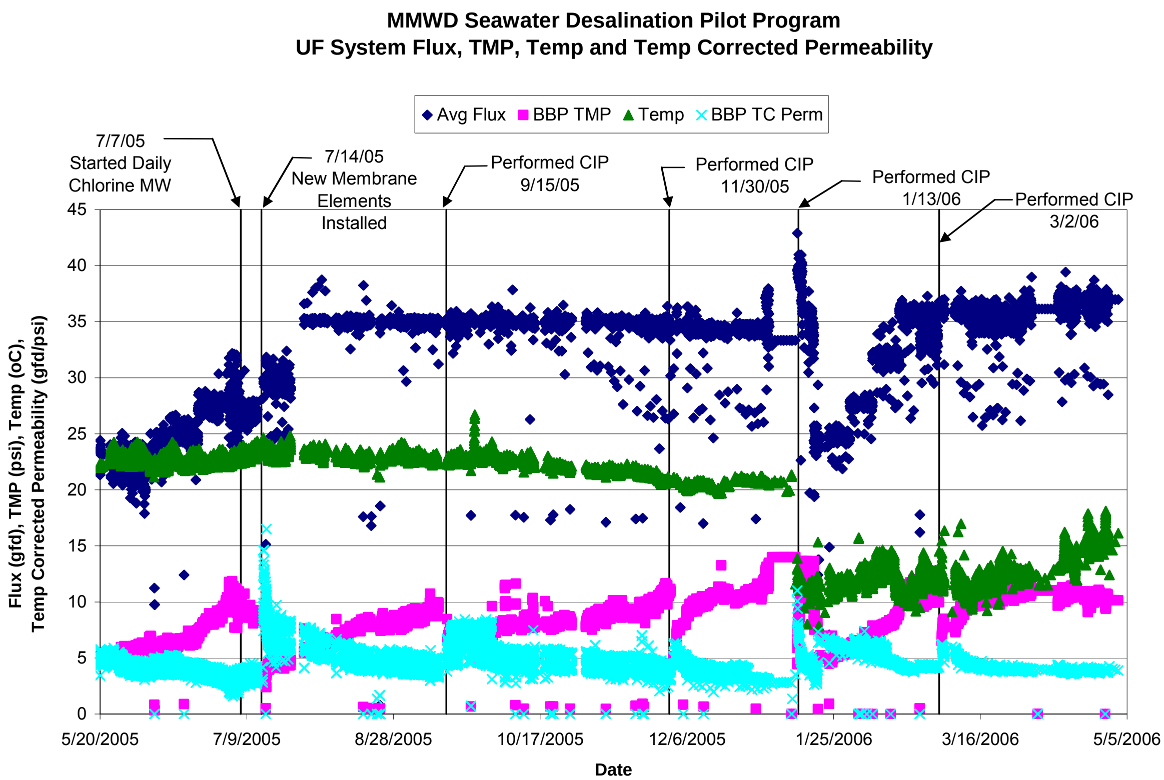
Time-dependent plots of MF and UF system flux, trans-membrane pressure (TMP), and temperature-corrected permeability are shown in Figures 6.1 and 6.2, respectively. These data are also presented in pilot data Figures 2.2 and 2.4 in Appendix 2.

Figure 6.1: MF System Flux, TMP, and Permeability



The MF system TMP rise and permeability decrease were relatively stable, with flux rates in the range of 30 to 35 gallons per foot squared per day (gfd) and with the backwash and chemical wash regimen described in Table 6.5 above. During the dry season (low source water turbidity and TOC), the MF system was able to operate for 60 days before cleaning. The MF system operated at relatively high flux rates, above 40 gfd, from September 2005 to November 2005 but the pilot unit could not achieve stable operation at these high flux rates at the onset of the wet season in December 2005. During the high-turbidity wet season, the flux rate was reduced to 30 gfd, and cleanings were conducted at closer to 30-day intervals because of the higher solids loading on the system.

Figure 6.2: UF System Flux, TMP, and Permeability



The UF system TMP rise and permeability decrease were relatively stable, with flux rates in the range of 25 to 35 gfd and with the backwash and chemical wash regimen described in Table 6.5 above. During the dry season, the UF system was able to operate at 35 gfd with 95% recovery, with an expected 60 days before cleaning. During the high-turbidity wet season, the UF flux rate was initially reduced to 25 gfd, and cleanings were conducted at closer to 30-day intervals because of the high solids loading on the system. The daily cleaning strategy was adjusted to include an extended aeration period in conjunction with a heated daily chemical wash. With the adjusted cleaning strategy, the UF system was able to achieve a flux of 35 gfd with a 95% recovery, and the TMP rise and permeability decrease were relatively stable although the TMP stabilized at a value (10-11 psi) that is near the maximum operating TMP (12 psi). The expected CIP frequency with the extended aeration cleaning is greater than 45 days.

The performance of the MF/UF systems indicate that a higher flux can be used in the dry summer months when source water turbidity and TOC levels are low, but must be reduced during wet periods when surface runoff and higher Delta flows increase solids and organics loading increase membrane fouling rate.

6.4.2.4 MF/UF Membrane Integrity

Membrane integrity testing (MIT) of the MF and UF systems over the pilot program was conducted daily and was within the standard system parameters. The MIT testing indicated that the membranes did not experienced damage from the strained feed water.

6.4.3 MF/UF Pretreatment System Waste

6.4.3.1 Backwash Wastes

The MF/UF pretreatment wastes were characterized during the pilot study and Table 6.7 summarizes the estimated general waste stream characteristics of the spent washwater from a MF/UF pretreatment system process. The volumes presented in Table 6.7 are approximate volumes for a 15-MGD facility. Technical Memorandum 8 in Appendix 1 describes and characterizes the MF/UF pretreatment system wastes in more detail.

Table 6.7: General Characteristics MF/UF Pretreatment System Spent Washwater

Process Waste	Constituents	Approx. TDS (mg/l)	Approx. TSS (mg/l)	Approx. Volume (gal./day)	Approx. Frequency	Treatment/ Disposal
Strainer BW	Dissolved solids; suspended solids	10,000 to 30,000	250	90,000	1 every 60 to 120 minutes	Remove solids; return to head of plant
MF/UF BW	Dissolved solids; suspended solids	10,000 to 30,000	170 to 370	2,400,000	1 every 22 to 30 minutes	Remove solids; return to head of plant

The spent washwater for the MF/UF system equipment contains solids filtered out from source water, adsorbed (or coagulated) organics as well as the dissolved solids present in the source water. The spent washwater from the strainer and MF/UF systems has a relatively small volume on a per-wash basis, but it occurs with a relatively high frequency as compared to conventional pretreatment. The treatment proposed for this type of waste would be to send it to a Solids Handling Equalization Basin. The recycled water would be returned to the head of the desalination plant and the solids would be treated and dewatered for disposal to a landfill as described in Sections 8 and 9 of this report.

6.4.3.2 MF/UF Cleaning Wastes

The MF and UF pilot systems were periodically removed from service and a chemical clean-in-place (CIP) procedure performed to restore the membrane permeability. Chemicals used during CIP included sodium hypochlorite and citric acid. Following completion of a CIP, the spent chemical solutions were neutralized using sodium bisulfite or caustic soda, respectively. It is anticipated that the neutralized CIP solution wastes from a full scale facility would to be disposed of by discharge to the San Rafael Sanitation District's (SRSD) sanitary sewer and to the Central Marin Sanitation Agency's (CMSA) plant for treatment.

Technical Memorandum No. 9 in Appendix 1 of this report provides a detailed discussion on MF/UF and RO system CIP wastes. The nature of the cleaning chemicals used by the MF/UF process and the quality of the spent CIP solution wastewater indicate that discharge of neutralized CIP wastes to the SRSD sanitary sewer and to the CMSA plant for treatment should be acceptable. CMSA reviewed Technical Memorandum No. 9 and commented that based on their current discharge permits, the CIP wastes would be acceptable for discharge to the sanitary sewer and treatment at CMSA's treatment plant.

6.5 First-Pass SWRO System

Two skid-mounted SWRO pilot units were used to demonstrate the impact of the pretreatment systems on the SWRO membranes. One SWRO pilot unit (MF/UF SWRO) received feed water from the MF/UF pretreatment system and the other (Conventional SWRO) received feed water from the conventional pretreatment system. The SWRO system skids were configured to permit testing of as many as three different manufacturer's membrane elements in parallel. The SWRO elements tested were 4-inch-diameter, 40-inch-long, spiral-wound, high-rejection, thin-film-composite (TFC) type provided by the following manufacturers: (1) Dow/Filmtec, (2) Hydranautics, (3) Toray, and (4) Koch. Both SWRO pilot units were a single-pass system with six membrane elements arranged in series to simulate a full-scale system RO design. Table 6.8 below presents the advertised characteristics of SWRO membrane elements used for the pilot program.

Table 6.8: SWRO Membrane Element Characteristics

		Manufacturer			
Parameter	**Units**	**Dow/Filmtec**	**Hydranautics**	**Toray**	**Koch**
Element Model	–	SW30HR LE	SWC4+	TM810/ 820	2822 SS-360 Premium
Membrane Material	–	Polyamide TFC	Polyamide TFC	Polyamide TFC	Polyamide TFC
Membrane Area (4-inch)	ft^2	85	80	73	73
Feed spacer thickness (4-inch)	mil	28	26	31	28
Membrane Area (8-inch)	ft^2	400	400	400	360
Feed spacer thickness (8-inch)	mil	28	26	31	28
Advertised Permeate Flow (8-inch)	GPD	7,500	6,500	6,000	5,500

		Manufacturer			
Parameter	**Units**	**Dow/Filmtec**	**Hydranautics**	**Toray**	**Koch**
Max. Calculated Element Flux (8-inch)	GFD	18.8	16.3	15	15.3
Advertised Salt Rejection (Minimum)	%	99.60	99.70	99.50	99.75
Advertised Single-element Boron Rejection	%	91	92	90	NA

NA – not available

6.5.1 SWRO Operations

The SWRO pilot units operated for approximately 4,500 hours from June 2005 through April 2006. The SWRO pilot systems were operated and optimized in accordance with the pilot-plant testing protocol, and adjustments were made based on source-water conditions during the pilot program. The project team performed the following SWRO system operations and testing activities:

- Operated three different SWRO elements in each of two parallel pilot units.
- Performed conductivity profiles on each membrane train.
- Replaced Dow and Toray elements that exhibited excessive permeate conductivities.
- Performed CIPs on both SWRO units.
- Increased feedwater recovery from 40 to 50%.
- Increased flux from 8 gfd to 10 gfd (and then back to 8 gfd during the wet season).
- Replaced Toray elements in SWRO Unit No. 1 with Koch elements.

6.5.2 First-pass SWRO System Performance

The SWRO systems performed well overall and demonstrated that the SWRO process can reliably desalinate Northern San Francisco Bay water. Sections 4 and 5 of this report discuss the permeate water quality from the first-pass SWRO systems. Technical Memorandum No. 10 in Appendix 1 provides a detailed evaluation of the SWRO system performance. This section provides an overview of the two SWRO systems' performance in terms of the primary process parameters used to assess RO system performance: normalized flow, salt passage, and vessel differential pressure (fouling). Pilot data Figures 4.2 through 4.8 in Appendix 2 present time-dependent operational data for MF/UF SWRO over the pilot program period. Pilot data Figures 5.2 through 5.8 in Appendix 2 present time-dependent operational data for Conventional SWRO over the pilot study period.

The SWRO elements from two manufacturers (Dow and Toray) exhibited poor performance initially in terms of salt rejection as compared to the advertised and projected performance. This performance shortfall was attributable to the hand-manufacture of these special elements for this pilot study, which were not available as a standard 4-inch product. The deficient elements were replaced with new elements, also hand manufactured, and the salt rejection improved to the expected levels. Elements for a full scale facility would be standard 8-inch or larger elements and not expected to have these performance problems.

A leak developed in the Hydranautics element vessel in the MF/UF SWRO after approximately 5 months of operation. The project team probed and inspected the elements and isolated the leakage to a single element in the train. The project team, with concurrence from the District and their advisor, decided to leave the element in place so that differences in the long-term fouling of the Hydranautics elements operating on the two pretreated feedwaters could be better determined.

Over the course of the pilot program, the SWRO pilot units were shut down periodically for planned operations, including raw water and pretreatment system shock chlorination, MF/UF CIPs and RO CIPs. To control project costs, the pilot plant was designed without the full redundancy and automated controls that are typical of a full-scale facility, which necessitated these planned shutdowns. RO unit shutdowns also occurred due to unplanned outages of the intake pump and pretreatment system and to the RO units as well. It is recognized that shut downs can have potential negative impacts on RO unit performance including: (1) increase in scaling or bio-fouling if the unit is not flushed after shutdown; (2) increase in salt passage due to mechanical stress on the elements and o-ring connections from startup and shutdown; and (3) reduced fouling due to relaxation and displacement of the fouling layer from permeate backflow. The project team carefully evaluated the performance of the SWRO systems throughout the testing period. Based on the overall SWRO system performance and SWRO membrane autopsy results, the team judged that the SWRO unit shutdowns did not negatively impact the physical integrity of the SWRO membrane elements nor the evaluation of the long-term fouling of the systems. Technical Memorandum Nos. 10 and 11 in Appendix 1 provide a detailed discussion of SWRO performance and results of autopsies conducted on selected RO elements following completion of the pilot testing, respectively.

6.5.2.1 Normalized Performance Parameters

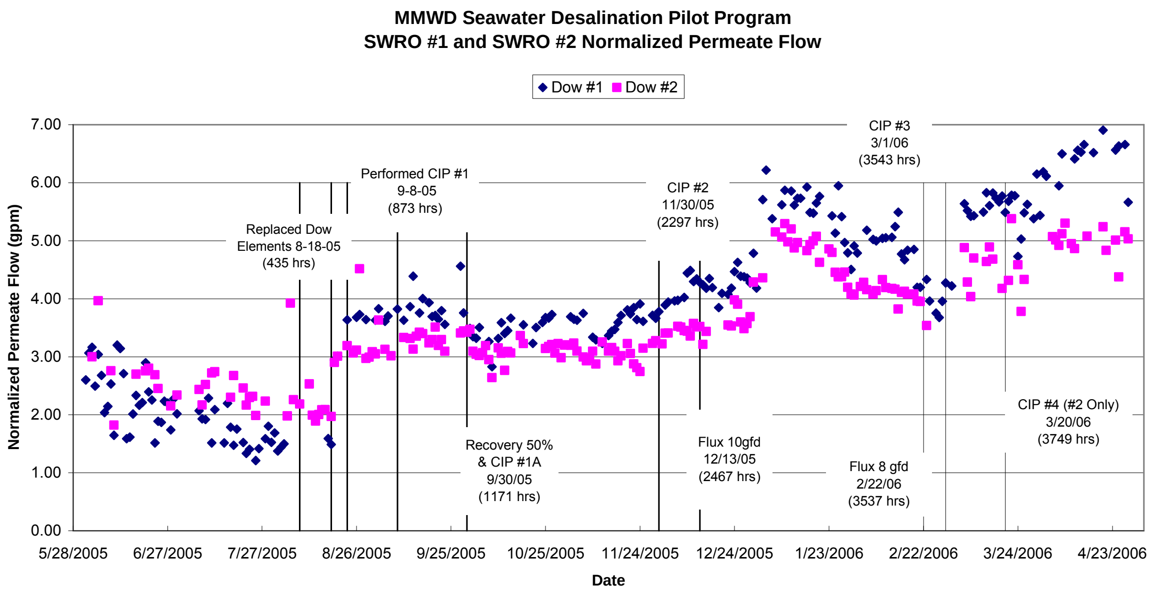
RO system performance was evaluated using the parameters listed below, The operating data from the SWRO units must be “normalized” through these performance parameters to account for the effects of variations in feed water temperature and salinity as wells as membrane flux and recovery that would otherwise mask changes caused by fouling.

- Normalized permeate flow (NPF), which measures the change in resistance of water flow through the RO membrane
- Normalized salt passage (NSP), which measures the change in resistance to salt (conductivity) flow through the membrane
- Normalized differential pressure (DPN), which measures the degree of accumulation of material in the feed/brine space

Figures 6.3 and 6.4 below show the NPF and the NSP for the Dow membrane trains in the MF/UF SWRO and Conventional SWRO. Only data from the Dow trains are presented herein to simplify comparison of the effect of the two pretreatment systems. Pilot data Figures 4.5 through 4.8 in Appendix 2 present time-dependent normalized operational data for all three membrane element trains in MF/UF SWRO over the pilot program period. Pilot data Figures

5.5 through 5.8 in Appendix 2 present time-dependent operational data for all three membrane element trains in Conventional SWRO.

Figure 6.3: Comparison of SWRO Normalized Permeate Flow



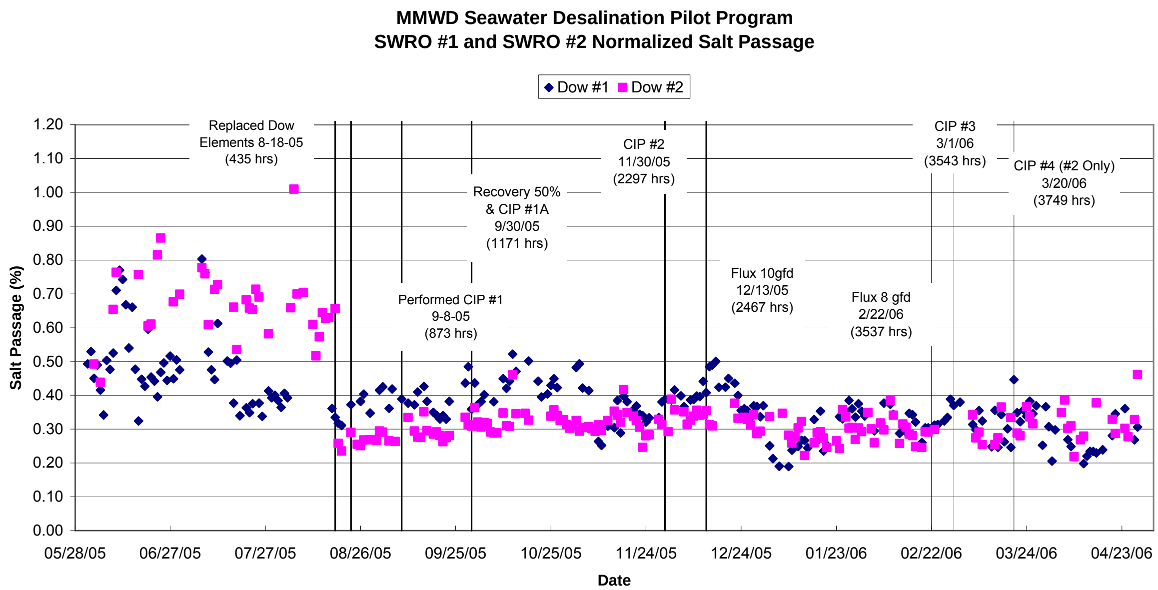
Note: MF/UF SWRO is SWRO #1; Conventional SWRO is SWRO #2

The trend in NPF for the Dow/Filmtec elements from MF/UF SWRO and from the Conventional SWRO are similar for the majority of the pilot program. The Dow/Filmtec elements were replaced in August 2005; the difference in the NFP for MF/UF and Conventional SWRO systems (SWRO Nos. 1 and 2 respectively) remained essentially constant until March 2006. The divergence of the NPFs in March and April of 2006 could be an indication of greater fouling in Conventional SWRO. The decrease in NPF from January 2006 to March 2006 could be indicative of membrane system fouling, but it also could be partially due to increasing source-water salinity after a sharp drop in salinity due to major winter storms (inadequate data normalization). See Figure 3.1 in Section 3. Wet testing of the number 2 Dow elements in the two trains at the end of the pilot testing showed no significant change in NPF (as measured by product flow) as compared to the initial wet test data.

The normalized salt passage (NSP) for the Dow/Filmtec elements from MF/UF and Conventional SWRO systems (SWRO Nos. 1 and 2 respectively) are presented in Figure 6.4 as a function of operating date. The NSP of the two units are essentially the same over the period of the pilot program, and are, generally, stable to slightly decreasing. The slight decrease in NSP over the study could be indicative of the formation of a fouling layer having some salt rejection properties, or the significant decrease in source water salinity in late December 2005 and January 2006 that continued through April 2006, or both. Wet testing of the number 2 Dow FilmTec elements in the two trains at the end of the pilot testing showed that salt passage was equal to or very slightly reduced following testing compared with new.

This indicates that fouling experienced during the testing (and chemical cleaning) had no adverse impact on salt rejection.

Figure 6.4: Comparison of SWRO Normalized Salt Passage



Note: MF/UF SWRO is SWRO #1; Conventional SWRO is SWRO #2

6.5.2.2 SWRO Membrane Fouling

This section describes probable contributors to RO membrane fouling associated with operation of the SWRO pilot units. Technical Memorandum No. 10 in Appendix 1 presents a more detailed analysis of membrane system fouling for the two SWRO systems over the course of the pilot program. The nature and rapidity of fouling experienced by RO systems operated with sea or estuarine waters depends on many factors, most notably source water quality and the type of treatment the source water is provided (pretreatment) prior to RO processing.

RO membrane fouling is a function of four primary factors:

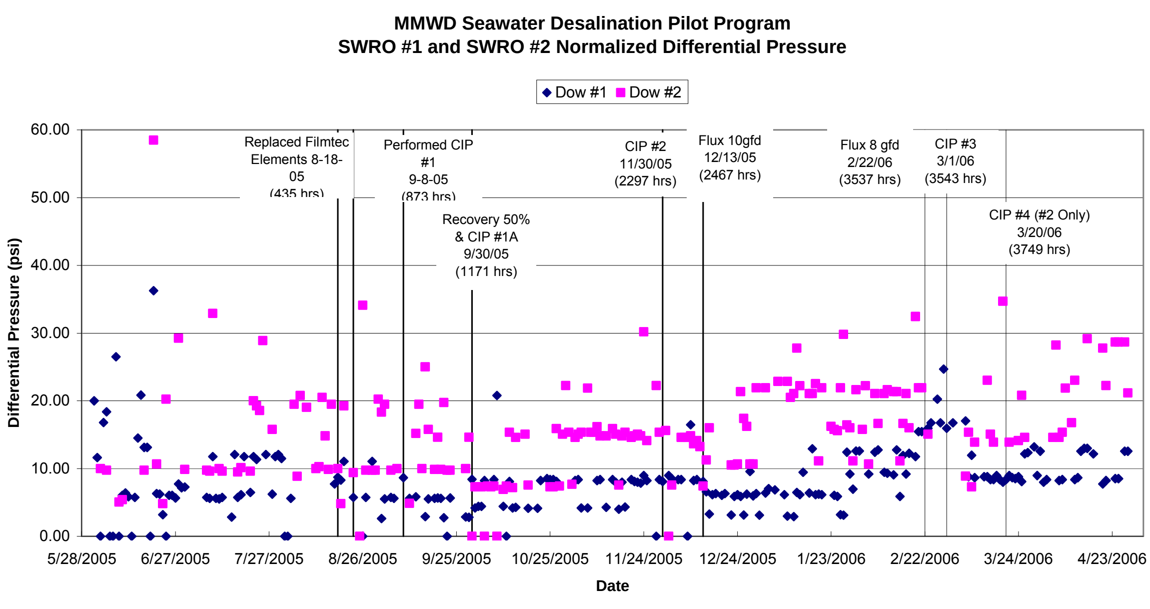
1. Scaling and depositions - precipitation of sparingly soluble salts
2. Particulate fouling - accumulation of particulate inorganic and particulate organic matter
3. Bio-fouling - attachment and growth of microbes, microorganisms, and/or marine life
4. Organic fouling - deposition of colloidal and dissolved organics

In the MMWD pilot program, MF/UF and conventional pretreatment systems were employed to control fouling caused by accumulation of inorganic/organic matter (factor #2) while a scale inhibitor was used to control scaling (factor #1). Bio-fouling (factor #3) was managed as-needed using periodic shock-chlorination of pretreatment systems, including filtrate tanks and piping, as well as reduction in bacterial concentrations through coagulation and/or filtration. The SDI values of the filtrates produced by the two pretreatments indicate that fouling by inorganic and organic particulate matter was adequately controlled. The use of antiscalant, combined with the low scaling potential of the Bay water at the moderate feedwater recoveries employed in the study, should effectively prevent scaling.

The primary foulants present in the feed water to the SWRO pilot units were soluble organics and marine organisms, including bacteria, associated nutrients, and water temperature that can cause biofouling. Ferric-coagulated colloids, not completely retained by the granular media filter, represent a secondary class of foulants.

Figure 6.5 below shows the normalized differential pressure (DPN) for the Dow membrane trains to permit comparison of the effect of the two pretreatment systems on the SWRO systems. Of the three RO performance parameters, DPN is the most sensitive to the accumulation of foulants in the feed/brine spacer, and to the growth of a biofilm. The DPN values for the Dow/Filmtec elements from the MF/UF and Conventional SWRO systems (SWRO Nos. 1 and 2 respectively) are similar and stable during the initial and middle of the pilot program period but show some divergence beginning in January 2006, which corresponds with an increase in Bay water turbidity and organics. See Figure 3.1 in Section 3 for the variation in source water turbidity and TOC over the pilot study.

Figure 6.5: Comparison of SWRO Normalized Differential Pressure



Note: MF/UF SWRO is SWRO #1; Conventional SWRO is SWRO #2

In the period between mid January and March 2006, MF/UF SWRO experienced fouling such that a CIP was required. We believe that the MF/UF SWRO DPN increase in January 2006 was mainly due to the growth of bacteria (mainly originating from the pilot tanks and piping as opposed to the source water) in the SWRO elements when TOC levels in the source water increased, increasing the amount of bioassimilable organic matter that would serve as a source of “food” for the bacteria in the RO feedwater or attached to the membrane surface. As the bacteria on the RO membrane surface increased, the differential pressure in the SWRO system increased.

In contrast to MF/UF SWRO, in the period between early January and March 2006, the near concurrent increase in DPN of Conventional SWRO with the start of the wet season indicates that the conventional pretreatment system was not as effective as the MF/UF system in controlling solids breakthrough to the RO system. The results of the membrane autopsy of the lead and second Dow FilmTec membrane elements showed that there was a greater amount of inorganic and organic foulants on the conventional pretreatment elements (Conventional SWRO) than there were on the MF/UF pretreatment elements (MF/UF SWRO). The CIP cleaning of the Conventional SWRO membranes removed the foulant and restored the DPN but the system exhibited continuing fouling through March and April 2006.

To minimize bio-fouling with conventional and MF/UF pretreatment in a full-scale facility, we recommend these measures:

- Adding a coagulant before the MF/UF filters during storm events and other periods with high source-water TOC to reduce bioassimilable organic matter.
- Operating the SWRO elements with a flux rate of 8 gfd during storm events and other periods with high source-water TOC.
- Conducting a CIP cleaning following large changes in source water quality such as occurred during the first major storm event of the wet season.

Technical Memorandum No. 10 in the Appendix presents a more detailed analysis of membrane system fouling for the two SWRO systems over the course of the pilot program.

6.5.2.3 SWRO Membrane Autopsy Results

The physical dissection and autopsy of an RO membrane, followed by characterization of membrane foulant, can be a useful tool in investigating and trouble-shooting the performance of an RO system. The information from the autopsy can help the project team to understand changes in membrane element productivity, salt rejection and pressure drop, and the amount of foulant, and to identify foulant characteristics (mix of inorganic, organic, and microbial material). The information from the autopsy may also help to highlight possible differences in the performance of the pretreatment systems in controlling RO membrane fouling and it may provide insight into operational strategies for minimizing fouling in a full-scale facility. A detailed discussion of the results of dissection and autopsy of selected membrane elements are discussed in Technical Memorandum No. 11 in Appendix 1.

Parallel and identical analysis of elements from the MF/UF and Conventional SWRO system were conducted to provide insight into differences between the two pretreatment systems with respect to degree and type of membrane foulant. The conclusions of the specialized and standard membrane analysis performed on the parallel elements include:

1. MF/UF pretreatment was more effective in limiting the amount of foulant deposited with the RO elements. Conventional pretreatment allowed more particulate material to accumulate within the element and at the membrane surface, particularly inorganic material. The foulant present in the elements pretreated by conventional treatment contained iron, most likely carryover from ferric coagulation, as well as clay particles, presumably from the source water. The clay particles (aluminum silicates) were significant and constituted the majority of the inorganic portion of the foulant, along with iron.

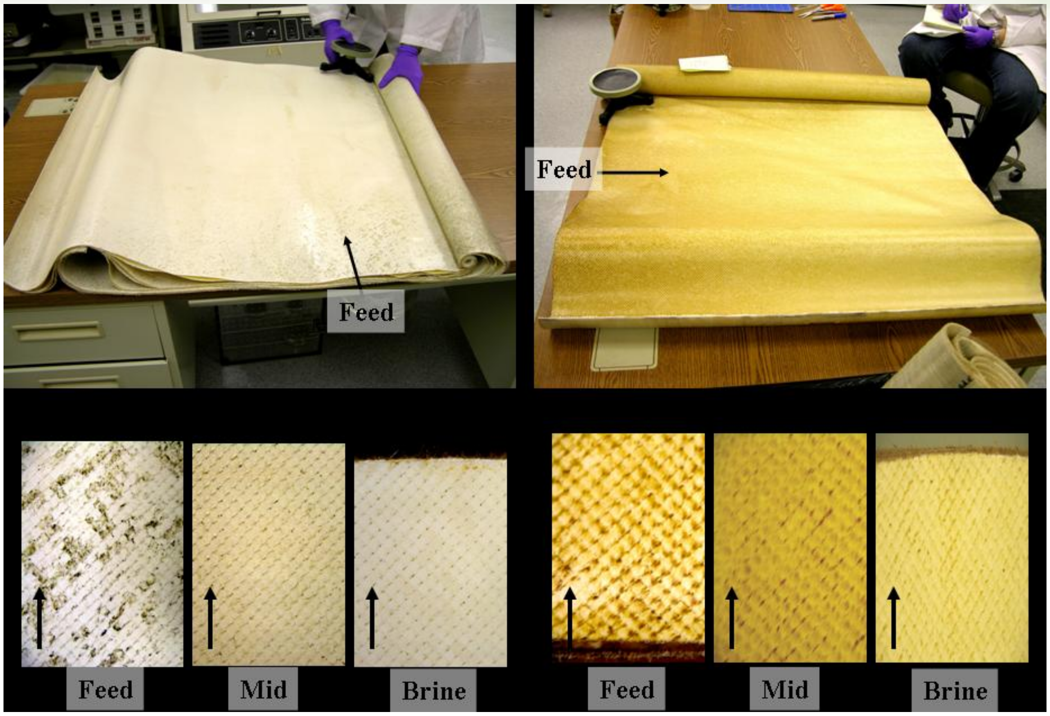
2. There were iron oxide particles in the permeate carrier of the elements pretreated by conventional treatment. This is an unusual finding and the cause of this is not clearly understood. Appreciable passage of dissolved or precipitated iron through a seawater RO membrane is not anticipated (passage rate should be <0.1 percent).

3. The presence of both proteins and carbohydrates (P/CH) in the foulant indicates that bacterial fouling occurred with both types of RO feed water pretreatment. The amount of biological material was greater in the foulant removed from the conventionally pretreated elements. The spatial pattern of P/CH deposition from feed to concentrate end as well as the P/CH ratio differed for each type of pretreatment. These differences may indicate a shift in the physiological state of the bacteria and the state of activity (exopolymeric substance secretion versus active growth phase) (Phone discussions with Don Phipps, Laboratory Autopsy Director, Orange County Water District).

4. Despite the presence of foulants and the noted differences, the performance of elements receiving the two types of pretreated feed waters was within membrane manufacturers’ specifications.

5. No chlorine uptake or damage was observed by the qualitative methods employed. This is consistent with wet test results, which indicated salt rejection in compliance with specifications.

Photos of SWRO Membrane Visual Analysis



SWRO Element with MF/UF Pretreatment

SWRO Element with Conventional Pretreatment

6.5.2.4 SWRO Cleaning Frequency

Since both source-water quality and pretreatment varies from location to location, the frequency and type of RO cleaning needed to maintain system performance also varies. The typical frequency of CIP cleaning for SWRO facilities is generally two to three times per year (every 4 to 6 months) where feed water pretreatment is satisfactory. Some SWRO facilities perform cleanings less frequently, while other facilities clean more often depending upon the level of foulants present and the ability of the pretreatment to adequately reduce or manage these foulants.

Technical Memorandum No. 10 in Appendix 1 presents a detailed discussion of the CIP cleanings performed on the two SWRO systems over the course of the pilot program and the expected SWRO system cleaning frequencies. For the purposes of the pilot study, CIPs were also conducted in conjunction with changes in the operating conditions of the SWRO units (flux and recovery) so that the effect of a change could be more clearly determined. Thus, CIPs were conducted more often during the program than they would be for a full-scale plant, where such changes are not part of a typical operating scenario.

The estimated annual number of CIP cleanings for each SWRO system during a typical year is presented in Table 6. A typical year could have a dry season of approximately 7 to 8 months and a wet period of approximately 4 to 5 months. The number of CIPs is based on the fouling performance of the SWRO systems described above and on the results of the membrane element autopsies conducted at the end of the pilot program. The autopsy results indicated that the SWRO elements after the conventional pretreatment generally had a greater amount of foulants than did the SWRO elements after the MF/UF pretreatment. This greater amount of fouling would lead to more frequent CIP cleanings.

Table 6.9: Estimated Annual Number of SWRO CIPs

SWRO System	Pretreatment Type	Typical Source Water	Estimated No. of CIPs	Estimated Total Annual CIP's
MF/UF SWRO	MF/UF Pretreatment	Dry Season	1	--
		Wet Season	2	--
		Total	--	3
Conventional SWRO	Conventional Pretreatment	Dry Season	1 to 2	--
		Wet Season	3	--
		Total	--	4 to 5

For the MMWD desalination facility, it is estimated that an SWRO system with MF/UF pretreatment would have one to two fewer CIPs per year than would an SWRO system with conventional pretreatment. Depending on the effectiveness of cleaning, this may result in a shorter membrane life for an RO system operated on feed water pretreated by conventional treatment.

6.5.2.5 SWRO Performance Conclusions

The performance of the elements operated in the MF/UF SWRO system is acceptable with respect to all performance parameters (NPF, NSP, and DPN). The increase in DPN and presence of bacteria on membrane surface of lead elements could be effectively managed through periodic disinfection and coagulation. Another potential approach to managing the impacts of biofuoling could be to replace the lead elements or rotate them into the tail position in the vessel.

Expectations and recommendations for a full-scale SWRO facility with MF/UF pretreatment include:

- Flux of 9 gfd is recommended based on minimizing fouling and reducing energy use. The recommended flux rate of 9 gfd is based on the performance of the SWRO systems during the pilot study at flux rates of 8 and 10 gfd. At a flux rate of 8 gfd the SWRO systems exhibited acceptable performance in both the wet and dry seasons as described above and in more detail in TM 10. At 10 gfd, the SWRO systems exhibited acceptable performance for a short period in the dry season but showed increased DPN in the wet season. The recommended 9 gfd provides some conservatism based on pilot study. Work by the Affordable Desalination Collaboration (ADC) has also shown advantages for operational energy savings by operating at lower flux rates and system recoveries. In evaluating total water cost (both capital and operational costs)

the ADC has recommend a SWRO system flux of 9 gfd and recovery of 50% for the lowest total water cost for ocean water desalination (Seacord, 2006).
- During wet-season or high-organics conditions, we recommend using a coagulant to reduce potential bio-fouling by reducing the level of dissolved organics (additional food source) that can promote biofouling.
- Frequency of disinfection (chlorination) of facilities from intake through RO piping should be increased during rainfall periods when biofouling potential is greatest.
- CIPs may be required every 4 to 6 months or less often under dry-season operating conditions.
- CIPs may be required every 3 to 4 months during wet-season conditions depending upon the effectiveness of recommended coagulation and periodic disinfection biofouling control methods.

The performance of the elements operated in the Conventional SWRO system is acceptable based on observed changes in NPF and NSP. The rate of DPN increase from particle fouling for Conventional SWRO was higher than for MF/UF SWRO and will increase the frequency of CIP chemical cleaning. Membrane life may be shorter, and CIP cleaning costs would be greater. Expectations and recommendations for a full-scale SWRO facility with conventional pretreatment include the following:

- Flux of 9 gfd is recommended based on reducing minimizing fouling and energy use.
- Frequency of disinfection (chlorination) of facilities from intake through RO piping should be increased during rainfall periods and when biofouling potential is greatest.
- CIPs may be required every 4 to 6 months under dry-season operating conditions.
- CIPs may be required every 2 to 4 months during wet-season conditions.
- Deep bed filter beds could improve filtration performance (discussed in Section 8).

A comparison of the MF/UF and conventional pretreatment systems based on performance, estimated capital and operating costs and non-cost factors is presented in Section 8 of the Report. The MF/UF pretreatment is the recommended pretreatment process.

6.5.3 SWRO System Wastes

The primary wastes from the first-pass SWRO and second-pass RO systems include brine wastes that contain concentrated dissolved solids from the source water and a small amount of anti-scalant and sodium bisulfite. Additional wastes include cleaning wastes from the RO systems and wastes associated with placing the RO systems in a lay-up condition for long shutdowns.

6.5.3.1 First-Pass SWRO and Second-Pass RO Brine Waste

The brine from the first-pass SWRO would be disposed of by blending with the relatively low-TDS effluent discharged into the San Francisco Bay from the current wastewater treatment facility owned and operated by the Central Marin Sanitation Agency (CMSA). The CMSA effluent would dilute the brine, and the resulting combined discharge would have a salinity nearer to that of the Bay than the current CMSA effluent. The second-pass RO brine is less concentrated and can therefore be recycled and blended with the feed to the first-pass SWRO process.

Table 6.10 summarizes the general characteristics of the first- and second-pass SWRO waste streams for a 15-MGD facility.

Table 6.10: RO Brine Waste General Characteristics

Brine	Constituents	Approx. TDS (mg/l)	Approx. TSS (mg/l)	Approx. Volume (gal./day)	Frequency	Treatment/ Disposal
First-Pass SWRO Brine	Dissolved solids, antiscalant, bisulfite	30,000 to 60,000	~0	15,000,000	Continuous	Blend with CMSA effluent and discharge through outfall
Second-Pass RO Brine	Dissolved solids, antiscalant	1,000	~0	Varies depending on source water quality	Continuous	Recycle to the feed for the first-pass SWRO

Technical Memorandum No. 8 in Appendix 1 presents more extensive waste characterization analysis of the first-pass SWRO brine based on analysis of brine samples collected during the pilot program. The first-pass SWRO brine quality will vary as the source-water quality varies. Bioassay testing of the brine and CMSA effluent also was conducted, and the results are presented in Section 7 of this report.

6.5.3.2 SWRO Cleaning Wastes

This section describes the general characteristics and expected frequency and volumes of the periodic chemical CIP waste from the RO membrane systems for a full-scale 15-MGD capacity desalination facility. These wastes are anticipated to be neutralized and disposed of by discharge at a controlled rate to the SRSD sanitary sewer and the CMSA plant for treatment.

Technical Memorandum No. 9 in Appendix 1 presents a detailed discussion on these wastes. The cleaning chemicals used by the desalination process and the quality of the spent CIP solution wastewater indicate that discharge of neutralized CIP wastes to the SRSD sanitary sewer and to the CMSA plant for treatment should be acceptable. The volume of wastes generated over a given period will depend on the cleaning approach, but in any case, this volume is expected to be in a range that would be acceptable to SRSD and to CMSA.

Staff from CMSA reviewed Technical Memorandum No. 9, and, on the basis of the analysis results in the TM and the reported range of flow rates from a 15-MGD facility, they conceptually agree with its assessment. CMSA Staff commented that the estimated CIP flow rate would not impact CMSA from a hydraulic perspective, and the Staff noted that the reported concentrations in Tables 2 and 3 of the TM are below CMSA's current local limits. These limits could change, however: the CMSA National Pollutant Discharge Elimination System (NPDES) permit renewal application has been submitted to the Regional Water Board and CMSA anticipates the new permit to be issued in October 2006; until then, CMSA will not know if their discharge limits for priority pollutants will change as a result of the Reasonable Potential Analysis. CMSA therefore cannot provide MMWD at this time with an opinion on the compliance of CIP discharge concentrations with potential future local limits.

References:

Thompson, John; *Four Years Later- Successful Performance of the Largest SWRO Plant in the Western Hemisphere at Pt. Lisas Trinadad,* AMTA Conference Proceedings, 2006.

Seacord, Thomas; *The Affordable Desalination Collaboration 2005,* AMTA Conference Proceedings, 2006.

Section 7: Environmental Studies

The MMWD Seawater Desalination Pilot Program was a valuable tool that enabled MMWD to conduct environmental studies to ensure that a full-scale desalination facility would not adversely impact the Northern San Francisco Bay (Bay) environment. The environmental studies conducted during the desalination pilot program included:

- Fish entrainment study of the intake
- Acute bioassay testing of the brine blended with CMSA effluent
- Chronic bioassay testing of the brine blended with CMSA effluent
- Analytical testing of the brine
- Analytical testing of the pretreatment solids residuals

These studies are described in this section.

7.1 Intake Entrainment Study

An Intake Entrainment Study was conducted in conjunction with the MMWD Seawater Desalination Pilot Program. Entrainment is the hydraulic capture of organisms by the suction field created by the water intake structure. The organisms involved are extremely small and potentially capable of passing through a fine mesh cylindrical fish screen. These organisms include phytoplankton, zooplankton, and early life stages of fish (ichthyoplankton). Operation of the pilot plant provided an opportunity to sample organisms entrained into the intake system to provide a basis for assessing the potential impacts of entrainment to local fish and macroinvertebrate populations.

Entrainment sampling from the pilot plant intake was conducted during both day and night, twice monthly over a period of one year (24 sampling events). Entrained fish eggs, fish larvae and macroinvertebrates were sampled by diverting water from the intake pipe, downstream of the positive barrier fish screen, into a plankton net. Organisms were identified to the lowest taxonomic level practicable and densities, expressed as the number of organisms per cubic meter of water, were calculated for each ichthyoplankton and selected macroinvertebrate. In addition to the entrainment sampling, samples were collected for a portion of the year in the source waters of the Bay surrounding the intake. Data analysis included various techniques for assessing the loss of equivalent adult fish, and the potential proportional losses of fish and macroinvertebrates from the source water populations.

The results of the Intake Entrainment Study will be presented in a separate report and in the Environmental Impact Report.

7.2 Pilot Program Bioassay Testing

The brine from the full-scale MMWD desalination facility is proposed to be discharged by mixing the brine with the relatively low-salt effluent that is discharged into the San Francisco Bay from the wastewater treatment facility owned and operated by the CMSA. The CMSA effluent would dilute the brine, with the resulting discharge often having a salinity nearer to that of the Bay than the current CMSA effluent.

The San Francisco Bay Area Regional Water Quality Control Board (RWQCB) requires acute and chronic bioassay testing of the proposed desalination facility's whole effluent to grant an NPDES discharge permit for the facility. Whole effluent (WE) is defined as the blend of brine and CMSA effluent that would be discharged into the Bay. The pilot plant produced brine that was representative of the brine that would come from a full-scale facility to conduct the required bioassay testing.

The RWQCB also required monthly bioassay testing of the pilot return water (combined brine and product water from the pilot plant) in order to permit operation of the pilot plant.

The RWQCB required that the SWRO brine from the pilot plant be combined with wastewater effluent from CMSA at various concentrations for the acute and chronic bioassay testing. The ratio of SWRO brine to CMSA effluent will vary throughout the year, and bioassays must evaluate the toxicity of the entire range of blends expected to constitute the WE. Table 7.1 presents the possible flow rate and salinity contributions from the two discharge streams that would constitute the WE from a full-scale desalination facility.

Table 7.1: Brine and CMSA Effluent Flow Rates

		SWRO Brine	CMSA Effluent
Typical Flow Rate (MGD)	Min.	1	4
	Avg.	4	11
	High.	15	17
Expected Salinity (mg/l)		60,000	810

It is important to note that the minimum brine flow rate from the desalination facility will not necessarily correspond with the minimum CMSA effluent flow rate. Maximum brine flow rates from the desalination plant are expected during dry months, when CMSA flow rates are lower. Maximum effluent flow rates from the CMSA facility occur during the winter months of high precipitation when the desalination plant production and brine flow rates would be low. Table 7.2 presents the range of salinity for WE discharges into San Francisco Bay from a full scale desalination facility.

The two blends that were selected to encompass the range of water-quality parameters in a future WE discharge are "Average Blend" 4:11 and "High Blend" 15:4 (SWRO brine to CMSA effluent), or 27% brine during the winter and 79% brine during the dry summer months. These blends have a salinity of approximately 16,500 mg/l and 47,500 mg/l, respectively compared to the average salinity in this portion of the Bay of approximately 22,000 mg/l and 33,000 mg/L for the nearby Pacific Ocean. CMSA was also conducting separate bioassay testing of the CMSA effluent (without any desal brine) during the pilot program bioassay testing. The results from the CMSA effluent chronic bioassay testing are provided in Table 7.4 below for comparison.

Table 7.2: Salinity of Potential WE Discharges to San Francisco Bay

Blend	SWRO Brine / CMSA Effluent Flow Rate Ratio (MGD)	Anticipated Salinity (ppm)	Percent Brine
High Brine Blend	15/4	47,539	79%
Average Brine Blend	4/11	16,594	27%
Low Brine	1/17	4,098	5.5%
No Brine	CMSA Only	810	0%

7.2.1 Acute Bioassays on Brine/CMSA Effluent Blend

This section summarizes the protocol and results of the acute bioassay testing conducted as part of the MMWD Seawater Desalination Pilot Program. Technical Memorandum No. 13 in Appendix 1 and the Acute Bioassay Test Report in Appendix 7 provide a more detailed discussion of the whole-effluent screening requirements and protocol, and the test results.

Acute bioassay tests were conducted on samples of SWRO brine blended with CMSA effluent to test for toxicity in the proposed brine/effluent discharge from a full-scale plant. Brine samples, simulating SWRO system operation in worst-case drought conditions, were collected from the pilot plant and blended with 24-hour composite samples of CMSA effluent. Two blends were prepared as described above, and a series of acute bioassay tests were conducted on a variety of aquatic species.

Based on discussions with MEC/Weston Solutions Staff at the Romberg Tiburon Center for Environmental Studies, RWQCB Staff, and staff from the consultant preparing the project Environmental Impact Report (EIR), the following aquatic species were selected for acute bioassay testing:

- Mysid shrimp (*Mysidopsis bahia)*
- Topsmelt (*Atherinops affinis*)
- Marine algae (*Thallasiosira pseudonanna*)

Table 7.3 presents the results of the acute bioassay testing on the WE blends of brine and CMSA effluent.

Table 7.3: Results of Whole Effluent Acute Bioassay Tests

Species	Test Episode	Sample	Mean Survival* (%)
Mysid shrimp (*Mysidopsis bahia*)	Episode 1	Lab Control	95
		Salinity Control	100
		Average Blend	95
		High Blend	100
	Episode 2	Lab Control	100
		Salinity Control	100
		Average Blend	95
		High Blend	100
	Episode 3	Lab Control	100
		Salinity Control	100
		Average Blend	95
		High Blend	95
Species	**Test Episode**	**Sample**	**Mean Survival (%)**
Topsmelt (*Atherinops affinis*)	Episode 1	Lab Control	90
		Salinity Control	75
		Average Blend	65
		High Blend	95
	Episode 2	Lab Control	100
		Salinity Control	100
		Average Blend	95
		High Blend	100
	Episode 3	Lab Control	95
		Salinity Control	100
		Average Blend	85
		High Blend	100
Species	**Test Episode**	**Sample**	**Cell Density (10^5 cells/mL)**
Marine algae (*Thalassiosira pseudonana*)	Episode 1	Lab Control	1.47
		Salinity Control	1.02
		Average Blend	2.64
		High Blend	1.82
	Episode 2	Lab Control	1.20
		Salinity Control	0.93
		Average Blend	1.52
		High Blend	2.40
	Episode 3	Lab Control	4.59
		Salinity Control	6.40
		Average Blend	8.42
		High Blend	13.6

* Average Blend treatment results statistically compared to Lab Control results ($\alpha = 0.05$). High Blend treatment results statistically compared to Salinity Control results ($\alpha = 0.05$).

In summary, no significant effects on survival were observed among the acute bioassays conducted with shrimp, topsmelt or marine algae during any of the three episodes of testing. These results were consistent between both SWRO brine/CMSA blend preparations. Consequently, no distinction in species sensitivity to the SWRO brine/CMSA discharge was detected.

7.2.2 Chronic Bioassays on Brine/CMSA Effluent Blend

This section summarizes the protocol and results of the chronic bioassay testing conducted as part of the MMWD Seawater Desalination Pilot Program. Technical Memorandum No. 13 in Appendix 1 provides a more detailed discussion of the whole-effluent screening requirements and protocol, and the test results. The Proposed Chronic Toxicity Screening Study Plan that was submitted to the RWCQB for approval, and the report from the laboratory that conducted the chronic bioassay tests are also provided in Appendix 7.

Chronic bioassay tests were conducted on samples of SWRO brine blended with CMSA effluent to test for toxicity in the proposed brine/effluent discharge from a full-scale plant. Brine samples, simulating SWRO system operation in worst-case drought conditions, were collected from the pilot plant and blended with 24-hour composite samples of CMSA effluent. Two blends were prepared as described above, and a series of chronic bioassay tests was conducted on a variety of aquatic species.

Based on discussions with MEC/Weston Solutions Staff at the Romberg Tiburon Center for Environmental Studies, RWQCB Staff, and staff from the consultant preparing the project EIR, the following aquatic species were selected for chronic bioassay testing:

- Marine Giant Kelp, (*Macrocystis pyrifera*), germination and growth test
- Bay Mussel, (*Mytilus edulis*), larval development and percent survival test
- Inland Silverside, (*Menidia beryllina*), survival and growth test
- Opossum Shrimp, (*Mysidopsis bahia*), survival and growth test
- Marine Diatom, (*Thalassiosira pseudonana*), growth test

For bioassay testing, the EPA standard procedures are to adjust the salinity of a sample water up or down to the salinity range that is appropriate for the species being tested. For example, the salinity of the average-blend WE sample was increased by adding standard sea salts and the salinity of the high-blend WE was decreased by adding pure water until the salinity was in the proper range for the species. This is done so that the impacts to the species from constituents in the water sample would not be masked by impacts to the species from incorrect water salinity. The RWQCB also required non-standard chronic bioassay testing using an unadjusted high-blend WE sample to investigate and confirm the impacts of the high salinity on the species. In a full-scale facility discharge, the high-blend WE discharge would be rapidly diluted as the effluent exits the CMSA outfall diffuser nozzles, such that the salinity of the discharge would match the surrounding salinity of the Bay.

After an initial round (Phase I) of chronic bioassay testing, the three most sensitive species were selected and two more rounds (Phase II) of chronic bioassay testing were conducted.

The three species selected for additional testing were the Giant Kelp, the Bay Mussel and the Inland Silverside fish. Table 7.4 summarizes of the results of the Phase I and II chronic bioassay testing on the three species for the average and high WE blends of brine and CMSA effluent. The results of similar chronic bioassay testing of the CMSA effluent without any brine, conducted by CMSA at the same time as the pilot program blended WE testing, are provided for comparison. Technical Memorandum No. 13 in Appendix 1 and the Chronic Bioassay Test Report in Appendix 7 provide a more detailed discussion of the results of the WE chronic bioassay testing including the Phase I results for all five species.

Table 7.4: Results of Whole Effluent Chronic Bioassay Tests

			Giant Kelp (*Macrocystis pyrifera*) Sporophyte Germination / Gametophyte Growth[c]			**Bay Mussel (*Mytilus edulis*) Laval Development**			**Inland Silverside (*Menidia beryllina*) Survival / Growth[c]**		
Bioassay Phase and Test Dates	Bioassay Endpoint		CMSA eff.	Avg. Blend	High Blend	CMSA eff.	Avg. Blend	High Blend	CMSA eff.	Avg. Blend	High Blend
Phase I (20-28 Feb 2006)	NOEC	Germination/ Survival	75%	100%	100%	--	100%	100%	75%	100%	100%
		Growth/ Development	<12.5%	5	50	<12.5%	25%	100%	75%	100%	100%
	LC_{25} or EC_{25} or IC_{25}	Germination/ Survival	>100%	>100%	>100%	--	>100%	>100%	84.2%	>100%	>100%
		Growth/ Development	64.9%	73	>100	15.5%	56.7%	>100%	77.8%	>100%	>100%
	TUc (100 / NOEC)	Germination/ Survival	<1.0	1.0	1.0	-	1.0[a]	1.0[a]	1.2	1.0[a]	1.0[a]
		Growth/ Development	1.5	1.4	2.0	6.4	1.8[a]	1.0	1.3	1.0	1.0
Phase II, Episode 1 (21-28 Mar 2006)	NOEC	Germination/ Survival		100%	100%	-	100%	100%		100%	100%
		Growth/ Development	-	25%	100%	12.5%	<5%	25%	-	100%	100%
	LC_{25} or EC_{25} or IC_{25}	Germination/ Survival	-	>100%	>100%	-	>100%	>100%	-	>100%	>100%
		Growth/ Development	-	>100%	>100%	30.5%	20.9%	>100%	-	>100%	>100%
	TUc (100 / NOEC)	Germination/ Survival	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0
		Growth/ Development	-	4.0	1.0	3.3	4.8[a]	4.0	-	1.0	1.0
Phase II, Episode 2 (5-14 April 2006)	NOEC	Germination/ Survival	-	100%	100%	--	100%	100%	-	100%	100%
		Growth/ Development	-	25%	75%	<12.5%	50%	100%	-	50%	100%
	LC_{25} or EC_{25} or IC_{25}	Germination/ Survival	-	>100%	>100%	--	>100%	>100%	-	>100%	>100%
		Growth/ Development	-	83.0%	>100%	28.4%	85.7%	>100%	-	>100%	>100%
	TUc (100 / NOEC)	Germination/ Survival	-	1.0	1.0	--	1.0	1.0	-	1.0	1.0
		Growth/ Development	-	1.2[b]	1.3	3.5	1.2[b]	1.0	-	2.0	1.0

NOEC: "No Observable Effect Concentration" is the highest concentration of toxicant (CMSA effluent or Brine/Effluent blend) to which organisms are exposed in a full life-cycle or partial life-cycle (short-term) test, that causes no observable adverse effects on the test organisms (ie, the highest concentration of toxicant concentration of toxicant in which the values for the observed responses are not statistically significantly different from the controls).

EC_{25} "Effect Concentration 25%" is the concentration of toxicant having an effect on 25% of the population, compared to the control.

IC_{25} "Inhibition Concentration 25%" is a calculated percentage of toxicant at which the test organism exhibits a 25% reduction in a biological function such as reproduction or growth.

TUc Chronic toxicity unit. USEPA recommends using a Tuc of 1.0 as the limit to indicate that no toxics are present in toxic amounts.

(a) TU value calculated as 100 / IC25

(b) TU value calculated as 100 / EC25

(c) Species are listed as identified by Weston Solutions. When a species within the same genus was used in a CMSA effluent bioassay, results are shown under the species in the same genus, even though the specific species may be different.

All bioassays conducted over Phase I and Phase II test episodes adhered to the method specifications provided in the U.S. EPA protocols implemented for this study. No major water quality deviations occurred, and reference toxicant test results showed that the organisms used for each test were, in general, appropriately sensitive. The chronic bioassay testing provided the following conclusions:

- Exposure to the average-brine WE blend did not cause statistically significant mortality to any of the five species tested across all three bioassay episodes.

- The average-brine WE blend did not elicit any statistically significant sub-lethal effects in three of the five species tested. The growth and development effects observed on Giant Kelp spore germ-tube growth in all three episodes and Bay Mussel embryo development during Phase I and Phase II, are considered to be nominal because there were only minor variations from the control treatments. These observed effects are expected to be eliminated with minimal receiving-water dilution. The growth and development effects of the average-brine WE blend were similar to that of the CMSA effluent without brine.

- Exposure to the high-brine WE blend did not cause statistically significant mortality to any of the five species tested across all three bioassay episodes.

- The high-brine WE blend did not elicit any statistically significant sub-lethal effects in three of the five species tested. The growth and development effects observed on Giant Kelp spore germ-tube growth and Bay Mussel embryo development during Phase I and Phase II were less significant than those observed from the average-brine blend exposures. As such, they are also considered nominal under the same reasoning discussed previously for the average-brine blend results.

- As expected, exposure to the unadjusted high-brine WE blend caused statistically significant but minor effects on mortality to all Phase II species tested, except the Bay Mussel embryos. The only substantial effects (i.e., LC50 below 100%) were observed with Inland Silverside (Phase I and Phase II, Episode 1), an estuarine fish and likely the most susceptible to higher salinities of all five test species. Results for the unadjusted blends are presented in the Appendix.

- The unadjusted high-brine WE blend elicited statistically significant sub-lethal effects during at least one episode in all species tested, except the Marine Algae. As with the observed effects on mortality, the only substantial sub-lethal effects (i.e. IC50 below 100%) were observed to the Inland Silverside (Phase I and Phase II, Episode 1).

- The unadjusted average-brine WE blend, tested during Phase I with the three species tolerant of lower salinities, did not elicit any statistically significant effects among those test species.

- The results of the chronic bioassay testing using the brine and CMSA effluent blends were similar to the results of the chronic bioassay testing using the CMSA effluent alone. The blended brine and CMSA effluent discharge from a full-scale MMWD desalination facility should not adversely impact the Bay environment and the facility should be able to obtain an NPDES permit from the RWQCB.

7.2.3 Pilot Return-Water Bioassays

Monthly acute bioassay sampling and analysis events were performed on the return water in accordance with the pilot plant NPDES permit and monitoring plan issued by the RWQCB. The two species used for this monthly test were topsmelt and mysid shrimp. Documentation of the test results was transmitted to MMWD to include in a monthly report on pilot operations to the RWQCB. The bioassay tests confirmed that the pilot-plant return water was suitable for return to the bay.

7.3 Analytical Testing of SWRO Brine

In accordance with the RWQCB permit to operate the pilot plant, the brine from the SWRO treatment process was analyzed for the requirements of the RWQCB's 6 August 2001 letter entitled "Requirement for Monitoring of Pollutants in Effluent and Receiving Water to Implement New Statewide Regulations and Policy". Samples of the SWRO brine were taken on 5 October 2005 and 14 February 2006 and were shipped to Caltest Analytical Laboratory (Caltest) where they were analyzed by Caltest or an affiliated laboratory. Results of these analyses can be found in Technical Memorandum No. 15 in Appendix 1.

7.4 Analytical Testing of Pretreatment Solids Residuals

The solids that are removed from the spent washwater from the conventional or MF/UF pretreatment systems would be thickened, dewatered, and sent to Redwood Landfill in Novato, California, for disposal. The settled solids from both conventional and MF/UF pretreatment systems include silts, organics, and coagulants. Bench tests were performed to determine the thickening and dewatering properties of the waste solids. Analytical testing of the dewatered solids was conducted to confirm that the solids are non-hazardous and can be disposed of at the Redwood Landfill. Tables summarizing the pretreatment system's solids analysis are included in Technical Memorandum 8 in Appendix 1.

The dewatered solids residuals from a full-scale desalination facility are not hazardous and are suitable for disposal at the Redwood Landfill.

Section 8: Comparison of Pretreatment Systems and Recommended Process

8.1 Comparison Methodology

The comparison of the conventional and MF/UF pretreatment systems is based on the assumptions and design criteria presented below. The two systems were evaluated based on the following:

- Capital Costs
- Operating Costs
- Non-Costs Factors such as filtrate water quality, impact on the downstream SWRO process, reliability and flexibility

A comparison of the capital, operating and non-cost factors for the two SWRO pretreatment alternatives provides the apparent best pretreatment alternative best-suited for the MMWD SWRO process.

8.1.1 Full Scale Pretreatment System Design Approach

The overall design approach for the full scale MMWD desalination facility is based on input from MMWD Staff, and looks to reliably meet finished water production and quality requirements while minimizing capital and operating costs of the facility. Because the full capacity of the seawater desalination facility is primarily required during dry periods (low rainfall years) and periods of drought, the design approach for the pretreatment systems is based on producing sufficient feedwater flow to the SWRO system during worst case dry period source water conditions. The dry period design conditions are described below and are characterized by:

- High salinity
- Low turbidity and suspended solids
- Elevated organic levels associated with an algal bloom

Sections 3 and 5 of this report provide a detailed description of the source water quality conditions. During wet periods (the rainy season of normal to high rainfall years) the desalination facility would be operated at reduced capacity since the full capacity of the system would not be needed. As was recommended in the report titled, “Seawater Desalination as a Possible Component of Integrated Water Resources for MMWD,” (Sheikh, 2001) the pretreatment systems would likewise have a reduced capacity during wet periods, corresponding with high source water turbidity conditions. For example, pretreatment systems would be designed to produce the full capacity during dry periods when solids are low and higher filtration rates can be sustained. During high turbidity periods, the filtration rates would be reduced to accommodate the increased solids loading in the source water and still maintain filtered water quality objectives and reasonable system backwash and cleaning frequencies. This approach saves capital costs since the systems are not “over-designed” based on full capacity during worst case wet weather source water conditions.

8.1.2 Expected Facility Operations

MMWD staff have projected potential future system water demands through the year 2025 to estimate the amount of desalination plant water that would be needed to meet those demands. The demand model projections incorporated use and supply factors based on normal rainfall years, low rainfall (dry) years and drought years. Based on these projections, in normal and dry years, the desalination plant would operate at lower production levels during the wet season (approximately December through April) and operate at increased production in the dry, summer season (approximately May through November). During droughts, the desalination plant would operate at full production levels all year or as required to meet water demands.

Based on MMWD staff projections, the potential operations scenarios for a full scale desalination facility would be as follows:

- Initial Operation:
  - In normal rainfall years: 4 MGD during the period May through November; 1 MGD during the period December through April.
  - In dry years: 10 MGD during the period April through Nov; 4 MGD during the period December through March.
  - In drought years: 10 MGD year round.

- Approximately 10 years later
  - In normal rainfall years: 8 MGD during the period May through November; 1 MGD during the period December through April.
  - In dry years, 12 MGD during the period April through November; 8 MGD during the period December through March.
  - In drought years: 15 MGD year round.

- Approximately Year 2025 and beyond:
  - In normal rainfall years: 12 MGD during the period May through November; 2 MGD during the period December through April.
  - In dry years: 15 MGD during the period April through November; 12 MGD during the period December through March.
  - In drought years: 15 MGD year round.

The range of production in normal rainfall years reflects lower production in the wet season, winter months and higher production in the dry season, summer months. During the low production periods of operation, process units would operate at lower flow rates or units would be removed from serviced and placed into lay-up conditions. Low production period operations are discussed in more detail in Section 9 of this report.

8.1.3 Facility Capacity

The design capacity of the proposed full scale MMWD desalination facility is based on meeting the planned production requirements listed above under worst-case, dry-period source water conditions represented by higher salinity, lower turbidity/suspended solids and either low or high TOC depending on whether an algal bloom is present or absent in the Bay at or near the intake. To meet these requirements, MMWD is considering a phased construction approach. The initial phase could be 5 MGD with incremental expansion to 10 MGD and final expansion to 15 MGD. MMWD is also considering an approach that would call for initial construction of a 5 MGD facility that could be rapidly expanded to 10 MGD in a period of approximately 12 months, in response to a severe drought that would require production of desalinated water at greater than 5 MGD. The approach to construction of a desalination plant necessary to permit rapid expansion is discussed in Section 10 of this report.

Figure 8.1 shows a simplified process flow schematic of the desalination facility to present the flows required through the plant to produce the required finished water capacity. The flow schematic shows the intake, pretreatment, first-pass SWRO, and optional second-pass RO processes, and the associated waste and recycled water streams. These processes are described in more detail in Sections 8 and 9 of the report.

Figure 8.1: Desalination Facility Simplified Process Flow Schematic

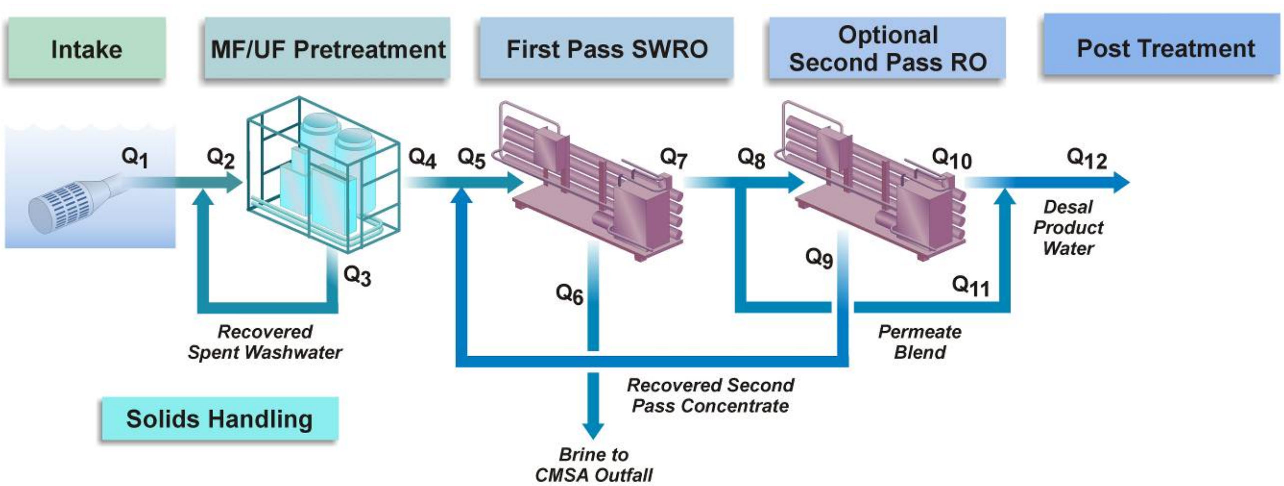


Table 8.1 below presents the maximum flow rates for the proposed full scale desalination facility corresponding to the labeled points (Q1, Q2, etc.) in Figure 8.1 for a 5, 10 and 15 MGD facility.

Table 8.1: Full Scale Desalination Facility Design Flow Rates

PLANT FLOW RATES AND RECOVERIES	Unit	Figure Flow Location	5-MGD	10-MGD	15-MGD
Maximum Drought Product Water Flow	MGD		5	10	15
Average Dry Period Product Water Flow	MGD		4	8	12
Minimum Product Water Flow	MGD		1	1	2
Average Pretreatment System Recovery	%		95	95	95
First Pass SWRO Recovery	%		50	50	52
Second Pass RO Recovery	%		90	90	90
Maximum Desal Facility Feed Water Flow	MGD	Q1	10.4	20.7	29.9
Pretreatment Feed Water Flow	MGD	Q2	10.9	21.7	31.4
Pretreatment Recycled Water Flow	MGD	Q3	0.5	1	1.5
Pretreatment Filtrate Flow	MGD	Q4	10.4	20.7	29.9
First Pass SWRO Feed Water Flow	MGD	Q5	10.8	21.4	31
First Pass SWRO Brine Flow	MGD	Q6	5.4	10.7	14.9
First Pass SWRO Permeate Flow	MGD	Q7	5.4	10.7	16.1
Optional Second Pass RO Feed Water Flow	MGD	Q8	3.7	7.3	11.1
Optional Second Pass RO Concentrate Recycle	MGD	Q9	0.4	0.7	1.1
Optional Second Pass RO Permeate Flow	MGD	Q10	3.3	6.6	10
First Pass Permeate Blend Flow	MGD	Q11	1.7	3.4	5
Desalination Facility Product Water Flow	MGD	Q12	5	10	15

The feed water flow rates shown above represent the maximum intake and pretreatment flows required to meet the finished water production capacities with the pretreatment, first pass RO and optional second pass RO system recoveries shown in the table and in a drought condition. Note that to keep the maximum brine flows from the facility to 15 MGD or less, when operating at the maximum capacity and with second pass RO, the recovery of the first pass SWRO process would be increased to 52 percent. At lower plant flow rates and depending on the source water conditions, the facility would be designed with the flexibility to operate at lower recoveries if desired to optimize system operations.

8.2 Pretreatment Design Criteria and Assumptions

As described above, because the full capacity of the seawater desalination facility is primarily required for low rainfall years and periods of drought, the pretreatment systems design approach is based on meeting the required capacity under worst case dry period source water conditions – higher salinity, lower turbidity and suspended solids and potentially high organics (TOC). Table 8.2 summarizes the design source water quality conditions for the pretreatment processes.

Table 8.2: Full Scale Pretreatment System Design Source Water Conditions

SOURCE WATER	Unit	Design Condition
Design Minimum Temperature	°C	10
Design Maximum Temperature	°C	20
Design Dry Season Turbidity Range (Avg/Max)	NTU	8 / 30
Wet Season Turbidity Range (Avg/Max)	NTU	43 / >200
Expected Average pH Range (Avg/Max)	pH units	7.8 / 8.1
Average Dry Season TOC	mg/l	0.50
Design Algal Bloom/Wet Season TOC	mg/l	5 to 10

8.2.1 Conventional Pretreatment Process

The preliminary design criteria for a full scale conventional pretreatment system are presented in Table 8.3 below. The pretreatment is designed to be expanded from an initial 5 MGD, to 10 MGD and to an ultimate 15 MGD product water capacity. The design criteria for a 5 MGD facility that would not be expanded (5 MGD Non-Exp.) is also shown.

Table 8.3: Conventional Pretreatment Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
RAPID MIX and FLOCCULATION					
Maximum Intake Flow	MGD	10.4	10.4	20.7	29.9
Maximum Recovered Water Flow	MGD	0.5	0.5	1	1.5
Maximum Process Feed Flow	MGD	10.9	10.9	21.7	31.4
Rapid Mix Units/Basins	number	1	1	2	3
Design Coagulant Dose					
Average Dry Season/Algal Bloom	mg/l	12.0	12.0	12.0	12.0
Average Wet Season	mg/l	25.0	25.0	25.0	25.0
Design Coagulant Aid	mg/l	0.5	0.5	0.5	0.5
Flocculation Time	minutes	30	30	30	30
Flocculation Stages (tapered)	number	3	3	3	3
Flocculation Basins	number	1	1	2	3
Capacity per Basin	MGD	11	11	11	11
Basin Materials	--	Coated Concrete	Coated Concrete	Coated Concrete	Coated Concrete
CONVENTIONAL SEDIMENTATION SYSTEM					
Maximum Process Feed Water Flow	MGD	10.9	10.9	21.7	31.4
Sedimentation Basins	number	1	1	2	3
Capacity per Basin	MGD	11	11	11	11

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Basin Hydraulic Detention Time	minutes	60	60	60	60
Plate/Tube Settler Overflow Rate (Top of Plates/Tubes)	gpm/ft^2	1.5	1.5	1.5	1.5
Basin Materials	--	Coated Concrete	Coated Concrete	Coated Concrete	Coated Concrete
CONVENTIONAL FILTRATION SYSTEM					
Maximum Process Feed Water Flow	MGD	10.9	10.9	21.7	31.4
Filter Basins	number	3	3	6	9
Redundant Filter Basin	number	1	1	1	1
Capacity per Basin	MGD	3.7	3.7	3.7	3.7
Design Filtration Rate (Dry Season)	gpm/ft^2	4	4	4	4
Design Deep Bed Filter Media					
Antracite Media	inches	36	36	36	36
Silica Sand Media	inches	24	24	24	24
Garnet Media	inches	12	12	12	12
Basin Materials	--	Coated Concrete	Coated Concrete	Coated Concrete	Coated Concrete
Backwash Source	--	Filtered Source	Filtered Source	Filtered Source	Filtered Source
Design Backwash Frequency (Dry Season- /Wet Season)	hrs	48/24	48/24	48/24	48/24
CONVENTIONAL FILTRATE TANK					
Maximum Process Feed Flow	MGD	10.9	10.9	21.7	31.4
Conventional BW Supply Volume	gal	280,000	280,000	560,000	560,000
SWRO Feed Pump Operational Volume 5 - minutes @ max flow	gal	40,000	40,000	80,000	120,000
Total Tank Operational Volume	gallons	320,500	320,500	641,000	680,000
Number of Tanks	number	1	1	2	2
Capacity of Tanks	gallons	350,000	350,000	700,000	700,000

8.2.1.1 Rapid Mix and Flocculation

Addition of a coagulant and polymer are required to condition particles in the Bay source water for settling and filtration with the conventional pretreatment system. The rapid mix system provides high energy mixing to rapidly disperse and mix the coagulation chemicals. The rapid mix could be accomplished with an in-line system or in the first chamber of the rapid mix/flocculation basins. The flocculation basins would be a three stage tapered flocculation zone to condition particles for settling and filtration. The flocculation zone would consist of initial flow distribution from the rapid mix into the first flocculation stage followed by baffle walls thereafter to provide uniform distribution of flow from each subsequent flocculation stage and into the sedimentation zone. Based on the MMWD pilot study data and on operational parameters for the conventional pretreatment system at the Point Lisas, Trinidad seawater desalination facility (Thompson, 2006), a total of 30 minutes of flocculation time is recommended with average ferric coagulant dose shown in Table 8.3 above.

To facilitate expansion, a single rapid mix and flocculation basin would be provided for each 5 MGD of facility product water capacity. The rapid mix and flocculation basins would be coated concrete basins for corrosion resistance.

8.2.1.2 Sedimentation

The flocculated water would be clarified in high-rate plate or tube type clarifiers/sedimentation basins. The plate or tube settlers provide a large amount of surface area for settling and help reduce the footprint and capital costs of the clarifier. Based on the MMWD pilot study data and on operational parameters for the conventional pretreatment system at Point Lisas, (Thompson, 2006) the clarifiers would operate at 1.5 gallons per minute per square foot (gpm/ft^2) surface loading rate at the 5 MGD facility finished water flow per unit. The clarifiers would have automated solids collection and transfer systems to pump settled solids to the solids handling system.

To facilitate expansion, a single sedimentation basin would be provided for each 5 MGD of facility product water capacity. The sedimentation basins would be coated concrete basins for corrosion resistance and include floating covers to reduce bio-growth in the basins and the plate/tube settlers.

8.2.1.3 Deep Bed Filtration

Single stage, deep bed multi-media gravity filters would provide filtration of the settled source water. Based on the MMWD pilot study data and on operational parameters for the conventional pretreatment system at the Point Lisas, Trinidad seawater desalination facility, the filters would have 72 inches of filter media, as described above, and would operate at 4 gpm/ft^2 filtration rate during the low turbidity dry season. During the high turbidity wet season, the filters would operate at 3 gpm/ft^2 or less to accommodate increased solids loading and to provide filtered water quality, since the full plant capacity is not required at these times.

Kennedy/Jenks-CH2M Hill recommends three filter basins to provide the initial filtrate required for a 5 MGD desalination facility. A fourth redundant filter basin would typically operate in parallel with the three main filters to ensure that feed to the downstream SWRO process would not be interrupted during filter backwash or filter servicing. This also permits minimizing the size of the filtrate water tank. For future expansion, groups of three filter basins would be provided for each 5 MGD of facility product water capacity. The filter basins would be coated concrete basins for corrosion resistance and the filter basins would be covered by a retractable basin cover to reduce bio-growth in the basins.

The filter basins would be backwashed with filtered source water stored in the filtrate water tank. The filter backwash would incorporate air-scour and would include a filter to waste step. Spent washwater and solids would be sent to the solids residuals handling system for recovery of water and thickening and dewatering of the solids.

8.2.1.4 Filtrate and Backwash Supply Tank

The filtrate and backwash supply tank is sized to provide a continuous supply of filtered water to the downstream SWRO process and store filtered water for use in filter backwashing. The tank size is based on providing water for two sequential filter cell backwashes as well as to provide operational control volume for the SWRO feed pumps described below. One tank would be provided for an initial 5 MGD facility and an additional tank would be provided for expansion to 10 and 15 MGD facility capacities.

8.2.1.5 Solids Residuals Handling

The solids residuals handling system would consist of an equalization basin(s) to capture the spent washwater, followed by a clarifier/thickener to settle and thicken the captured solids. The supernatant from the clarifier/thickener would be returned to the head of the plant (ahead of the rapid mix system) and the solids would be sent to centrifuges for dewatering.

The solids would be disposed of at a local municipal landfill (Redwood Landfill). The limit for solids disposal at Redwood Landfill is 20% solids. Additional discussion of the solids handling system for the full-scale facility is provided in Section 9. Centrate and washdown water from the dewatering process would be sent to the sanitary sewer so as not to introduce high molecular weight polymers used in dewatering to the source water. These polymers could lead to fouling of the SWRO membranes.

The preliminary design criteria for solids residual handling specific to a conventional pretreatment system are presented in Table 8.4 below. The solids handling system is designed to handle residuals from an initial 5 MGD or 10 MGD to an ultimate 15 MGD product water capacity. The solids residuals handling system design criteria for the gravity clarifier thickener and solids dewatering systems for a full scale facility is described in more detail in Section 9. The main difference in the solids residual handling system between the conventional pretreatment system and the MF/UF pretreatment system is that the size of the equalization basin, which is larger for the conventional system because of greater volumes of spent backwash water produced per backwash event. The conventional system produces approximately 50% more solids in the dry season (summer) and approximately 12% more solids in wet season (winter) than the MF/UF pretreatment system.

Table 8.4: Conventional Pretreatment Solids Handling System Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
SOLIDS RESIDUALS HANDLING SYSTEM					
Summer Pretreatment Design Conditions					
Maximum Pretreatment Design Flow	MGD	10.9	10.9	21.7	31.4
Average Influent Turbidity	NTU	9.0	9.0	9.0	9.0

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Winter Pretreatment Design Conditions					
Maximum Pretreatment Design Flow	MGD	8.60	8.60	8.60	21.60
Average Influent Turbidity	NTU	42.0	42.0	42.0	42.0
Conventional System Solids Loading					
Summer Pretreatment Design Conditions					
Dry Season Design Backwash Frequency	hrs	48	48	48	48
Filter Backwash Volume	gpd	210,000	210,000	420,000	630,000
Sedimentation Basin Blowdown Volume	gpd	43,000	43,000	86,300	130,000
Filter to Waste Volume	gpd	121,000	121,000	242,000	363,000
Total Backwash-related Volume	gpd	374,000	374,000	748,300	1,123,000
Ferric Chloride Dose	mg/l	12.0	12.0	12.0	12.0
Filter Polymer Aid Dose	mg/l	0.5	0.5	0.5	0.5
Total Suspended Solids	mg/l	19.4	19.4	19.4	19.4
Conventional Pretreatment Solids	lb/d	1,880	1,880	3,740	5,620
Wet Solids at 2.5%	gal/d, 7d/wk	9,000	9,000	18,000	27,000
Winter Pretreatment Design Conditions					
Wet Season Design Backwash Frequency	hrs	24	24	24	24
Filter Backwash Volume	gpd	420,000	420,000	560,000	1,120,000
Sedimentation Basin Blowdown Volume	gpd	105,700	105,700	111,300	273,000
Filter to Waste Volume	gpd	242,000	242,000	323,000	645,000
Total Backwash-related Volume	gpd	767,700	767,700	994,300	2,038,000
Ferric Chloride Dose	mg/l	25	25	25	25
Filter Polymer Aid Dose	mg/l	0.5	0.5	0.5	0.5
Total Suspended Solids	mg/l	67.1	67.1	67.1	67.1
Conventional Pretreatment Solids	lb/d	4,820	4,820	4,820	12,090
Wet Solids at 2.5%	gal/d, 7d/wk	23,000	23,000	23,000	57,000
Equalization Basins – Conventional System					
Washwater EQ Basin					
Number of Basins	number	2	2	2	3
Volume per Basin	gal	150,000	150,000	150,000	150,000
EQ Basin Volume	gal	300,000	300,000	300,000	450,000
Filter to Waste EQ Basin					
Number of Basins	number	1	1	1	1
Volume per Basin	gal	160,000	160,000	160,000	160,000

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Expected Wet Tons of Dewatered Residuals					
Dewatered Solids at 25% - Summer	tons/d	4.7	4.7	9.4	14.1
Dewatered Solids at 25% - Winter	tons/d	12.1	12.1	12.1	30.2

8.2.2 MF/UF Pretreatment Process

The preliminary design criteria for a full scale MF/UF pretreatment system are presented in Table 8.5 below. The pretreatment is designed to be expanded from an initial 5 MGD or 10 MGD to an ultimate 15 MGD product water capacity. The design criteria for a 5 MGD facility that would not be expanded (5 MGD Non-Exp.) are also shown.

Table 8.5: MF/UF Pretreatment Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
SOURCE WATER STRAINER					
Maximum Intake Flow	MGD	10.4	10.4	20.7	29.9
Maximum Recovered Water Flow	MGD	0.5	0.5	1	1.5
Maximum Process Feed Flow	MGD	10.9	10.9	21.7	31.4
Nominal Particle Size Removal	microns	100	100	100	100
Process Units	number	5	5	10	15
Capacity, each	MGD	2.2	2.2	2.2	2.2
Backwash Source	--	Filtered Source	Filtered Source	Filtered Source	Filtered Source
Approx. Backwash Volume per unit wash	gal	2,400	2,400	2,400	2,400
Approx. Total Backwash Volume	gpd	29,000	29,000	57,750	86,750
Strainer Materials	--	Plastic	Plastic	Plastic	Plastic
RAPID MIX and Coagulation	**Unit**				
Maximum Process Feed Flow	MGD	10.9	10.9	21.7	31.4
Rapid Mix Units/Basins	number	1	1	2	3
Design Average Coagulant Dose					
MF/UF - Algal Bloom (2 week event)	mg/l	10.0	10.0	10.0	10.0
Coagulation Time	minutes	10	10	10	10
Flocculation Stages (tapered)	number	2	2	2	2
Flocculation Basins	number	1	1	2	3
Capacity per Basin	MGD	11	11	11	11
Basin Materials	--	Coated Concrete	Coated Concrete	Coated Concrete	Coated Concrete

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
MF/UF FILTRATION SYSTEM	**Unit**				
Maximum Process Feed Flow	MGD	10.9	10.9	21.7	31.4
Membrane Classification	--	MF/UF	MF/UF	MF/UF	MF/UF
Membrane Material	--	PVDF	PVDF	PVDF	PVDF
MF/UF Filter Basins	number	2	2	4	6
Redundant Filter Basin	number	1	1	1	1
Reserve Capacity per Basin	%	25	25	25	25
Capacity per Basin	MGD	5.5	5.5	5.5	5.5
MF Design Flux Rate - (Dry Season - 3 Basins)	gfd	33	33	33	33
MF Design Flux Rate - (Dry Season - High TOC - 4 Basins)	gfd	25	25	25	25
UF Design Flux Rate - (Dry Season - 3 Basins)	gfd	33	33	33	33
UF Design Flux Rate - (Dry Season - High TOC -4 Basins)	gfd	25	25	25	25
Basin Materials	--	coated concrete	coated concrete	coated concrete	coated concrete
Backwash Source	--	MF/UF Filtrate	MF/UF Filtrate	MF/UF Filtrate	MF/UF Filtrate
Design System Recovery (Dry Season/High TOC - Wet Season)	%	95/93	95/93	95/93	95/93
Design Chemical Wash Frequency	per day	1	1	1	1
Design CIP Frequency (Dry Season)	days	45	45	45	45
Design CIP Frequency (High TOC/Wet Season)	days	30	30	30	30
MF/UF FILTRATE TANK	**Unit**				
Maximum Process Feed Flow	MGD	10.9	10.9	21.7	31.4
MF/UF BW Supply Volume	gal	5,000	5,000	10,000	15,000
Strainer BW Supply Volume	gal	2,500	2,500	5,000	7,500
SWRO Feed Pump Operational Volume 5 -minutes @ max flow	gal	40,500	40,500	80,000	121,000
Total Tank Operational Volume	gallons	48,000	48,000	95,000	143,500
Number of Tanks	number	1	1	2	2
Capacity of Tanks	gallons	50,000	75,000	150,000	150,000

8.2.2.1 Strainers

A strainer system with 100 micron nominal removal is required ahead of the MF/UF filters to protect the membrane fibers from damage. Based on the pilot study, Kennedy/Jenks-CH2M Hill recommends the plastic compressed disc type strainer over the metallic wedge-wire type strainer. The conceptual capital level cost of the two strainer systems is similar and the plastic disk type strainer has the following advantages:

- Fewer solids in the strained water.
- Corrosion resistant materials reduce maintenance costs.
- Compressed disk system housing design provided for easy inspection and maintenance as compared to the heavy bolted wedge-wire screen housing.

Five strainer process units would be provided for an initial 5 MGD desalination facility with an additional five units for each additional expansion.

8.2.2.2 Rapid Mix and Coagulation

Periodic addition of a coagulant may be required ahead of the MF/UF filters to reduce high levels of organics in the Bay source water to reduce bio-fouling of the MF/UF and SWRO membrane elements. High source water organics could occur during dry season algae blooms in the Bay or during the first flush of storm runoff into the Bay from a major winter storm, as was experienced during the pilot study. Coagulant would be added to the source water to create floc particles. When floc particles are created, the organics tend to be adsorbed by the floc particles. This permits the membrane filters to remove part of the “dissolved organics” from the water by filtration. The coagulant can also extend the time between membrane cleanings by helping to convert dissolved organics that would foul the membranes to coagulated organics.

The rapid mix system provides high energy mixing to rapidly disperse and produce coagulation. The flocculation basins would be a two stage tapered coagulation zone to provide mixing energy and contact time for the dissolved organics to be adsorbed to the floc particles. Based on the pilot study, a total of 10 minutes of coagulation/flocculation contact time is recommended with an average ferric chloride coagulant dose shown in Table 8.4 above.

To facilitate expansion, a single rapid mix and flocculation basin would be provided for each 5 MGD of facility product water capacity. The rapid mix and flocculation basins would be lined concrete basins. The rapid mix and coagulation system could be bypassed when not required for organics removal. Facility operators would monitor source water TOC levels with an on-line instrument in the summer months during periods of expected algae blooms to initiate and stop coagulation ahead of the MF/UF systems as required.

8.2.2.3 MF/UF Filtration

Outside-in, oxidant resistant, MF or UF hollow-fiber membrane filters would provide filtration of the strained (and periodically coagulated) source water. The MMWD pilot study tested submerged type membrane systems and the design criteria presented in this report are based on submerged membrane systems. However, pressurized, outside-in hollow-fiber MF and UF membrane systems have been demonstrated on high turbidity surface waters and have similar performance characteristics as submerged membrane systems. Kennedy/Jenks-CH2M Hill recommends that MMWD consider pressure MF/UF systems in the preliminary design of a full scale facility as they could have significant advantages for the full-scale facility (slab on grade construction, no coated concrete tanks, use of HDPE feed and permeate headers on the membrane racks). The performance data from the piloted submerged MF/UF systems could be used to develop design criteria for a pressure system.

Kennedy/Jenks-CH2M Hill recommends two MF/UF filter basins to provide the initial filtrate required for a 5 MGD desalination facility. A third redundant MF/UF filter basin would typically operate in parallel with the main basins to ensure that feed water to the downstream SWRO process would not be interrupted during filter backwash or filter CIP. This also permits minimizing the size of the filtrate water tank. For future expansion, groups of two MF/UF filter basins would be provided for each 5 MGD of facility product water capacity. The filter basins would be coated concrete basins for corrosion resistance and the filter basins would be covered by a retractable basin cover to reduce bio-growth in the basins.

The MF/UF filters would operate at the flux rates and recovery described in Table 7.4 above. Based on the pilot study, the MF/UF filters would have higher filtration rates during the low turbidity dry season in the absence of algal blooms. During periods of high source water organics when the full system capacity is required, the flux would be reduced and the redundant basin could be utilized to maintain full system capacity at the lower flux. During the high turbidity wet season, the filters could operate at lower fluxes since the full plant capacity is not required at this time.

The MF/UF filter would be backwashed with MF/UF filtrate stored in the filtrate and backwash supply tank. The MF/UF filter backwash includes air-scour provided by dedicated blowers. Spent washwater and solids would be sent to the solids residuals handling system for recovery of water and thickening and dewatering of the solids.

8.2.2.4 Filtrate and Backwash Supply Tank

The filtrate and backwash supply tank provides is sized to permit continuous feed to the downstream SWRO process and storage of backwash supply water for the MF/UF filters. The tank size is based on providing water for two sequential MF/UF filter backwashes as well as to provide operational control volume for the SWRO feed pumps described below. One tank would be provided for an initial 5 MGD facility and an additional tank would be provided for expansion to 10 and 15 MGD facility capacities.

8.2.2.5 Solids Residuals Handling

The solids residuals handling system would consist of an equalization basin to capture the spent washwater, followed by a clarification/thickening process to settle and thicken the captured solids. A coagulant is required to be added to the spent washwater prior to the thickener clarifier to condition the solids for more effective settling/clarification. During periods when coagulant is dosed upstream of the MF/UF system, coagulant addition to the equalized washwater flow may not be required. Some settling of solids would occur in the equalization basin. The conditioned washwater would be sent to a clarifier/thickener. The supernatant from the clarifier/thickener would be returned to the main treatment process at a point upstream of the strainers while the thickened solids would be sent to centrifuges for dewatering. Centrate and washdown water from the dewatering process would be sent to the sanitary sewer so as not to introduce high molecular weight organic polymers used in dewatering to the source water. These polymers could lead to fouling of the SWRO membranes. The solids residuals handling system for a full scale facility is described in more detail in Section 9.

The preliminary design criteria for solids residual handling specific to a MF/UF pretreatment system are presented in Table 8.6 below. The pretreatment is designed to be expanded from an initial 5 MGD, to 10 MGD to an ultimate 15 MGD product water capacity. The solids residuals handling system design criteria for the gravity clarifier thickener and solids dewatering systems for a full scale facility is described in more detail in Section 9. The main difference in the solids residual handling system between the conventional pretreatment system and the MF/UF pretreatment system is that the size of the equalization basin is larger for the conventional system and the conventional system produces approximately 50% more solids in the dry season (summer) and approximately 12% more solids in wet season (winter).

Table 8.6: MF/UF Pretreatment Solids Handling System Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
SOLIDS RESIDUALS HANDLING SYSTEM					
Summer Pretreatment Design Conditions					
Maximum Pretreatment Design Flow	MGD	10.9	10.9	21.7	31.4
Average Influent Turbidity	NTU	9.0	9.0	9.0	9.0
Winter Pretreatment Design Conditions					
Maximum Pretreatment Design Flow	MGD	8.60	8.60	8.60	21.60
Average Influent Turbidity	NTU	42.0	42.0	42.0	42.0
MF/UF System Solids Loading					
Summer Pretreatment Design Conditions					
System Recovery	percent	95%	95%	95%	95%
Ferric Chloride Dose	mg/l	0	0	0	0
Pretreatment TSS	mg/l	11.7	11.7	11.7	11.7
Pretreatment Solids	lb/d	1,140	1,140	2,260	3,390
Backwash Volume					
Strainer	gpd	29,000	29,000	58,000	87,000
MF/UF Unit	gpd	795,000	795,000	1,583,000	2,378,000
Total Backwash Volume	gpd	824,000	824,000	1,641,000	2,465,000
MF/UF Residuals Coagulant Dose (Ferric Chloride)	mg/l	25	25	25	25
MF/UF Residuals Coagulant TSS	mg/l	12.0	12.0	12.0	12.0
MF/UF Residuals Coagulant Solids	lb/d	83	83	165	247
MF/UF Pretreatment Solids	lb/d	1,223	1,223	2,425	3,637
Wet Solids at 2.5%	gal/d, 7d/wk	5,200	5,200	11,000	16,000

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Winter Pretreatment Design Conditions					
System Recovery	percent	93%	93%	93%	93%
Ferric Chloride Dose (Periodic)	mg/l	10	10	10	10
Pretreatment TSS	mg/l	59.4	59.4	59.4	59.4
Pretreatment Solids	lb/d	4,260	4,260	4,260	10,710
Backwash Volume					
Strainer	gpd	22,000	22,000	22,000	54,000
MF/UF Unit	gpd	602,000	602,000	602,000	1,512,000
Total Backwash Volume	gpd	624,000	624,000	624,000	1,566,000
MF/UF Residuals Coagulant Dose (Ferric Chloride)	mg/l	15	15	15	15
MF/UF Residuals Coagulant TSS	mg/l	7.2	7.2	7.2	7.2
MF/UF Residuals Coagulant Solids	lb/d	37.5	37.5	37.5	94.0
MF/UF Pretreatment Solids	lb/d	4,298	4,298	4,298	10,804
Wet Solids at 2.5%	lb/d	20,000	20,000	20,000	52,000
Equalization Basins – MF/UF Pretreatment					
Washwater EQ Basin					
Number of Basins	number	2	2	2	3
Volume per Basin	gal	50,000	50,000	50,000	50,000
EQ Volume	gal	100,000	100,000	100,000	150,000
Expected Wet Tons of Dewatered Residuals					
Dewatered Solids @ 25% - Summer	tons/d	3.1	3.1	6.1	9.1
Dewatered Solids @ 25% - Winter	tons/d	10.7	10.7	10.7	27.0

8.3 Comparison of Pretreatment System Performance and Non-Cost Factors

Non-cost factors can help to define an apparent best alternative. The following non-cost factors were used to further compare the SWRO Pretreatment alternatives: filtrate water quality, SWRO system performance, treatment reliability, flexibility/operation and facility environmental/aesthetics.

Table 8.7 presents a comparison of the non-cost factors for the different drinking water source alternatives. The non-cost factors were evaluated with the most advantageous alternative receiving the lowest score with 1 being the best and 5 being the least desirable.

Table 8.7: Non-Cost Factor Comparison of the Drinking Water Source Alternatives

SWRO Pre-Treatment Alternative	Filtrate Water Quality	SWRO Performance Impact	Treatment Reliability/ Flexibility	Environmental /Facility Aesthetics	Overall Score
Conventional Pretreatment System	3	3	2	3	11
MF/UF Pretreatment System	2	2	1	2	7

8.3.1 Filtrate Water Quality

Filtrate water quality is the overall quality of the water in terms of particulate solids in the filtrate, as measured by turbidity and SDI and organics levels in the filtered water. The higher the filtrate water quality, the less long-term fouling is expected in the SWRO membrane system. Table 8.8 presents a summary of filtrate water quality presented in Section 6.

Table 8.8: Comparison of Pretreatment Filtrate Quality

Filtrate Water Quality Parameter	Conventional Pretreatment	MF Pretreatment	UF Pretreatment
Average Turbidity	0.1	0.06	0.05
Average SDI	3.89	2.61	2.56
Average TOC reduction with Coagulant	35%	50%	50%

The MF/UF pretreatment has a filtrate higher water quality than conventional pretreatment in terms of turbidity and SDI. The lower levels of particulate matter from the MF/UF pretreatment will lead to less particulate fouling of the SWRO system over the life of the system. The MF/UF pretreatment filtrate water quality is also typically more consistent than that of conventional pretreatment.

In terms of organics removal, coagulation followed by MF/UF filtration has equal to or better water quality than conventional pretreatment. The reduction of dissolved colloids and organics (TOC) in the pretreatment is primarily due to the chemistry of coagulation. The MF/UF filters provide a greater level of filtration to remove the coagulated particles.

8.3.2 Impact on SWRO System Fouling

The normalized differential pressure (DPN) values for the SWRO elements from MF/UF SWRO were lower at the end of the pilot study that the DPN values for the Conventional SWRO system. Based on the SWRO membrane autopsy data, the Conventional SWRO system had greater levels of inorganic and organic foulants. While the standard CIP cleanings generally remove most of these foulants, a very small amount of foulant typically remains in the membrane element. Over time, the foulants that are not removed will lead to greater differential pressure across the SWRO system. Therefore, even though there was only a small difference in the DPN values between MF/UF SWRO and Conventional SWRO after nine months of pilot operation, it is likely that the DPN for the conventional pretreatment SWRO system could increase faster than that of the MF/UF pretreatment SWRO system over several years of operation. If CIPs are not effective in managing the increase, the SWRO membrane elements following conventional pretreatment would have greater DPN values over time, a shorter life and higher cleaning and spent cleaning solution disposal costs.

8.3.3 System Reliability and Flexibility

Treatment reliability is the dependability of the treatment process to produce high quality filtrate. Flexibility is the ability of the plant to respond to changes in source water quality and the degree of complexity in operating the facility. Conventional treatment is a proven filtration technology for surface water and seawater applications and, with proper chemical conditioning, can reliably produce relatively high quality filtrate and handle variable source water conditions. MF/UF treatment is a newer technology that is now recognized as a proven filtration technology for surface water treatment and is starting to be used in seawater applications. Since the MF/UF system is not dependent on coagulation for particulate removal and responds well to rapid variation in source water quality, it has a better ranking in this category.

8.3.4 Environmental and Aesthetic Impacts

Environmental and aesthetic considerations relate to visual impacts, noise, land use and solids disposal impacts. The MF/UF system has a smaller footprint, uses fewer process chemicals and therefore produces less solids residuals than the conventional pretreatment. This leads to fewer chemical deliveries and fewer solids removal trucks at the site for the MF/UF system, and gives the MF/UF pretreatment system a better ranking in this category.

8.4 Comparison of Pretreatment System Capital and Operating Costs

The capital and operating costs for 10 MGD desalination facility with conventional pretreatment and with MF or UF pretreatment are presented in Section 10 and were developed using an in-depth parametric cost estimating model. The conceptual level capital and operating costs from the model are based on the design criteria developed from the MMWD pilot testing and were also evaluated and adjusted for MMWD project specific aspects.

The desalination facility using MF/UF pretreatment had a lower overall capital cost by approximately 20 percent and a lower annual operating cost by approximately 10 percent. The detailed cost tables in Section 10 of the report show the areas of capital and operational savings of the MF/UF system over the conventional pretreatment system for the overall desalination facility.

8.5 Recommended Apparent Best Pretreatment Alternative

Table 8.9 presents a comparison of the capital, operating and non-cost factors for the two SWRO pretreatment alternatives. The alternative capital costs, operating costs, and non-cost factors were ranked with the most advantageous alternative in each category receiving the lowest score with 1 being the best and 3 being the least desirable. Equal weight is given for each of the three evaluation factors in this comparison.

Table 8.9: Cost and Non-Cost Factor Comparison of the SWRO Pretreatment Alternatives

SWRO Pre- Treatment Alternative	Capital Costs	Operating Costs	Non Cost Factors	Overall Score	Overall Rank
Conventional Pretreatment System	2	2	2	6	2
MF/UF Pretreatment System	1	1	1	3	1

Based on the MMWD SWRO pilot study and the cost and non-cost evaluation presented above, the recommended pretreatment system that is best-suited for pretreatment of San Francisco Bay water ahead of the SWRO process is the MF/UF pretreatment system.

References:

Sheikh, Bahmin; *Seawater Desalination as a Possible Alternative Component of Integrated Water Resources for MMWD,* Marin Municipal Water District, June 2001.

Thompson, John; *Four Years Later- Successful Performance of the Largest SWRO Plant in the Western Hemisphere at Pt. Lisas Trinadad,* AMTA Conference Proceedings, 2006.

Section 9: Recommended Full Scale Desalination Facility Process

This section presents the recommendations for the treatment processes and operating parameters for a full scale seawater desalination facility for MMWD. The recommendations are based on the performance of the systems over the period of the MMWD pilot study as well as information from other published studies and operating seawater desalination systems.

9.1 Full-Scale Overall Facility Design Approach

The overall design approach for the full scale MMWD desalination facility is based on input from MMWD Staff, and looks to reliably meet water production requirements and minimize the capital and operating costs of the facility. Because the full capacity of the seawater desalination facility is primarily required for dry periods (low rainfall years) and periods of drought, the pretreatment systems design approach is based on meeting the required capacity under worst case dry period source water conditions. The dry period design conditions are described below and are characterized by:

- High salinity
- Low turbidity and suspended solids
- Potentially high organics from an algal bloom

Sections 3 and 5 of this report provide a detailed description of the source water quality conditions. During wet periods (the rainy season of normal to high rainfall years) the desalination facility would be operated at reduced capacity since the full capacity of the system would not be needed. As was recommended in the June 2001 report titled, "Seawater Desalination as a Possible Component of Integrated Water Resources for MMWD," the pretreatment systems would have a reduced capacity under wet period, extremely high source water turbidity conditions. Table 9.1 presents the source water design criteria assumptions for the full scale MMWD desalination facility.

Table 9.1: Source Water Design Criteria Assumptions

SOURCE WATER PARAMETER	Unit	Design Criteria Assumption
Design Minimum Temperature	°C	10
Design Maximum Temperature	°C	20
Design Average Dry Season TDS	mg/l	22,000
Design Drought Maximum TDS	mg/l	32,000
Design Average Wet Season TDS	mg/l	13,000
Design Dry Season Turbidity Range (Avg/Max)	NTU	8 / 30
Wet Season Turbidity Range (Avg/Max)	NTU	43 / >200
Expected Average pH Range (Avg/Max)	pH units	7.8 / 8.1
Average Dry Season TOC	mg/l	0.50
Design Algal Bloom/Wet Season TOC	mg/l	5 to 10

9.1.1 Facility Operations and Capacity

The potential operations of a full scale desalination facility are described in Section 8.

The design capacity of the proposed full scale MMWD desalination facility is based on meeting the required operational production under worst case dry period source water conditions – higher salinity, lower turbidity and suspended solids and potentially elevated TOC. To meet the water supply scenarios described above, MMWD is considering a phased approach to construction of a desalination facility with an ultimate capacity of 15 MGD. The initial phase could be 5 MGD with future expansion to 10 MGD and ultimately 15 MGD. The approach to facility expansion is described in more detail in Section 10.

Table 9.2 below presents the design maximum, average and minimum flow rates for desalination facility production capacities of initially 5 MGD with expansion to 10 MGD and ultimately 15 MGD as described in Section 8.

Table 9.2: Full Scale Desalination Facility Design Flow Rates

PLANT FLOW RATES AND RECOVERIES	Unit	Figure Flow Location	5-MGD	10-MGD	15-MGD
Maximum Drought Product Water Flow	MGD		5	10	15
Average Dry Period Product Water Flow	MGD		4	8	12
Minimum Product Water Flow	MGD		1	1	2
Average Pretreatment System Recovery	%		95	95	95
First Pass SWRO Recovery	%		50	50	52
Second Pass RO Recovery	%		90	90	90
Maximum Desal Facility Feed Water Flow	MGD	Q1	10.4	20.7	29.9
Pretreatment Feed Water Flow	MGD	Q2	10.9	21.7	31.4
Pretreatment Recycled Water Flow	MGD	Q3	0.5	1	1.5
Pretreatment Filtrate Flow	MGD	Q4	10.4	20.7	29.9
First Pass SWRO Feed Water Flow	MGD	Q5	10.8	21.4	31
First Pass SWRO Brine Flow	MGD	Q6	5.4	10.7	14.9
First Pass SWRO Permeate Flow	MGD	Q7	5.4	10.7	16.1
Optional Second Pass RO Feed Water Flow	MGD	Q8	3.7	7.3	11.1
Optional Second Pass RO Concentrate Recycle	MGD	Q9	0.4	0.7	1.1
Optional Second Pass RO Permeate Flow	MGD	Q10	3.3	6.6	10
First Pass Permeate Blend Flow	MGD	Q11	1.7	3.4	5
Desalination Facility Product Water Flow	MGD	Q12	5	10	15

The feed water flow rates shown above represent the maximum intake and pretreatment flows required to meet the finished water production capacities with the pretreatment, first pass RO and optional second pass RO system recoveries shown in the table and in a drought condition. However, the full scale desalination facility would have flexibility to operate over a range of system recoveries and process flow rates depending on the source water conditions. For example, during periods of average or lower salinity bay water quality conditions, the second pass RO system may not be required to meet the water quality objectives. Also, during periods of lower system production requirements, the first pass RO system could be operated at a lower recovery to reduce the energy usage of the facility.

9.1.2 Overall Design Criteria and Assumptions

The preliminary design criteria presented below are based on constructing a full scale desalination facility with an initial production capacity of 5 MGD or 10 MGD, and the ability to expand to 15 MGD. The preliminary design criteria for a 5 MGD facility that would not be expanded (5 MGD Non-Exp.) are also shown. The design criteria for expansion assumes that in some cases, certain systems such as the intake and source water pipelines, would be sized and constructed for the full 15 MGD capacity during an initial 5 MGD phase of the facility. For these components it is generally less expensive for the overall project to install a single larger pipe, than to construct parallel pipes during expansion. MMWD is also considering an approach that would call for initial construction of a 5 MGD facility that could be rapidly expanded to 10 MGD in a period of approximately 12 months, in response to a severe drought. The approach to construction of a desalination plant necessary to permit rapid expansion are discussed in Section 10 of this report.

9.2 Overall Process and Conceptual Plan

Figures 9.1 and 9.2 below present the overall project plan and the process flow diagram for the MMWD desalination facility. The overall treatment process for a full scale desalination facility includes the following major components:

- Intake System
- Pretreatment System
- First Pass SWRO System
- Optional Second Pass SWRO System
- Post Treatment and Disinfection System
- Solids Residuals Handling System
- Brine Discharge System
- Ancillary Support Systems

Descriptions and preliminary design criteria for the major treatment processes are provided below. The MMWD full scale desalination facility would include the following major site buildings or process areas:

- Operations and Maintenance Building
- Chemical Storage Area
- Pretreatment Process Area/Basins
- First Pass SWRO and Second Pass RO Building
- Post Treatment Process Area and Finished Water Disinfection Tanks
- Solids Residuals Handling Basins and Dewatering Building

The facilities would be designed to the greatest extent possible with common walls to facilitate seismic foundation design and to minimize the seismic foundation costs

Figure 9.1: Overall Project Plan

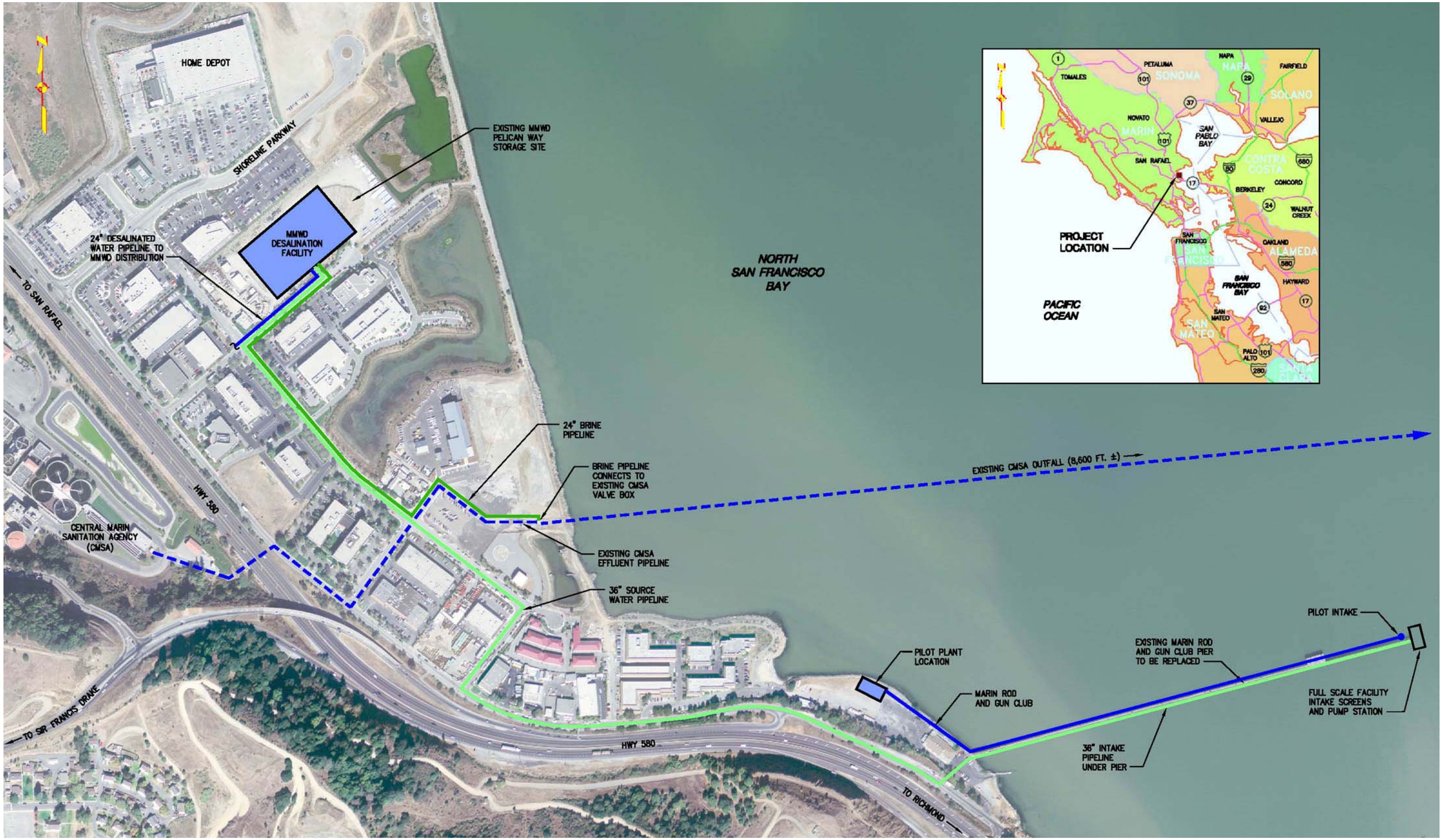
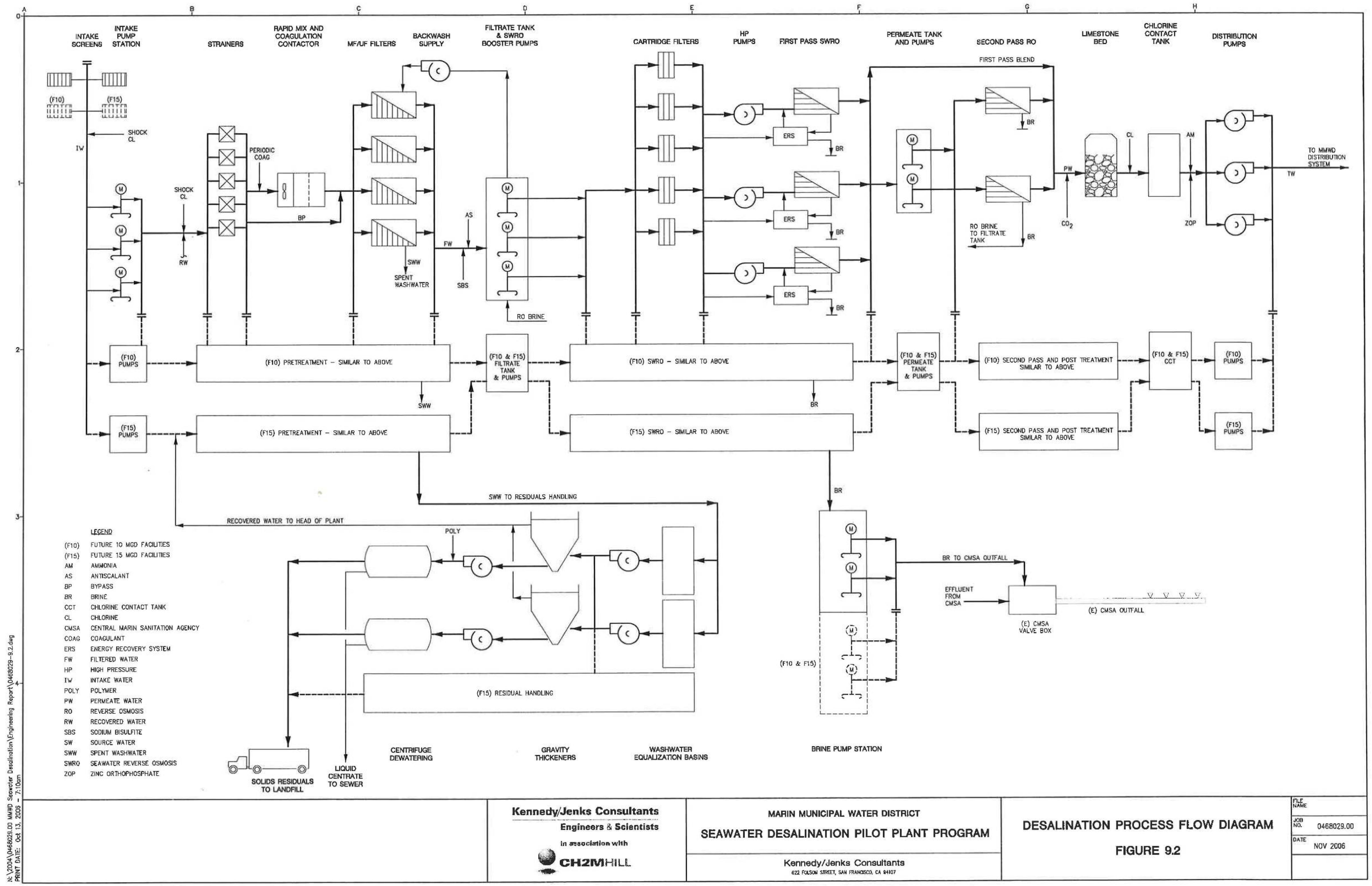


Figure 9.2: Desalination Process Flow Diagram



9.3 Intake System

The intake system consists of intake screens, an intake pipeline and an intake pump station to pump water from the intake location to the desalination facility. The preliminary design criteria for a full scale surface water intake system are presented in Table 9.3 below. The intake system is designed to be expanded from an initial 5 MGD or 10 MGD to an ultimate 15 MGD product water capacity. The preliminary design criteria for a 5 MGD facility that would not be expanded (5 MGD Non-Exp.) are also shown.

9.3.1 Design Criteria

Table 9.3: Intake System Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
INTAKE SCREENS					
Maximum Source Water Flow	MGD	10.4	10.4	20.7	29.9
Number of Intake Screens	number	1	1	2	3
Number of Spare Screens	number	1	1	1	1
Unit Capacity @ Max. Flow	MGD	10.5	10.5	10.5	10.5
Screen Slot Size	inches	0.09	0.09	0.09	0.09
Approach Velocity	fps	<0.33	<0.33	<0.33	<0.33
Screen Material	--	Copper-Nickel	Copper-Nickel	Copper-Nickel	Copper-Nickel
Cleaning Approach	--	Periodic Air-Burst	Periodic Air-Burst	Periodic Air-Burst	Periodic Air-Burst
Air Compressors	number	2	2	2	2
INTAKE PIPELINE	**Unit**				
Maximum Source Water Flow	MGD	10.4	10.4	20.7	29.9
Number of Intake Pipelines	number	1	1	1	1
Pipeline Diameter	inches	24	36	36	36
Approx. Pipeline Length	feet	2500	2500	2500	2500
Flow Velocity at Max Flow per pipe	fps	5.4	2.2	4.4	6.6
Pipeline Material	--	HDPE	HDPE	HDPE	HDPE
Cleaning Approach	--	Shock Chlor./ Pigging	Shock Chlor./ Pigging	Shock Chlor./ Pigging	Shock Chlor./ Pigging
INTAKE PUMP STATION	**Unit**				
Maximum Source Water Flow	MGD	10.4	10.4	20.7	29.9
Minimum Source Water Flow	MGD	2	2	2	4
Low Flow Pumps	number	3	3	3	3
Capacity	MGD	5.5	5.5	5.5	5.5

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
High Flow Pumps	number	0	0	1	2
Capacity	MGD	--	--	11	11
Speed Control	type	VFD	VFD	VFD	VFD
Pump Materials	--	Duplex SS	Duplex SS	Duplex SS	Duplex SS
SOURCE WATER PIPELINE	**Unit**				
Maximum Source Water Flow	MGD	10.4	10.4	20.7	29.9
Number of Intake Pipelines	number	1	1	1	1
Pipeline Diameter	inches	24	36	36	36
Flow Velocity at Maximum Flow	fps	2.2	2.2	4.4	6.6
Approx. Pipeline Length	feet	5500	5500	5500	5500
Pipeline Material	--	HDPE	HDPE	HDPE	HDPE
Cleaning Approach	--	Shock Chlor./ Pigging	Shock Chlor./ Pigging	Shock Chlor./ Pigging	Shock Chlor./ Pigging

9.3.2 Intake Process Description

The preliminary intake system design concept from MMWD's 1990 SWRO desalination preliminary design report proposed to support intake pumps and the intake pipeline from a re-built concrete pier at the Marin Rod and Gun Club site, approximately one mile from the proposed full scale desalination facility site at Pelican Way. This intake system design concept is largely based on minimizing fill in the San Francisco Bay to facilitate permitting of the intake system. The design and cost estimates in this report are based on the 1990 concept; however, an alternative approach to the intake system is also discussed below.

9.3.2.1 Intake Screens

The intake screens are designed to meet State and Federal criteria to minimize marine organism impingement and entrainment. For a full scale facility the intake screen would be made entirely of copper-nickel and would be designed with an access plate to facilitate easier access to the internals of the screen for maintenance. The screens would be periodically air-burst cleaned and for periodic screen maintenance in a full scale intake system, divers could physically scrub the screens or a screen could be raised or removed for physical cleaning. The interior of piping near the intake screens where light could cause bio-growth could be coated with bio-growth resistant paint.

For a 5 MGD desalination facility, one primary screen and one backup screen would be installed to feed the entire plant. For future expansion, additional screens would be provided as shown above. The intake system would have the ability to take one screen out of service and provide the full flow to the plant. The intake screens would be connected to a common header pipe to feed the intake pumps.

9.3.2.2 Intake and Source Water Pipeline

A single intake and source water pipeline would be provided for the full scale facility that would permit the facility to expand to 15 MGD without additional significant permitting or intake pipeline construction costs. The intake pipeline is defined as the pipeline that connects the intake screens and facilities on the pier out in the Bay to the onshore pipeline. The source water pipeline is defined as the onshore pipeline from the pier to the desalination facilities. The intake and source water pipeline is sized to provide a reasonably flow velocity and headloss in the pipeline at the future flowrates and to account for moderate bio-growth in the pipeline over time.

Based on the pilot study, Kennedy/Jenks-CH2M Hill recommends periodic shock chlorination of the intake pipe for a full scale facility to control bio-growth. The intake shock chlorinations could be semi-annual to annual events. The shock chlorination could be accomplished with the pipeline in operation or isolated. A 6-inch pipeline could be used to deliver chlorine solution to the intake pipeline and circulate the solution as well as to assist in pipeline cleaning operations. The chlorinated water from a shock-chlorination would be sent to the desalination facility and could be neutralized with bisulfite in the pretreatment system or directed to the solids handling system.

9.3.2.3 Intake Pumps and Electrical Equipment

To provide the wide range of flows between the maximum and minimum intake flow rates for the 10 and 15 MGD desalination facility, the intake pump station would have both low and high capacity pumps. Three low-capacity intake pumps would be provided for the 5 MGD desalination facility. Two pumps would provide the required flow with the third pump as a standby. For each facility expansion, an 11 MGD pump would be provided as presented in the table above. The pumps would be in pump cans that connect to a common intake header beneath the pier. The intake screens would be attached to the intake header.

The intake pumps would be controlled by variable frequency drives (VFD). To locate the intake pumps at the end of the pier, the pump VFDs would also need to be located at the end of the pier. VFDs are typically located within several hundred feet of the equipment they control and the 2,000 foot pier would make it impractical to locate the VFDs on shore. A small enclosure should be provided at the end of the pier to house the intake pump electrical equipment. The PG&E electrical service transformer for the intake pumps would be housed in a small electrical building on shore near the pier. Large electrical conduits would be required to connect the on-shore electrical service with the pump station at the end of the 2,000-foot-long pier.

9.3.2.4 Intake Pier and Alternatives

The MMWD 1990 SWRO desalination preliminary design report proposed to support the intake pumps and the intake pipeline from a re-built concrete pier at the Marin Rod and Gun Club site. This intake system design concept is largely based on minimizing “fill” in the San Francisco Bay to facilitate permitting of the intake system. The “fill” associated with the intake system is anything that takes up volume in the Bay and could include:

- Intake screens and common header pipe

- Intake pump cans
- Intake pipeline

The re-built Rod and Gun Club pier would support the intake pipeline above the Bay so as not to create fill. The intake screens and intake pump cans would still be fill since they are in the water. The rebuilt pier also could be designed to permit vehicle access to the screens and equipment at the end of the pier.

In discussions with the Consultant preparing the Environmental Impact Report (EIR) for the environmental permitting of the project, another alternative to provide an intake that would minimize “fill” in the San Francisco Bay would be to bury the intake pipeline in the Bay muds. With this intake concept, the intake pipeline would be placed just beneath the Bay floor with nominal cover and the intake screens and intake header would be supported with several piles at the intake location. The intake screens could still be out near the existing pier or at another location and, if not under the pier, would be marked with a navigational marker. The only Bay “fill” would be the intake screens and common header pipe.

The intake pump station would be located on-shore and fed by gravity. Because there is no need for a pier, the intake could extend out from the Pelican Way site eliminating the source water pipeline to the desalination facility. This intake approach has the following advantages over the re-built pier approach:

- Less or equal Bay fill.
- Possibly less construction disturbance to the Bay since the existing pier does not need to be demolished and a new pier built. This is balanced by the construction disturbance to bury the intake pipeline.
- Capital cost of a new pier is avoided.
- Capital cost of approximately one mile of source water pipeline is avoided.
- Intake pump station is on-shore at Pelican Way site and pumps and electrical equipment can be maintained without going to the end of a pier.
- Significant electrical costs in getting power out to the intake pumps at the end of a pier are avoided.
- Negotiations with the Rod and Gun Club and issues with public access to a re-built Rod and Gun Club pier are avoided.

The submerged intake pipeline described above is common at many desalination facilities around the world. A possible disadvantage of this intake approach is that periodic maintenance to the intake system would need to be done by divers from a boat or barge. However, the potential advantages of this alternative intake could outweigh this disadvantage.

Given the potential for significant capital cost savings and the possible advantages from a permitting perspective of less Bay fill and possibly less construction disturbance, Kennedy/Jenks-CH2M Hill recommend that MMWD further investigate the best apparent intake system for a full scale desalination facility.

9.4 Pretreatment System

The recommended pretreatment system is MF/UF pretreatment as discussed in detail in Section 8 of this report.

9.5 Seawater Reverse Osmosis System (First Pass)

The SWRO system consists of low pressure booster pumps, cartridge filters, single pass SWRO trains with high pressure pumps and energy recovery units to desalt the Bay water to meet, in conjunction with a second pass RO system where needed, the water quality objectives described in Sections 3, 4, and 5 of this report. The preliminary design criteria for a full scale SWRO system are presented in Table 9.4 below. The SWRO system is designed to be expanded from an initial 5 MGD or 10 MGD and to an ultimate 15 MGD product water capacity.

9.5.1 Design Criteria

Table 9.4: SWRO System Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
SWRO BOOSTER PUMPS	**Unit**				
Maximum Pretreatment Filtrate Flow	MGD	10.4	10.4	20.7	29.9
2^{nd} Pass RO Concentrate Recycle	MGD	0.4	0.4	0.7	1.1
Maximum SWRO Feed Flow	MGD	10.8	10.8	21.4	31
Minimum Feed Water Flow	MGD	2.0	2.0	2.0	4.0
Low Flow Pumps	number	3	3	3	3
Capacity	MGD	5.5	5.5	5.5	5.5
High Flow Pumps	number	0	0	1	2
Capacity	MGD	--	--	11	11
Speed Control	type	VFD	VFD	VFD	VFD
Pump Materials	--	Duplex SS	Duplex SS	Duplex SS	Duplex SS
CARTRIDGE FILTRATION SYSTEM	**Unit**				
Maximum Process Feed Flow	MGD	10.8	10.8	21.4	31
Nominal Filter Rating	micron	5	5	5	5
Cartridge Filter Housings	number	4	4	8	12
Redundant Filter Housing	number	1	1	1	1
Design Capacity (each)	MGD	2.7	2.7	2.7	2.7
Housing Materials	--	FRP	FRP	FRP	FRP

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
SWRO HP PUMPS AND ENERGY RECOVERY	**Unit**				
Maximum Process Feed Flow	MGD	10.8	10.8	21.4	31
Minimum Feed Water Flow	MGD	2.0	2.0	2.0	4.0
HP SWRO Feed Pumps	number	2	2	3	4
Approx. Capacity (Permeate)	MGD	5.4	5.4	5.4	5.4
Approx. Maximum Pressure	psi	1080	1080	1080	1080
Speed Control	type	VFD	VFD	VFD	VFD
Pump Materials	--	Duplex SS	Duplex SS	Duplex SS	Duplex SS
Energy Recovery Process	type	Pressure Exchanger	Pressure Exchang er	Pressure Exchang er	Pressure Exchang er
Energy Recovery Booster Pumps	number	2	2	3	4
Approx. Capacity (brine flow)	MGD	5.4	5.4	5.4	5.4
Approx. Maximum Pressure	psi	75	75	75	75
Speed Control	type	VFD	VFD	VFD	VFD
Pump Materials	--	Duplex SS	Duplex SS	Duplex SS	Duplex SS
FIRST PASS SWRO MEMBRANE SYSTEM	**Unit**				
Maximum Process Feed Flow	MGD	10.8	10.8	21.4	31
Maximum SWRO Permeate Flow	MGD	5.4	5.4	10.7	16.1
SWRO Process Skids	number	3	3	3/2	3/2
Permeate Capacity per Skid - maximum	MGD	1.8	1.8	1.8/2.7	1.8/2.7
Permeate Capacity per Skid - minimum	MGD	1	1	1 / 2.5	1 / 2.5
Design Flux Rate	gfd	9	9	9	9
Design Recovery - Max. Drought Salinity	%	50	50	50	52
SWRO Membrane Array	--	Single Stage	Single Stage	Single Stage	Single Stage
SWRO Membrane Material	--	TFC	TFC	TFC	TFC
SWRO Membrane Element Diameter	inches	8	8	8	8
SWRO Membrane Elements per Vessel	number	7	7	7	7
Average Antiscalant Dose	mg/l	1.5	1.5	1.5	1.5
Average Bisulfite Dose	mg/l	1.5	1.5	1.5	1.5
SWRO Brine Flow at Max Production and Design Recovery	MGD	5.4	5.4	10.7	14.9
FIRST PASS PERMEATE TANK	**Unit**				
Maximum Process Feed Flow to 2nd Pass RO - Design Drought Salinity	MGD	3.7	3.7	7.3	11.0
Approx. Volume to Flush SWRO Skid on Shutdown	gallons	5,000	5,000	10,000	10,000

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
BWRO Feed Pump Operational Volume 5 -minutes @ max flow	gallons	12,800	12,800	25,700	38,500
Total Tank Operational Volume	gallons	17,800	17,800	35,700	48,500
Number of Tanks	number	1	1	2	2
Capacity of Tank	gallons	20,000	25,000	25,000	25,000

9.5.2 First Pass SWRO Process Description

9.5.2.1 Booster Pumps and Cartridge Filters

Filtered water from the pretreatment system filtrate tank(s) would be pumped through cartridge filters with low pressure booster pumps. The booster pumps provide the pressure necessary for cartridge filtration as well as the required net positive suction head at the inlet to the SWRO high pressure pumps. The cartridge filter elements are 5 micron nominal polypropylene disposable filters that help protect the SWRO units from particulate damage and can help to reduce particulate fouling.

A few small SWRO systems have been designed without a filtrate tank and low pressure booster system, instead using pressure granular media filters or the discharge pressure from MF/UF systems to provide the net positive suction head at the inlet to the SWRO high pressure pumps. This requires more sophisticated controls and safeguards to ensure the SWRO systems receive a constant feed rate as the pretreatment systems go on and off for backwashing, cleaning, etc. This approach saves the cost of the low pressure pump station and reduces the size of filtrate storage. Some filtrate storage for backwash supply is still required. Kennedy/Jenks-CH2M Hill are not aware of any large surface water SWRO systems that have eliminated the filtrate storage and low pressure booster systems and do not recommend this approach for the MMWD desalination facility.

Since MF/UF provides filtration down to 0.2/0.02 microns, respectively, if MF/UF would be employed for pretreatment, there is the option to eliminate the cartridge filters and feed the high pressure pumps directly off the head of the filtrate tank either using a wetwell or drywell pump configuration. This approach reduces costs associated with both the booster pump system and cartridge filter system but requires that appropriate safeguards be used to prevent entrainment of solids in the high pressure pumps and lead elements, particularly during system commissioning. Also any biogrowth occurring in the filtrate tank or piping that would slough off into the RO feedwater would not be captured and would contribute to RO element fouling. The Kennedy/Jenks-CH2M HILL team recommends that a booster pump station and cartridge filtration system be included in the design subject to further investigation and consideration at a later date.

The low pressure booster pumps and cartridge filters would be manifolded to common headers for system flexibility. The systems would include process units as shown in Table 9.4 above to accommodate system expansion.

9.5.2.2 SWRO trains

The SWRO trains would be single pass, single stage systems with seven elements. Based on the MMWD pilot study results, the SWRO systems would be designed to operate at 8 to 9 gfd average flux and 50% recovery during drought conditions. During lower source water salinity, the SWRO systems could potentially be operated at higher recoveries and or higher flux rates depending upon the SDI and TOC levels in the RO feedwater.

Two 2.7 MGD SWRO trains would be provided for the 5 MGD facility with two more SWRO skids added for each expansion. Approximately two-thirds of the first pass SWRO train permeate flow (1.8 MGD) would be used as feedwater to the second pass RO system. The remainder (0.9 MGD) would be blended with the second pass RO permeate. The actual capacity of the RO trains will be variable depending on the source water TDS and blend ratio with 2nd pass RO system. To help minimize project costs, the SWRO system does not include a redundant train. During cleaning or maintenance of a SWRO train, the plant capacity would be reduced for that short period of time. Depending on the source water conditions, the remaining SWRO systems could be operated at higher recoveries and or higher flux rates to produce more water if required.

9.5.2.3 High Pressure Pumps and Energy Recovery

Each SWRO train could have a dedicated high pressure pump and energy recovery system or the pumps and energy recovery could be designed as a manifolded “pressure center” for potentially greater system efficiency and flexibility. While the “pressure center” design approach has typically been used on large facilities such as the Ashkelon SWRO facility and the Yuma Desalter Facility, it can offer increased flexibility for smaller facilities as well. The proposed high pressure pump and energy recovery system could be the same system that is being tested and demonstrated by the Affordable Desalination Collaboration at their demonstration facility in Port Hueneme, California (Seacord, 2006). This high pressure pump and energy recovery system is currently one of the most advanced technologies available to minimize the SWRO energy use.

The high pressure pump would be a variable speed controlled, high-efficiency centrifugal pump designed to provide the pressures and flows for the system in conjunction with the high-efficiency pressure exchanger energy recovery device. The design conditions would be for the maximum historical San Francisco Bay drought conditions. However, the variable speed drives on the system pumps would permit operation of the SWRO system over the range of RO feedwater salinities and temperatures typical of the San Francisco Bay source water.

9.5.2.4 SWRO Membrane Elements

The MMWD SWRO pilot study tested four different high rejection SWRO elements from the four leading SWRO membrane manufacturers available in the United States as described in Section 6 above.

The proposed SWRO elements would be 8-inch diameter, thin film composite (TFC) SWRO membrane elements. Although the high salt and high boron rejection elements were pilot tested, a second pass RO system will be required to meet the water quality objectives for the facility when Bay water salinity and boron levels are at or near the maximum historical level.

New high flow and lower energy SWRO membrane elements have recently been introduced that have slightly lower salt and boron rejection than the tested high rejection elements. It is likely that the capital and operational savings as a result of lower energy and higher flow from these new SWRO elements could be greater than the additional capital and operating cost for a larger second pass RO for water quality objectives.

Based on the results of the MMWD SWRO pilot study, the normalized differential pressure of the Hydranautics elements was consistently greater than that of the other elements in the same SWRO train (see Section 6 of this report and TM 10 in the Appendix). One reason for this could be the Hydranautics elements smaller feed/brine channel spacer. The smaller feed/brine channel spacer would have a tendency to accumulate solids at a greater rate or exhibit a higher differential pressure at similar solids accumulation compared to thicker channel spacers. Some firms that operate a number of SWRO systems around the world believe that a larger feed channel spacer reduces fouling potential. Based on the pilot study data, MMWD should consider specifying a minimum feed/brine channel spacer size (for example 28-mm) for the project SWRO elements consistent with that used in pilot elements demonstrating lower differential pressure increases. See Section 6 and TM 10. All the manufacturers, including Hydranuatics, can make elements with larger feed spacers so this would not preclude any manufacturer from bidding on a full-scale facility.

While the MMWD SWRO facility design presented in this report is based on 8-inch diameter elements, large diameter (16- to 18-inch diameter) SWRO elements could potentially provide 10 to 15% capital cost savings for the SWRO equipment. However, there are currently no SWRO systems that use the large diameter SWRO membranes. MMWD could evaluate large diameter SWRO membranes in the future after they become proven through operation.

9.5.2.5 First Pass Permeate Tank

Permeate from the first pass SWRO system would flow to a storage tank. The tank would provide for (1) automatic flushing of the first pass trains on shutdown, and (2) a source of feedwater supply for the second pass RO trains. VFD-driven feed pumps for the 2nd pass trains would be located on the tank along with the flush pumps to provide for automatic flushing of the first pass system on shutdown and to provide feed to the second pass trains. Remaining first pass permeate would flow through the tank to be blended with second pass permeate prior to stabilization and disinfection.

9.6 Optional Second Pass Reverse Osmosis System

While all the first pass SWRO elements generally performed well and in accordance with their projected performance, some elements had greater boron, sodium and chloride rejection than others. Based on the finished water quality projections described in Section 4 of this report, with the current generation of SWRO membrane elements, a second pass RO system may be desired under drought conditions to meet MMWD's more stringent TDS, chloride and sodium requirements. See Section 3 for a discussion on the finished water quality objectives. However, the second pass RO system is optional since the first pass SWRO desalinated water would meet state and federal water quality requirements.

If MMWD elects to include a second pass RO system in the full scale facility, Kennedy/Jenks-CH2M Hill recommend specifying, competitively bidding and pre-selecting the first pass SWRO and second pass brackish water RO (BWRO) systems together. The first pass SWRO and second pass RO systems would be specified to meet the water quality performance objectives of the project and could include both a capital and life-cycle evaluation. The approach to pre-selecting the first pass SWRO and second pass RO systems together provides for the possibility that at the time of bidding, one manufacturer could meet the water quality objectives with only a first pass SWRO system while a second manufacturer may need a partial second pass RO system. Another alternative could be that lower energy SWRO elements (with lower boron rejection) could be combined with second pass RO to optimize the overall system. This approach would permit competitive bidding and provide the most cost effective desalination system at the time of bidding that would meet the project objectives. Additionally, having one supplier for both systems ensures that only one party has responsibility for provide overall RO system performance guarantees.

For this report, design criteria for a second pass RO system is provided in case MMWD elects to include a second pass RO system in the overall project. However, the costs of the second pass system in Section 10 are shown as optional.

9.6.1 Design Criteria

The preliminary design criteria for a full scale second pass RO (brackish water RO (BWRO)) system are presented in Table 9.5 below. The second pass RO system is designed to be expanded from an initial 5 MGD or 10 MGD to an ultimate 15 MGD product water capacity.

Table 9.5: Second Pass RO Design Criteria

SECOND PASS RO MEMBRANE SYSTEM	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Maximum Process Feed Flow to 2nd Pass RO - Design Drought Salinity	MGD	3.7	3.7	7.3	11.0
BWRO Process Skids	number	2	2	2/1	2/2
Design Flux Rate	gfd	16	16	16	16
Design Recovery - Max. Drought Salinity	%	90	90	90	90
Permeate Capacity per Skid - maximum	MGD	1.7	1.7	1.7/3.3	1.7/3.3
BWRO Membrane Array	--	2 Stage	2 Stage	2 Stage	2 Stage
BWRO Membrane Material	--	TFC	TFC	TFC	TFC
BWRO Membrane Element Diameter	inches	8	8	8	8
BWRO Membrane Elements per Vessel	number	7	7	7	7
Average Sodium Hydroxide Dose	mg/l	2.5	2.5	2.5	2.5
Average Antiscalant Dose	mg/l	1.5	1.5	1.5	1.5
BWRO Concentrate Recycle Flow	MGD	0.4	0.4	0.7	1.1

9.6.2 Second Pass RO Process Description

9.6.2.1 RO Trains

The optional second-pass RO trains would be a two-stage brackish water RO system designed to operate at approximately 90% recovery. The trains will use 8-inch diameter by 40-inch long low pressure brackish water thin film polyamide membrane elements. Depending on the timing of the full-scale facility design, the use of 16-inch diameter by 40-inch long elements could be considered provided they are commercially available from more than one element manufacturer whose product is considered applicable to the design. The system could incorporate energy recovery for inter-stage boost to improve the overall efficiency and performance of the system if the present worth savings is greater than the capital cost of the energy recovery system. Two 1.67 MGD trains would be provided to produce 3.33 MGD of second pass permeate for an initial 5 MGD system. A third and fourth train, having a capacity of 3.33 MGD, would be added for a 10 and 15 MGD system, respectively.

9.6.2.2 Sodium Hydroxide pH Adjustment System

As described in Section 4, Table 4.2 above, the addition of sodium hydroxide to increase the pH of the first pass SWRO permeate significantly increases the boron rejection of the 2nd pass thereby minimizing its size. Sodium hydroxide would be used to increase the pH of the second pass RO feed to between 9 and 10 pH units.

9.7 Post Treatment System

The desalination facility post treatment system would consist of (1) carbon dioxide and lime/calcite addition to stabilize the water through an increase in pH, calcium and bicarbonate ions, and (2) disinfection to satisfy the requirements of the EPA and DHS for *Giardia* and virus inactivation under the Surface Water Treatment Rule. A zinc orthophosphate corrosion inhibitor and ammonia would also be added to the finished water from the desalination facility for additional finished water stabilization and chloramination consistent with what the District currently uses with their existing water supplies. The preliminary design criteria for a full scale desalination facility post treatment system are presented in Table 9.6 below. The post treatment system is designed to be expanded from an initial 5 MGD or 10 MGD and to an ultimate 15 MGD product water capacity.

9.7.1 Design Criteria

Table 9.6: Post Treatment System Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
POST TREATMENT SYSTEM					
Maximum SWRO Permeate Blend Flow	MGD	1.7	1.7	3.4	5
Maximum Second Pass RO Permeate Flow	MGD	3.3	3.3	6.6	10
Maximum Process Feed Flow	MGD	5	5	10	15

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Design Finished Water pH Range	mg/l	7.8 - 8.2	7.8 - 8.2	7.8 - 8.2	7.8 - 8.2
Design Finished Water Hardness Range	mg/l	60 - 80	60 - 80	60 - 80	60 - 80
Design Finished Water Alkalinity Range	mg/l	60 - 80	60 - 80	60 - 80	60 - 80
Design CO_2 Dose	mg/l	75	75	75	75
Design CO_2 Addition Rate	ppd	3,130	3,130	6,260	9,380
CO_2 Storage and Feeder Units	number	1	1	2	3
CO_2 Storage Capacity (each)	pounds	100,000	100,000	100,000	100,000
Design Lime/Calcite Dose	mg/l	65	65	65	65
Design Lime/Calcite Addition Rate	ppd	2,710	2,710	5,420	8,130
Lime/Calcite Storage and Feed Beds	number	1	1	2	3
Lime/Calcite Storage Capacity (each)	pounds	100,000	100,000	100,000	100,000
Avg. Zinc Orthophosphate Dose (as P)	mg/l	1.1	1.1	1.1	1.1
DISINFECTION SYSTEM	**Unit**				
Maximum Process Feed Flow	MGD	5	5	10	15
DHS Multi-Barrier Minimum Inactivation Requirement	log	0.5-log *Giardia*/2-log virus	0.5-log *Giardia*/2 -log virus	0.5-log *Giardia*/2 -log virus	0.5-log *Giardia*/ 2-log virus
CT Design Temperature -pH combinations	--	10°C - 8.5 pH units	10°C - 8.5 pH units	10°C - 8.5 pH units	10°C - 8.5 pH units
CT Design Free Chlorine Residual	mg/l	2	2	2	2
Free Chlorine CT for 0.5-log *Giardia* inactivation	mglL-min	33.0	33.0	33.0	33.0
Free Chlorine CT for 2 log *virus* inactivation	mglL-min	3.0	3.0	3.0	3.0
Disinfection Reservoir (Chlorine Contact Tank)					
Design Reservoir Hydraulic Efficiency (T_{10}/T)	--	0.5	0.5	0.5	0.5
Required Reservoir CT Volume at max. flow	gallons	120,000	120,000	240,000	360,000
Distribution Pump Operational Control Volume - 5 minutes @ max flow	gallons	17,500	17,500	35,000	52,500
Total Reservoir Volume	gallons	137,500	137,500	275,000	412,500
Number of Reservoirs	number	1	1	2	2
Reservoir Volume, each	gallons	150,000	200,000	400,000	400,000
DISTRIBUTION BOOSTER PUMPS	**Unit**				
Maximum Process Feed Flow	MGD	5	5	10	15
Minimum Feed Water Flow	MGD	2	2	2	2
Approx. Pump Discharge Pressure	psi	100	100	100	100
Low Flow Pumps	number	3	3	3	3
Capacity	MGD	2.5	2.5	2.5	2.5

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
High Flow Pumps	number	0	0	1	2
Capacity	MGD	--	--	5	5
Speed Control	type	VFD	VFD	VFD	VFD

9.7.2 Post Treatment Process Description

9.7.2.1 Carbon Dioxide Feed System

Liquid carbon dioxide (CO_2) would be stored on site in horizontal insulated storage units. The horizontal storage systems provide for better aesthetics at the Pelican Way site and are better suited for the seismic conditions. The CO_2 storage would provide approximately 30 days of storage at maximum flow conditions.

The liquid CO_2 would be vaporized into a gas and then dissolved into a carrier solution under high pressure to create a carbonic acid feed solution. This approach improves the efficiency of the system and permits the CO_2 to be rapidly mixed into solution a short time and in a pipeline without a large baffled tank. The CO_2 would be added to further depress the pH of the blended permeate and to add alkalinity. The blended permeate would be flow over a bed of calcite or limestone chips to add increase the pH and calcium concentration and to convert the dissolved CO_2 to bicarbonate ion. By first depressing the permeate pH with CO_2, the limestone chips more readily dissolve in the blended permeate.

9.7.2.2 Lime Feed System

Kennedy/Jenks-CH2M Hill recommend using limestone chip beds to add hardness and alkalinity to the finished water similar to the system that is being used successfully at the Ashkelon desalination facility. The limestone chip beds are significantly more “Operator friendly” than dry lime feed systems with less maintenance and mess, and greater system reliability. The limestone beds would be sized to provide approximately 30 days supply of limestone at the maximum flow conditions. The pre-acidification of the blended permeate and the limestone bed contactor design helps eliminate the need for post limestone bed filtration.

9.7.2.3 Disinfection

The conventional or MF/UF pretreatment systems described in Section 8 of this report, in conjunction with the SWRO systems will provide pathogen removal to meet the requirements of the California Department of Health Services (DHS).

Properly designed and operated conventional flocculation, sedimentation and filtration treatment processes are credited by DHS with 2.5-log removal for *Giardia* and *Cryptosporidium* and are credited with 2-log removal for viruses. To meet the overall 3-log removal/inactivation requirements for *Giardia* and the overall 4-log removal/inactivation requirements for viruses, an additional 0.5-log *Giardia* and 2-log virus inactivation is required.

MF and UF membranes have demonstrated over 6-log removal of particles and are credited by DHS with 4-log removal for *Giardia* and *Cryptosporidium.* The MEMCOR CS MF membrane system is currently credited with 1.5-log removal for viruses. The Zenon Zeeweed

1000 UF membrane system is currently credited with 3.5-log removal for viruses. In addition, DHS requires that surface water treatment systems provide multi-barrier treatment – both removal and inactivation. Therefore, even though membrane systems may exceed the SWTR removal/inactivation objectives for *Giardia* through removal alone, DHS requires an additional 0.5-log *Giardia* or 2-log virus inactivation, whichever is greater. The MF system would require 2.5-log inactivation of viruses.

RO membranes are a treatment process that utilize a semi-permeable, spiral wound membrane to remove dissolved salts and other dissolved constituents from water. The RO membrane system typically provides approximately 99.6% removal of dissolved salts and also provides an excellent barrier to larger particles and microbes, including bacteria, *Giardia cysts*, *Cryptosporidium oocysts* and viruses.

Many spiral wound RO membrane systems have not been specifically tested and approved as an alternative surface water filtration technology by DHS under the California Surface Water Treatment Rule (CCR, Title 22, Chapter 17, Section 64652(f)). However, DHS has granted the spiral wound RO membrane treatment process 2-log removal credits for *Giardia*, *Cryptosporidium*, and virus for other surface water desalination projects in California based on the log reduction in TDS through the system. It is probable that DHS would grant the same removal credits for the SWRO process in a full scale MMWD desalination facility.

Table 9.7 below summarizes the probable pathogen removal/inactivation credits achieved by a conventional or MF/UF pretreatment system and RO system, the required inactivation to be achieved with free chlorine, and the total removal/inactivation credits achieved for a full scale MMWD desalination facility.

Table 9.7: Summary of Pathogen Removal/Inactivation for the MMWD Desalination Facility

	Probable DHS Required Removal and Inactivation	DHS Conventional Removal Credit	DHS MF/UF Removal Credits	Probable DHS RO Removal Credits	Minimum Required Chlorine Inactivation	Total System Removal/ Inactivation
Giardia	3-log	2.5-log	4-log	2-log	0.5-log	5 to 6.5
Cryptosporidium	2-log	2 -log	4-log	2-log	0	4 to 6
Virus	4-log	2-log	1.5/3.5-log	2-log	2-log	5.5 to 7.5

No matter which pretreatment system is selected for the full-scale desalination facility, an additional 0.5-log *Giardia* and 2-log virus inactivation is required to meet the DHS multi barrier approach to surface water treatment. This inactivation would be achieved with free chlorine in a disinfection contact tank.

9.7.2.4 Disinfection Clearwell and Distribution System Pump Station

Free chlorine will be added as a disinfectant to the desalinated and stabilized water from the MMWD desalination facility. The free chlorine concentration-contact time (CT) requirements will be achieved in a chlorine contact tank (CCT)(s). The minimum design CT to meet the pathogen inactivation requirements is based on the worst-case conditions of minimum temperature (10°C) and maximum pH (8.5). The CCT would be designed with baffled inlet and outlets and moderate inter-basin baffles to achieve a hydraulic efficiency of at least 0.5. Based on these conditions, the CT to achieve 0.5-log *Giardia* and over 2-log virus inactivation is 33-mg/l-min with 2-mg/l of free chlorine residual exiting the clearwell. Ammonia would be dosed to the disinfected water exiting the CCT to convert the free chlorine residual to a chloramine residual to match MMWD's current water supplies.

The CCT would have minimal operational storage to minimize seismic foundation costs for the tank at the desalination facility site. Distribution pumps would boost water from the desalination facility into the distribution system for use and storage at reservoirs in the distribution system. The distribution system pump station would include process units as shown in the table above to accommodate system expansion.

9.8 Solid Residuals Handling System

The design of a full-scale 5 to 15 MGD desalination facility, including the waste handling and treatment systems should provide the flexibility to permit shutting down processes for cleaning and maintenance, while continuing to produce desalinated water, in some cases at reduced flow. This approach could entail multiple treatment trains and/or redundant process units such that a portion of the process flow could always be maintained.

Kennedy/Jenks-CH2M Hill also recommends that selected waste flows be treated and recycled, in order to improve overall water recovery and minimize discharges to the sanitary sewer. For example, strainer and filter (either granular media or membrane) backwash water would be sent to an equalization basin and to a high-rate clarifier/thickener where solids removal would occur. The decanted or clarified water would then be returned to the head of the facility. Second pass RO brine would be returned to the head of the first pass SWRO, since that residuals stream is suitable for recycling at that location. First pass SWRO brine, MF/UF and SWRO chemical cleaning solutions and solids handing dewatering centrate would not be recycled.

9.8.1 Design Criteria

The preliminary design criteria for the solids residuals gravity thickener and dewatering systems for a full scale desalination facility are presented in Table 9.8 below. These criteria are essentially independent of the type of pretreatment (membrane or conventional) that is selected for the full scale facility. Section 8 provides additional solids residuals treatment system design criteria that are specific to the conventional and MF/UF pretreatment systems. The solids residuals treatment system is designed to be expanded from an initial 5 MGD or 10 MGD to an ultimate 15 MGD product water capacity.

Table 9.8: Solids Handling System Design Criteria

PROCESS DESCRIPTION	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Gravity Thickener System					
Gravity Thickeners	number	1	1	1	2
Redundant Gravity Thickeners	number	1	1	1	1
Capacity per Unit	gpm	1,500	1,500	1,500	1,500
Solids Loading per unit (Winter Season)	ppd/SF	2.5	2.5	2.5	3.0
Hydraulic Loading per unit (Summer Season)	gpd/SF	820	820	820	630
Basin Diameter	ft	50	50	50	50
Side Water Depth	ft	16	16	16	16
Gravity Thickener Feed Pumps	number	2	2	2	3
Gravity Thickener Feed Pump Capacity	gpm	1,500	1,500	1,500	1,500
Centrifuge Dewatering System					
Centrifuge Units	number	1	1	1	2
Redundant Units	number	1	1	1	1
Capacity per Unit	gpm	80	80	80	80
Centrifuge Feed Pumps	number	2	2	2	3
Centrifuge Feed Pump Capacity	gpm	80	80	80	80
Average Centrate flow rate	gpm	10	10	20	30
Minimum Dewatered Sludge Concentration	percent	25%	25%	25%	25%

9.8.2 Solids Residuals Handling Process Description

9.8.2.1 Equalization

The major waste water streams that would flow to the equalization basin includes spent washwater from the conventional or MF/UF filter backwash, washwater from the strainer backwash and decant water from the solids clarifier/thickener. A separate basin would capture conventional filter-to-waste water to return to the head of the plant without additional treatment. The design criteria for the equalization basins depend on the pretreatment type and are presented in Section 8 above. The main difference in the solids residual handling system between the conventional pretreatment system and the MF/UF pretreatment system is that the size of the basin. A larger basin is required for the conventional system because of greater volumes due to lower backwash frequency. Coagulants would be added to the MF/UF spent washwater in the equalization basin to help condition them for clarification and thickening in the next process unless coagulant was being feed upstream of the MF/UF system to remove TOC.

9.8.2.2 Clarification and Thickening

Solids from the various pretreatment processes would be settled and thickened in gravity thickeners. Two units would be provided for an initial 5 and 10 MGD facilities and a third basin would be provided for expansion to 15 MGD. The supernatant from the gravity thickeners would be returned to the head of the treatment train. The thickened solids would be sent to a dewatering system.

9.8.2.3 Dewatering

Dewatering of the thickener solids reduces the overall volume and weight of the solids for offsite disposal, lowering disposal costs. The dewatering system will take influent solids at a concentration between 2 and 3% and produce a cake having approximately 25% solids by weight that can be conveyed to a truck for hauling to the Redwood Landfill. The minimum solids acceptance criteria for the Redwood Landfill is 20% solids. Expected volumes of thickened and dewatered solids for a full scale desalination facility with conventional and MF/UF pretreatment are presented in Section 8 of this report. Two alternatives for dewatering solids were evaluated for the MMWD full scale desalination facility: 1) Solid-Bowl Centrifuge; and 2) Belt Filter Press.

Centrifugal dewatering is a high speed process that uses centrifugal force generated from rapid rotation of a cylindrical bowl to separate solids from liquid. A solid-bowl centrifuge operates as a continuous feed unit which removes solids using a scroll conveyor and discharges liquid over an end weir. The bowl is a conical-shape which helps lift solids out of the liquid allowing them to dry on an inclined surface before being discharged. A typical centrifuge thickening system consists of:

- Solids feed pumps
- Polymer storage, activation, and feed equipment
- Dewatered solids transfer pumps
- Centrifuge with integrated washwater system
- Flow monitoring controls and associated electrical equipment

The major advantages of a solid-bowl centrifuge for dewatering include:

- Small amount of floor space relative to hydraulic capacity
- Higher solids concentration
- Minimal polymer use required at high loading rates
- Minimal exposure of operators to waste stream due to the centrifuge being completely enclosed
- Minimal amount of washwater for cleaning
- Stable performance over various conditions
- Easy removal and replacement of major maintenance items

The disadvantages of a solid-bowl centrifuge for dewatering include:

- Higher power consumption than belt filter press
- Higher relative level of noise

Belt filter presses (BFP) are continuous-feed dewatering devices that involve application of polymers for chemical conditioning, gravity drainage, and mechanically applied pressure to dewater solids. Conditioned solids are first introduced on a gravity drainage section where they are allowed to thicken. A majority of the free water is removed from the solids by gravity. Following gravity drainage, pressure is applied in a low-pressure section, where solids are squeezed between opposing porous cloth belts. Squeezing forces additional water from the solids. The final dewatered cake is removed from the belts by scraper blades. A typical BFP system consists of:

- Solids feed pumps
- Polymer storage, activation, and feed equipment
- Solids cake conveyor
- Belt press with integrated washwater booster pumps and compressed air
- Flow monitoring controls and associated electrical equipment

The major benefits of using a BFP for dewatering include:

- Lower power consumption.
- Relatively simple maintenance that can usually be completed by plant maintenance staff.
- Relatively low level of noise.

The major disadvantages of using a BFP for dewatering include:

- High level of operator attention required if the feed solids vary in concentration.
- Required belt washing is time consuming and requires large volumes of washwater.
- Required building footprint is larger than for centrifuge system.
- Solids concentration achievable typically less than that achieved by a centrifuge (higher solids disposal cost).

Table 9.9 presents an overall comparison of the relative cost and non-cost factors for the solids residuals dewatering alternatives. The cost and non-cost factors were evaluated with the most advantageous alternative receiving the lowest score with 1 being the best and 5 being the least desirable.

Table 9.9: Cost and Non-Cost Factor Comparison of the Solids Dewatering Alternatives

Dewatering Alternative	Capital Costs	Operating Costs	Reliability/ Flexibility	Building Footprint	Overall Score
Centrifuge	1	2	1	1	5
Belt Filter Press	2	1	2	2	7

The relative capital cost saving associated with a smaller building for a centrifuge system, together the greater flexibility and reliability of the centrifuge system above result in the centrifuge being the preferred alternative for the dewatering step in the solids handling system.

Thickened solids from the gravity thickeners would be dewatered by centrifuges in a dewatering area. Two centrifuges would be provided for an initial 5 or 10 MGD facilities and a third centrifuge would be provided for expansion to 15 MGD. The 25% solids cake would be conveyed to a truck for hauling to the Redwood Landfill. The small volume of dewatering centrate would be sent to the sanitary sewer so as not to introduce polymers that could foul the SWRO membranes into the main process flow.

9.9 Brine Handling System

The brine from the first pass SWRO system would be disposed of by first mixing with low TDS wastewater effluent and then discharged into the San Francisco Bay. The effluent would come from the wastewater treatment facility owned and operated by the Central Marin Sanitation Agency (CMSA). The CMSA effluent would dilute the brine so that the resulting discharge would often have a salinity nearer to that of the Bay than the current CMSA effluent.

9.9.1 Design Criteria

The preliminary design criteria for a full scale brine handling system are presented in Table 9.10 below.

Table 9.10: Brine Handling System Design Criteria

Process Description	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Brine Pump Station					
Brine Flowrate at Max Capacity and Design Recovery	MGD	5.4	5.4	10.7	14.9
Approx. Pump Discharge Pressure	psi	10	10	10	10
Brine Pumps	number	1	1	2	3
Redundant Brine Pumps	number	1	1	1	1
Capacity	MGD	5.5	5.5	5.5	5.5
Speed Control	type	VFD	VFD	VFD	VFD

Process Description	Unit	5-MGD Non-Exp.	5-MGD Exp.	10-MGD Exp.	15-MGD
Brine Pipeline					
Number of Brine Pipelines	number	1	1	1	1
Pipeline Diameter	inches	18	24	24	24
Flow Velocity at Maximum Flow	fps	5	2.8	5.4	7.4
Approx. Pipeline Length	feet	2,000	2,000	2,000	2,000
Pipeline Material	--	HDPE	HDPE	HDPE	HDPE

9.9.2 Brine Handling Process Description

9.9.2.1 Brine Pump Station and Pipeline

To permit taking full advantage of SWRO system energy recovery, to eliminate the potential for backpressure on the SWRO system and to facilitate system operations and controls, a low head brine pump station would pump the brine to the point of blending with CMSA effluent.

A single pipeline would be constructed initially with sufficient capacity to convey brine from the SWRO facility at build-out capacity of 15 MGD, thereby eliminating the need to construction an additional pipeline in the future. The brine pipeline is defined as the pipeline that connects the desalination facility to the existing CMSA outfall at the onshore valve box before the outfall extends out into the Bay. The brine pipeline is sized to provide a moderate flow velocity and headloss in the pipeline at the future flowrates.

9.9.2.2 Blending with CMSA Effluent

The brine pipeline would connect to the existing 84-inch diameter CMSA outfall at the onshore valve box before the outfall extends out into the Bay. Blending of the brine and CMSA effluent would take place in the valve box and in the length of the CMSA outfall. The brine pipeline would have appropriate isolation valves and check valves to ensure that effluent does not migrate back up the brine pipeline during periods of low flow from the desalination facility.

9.10 Chemical Systems

The chemical storage and feed systems for a full scale desalination facility would include:

- Coagulant
- Coagulant Aid Polymer (conventional pretreatment only)
- Antiscalant
- Sodium Bisulfite
- Carbon Dioxide
- Limestone/Calcite
- Zinc Orthophosphate
- Sodium Hypochlorite
- Ammonia

- Sodium Hydroxide
- Citric Acid

The chemical storage tanks and feed equipment would be located together in a dedicated chemical storage area potentially along with the CIP tanks and equipment for cleaning the membrane systems. Small quantities of dry or liquid chemicals for SWRO CIPs would be stored in a dedicated portion of the SWRO and second pass RO process areas. Quantities of these chemicals will be minimized through on-demand deliveries. Preparation of solutions would be performed using the RO CIP system. Chemical systems for the solids residuals handling and dewatering system could potentially be located in or adjacent to these treatment systems. The chemical storage area would be designed using one bulk storage tank for each chemical for a 5 MGD desalination facility and two bulk tanks for plant expansions. The chemical tanks would generally be designed to permit delivery of full chemical truck loads and to permit approximately 30 days of chemical storage at average usage rates and no less than two weeks of storage at maximum usage rates.

References:

Seacord, Thomas; *The Affordable Desalination Collaboration 2005,* AMTA Conference Proceedings, 2006.

Section 10: Desalination Facility Conceptual Capital and Operating Cost Estimates

10.1 Basis of Cost Estimate Development

10.1.1 Cost Estimating Model

The capital and operating cost estimates for the MMWD Seawater Desalination Facility are presented in this section. These cost estimates were developed using an in-depth parametric cost estimating model developed by CH2M HILL. The model, called CPES (CH2M HILL's Parametric Cost Estimating System), includes individual cost modules for each water treatment unit operation. Each module in CPES (e.g., pipeline, pump station, water treatment plant unit process) was developed using standard equipment/process arrangement drawings derived from actual full-scale treatment plant designs that have been constructed and are operational. From the standard general arrangement drawings, physical dimensions and specific components are itemized and tied to design criteria and other user inputs so that the size and layout of the unit operation can be defined. Once the "right sizing" is completed, the model generates quantity take-offs for excavation, concrete, process equipment, mechanical, miscellaneous metals, instrumentation and building materials. A robust construction cost estimate is then generated by applying RS Means unit cost data (updated annually), as well as major process equipment cost algorithms (updated every 3 years based on supplier budget quotes over a range of equipment sizes/capacities) to the quantity take-off information.

Operating and maintenance (O&M) cost estimates are calculated based on quantities and usage of chemicals, power and consumable equipment (e.g., membranes and cartridge filters) defined in each module in combination with user-defined input units for electrical, chemical, consumable, and labor costs.

Capital and O&M cost estimates presented herein were developed based on specific design criteria defined through the pilot testing and unit costs for power, chemicals and labor representative of the San Francisco Bay area. The cost model parameters were also evaluated and adjusted for MMWD project specific aspects. In this manner, CPES develops project specific capital and annual cost estimates for the MMWD desalination facility.

The use of CPES provides the following benefits:

- increases the accuracy of conceptual cost estimating by calculating quantity take-offs based on the design criteria and applying a unit cost versus the conventional cost-curve approach;

- allows more accurate cost estimates to be developed before any design drawings are produced

Table 10.1 below presents a summary of standard cost estimating level description, accuracy and recommended contingencies based on the level of the project. This data was complied from the Association for the Advancement of Cost Engineering (AACE).

Table 10.1: Standard AACE Cost Estimating Guidelines

Cost Estimate Class[a]	Project Level Description	Estimate Accuracy Range	Recommended Estimate Contingency
Class 5	Planning	-30 to +50%	30 to 50%
Class 4	Conceptual (1 to 5% Design)	-15 to +30%	25 to 30%
Class 3	Preliminary (10 to 30% Design)	-10 to +20%	15 to 20%
Class 2	Detailed (40 to 70% Design)	-5 to +15%	10 to 15%
Class 1	Final (90 to 100% Design)	-5 to +10%	5 to 10%

Notes:

(a) Association for the Advancement of Cost Engineering, 1997. International Recommended Practices and Standards.

Although the CPES model typically provides a more accurate project cost than other, more traditional cost curve approaches, the level of accuracy for the capital and operating cost estimates presented below should be considered to represent between a Class 4 and Class 5 estimate with an accuracy in the range of approximately minus 30% to plus 50%, in accordance with standard cost estimating guidelines in table 10.1. Although no design has been formally conducted in association with the development of the CPES cost estimates, preliminary design criteria have been developed through the conduct of the pilot study (as presented in Sections 8 and 9) and a basic understanding of site conditions and environmental issues have been developed through project specific studies. Consequently, a contingency of 25%, reflecting that used with a Class 4 estimate, has been applied to the cost estimates presented in this section.

The cost estimate tables also include a factor for escalation to the mid-point of construction. We have used three years, at approximately 5% inflation per year, to calculate the escalation cost estimate. This is based on the trend of the San Francisco Engineering News Record construction cost index which reflects recent more rapid construction costs seen since 2004.

In addition to the escalation to the mid-point of construction, Kennedy/Jenks-CH2M HILL recommend including a market uncertainty factor of 15%. This factor accounts for uncertainty in construction costs due to the availability of Contractors and the volume of other construction work at the time of bidding. For example, the upcoming work planned by the San Francisco Public Utilities Commission (over $6 billion in water and wastewater work in the next 15 years) and work created by natural disasters reduces the availability of Contractors for construction services and may drive up prices. MMWD should re-evaluated this factor as the project moves closer to the bidding phase to account for the actual construction and bidding climate observed at the time.

10.2 Overall Design Criteria and Assumptions

The project preliminary design criteria and facility capacity and operations assumptions are described in Sections 8 and 9 of the report. Additional assumptions used to develop the cost estimates are presented below.

10.2.1 Materials Assumptions

The process equipment materials used in a seawater desalination facility must be suitable for high salinity water and designed for the appropriate system pressures and conditions. The general construction materials such as for buildings and concrete basins, etc. must also be suitable for a corrosive environment. The cost model incorporated the following materials, approaches and current costs for the capital costs estimate:

- high pressure pumps, valves, piping and fittings – super duplex or super-austenitic “seawater grade” stainless steel
- main process piping – HDPE, fiberglass or PVC
- concrete basins – protective epoxy coatings
- building surfaces – extra protective coatings for the marine environment

10.2.2 Operational Scenario Assumptions

As described in Section 8, MMWD staff projected potential future system water demands through the year 2020 to estimate the amount of desalination plant water that would be needed to meet those demands. The demand model projections incorporated use and supply factors based on normal rainfall years, low rainfall (dry) years and drought years. Based on these projections, in normal and dry years, the desalination plant would operate at lower production levels during the wet season (approximately December through April) and operate at increased production in the dry, summer season (approximately May through November). During droughts, the desalination plant would operate at full production levels all year or as required to meet water demands.

Based on MMWD staff projections, the potential operations scenarios for a full scale desalination facility would be as follows:

- Initial Operation:
  - In normal rainfall years: 4 MGD during the period May through November; 1 MGD during the period December through April.
  - In dry years: 10 MGD during the period April through Nov; 4 MGD during the period December through March.
  - In drought years: 10 MGD year round.

- Approximately 10 years later or about 2015
  - In normal rainfall years: 8 MGD during the period May through November; 1 MGD during the period December through April.
  - In dry years, 12 MGD during the period April through November; 8 MGD during the period December through March.
  - In drought years: 15 MGD year round.

- Approximately Year 2020 and beyond:
  - In normal rainfall years: 12 MGD during the period May through November; 2 MGD during the period December through April.
  - In dry years: 15 MGD during the period April through November; 12 MGD during the period December through March.
  - In drought years: 15 MGD year round.

10.2.3 Construction Approach for Typical and Rapid Expansion

To meet some or all of the plant capacity described in the operations assumptions above, MMWD is considering several different approaches to designing and constructing a full scale desalination Facility. Cost estimates were developed for the initial construction phase of each of these approaches as described below. The approaches are as follows:

Case A: A 5 MGD Facility that is not designed for expansion

Case B: A 5 MGD Facility that is designed for typical expansion. This facility could be expanded to 10 or 15 MGD in later phases.

Case C: A 5 MGD Facility that is designed for a rapid expansion to 10 MGD in a second phase. It could be expanded to 15 MGD using a typical approach in a third phase.

Case D: A10 MGD Facility that is designed for typical expansion to 15 MGD.

In Cases A-C, the first phase results in construction of a 5 MGD facility, while in Case D, the first phase results in construction of a 10 MGD facility. The differences in those three facilities are presented in Table 10.2 below.

Table 10.2: Comparison of Construction Approaches

Comparison of Key Components	Case A: 5 MGD non-expandable	Case B: 5 MGD typical future expansion	Case C: 5 MGD rapid future expansion	Case D: 10 MGD typical future expansion
Site layout capacity	5 MGD	Allows for 15 MGD	Allows for 15 MGD	Allows for 15 MGD
Intake, raw water, and brine pipelines capacity	5 MGD	15 MGD	15 MGD	15 MGD
Buildings, tanks capacity	5 MGD	5 MGD	10 MGD	10 MGD
Piping stub-outs for future connections	None	Available	Available	Available
Installed process equipment capacity	5 MGD	5 MGD	5 MGD	10 MGD

For Case A, all facilities, including the intake and the raw water and brine pipelines would only be sized for a 5 MGD facility and the facility would not be designed with any features to facilitate future expansion.

For Case B, the intake and brine pipelines would be sized for a 15 MGD facility and the remainder of the facility would be designed initially for 5 MGD with the ability to expand to 10 MGD and/or 15 MGD in the future. For this type of expansion, space would be reserved for construction of additional, parallel process trains, tanks and clearwells adjacent to the initial trains. Pipe stub-outs would be provided during the initial construction phase for interconnection of future facilities. In the initial phase of construction, structures and buildings would only be constructed for 5 MGD. The buildings would generally be designed to add on additional space by extending the building. This approach provides the lowest initial capital cost for the facility while still providing the ability to expand in the future.

For Case C, the intake and brine pipelines would again be sized and initially constructed for a 15 MGD facility. In addition, all facilities would be also be initially designed for 10 MGD capacity, but major process equipment (pumps, MF/UF cassettes, cartridge filters, RO trains, etc.) would be installed initially to produce only 5 MGD of desalinated water. This approach would require constructing the structural, building, major site and process piping, residuals handling, chemical storage and tank facilities for 10 MGD during the initial phase. For expansion from 5 to 10 MGD, MMWD would contract with membrane system suppliers (MF/UF and RO) to supply, install and start-up the MF/UF, first pass (and if required, second pass RO systems) to rapidly provide the additional 5 MGD of capacity.

The rapid capacity expansion construction approach would require a greater initial capital investment by MMWD compared to an initial-phase 5 MGD facility but would provide the ability to rapidly expand from 5 MGD to 10 MGD in a period of approximately 12 months to permit increased desalinated water production should a drought require more than 5 MGD of desalinated water. The typical expansion time could be approximately 24 to 36 months.

For Case D, the approach for expansion from 10 MGD to 15 MGD would be the “typical” approach where space would be reserved on the site for the major civil and process facilities for the expansion.

10.3 Desalination Facility Conceptual Capital Cost Estimates

This section presents conceptual level capital construction cost estimates for the MMWD Desalination Facility and compares cost of a facility with conventional and MF/UF pretreatment. A description of the costs components are provided below.

10.3.1 Comparison of Desalination Facility Conceptual Capital Cost Estimates with Conventional and MF/UF Pretreatment Systems

Table 10.1 presents a comparison of conceptual level construction cost estimates for a 10 MGD expandable to 15 MGD capacity MMWD Desalination Facility with conventional and MF/UF pretreatment. The costs are provided by major process area. The cost estimates for general civil site work, yard piping and electrical and the plant instrumentation and control systems are estimated as percentages of the process equipment construction costs at the values shown in the table. These cost estimates assume a conventional design, bid and build approach to project procurement. Typical Contractor markups for overhead, profit and bonding are also shown and a project contingency is included.

The project unit cost per gallon of plant capacity ($ per gallon) is also shown in Table 10.3. Because this cost estimate is for a 10 MGD facility expandable to 15 MGD, the unit cost per gallon is higher then would typically be expected for a 10 MGD capacity non-expandable facility.

Table 10.3: Comparison of Desalination Facility Conceptual Capital Costs with Conventional and MF/UF Pretreatment Systems

10 MGD Expandable to 15 MGD SWRO Desalination Facility		
Unit Process Description	**Conventional Pretreatment**	**MF/UF Pretreatment**
Rapid Mix	$887,000	$887,000
Flocculation	$4,086,000	$1,615,000
Sedimentation	$8,303,000	$0
Conventional Filters	$10,199,000	$0
Strainers, UF Membrane Filters and Building	$0	$11,533,000
Filtrate and Backwash Supply Tank	$1,071,000	$410,000
SWRO Feed Pump Station	$1,193,000	$1,193,000
1st Pass SWRO and Building	$16,745,000	$16,745,000
Permeate Tank	$153,000	$153,000
Chlorine Contact Tank	$1,174,000	$1,174,000
Distribution Booster Pumps	$1,294,000	$1,294,000
Liquid Chemicals	$3,162,000	$2,438,000
Dry Chemicals	$599,000	$599,000
Carbon Dioxide	$494,000	$494,000
Backwash Equalization Basin	$2,057,000	$253,000
Gravity Thickener	$2,213,000	$1,519,000
Centrifuges	$2,226,000	$2,226,000
Backwash Supply Pump Station	$562,000	$0
Brine Pump Station	$792,000	$792,000
O&M Building	$600,000	$600,000
Subtotal	**$57,810,000**	**$43,925,000**
Cost per gallon capacity (10 MGD)*	$5.78	$4.39
Additional Project Costs		
Sitework (Conv. @ 8% / UF @ 6%)	$4,625,000	$2,636,000
Yard Electrical (Conv. @ 7% / UF @ 8%)	$4,047,000	$3,514,000
Yard Piping (Conv. @ 9% / UF @ 8%)	$5,203,000	$3,514,000

10 MGD Expandable to 15 MGD SWRO Desalination Facility		
Unit Process Description	**Conventional Pretreatment**	**MF/UF Pretreatment**
Plant Instrumentation and Controls (Conv. @ 6% / UF @ 5%)	$3,469,000	$2,197,000
Subtotal Including Additional Project Costs	**$75,154,000**	**$55,786,000**
Cost per gallon capacity (10 MGD)*	$7.52	$5.58
MMWD Specific and Other Costs		
Plant Seismic Piles	$3,800,000	$2,400,000
Protective Coatings	$2,000,000	$660,000
Transmission Pipelines		
Raw Water Transmission Line	$1,727,000	$1,727,000
Brine Transmission Line	$494,000	$494,000
Intake System Components		
New Concrete Intake Pier	$4,100,000	$4,100,000
Intake Screens and Pump Station on Pier	$2,593,000	$2,593,000
Raw Water Pipeline on the Pier	$2,505,000	$2,505,000
Basic Cost including MMWD Specific Costs	**$92,373,000**	**$70,265,000**
Cost per gallon capacity (10 MGD)*	$9.24	$7.03
Contractor Markups		
Overhead @ 6% on Basic Cost	$5,543,000	$4,216,000
Profit @ 9% on Basic Cost	$8,314,000	$6,324,000
Mob/Bonds/Insurance @ 3% on Basic Cost	$2,772,000	$2,108,000
Subtotal including Contractor Markups	**$109,002,000**	**$82,913,000**
Contingency		
Contingency @ 25% on Basic Cost	$23,094,000	$17,567,000
Subtotal including Contingency	**$132,096,000**	**$100,480,000**
Escalation to Mid-Point of Construction @ 5% per year for three years	$13,856,000	$10,540,000
Subtotal including Escalation	**$145,952,000**	**$111,020,000**
Construction Market Uncertainty @ 15% on Basic Cost	$13,855,950	$10,539,750
Total Construction Cost	**$159,807,950**	**$121,559,750**
Non-Construction Costs		
Permitting @ ~1% on Basic Cost	$700,000	$700,000
Engineering @ 8% on Basic Cost	$7,390,000	$5,622,000

10 MGD Expandable to 15 MGD SWRO Desalination Facility		
Unit Process Description	**Conventional Pretreatment**	**MF/UF Pretreatment**
Services during Construction @ 5% on Basic Cost	$4,619,000	$3,514,000
Total SWRO Facility Cost including Non-Construction Costs	**$172,517,000**	**$131,396,000**
Cost per gallon capacity (10 MGD)*	$17.25	$13.14
MMWD Distribution System Improvements Cost	$42,000,000	$42,000,000
Cost of Optional 2nd Pass RO (including all markups)	$10,500,000	$10,500,000

10.3.1.1 Seismic Foundation Cost Estimate

The proposed site for a full scale desalination facility at MMWD's storage facility at Pelican Way in San Rafael, California was selected from six potential sites. Through a rigorous site evaluation process, the Pelican Way site was determined to be the best apparent site for the project. Although the site has many advantages, site soil is underlain with bay mud and structures at the site must be supported on piles to provide adequate support for seismic events. This is similar to other facilities located near the Bay such as the CMSA wastewater treatment plant.

Based on a geotechnical report of the proposed site titled, "Preliminary Geotechnical Study, Desalination Water Project, MMWD" and dated 6 November 1990, the desalination facility structures at the Pelican Way site would supported on a grade beam and slab foundation with pile supports. The geotechnical report recommended that all structures be pile supported with piles extending to bedrock, for a pile length of 125 to 130 feet. For estimating the cost of the seismic foundations the piles were assumed to be 125 foot long, 14" diameter pre-cast concrete piles. Based on the geotechnical report, the service load capacity of each pile was assumed to be 65 tons.

Conceptual level cost estimates for the site specific seismic foundation requirements were developed based on the 1990 geotechnical report, current Building Code seismic requirements, and on the approximate footprint of the proposed process buildings, tanks and basins. The estimated installed cost for the piles is $37 per linear foot of piling, based on recent projects Kennedy/Jenks has constructed in the San Francisco Bay area. For relatively deep water holding structures such as the flocculation and sedimentation basins, the piles were estimated to be at 9-foot spacing at a cost of $55 per square foot of basin area. For more shallow water holding structures such as the MF/UF filter basins, the piles were estimated to be at 11-foot spacing at a cost of $40 per square foot of basin area. For slab-on-grade buildings such as the RO Building, the piles were estimated to be at 14-foot spacing at a cost of $25 per square foot of building area.

For the desalination facility with conventional pretreatment alternative, the total area supported on piles would be approximately 113,000 square feet. For the MF/UF pretreatment alternative, the area supported on piles would be approximately 81,000 square feet.

10.3.1.2 Intake Pier and MMWD Distribution System Improvements Cost Estimate

The cost for the intake pier replacement is based on the design presented in the preliminary design from the 1991 pilot study and adjusted for increased cost estimates for piles, concrete and steel materials costs and general inflation to December 2006 based on the San Francisco Engineering News Record construction cost index.

The cost for the MMWD distribution system improvements for the desalination project was provided by MMWD staff and is based on the design presented in the preliminary design from the 1991 pilot study and adjusted for increased cost estimates and general inflation to December 2006 based on the San Francisco Engineering News Record construction cost index.

10.3.2 Desalination Facility Costs for Different Capacities

Table 10.4 presents conceptual level capital cost estimates for a full scale MMWD Desalination Facility as described in Sections 8 and 9. Conceptual level capital cost estimates are presented for:

Case A: A 5 MGD Facility that is not designed for expansion

Case B: A 5 MGD Facility that is designed for typical expansion. This facility could be expanded to 10 or 15 MGD in later phases.

Case C: A 5 MGD Facility that is designed for a rapid expansion to 10 MGD in a second phase. It could be expanded to 15 MGD with a typical approach in a third phase.

Case D: A10 MGD Facility that is designed for typical expansion to 15 MGD.

Table 10.4: Desalination Facility Conceptual Capital Cost Estimates for Different Capacities and Construction Approaches

MMWD Desalination Facility				
SWRO Facility Processes	**Case A: 5 MGD Not Expandable**	**Case B: 5 MGD "Typical" Expansion**	**Case C: 5 MGD "Rapid" Expansion**	**Case D: 10 MGD "Typical" Expansion**
Rapid Mix	$508,000	$508,000	$844,000	$887,000
Flocculation	$869,000	$869,000	$1,383,000	$1,615,000
Strainers, UF Membrane Filters and Building	$7,885,000	$7,885,000	$8,461,000	$11,533,000
Filtrate and Backwash Supply Tank	$206,000	$206,000	$410,000	$410,000
SWRO Feed Pump Station	$803,000	$803,000	$1,193,000	$1,193,000
1st Pass SWRO and Building	$9,962,000	$9,962,000	$12,965,000	$16,745,000
Permeate Tank	$153,000	$153,000	$153,000	$153,000
Chlorine Contact Tank	$540,000	$540,000	$1,174,000	$1,174,000
Distribution Booster Pumps	$853,000	$853,000	$963,000	$1,294,000

MMWD Desalination Facility				
SWRO Facility Processes	**Case A: 5 MGD Not Expandable**	**Case B: 5 MGD "Typical" Expansion**	**Case C: 5 MGD "Rapid" Expansion**	**Case D: 10 MGD "Typical" Expansion**
Liquid Chemicals	$1,836,000	$1,836,000	$2,438,000	$2,438,000
Dry Chemicals	$585,000	$585,000	$599,000	$599,000
Carbon Dioxide	$388,000	$388,000	$494,000	$494,000
Backwash Equalization Basin	$253,000	$253,000	$253,000	$253,000
Gravity Thickener	$1,305,000	$1,305,000	$1,519,000	$1,519,000
Centrifuges	$1,825,000	$1,825,000	$2,226,000	$2,226,000
Brine Pump Station	$541,000	$541,000	$598,000	$792,000
O&M Building	$600,000	$600,000	$600,000	$600,000
Subtotal	**$29,112,000**	**$29,112,000**	**$36,273,000**	**$43,925,000**
Additional Project Costs				
Sitework (5% for non exp./ 6% for exp.)	$1,456,000	$1,747,000	$2,695,000	$2,636,000
Yard Electrical (7% for non exp. / 8% for exp.)	$2,038,000	$2,329,000	$3,593,000	$3,514,000
Yard Piping (7% for non exp. / 8% for exp.)	$2,038,000	$2,329,000	$3,593,000	$3,514,000
Plant Instrumentation and Controls (5%)	$1,456,000	$1,456,000	$2,246,000	$2,197,000
Subtotal Including Additional Project Costs	**$36,100,000**	**$36,973,000**	**$48,400,000**	**$55,786,000**
MMWD Specific and Other Costs				
Plant Seismic Piles	$1,440,000	$1,440,000	$2,400,000	$2,400,000
Protective Coatings	$442,000	$442,000	$660,000	$660,000
Transmission Pipelines				
Raw Water Transmission Line	$1,315,000	$1,727,000	$1,727,000	$1,727,000
Brine Transmission Line	$420,000	$494,000	$494,000	$494,000
Intake System Components				
New Concrete Intake Pier	$4,100,000	$4,100,000	$4,100,000	$4,100,000
Intake Screens and Pump Station on Pier	$1,558,000	$1,975,000	$2,284,000	$2,593,000
Raw Water Pipeline on the Pier	$1,900,000	$2,505,000	$2,505,000	$2,505,000
Basic Cost including MMWD Specific Costs	**$47,275,000**	**$49,656,000**	**$62,570,000**	**$70,265,000**
Contractor Markups				
Overhead @ 6% on Basic Cost	$2,837,000	$2,980,000	$3,755,000	$4,216,000
Profit @ 9% on Basic Cost	$4,255,000	$4,470,000	$5,632,000	$6,324,000
Mob/Bonds/Insurance @ 3% on Basic Cost	$1,419,000	$1,490,000	$1,878,000	$2,108,000
Subtotal including Contractor Markups	**$55,786,000**	**$58,596,000**	**$73,835,000**	**$82,913,000**

MMWD Desalination Facility				
SWRO Facility Processes	**Case A: 5 MGD Not Expandable**	**Case B: 5 MGD "Typical" Expansion**	**Case C: 5 MGD "Rapid" Expansion**	**Case D: 10 MGD "Typical" Expansion**
Contingency @ 25% on Basic Cost	$11,819,000	$12,414,000	$15,643,000	$17,567,000
Subtotal including Contingency	**$67,605,000**	**$71,010,000**	**$89,478,000**	**$100,480,000**
Escalation to Mid-Point of Construction @ 5% per year for three years on Basic Cost	$7,092,000	$7,449,000	$9,386,000	$10,540,000
Subtotal including Escalation	**$74,697,000**	**$78,459,000**	**$98,864,000**	**$111,020,000**
Construction Market Uncertainty @ 15% on Basic Cost	$7,092,000	$7,449,000	$9,386,000	$10,540,000
Total Construction Cost	**$81,789,000**	**$85,908,000**	**$108,250,000**	**$121,560,000**
Non-Construction Costs				
Permitting @ ~1% on Basic Cost	$700,000	$700,000	$700,000	$700,000
Engineering @ 8% on Basic Cost	$3,782,000	$3,973,000	$5,006,000	$5,622,000
Services during Construction @ 5% on Basic Cost	$2,364,000	$2,483,000	$3,129,000	$3,514,000
Total Desalination Facility Cost including Non-Construction Costs	**$88,635,000**	**$93,064,000**	**$117,085,000**	**$131,396,000**
MMWD Distribution System Improvements Cost	$22,600,000	$22,600,000	$42,000,000	$42,000,000
Total Project Cost including Distribution System Costs	**$111,235,000**	**$115,664,000**	**$159,085,000**	**$173,396,000**
Cost of Optional 2nd Pass RO (including all markups)	$5,500,000	$5,500,000	$6,500,000	$10,500,000

10.4 Desalination Facility Conceptual Operating Cost Estimates

This section presents conceptual level annual operational cost estimates for a 10 MGD capacity, MMWD Desalination Facility with conventional and MF/UF pretreatment. This cost comparison is used in Section 8 to evaluate the recommended pretreatment system for the desalination facility. Based on the recommended MF/UF pretreatment system, conceptual level annual operational costs are also presented for a 5 and a 10 MGD Facility operating under average and drought year conditions.

Table 10.5 and 10.6 below present the weighted average conditions and drought conditions to be used in the cost model for a 5 and 10 MGD plant based on the operational scenarios presented earlier:

Table 10.5: Operating Conditions for a 5 MGD Desalination Facility

Parameter	Average Year Dry Period	Average Year Wet Period	Weighted Average	Drought Period
Operating Period (months)	7	5	--	12
First Pass SWRO Production, MGD	4	1	2.75	5
TDS, ppm	21,800	13,800	18,500	32,000
Temp, °C	15	10	13	13
SWRO Feed Pressure, PSIG	625	500	575	970
On-line Factor, %	95	95	95	95

Table 10.6: Operating Conditions for a 10 MGD Desalination Facility

Parameter	Average Year Dry Period	Average Year Wet Period	Weighted Average	Drought Period
Operating Period (months)	7	5	--	12
First Pass SWRO Production, MGD	8	1	5.1	10
TDS, ppm	21,800	13,800	18,500	32,000
Temp, ^{o}C	15	10	13	13
SWRO Feed Pressure, PSIG	625	500	575	970
On-line Factor, %	95	95	95	95

10.4.1 Comparison of Desalination Facility Conceptual Operating Costs with Conventional and MF/UF Pretreatment Systems

The conceptual level annual operating and maintenance (O&M) cost estimates are presented as both total O&M costs for each major process area and by overall category. The O&M cost categories include:

- power use;
- pretreatment and post treatment chemical use, and MF/UF and SWRO CIP chemical use;
- MF/UF membrane replacement, cartridge filter replacement, SWRO membrane replacement;
- solids residuals costs and disposal;
- maintenance costs; and
- labor costs.

Table 10.7 presents a comparison of the conceptual operating costs for a full scale 10 MGD desalination facility with conventional and MF/UF pretreatment systems. The costs are based on average summer time water quality conditions and average plant operation.

Table 10.7: Comparison of Desalination Facility Conceptual Operating Costs with Conventional and MF/UF Pretreatment Systems

10 MGD SWRO Desalination Facility at Average Operating Conditions		
Unit Process Description	**Conventional Pretreatment**	**MF/UF Pretreatment**
Intake Screens and Pump Station	$184,000	$184,000
Rapid Mix	$36,000	$36,000
Flocculation	$152,000	$80,000
Sedimentation	$261,000	$0
Conventional Filters	$402,000	$0
Strainers and UF Membrane Filters	$0	$678,000
Filtrate and Backwash Supply Tank	$15,000	$15,000
SWRO Feed Pump Station	$161,000	$161,000
1st Pass SWRO	$2,747,000	$2,745,000
Permeate Tank	$6,000	$6,000
Chlorine Contact Tank	$43,000	$43,000
Distribution Booster Pumps	$271,000	$271,000
Liquid Chemicals	$1,276,000	$658,000
Dry Chemicals	$285,000	$285,000
Carbon Dioxide	$99,000	$99,000
Backwash Equalization Basin	$10,000	$10,000
Gravity Thickener	$56,000	$56,000
Centrifuges	$185,000	$151,000
Backwash Supply Pump Station	$56,000	$0
Brine Pump Station	$79,000	$79,000
O&M Building	$4,000	$4,000
Subtotal O&M Cost	**$6,328,000**	**$5,561,000**
Labor	$1,065,000	$1,065,000
Total Annual O&M Cost	**$7,393,000**	**$6,626,000**

A breakdown of O&M costs by power, chemicals, labor, membrane replacement, sludge disposal and maintenance for the conventional and MF/UF seawater desalination facilities are presented in Table 10.8 below. The “Membrane Replacement” category includes UF and/or RO membrane and cartridge filter replacement costs. The “Maintenance” category includes maintenance and other miscellaneous costs.

Table 10.8: Comparison of Desalination Facility Conceptual Operating Costs by Cost Category

10 MGD SWRO Desalination Facility at Average Operating Conditions		
O&M Cost Category	**Conventional Pretreatment**	**MF/UF Pretreatment**
Chemicals	$1,494,000	$1,140,000
Power	$2,775,000	$2,724,000
Membrane Replacement	$279,000	$424,000
Solids Disposal	$79,000	$45,000
Maintenance	$1,701,000	$1,228,000
Labor	$1,065,000	$1,065,000
Total Annual O&M Cost	**$7,393,000**	**$6,626,000**

10.4.1.1 Chemicals

Chemical usage for the conventional pretreatment system alternative includes continuous addition of ferric chloride coagulant and coagulant aid polymer.

Chemical usage for the MF/UF pretreatment system alternative includes sodium hypochlorite addition once per day for the system chemical wash and periodic CIP cleanings as described in Section 8. Addition of ferric chloride coagulant could be required periodically for events with high organics in the source water.

Overall facility chemical use includes pretreatment and CIP chemicals for the SWRO system and post treatment lime, CO_2, chlorine, ammonia and corrosion control inhibitor.

10.4.1.2 Power

The major power use for the desalination facility is for desalting the Bay water through the first pass SWRO membranes. Other power requirements include pumping the water from the Bay to the desalination facility and pumping the treated water into the distribution system.

The major power use for conventional pretreatment system includes continuous rapid mix and flocculation mixing, backwash pumps and airwash blowers. The major power use for MF/UF pretreatment system includes the energy to pump the feed water through the feed strainers, the filtrate pumps to draw the water through the hollow membrane fibers, backwash pumps and air-scour blowers or compressors. Based on the pilot study, the average pressure drop across the feed strainers is 3 psi. The average trans-membrane pressure across the submerged MF/UF membranes is 8 psi. For this report, full scale facility power costs are estimated at $0.12 per kW/hr.

10.4.1.3 MF/UF Membrane Replacement

The MF/UF membrane replacement costs are estimated at $700 per membrane element. An MF/UF membrane life expectancy of 7 years is now typical for surface water sources. Based on the MMWD pilot study data, this 7 year life expectancy is also anticipated for MF/UF filtration of Bay water. The membrane replacement cost is the annual amount that should be set aside for future membrane replacement. These costs are included in the UF membranes O&M cost item.

10.4.1.4 SWRO Membrane Replacement

The SWRO membrane replacement costs are estimated at $600 per membrane element. Based on the MMWD pilot study data, the normalized differential pressure (DPN) increase for SWRO elements downstream of conventional pretreatment was greater than the SWRO with MF/UF pretreatment. See the discussion of SWRO membrane performance in Section 6. For conventional pretreatment the predicted SWRO membrane life is 5 years. For MF/UF pretreatment the predicted SWRO membrane life is 6 years. The membrane replacement cost is the annual amount that should be set aside for future membrane replacement. These costs are included in the first pass SWRO O&M cost item.

10.4.1.5 Cartridge Filter Replacement

The cartridge elements are 5 micron nominal filters and help protect the SWRO units from particulate damage and fouling. The filter elements are typically changed out based on differential pressure or time. The cost of a 5 micron 50-inch cartridge filter element is approximately $10 per element.

Based on the MMWD pilot study operations, the cartridge filters for the conventional pretreatment system were replaced every 1 to 3 months based on high differential pressure. For conventional pretreatment, eight element changes per year could be expected. The cartridge filters for the MF/UF pretreatment system were replaced due to CIP events and in general did not require change out due to differential pressure. In a full scale facility cartridge filters for MF/UF pretreatment system could be changed out every 4 to 6 months based on time. For MF/UF pretreatment, three element changes per year could be expected. These costs are included in the first pass SWRO O&M cost item.

10.4.1.6 Solids Residuals Handling

Because of the continuous coagulant and polymer feed for conditioning of the water for filtration, the conventional system produces approximately 50% more solids in the dry season (summer) period and approximately 12% more solids in wet season (winter) period. The solids would be captured and dewatered and trucked to the nearby Redwood Landfill. The cost of disposal for 25% solids at the Redwood Landfill is approximately $60 per wet ton. These costs are included in the centrifuge/solids disposal O&M cost item.

10.4.1.7 Maintenance

A maintenance allotment is recommended to be included as an annual cost amount that would be used for periodic maintenance or reserved each year for long term maintenance on equipment and structures such as repairing equipment, repainting tanks and buildings, etc. The maintenance costs for equipment and facilities were generally estimated at 2 percent of the capital cost of the equipment or facilities. Because the design includes “seawater grade” super-duplex stainless steel, and protective coatings on the concrete to reduce maintenance costs, and membrane replacement costs are accounted for separately, the maintenance costs for the UF system, and SWRO system were estimated at 1 percent of estimated capital cost.

10.4.1.8 Intake and Brine Outfall Maintenance

The intake screen for the pilot study required physical cleaning every four to eight weeks to remove bio-growth from the screen. The bio-growth attached to the stainless steel and plastic parts of the intake screen. The copper-nickel components of the intake screen did not experience as significant bio-growth but would still require periodic cleaning. The design for the full scale intake assumes the intake screens would be made entirely out of copper-nickel components to minimize bio-growth and corrosion. The maintenance costs associated with the intake screens assume physical inspection and cleaning of the intake screens every three months either in place with divers or by removing a screen. Assuming hiring a dive team to perform the maintenance at $10,000 per cleaning, the annual screen maintenance costs could be $40,000.

Based on discussion with MMWD Staff, the cost of brine disposal is expected to be negotiated with CMSA based on maintenance costs for the existing outfall. Since the brine discharge to the outfall may cause an increase in solids deposition within the outfall, MMWD would negotiate with CMSA to pay the costs for the increased maintenance cost resulting from the brine discharge.

10.4.1.9 Labor

From discussions with MMWD staff, the following operations and maintenance staff are estimated for a full scale facility: One supervising operator at $150,000 per year salary and benefits; four operators for full time operations staffing of 24 hours per day, seven days per week and coverage for holidays and vacations at $95,000 per year salary and benefits; two maintenance staff at $105,000 per year salary and benefits. Other staff positions for the facility such as laboratory, clerical, etc. would come from MMWD's current laboratory and facility support staff.

While the conventional pretreatment system alternative would typically require more attention from Operations Staff than the MF/UF pretreatment system to ensure proper coagulation and filtration, a full scale facility would be automated and designed to assist the Operations Staff with monitoring and control. The labor effort for the two pretreatment systems is estimated to be the same.

10.4.2 Desalination Facility Operating Costs for Different Capacities

Table 10.9 presents conceptual level annual operating costs for a full scale MMWD Desalination Facility as described in Sections 8 and 9. Conceptual level capital costs are presented for a 5 and 10 MGD Facility operating in average and drought conditions as described in the operating assumptions above.

Table 10.9: Desalination Facility Conceptual Operating Costs for Different Capacities and Conditions

MMWD Desalination Facility				
O&M Cost Category	**5 MGD Average Conditions**	**5 MGD Drought Conditions**	**10 MGD Average Conditions**	**10 MGD Drought Conditions**
Chemicals	$628,000	$1,399,000	$1,140,000	$2,797,000
Power	$1,408,000	$3,289,000	$2,724,000	$7,042,000
Membrane Replacement	$215,000	$213,000	$424,000	$424,000
Solids Disposal	$27,000	$87,000	$45,000	$173,000
Maintenance	$795,000	$795,000	$1,228,000	$1,228,000
Labor	$1,650,000	$1,650,000	$1,065,000	$1,650,000
Total Annual O&M Cost	**$4,138,000**	**$6,848,000**	**$6,626,000**	**$12,729,000**

Figures 10.1 and 10.2 present the categories of the operating cost estimates as a percentage of the total for average and drought conditions.

Figure 10.1: O&M Costs for SWRO Plant under Average Conditions

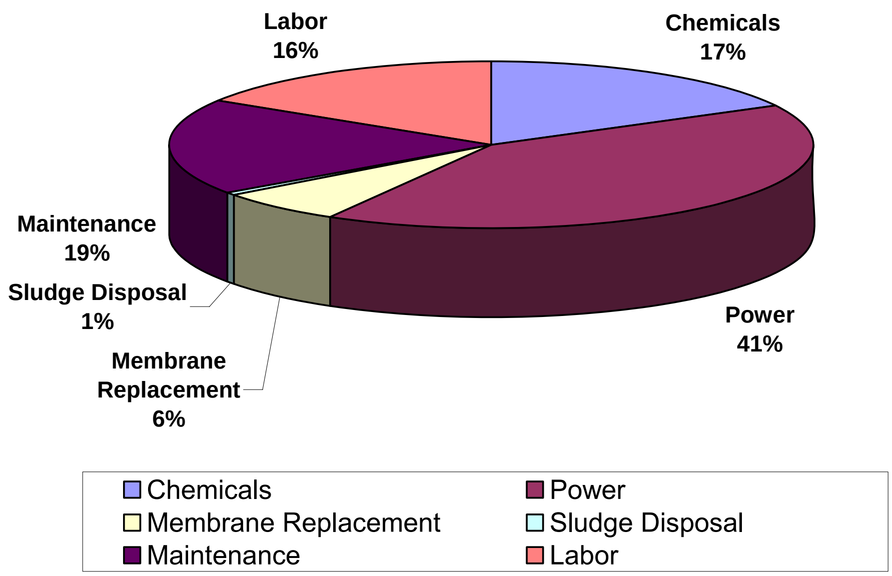
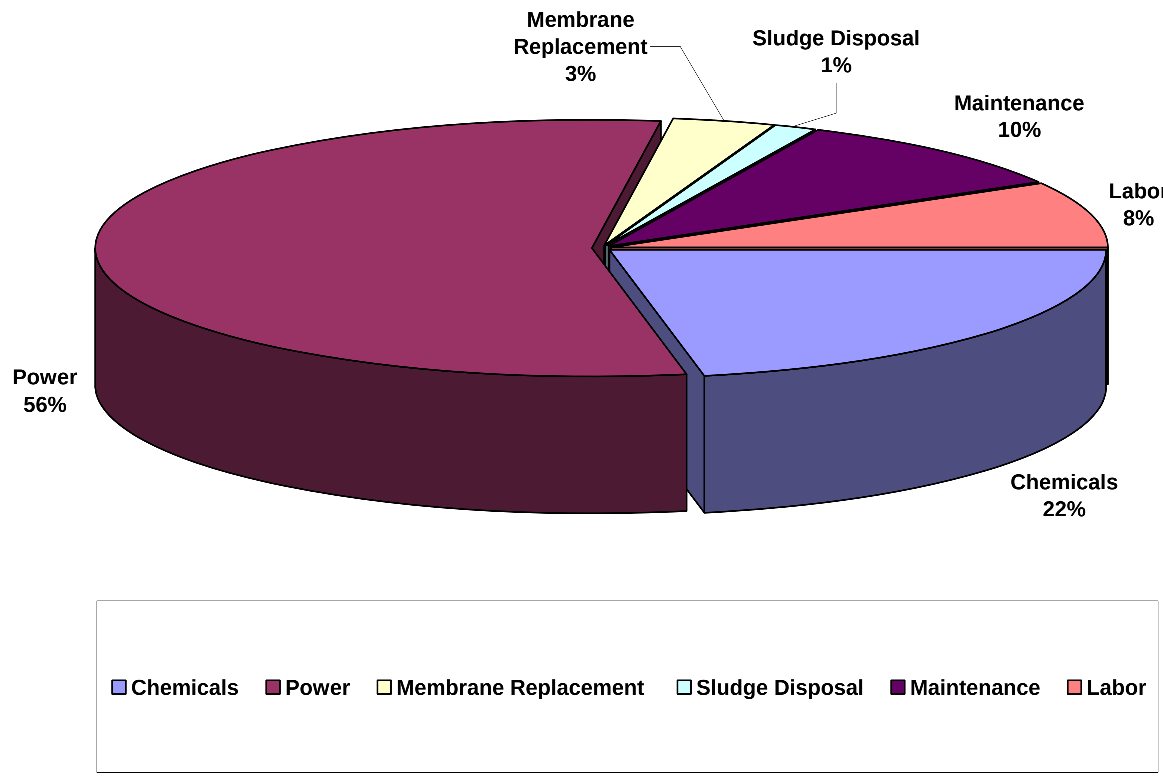


Figure 10-2: O&M Costs for SWRO Plant under Drought Conditions



Under drought conditions the power use increases due to the increased salinity of the Bay source water and the increased plant production. The cost of chemicals increases in a drought due to the increased plant production.

Appendices

Provided on CD (attached)