

3 January 2006

Technical Memorandum No. 7

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Subject: First and Second Pass RO Permeate and Finished Water Quality
MMWD Seawater Desalination Pilot Plant Program
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INTRODUCTION

This technical memorandum, TM-7, summarizes the actual and predicted water quality from the first pass seawater reverse osmosis (SWRO) and the second pass reverse osmosis system (2nd Pass RO) for the MMWD Seawater Desalination Pilot Plant Program and from a potential future full-scale SWRO Facility.

This memorandum also presents objectives for, and an evaluation of, the general water quality of the SWRO finished water from a full scale SWRO Facility. An evaluation of more extensive regulated and non-regulated constituents in the source and finished water will be presented in a separate memorandum.

POST TREATMENT SYSTEM OBJECTIVES

The objectives of the SWRO, 2nd Pass RO, and post treatment systems are to provide finished water that:

- meets or is better than State and Federal water quality requirements
- meets or is better than MMWD's additional and more stringent water quality objectives
- tastes equal to or better than MMWD's current water supplies
- is stable and similar to MMWD's current water supplies in terms of corrosivity

In evaluating the post treatment objectives and requirements for the MMWD seawater desalination pilot program, the Kennedy/Jenks-CH2M Hill team performed the following steps:

- Worked with MMWD to develop appropriate finished water objectives.
- Evaluated the pilot study source water quality data and compare it to historical source water quality data.

Technical Memorandum No. 7

3 January 2006

Page 2 of 18

- Evaluated the permeate quality from the SWRO membrane elements and compared this to the permeate quality predicted from the RO element manufacturer’s software programs.
- Used the software programs to predict the full-scale SWRO system permeate water quality from treatment of Pacific Ocean water and Bay water based on historical maximum and average pilot plant feed water quality.
- Compared actual (as measured during pilot testing) and software-predicted first pass SWRO permeate quality, both initial and at end of membrane life, with the MMWD finished water objectives to determine if partial second pass RO will be required to meet boron, sodium or chloride objectives.
- Modeled requirements for lime and carbon dioxide addition to the RO permeate to produce a stabilized water that matches the stability of the existing MMWD water sources and compared the resulting increase in TDS and ions from such addition to the finished water objectives.

PROPOSED FINISHED WATER QUALITY OBJECTIVES

The proposed general water quality objectives for the MMWD pilot plant program finished water are shown below. Table 1 lists specific mineralogical objectives of the finished water that 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 of the finished water for evaluating post treatment processes for water stabilization.

Table 1: Proposed General Mineralogical Objectives for the MMWD SWRO Pilot Plant Finished Water

| Parameter | units | MMWD Treated Reservoir | | | Sonoma County Water | | | SWRO Pilot Objectives | | |
|------------|-------|------------------------|-------|-------|---------------------|------|------|-----------------------|-----|-----|
| | | 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 | 8.2 | 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 | 0.3 | 0.5 | – |
| SAR | – | – | – | – | – | – | – | 3 | 6 | – |

Technical Memorandum No. 7

3 January 2006

Page 3 of 18

| Parameter | units | MMWD Treated Reservoir | | | Sonoma County Water | | | SWRO Pilot Objectives | | |
|-----------|-------|------------------------|-------|-------|---------------------|------|-------|-----------------------|-----|------|
| | | avg | max | min | avg | max | min | avg | max | min |
| 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:**
1. Corrosion quarterly data from 2000-2004 (pH, LSI,AGI,Cu and Fe mpy)
 2. WQ Parameter quarterly data from 2000-2004 for treated reservoir (n=32)
 3. WQ Parameter quarterly data from 2002-2004 for SCWA (n=6)
 4. Chloride and TOC values post ferric chloride changeover
 5. Sodium Adsorption Ratio (SAR); Langlier Saturation Index (LSI)
 6. Ryzner Index (RI); Aggressiveness Index (AI); Larsen Index (LNI)

General Mineral Water Quality Objectives

The proposed general mineral water quality objectives for the MMWD Pilot plant program finished water are generally in 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, and pH objectives are based on providing a finished water similar to MMWD’s current water supplies. By matching these general mineral characteristics, the taste of the finished water should not change for the customer when they get one source or another.

Sodium, Chloride and Boron Objectives

The levels of sodium, chloride and boron in the first pass SWRO permeate are expected to be higher than the levels in MMWD’s current water sources. A second pass brackish water RO system is expected to be required to further reduce the levels of these elements in the finished water to meet water quality goals.

The SWRO finished water objectives for sodium are based on providing what is typically called a “low-sodium water” of less than 50 mg/l.

The chloride objective is an initial estimate based on the proportion of chloride to sodium in the bay source water.

The SWRO finished water boron objective although higher than MMWD’s current supplies, is well below the California Department of Health (DHS) goal of 1 mg/l and equal to and below the World Health Organization (WHO) target level of 0.5 mg/L. This low boron objective is based on MMWD Staff’s desire to provide a finished water meets or is better than water quality standards and that is close to the quality of their existing sources.

Technical Memorandum No. 7

3 January 2006

Page 4 of 18

Sodium Adsorption Ratio

The sodium adsorption ratio (SAR) is a parameter that estimates the negative impact of excessive sodium in irrigation water. Excessive sodium in relation to calcium and magnesium in the soil can cause damage to the soil structure and a decline in water infiltration rates. The SAR is calculated by the formula:

$$\text{SAR} = [\text{Na (meq/l)}] / ([\text{Ca (meq/l)} + \text{Mg (meq/l)}]/2)^{1/2}$$

The target SAR for the finished water is below approximately 3 to 6 based on typical guidelines for water quality for irrigation. High SAR values represent excessive sodium in the water. Low values represent greater levels of Ca and Mg ions. Given the very low level of Ca and Mg projected in the RO permeate, Ca levels will have to be increased relative to sodium during post-treatment to provide a SAR of less than 3 to 6.

Water Corrosion Control Objectives

There are a number of corrosion indices and characteristics that relate to the probable corrosion of various materials in water including the Langelier Index, Ryznar Index, Aggressive Index and Larson Index. An explanation of what these indices mean and reference to corrosion of a particular material is described below:

Langelier Index (LSI) – This is an index of calcium carbonate saturation developed nearly 70 years ago by Dr. Wilfred Langelier, Professor of Sanitary Chemistry at the University of California, Berkeley.

The Langelier Index is calculated as $\text{LSI} = \text{pH} - \text{pH}_s$. The pH_s of calcium carbonate saturation is calculated from TDS, temperature, calcium, and bicarbonate concentrations:

$$\text{pH}_s = \text{Temperature} + \text{TDS} - \text{Ca} - \text{Alkalinity Factors}$$

Temperature, calcium, and alkalinity have major effects, while TDS has a minor effect on pH_s . Elevation in temperature lowers the pH_s . What this implies is that if TDS, calcium, and alkalinity are constant, then, as temperature rises, calcium carbonate will precipitate at lower pH, a condition observed with high hardness hot water in dishwashers, glasses, etc. (Singley, 1985).

Cement and concrete are largely composed of calcium carbonate. At negative Langelier Indices there is a tendency for the calcium and carbonate to leach out from the cement, leaving a weak matrix of aluminum and silicate as well as roughened surfaces, which increases friction and low flow capacity in pipelines (Holtschulte, 1985). While at positive Langelier Indices there is a tendency to form calcium carbonate scales, which provides some protection of metals from corrosion, but if too high then excessive and roughened films will form, pipe diameter will be reduced and also result in flow loss (Ryder, 1985).

Technical Memorandum No. 7

3 January 2006

Page 5 of 18

The most desirable range of LSI is between -1 and +1, where neither scale deposition nor calcium leaching is excessive (Vik, 1996).

MMWD currently adds a zinc orthophosphate corrosion inhibitor to their reservoir water (which has a negative LSI) to provide corrosion protection in the distribution system. The LSI index objective for the SWRO finished water could be a positive value or could be similar to the treated reservoir water supply with the addition of a corrosion inhibitor.

Ryznar Index (RI) - This index is derived from the formula $RI = 2 \text{pH}_s - \text{pH}$, and was developed from the Langelier Index by Dr. Ryznar, a chemist with Nalco Water Conditioning Company of Illinois, empirically by observations of steel pipe corrosion (EES-K/J 1989). A relatively benign condition occurs in the R.I. range of 6 to 8, however, above 8, corrosion of steel or cast/ductile iron more rapidly occurs and increased metal leaching and aggravated corrosion occurs, while below 6 – scale formation is prevalent (Singley 1985).

Aggressive Index (A.I.) - This index was originally developed by the AWWA Standards Committee for Asbestos Cement Pipe as a simplified calcium carbonate saturation degree measurement, considering only the water pH, calcium and alkalinity concentration, while neglecting the relatively minor effects of TDS and the relatively low temperature range of water distribution piping. It is computed as:

$$\text{A.I.} = \text{pH} + \log (\text{Ca} \times \text{Alk}) \text{ (expressed as CaCO}_3\text{)}$$

Above an A.I. of 12 no cement deterioration is expected, while unprotected cement is not recommended when A.I. is less than 10. A.I. ranges in between are increasingly more aggressive, approaching 10 (Singley, 1985).

Larson Index (LNI): The Larson Index (LNI) was developed by Dr. Thurston Larson, Chemist of the Illinois Water Service in the 1950s, and a former National President of AWWA. Dr. Larson's concerns were the factors that aggravated pitting type corrosion in steel and iron pipe. He found that the strong acidic anions, chloride and sulfate as a portion of total anions, the remainder being predominantly bicarbonate, were highly relevant factors (EES-KJC, 1989). Thus, the Larson's ratio is:

$$\text{LNI} = \text{Cl} + \text{SO}_4/\text{HCO}_3 \text{ as milliequivalents per liter}$$

When this ratio exceeds 0.4, deep pitting corrosion will predominate, and be increasingly aggravated as LNI values exceed 0.4

The chemical basis of this observation is that both chloride and sulfate form the strong acids hydrochloric or sulfuric at the base of an anodic pitting site, as compared to the weak buffering carbonic acid of bicarbonate (Stumm, 1960).

Technical Memorandum No. 7

3 January 2006

Page 6 of 18

HISTORICAL AND PILOT PLANT SOURCE WATER QUALITY

Table 2 below presents general and mineralogical water quality data as it relates to the performance of the SWRO systems for typical Pacific Ocean water, historical maximum levels in North San Francisco Bay water and the Bay water quality that served as feedwater to the pilot plant during the study period. During the study period, the pilot plant feedwater parameters were generally lower than but consistent with the historical maximum parameter levels in the Bay. As expected, the pilot plant feedwater parameters were also lower than but consistent with Pacific Ocean water quality parameters. A full scale SWRO facility would need to be able to treat the worst case (highest salinity) historical maximum San Francisco Bay water quality parameter levels.

Table 2: Historical and Pilot Study Source Water Quality

| Parameter | units | Typical Pacific Ocean Seawater ^a | Historical North San Francisco Bay Water Quality ^b | Pilot Study Feed Water (Bay Water) Quality ^c | | |
|--------------|----------|---|---|---|--------|--------|
| | | | | Avg. | Max. | Min. |
| TDS | mg/L | 34,465 | 32,000 | 21,700 | 25,500 | 11,000 |
| Conductivity | umhos/cm | – | 48,000 | 39,200 | 46,000 | 20,000 |
| Calcium | mg/L | 400 | 371 ^d | 220 | 300 | 140 |
| Magnesium | mg/L | 1272 | 1,181 ^d | 755 | 910 | 580 |
| Sodium | mg/L | 10,560 | 9,805 ^d | 7,100 | 8,100 | 6,000 |
| 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 | 12,000 | 14,000 | 6,800 |
| 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 |

- (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) Eight to ten sample events from 21 March 2005 to 25 October 2005.
- (d) Value calculated by taking the ratio of analyte to TDS in typical seawater and multiplying by the San Francisco Bay TDS historical max.

Technical Memorandum No. 7

3 January 2006

Page 7 of 18

FIRST PASS SWRO WATER QUALITY RESULTS

MMWD Pilot SWRO Membranes

The three first pass SWRO membranes elements tested to date at the MMWD Seawater Desalination Pilot Plant are: 1) Dow/Filmtec; 2) Hydranautics; and 3) Toray. Table 3 presents relevant performance parameters as measured from testing conducted by the suppliers at standard conditions (TDS: 32,000 ppm, temperature: 25 degrees C, recovery: 8 to 10%) for a single element. Elements from a fourth supplier, Koch, were installed in one SWRO unit approximately two-thirds of the way through the study.

Table 3: SWRO Membrane Element Performance Parameters

| | | 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 | NA |
| Feed spacer thickness (4-inch) | mil | 28 | NA | NA | 28 |
| Membrane Area (8-inch) | ft ² | 400 | 400 | 400 | 360 |
| Feed spacer thickness (8-inch) | mil | 28 | NA | NA | 28 |
| Advertised Permeate Flow (8-inch) | GPD | 7,500 | 6,500 | 6,000 | 5,500 |
| 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 |

Technical Memorandum No. 7

3 January 2006

Page 8 of 18

| | | Manufacturer | | | |
|----------------------------|-------|--------------|--------------|-------|------|
| Parameter | Units | Dow/Filmtec | Hydranautics | Toray | Koch |
| Advertised Boron Rejection | % | 91 | 92 | 90 | NA |

NA – not available

Actual vs. Predicted Membrane System Water Quality

Tables 4, 5, and 6 below present a “snapshot” comparison of the predicted and actual water quality results for the three first pass SWRO membranes elements tested at the MMWD Seawater Desalination Pilot Plant. The source water and permeate water quality results were obtained on the same day and the respective manufacturer’s membrane performance model was used to calculate the predicted permeate quality at the actual operating conditions. The following parameters were used in the membrane performance model:

- Temperature of 21 deg C.
- 40% recovery
- 8 gfd flux
- single pass
- single stage, six-element array
- 3-month membrane life

Table 4: Dow/Filmtec Permeate Quality - Actual vs. Predicted

| Parameter | units | Source Water Quality ^a | Dow/Filmtec Standard Model WQ Prediction ^b | Dow/Filmtec Actual WQ Results ^c |
|---------------|-------------|-----------------------------------|---|--|
| TDS | mg/L | 29,000 | 99 | 84 |
| Conductivity | umhos/cm | 49,000 | NA | 180 |
| Calcium | mg/L | 337 ^d | 0.33 | 0.24 |
| Magnesium | mg/L | 830 | 0.82 | 0.7 |
| Sodium | mg/L | 7,874 | 35 | 34 |
| Potassium | mg/L | 320 ^d | 1.62 | NA |
| Ammonia | mg/L | ND | ND | ND |
| Barium | mg/L | ND | ND | ND |
| Strontium | mg/L | 10.9 ^d | 0.01 | NA |

Technical Memorandum No. 7

3 January 2006

Page 9 of 18

| | | Source Water Quality ^a | Dow/Filmtec Standard Model WQ Prediction ^b | Dow/Filmtec Actual WQ Results ^c |
|-----------------|-------------|-----------------------------------|---|--|
| Parameter | units | | | |
| Bromide | mg/L | NA | NA | NA |
| Bicarbonate | mg/L | 83.3 | 0.79 | 1.7 |
| Temperature | °C | 20 | NA | NA |
| pH | units | 7.94 | 6.1 | 5.7 |
| Sulfate | mg/L | 1,900 | 0.77 | ND |
| Chloride | mg/L | 14,000 | 57 | 48 |
| Fluoride | mg/L | 0.76 | 0.00 | ND |
| Boron | mg/L | 3.3 | 0.5 | 0.44 |

(a) Sample collected at pilot plant intake on 9/13/05.

(b) Output of Dow/Filmtec Standard Model.

(c) Sample collected from Dow Filmtec SWRO#2 pilot plant production water on 9/13/05.

(d) Value calculated by taking the ratio of analyte to TDS in typical seawater and multiplying by the TDS of the source water.

Table 5: Hydranautics Permeate Quality - Actual vs. Predicted

| | | Source Water Quality ^a | Hydranautics Standard Model WQ Prediction ^b | Hydranautics Actual WQ Results ^c |
|-----------------|-------------|-----------------------------------|--|---|
| Parameter | units | | | |
| TDS | mg/L | 28,000 | 106 | 78 |
| Conductivity | umhos/cm | 50,000 | NA | 150 |
| Calcium | mg/L | 300 | 0.29 | 0.22 |
| Magnesium | mg/L | 910 | 0.89 | 0.64 |
| Sodium | mg/L | 8,100 | 38 | 29 |
| Potassium | mg/L | 350 | 2.06 | 1.4 |
| Ammonia | mg/L | ND | ND | ND |
| Barium | mg/L | 0.27 | 0.000 | ND |
| Strontium | mg/L | 5.9 | 0.006 | ND |
| Bromide | mg/L | NA | NA | 0.18 |
| Bicarbonate | mg/L | 83.3 | 0.93 | 1.2 |
| Temperature | °C | 20 | NA | NA |
| pH | units | 7.94 | 6.0 | 6.3 |
| Sulfate | mg/L | 1,900 | 2.02 | ND |
| Chloride | mg/L | 14,000 | 62 | 36 |
| Fluoride | mg/L | 0.790 | 0.01 | ND |

Technical Memorandum No. 7

3 January 2006

Page 10 of 18

| | | Source Water Quality ^a | Hydranautics Standard Model WQ Prediction ^b | Hydranautics Actual WQ Results ^c |
|--------------|-------------|-----------------------------------|--|---|
| Parameter | units | | | |
| Boron | mg/L | 2.7 | 0.34 | 0.68 |

(a) Sample collected at pilot plant intake on 8/16/05.

(b) Output of Hydranautics Model.

(c) Sample collected from Hydranautics SWRO#2 pilot plant production water on 8/16/05.

Table 6: Toray Permeate Quality - Actual vs. Predicted

| | | Source Water Quality ^a | Toray Standard Model WQ Prediction ^b | Toray Actual WQ Results ^c |
|-----------------|-------------|-----------------------------------|---|--------------------------------------|
| Parameter | units | | | |
| TDS | mg/L | 29,000 | 128 | 130 |
| Conductivity | umhos/cm | 49,000 | NA | NA |
| Calcium | mg/L | 337 | 0.48 | NA |
| Magnesium | mg/L | 830 | 1.17 | NA |
| Sodium | mg/L | 8,886 | 46 | 49 |
| Potassium | mg/L | 320 | 1.86 | NA |
| Ammonia | mg/L | 0.33 | 0.0052 | NA |
| Barium | mg/L | 4.2 | 0.0059 | NA |
| Strontium | mg/L | 10.9 | 0.0154 | NA |
| Bromide | mg/L | NA | NA | 0.26 |
| Bicarbonate | mg/L | 122 | 0.92 | NA |
| Temperature | °C | 20 | NA | NA |
| pH | units | 7.9 | 5.94 | NA |
| Sulfate | mg/L | 1,900 | 3.6 | NA |
| Chloride | mg/L | 14,000 | 73 | 66 |
| Fluoride | mg/L | 0.76 | 0.0024 | NA |
| Boron | mg/L | 3.3 | 0.64 | 0.94 |

(a) Sample collected at pilot plant intake on 9/13/05.

(b) Output of Toray Standard Model.

(c) Sample collected from Toray SWRO#2 pilot plant production water on 9/13/05

The water quality “snapshots” in the tables above show that the piloted membrane systems are performing equal to or better than predicted for TDS, sodium and chloride, key first pass water quality parameters. Dow FilmTec and Hydranautics actual performance was consistently less than predicted, whereas Toray’s was equivalent or slightly greater. Both Dow FilmTec and Hydranautics actual and predicted permeate values for TDS and sodium met MMWD finished water quality goals (Table 1), but did not for chloride. For Toray, actual and estimated permeate

Technical Memorandum No. 7

3 January 2006

Page 11 of 18

quality met the TDS goal, was at the maximum goal value for sodium and above the goals for chloride.

For all three elements the predicted permeate boron levels were at or above the finished water goal. For the Hydranautics and Toray elements the actual boron levels were above the projected levels.

Although the actual results from the elements are generally better than the standard modeled results, the basis of system design should be the standard modeled results under “worst case” conditions to ensure that the full scale facility can meet the water quality objectives over the projected life of the RO plant. This would account for the need to treat Bay water at maximum historical values with RO membranes that are at the end of their assumed useful life (5 years). Furthermore, in typical contracts for purchasing membrane elements for a full scale facility, the guaranteed performance of the membrane elements is based on the manufacturer’s standard element performance model, both at year zero and end of membrane life (3 or 5 years).

PREDICTED FULL-SCALE FACILITY MEMBRANE SYSTEM PERMEATE QUALITY

Tables 7, 8, and 9 below present the predicted permeate quality results from a full scale facility operating on typical Pacific Ocean seawater, the historical maximum SF Bay water and the average Bay water quality during the pilot study for the three first pass SWRO membranes elements tested at the MMWD Seawater Desalination Pilot Plant. The respective manufacturer’s membrane performance model was used to predict permeate quality for a full-scale system. The following parameters were used in the membrane performance models:

- 50% recovery
- 10 gfd flux
- Single pass
- 8-inch SWRO elements
- Single stage, six-element array
- 5-year membrane life
- Maximum water temperature (21°C)

Technical Memorandum No. 7

3 January 2006

Page 12 of 18

Table 7: Dow/Filmtec Full Scale System Predicted Permeate Quality – Single Pass RO Treatment

| Parameter | units | Finished Water Objectives | | Typical Pacific Ocean ^a | Historical North SF Bay ^b | Average Pilot WQ ^c |
|-----------------|-------------|---------------------------|------|------------------------------------|--------------------------------------|-------------------------------|
| | | Avg. | Max. | | | |
| TDS | mg/L | 120 | 180 | 152 | 141 | 96 |
| Conductivity | umhos/cm | – | – | NA | NA | NA |
| Calcium | mg/L | 20 | 30 | 0.47 | 0.43 | 0.25 |
| Magnesium | mg/L | – | – | 1.52 | 1.4 | 0.87 |
| Sodium | mg/L | 30 | 50 | 53 | 49 | 34 |
| Potassium | mg/L | – | – | 2.2 | 2.2 | 1.5 |
| Ammonia | mg/L | – | – | 0.02 | 0.02 | 0.00 |
| Barium | mg/L | – | – | 0.00 | ND | 0.01 |
| Strontium | mg/L | – | – | 0.02 | 0.02 | 0.00 |
| Bromide | mg/L | – | – | NA | NA | NA |
| Bicarbonate | mg/L | 60 | 110 | 1.3 | 1.2 | 0.86 |
| Temperature | °C | – | – | NA | NA | NA |
| pH | units | 8 | 8.2 | 6.4 | 6.4 | 6.0 |
| Sulfate | mg/L | – | – | 1.2 | 1.11 | 0.7 |
| Chloride | mg/L | 50 | 70 | 88 | 81 | 56 |
| Fluoride | mg/L | – | – | 0.01 | 0.01 | 0.00 |
| Boron | mg/L | 0.3 | 0.5 | 0.73 | 0.69 | 0.41 |

(a) Predicted water quality based on typical Pacific Ocean water quality shown in Table 2 above.

(b) Predicted water quality based on maximum Historical Bay water quality shown in Table 2 above.

(c) Predicted water quality based on average Pilot Study water quality shown in Table 2 above

Based on the predicted water quality above, a full-scale desalination facility using Dow/Filmtec SW30HR LE elements would require a partial second pass RO treatment of the permeate to reduce both chloride and boron to meet the water quality objective (maximum value) during a drought period when salinity levels would approach or exceed the historical SF Bay maximum water quality levels. The second pass RO system may also be required to meet boron removal objectives during average SF Bay water quality conditions based on predicted 1st pass permeate boron levels.

Technical Memorandum No. 7

3 January 2006

Page 13 of 18

Table 8: Hydranautics Full Scale System Predicted Permeate Quality - Single Pass RO Treatment

| Parameter | units | Finished Water Objectives | | Typical Pacific Ocean ^a | Historical North SF Bay ^b | Average Pilot WQ ^c |
|--------------------------|-------------|---------------------------|------|------------------------------------|--------------------------------------|-------------------------------|
| | | Avg. | Max. | | | |
| TDS | mg/L | 120 | 180 | 189 | 175 | 100 |
| Conductivity | umhos/cm | – | – | NA | NA | NA |
| Calcium | mg/L | 20 | 30 | 0.54 | 0.49 | 0.24 |
| Magnesium | mg/L | – | – | 1.7 | 1.6 | 0.82 |
| Sodium | mg/L | 30 | 50 | 68 | 63 | 36 |
| Potassium | mg/L | – | – | 3.1 | 3.0 | 1.7 |
| Ammonia | mg/L | – | – | 0.00 | 0.00 | 0.00 |
| Barium | mg/L | – | – | 0.007 | ND | 0.005 |
| Strontium | mg/L | – | – | 0.017 | 0.000 | 0.003 |
| Bromide | mg/L | – | – | NA | NA | NA |
| Bicarbonate | mg/L | 60 | 110 | 1.8 | 1.7 | 1.1 |
| Temperature | °C | – | – | NA | NA | NA |
| pH | units | 8 | 8.2 | 6.4 | 6.4 | 6.0 |
| Sulfate | mg/L | – | – | 3.7 | 3.42 | 1.95 |
| Chloride | mg/L | 50 | 70 | 107 | 101 | 57.5 |
| Fluoride | mg/L | – | – | 0.02 | 0.02 | 0.01 |
| Boron^d | mg/L | 0.3 | 0.5 | 1.2 | 1.1 | 0.63 |

- (a) Predicted water quality based on typical Pacific Ocean water quality shown in Table 2 above.
- (b) Predicted water quality based on maximum Historical Bay water quality shown in Table 2 above.
- (c) Predicted water quality based on average Pilot Study water quality shown in Table 2 above
- (d) Based on actual piloted boron removal rates of approximately 75%.

Based on the predicted water quality above, a full-scale desalination facility using Hydranautics SWC4+ elements would require partial second pass RO treatment of the permeate to reduce sodium, chloride and boron to meet the water quality objective (maximum value) during a drought period when salinity levels would approach or exceed the historical SF Bay maximum water quality levels. The second pass RO system would also be required to meet boron removal objectives during average SF Bay water quality conditions based on predicted 1st pass permeate boron levels.

Technical Memorandum No. 7

3 January 2006

Page 14 of 18

Table 9: Toray Full Scale System Predicted Permeate Quality – Single Pass RO Treatment

| Parameter | units | Finished Water Objectives | | Typical Pacific Ocean ^a | Historical North SF Bay ^b | Average Pilot WQ ^c |
|--------------------------|-------------|---------------------------|------|------------------------------------|--------------------------------------|-------------------------------|
| | | Avg. | Max. | | | |
| TDS | mg/L | 120 | 180 | 212 | 202 | 96 |
| Conductivity | umhos/cm | – | – | NA | NA | NA |
| Calcium | mg/L | 20 | 30 | 0.78 | 0.75 | 0.3 |
| Magnesium | mg/L | – | – | 2.5 | 2.4 | 1.0 |
| Sodium | mg/L | 30 | 50 | 75.4 | 71.8 | 34.2 |
| Potassium | mg/L | – | – | 3.1 | 2.9 | 1.5 |
| Ammonia | mg/L | – | – | 0.0084 | 0.0087 | 0.0 |
| Barium | mg/L | – | – | 0.0098 | 0.0093 | 0.0068 |
| Strontium | mg/L | – | – | 0.0255 | 0.024 | 0.0036 |
| Bromide | mg/L | – | – | NA | NA | NA |
| Bicarbonate | mg/L | 60 | 110 | 1.77 | 1.69 | 0.87 |
| Temperature | °C | – | – | NA | NA | NA |
| pH | units | 8 | 8.2 | 6.1 | 6.4 | 5.9 |
| Sulfate | mg/L | – | – | 6.6 | 6.3 | 2.8 |
| Chloride | mg/L | 30 | 50 | 121 | 116 | 55 |
| Fluoride | mg/L | – | – | 0.006 | 0.0058 | 0.0021 |
| Boron^d | mg/L | 0.3 | 0.5 | 1.29 | 1.2 | 0.7 |

- (a) Predicted water quality based on typical Pacific Ocean water quality shown in Table 2 above.
- (b) Predicted water quality based on maximum Historical Bay water quality shown in Table 2 above.
- (c) Predicted water quality based on average Pilot Study water quality shown in Table 2 above
- (d) Based on actual piloted boron removal rates of approximately 72%.

Based on the predicted water quality above, a full-scale desalination facility with a Toray SWRO membrane system would require second pass RO treatment of the permeate to reduce TDS, sodium, chloride and boron to meet the water quality objective (maximum value) during a drought period when salinity levels would approach or exceed the historical SF Bay maximum water quality levels. The second pass RO system will also be required to meet boron removal objectives during average SF Bay water quality conditions based on predicted 1st pass permeate boron levels.

Based on the initial operating performance of the Koch membrane elements we expect the water quality from a full-scale facility with Koch membrane elements would fall in the range of the water quality from the other three element types.

Technical Memorandum No. 7

3 January 2006

Page 15 of 18

SECOND PASS RO SYSTEM

The full-scale SWRO facility will require partial second pass RO treatment of the first-pass SWRO permeate to meet the average and maximum treated water quality goals during a drought period for TDS, sodium, chloride and boron . Table 11 presents the projected boron and salt rejection for a second pass RO system treating first pass SWRO permeate for the historical maximum SF Bay water quality. To improve boron removal, the feed to the second pass RO would be conditioned to raise the pH. The table shows predicted boron removal for pH 9.0, 9.5 and 10.0. The following parameters were used in the second-pass membrane performance model:

- 90% recovery
- 20 gfd flux
- 8-inch BWRO elements (Hydranautics ESPA B)
- Two-stage system with six-element array
- 5-year membrane life
- Maximum water temperature (21 deg C)

Table 10: Projected Boron Rejection for Second Pass RO system

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

Tables 11 and 12 show the predicted boron levels in the second pass permeate and in various blends of second pass and first pass permeate. The ratios in the table are second-pass to first pass blend ratios. Table 12 presents predicted finished water boron levels for the historical maximum SF Bay water quality. Table 13 presents predicted finished water boron levels for the average SF Bay water quality from the pilot.

Technical Memorandum No. 7

3 January 2006

Page 16 of 18

Table 11: Projected Finished Water Boron for Historical Max. SF Bay Water

| Feed Water pH | 1st Pass Permeate Boron (mg/l) | 2nd Pass Permeate Boron (mg/l) | Blended Permeate 1:1 Boron (mg/l) | Blended Permeate 2:1 Boron (mg/l) | Blended Permeate 3:1 Boron (mg/l) | Blended Permeate 4:1 Boron (mg/l) |
|---------------|--------------------------------|--------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| 9.0 | 1.1 | 0.55 | 0.83 | 0.73 | 0.69 | 0.66 |
| 9.5 | 1.1 | 0.33 | 0.72 | 0.59 | 0.52 | 0.48 |
| 10.0 | 1.1 | 0.22 | 0.66 | 0.51 | 0.44 | 0.40 |

Table 12: Projected Finished Water Boron for Average SF Bay Water

| Feed Water pH | 1st Pass Permeate Boron (mg/l) | 2nd Pass Permeate Boron (mg/l) | Blended Permeate 1:1 Boron (mg/l) | Blended Permeate 2:1 Boron (mg/l) | Blended Permeate 3:1 Boron (mg/l) | Blended Permeate 4:1 Boron (mg/l) |
|---------------|--------------------------------|--------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| 9.0 | 0.69 | 0.35 | 0.52 | 0.46 | 0.43 | 0.41 |
| 9.5 | 0.69 | 0.21 | 0.45 | 0.37 | 0.33 | 0.30 |
| 10.0 | 0.69 | 0.14 | 0.41 | 0.32 | 0.28 | 0.25 |

The approach to meeting the boron goals in the finished water during the average and worst-case maximum water quality conditions would be with a combination of pH adjustment and second-pass permeate to first pass permeate blending. For example, assuming a 2:1 second-pass permeate to first pass permeate blending ratio, during average water quality conditions the boron objective would be met with minimal pH adjustment. As the feed water boron levels increase, the feed water pH would be increased up to 10 to maintain boron levels in the finished water below the target. Another alternative could be to design a full-scale plant with greater second-pass RO capacity and operate more or less second pass RO units to meet the desired boron objective. For the purposes of meeting MMWD finished water quality goals, this memorandum assumes a 2:1 second-pass permeate to first pass permeate blending ratio for the following finished water quality modeling.

A third option is to adjust the pH of the first pass RO feedwater to increase boron rejection. This option could be attractive where the first pass RO system uses Dow FilmTec and Hydranautics elements that are capable of meeting the finished water TDS and sodium goals and provided the chloride goal were relaxed to accommodate permeate chloride levels from these elements. Pilot testing of Dow FilmTec, Hydranautics and Toray elements on similar source water in Asia Pacific showed that the boron passage through these elements could be reduced by 50 percent through feedwater pH adjustment to 9.5 (resulting in a decrease in the first pass permeate boron concentration by 50 percent). The attractiveness of this option must consider the comparative lifecycle costs of feedwater pH adjustment (caustic dosing) versus that of second

Technical Memorandum No. 7

3 January 2006

Page 17 of 18

pass RO installation and operation. Such a comparative evaluation is beyond the scope of the current pilot study work, but should be performed as part of future preliminary design work for the project.

POST TREATMENT STABILIZATION

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

Table 14 presents water quality parameters of the SWRO Facility stabilized water stabilization with quick lime followed by carbon dioxide (CO₂) addition. This approach adds hardness and alkalinity the permeate to control the pH of the finished water while minimizing the addition of sodium and other ions that would increase TDS. The water quality was modeled using the American Water Works Association (AWWA) Rothenberg, Tamburini & Windsor (RTW) Model for Corrosion Control and Process Chemistry. The model is based on a blend of 33 percent 1st pass permeate and 67% second pass permeate. The second pass RO was modeled as operating with a pH of 9.5 for enhanced boron removal. The modeled permeate quality is based on the Hydranautics first pass and second pass membrane elements. The stabilized finished water quality is expected to be similar for the Dow, Toray and Koch elements.

Post-treatment of first pass RO permeate for corrosion control was not conducted because of the unacceptable levels of boron and other critical inorganic ions in this stream.

Table 13: Stabilized 1st&2nd Pass RO Permeate Blend Quality

| | | SWRO Finished Water Objectives | | | Stabilized 1 st &2 nd Pass RO Permeate Blend Quality | |
|----------------------|----------------------------|--------------------------------|-----|-----|--|------------------|
| Parameter | units | avg | max | min | SF Bay Historical Max | Average Pilot QW |
| 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 | 0.3 | 0.5 | – | 0.4 | 0.2 |

Technical Memorandum No. 7

3 January 2006

Page 18 of 18

| Parameter | units | SWRO Finished Water Objectives | | | Stabilized 1 st &2 nd Pass RO Permeate Blend Quality | |
|-----------|-------|--------------------------------|-----|------|--|------------------|
| | | avg | max | min | SF Bay Historical Max | Average Pilot QW |
| SAR | – | 3 | 6 | – | 1.3 | 1.0 |
| 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 |

^aDose

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 is based on:

- First pass SWRO at end of membrane life (5 years) under most challenging source water quality conditions
- Second pass BWRO with increased pH to enhance boron removal (pH 9 to 10)
- 2:1 blend of second pass BWRO permeate with first pass SWRO permeate
- Addition of approximately 50 to 75 mg/l of lime
- Addition of approximately 60 to 85 mg/l of carbon dioxide (CO₂)

The ratio of second pass BWRO permeate to first pass SWRO permeate is important for controlling the levels of sodium, chloride and boron in the finished water but does not significantly impact the amount of lime and carbonic acid that must be dosed into the blended permeate to provide stabilization. This is because the first pass SWRO effectively removes most of the hardness and alkalinity from the water with little left for removal by the second pass system. One option to minimize the amount and therefore the cost of lime and CO₂ addition, is to operate with a slightly negative Langelier Saturation Index and add a corrosion inhibitor. MMWD currently adds a corrosion inhibitor to its reservoir water supply.

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