Section 6
Performance of the RO System Alternatives

The **scwd²** pilot plant included two seawater reverse osmosis (SWRO) skids that could be configured into four parallel reverse osmosis (RO) systems. Three RO system configurations and several SWRO membranes from different manufacturers were evaluated to determine which system configuration and membrane type would meet water quality goals and use the lowest amount of energy. This section reports the results of this evaluation.

6.1 RO System Water Quality Objectives

The primary water quality objectives for the desalinated water are:

- Bromide: ≤0.5 mg/L to minimize the impact on DBP formation in the distribution system.
- Chloride: <150 mg/L to protect plants during irrigational use.
- Boron: <1.0 mg/L to achieve the spirit of DPH notification goal without rounding and to protect plants during irrigational use.[1]

6.2 RO System Alternative Configurations

Cost and performance of a SWRO system depends on the selection of the system configuration and membrane type. The following three configurations were tested to assess impacts on energy use and water quality:

1. Single-stage SWRO - Figure 6-1 provides a schematic of this configuration. This configuration was tested as the baseline for comparison because it is typically the option with the lowest energy use and RO system equipment costs. This configuration was tested with "low energy" (LE) SWRO membranes from four different manufacturers to assess energy use and salt rejection to achieve water quality goals.

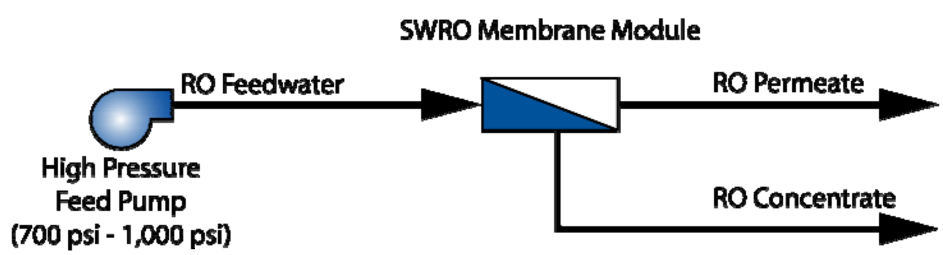

Figure 6-1
Single-Stage SWRO Configuration

[1] The DPH notification goal is 1 mg/L without a decimal point which provides rounding to the nearest integer. DPH confirmed that any observed result between 1 and 1.44 mg/L can be reported as 1 mg/L.

2. Single-stage SWRO with a partial Second Pass LPRO - Figure 6-2 provides a schematic of this configuration. A second pass removes additional salts from the first pass RO permeate; the second pass permeate is then blended with the first pass permeate to provide lower overall salt concentrations. A 20% partial 2nd pass with "high boron rejection" low pressure reverse osmosis (LPRO) membranes was tested downstream of the single-stage systems to confirm performance in achieving boron concentrations of less than 1.0 milligrams per liter (mg/L).

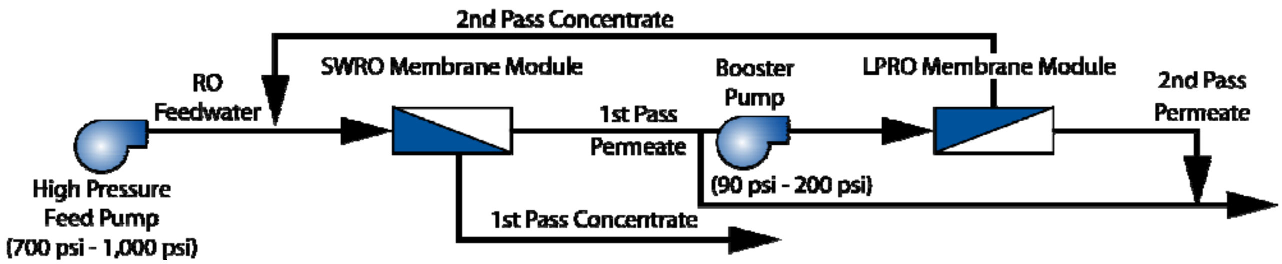

Figure 6-2
Single-Stage SWRO Configuration with a Partial Second Pass LPRO

3. Two-Stage LPRO/SWRO - Figure 6-3 provides a schematic of this configuration, which uses low pressure reverse osmosis (LPRO) membranes in the first stage instead of SWRO membranes. "High boron rejection" LPRO membranes were tested in the first stage and LE SWRO membranes were tested in the 2nd stage. The pressure range for the high pressure pump in the second stage is higher than the feed pump in Figure 6-2 because the salinity will be higher entering the 2nd stage SWRO membranes.

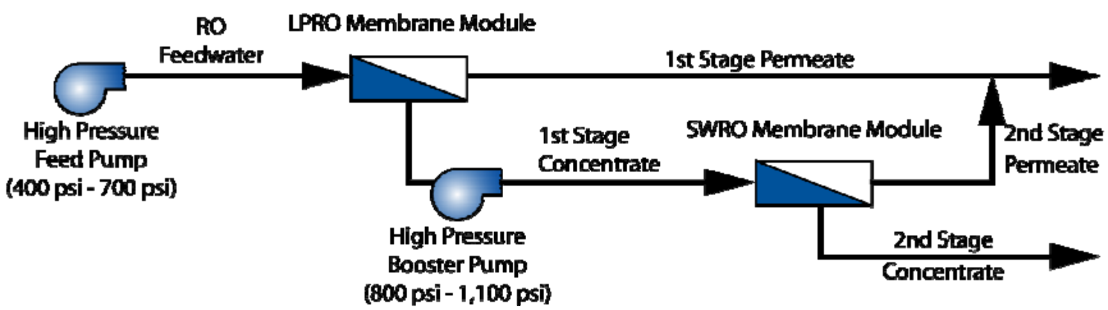

Figure 6-3
Two-Stage LPRO/SWRO Configuration

The two-stage LPRO/SWRO configuration was tested because initial energy projections (using software models provided by RO manufacturers) indicated that it could reduce energy use at recovery rates of 55% or greater when compared to single-stage SWRO and 2-stage SWRO/SWRO configurations. Figure 6-4 displays the results of initial projections; a reduction of 1.0 kilowatt per hour (kWh) per 1,000 gallons provides a reduction in power costs of approximately $120,000 per year assuming 2.5 million gallons per day (mgd) of RO permeate and the current estimated unit energy cost of $0.13 per kWh. The reduction in energy use is due to the lower pressure requirements of LPRO membranes; the tradeoffs are that the LPRO membranes reject fewer salts and that a second high pressure booster pump is required between the first and second stage. The second stage utilizes SWRO membranes with higher salt rejection to treat the remaining seawater. The configuration includes combining the RO permeate streams from each stage to improve water quality. The energy use estimated in Figure 6-4 is higher than expected for the proposed facility. This is because it was estimated prior to pilot testing and used lower assumptions for the energy recovery device and pump efficiencies. Energy use estimates presented later in Section 6.4 and shown on Figure 6-8 are based on efficiencies provided by the energy recovery device and pump manufacturers and the actual pilot test results.

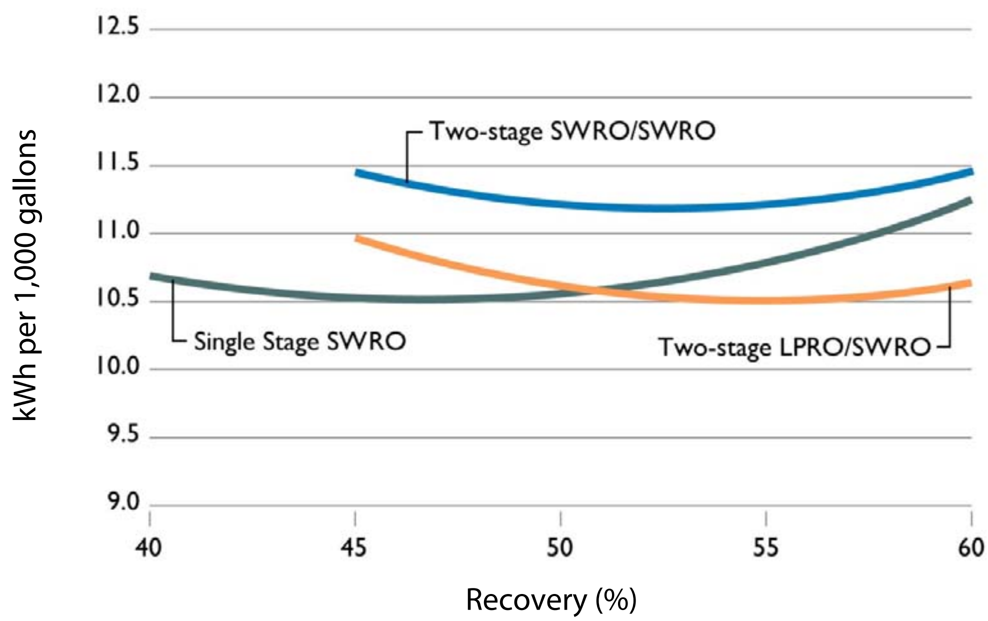

Figure 6-4
Projected Energy Use Prior to Pilot Testing

6.3 RO System Water Quality Results

The water quality results of each alternative configuration are shown in Figure 6-5 (boron) and Figure 6-6 (TDS). Each figure shows actual test results (labeled as observed) along with computer projections based on manufacturer provided software. The test results match closely with the projected results. Because the computer projections were done first, the actual results came as no surprise – both the single-stage SWRO configuration and the single-stage SWRO + partial second pass LPRO configuration met the boron and TDS goals, while the two-stage LPRO/SWRO configuration did not.

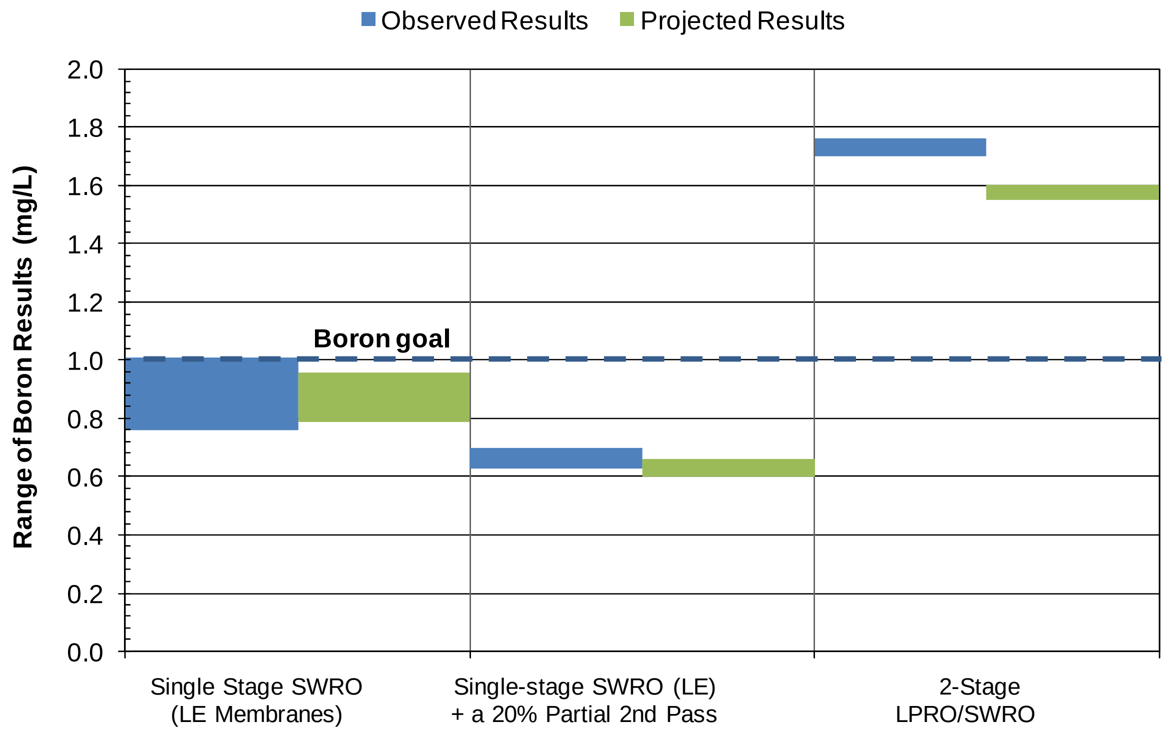

Figure 6-5
Boron Results for the Three RO System Configurations

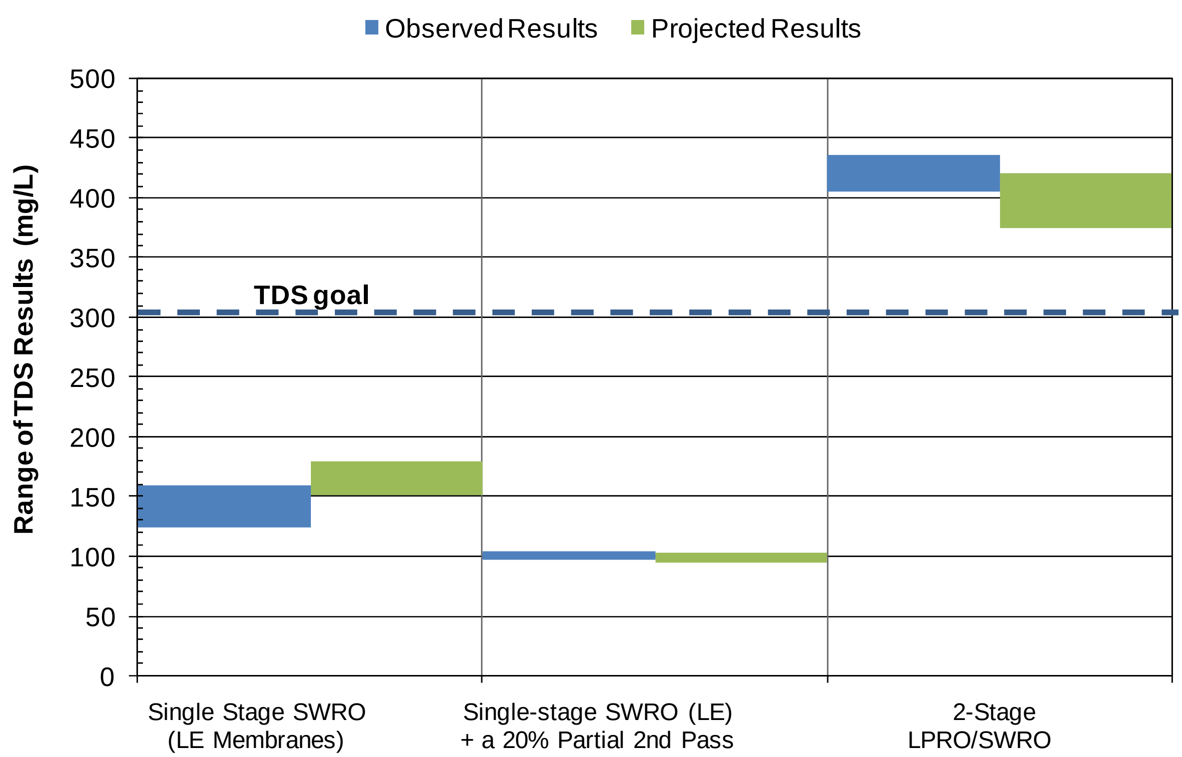

Figure 6-6
TDS Results for the Three RO System Configurations

Figure 6-7 compares the expected bromide concentrations at 17°C during long-term use based on projections using RO design software. This figure also shows the comparison between two different single-stage SWRO configurations. One of the configurations only uses normal low energy (LE) SWRO membranes, while the other configuration uses a hybrid combination of low energy SWRO membranes and high rejection (HR) SWRO membranes. A 20% partial second pass was used in pilot testing. However, projections indicate that a 25% partial second pass will be required to achieve a bromide goal of ≤0.3 mg/L which is a potential goal for control of total trihalomethanes (TTHM) as described in TM No. 7 in Appendix A.

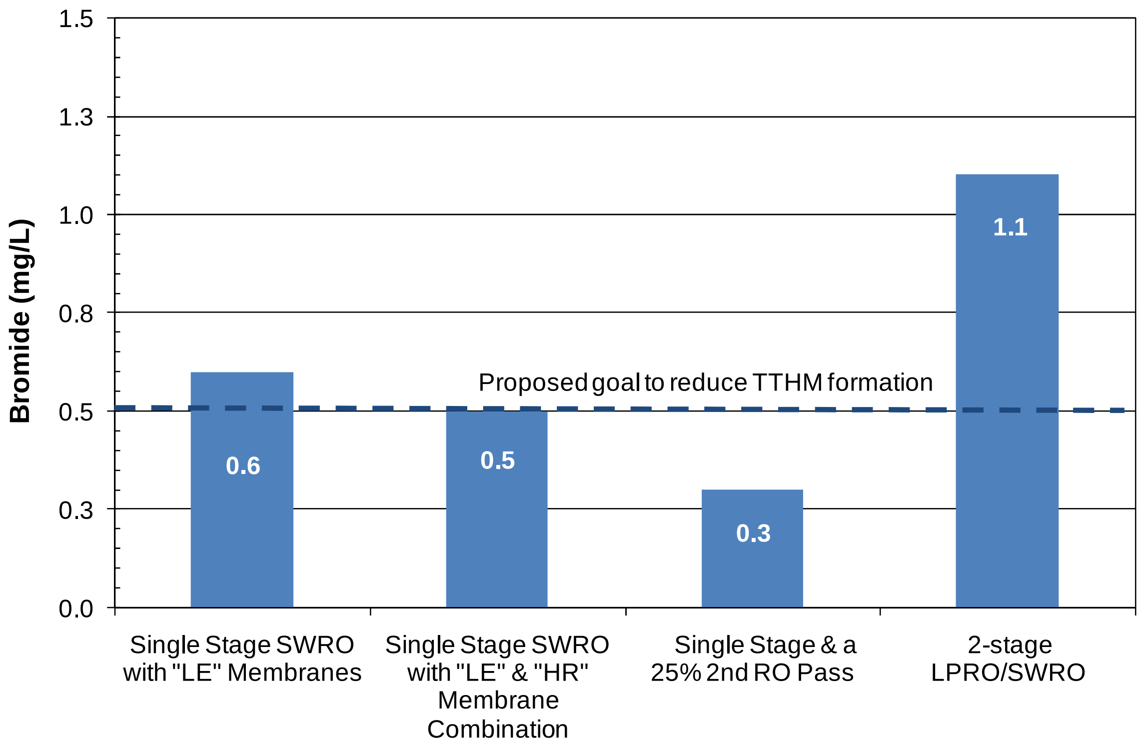

Figure 6-7
Expected Long-term Bromide
Concentrations During Summer Months

The projections indicate that: (1) the single-stage SWRO configuration will require a combination of low energy and high rejection membranes to achieve a bromide goal of ≤0.5 mg/L; (2) the single-stage SWRO with LE membranes will require a 25% partial second pass to achieve a bromide goal of less than ≤0.3 mg/L; and (3) the two-stage LPRO/SWRO configuration using high rejection LPRO and SWRO membranes will not achieve a bromide goal of ≤0.5 mg/L.

6.4 Projected Long-term Energy Use

Energy use increases and salt rejection decreases as RO membranes age. This is due to multiple variables including membrane compaction, degradation, fouling, cleaning frequency, and other factors.

Figure 6-8 shows the actual pilot-scale and projected full-scale power use for each configuration. The power use without energy recovery is based on the actual pilot plant test results. Data was sent to two energy recovery device manufacturers (Energy Recovery International and Pump Engineering, Inc.) to estimate the amount of power that can be recovered from the RO concentrate stream prior to discharge. The projections assumed a membrane age of 5 years, a feedwater temperature of 14°C, a 7% annual flux decline, a TDS concentration of 36,000 mg/L and the same RO membranes and configurations simulated to achieve the bromide concentrations shown in Figure 6-7. The projections indicate that (1) the single-stage configuration will have the lowest energy use after energy recovery, (2) a 25% partial second pass adds a minor increase in energy use, and (3) less energy is available for recovery when using the two-stage configuration. When considering the actual energy (i.e., with energy recovery), the 0.7 kWhr per 1,000 gallons savings provided by the single-stage configuration vs. 2-stage configuration is worth approximately $85,000 per year assuming 2.5 mgd of RO permeate production and the current estimated unit cost of $0.13 per kWh.

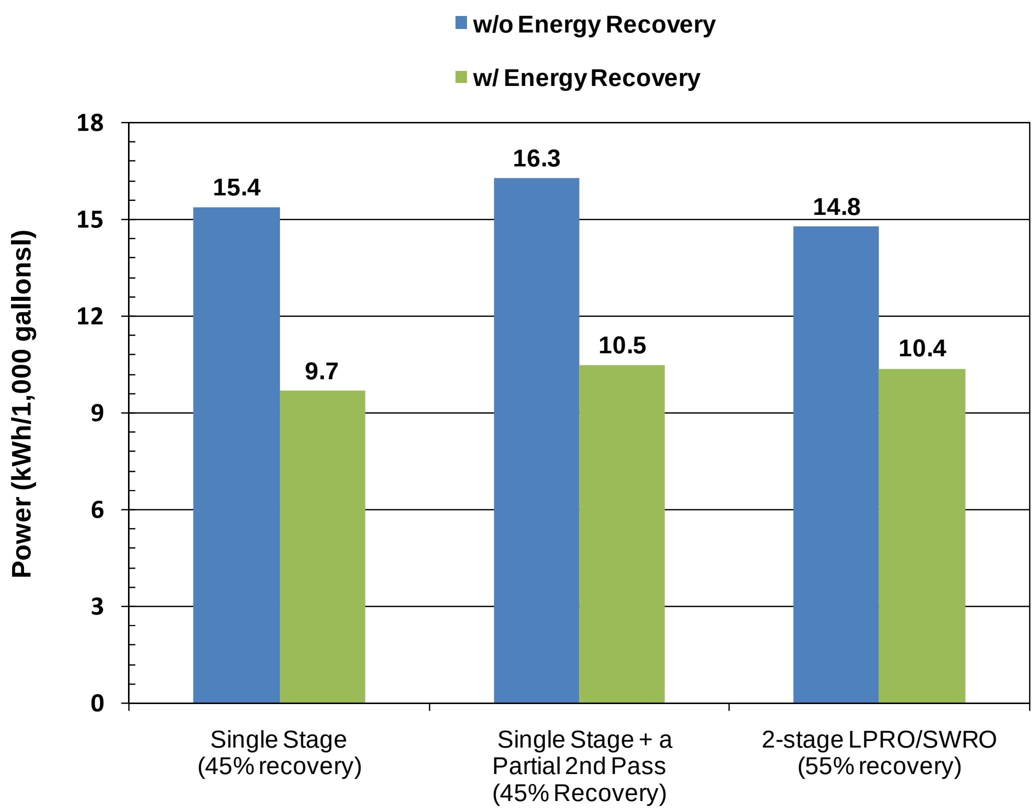

Figure 6-8
Comparison of Projected Initial Energy Use For Each RO Membrane Configuration Before and After Energy Recovery

The results from the evaluation indicated that the single-stage configuration will provide the best balance of both energy use and water quality at the proposed desalination plant.

6.5 Recommended RO System Configuration

By combining the test results with RO design software projections, it was determined that to meet the water quality goals in a cost effective manner the seawater desalination plant should use a single-stage SWRO membrane configuration with a hybrid combination of both HR and LE SWRO membranes.

If future water quality regulations require lower bromide or boron levels, RO membranes can be replaced as needed with "high rejection" (HR) membranes or a second pass RO system can be retrofitted into the system as follows:

- A single-stage SWRO membrane configuration with all HR SWRO membranes, or
- A single-stage SWRO membrane configuration followed by a 25% partial second pass.

6.6 Summary

Three different RO membrane system alternatives were tested at the pilot plant. The actual test results were supplemented with computer projections for water quality performance and energy use. The testing and computer projections determined that two-stage LPRO/SWRO configuration did not meet boron and bromide water quality goals, while the single-stage SWRO and single-stage SWRO plus partial second pass LPRO configurations did meet these goals. A single-stage SWRO configuration had the lowest energy consumption after taking energy recovery from the concentrate into account.