THE AFFORDABLE DESALINATION COLLABORATION
10 MGD CONCEPTUAL CASE STUDY

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ABSTRACT

The Affordable Desalination Collaboration (ADC) is a nonprofit organization which has successfully demonstrated SWRO in the range of 6.0-7.6 kWh/kgal (1.6 -2.0 kWh/m^3) of permeate produced. Previous publications by the ADC have focused on large plants, approximately 50- MGD in size.[1] In presenting these results and discussing the scalability of the ADC's data, it was identified that medium sized (i.e., 10-MGD) plants require different design considerations to realize similar energy savings. This paper presents a conceptual design and costs for a medium size (10 MGD) SWRO plant based upon the ADC's 2006 demonstration project in Port Heuneme, California.

The conceptual design for the facility includes open ocean intake, pretreatment, multiple trains with dedicated high pressure pumping and energy recovery, and permeate post treatment. The conceptual facility is based on a stand-alone design with access to an existing outfall for brine disposal.

INTRODUCTION

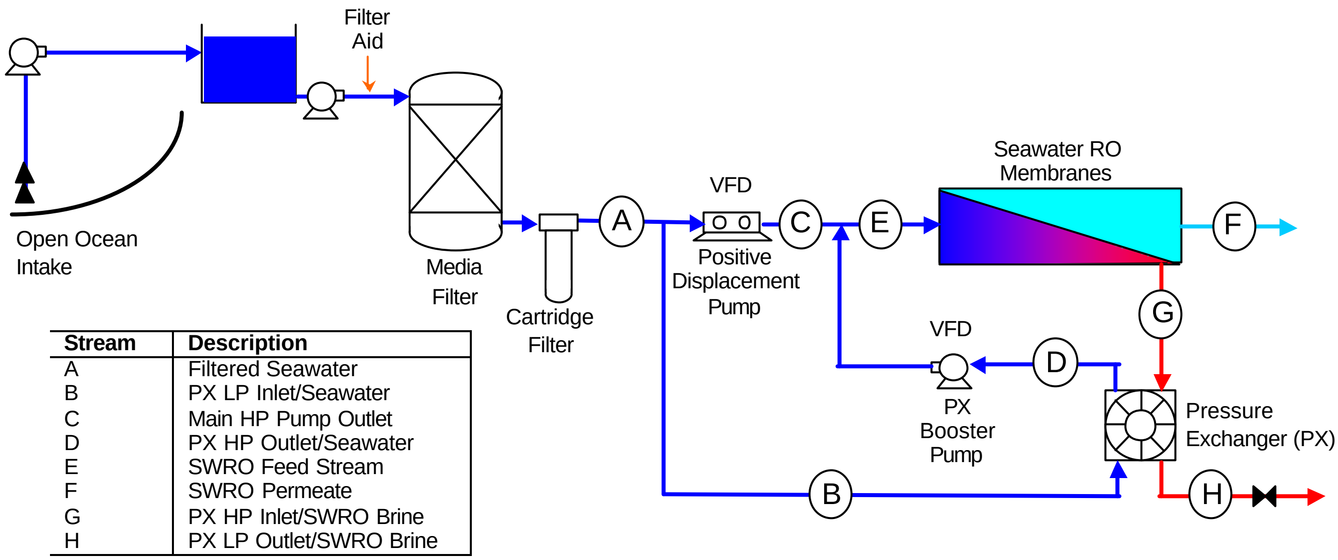
The World Health Organization (WHO) estimates that the number of people living in regions with water availability problems will almost double, from 1.5 billion in 1990 to 2.8 billion in 2050. Populations that reside in coastal areas have a tremendous water resource, seawater, which makes up 95% of the world's water, but is not suitable for potable consumption without proper treatment. Historically, the limiting factor in the use of this resource has been the cost of desalination, which is due, in part, to its high-energy consumption.

The ADC has operated a full-scale demonstration plant at the U.S. Navy's Seawater Desalination Test Facility in Port Hueneme, California from May 2005- April 2006. The ADC has achieved the goal of demonstrating record low energy consumption for SWRO at 6.0 kWh/kgal (1.58 kWh/m^3).

ADC STUDY MATERIAL AND METHODS

Process Flow Diagram and Equipment Design Criteria

The ADC demonstration plant was designed to produce between 48,100 to 75,600 gpd (182 to 286 m^3/day) of permeate using existing technologies that minimize power consumption. **Figure 1** presents a process flow diagram for the ADC's SWRO plant. The process uses an open intake, media filters, a bag filter, a high efficiency positive displacement pump, and an isobaric energy recovery device. The design criteria for these components are presented in **Table 1**.



Stream	Description
A	Filtered Seawater
B	PX LP Inlet/Seawater
C	Main HP Pump Outlet
D	PX HP Outlet/Seawater
E	SWRO Feed Stream
F	SWRO Permeate
G	PX HP Inlet/SWRO Brine
H	PX LP Outlet/SWRO Brine

Figure 1. Process Flow Diagram - ADC's Demonstration Scale SWRO plant

Table 1. Design Criteria for ADC's SWRO Demonstration Scale Equipment

Parameter	Unit	Value
Media Filter		
Loading Rate	gpm/ft^2	3 to 6
Depth/Grain Size/U.C. of Anthracite	in/mm/-	18 / 0.85-0.95 / <1.4
Depth/Grain Size/U.C. of Sand	in/mm/-	10 / 0.45-0.55 / <1.4
Depth/Grain Size/U.C. of Gravel	in/mm/-	6 / 0.3 / <1.4
Cartridge Filter		
Cartridge Specs		#2, 5-micron
Loading Rate	gpm/10-in.	~1
Membrane System		
Models		FILMTEC™ SW30HR-380, FILMTEC™ SW30XLE-400*i*, FILMTEC™ SW30HR LE-400*i*
Diameter	inch	8
Elements per Vessel	No.	7
Vessels	No.	3
High Pressure Pump [1]		
Type		Positive Displacement
TDH	ft (psig)	1385 to 2305 (600 to 1000)
Energy Recovery [2]		
Type		Isobaric
PX Booster Pump [3]		
Type		Multi-stage Centrifugal
TDH	ft (psig)	70 to 115 (20 to 50)

1 David Brown Union, Model TD-60
2 Energy Recovery, Inc., Model PX-70S
3 Energy Recovery, Inc., Model HP-8504

Cost Estimating Procedures

A present value analysis model, which accounts for both capital and operating costs was used to establish the most affordable operating condition. The conditions for the present value analysis model were established as part of the testing protocol, early during the ADC's development. The conceptual 10 MGD design parameters are presented in **Table 2**.

Capital cost was determined under the assumption that the SWRO facilities would be stand alone with an existing disposal outfall. Therefore, capital costs developed include intake, treatment and distribution facilities. Pretreatment was considered similar to the demonstration scale test equipment, however, media filter cost and operation/ maintenance were estimated in accordance with the deep bed filter concepts used for the Point Lisas SWRO facility in Trinidad (i.e., 4 gpm/ft^2, 5-ft anthracite, 2.5-ft sand, 2-ft garnet).[2] This design is assumed to be more compatible with challenging raw water qualities (i.e., than the ADC's demonstration scale media filters), such as those associated with red tide events. The cost estimating of the membrane system was based on the ADC demonstration units design with the exception of the high pressure pumping. Six trains with dedicated centrifugal pumps and isobaric energy recovery was best suited to match the ADC operating parameters and provide a realistic facility design for a 10 MGD plant. Post treatment costing is based on typical treatment of RO permeate to insure a finished water that meets or exceeds potable water standards.

Table 2. Present Value Analysis Conditions

Project Size	10 MGD	Intake/High Service Pmp Motor Eff.	95%
Capital Cost[1]	Determined with WTCOST Model and Manufacturer Quotes	SWRO Process Energy Demand	model data[2]
		Membrane Life	Refer to **Table 5**
		Membrane Element Cost[3]	$475 to $600
Electrical Systems	15% of Capital Cost	Pressure Vessel[4]	$8000
Instrumentation & Control	12% of Capital Cost	Ferric Chloride Cost	$0.23/lb
Project Life	30 years	Ferric Chloride Dose	10 mg/L
Bond Payment Period	30 years	Gas Chlorine Dose (pretreatment)	2 mg/L
Interest	5%	Sodium Hypochlorite Cost	$0.25/lb.
Construction Contingencies	15% of capital cost	Sodium Bisulfite Dose	4.6 mg/L
Contractor OH&P	10% of capital cost	Sodium Bisulfite Cost	$0.3/lb.
Engineering & Const. Mgmt.	25% of capital cost	Cartridge Filter Loading Rate	4 gpm/10-in.
Permitting Cost	$5-million	Cartridge Filter Cost	$2.50 /10-in.
Annual Maintenance Costs	1.5% of capital cost	Cartridge Filter Life	1000 hours
Labor	14 operators @ $55,000/yr ea. + 1.75 multiplier for overhead	Carbon Dioxide Dose	16 mg/L
		Carbon Dioxide Cost	$0.04/lb
Power Costs	$0.12 per kW-hr	Lime Dose	44 mg/L
Intake Pump TDH	200 ft H_2O	Lime Cost	$0.05/lb.
High Service Pump TDH	200 ft H_2O	Gas Chlorine Dose (finished water)	1.5 mg/L
Intake/High Service Pmp Eff.	80%		

Note: O&M does not include administrative, laboratory, legal, reporting or management fees since these costs vary widely.

1 Includes intake and intake pump station, prechlorination/dechlorination systems, ferric chloride system, media filtration, media filter backwash system, filtered water lift station, cartridge filters, SWRO equipment, RO bldg., permeate flush system, clean-in-place system, transfer pump station, process piping, yard piping, lime system, carbon dioxide system, chlorination system, high service pump station, site work.

2 Feed Pressure Data for operating points were used to develop RO specific energy using ERI PX Power Model©

3 SW30HR-380 = $475/ea.; SW30XLE-400*i* = $600/ea.; SW30HR LE-400*i* = $500/element.

4 Installed, includes all ancillary piping, frames and fittings.

Table 3 establishes the expected membrane life and the cumulative annual replacement rate (CARR) based on recovery and membrane flux. The CARR values presented in **Table 3** are based upon industry experience when treating water of similar quality. The expected membrane life is used to estimate membrane replacement cost. Membrane replacement resulting from warranty maintenance by the manufacture was not part of the replacement cost. Cost resulting from the cumulative annual replacement rate (CARR) is built into the membrane element cost by the manufacturer during the membrane warranty period.

Table 3. Membrane Life & Annual Replacement Rate

	Flux					
	6 GFD		7.5 GFD		9 GFD	
Recovery	**CARR[1]**	**Membrane Life**	**CARR[1]**	**Membrane Life**	**CARR[1]**	**Membrane Life**
35%	7%	6.5 yrs	8%	6.25 yrs	9%	6 yrs
42.5%	9%	6 yrs	10%	5.75 yrs	11%	5.5 yrs
50%	11%	5.5 yrs	12%	5.25 yrs	13%	5 yrs

1 Cumulative Annual Replacement Rate (CARR). The percentage of membrane elements that would be replaced to maintain a performance requirement (i.e., permeate quality and energy) for a 5-year warranty.

10 MGD CASE STUDY

Design Concept

The cost estimating parameters stated above and the following design concepts are the basis for the costs presented in this paper. Design concepts of interest when considering how to configure a medium sized, 10-MGD SWRO plant to match the efficiency demonstrated during the ADC's testing include:

- Pump Selection
- Pump Station Design

Pump Selection. The type of pump to choose for a specific application is dependant on the purpose, efficiency, pump curve characteristics, cost, maintenance requirements, and historical operation success. Deciding what type of pump to use is therefore a function of each application. Common pumps used for SWRO include both centrifugal pump and positive displacement pumps. Advantages and disadvantages of each pump are listed in the table below.

Table 4. Pump Type Comparisons

Pump Type	Advantages	Disadvantages	Notes
Centrifugal	• Low Maintenance • Available in wide range of flows	• Lower efficiency	• Very large pumps can be as efficient as PD pumps
Positive Displacement (PD)	• High efficiency • Flat pump curve	• Pulsating flow • High Maintenance • Application limited to lower flow rates	

As indicated in **Table 4**, pump sizing can be a significant consideration in order to obtain energy efficiency. The efficiency of a centrifugal pump is a function of rotational speed and capacity.[3] As shown in **Figure 2**, for a centrifugal pump, efficiency increases with the flow capacity of the pump. Therefore, to maximize efficiency, pumps that perform duties such as intake raw water pumping, filtered water lift pumping, permeate lift pumping and finished water pumping might be designed to maximum flow rate per pump. However, as pump size increases, for a small or medium sized plant (e.g., up to 10 MGD), flexibility in how the plant is operated can be sacrificed. Therefore, to minimize power use, in addition to pump type, pump station design must also be considered in the context of how the plant is operated.

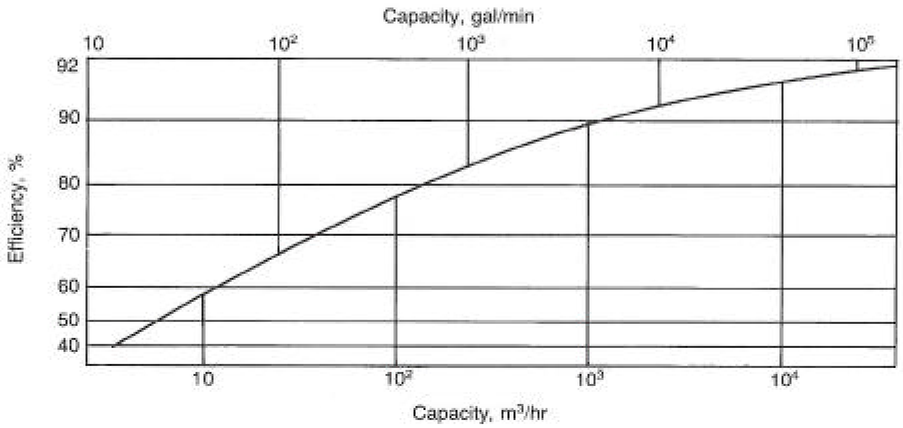


Figure 2. Maximum Pump Efficiency Attainable at the Best Operating Point [3]

Pump Station Design. In order to achieve maximum efficiency within the SWRO process, pump station design should be carefully considered. Two pump station designs are typically used to supply high-pressure water to the RO trains. These include:

- Dedicated pumps for every train.
- Three center design where pumps and energy recovery are separated from the trains and a feed manifold is common to all of the trains.

By separating the high pressure pumping, energy recovery and membrane banks, a three-center design has proven to be a successful technique for maximizing efficiency of individual equipment in an SWRO facility. Such a design concept has been employed at the 72 MGD Ashkelon SWRO facility.[4] With a three-center design, each component can be sized to achieve maximum efficiency and provide an SWRO facility that can maintain a high online factor and low specific energy. However, in the case of a 10 MGD facility, a pump center design may not realize as much energy savings due to the lower flow rates and potentially lower online factor. Operating flexibility is also sacrificed in order to increase the pump sizes.

Because of the lower flow rates associated with a medium sized facility, similar efficiencies can be realized for a dedicated train high-pressure pump station design when compared to a three-center design. Dedicated centrifugal pumps for a six-train SWRO design would have efficiencies of approximately 80% each. A pump center with two centrifugal pumps providing the SWRO feed flow rate (i.e., equal to the permeate flow due to the isobaric energy recovery system design) would achieve an efficiency of 83%. This small gain in efficiency is not significant to the overall energy consumption of the facility. Therefore, to maintain flexibility for a lower online factor, a dedicated pump design concept using centrifugal pumps is used for the medium sized facility design presented in this paper.

10 MGD SWRO Design Concept. **Figure 3** presents the ADC's conceptual 10 MGD process design. As presented in **Figure 3**, a six train dedicated pump SWRO system was used as the basis of the ADC's evaluation. A new ocean intake, inline coagulation and deep bed media filtration, disposal to an existing outfall and post treatment with lime and carbon dioxide were used for estimating costs. The access to the existing outfall was assumed because there is typically some economic advantage for locating a seawater desalination plant.

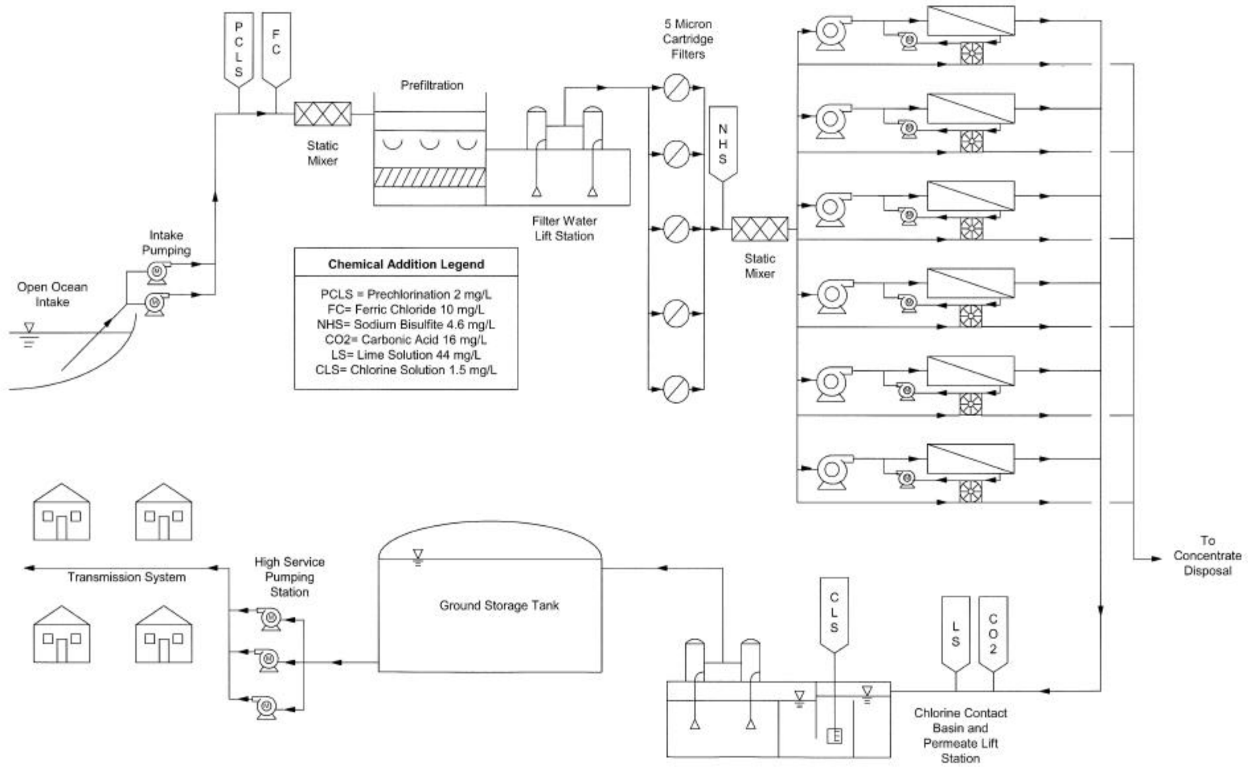


Figure 3. Conceptual 10 MGD SWRO facility (Dedicated Pump Design)

RESULTS AND DISCUSSION

Raw Water Quality and Pretreatment

Typical seawater quality tested during this study is summarized in **Table 5**. As noted, the SWRO average feed water temperature was 15.2°C, which would be representative of an ocean open intake, such as the one proposed for the ADC's 10 MGD case study. The ADC's data should be taken in the context of this information. Some locations along the Pacific Ocean may have slightly different TDS concentrates and once through cooling applications would have higher temperatures, both of which would lead to different permeate qualities and energy consumptions.

Table 5. Average Seawater Quality

Parameter	Average	Parameter	Average	Parameter	Average
Temperature	15.2 °C	Calcium	395 mg/L	Bicarbonate	135 mg/L
Total Dissolved Solids	31,688	Magnesium	1,230 mg/L	Chloride	19,345 mg/L
Conductivity	49,524 mhos	Sodium	10,370 mg/L	Sulfate	2,090 mg/L
pH	8.0	Potassium	340 mg/L	Fluoride	< 25 mg/L
Turbidity	1.8 NTU	Barium	0.21 mg/L	Bromide	< 125 mg/L
Boron	4.82 mg/L	Strontium	7.2 mg/L	Silica	6.85 mg/L
		Aluminum	0.21 mg/L		

The design of the pretreatment process for the ADC's demonstration scale equipment was based upon more than ten years of experience treating the Pacific Ocean from the Navy's intake in Port Hueneme, California. The design included in-line coagulation and direct media filtration (i.e., criteria established in **Tables 1** and **2**). Shortly after the ADC's plant was commissioned in May 2005, a red tide event occurred that was significantly worse (i.e., both water quality and duration of the event) than any previous red tide event previously experienced. As a result, the ADC's media filtration pretreatment was challenged to produce water with turbidity and silt density index (SDI) values acceptable for the SWRO system. Additionally, media filter differential pressure would increase rapidly over the course of only two days. This made operating the SWRO equipment impractical and the ADC's equipment remained shutdown until October 2005 when the red tide event ended.

The implications of these pretreatment troubles are such that for reliability purposes, some may wonder if media filtration is an appropriate pretreatment. However, even the membrane pretreatment systems that were pre-treating Pacific Ocean water during the summer of 2005 were challenged to produce an adequate capacity.[5] While membrane pretreatment production capacity poses a similar reliability issue, the quality of membrane pretreated water produced was always acceptable. These authors believe that media filtration can be designed such that it can respond to challenging water quality events. Such a design was implemented and has performed successfully at the Point Lisas SWRO plant in Trinidad.[2,6] Therefore, the Point Lisas media filtration design will be used as a basis for further cost estimation. This design should be tested during a California red tide event to validate this assumption.

Once the red tide event had abated, the ADC's equipment was operated in accordance with the testing protocol. During the testing period, seawater and filtered water turbidity and SDI were monitored daily. The results of these recordings throughout the testing duration are reported in **Figure 4**.

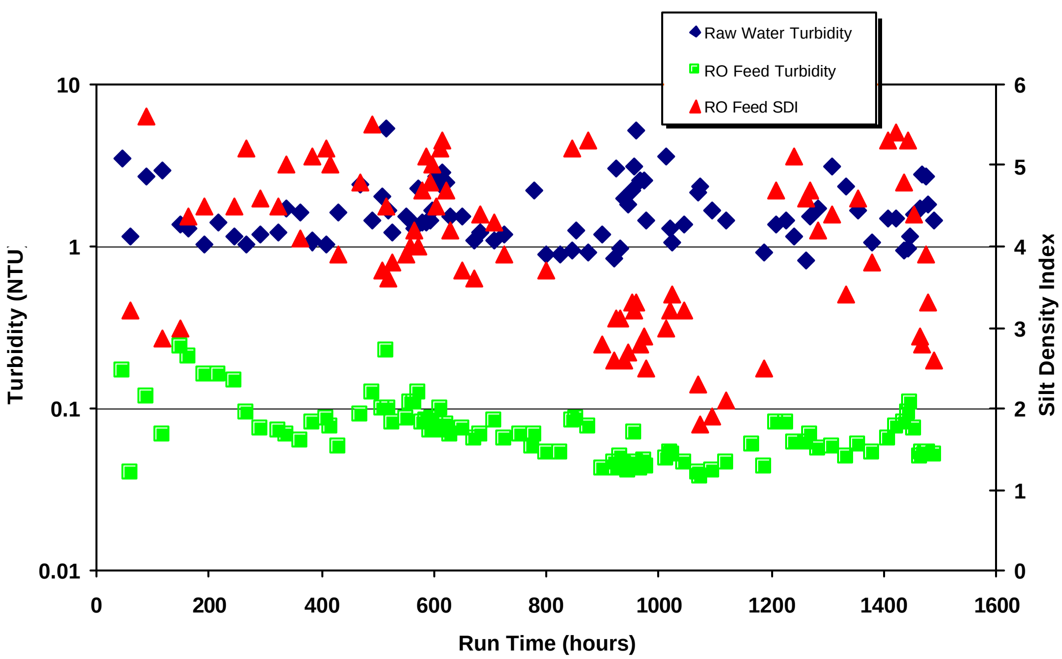


FIGURE 4. ADC Demonstration Scale Test Pretreatment Performance

Permeate Water Quality

The impact of flux and recovery on permeate boron and TDS concentrations is presented in **Figures 5 and 6**. These data were collected with varying flux and recovery during the ADC's testing program. Points of interest include the following:

- When flux increases, permeate TDS and boron concentrations decrease, when recovery increases, permeate TDS and boron concentrations increase due to the scientific principles of diffusion.
- All permeate conditions met the boron removal goal of 1.44 mg/L or less to comply with California's action level for boron in potable water. At the lowest flux tested, the SW30XLE-400*i* membrane produced marginally acceptable levels of boron in the permeate.
- The low energy membrane elements (i.e., SW30XLE-400*i* and SW30HR LE-400*i*) demonstrated the ability to produce acceptable permeate quality with respect to TDS and boron. The high rejection membrane model (SW30HR-380) demonstrated better permeate quality but at the expense of energy. The high rejection low energy element (SW30HR LE-400*i*) produced water with only slightly higher permeate concentrations than the high rejection membrane model (SW30HR-380).

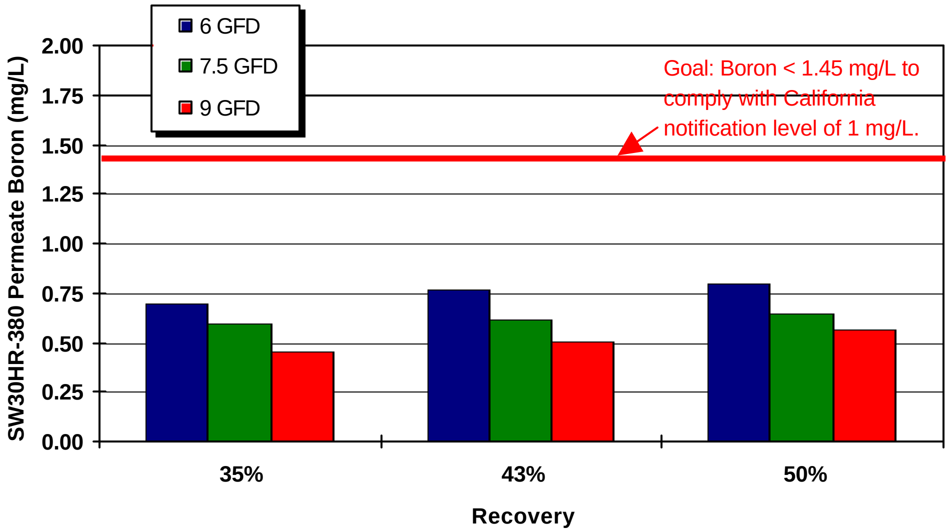
Because each membrane tested was capable of producing water of acceptable quality, each condition tested was evaluated in the cost model. It should be recognized however, that if the ADC test had been fed a higher temperature seawater, more typical of a co-located SWRO plant taking warm water from a once through cooling power plant, that the SW30XLE-400*i* membrane would very likely not produce acceptable water quality at a flux of 6 gfd. Therefore, the data presented herein should be taken in context with the raw water quality data presented in **Table 5**. If the test had been performed at a higher temperature, the SW30HR-380 and SW30HR LE-400*i* membranes would also produce permeate with higher concentrations of TDS and boron, and the feed pressures and power consumption would have been less. Further testing is needed to quantify the true impact of temperature on these results. Additionally, SWRO system designers should consider public issues related to water quality, in addition to water costs when selecting design conditions such as flux, recovery and membrane elements.

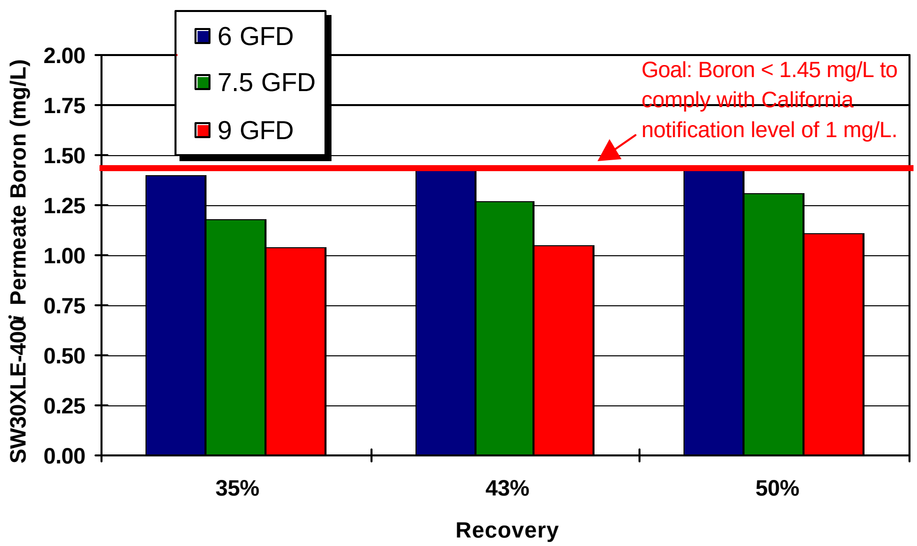
10 MGD Conceptual Energy Consumption

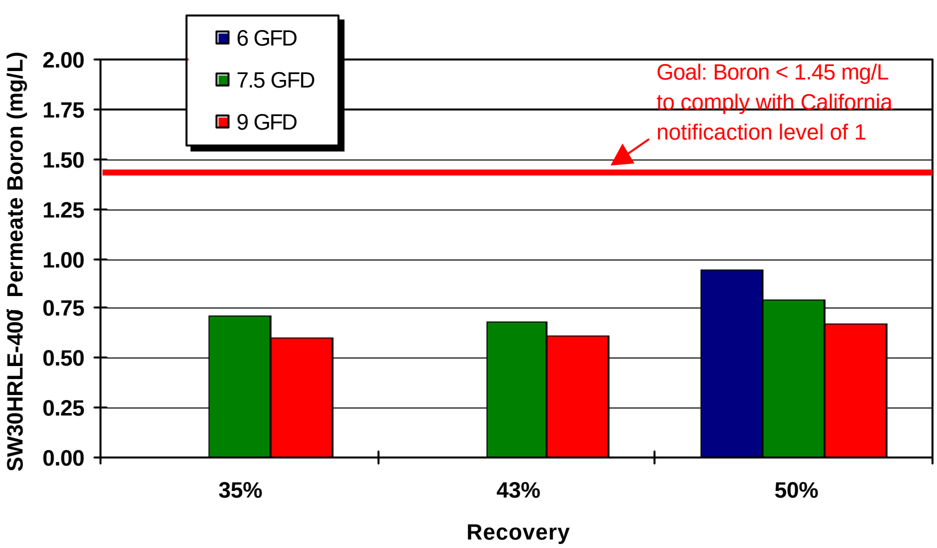
Because of the lower efficiency associated with the small centrifugal pumps that are used in the ADC's conceptual 10-MGD design, the ADC's specific energy data measured during the demonstration study are not reflective of what a 10 MGD plant is capable of. Therefore the results need to be adjusted to reflect more realistic specific energy numbers associated with a less efficient centrifugal pump.

The membrane feed pressure and differential pressure data collected during the ADC's demonstration plant operation were used to calculate the RO specific power for the less efficient centrifugal pump. A power model was used to calculate the RO specific energy data, which includes the power consumption of the high-pressure pump as well as the booster pump, which is required with a isobaric energy recovery device. The power model used is a transparent method for calculating SWRO system power requirements and is available for download off of the internet. [7]

FIGURE 5. Permeate Boron Concentrations

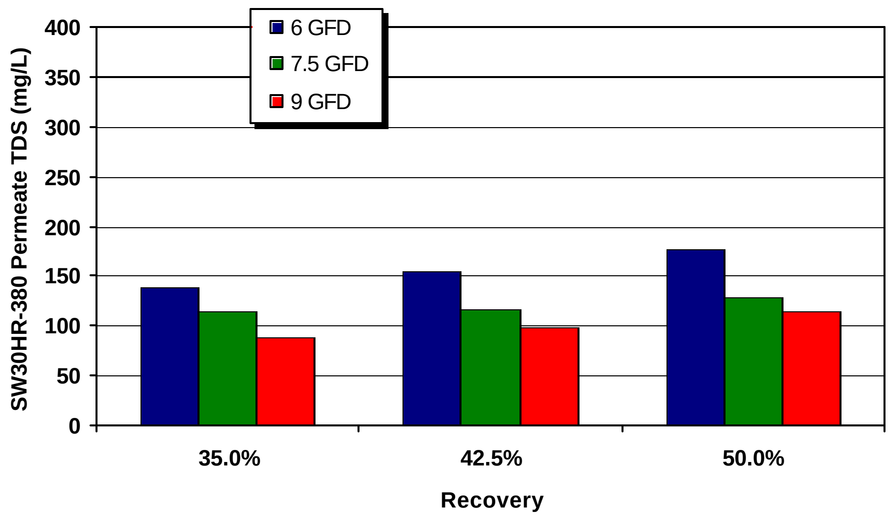


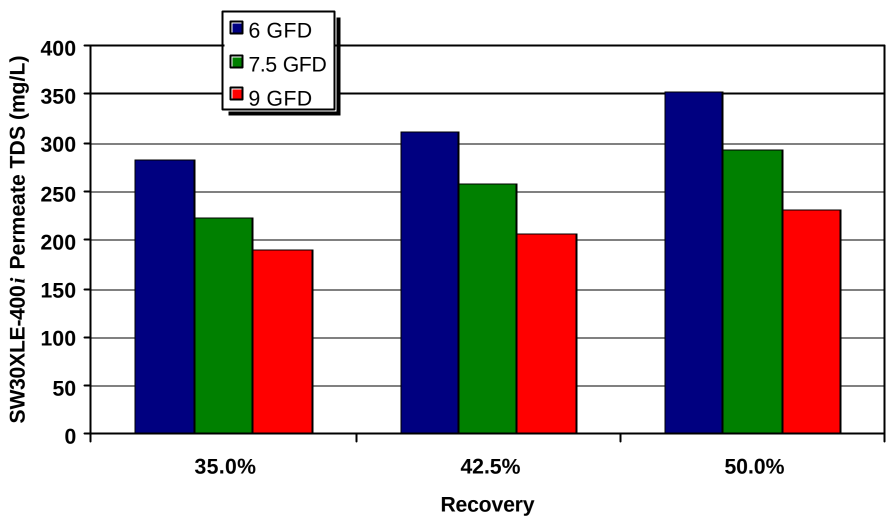




NOTE: 1. A 1.44 mg/L boron concentration meets the California requirement for a 1 mg/L Notification Level. Results must be rounded up to the nearest 0.1 mg/L.

FIGURE 6. Permeate TDS Concentrations





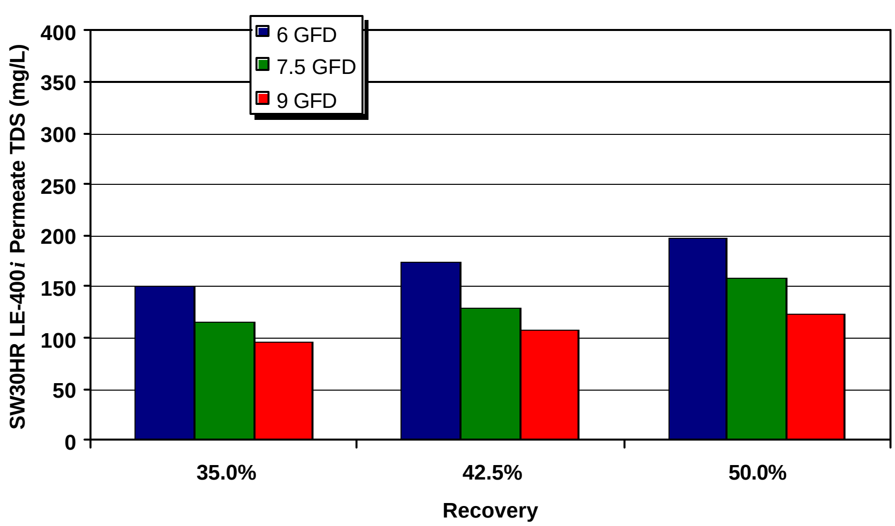


Figure 7 presents specific power graphs for each of the membranes tested, corrected to reflect the lower efficiency centrifugal pumps used in the ADC's 10 MGD conceptual design. The following observations can be made based upon these graphs:

- As expected, the low energy membrane element (i.e., SW30XLE-400i) requires less energy than the other membranes. The low energy high rejection element (i.e., SW30HRLE-400*i*) required only slightly less energy than the standard high rejection element (i.e., SW30HR-380).
- Though the RO specific power generally increases with recovery rate, the total energy required for treatment decreases with increasing recovery. This is due to the increased volume of feed water that must be treated at lower recovery rates to obtain the same volume of permeate. Therefore, these graphs show the importance of analyzing a facility process as a whole, and not just the RO specific power.
- Previously reported ADC specific power data demonstrated a range of 6.0 to 8.9 kW-hr/kgal at the most affordable point for a 50 MGD design. Adjustments that account for the use of a centrifugal high pressure feed pump in a 10 MGD facility result in a higher specific power, estimated to range from 6.6 to 9.8 kW-hr/kgal.

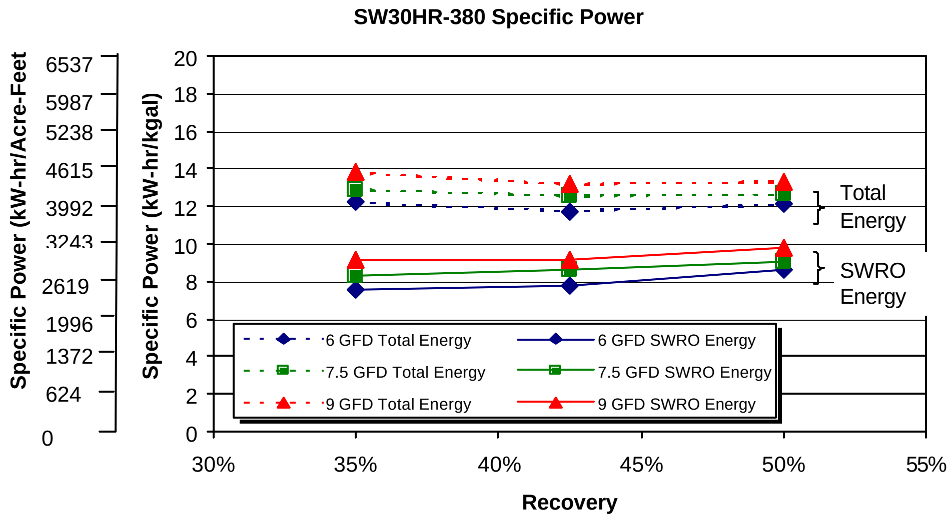
10 MGD Conceptual Costs

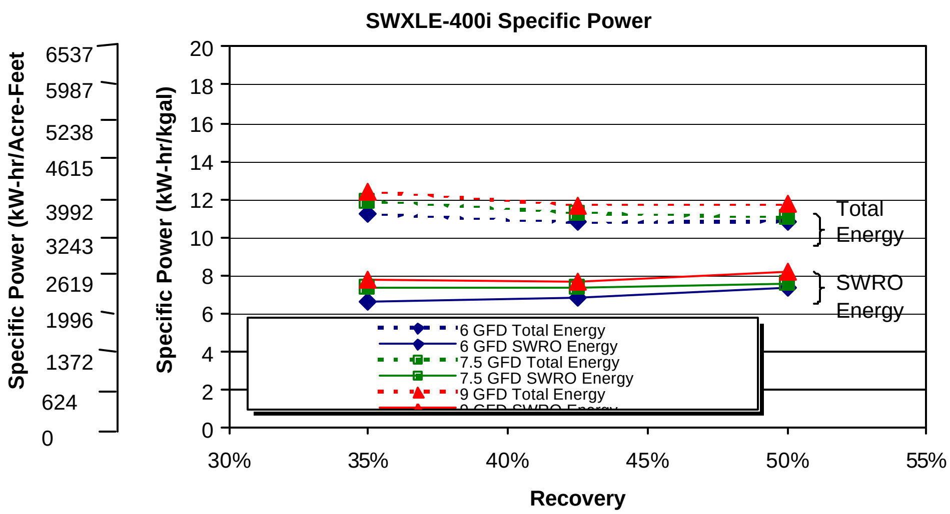
Estimated costs for the ADC's conceptual 10 MGD facility are presented in **Figure 8**. The costs include the estimated capital cost as well as the operation and maintenance costs over the range of flux and recovery conditions tested for each membrane during the ADC's demonstration study. As presented previously, these costs assume that the facility has an new open ocean intake, in-line coagulation, deep bed media filtration, six SWRO trains with dedicated pumps, lime and carbon dioxide post treatment, new finished water pumping facilities, and utilizes and existing ocean outfall.

The following findings are drawn from these cost estimates:

- There is generally a downward trend in costs per unit volume as recovery increases due to the cost associated with feed water pretreatment. A recovery rate of 50% was demonstrated to produce the lowest estimated total water cost. Operating at a recovery of 50% is contrary to the recommendation of some in the industry that advocate lower recoveries to maximize membrane life, reduce cleaning frequencies and produce the highest quality permeate.[8,9] However, the impact of high recovery on membrane replacement costs, cleaning frequencies and permeate quality are factored into the ADC's cost estimate using the CARR values presented previously in Table 3. The CARR accounts for the annual replacement of membranes to maintain system performance with respect to power and permeate quality. Therefore, it can be concluded that reducing capital costs associated with pretreatment are estimated to be more important to designing an SWRO process with long membrane life, low cleaning frequencies, and the lowest SWRO energy consumption.
- Capital costs associated with SWRO pumping are constant when using an isobaric energy recovery system. This is because the energy recovery system is sized to handle the concentrate flow and the feed pumping system is designed to pump a flow rate equal to the permeate produced. The added costs for the energy recovery system are incorporated into the ADC's cost estimate for lower recovery rates, as are the added costs for a slightly higher total dynamic head resulting from higher recovery rates.

Figure 7. Specific Power - Corrected for 10-MGD





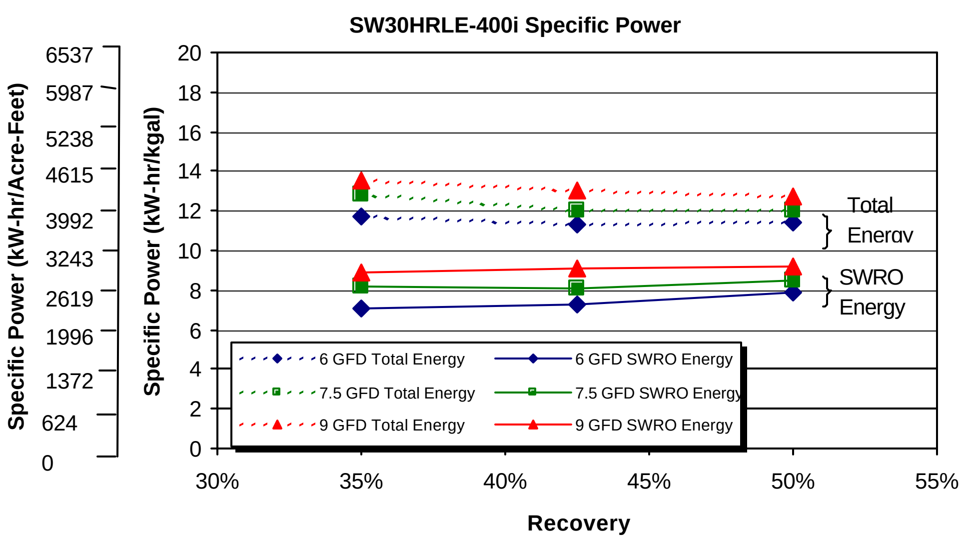
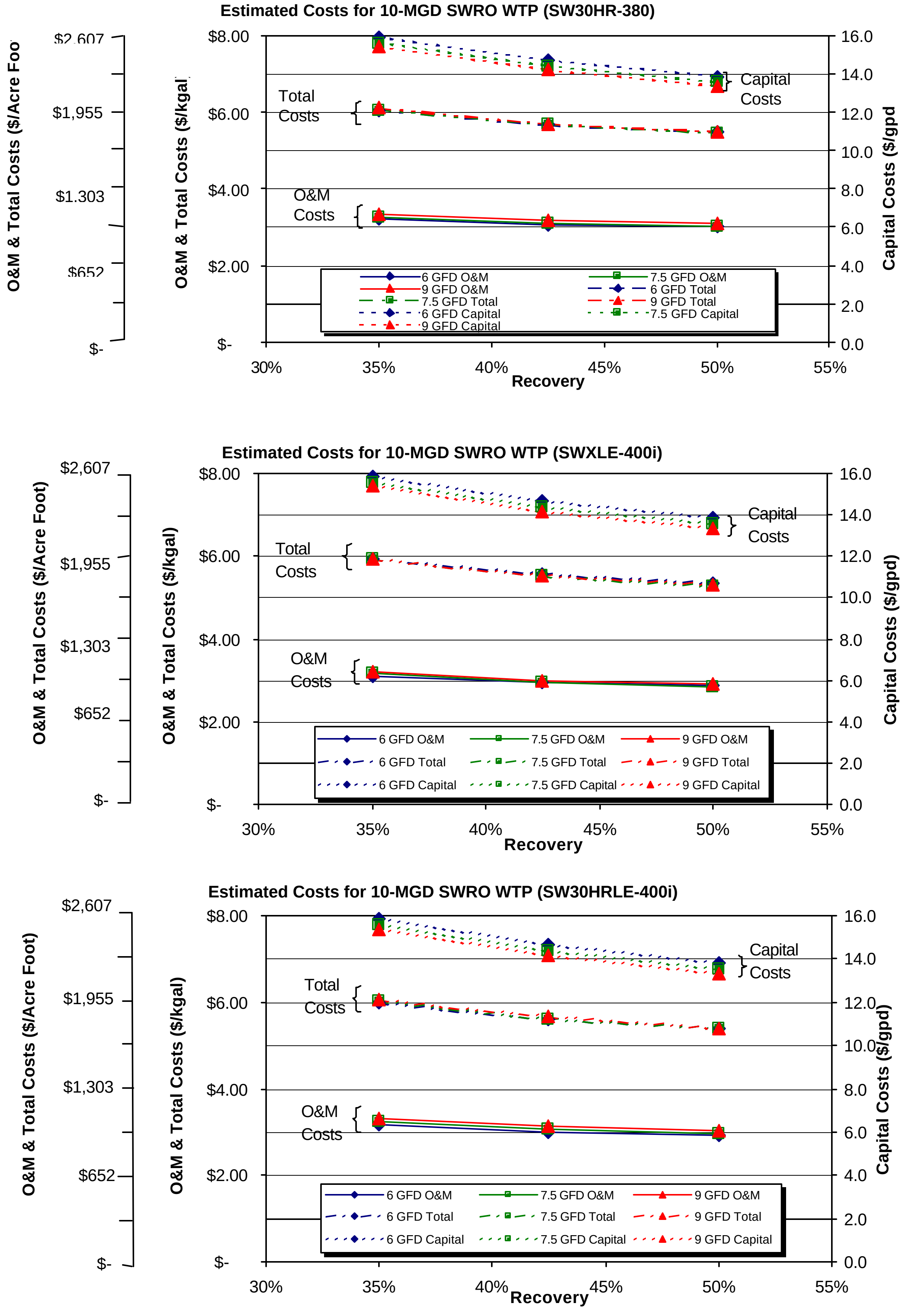


Figure 8. Estimated Costs - 10 MGD SWRO WTP



- Higher flux results in lower capital cost yet little difference in operating was observed. Typically, designers will choose higher flux rates to minimize capital costs and produce the best quality water even though power costs, membrane replacement costs and in some cases, cleaning costs may increase as a result. Again, the ADC's costs presented in Figure 8 account for these added O&M costs resulting from higher flux rates using the CARR values presented in Table 3. Our results provide further credence to the industry's experience that these types of operating costs are negligible when compared on a life cycle basis.[10] It should be noted, however, that not all SWRO users will care to operate their RO plants in a manner that results in higher operations costs, despite the projected lifecycle cost savings.
- O&M costs comprise approximately 52% to 57% of the total water cost. SWRO power consists of approximately 23% to 29% of the total water cost. This is a significant reduction over the industry's perception, where some believed that power costs represent 50% of the total water costs for an SWRO facility.

CONCLUSIONS

The following results and conclusions can be taken from the ADC's demonstration study data and the conceptual 10 MGD SWRO facility:

- The ADC's results must be viewed within the context of the raw water quality conditions tested. These conditions include low feed water temperatures (i.e., when compared to once through cooling systems). At higher temperatures, a flux of 6 gfd will produce water with higher concentrations of TDS with a lower specific energy.
- Increasing flux (at constant recovery) on the SWRO membranes results in lower concentrations of TDS and boron in the permeate.
- Increasing recovery (at constant flux) results in higher concentrations of TDS and boron in the SWRO permeate.
- Pump type, pump size and pump station design should be considered to reduce power consumption. Centrifugal pumps were chosen for the ADC's 10 MGD case study due to the flow rates, train sizes, low maintenance, and need for operational flexibility.
- For a 10 MGD SWRO plant, adjusted efficiency due to use of less efficient centrifugal high pressure pumps results in a specific power consumption ranging from 6.6 to 9.8 kWhr/kgal. Previously published ADC operations data demonstrated specific power consumption ranging from 5.98 to 8.90 kWhr/kgal for a 50 MGD SWRO plant.[1] Despite the less efficient centrifugal high pressure pumps, the power required is still approximately a 30% reduction over what industry experts have recently been using for their planning efforts.[11]
- A recovery rate of 50% consistently demonstrated the lowest estimated total water costs.
- Based upon the ADC's cost model, the costs for a 10 MGD SWRO plant with a new open ocean intake, deep bed media filtration, six SWRO trains with dedicated feed pumps, post treatment and ancillary product and finished water pumping are estimated to range from $1,725 to $1,970/AF ($5.29 to $6.05/kgal).

RECOMMENDATIONS

The authors offer the following recommendations to advance and improve upon the work presented in this paper:

- Pretreatment is a critical aspect of a successful seawater RO process. While media filtration is very capable of meeting the SDI and turbidity standards required for RO, the red tide event that occurred early during the study resulted in excessive backwashing frequencies and ultimately placing the study on standby. While the persistence of this event was an apparent anomaly in California, and even those seawater systems treating the Pacific Ocean using membrane pretreatment were challenged to produce enough water, the membrane pretreatment provided a consistent and reliable quality of water, which the ADC's media filter design could not. As a result, the authors recommend a further study to compare other types of media and advanced filtration designs.
- SWRO system designers should consider public values to issues such as water quality and cost when selecting design conditions such as flux, recovery and membrane type. The community values may require the use of a membrane that rejects more TDS and boron, but requires more energy to produce water. Factors of safety in permeate quality may also be considered. The data presented in this paper indicated that the SW30XLE-400*i* membrane barely met the California standard for boron at a flux of 6 gfd. A higher flux or use of a different membrane may make sense for some communities.
- The ADC's test results represent conclusions based upon the performance of new membranes. The concept of the Cumulative Annual Replacement Rate (CARR) was used to adjust costs and normalize performance with respect to permeate quality and energy consumption. Long term testing is required to validate the flux and recovery at the most affordable operating point. In addition, long term testing required to determine how specific power will vary with time and cleaning cycles. Furthermore, industry experience indicates that high flux and high recovery operation results in more frequent chemical cleaning and shorter membrane life. However, when balanced with capital costs on a life cycle basis, incurring these incidental operating costs often proves to be more economical, but more labor intensive to maintain.[10] A longer study is required to help quantify the differences that could not be derived from the ADC's data due to the short testing duration.
- Additional configurations for the SWRO system should be tested to compare alternate membrane types, energy recovery devices and pumping technologies. Many manufacturers have comparable technologies that are worthy of testing.
- Cost estimates should consider the possible economy of large diameter pressure vessels and membrane elements which may reduce capital costs by approximately 20%.[12]
- Seek out, test and demonstrate system designs and technologies that can increase the achievable recoveries of SWRO systems.
- Seek out, test and demonstrate new pump, energy recovery and system designs that avoid the efficiency losses associated with the small or medium sized centrifugal pumps.

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