ADC baseline tests reveal trends in membrane performance

John MacHarg, Affordable Desalination Collaboration, **Thomas F Seacord**, PE, and **Bradley Sessions**, Carollo Engineers, PC

The Affordable Desalination Collaboration (ADC) has completed a major milestone in its test program that profiles the state-of-the-art performance for seawater reverse-osmosis (SWRO) technology. This testing ran over two years and involved operating seven sets of standard 8 in diameter membranes in seven-element pressure-vessels including:

- FilmTec SW30HR-380, SW30XLE-400i, SW30HRLE-400i, Internally Staged Design (ISD) Hybrid
- Koch TFC 2822HF-400
- Hydranautics SWC5
- Toray TM820E-400.

All other associated equipment and designs used in these tests also represented state-of-the-art, off-the-shelf technology. Key system variables of recovery and flux ranged from 35-50% and 6-10 gallons per day (gpd) per square foot of membrane (gfd). The testing provides a body of data that can be used to define and project the performance of state-of-the-art SWRO for Southern California applications as well as a benchmark for the performance of new technologies and designs.

ADC Pilot System

The ADC demonstration plant was designed to produce between 48,100 to 75,600 gpd (182-286 m^3/d) of permeate flow using existing full-scale technologies that minimized power consumption.

Figure 1 presents a process flow diagram for the ADC's SWRO plant located at the US Navy Seawater Desalination Test Facility in Port Hueneme, California. The process uses an open ocean intake, media filters, 5 micron 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 (*see page 32*).

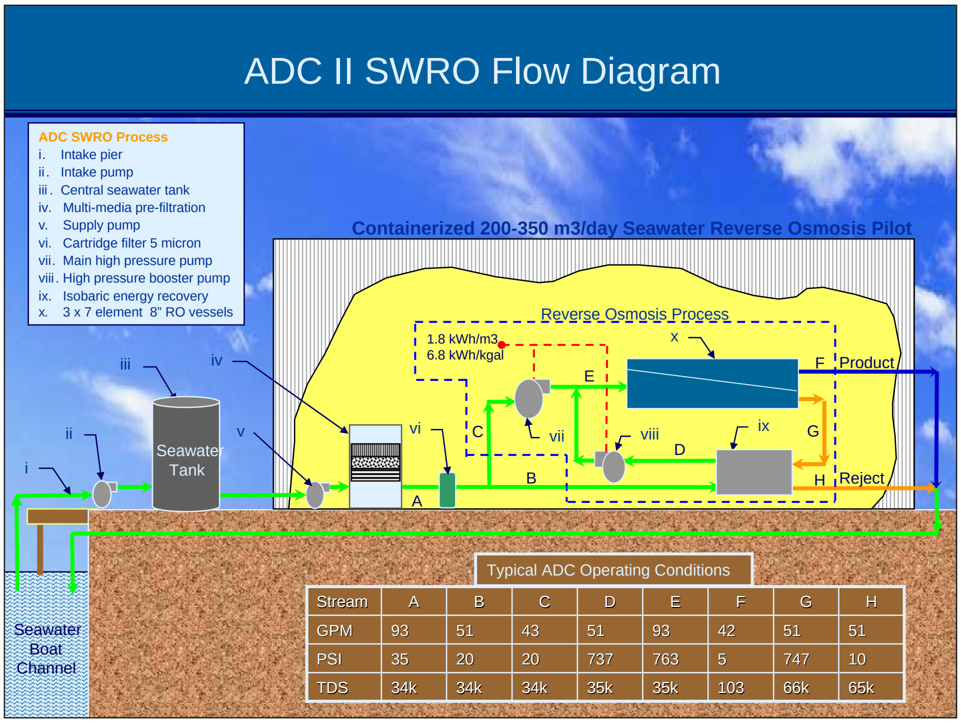
Test protocol

Demonstration-scale tests of each membrane set occurred in approximately seven 9-week phases. As presented in Table 2 (*see page 32*), each phase of testing has the following features.

The membranes were allowed to stabilize ("ripening") for two weeks at baseline conditions of 7.5 gfd and 42.5% recovery was performed. This "ripening" period ensured that the membrane and system performance were operating satisfactorily and at steady-state conditions.

The ADC tested each membrane set at a predetermined matrix of 9 and 12 fluxes and recovery points for ADC I and II respectively. ADC I tested 3 sets of FilmTec membranes at flux rates of 6, 7.5 and 9 gfd and 35, 42.5 and 50% recovery. ADC II extended and optimized this test regime to include 6, 7.5, 9 and 10 gfd at 42.5, 46 and 50% recovery according to Table 2.

The ADC eliminated the 35% recovery point from ADC II testing due to the results from ADC I that showed significantly higher costs at this lower recovery point . Finally, in the case of the FilmTec ISD configuration, the ADC tested a point at 9 gfd and 55% recovery, according with the manufacturer's request.



Stream	A	B	C	D	E	F	G	H
GPM	93	51	43	51	93	42	51	51
PSI	35	20	20	737	763	5	747	10
TDS	34k	34k	34k	35k	35k	103	66k	65k

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

Each data point from the above flux-and-recovery matrix was input to a net present value (NPV) model to determine the most affordable point (MAP) of operation. As part of determining the MAP, a specific set of water-quality goals was established based on EPA Secondary Water Treatment Goals (TDS < 200 mg/l and boron < 1.045 mg/l).

In some cases, where these goals were not achieved at any of the matrix operating points, the ADC simply ran the demonstration at the MAP, noting the higher TDS and boron figures. Note that the test protocol outside the NPV analysis provides general water-quality goals of TDS < 500 mg/l and boron < 1.45 mg/l, to account for applications that may have less stringent water-quality requirements.

At the end of the 12-point matrix testing and at the end of the 2-3 week MAP testing, the baseline conditions of 42.5% recovery and 7.5 gfd were retested to confirm that membrane and system performance had remained stable from the first two weeks of testing.

RESULTS AND DISCUSSION

Raw Water Quality

Raw feed water was taken from an open intake at the end of a pier located in the Port Hueneme shipping channel fed by the Pacific Ocean. Typical seawater quality tested during this study is summarized in Table 3 (*see page 32*).

As noted, the SWRO average feed water temperature was 59°F/15°C with a high of 68°F/20°C and a low of 54°F/12°C. It should be noted that once through cooling applications using a co-

ADC Mission and Members

The mission of the Affordable Desalination Collaboration (ADC) is to demonstrate affordable, reliable and environmentally responsible reverse-osmosis (RO) desalination technologies and to provide a platform by which cutting-edge technologies can be tested and demonstrated on their ability to reduce the overall cost of the seawater reverse-osmosis (SWRO) treatment process.

The ADC is a non-profit organization comprising the following group of industry-leading companies, state and government agencies:

- California Department of Water Resources
- California Energy Commission
- Carollo Engineers
- City of Santa Cruz Water Department
- Energy Recovery, Inc.
- FilmTec Corporation
- GE Zenon
- Hydranautics – A Nitto Denko Company
- Koch Membranes
- Metropolitan Water District of Southern California
- Naval Facilities Engineering Service Center
- Pentair Water Treatment - CodeLine Division
- Poseidon Resources
- Sandia National Laboratories
- Toray Membranes
- U.S. Bureau of Reclamation
- West Basin Municipal Water District

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located power plant intake would have higher temperatures, which would lead to different permeate qualities and energy consumptions than those reported by the ADC.

Highest temperatures tended to occur in the fall months, while the lowest temperatures were seen in spring. Feed salinity and boron remained very stable over the three years of recorded data with an average of 35,000 mg/l TDS and 5 mg/l boron.

As shown in Figure 2, ADC I tested three sets of FilmTec membranes exclusively and ADC II tested one set of membranes from each of the leading manufacturers including the Toray – TM820E-400, Koch – TFC 28822HF-400, Hydranautics – SWC5 and FilmTec (ISD) Hybrid Configuration.

Parameter		Unit	Value
Media Filter			
	Loading Rate	gpm/ft²	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		22 each, #2, 5 micron x 40 in
	Loading Rate	gpm/10-in	~1
Membrane System			
	Models		**ADC I Test** FilmTec™ SW30HR-380, FilmTec™ SW30XLE-400i, FilmTec™ SW30HR LE-400i **ADC II Test** Koch TFC 2822HF-400 Hydranautics SWC5 FilmTec™ ISD Hybrid Toray TM800E-400
	Diameter	inch	8
	Elements per Vessel	No.	7
	Vessels	No.	3
High Pressure Pump	Type Model		Positive Displacement David Brown Union, Model TD-60
	TDH	ft (psig)	1385 to 2305 (600 to 1000)
Energy Recovery	Type Model		Pressure Exchanger Energy Recovery, Inc. Model PX-70S
PX Booster Pump	Type Model		Centrifugal Energy Recovery, Inc. Model HP-8504
	TDH	ft (psig)	70 to 115 (20 to 50)

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

Flux, gfd	6			7.5			9			10		
Recovery, %	42.5	46.0	50.0	42.5	46.0	50.0	42.5	46.0	50.0	42.5	46.0	50.0
HP pump, gpm	36.5	36.5	36.5	45.3	45.3	45.3	54.0	54.0	54.0	54.0	54.0	54.0
PX Booster Pump, gpm	45.9	39.6	33.5	57.7	49.9	42.3	69.5	60.1	51.0	69.5	60.1	51.0
Permeate, gpm	35.0	35.0	35.0	43.8	43.8	43.8	52.5	52.5	52.5	52.5	52.5	52.5
PX Inlet, gpm	45.9	39.6	33.5	57.7	49.9	42.3	69.5	60.1	51.0	69.5	60.1	51.0
Concentrate, gpm	47.4	41.1	35.0	59.2	51.4	43.8	71.0	61.6	52.5	71.0	61.6	52.5

Table 2. ADC II 12-Point Flux-and-Recovery Matrix

	Temp. °F / °C	Feed pH	Feed salinity Ktds	Feed Boron mg/l	Raw Feed Turbidity NTU	RO Feed Turbidity NTU	RO Feed SDI
Low	54 / 12	7.22	33.40	3.90	0.24	0.03	1.8
High	68 / 20	8.75	36.81	5.53	12.00	0.25	11.4
Average	59 / 15	7.88	35.39	4.78	1.45	0.07	4.0

Table 3. Sea/Feed Water Quality

Feed Water Turbidity and Pretreatment Performance

The pretreatment process for the ADC's demonstration-scale equipment included in-line coagulation and media filtration, followed by 5 micron cartridge filtration (see criteria established in Table 1).

Initially during ADC I, in 2005, Southern California experienced localized and prolonged periods of red tides and extensive algae blooms throughout the summer. Red tides tend to occur most frequently in the spring and fall months and average 1-2 weeks in duration. The summer of 2005 was recognized as an anomalous period.

By contrast, from the start of ADC II in August 2007 until July 2008, the ADC has experienced approximately eight discrete days in which satisfactory water quality could not be achieved using the basic multimedia system. In full-scale applications, more robust designs would be applied to ensure that water quality and continuous operation could be maintained through these challenging but brief events that occur in Southern California coastal waters.

In general, the ADC pretreatment system has performed very well for the specific application. On average, the media filtration system has reduced feed water turbidity by 95% and yielded an average RO feed water SDI of approximately 4.0. The 5 micron string-wound cartridge filtration system was used at an approximate one gallon per minute (gpm) per 10 in of equivalent cartridge length. Cartridge differential pressures at baseline conditions resulted in differential pressure increases at a rate of approximately one psi per month of operation.

Membrane Performance

Over a period of three years, the ADC tested seven different membrane sets as outlined in Table 1. The data demonstrate that low energy consumption and satisfactory water quality can be achieved with all the leading membrane manufactures products.

The testing was performed consecutively through varying water quality conditions and should not be considered as side-by-side testing. The graphs represent the actual operating data that has not been normalized.

Therefore, the following results should not be used to make precise "apples to apples" comparisons of each manufacturer's membrane performance. Instead, they provide a benchmark for SWRO energy consumption for Southern California and reveal general trends in membrane performance.

Permeate Water Quality

The impact of flux and recovery on permeate boron and TDS concentrations is presented in Figures 4.1 and 4.2 (page 34). The data were collected over the flux and recovery points shown in Table 2.

In the interest of saving space, we are only showing the graphs from 6 and 9 gfd. The complete data set can be found on the ADC web site www.affordabledesal.com on the Data Page. Notable trends include the following:

- Due to the scientific principles of diffusion, when flux increases, permeate TDS and boron concentrations decrease; when recovery increases, permeate TDS and boron concentrations increase.
- The low-energy membrane elements (SW30XLE-400i, ISD Hybrid and TFC 2822HF-400) demonstrated the ability to produce acceptable permeate quality with respect to TDS and boron. The higher rejection membrane models (SW30HR-380, SW30HRLE-400i, TM800E-400 and SWC5) demonstrated better permeate quality but at the expense of higher energy consumption, with the exception of the Hydranautics SWC5. The SWC5 demonstrated the best water quality of all the membranes that were tested, while being a relatively low- to mid-range energy consumer.

Figure 2. Feed Water Salinity, Boron and Temperature

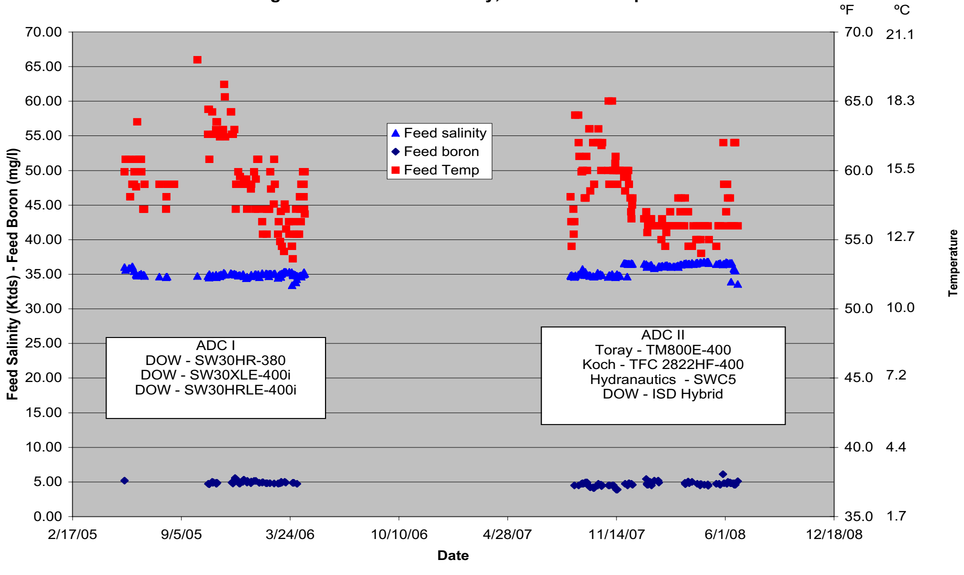
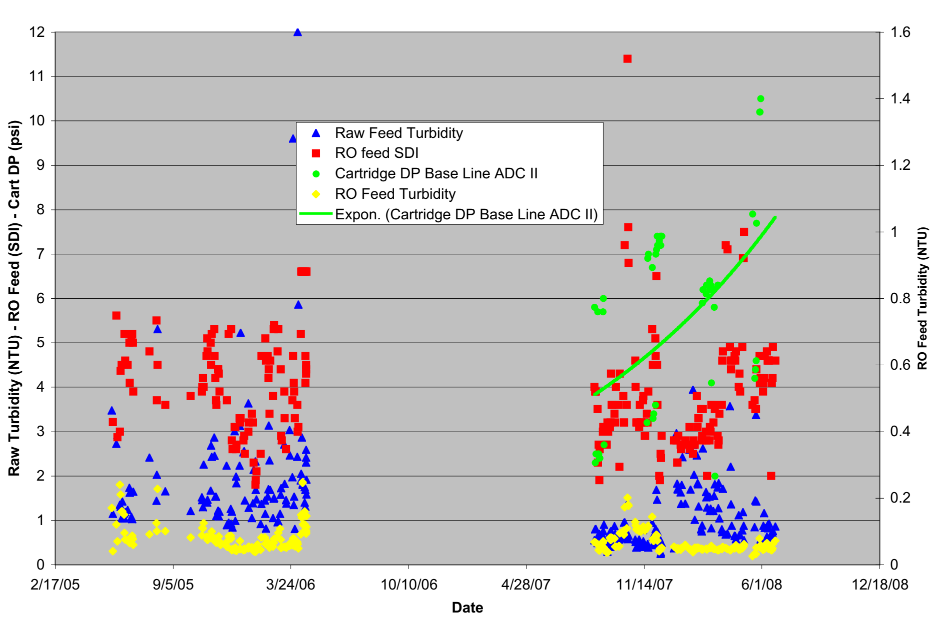


Figure 3. Feed Water Turbidity and Pre-treatment Performance



- The low-energy, low-rejection membranes produced permeate TDS levels approximately twice the high-energy, high-rejection membranes.

In some cases, using the low-energy membranes at the lower flux rates, the general water quality goals of TDS < 200 mg/l and boron < 1.045 mg/l could not be met. It should be recognized in these cases 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, the low-energy membranes may not be the best choice even at their lower cost for water.

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.

Energy Consumption

The ADC's demonstration-scale plant used off-the-shelf, state-of-the-art pumps and energy-recovery technology that are comparable in efficiency and energy consumption to the largest plants being designed today (*ie* approximately 50

MGD (190,000 m^3/d)). We will dedicate a section later in this article to explain how the ADC's results translate to various other plant sizes.

Figures 5.1 and 5.2 present specific power for each of the membranes tested. The following observations can be made based upon these graphs:

- As expected, the low-energy membrane elements (SW30XLE-400i, ISD Hybrid and TFC 2822HF-400) required less energy than the other membranes, but at the expense of permeate water quality.
- The lowest energy consumption was achieved with the FilmTec SW30XLE-400i membrane and was 6.0 kWh/kgal (1.58 kWh/m^3) @ 42% recovery and 6 gfd. The ADC considers this to be a world record for an SWRO system operating at commercially viable recovery and flux rates.
- Though specific power for the SWRO process generally increases with recovery, the total energy required for treatment decreases with increasing recovery. This is due to the increased volume of raw feed water that must be pumped and 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 SWRO specific power.
- ADC total treatment energy demonstrated a range of 10.4 to 11.3 kWh/kgal (2.75-2.98 kWh/m^3) at the most affordable point for a 50 MGD design.

Figure 4.1 Permeate Quality vs Recovery at 6 gfd

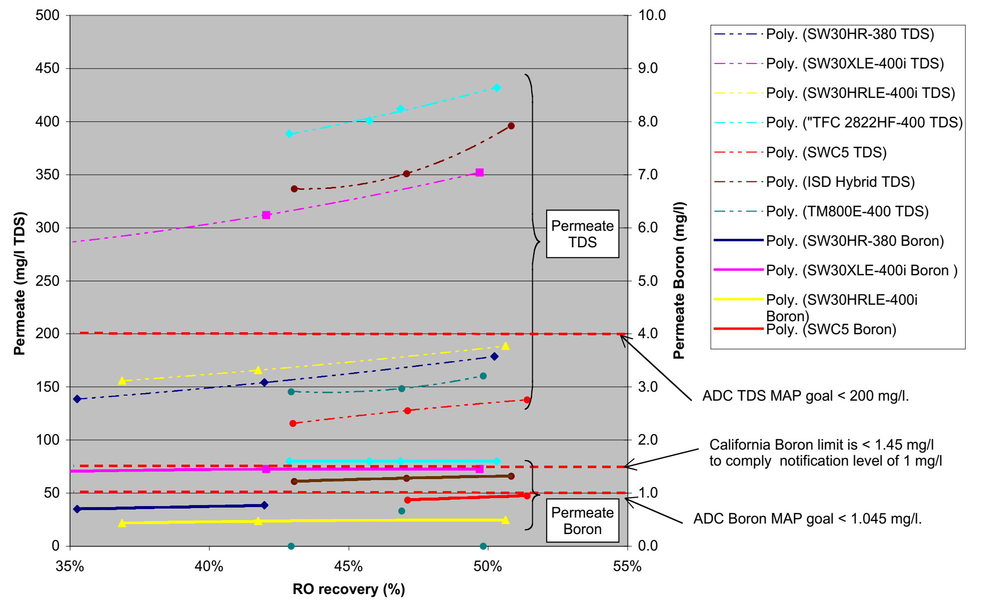
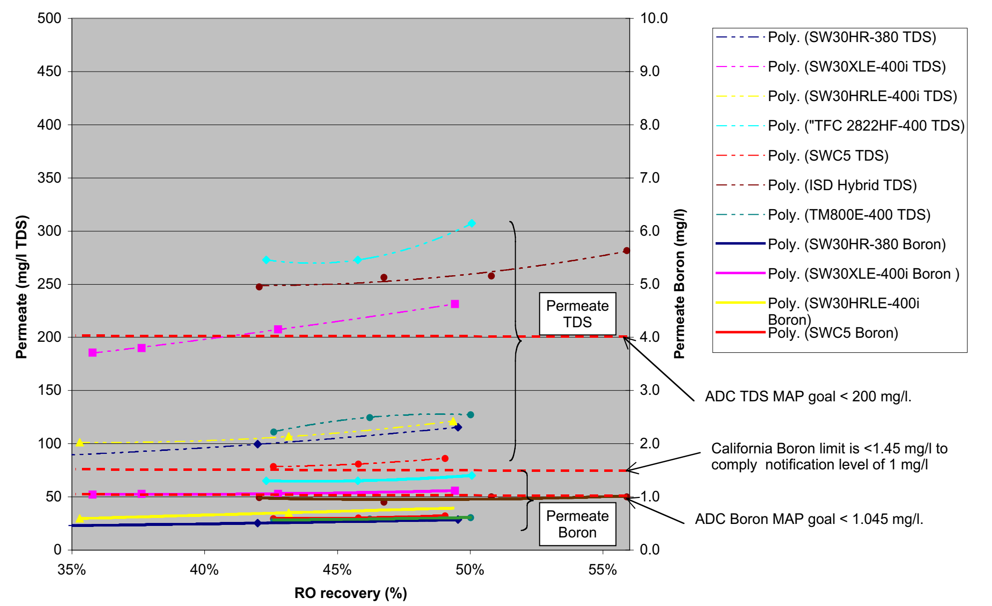


Figure 4.2 Permeate Quality vs Recovery at 9 gfd



50 MGD Conceptual Costs

Cost Estimating Procedures

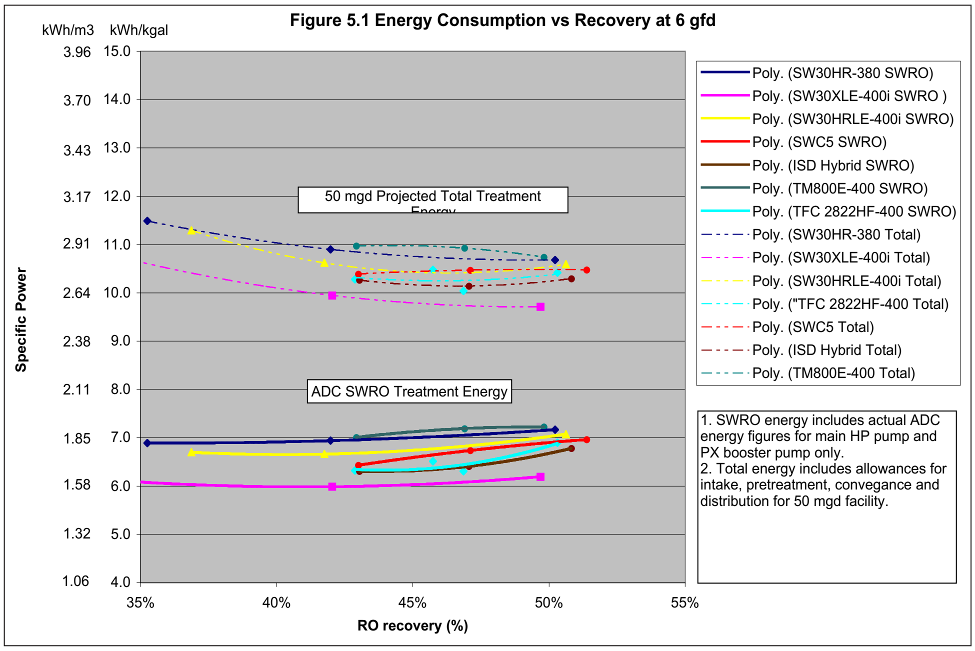
A net-present-value (NPV) analysis model, which accounts for both capital and operating costs, was developed and used to establish the most affordable operating point (MAP). The NPV analysis model was used at the completion of the flux/recovery variation tests, presented previously in Table 2, to establish the MAP for the demonstration test.

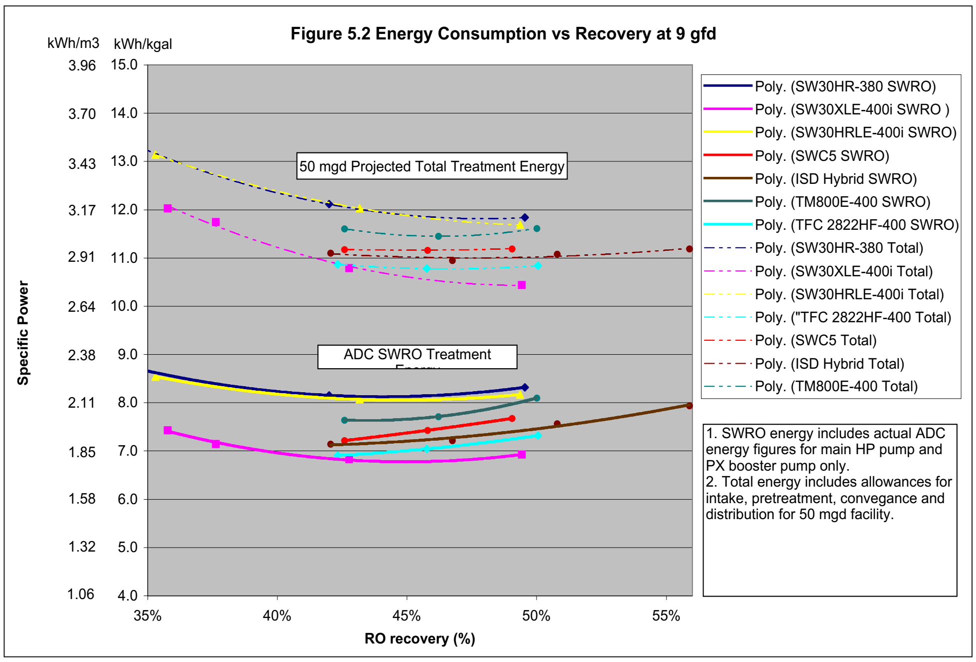
As mentioned earlier, as part of determining the MAP, the ADC also considered a specific set of water-quality goals of TDS < 200 mg/l and boron < 1.045 mg/l for the MAP. In some cases where these goals were not achieved at any of the matrix operating points, the MAP was demonstrated noting the higher TDS and boron figures.

Some of the assumptions and conditions for the present value analysis model are presented in Table 4. A complete version of the model can be found on the ADC's web site on the Data Page at www.affordabledesal.com.

As noted in Table 4 (*see page 36*), capital cost was determined under the assumption that the SWRO facilities would be co-located with a power plant. Therefore, the capital costs developed do not include any new intake or outfall facilities.

Pretreatment was considered similar to the demonstration-scale test equipment, however, media filters were estimated in accordance with the deep-bed filter concepts use for the Point Lisas SWRO facility in Trinidad (ie, 4 gpm/ft^2, 5-ft anthracite, 2.5-ft sand, 2-ft garnet).7 Such a design is assumed to be more compatible with challenging raw water qualities such as those associated with red tide events.





Project Size	50 MGD	Intake/High Service Pmp Motor Eff.	95%
Capital Cost [1]	Determined with WTCOST	SWRO Process Energy Demand	Study data[2]
	Model and Manufacturer Quotes	Membrane Life	Refer to **Table 5**
Electrical Systems	12% of Capital Cost	Membrane Element Cost	$550
Instrumentation & Control	10% of Capital Cost	Pressure Vessel [3]	$8547
Project Life	30 years	Sodium Hypochlorite Dose (pretreatment)	2 mg/L
Bond Payment Period	30 years	Sodium Hypochlorite Cost	$1.2/lb.
Interest	5%	Sodium Bisulfite Dose	4.6 mg/L
Construction Contingencies	15% of capital cost	Sodium Bisulfite Cost	$0.3/lb.
Contractor OH&P	10% of capital cost	Cartridge Filter Loading Rate	3 gpm/10-in.
Engineering & Const. Mgmt.	25% of capital cost	Cartridge Filter Cost	$5/10-in.
Permitting Cost	$10-million	Cartridge Filter Life	1000 hours
Annual Maintenance Costs	1.5% of capital cost	Carbon Dioxide Dose	16 mg/L
Labor (burdened)	25 operators @ $96,250/yr ea.	Carbon Dioxide Cost	$0.04/lb
Power Costs	$0.11 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	Sodium Hypochlorite 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.
Includes intake pump station, prechlorination/dechlorination systems, ferric chloride systems, 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 Power meter readings
3 Installed, includes all ancillary piping, frames and fittings.
4 Land cost are not included in the Present Value Analysis

Table 4. Present Value Analysis Conditions

Current operation of the ADC demonstration pilot includes operation of a Zenon ultrafiltration (UF) pretreatment system, and future reporting may include an analysis of alternative pretreatment systems such as UF and media filters.

Table 5 (page 37) establishes the expected membrane life and the cumulative annual replacement rate (CARR) with respect to recovery and membrane flux. The expected membrane life is used to estimate membrane replacement cost. Membrane replacement resulting from warranty maintenance by the manufacturer was not part of the replacement cost.

Cost Estimates

Estimated cost for the ADC's conceptual 50 MGD facility are presented in Figures 6.1 and 6.2. The costs include the estimated capital cost as well as the operation and maintenance cost 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 can share an existing 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 the utilization of an 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 feedwater pumping and pretreatment. A recovery rate of 50% was demonstrated to be 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.

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 5. 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 influential on total water costs than designing an SWRO process with long membrane life, low cleaning frequencies, and the lowest SWRO energy consumption.

- At the manufacture's request, the ADC operated the FilmTec ISD Hybrid membranes at 9 gfd and at an extended 55% recovery. This extended recovery point achieved an estimated 3% savings in the total treatment costs. Furthermore, the curve still trends downward indicating additional savings are possible at higher recoveries.
- Figure 7 demonstrates how higher flux resulted in lower capital cost. However, these costs savings were offset by an increase in operating costs resulting in almost no difference in the total treatment costs. Designers may choose higher flux rates to minimize capital costs and produce the best quality water even though power costs, membrane replacement costs and cleaning costs may increase as a result. Again, the ADC's costs presented in Figure 7 account for these added O&M costs resulting from higher flux rates using the CARR values presented in Table 5.
- Operation and maintenance (O&M) costs comprise approximately 45% of the total water cost. SWRO power consists of approximately 22% of the total water cost. This is a significant reduction over the industry's perception, where it is commonly believed that power costs represent 50% of the total water costs for an SWRO facility.

Figure 6.1 Costs vs Recovery at 6 gfd - 50 MGD SWRO WTP

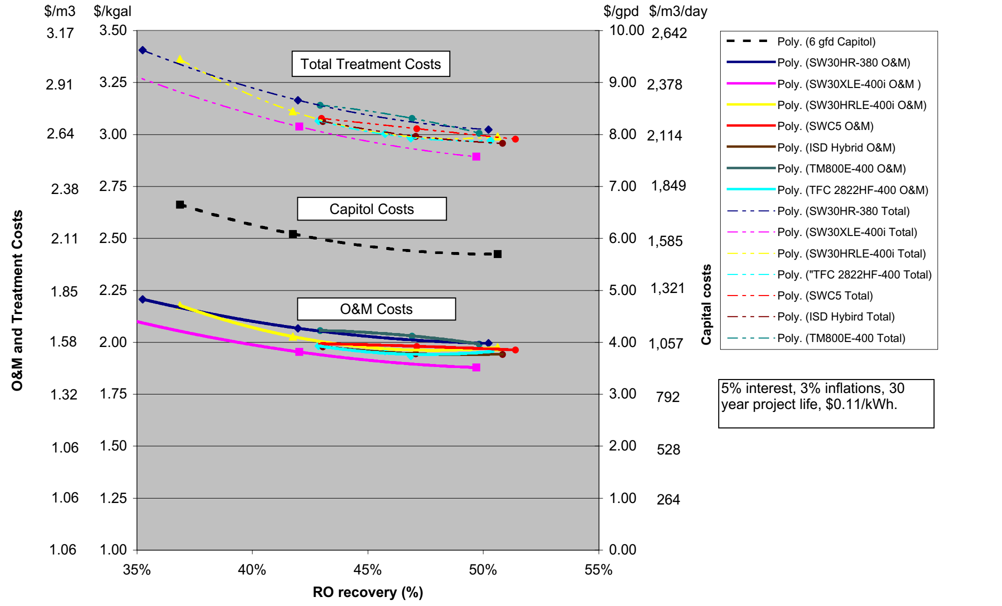
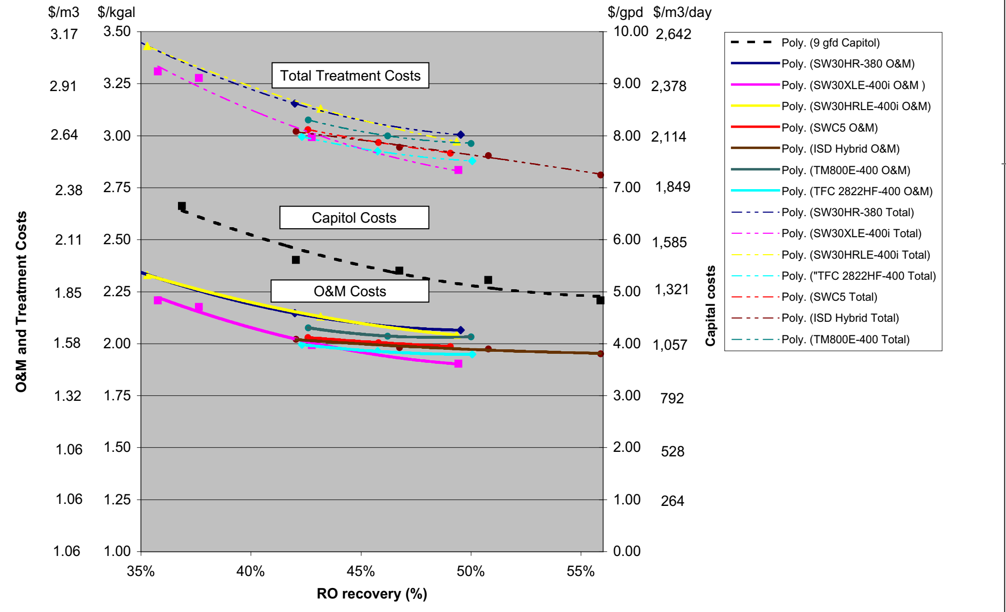


Figure 6.2 Costs vs Recovery at 9 gfd - 50 MGD SWRO WTP



	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.

Table 5. Membrane Life and Annual Replacement Rate.

ADC Data and Scale

The ADC demonstration plant employs a David Brown Union TD-60 positive-displacement main high-pressure pump that operates at very high efficiencies of 88-90%. Although positive-displacement plunger pumps operate at high efficiency, they cannot be employed in very large systems because of their high maintenance requirements and pulsating flows.

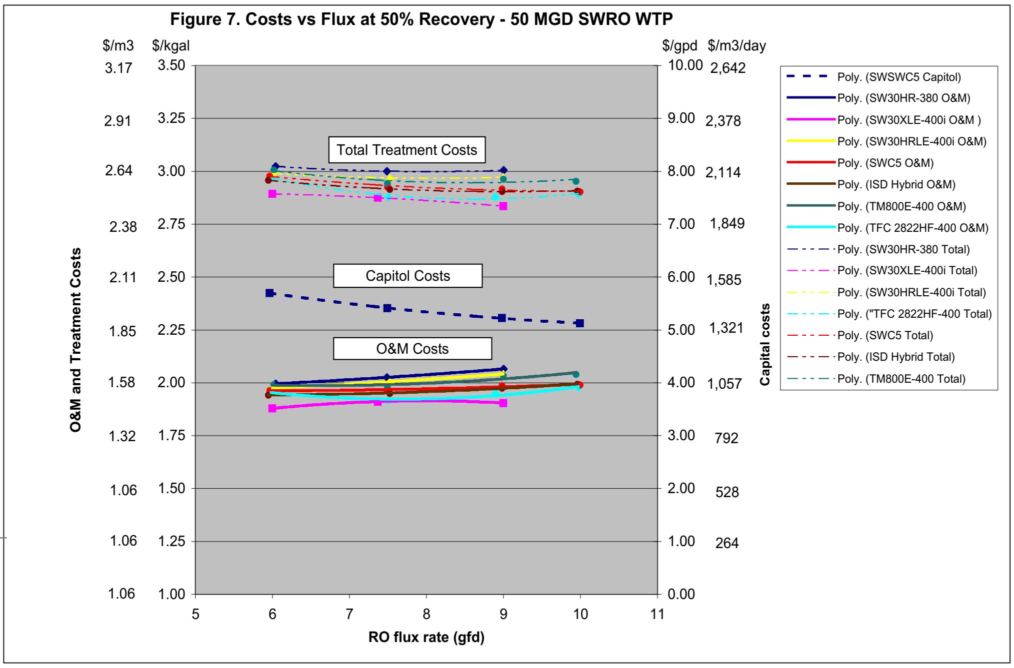
In the larger full-scale systems, centrifugal pumps with efficiencies between 65-88% are used. The achievable efficiency of a centrifugal pump depends on the size or flow rate of the pump, where lower flows typically will operate at lower efficiency compared to the larger pumps .

Table 6 (*page 38*) projects the total power consumption of a 0.3 MGD system that employs a 69% efficient centrifugal main high-pressure pump and

Energy consumption of various system capacities				
Treatment Step	**ADC MAP**	**0.3 mgd(2)**	**10 mgd(2)**	**50 mgd(2)**
RO Process	7.8 / 2.06 (1)	10.6 / 2.80	9.1 / 2.40	8.0 / 2.11
Intake (2)	2.17 / 0.57	2.01 / 0.53	1.74 / 0.46	1.72 / 0.45
Pre-filtration (2)	1.14 / 0.30	1.05 / 0.28	0.91 / 0.24	0.90 / 0.24
Permeate treatment (2)	0.25 / 0.07	0.23 / 0.06	0.17 / 0.04	0.16 / 0.04
Permeate distribution (2)	1.27 / 0.33	1.17 / 0.31	0.86 / 0.23	0.85 / 0.22
Total Treatment	12.6 / 3.33	15.1 / 3.99	12.8 / 3.38	11.6 / 3.06

1. MAP average value from the 4 membrane sets that met MAP water quality goals of <200 mg/l TDS and <1.045 mg/l Boron. 2. Projected values based on typical parameters and conditions. 3. kWh/kgal / kWh/m[3]

Table 6. ADC Power Consumption and System Projections



70% efficient intake and prefiltration pumps to be 15.1 kWh/kgal (3.99 kWh/m^3). By contrast, the 50 MGD projections use an efficiency of 88% for the main high-pressure pump and 80% for the intake and prefiltration pumps. In addition, the motors and control systems are generally more efficient for the largest systems resulting in a total treatment power of 11.6 kWh/kgal (3.06 kWh/m^3).

Figure 8 provides a graphical view of how the energy consumption of a system will vary with size. The largest systems have the potential to be even a more efficient than the ADC pilot because they can employ more efficient motors and control systems.

Table 7 provides figures on the associated key system parameters and performance from the ADC pilot with these values also projected over various system capacities.

According to the ADC's 50 mgd net present value model, the projected cost of water over the 4 MAP's ranged from \$2.90-3.00/kgal (\$0.77-\$0.79/m^3) with an average of \$2.95/kgal (\$0.78/m^3).

CONCLUSIONS

The following results and conclusions can be made from the ADC's demonstration study data and a conceptual 50 mgd SWRO facility:

- Testing was performed consecutively and was not conducted as a side-by-side evaluation. Therefore the results should not be used to make direct performance comparisons of the manufacturers' membranes. The results provide a bench mark for SWRO energy consumption in Southern California.
- According to the performance data and NPV estimates, higher recovery consistently resulted in a projected lower total cost of water. Furthermore, the trend showed that costs could be reduced further by operating at higher recoveries than those tested in the ADC protocol.
- 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 raw feed water that must be pumped and treated at lower recovery rates to obtain the same volume of permeate.
- According to the performance data when analyzed by the NPV model, flux variations from 6-10 gfd were estimated to result in almost no change in the total treatment costs.
- Higher flux produced better water quality and it was estimated to have little effect on the total treatment costs.

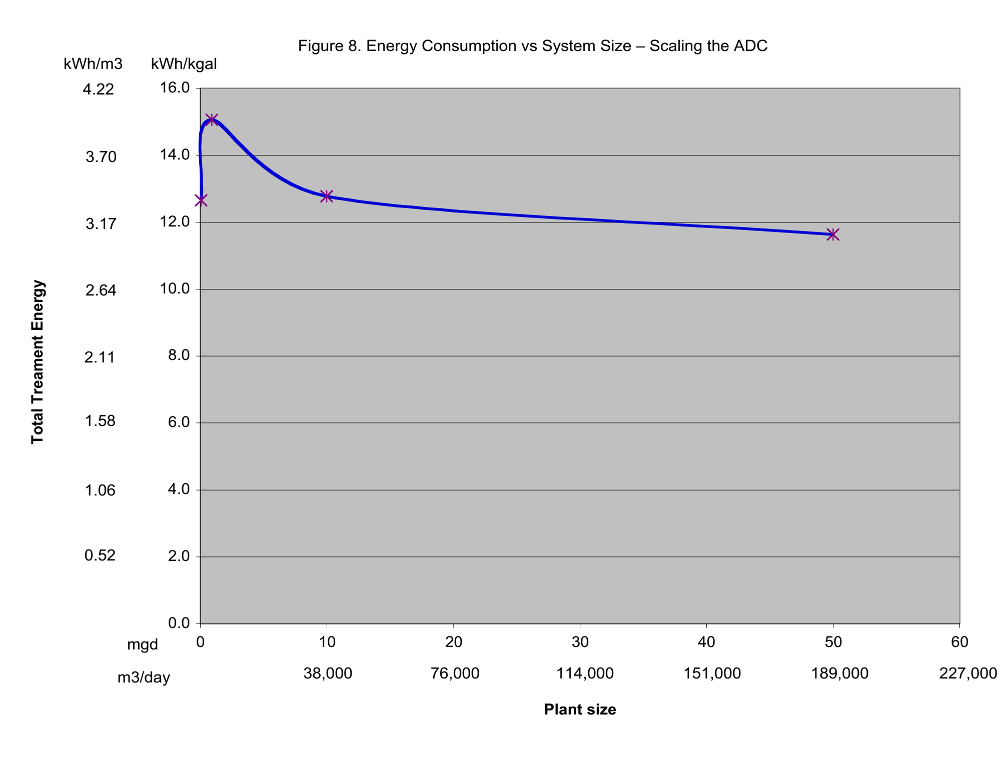
The ADC has been able to demonstrate energy consumption for seawater desalination at levels of 10.4 to 11.3 kWh/kgal (2.75-2.98 kWh/m^3) at a projected total cost of \$2.83-3.00/kgal (\$0.75-\$0.79/m^3). These energy levels and cost figures are comparable to other traditional sources. For example, in Southern California, the State Water Project, which transports water from Northern California to Southern California, consumes on average 10.4 kWh/kgal (2.75 kWh/m^3) . And in San Diego, California, end-users can pay more than \$6.00/kgal (\$1.58/m^3) . Therefore, Southern Californian seawater desalination is an affordable and reliable new source of high quality fresh water.

FUTURE STUDIES

In the future the ADC will be demonstrating new flow schemes to help increase the achievable recoveries of today's system using off-the-shelf components. In addition, the ADC plans

Process Variables	***ADC MAP Average***	***Projections***
System capacity, mgd	0.08	0.3-50
RO feed pressure, psi / bar	914 / 63	914 / 63
Flux, gfd	9.0	9.0
RO recovery, %	48%	48%
Permeate quality, TDS	119	119
Permeate Boron, mg/l	0.7	0.7
Raw water, TDS	35,640	35,640
Raw water temperature, °F / °C	60 / 15.5	60 / 15.5

Table 7. ADC Operating Parameters and Performance



to test new prefiltration, pump and energy-recovery technologies to measure the ability of these new technologies to reduce the overall cost to produce water.

AUTHORS

John P MacHarg is Managing Director-CEO of The Affordable Desalination Collaboration and President of Ocean Pacific Technologies, Inc. Previously he was the General Manager of Energy Recovery Inc. where he was involved in the development, commercialization and marketing of pressure exchanger energy recovery technology for desalination systems. He was also a Vice President at Village Marine Technology where he worked in the design, manufacture and sales of packaged seawater desalination equipment. He has been working within the desalination industry for over 17 years.

Tom Seacord is an Associate and Project Manager with Carollo Engineers, P.C. and has been specifically dedicated for the past 10 years in the area of desalination. He is a licensed professional engineer and has a B.S. and M.S. degree in Civil Engineering from Clarkson University. Tom worked on planning, pilot testing, design, construction and start-up of desalination treatment plants in California, Florida, Kansas, Missouri, South Carolina, Texas and Utah. Tom is a current member of the AMTA Board of Directors and the current Chairperson of the Government Affairs Committee. He is a member of AMTA, SEDA, IDA, and AWWA.

He sits on the Board of Directors for the ADC.

Bradley Sessions has been with Carollo Engineers in Boise, Idaho for 2 years. Previously he worked throughout the Caribbean basin designing, building and operating SWRO facilities for Consolidated Water, Ltd. and was involved in the R&D of the DWEER energy recovery system with Desalco, Ltd.

PEER REVIEW

Gerry Filteau, Separation Processes, Inc.
Paige Gourley, Hydranautics Membranes
Phil Lauri, West Basin Municipal Water District
Rick Lesson, Koch Membranes
Victor Verbeek, Toray Membranes

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