The Affordable Desalination Collaboration 2005

Authors: John P. MacHarg, Steven D. Coker, Thomas F. Seacord

Presenter: John P. MacHarg, ADC Managing Director

Abstract

The Affordable Desalination Collaboration (ADC) is a non-profit organization comprised of a group of leading companies and agencies within the desalination industry that have agreed to combine their efforts and share their expertise in a mission to help make desalination more affordable. Some of the member participants include:

- Avista Technologies
- California Department of Water Resources
- California Energy Commission
- Carollo Engineers
- David Brown Union Pump Company
- Energy Recovery, Inc.
- FilmTec Corporation
- Marin Municipal Water District
- Municipal Water District of Orange County
- Pentair Water Treatment-CodeLine Division
- Piedmont Pacific Corporation
- Poseidon Resources
- Rolled Alloys
- San Diego County Water Authority
- Santa Cruz City Water Department
- U.S. Bureau of Reclamation
- U.S. Naval Facilities Engineering Service Center
- U.S. Desalination Coalition
- WaterEye
- West Basin Municipal Water District
- Young Engineering and Manufacturing, Inc.

The Project has built and is operating a full-scale demonstration plant at the U.S. Navy's Seawater Desalination Test Facility in Pt. Hueneme, California. The major goal of the Affordable Desalination Collaboration 2005 is to demonstrate SWRO in the range of 1.5-2.0 kWh/m^3 (5.7-7.6 kWh/kgal) of permeate produced. The budget for this first demonstration project is approximately US$ 690,000.00 and it is scheduled to run from April-November 2005.

According to WHO estimations, the number of people living in regions with moderately severe to severe water availability problems will almost double, from 1.5 billion in 1990 to 2.8 billion in 2050. Since many of these water stressed populations reside in coastal areas, seawater desalination represents a significant water resource. However, the main factor limiting the use of this resource has been the cost of desalination, which is due, in part, to its high energy consumption. Therefore, it can be argued that energy consumption of SWRO plants is the single most important variable in pushing the technology forward as a reliable, affordable and environmentally responsible source of fresh water. Reducing the power consumption of SWRO to the levels of other conventional methods used in areas like Israel and California would be a monumental achievement and in some cases SWRO has already achieved this goal. For example, it requires between 1.6-3.1 kWh/m^3 (6.1-11.7 kWh/kgal) to pump water to various areas in Southern California by way of the State Water Project and Colorado River Aqueducts (2), and by taking advantage of some of the new design paradigms that recently developed technologies create, it is now possible to operate SWRO between 1.5-2.0 kWh/m^3 (5.7-7.6 kWh/m^3) of permeate produced.

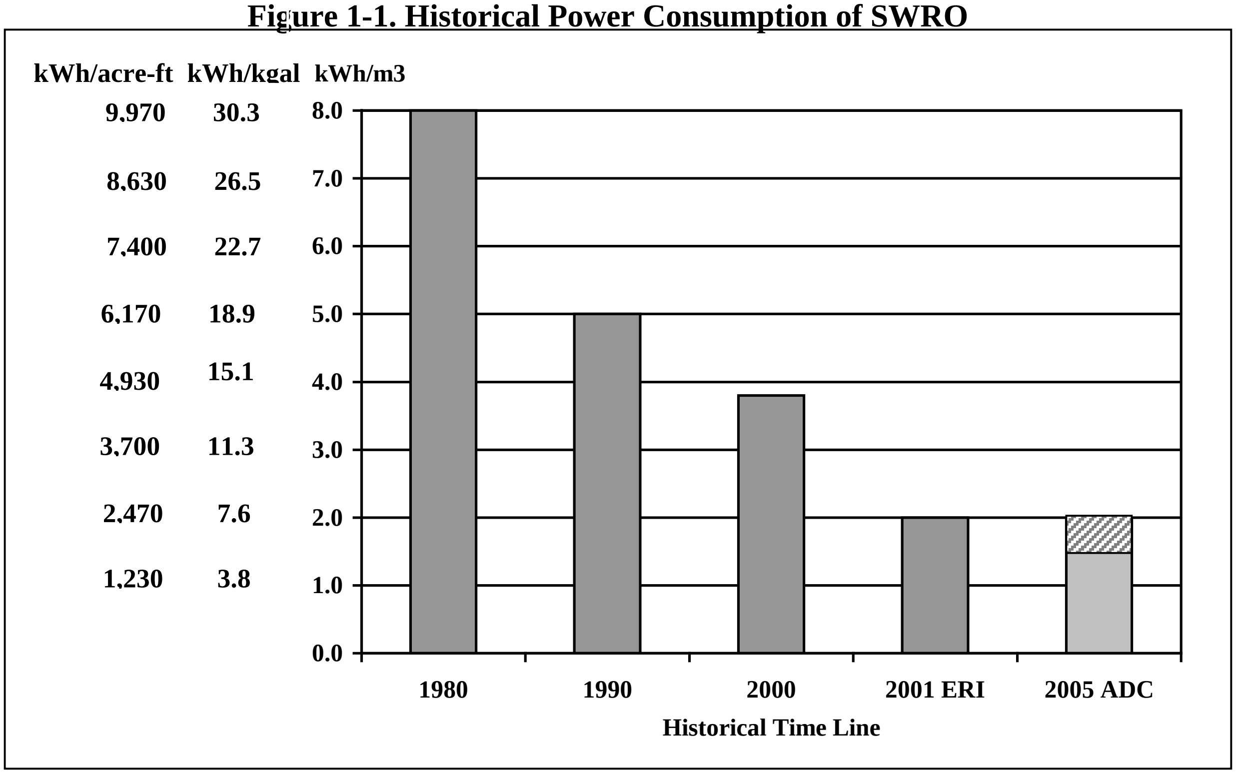
Despite these advances, major SWRO projects are still being designed and budgeted at 3-5 kWh/m^3 (11.3-18.9 kWh/kgal) and this is why the ADC has assembled in order to demonstrate that SWRO is now a reliable, affordable and environmentally responsible source of fresh water. This paper will present the preliminary results from the ADC demonstration project 2005.

I. INTRODUCTION

Energy is the single largest cost component of operating a seawater desalination system. Early distillation systems consumed as much as 25 kilowatt hours per cubic meter (kWh/m^3) (95 kilowatt hours per 1000 gallons (kWh/kgal), (30,840 kilowatt hours per acre foot (kWh/acre-ft). In the late 70's, early seawater reverse osmosis (SWRO) systems consumed as much as 20 kWh/m^3 (75 kWh/kgal, 24,680 kWh/acre-ft). By the mid 80's, through improvements in the achievable recoveries of RO membranes and efficiencies of the pumping and energy recovery systems, these numbers were reduced to as low as 8 kWh/m^3 (30 kWh/kgal, 9868 kWh/acre-ft). Although these improvements were dramatic, SWRO was still energy intensive and was only practical in special economic zones and/or where energy was inexpensive. Energy still accounted for as much as 75% of the total operating costs of SWRO systems. For this reason the RO industry re-doubled its efforts through the 90's to create improvements in both the membranes, energy recovery and pumping systems and by the late 90's had achieved energy consumption levels as low as 3.5 kWh/m^3 (13 kWh/kgal, 4320 kWh/acre-ft) (3).

RO technology had come a long way from the early days of 20 kWh/m^3, and by the turn of the millennium, SWRO had become far more widely applied throughout the world. However, the pumping and energy recovery systems that were being used were still achieving overall efficiencies of only 50-75%. These low efficiencies were continuing to push the membrane manufacturers to develop high rejection, high pressure membranes that could achieve higher recovery rates to reduce the RO feed flow rates and consequently the pumping power required by the systems. Around this same time there was a shift to new isobaric energy recovery technologies that could yield 93-97% net transfer efficiencies. As a result of these new technologies, almost overnight SWRO energy consumption dropped to as low as 2.0 kWh/m^3 (7.6 kWh/kgal, 2467 kWh/acre-ft). Now even further improvements are possible by combining these new devices with other advanced membrane and pumping technologies.

Figure 1-1. Historical Power Consumption of SWRO



The major goal of the ADC 2005 is to demonstrate SWRO at 1.5-2.0 kWh/m^3 (5.7-7.6 kWh/kgal, 1850-2500 kWh/acre-ft) of permeate produced for the RO process. The ADC will also establish the relationships between RO recovery rate, membrane salt rejection, permeate quality, boron levels, feed pressure, and energy consumption. These relationships will help to guide the SWRO industry as to what recoveries, flux rates and salt rejection rates are optimal when using today's best available technologies.

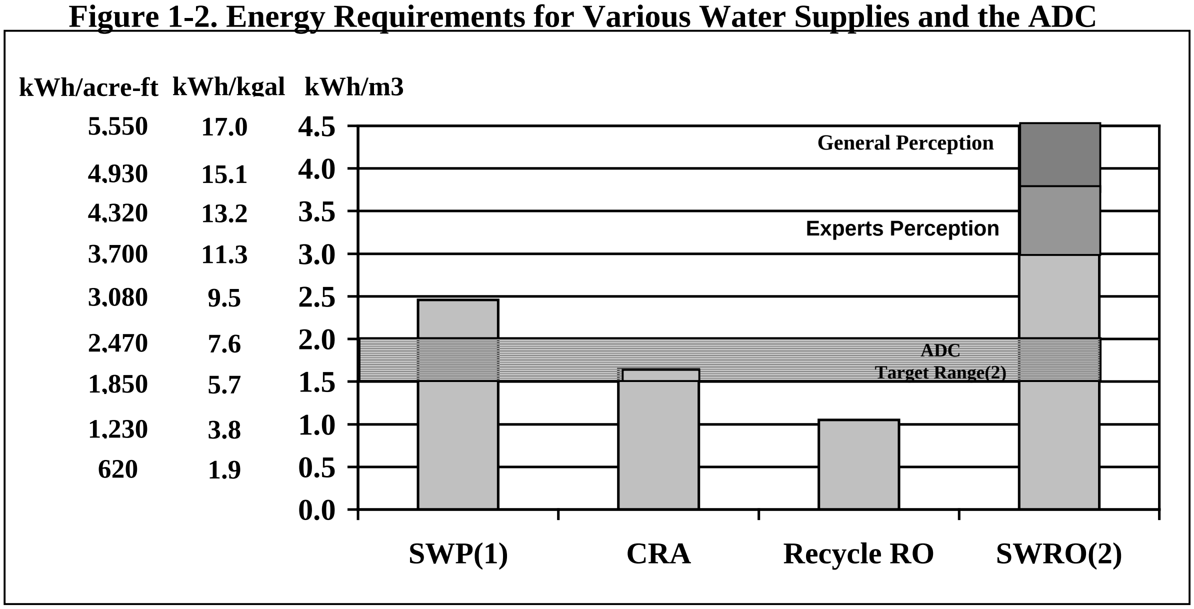
1.1 General Background

There is a common perception that SWRO is an energy intensive process and therefore not generally affordable. In the past this was a certain fact, but recent developments in the field have significantly changed the cost equation for this technology. These developments have been happening at such a rapid rate that even industry experts are not fully aware of the extent to which energy consumption in SWRO plants has been reduced. Government officials, decision makers and experts alike will benefit by knowing what is possible today.

The ADC has built a 200-300 m^3/day SWRO plant and is currently demonstrating fresh water production at 2.0 kWh/m^3 (7.6 kWh/kgal, 2500 kWh/acre-ft) and we hope to reach levels as low as 1.5 kWh/m3 (5.7kWh/kgal, 1850 kWh/acre-ft). These low energy consumption levels when combined with the latest technological improvements to help reduce desalination plant capital and maintenance costs should lower the overall cost of SWRO to within the range of what is affordable by many municipal consumers today.

It can be argued that the energy consumption of SWRO plants is the single most important variable in pushing the technology forward as a reliable, affordable and environmentally responsible source of fresh water. Energy consumption is often the single largest cost in operating an SWRO plant and carries the most significant environmental impact concerns. Reducing the power consumption of SWRO to the levels of other conventional methods used in areas like Israel and California would be a monumental achievement and Figure 2 shows that the ADC has demonstrated that the technology has arrived.

Figure 1-2. Energy Requirements for Various Water Supplies and the ADC



Notes:
1.SWP does not include distribution beyond Castaic Lake or treatment.
2.ADC target range does not include supply or distribution. I.e. RO Process only.
3.SWP = California State Water Project
4.CRA = Colorado River Aqueduct Project
5.Source: Water Sources Powering Southern California, by Robert C. Wilkinson Ph.D., January 2004.

1.2 Innovation and Technological Advancements

There have been some major advances in energy recovery, pumping and membrane technologies of SWRO systems over the past three to five years. The most significant advances include the new isobaric energy recovery technologies, the use of very large, high efficiency centrifugal pumps, and advances in membrane technology.

The ADC demonstration plant uses the Energy Recovery, Inc. Pressure Exchanger™ for their extremely high efficiency in recuperating the brine energy of an RO waste stream. The device reduces the power required for SWRO systems by as much as 60%. ERI systems are operating around the world on all size desalination plants from 50-50,000 m3/day. The project also chose David Brown Union Pumps for their specific experience with very large, highly efficient centrifugal pumps. Although the pump used in the ADC pilot was a much smaller positive displacement pump operating at approximately 90% efficiency, the David Brown Union centrifugal pumps running at the 35 mgd Trinidad Pt. Lisas plant, are operating at comparable efficiencies of 88%(4). FILMTEC Membranes were selected for the ADC demonstration plant because of their new XLE low energy technology. Their XLE membranes are ideally suited to operate with isobaric energy recovery technologies where recoveries around 45% and low pressure operating cycles are optimal.

These technologies represent the Core RO Technologies for the ADC 2005 project. The goal of the ADC 2005 project is to combine and optimize the best available technologies to create a system that produced fresh water from seawater water at overall energy consumption rates of 1.5-2.0 kWh/m^3 (5.7-7.6 kWh/kgal, 1850-2500 kWh/acre-ft). In addition, a primary objective of the 2005 project is to use commercially available and scaleable equipment and technologies like those mentioned above as well as standard plant designs that can be directly and economically scaled up to the municipal level. For example, ADC 2005 used standard 7-element x 8-inch diameter CodeLine pressure vessels and recoveries between 40-45% at flux rates of 6-9 gallons per square foot per day (gfd).

An energy consumption rate of 1.7 kWh/m^3 (6.6 kWh/kgal, 2200 kWh/acre-ft) is approximately 1/12th of the energy required by the original SWRO systems and is less than 1/2 of the energy that was required by the best system designs of just a few years ago. More importantly, energy consumption rates between 1.5-2.0 kWh/m^3 are far less than what is generally perceived to be possible today.

1.3 System Design

ADC 2005 used a combination of state-of-the-art technologies and optimized designs to reduce the power consumption of the SWRO system. Below is a simple flow diagram for a typical Pressure Exchanger (PX™) SWRO system. This is the basic design employed for the demonstration plant. The brine from the SWRO membranes (G) passes through the PX, where its energy is transferred directly to a portion of the incoming raw seawater at up to 97% efficiency. This pressurized seawater stream (D), which is nearly equal in volume and pressure to the reject stream, passes through a PX booster pump to add the small amount of pressure lost to friction in the PX, the membranes and the associated piping. The PX booster pump also serves to drive the flow of the high-pressure stream through the PX (G and D). Fully pressurized seawater then merges with the main seawater flow to the SWRO system after the main high-pressure (HP) pump.

Figure 1-3. Typical SWRO-PX System Flow Path

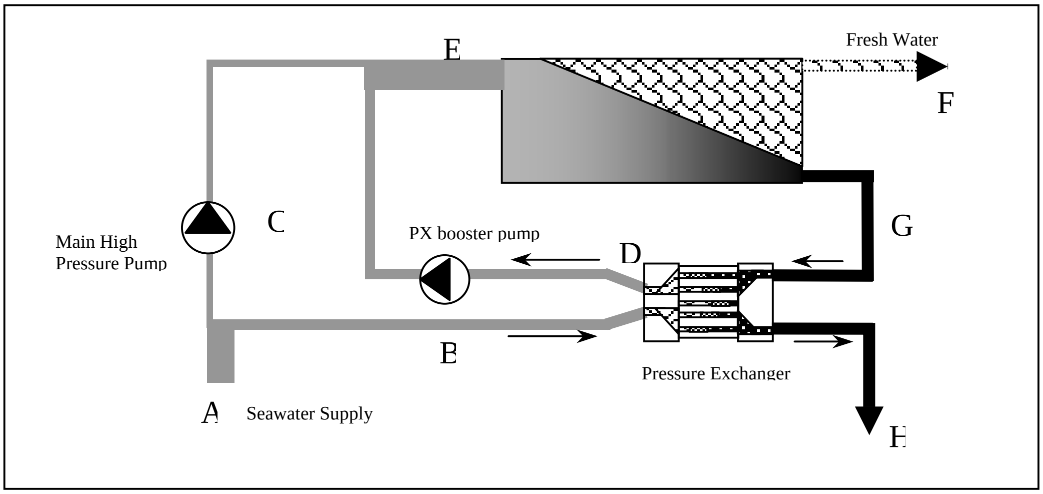


Table 1-1. Example Flow Rates and Pressures

STREAM	DESCRIPTION	FLOW RATE	PRESS. PSI/BAR
A	Seawater supply	100	29 / 2.0
B	PX LP Inlet/ Seawater	54	29 / 2.0
C	Main HP Pump outlet	46	700 / 48
D	PX HP Outlet/ Seawater	54	670 / 46
E	SWRO Feed Stream	100	700 / 48
F	SWRO Product Water	45	5 / 0.3
G	PX HP Inlet/ SWRO Brine	55	685 / 47
H	PX LP Outlet/ SWRO Brine	55	15 / 1.0

In an SWRO-PX system, the main HP pump is sized to equal the permeate flow plus a small amount of bearing lubrication flow, not the full SWRO feed flow. Therefore, the PX significantly reduces flow through the main HP pump. This point is significant because a reduction in the size of the main pump results in lower power consumption and operating costs. In a typical SWRO-PX system, the main pump will provide 46% of the energy, the booster will provide 2% and the PX will provide the remaining 52%. Since the PX uses no external power, the total power savings is 52% compared to a system with no energy recovery.

The pre-filtration is composed of standard multi-media filters followed by 5 micron cartridge filtration. A pre-filtration study to determine the optimum coagulant formula and dosage was conducted by Avista Technologies in order to maximize the efficiency of the media filtration process. They initially selected their RoQuest™ 4000 organic coagulant and ferric sulphate formula to be dosed at 4 ppm. Turbities of less than 0.1 NTU and SDI's below 5 have been achieved as a result. No SWRO pre-treatment (antiscalent) or post treatment chemical injection is being used. See Section 5 for the detailed system P&ID and system description.

1.3 Feed Water Quality

The ADC is demonstrating low energy seawater desalination at the US Naval Base in Port Hueneme, California. The feed water is taken from an open intake directly from the sea. Generally the temperature and salinity are quite stable in these Southern California waters. However there are periodic pre-filtration challenges associated with algae plumes and red tides. Table 1-2 provides the typical conditions for the test.

Table 1-2. Raw Water Quality

Parameter	Units	Value
Total dissolved solids	mg/l	32,433
Conductivity	uS	50,530
Temperature	Celcius	15
Boron	mg/l	5.2
PH	-	7.3
Total alkalinity	ppm calcium carbonate	82.0
Turbidity	NTU	0.34
Particle count	#/ml of 2-50 microns	3042

1.4 Specific Power Consumption

The data gathered from the tests are used to develop graphs that show the power consumption rate and water quality that can be achieved at each operating condition. Power consumption rate is measured to include the following electrical loads:

- SWRO High Pressure Positive Displacement Pump and variable frequency drive (VFD) (P2)
- SWRO PX Booster Pump and VFD(P3)

The following is not included in the power consumption rate measurements

- SWRO Intake Lift Pump (P1)
- Chemical Metering Pumps
- Instrumentation and Controls
- Product water pumping

Table 3 below provides a power model for this system showing a power consumption of 1.86 kWh/m^3 (7.02 kWh/kgal, 2,289 kWh/acre-ft).

Table 1-3. SW30XLE-400*i*, 7.2 gfd, 45% recovery, 60°F

		A	B	C	D	E	F	G	H
FLOW	GPM	93	51	43	51	93	42	51	51
	m^3/hr	21.2	11.5	9.7	11.5	21.2	9.5	11.7	11.7
	m^3/day	509	277	232	277	509	229	280	280
PRESSURE	PSI	19	19	763	737	763	0	747	9
	bar	1.3	1.3	52.6	50.8	52.6	0.0	51.5	0.6
QUALITY		TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

PX-70	QTY	**1**
PX UNIT FLOW	GPM	51
PX Internal Bypass	GPM	1
PX Differential HP side	PSI	10
PX Differential LP side	PSI	10
PX efficiency	%	96.3
Membrane Differential	PSI	16
Recovery	%	45%
HIGH PRESS. PUMP		
Power	kW	16.6
BOOSTER PUMP		
Power	kW	1.1
Seawater Feed Pump kW		n/a

TOTAL RO PROCESS POWER CONSUMPTION

Total RO Process (kW)	17.7

SPECIFIC POWER CONSUMPTION

kWh/m3 Permeate	1.86
kWh/1000 gal Permeate	7.02
kWh/acre-ft Permeate	2289

While the SWRO intake lift pump may provide suction side pressure to the High Pressure Positive Displacement pump, thereby reducing the overall TDH, it will not be included in the power monitoring. For the affordability analysis, an intake pump's horse power will be assumed based upon flow and a overall lift TDH of 200 ft of H_2O.

II. TEST PROTOCOL

A test protocol was developed to serve as a guide for this project's testing and data analysis. The test protocol contains the following key elements:

- Statement of the testing goals.
- Description of the equipment.
- Design parameters, hydraulic conditions, and water quality data to be tested throughout the project.
- Frequency of data collection and points of monitoring.
- Analytical methods, membrane cleaning and storage protocols.
- Present value analysis conditions.

A complete testing protocol is available on the ADC's website at www.affordabledesal.com.

2.2 SWRO Demonstration Scale Testing

Demonstration scale tests of the SWRO system will occur in three, nine-week phases over six months using the equipment depicted in **Figure 1-3**. As presented in **Table 2-1**, each phase of testing consists of the following:

- Two and one half weeks (weeks 1-3) of "ripening" at the flux and recovery rate determined by modeling to be the projected low energy point. This "ripening" period has been included based upon past experience operating new membranes. Experience has indicated that approximately two and one half weeks are required before some new membrane's performance (e.g., pressure and salt rejection) reaches a steady state condition.

- Two weeks (weeks 3-5) of testing at different fluxes and recoveries. Each flux and recovery will be operated for two days. These flux rates include 6, 7.5 and 9 gallons per square foot of membrane area per day (gfd). Flux rate can be determined as follows:

$$F_w = \frac{Q_{P-SYS} \times 1440}{A_{SYS}} \qquad \textbf{Equation 1}$$

Where: F_w = Flux of water, gfd
$Q_{P\text{-}SYS}$ = SWRO system permeate flow, gpm
A_{SYS} = Membrane surface area for the SWRO system, ft^2

Table 2-1 Schedule of Testing Conditions
SEAWATER RO DEMONSTRATION STUDY
Affordable Desalination Collaboration

Parameter	Week 1-3	Week 3		Week 4				Week 5			Week 6-9
		Day 4-5	Day 6-7	Day 1-2	Day 3-4	Day 5-6	Day 7-1	Day 2-3	Day 4-5	Day 6-7	
PHASE 1											
Membrane	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380	SW30HR-380
Flux	7.5	6	6	6	7.5	7.5	7.5	9	9	9	TBD
Recovery	42.5%	35%	42.5%	50%	35%	42.5%	50%	35%	42.5%	50%	TBD
PHASE 2											
Membrane	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*	SW30XLE-400*i*
Flux	7.5	6	6	6	7.5	7.5	7.5	9	9	9	TBD
Recovery	42.5%	35%	42.5%	50%	35%	42.5%	50%	35%	42.5%	50%	TBD
PHASE 3											
Membrane	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*	SW30HR LE-400*i*
Flux	7.5	6	6	6	7.5	7.5	7.5	9	9	9	TBD
Recovery	42.5%	35%	42.5%	50%	35%	42.5%	50%	35%	42.5%	50%	TBD

NOTE:
1. TBD = To be determined.
2. All membranes have 400 ft^2 of surface area.

As indicated in Table 2-1, the recovery rate will be increased from 35% to 42.5% to 50%. Recovery rate can be determined as follows:

$$R = \frac{Q_{P-SYS}}{Q_{F-SYS}} \qquad \textbf{Equation 2}$$

$$Q_{F-SYS} = Q_{F-HP\,Pump} + Q_{PX\,Pump} \qquad \textbf{Equation 3}$$

Where: R = Recovery, %
$Q_{F\text{-}SYS}$ = SWRO system feed flow, gpm
$Q_{F\text{-}HP\ Pump}$ = High pressure positive displacement pump flow, gpm
$Q_{PX\ Pump}$ = PX booster pump flow, gpm

Between each flux and recovery condition, the original flux and recovery (i.e., the flux and recovery tested during weeks 1-3), will be retested to confirm membrane performance at baseline conditions.

- Three weeks of operating at the flux and recovery determined, *through testing*, to result in the most affordable operation, as determined by a present value analysis, using the criteria identified later in this section.

The data gathered from these tests shall be used to develop graphs that show the power consumption rate and water quality that can be achieved at each condition. Power consumption rate shall be measured to include the following electrical loads:

- SWRO High Pressure Positive Displacement Pump (P2)
- SWRO PX Booster Pump (P3)

The following will not be included in the power consumption rate measurements

- SWRO Intake Lift Pump (P1)
- Chemical Metering Pumps
- Instrumentation and Controls
- Product water pumping

While the SWRO intake lift pump may provide suction side pressure to the High Pressure Positive Displacement pump, thereby reducing the overall TDH, it will not be included in the power monitoring. For the affordability analysis, an intake pump's horsepower will be assumed based upon flow and a overall lift TDH of 200 ft of H_2O.

III. OPERATING DATA AND SYSTEM ANALYSIS

It is an objective of this project to establish trends between membrane formulation and salt rejection rates, permeate quality, boron levels, feed pressure, RO recovery, flux, mechanical efficiencies and energy consumption.

3.1 Mechanical Efficiency and Optimization

Figure 3-1 shows how plant size can dramatically impact the specific power consumption of SWRO systems. This has always been the case; however with the newer isobaric energy recovery technologies plant sizes from 100-500 m3/day can easily be as efficient as the largest plants. It should also be noted that the largest trains and/or newer "pressure center" designs could be as efficient as the ADC pilot.

Table 3-1. Mechanical efficiencies for various train sizes.

Train Size (m3/day)	ADC	500	1,000	5,000	10,000	15,000	25,000	32,000
HP Pump efficiency	90%	90%	69%	78%	81%	84%	96%	88%
HP motor efficiency	95%	91%	92%	94%	94%	95%	86%	96%
HP VFD efficiency	97%	97%	97%	97%	97%	97%	97%	97%
PX booster pump efficiency	60%	63%	62%	76%	81%	84%	88%	89%
PX booster motor efficiency	92%	90%	91%	93%	94%	95%	95%	96%
PX booster VFD efficiency	97%	97%	97%	97%	97%	97%	97%	97%
PX efficiency	96%	95%	96%	95%	94%	95%	94%	94%

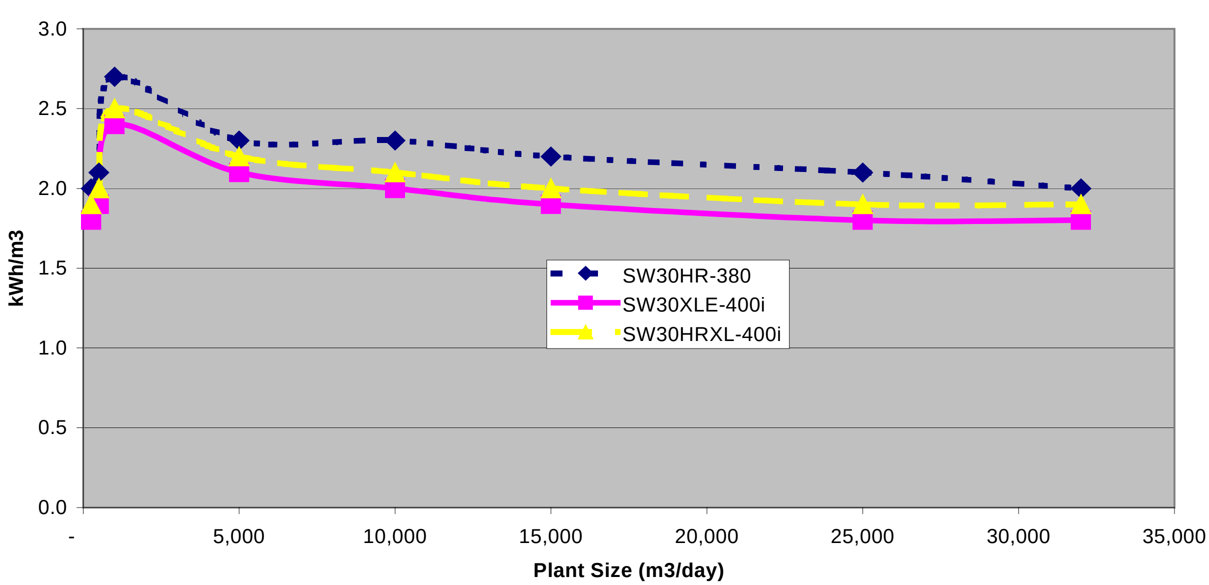
Notes. Pump and motor efficiencies were taken from ERI's industry standard power and efficiency calculator revision 11-22-04.

Table 3-2. Specific Power For Various Systems and a Given Feed Pressure

Train Size (m3/day)	ADC	500	1,000	5,000	10,000	15,000	25,000	32,000
SW30HR-380 kWh/m3 @ 7.5 gfd, 45% rec and 840 psi	2.0	2.1	2.7	2.3	2.3	2.2	2.1	2.0
SW30XLE-400i kWh/m3 @ 7.5 gfd, 45% rec and 753 psi	1.8	1.9	2.4	2.1	2.0	1.9	1.8	1.8
SW30HRLE-400i kWh/m3 @ 7.5 gfd, 45% rec and 787 psi	1.9	2.0	2.5	2.2	2.1	2.0	1.9	1.9

Note: Feed pressures for low energy membranes were calculated using ROSA 5.4 32,000 mg/l NaCl, 60°F, 45% recovery, 7.5 gfd, 1.0 FF.

Figure 3-1. Specific Power Consumption vs Plant Size



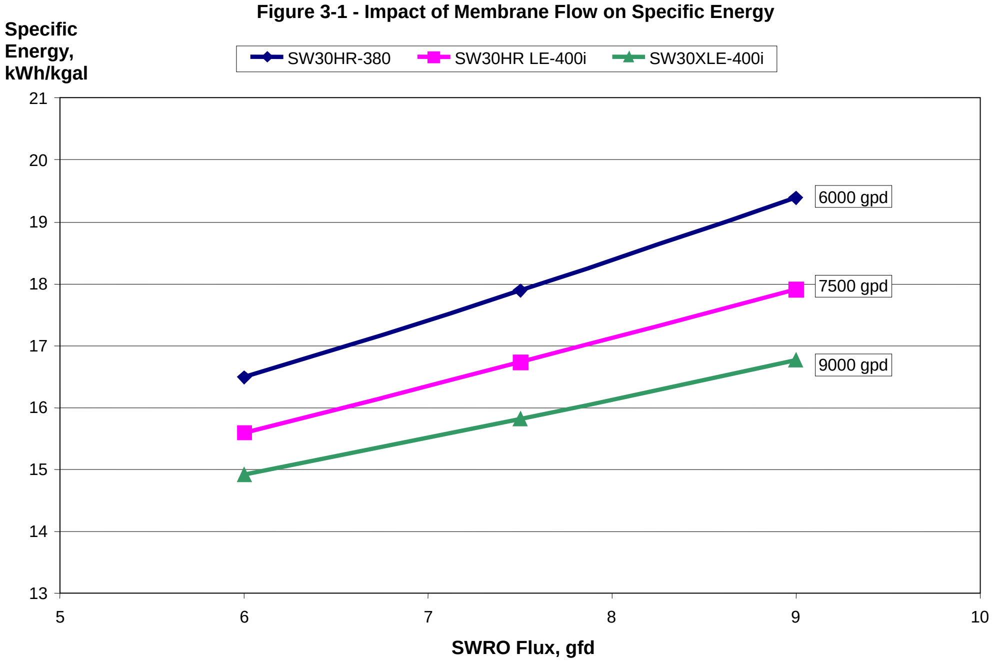
3.2 Membrane Efficiency and Optimization

One of the most significant energy inefficiencies in operating SWRO plants today is the membranes and the way the membranes are utilized(5). The energy efficiency of a membrane array in a SWRO system operating at 50% recovery in the Caribbean has been calculated to be approximately 43%(6). Another study reported that the largest energy cost associated with SWRO is the pressure loss across the membrane (feed to permeate)(7). In order to reduce the energy losses in SWRO plants as a result of the inefficient use of energy by the membranes, it is necessary to increase the flow of the membranes while maintaining or improving the rejection characteristics.

The base case for this full-scale demonstration plant was generated with FILMTEC SW30HR-380 elements, which were introduced by The Dow Chemical Company in 1996 and have a flow rate of 6000 gallons per day (gpd) and rejection of 99.6% under standard test conditions. Advancements in membrane chemistry and element construction technology have resulted in the introduction in 2003 of FILMTEC SW30HR LE-400 (7500 gpd and 99.75% rejection) and in 2004 of FILMTEC SW30XLE-400 (9000 gpd and 99.7% rejection). A thorough discussion of the system design and cost implications of these newly developed seawater membranes was presented previously(8). It was shown that with the availability of higher flow membranes, the system designer has greater latitude for optimization of system capital costs and/or operating costs. In the simplest view, higher flow membranes allow the designer the option of reducing the system operating pressure (lower energy costs) or of increasing the system output and recovery (lower capital costs). In order to further reduce the energy requirements of the membranes, the higher flow elements used in these tests also incorporated the *iLEC*™ technology which eliminates the element interconnectors and further reduces the permeate-side pressure losses(9).

A computer model was used to calculate the energy requirements of SWRO systems utilizing elements of various flow specification values. For these calculations the system recovery was set at 42.5% with a feed TDS ~36,000 mg/l. A pump efficiency of 80% was used and no credit was taken for energy recovery in the calculations. Figure 3-1 shows the impact of element flow on the specific energy requirement of a SWRO plant operating in a system flux range of 6-9 gfd. Under these conditions, a SWRO plant with 9000 gpd elements will operate at a specific energy requirement that is 10-14% less than the same plant with 6000 gpd elements.

Figure 3-1 - Impact of Membrane Flow on Specific Energy



Notes: 32,000 mg/l NaCl, 25°C, 8% recovery, 800 psig

IV. CONCLUSION(S)

The major goal of the ADC in 2005 is to demonstrate SWRO at 1.5-2.0 kWh/m^3 (5.7-7.6 kWh/kgal, 1850-2500 kWh/acre-ft) of permeate produced for the RO process. Using the DOW FILMTEC SW30HR-380 elements, which were introduced to the market in 1996 we have already achieved 2.0 kWh/m3. Going forward and testing the new generation FILMTEC SW30HR LE-400 and FILMTEC SW30XLE-400 we expect to see at least a 10-14% reduction in energy below the 2.0 kWh/m3 that we have already demonstrated. We hope that our work will help guide the SWRO industry as to what recoveries, flux rates and salt rejection rates are optimal when using today's best available technologies.

We would like to thank all of the participating members and participants in the ADC which include:

- Avista Technologies
- California Department of Water Resources
- California Energy Commission
- Carollo Engineers
- David Brown Union Pump Company a subsidiary of Textron
- Energy Recovery, Inc.
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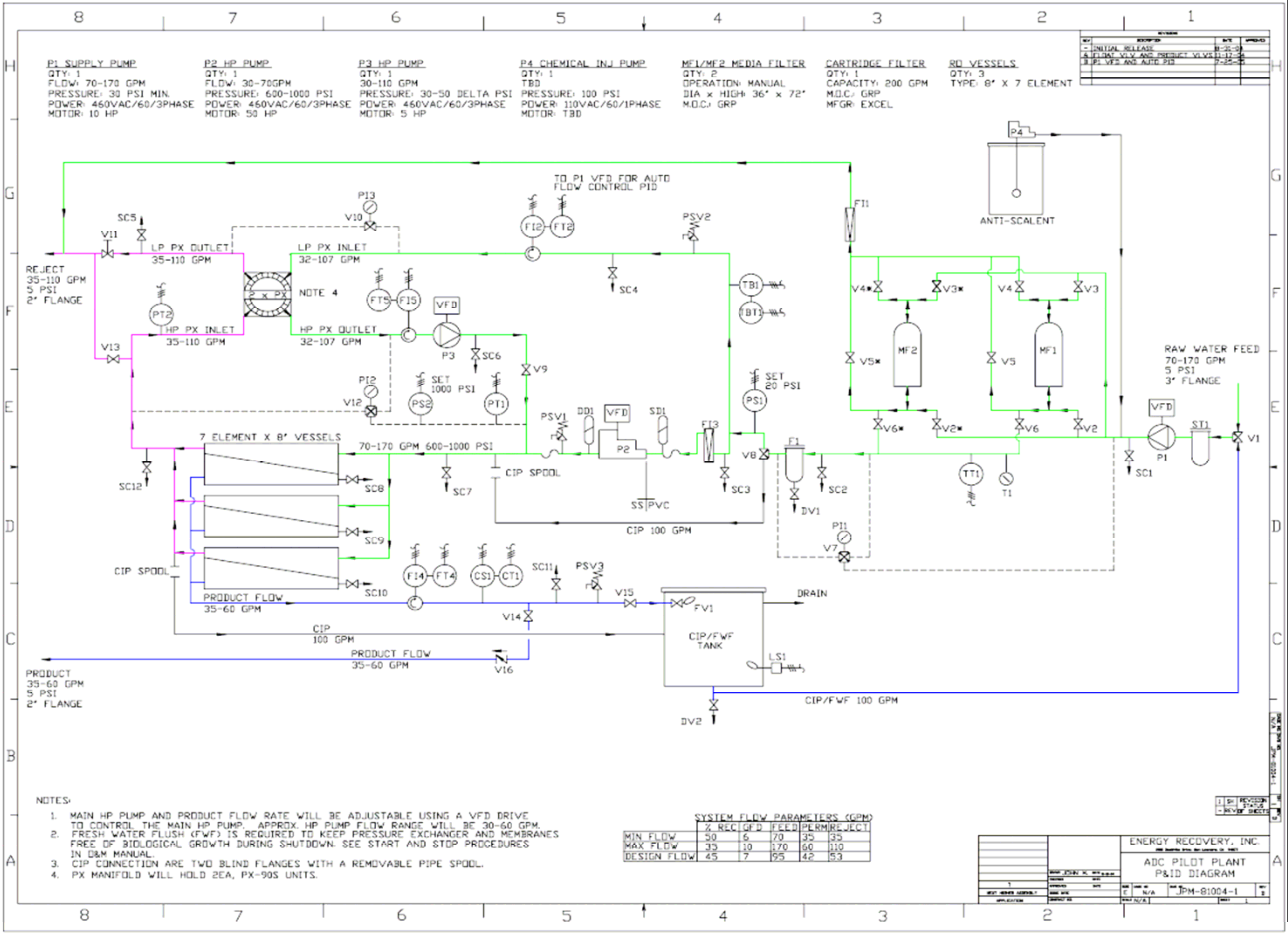
- U.S. Bureau of Reclamation
- U.S. Naval Facilities Engineering Service Center Seawater Desalination Test Facility
- U.S. Desalination Coalition
- WaterEye
- West Basin Municipal Water District
- Young Engineering and Manufacturing, Inc.

They have contributed their time, resources and money without which this project could not have been undertaken.

V. DRAWINGS AND DIAGRAMS


P1 SUPPLY PUMP
QTY: 1
FLOW: 70-170 GPM
PRESSURE: 30 PSI MIN.
POWER: 460VAC/60/3PHASE
MOTOR: 10 HP
P2 HP PUMP
QTY: 1
FLOW: 30-70GPM
PRESSURE: 600-1000 PSI
POWER: 460VAC/60/3PHASE
MOTOR: 50 HP
P3 HP PUMP
QTY: 1
30-110 GPM
PRESSURE: 30-50 DELTA PSI
POWER: 460VAC/60/3PHASE
MOTOR: 5 HP
P4 CHEMICAL INJ PUMP
QTY: 1
TBD
PRESSURE: 100 PSI
POWER: 110VAC/60/1PHASE
MOTOR: TBD
MF1/MF2 MEDIA FILTER
QTY: 2
OPERATION: MANUAL
DIA x HIGH: 36" x 72"
M.O.C.: GRP
CARTRIDGE FILTER
QTY: 1
CAPACITY: 200 GPM
M.O.C.: GRP
MFGR: EXCEL
RO VESSELS
QTY: 3
TYPE: 8" X 7 ELEMENT
ANTI-SCALENT
TO P1 VFD FOR AUTO FLOW CONTROL PID
REJECT
35-110 GPM
5 PSI
2" FLANGE
LP PX OUTLET
35-110 GPM
LP PX INLET
32-107 GPM
NOTE 4
HP PX INLET
35-110 GPM
HP PX OUTLET
32-107 GPM
SET 1000 PSI
SET 20 PSI
7 ELEMENT X 8" VESSELS
70-170 GPM 600-1000 PSI
CIP SPOOL
CIP 100 GPM
RAW WATER FEED
70-170 GPM
5 PSI
3" FLANGE
PRODUCT FLOW
35-60 GPM
CIP
100 GPM
CIP/FWF TANK
DRAIN
CIP/FWF 100 GPM
PRODUCT
35-60 GPM
5 PSI
2" FLANGE
NOTES:
1. MAIN HP PUMP AND PRODUCT FLOW RATE WILL BE ADJUSTABLE USING A VFD DRIVE TO CONTROL THE MAIN HP PUMP. APPROX. HP PUMP FLOW RANGE WILL BE 30-60 GPM.
2. FRESH WATER FLUSH (FWF) IS REQUIRED TO KEEP PRESSURE EXCHANGER AND MEMBRANES FREE OF BIOLOGICAL GROWTH DURING SHUTDOWN. SEE START AND STOP PROCEDURES IN O&M MANUAL.
3. CIP CONNECTION ARE TWO BLIND FLANGES WITH A REMOVABLE PIPE SPOOL.
4. PX MANIFOLD WILL HOLD 2EA, PX-90S UNITS.
SYSTEM FLOW PARAMETERS (GPM)
% REC | GFD | FEED | PERM | REJECT
MIN FLOW | 50 | 6 | 70 | 35 | 35
MAX FLOW | 35 | 10 | 170 | 60 | 110
DESIGN FLOW | 45 | 7 | 95 | 42 | 53
ENERGY RECOVERY, INC.
ADC PILOT PLANT
P&ID DIAGRAM
JPM-81004-1

VI. SAMPLE DATA FILMTEC SW30HR-380 ELEMENTS

Date		Pressure					Flow				Power		Calculated Values		
MM/DD/YY	Influent Temp. (°C)	$P_{HP\ pump\ In}$ (psi)	$P_{PX\text{-}LP\ Outlet}$ (psi)	$P_{RO\text{-}Feed}$ (psi)	$P_{RO\text{-}Brine}$ (psi)	$P_{Product}$ (psi)	$Q_{HP\ Pump}$ (gpm)	$Q_{HP\text{-}PX\ Out}$ (gpm)	$Q_{LP\text{-}PX\ Inlet}$ (gpm)	$Q_{Product}$ (gpm)	POWER HP+PX Bstr (kw)	Power Factor	kWh/m3*	Flux*	RO* Recovery
05/24/05	15.5	40	32.5	825	820	1.5	41	56.4	57.8	40	nm	nm	n/a	7.40	41%
05/26/05	16	33	25.5	825	815	1.5	40	55.8	58.95	40	18.1	0.895	1.99	7.22	40%
06/01/05	16	37.5	30.5	840	830	1.7	42	55.85	56.35	41.6	18.71	0.895	1.96	7.58	43%
06/03/05	14.5	24	17	870	860	2	41	55.94	57.37	41.6	19.55	0.893	2.10	7.40	42%
06/07/05	15	29	21.5	870	860	2	41	56.2	56.83	41.6	19.6	0.893	2.10	7.40	42%
06/08/05	15	38.5	31.4	859	850	2.5	42	56.03	57.22	41.6	19.12	0.892	2.00	7.58	42%
06/10/05	15	38.4	31	860	850	1.9	42	56.2	57.58	41.8	19.2	0.893	2.01	7.58	42%
06/11/05	15.5	37.5	28.5	809	801	0.25	34.2	44.8	45.3	33.5	14.6	0.845	1.88	6.17	43%
06/13/05	14.9	31.9	24.5	845	839	2.2	41	56.32	57.26	41.2	18.9	0.889	2.03	7.40	42%
06/14/05	16	35.8	28.2	840	830	1.8	41	56.25	58.22	41.2	18.7	0.892	2.01	7.40	41%
06/15/05	17.5	37.5	30.2	839	822	1.2	41	56.38	58.13	41.2	18.5	0.89	1.99	7.40	41%
06/16/05	16	35.2	28	841	835	1.7	41	56.3	57.22	41.2	18.5	0.883	1.99	7.40	42%
06/20/05	16	37.5	30.5	850	840	2.5	41	56.15	56.85	41.4	18.8	0.89	2.02	7.40	42%
06/21/05	15.5	38.5	31.5	855	840	2.2	41.5	55.65	57.26	41.3	18.9	0.896	2.00	7.49	42%
06/23/05	14	39.8	32.5	862	855	2.2	41	56.12	57.95	41.2	19.2	0.896	2.06	7.40	41%
06/24/05	14	28.2	21	878	861	1.8	42	56.45	57.71	41.1	19.4	0.895	2.03	7.58	42%
06/26/05	14	38	30.5	859	850	1.2	41.5	56.47	58.46	41.3	19.3	0.897	2.05	7.49	42%
06/27/05	15	26	18.8	865	859	1.5	41	56.01	58.29	41	19.3	0.897	2.07	7.40	41%
06/28/05	15	37.5	30.5	865	859	1.5	42	55.89	57.23	42	19.2	0.893	2.01	7.58	42%
06/29/05	14	38.4	31.2	865	860	2.2	41.8	56.06	57.48	41.3	19.4	0.901	2.04	7.54	42%

Date	pH			Conductivity (mS/cm)					Turbidity (NTU)			SDI	Boron (mg/L)	
MM/DD/YY	$pH_{Seawater}$	$pH_{Product}$	pH_{Brine}	$C_{Seawater}$	$C_{PX\text{-}HP\ outlet}$	$C_{RO\ Feed}$	$C_{Product}$	C_{Brine}	$NTU_{Seawater}$	$NTU_{MF\text{-}out}$	$NTU_{RO\text{-}Feed}$	$SDI_{RO\text{-}Feed}$	$B_{Seawater}$	$B_{Product}$
05/24/05	7.83	7.81	7.81	51.17	55.72	51.46	262.2	81.72	3.47	0.16	0.17	nm		
05/26/05	7.76	8.78	7.44	50.48	53.76	50.86	238.2	79.95	1.14	0.09	0.04	3.21		
06/01/05	8.03	8.97	7.63	50.35	54.83	51.24	250.4	82.14	2.72	0.15	0.12	5.61		
06/03/05	7.88	8.72	7.53	50.44	54.72	51.16	199.1	82.01	2.92	0.07	0.07	2.87		
06/07/05	7.64	9.04	7.29	50.36	54.94	51.56	201.6	82.65	1.35	0.14	0.24	3		
06/08/05	7.42	8.34	7.45	51	55.14	51.49	224	82.44	1.3	0.056	0.21	4.37		
06/10/05	7.38	7.82	7.05	49.95	54.1	50.6	218.1	80.87	1.04	0.06	0.16	4.5		
06/11/05	7.22	7.85	7.02	50.08	54.6	50.6	262.5	81.65	1.42	0.073	0.16	nm		
06/14/05	7.83	6.57	7.73	49.51	53.36	50.01	239.6	79.3	1.15	0.082	0.15	4.5		
06/15/05	7.82	6.86	7.63	48.84	52.92	49.79	247.5	78.8	1.04	0.09	0.095	5.2		
06/16/05	7.63	6.04	7.55	48.85	53.19	49.68	233.5	79.04	1.18	0.077	0.075	4.6		
06/20/05	7.75	6.52	7.6	49.05	53.35	49.89	230.8	78.85	1.23	0.078	0.074	4.5		
06/23/05	7.66	5.66	7.46	49.52	53.44	50.06	221.6	78.72	1.73	0.072	0.07	5		
06/24/05	7.49	6.4	7.5	49.37	53.09	49.65	201.1	78.97	1.62	0.064	0.064	4.1		
06/27/05	7.68	6.54	7.56	49.24	53.12	49.71	203.3	78.42	1.07	0.075	0.083	5.1	5.183	0.617
06/28/05	7.67	6.47	7.53	49.08	53.32	499.86	212.5	78.9	1.02	0.082	0.087	5.2		
06/29/05	7.72	6.51	7.54	49.59	53.12	49.83	222.5	79.19	nm	0.078	0.077	5		

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Authors:

John P. MacHarg, Affordable Desalination Collaboration, USA, e-mail: johnmacharg@hotmail.com
Steven D. Coker, FilmTec Corporation, USA, e-mail: sdcoker@dow.com
Thomas F. Seacord, Carollo Engineers, USA, e-mail: tseacord@carollo.com