INITIAL EVLAUATION OF THE SUBFLOOR WATER INTAKE STRUCTURE SYSTEM (SWISS) VS. CONVENTIONAL MULTIMEDIA PRETREATMENT TECHNIQUES

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Assistance Agreement No. 98-FC-81-0044

Desalination Research and Development Program Report No. 66

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The objective of this research was to ultimately demonstrate that a reduction by 20-32% in initial capital expenditure costs as well as a reduction of operation and maintenance (O&M) of SWRO facilities could be achieved using an advanced intake/pretreatment concept termed the Subfloor Water Intake Structure System (SWISS). Results of this initial research effort have been highly successful. The level of filtration that is created with the SWISS design is equivalent to a deep bed slow sand filter and, therefore, provides filtration of particles down to the 1 to 10 micron size range. The quality of raw water directly exiting the SWISS is, in many ways, superior to RO feed water pretreated with conventional direct filtration systems. It effectively eliminates the need for costly media pretreatment and associated capital and O&M costs for water treatment facilities.

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Mission Statements

U.S. Department of the Interior

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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INITIAL EVALUATION OF THE SUBFLOOR WATER INTAKE STRUCTURE SYSTEM (SWISS) VERSUS CONVENTIONAL MULTIMEDIA PRETREATMENT TECHNIQUES

1.0 EXECUTIVE SUMMARY

Open ocean intakes are well known for creating problems for long-term operation of seawater reverse osmosis (SWRO) facilities. These intakes allow impurities (biological organisms-both macro and micro, colloidal solids, suspended solids such as silt and clay, etc.) found in the open ocean, access to the inner workings of the SWRO facility. The facility must then be equipped with an array of pretreatment components, which add significant capital and maintenance cost to the production of potable water. The dissolved oxygen levels associated with open ocean intake systems support the growth of these organisms, and cause long-term deterioration of polymeric RO membranes due to oxidation. Conventional solutions to these problems are the use of an elaborative array of equipment and chemical addition to remove unwanted waterborne constituents.

Overall, the capital and operation and maintenance (O&M) costs associated with these complex pretreatment systems can range from 20-30% of the total SWRO facility costs. In addition, capital plus O&M costs associated with the intake subsystem can range from 10-20% of the total SWRO facility costs.

One solution to the high cost associated with the use of open ocean intake structures is to utilize the natural filtering properties and the low dissolved oxygen levels of the seafloor. This can be done by locating an intake system within the porous strata of the seafloor. The following two techniques are the focus of this research effort:

- Vertically jetting an intake structure beneath the sub-floor of a body of water, and
- Utilizing horizontal directional drilling (HDD) techniques to position a horizontal well within the seafloor.

The objective of this research effort was to ultimately demonstrate that a reduction by 20-32% in initial capital expenditure costs as well as a reduction of operation and maintenance (O&M) of SWRO facilities could be achieved using an advanced intake/pretreatment concept termed the Subfloor Water Intake Structure System (SWISS). Results of this initial research effort have been highly successful. The level of filtration that is created with the SWISS design is equivalent to a deep bed slow sand filter and, therefore, provides filtration of particles down to the 1 to 10 micron size range. The quality of raw water directly exiting the SWISS is, in many ways, superior to RO feed water pretreated with conventional direct filtration systems. It effectively eliminates the need for costly media pretreatment and associated capital and O&M costs for water treatment facilities.

2.0 BACKGROUND

Open ocean intakes are well known for creating problems for long-term operation of seawater reverse osmosis (SWRO) facilities. These intakes allow impurities (biological organisms-both macro and micro, colloidal solids, suspended solids such as silt and clay, etc.) found in the open ocean, access to the inner workings of the SWRO facility. The facility must then be equipped with an array of pretreatment components, which add significant capital and maintenance cost to the production of potable water. Mussels, barnacles, algae, and bacteria grow throughout the piping and pretreatment systems and can create blockage of pipes and clogging of filtration systems. The dissolved oxygen levels associated with open ocean intakes systems support the growth of these organisms, and cause long-term deterioration of polymeric RO membranes due to oxidation.

Conventional solutions to these problems are the use of an elaborative array of equipment and chemical addition to remove unwanted waterborne constituents. The typical intake for reverse osmosis (RO) plants often includes an open water intake structure located offshore incorporating a large mesh screen to prevent large material and fish life from entering the plant. In addition, rotating fine mesh screens (1/2-inch typically) are then used to remove debris and other objects small enough to pass through the offshore grate. Chlorination is typically applied at the forebay to prevent mussels, barnacles, algae, and bacteria from growing in the downstream piping and pretreatment components. Dechlorination with sodium bisulfite is then necessary to prevent chlorinated water from entering the SWRO elements, which are severely damaged by contact with chlorine. Some SWRO facilities use high doses of sodium bisulfate instead of chlorine to control growth in the piping and pretreatment system. Chemical coagulants are also added prior to pretreatment to improve filtrate quality. In addition to these operations associated with pretreatment systems, pipelines and media housings may have to be physically cleaned to remove marine growth. Pretreatment system components usually include two stages of media filtration followed by cartridge filters. If the use of these chemicals and processes could be avoided, a significant advantage for SWRO facility operations could be realized.

Overall, the capital and operation and maintenance (O&M) costs associated with these complex pretreatment systems can range from 20-30% of the total SWRO facility costs. In addition, capital plus O&M costs associated with the intake subsystem can range from 10-20% of the total SWRO facility costs.

In an article entitled "Pretreatment Cost Evaluation of Surface-Water Versus Alternative Intake Systems For Seawater Membrane Water Treatment Plants", Robert Wright, PE, performed an economic comparison of surface water intakes and beach wells (Wright, 1996). He found that alternative feedwater systems, which reduce pretreatment requirements, substantially lower the capital, and operating and maintenance costs for water treatment. Depending on plant capacity, a reported cost savings of up to 50% for capital and O&M expenses of beach well systems as compared to surface water intake systems can be achieved. He wrote:

> *"The capital cost ratio is relatively constant for the system sizes analyzed with a range from 1.81 to 1.99. Under certain circumstances, the surface-water intake system can cost up to three times greater than a beach well system. The O&M cost ratio is the highest in smaller systems and levels out to about 1.25 on the larger volume systems."*

One solution to the high cost associated with the use of open ocean intake structures is to utilize the natural filtering properties and the low dissolved oxygen levels of the seafloor. This can be done by locating an intake system within the porous strata of the seafloor. The utilization of horizontal directional drilling (HDD) techniques to position a horizontal well within the seafloor was the focus of this project.

Horizontal Directional Drilling (HDD)

Horizontal directional drilling techniques can place a horizontal well in position 10 to 15 feet under the seafloor. The reason this form of well drilling has not been used up to now for seawater intakes is that it is very difficult to develop a horizontally drilled well for long-term use with conventional well packing techniques. A new product that has recently become commercially available is a porous polyethylene well pipe that is reported to not require additional external media packing for long-term operation. Instead, its porous structure acts as a well screen and packing all in one. This product could make horizontal drilling of wells under the ocean feasible and economical for the first time.

Numerous advantages can be realized using a seafloor intake structure or well. By using the natural strata beneath a body of water to filter water before pumping to a SWRO facility, all suspended solids, particulates and colloids in the body of water are removed. Because of that, coagulation may not be necessary, and pre-filtration system components may be reduced and/or simplified. Chlorination and dechlorination treatment stages may be omitted due to the dramatic reduction of biological life in the desalination facility feedwater. Climatic and seasonal factors (such as red tide), which affect open ocean water quality, will not significantly affect the quality of water drawn from a seafloor structure. Additional promising advantages of a seafloor intake system include:

- Reduced or eliminated requirements for maintenance operations to remove marine growth due to the early removal of organisms in larval stage, and naturally low dissolved oxygen levels;
- Less likelihood of damage to intake structures from collision or severe sea conditions;
- Reduction or elimination of requirements to build/use supporting or protective structures (such as piers); and
- A visually and physically less obtrusive system in areas where the shoreline has multiple uses.

Overall, the advantages of a seafloor intake system should lead to dramatically lower SWRO facility capital, operation, and maintenance costs.

3.0 SELECTION OF WELLSCREEN MATERIALS

3.1 Survey of Commercially Available Wellscreens.

A survey of manufacturers that provide well screen products considered current state-of-the-art was conducted. The survey showed that fully developed technologies, considered applicable for this research effort, fell within four basic configurations: (1) porous plastic, (2) "v-wire" wrapped, (3) gravel/sand packed, and (4) filter mesh. The paragraphs that follow describe the well screen technologies surveyed within each of these generic configurations.

Porous Plastic

Schumasoil® is a porous polyethylene well screen produced by US Filter. In addition, the company has distributors in Germany, France and Japan. This product is manufactured in sizes from 1 inch to 7 inch outside diameter (OD) and pore sizes of 20 to 500 microns (μm). The total open surface area typically varies between 30 to 36%. Figure 1 illustrates the construction of this screen. Table 1 presents flow rate design criteria for typical applications.

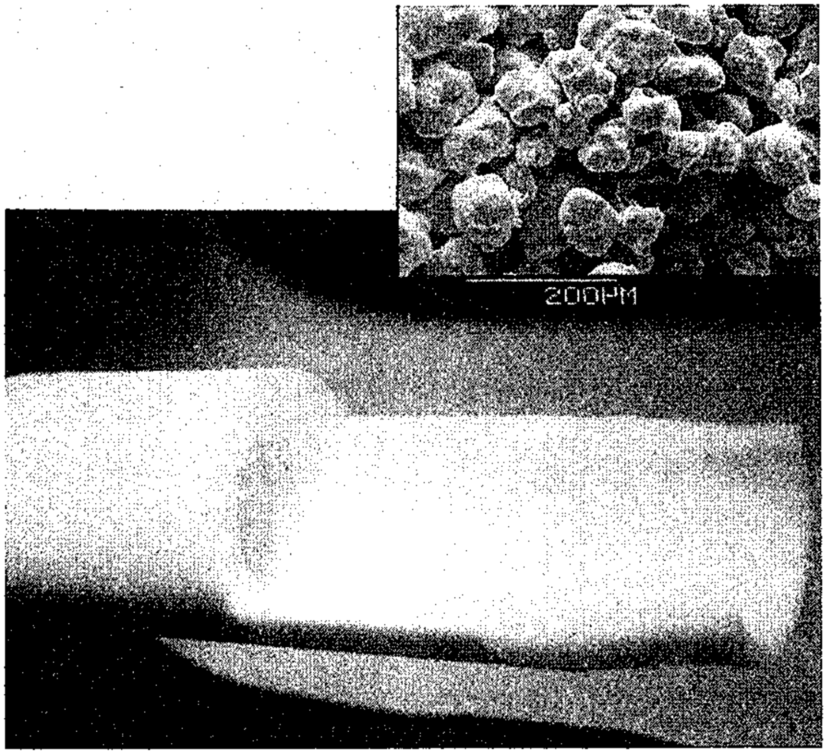


Figure 1. Schumasoil Wellscreen Construction.

Table 1. Flow Rate Design Criteria for Typical Applications.

Pore Size	1.18" OD	1.97" OD	2.95" OD	4.92" OD	7.09" OD	Gr. Size Pass Through (units)
500μm	N/A	N/A	9.45 gpm/ft	15.75 gpm/ft	22.68 gpm/ft	170
200μm	0.46 gpm/ft	0.76 gpm/ft	1.14 gpm/ft	1.90 gpm/ft	2.73 gpm/ft	80
80μm	0.14 gpm/ft	0.24 gpm/ft	0.35 gpm/ft	0.59 gpm/ft	0.85 gpm/ft	40
40μm	0.08 gpm/ft	0.14 gpm/ft	0.21 gpm/ft	0.34 gpm/ft	0.49 gpm/ft	20

V-Wire Wrapped

Johnson Screens by UOP manufactures PVC plastic screen that is resistant to corrosion from salts and gases commonly found in seawater. The screen is a continuous slot, wire-wound design that provides maximum inlet area consistent with strength requirements. It is fabricated by circumferentially wrapping a triangularly shaped wire around a circular array of inner rods. The orientation of the wire is such that it produces inlet slots with sharp outer edges, widening inwardly so as to minimize clogging. Each juncture between the horizontal wire and the vertical rods is sonic welded. Figure 2 illustrates the screen construction.

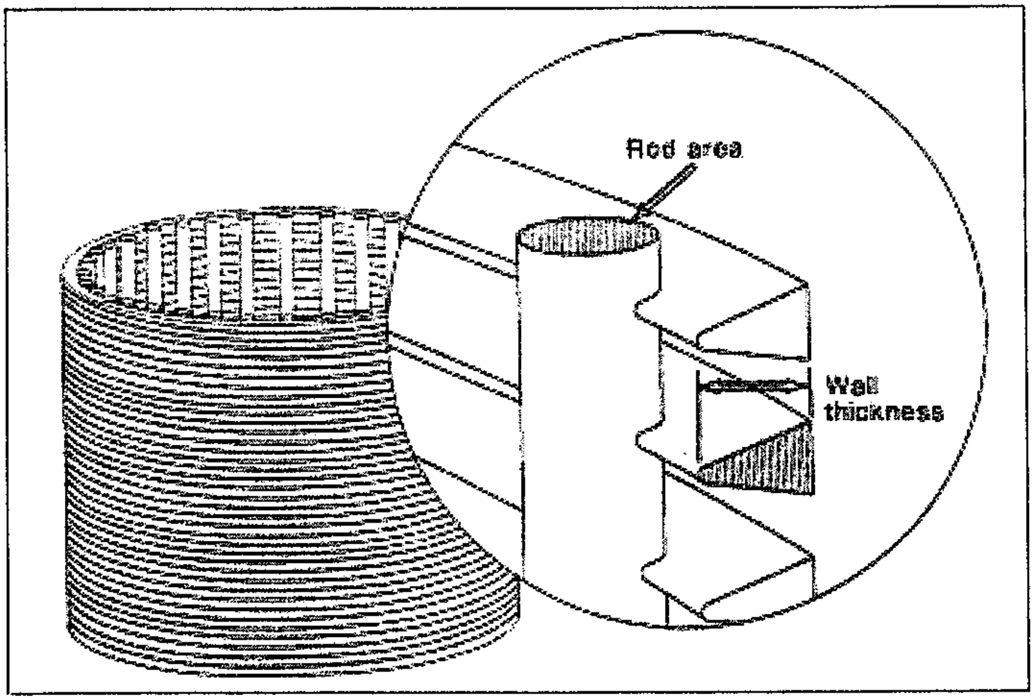


Figure 2. Vee-Wire Construction Detail.

The Vee-Wire screen is available in nominal pipe sizes from 1 ¼ inches to 8 inches with rated slot opening sizes from 6 to 60 slot (i.e. 0.006 inches to 0.06 inches). Table 2 presents engineering specifications for the range of sizes considered for this research effort.

Table 2. Vee-Wire Design Specifications.

Nom. Size	OD	Clear ID	Open Area (sq. inches) Per Foot of Screen						
			6 slot	10 slot	15 slot	20 slot	30 slot	40 slot	60 slot
1 ¼"	1.66"	1.12"	3	5	8	10	13	17	22
1 ½"	1.90"	1.41"	4	6	9	11	15	19	25
2"	2.37"	1.88"	5	7	11	14	19	24	32
3"	3.50"	2.81"	5	9	13	16	23	29	39
4"	4.50"	3.81"	7	12	17	22	30	37	50

Gravel/Sand Packed

Pre-packed well screens are manufactured by a number of suppliers. One of the most promising of these is the PVC Vee-Pack produced by Johnson Screens. The Vee-Pack consists of an inner screen and an outer screen with a prescribed filter sand packed into the annulus. The sand pack consists of uniform, well-rounded, pre-washed silica sand. This space is divided into channels by blades, which extend the entire vertical length of the screen, ensuring that the filter pack will stay uniformly positioned around the screen. This design element reduces the likelihood of bare spots, which allow geologic sediments to enter the well. The screen is designed and constructed in a similar fashion as the Vee-Wire, having inlet slots with sharp outer edges, widening inwardly so as to minimize clogging. The inner screen is fabricated with an ultra-narrow face wire for maximum flow rate. Figure 3 illustrates this configuration.

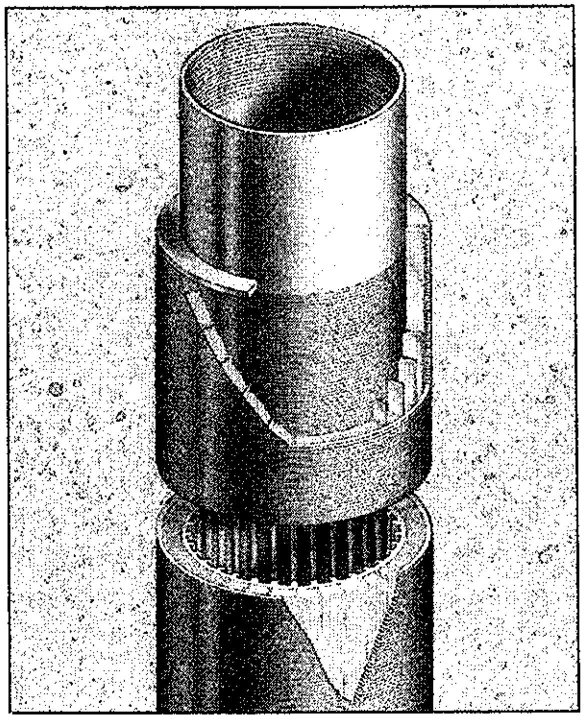


Figure 3. Vee-Pack Screen Configuration.

Possible applications for the Vee-Pack screen include:

- Silty, fine-grained sediments;
- Caving or heaving sands;
- Horizontal or angular drilled wells; and
- Dewatering of silty sands.

This screen is available in nominal pipe sizes 2-inch and 4-inch. Table 3 presents design specifications for this screen.

Table 3. PVC Vee-Pack Design Specifications.

Pipe Size (inches)	Diameter		Standard Lengths (ft)	Open Area (sq. in/ft)			Strength		
	OD (in)	ID (in)		40x60 Pack (8 slot)	20x40 Pack (12 slot)	10x20 Pack (20 slot)	Collapse (psi)	Tensile (lbs)	Hanging Wt. (lbs)
2	3.63	2.0	2.5, 5, 10	6.1	8.9	14.0	250	1,100	425
4	5.67	4.0	2.5, 5, 10	9.3	13.8	21.7	150	1,600	525

Filter Mesh

Filter mesh well screens can be an innovative way of preventing fine sand from entering a well, while at the same time providing high open areas to allow maximum flow rates while minimizing entrance velocity. They can be fitted to any type of perforated base pipe. Bedrock Enterprises produces the Hydroquest Filtermesh well screens. The three-layered filter mesh system is pulled over the base pipe and sealed at each end. The screen system is made up of five basic components:

- Base pipe – perforated or slotted plastic or high density polyethylene (HDPE) pipe;
- Inner coarse mesh – channels water flow towards the base pipe perforations;
- Filtermesh – this layer is chosen to fit the geological characteristics of the well site;
- Outer coarse mesh – protects the two inner meshes from damage during transportation and installation; and
- Heat shrink seal – seals the end of the system and prevents the three layered mesh from migrating along the base pipe during installation.

Figure 4 illustrates the construction and configuration of the Hydroquest system.

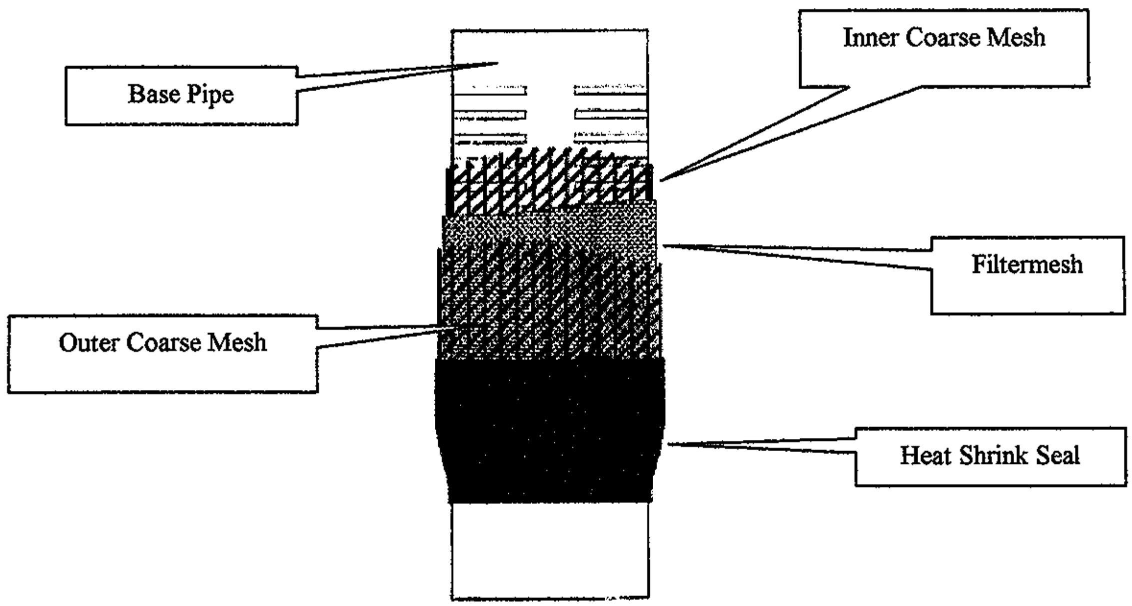


Figure 4. Hydroquest Wellscreen.

Filter mesh well screen systems can have a much higher open area as compared to wire wrapped screens. Table 4 compares slot opening and open areas for the Hydroquest filter mesh systems available.

Table 4. Slot Size and Open Areas for Hydroquest.

Product	Slot Opening	Open Area
HQ 40	0.040"	58%
HQ 30	0.030"	52%
HQ 20	0.020"	49%
HQ 15	0.015"	48%
HQ 10	0.010"	43%
HQ 08	0.008"	43%
HQ 06	0.006"	40%
HQ 04	0.004"	31%

4.0 TEST DESCRIPTION

The ultimate objective of this project is to demonstrate that a reduction by 20-32% in initial capital expenditure costs as well as a reduction of operation and maintenance (O&M) of SWRO facilities can be achieved using an advanced intake/pretreatment concept termed the Subfloor Water Intake Structure System (SWISS). Development of this concept would represent a significant savings potential for facilities utilizing RO membrane technologies to produce potable water from high salinity water supply sources. This concept was demonstrated by the side-by-side operation of the SWISS and an open ocean intake structure. Each intake system was operated using essentially identical reverse osmosis test skids. The ***first*** was designated as the "control" unit and was operated using feed water from the open ocean intake. This unit was equipped with the conventional pretreatment equipment that is required for open ocean intake systems. Specifications and details of this system are presented later in this Section. The ***second*** unit was an identical RO skid operated using feed water from the SWISS. This unit was operated using only the SWISS as intake and pretreatment all-in-one. Specifications and details of this system configuration are presented later in this Section.

The test systems were operated together from June 1999 through August 1999, during which time data on all operation and maintenance parameters were collected. Maintenance requirement data collected included:

- Multi-media filter backwashing requirements for the open ocean intake,
- Cartridge filter element replacement required for each intake system, and
- Chemical dosage requirements for each intake system.

Operational data collected included:

Sample / Parameter	Turbidity	SDI	Cond.	pH	Flow Rate	Temp	DO
Open ocean intake effluent	X	X			X		
SWISS effluent	X	X			X		
Membrane influent (control)	X	X	X	X			X
SWISS membrane influent	X	X	X	X			X
RO product water (SWISS)			X		X	X	
RO product water (control)			X		X	X	

Performance data for each of the two RO elements on the test skid was collected. A sample data sheet outlining detailed data parameters collected during testing is provided in Appendix A.

4.1 Open Ocean Intake System

The conventional RO system was operated using a standard open-ocean intake, shown in Figure 5 of Appendix B. This system utilized the normal pretreatment, as well as antiscalant and coagulant injection systems that are required of all conventional desalination plants. A schematic representation of this test system is provided in Figure 6 (see Appendix B).

The seawater intake pump draws water in from the Port Hueneme harbor through an intake screen and 30-mesh strainer. Major elements of the test system include: (1) multimedia filter, (2) cartridge filter, (3) coagulant injection, (4) antiscalant injection, and (5) RO system.

Multimedia filter

The media filter utilized for this effort (see Figure 7, Appendix B) was a 16-inch diameter FRP housing that was packed with a standard media, which included: ¼ x ¼ quartz, 8 x 12 garnet, 36 mesh garnet, 0.5 mm silica sand, and 0.8 mm anthracite. The depth for each media layer is shown in Table 5.

Table 5. Media and Depths Used for MMF.

	Media Type	Layer Depth
Top	0.8 mm anthracite	14.0."
↓	0.5 mm silica sand	11.0"
	36 mesh garnet	7.0"
	8 x 12 garnet	4.5"
Bottom	¼ x ¼ quartz	5.5"

Raw water flow rate through the media filter ranged between 4.2 and 5.0 gpm. Using 1.4 ft^2 as the cross-sectional area of the filter, this provided a loading rate range of 3-3.6 gpm/ft^2.

Cartridge filter

A cartridge filter was installed in the RO feed line just upstream of the high-pressure pump on the RO skid. The cartridge filter used was a standard single element, 5-micron, 20-inch housing, manufactured by Eden Equipment Company, PN XL1-FP005-PCL-20. For the RO feed water flow rate range of 4.2 to 5.0 gpm, the loading rate for the filter element is calculated at 2.1 to 2.5 gpm per 10-inch element length.

Chemical injection

The conventional RO system was operated using coagulant and antiscalant injections. The chemicals utilized were produced by Argo Scientific in San Marcos, California. Table 6 presents the specific chemical used, batch concentration, chemical feed rate, and feed water concentration for each injection point. The location of injection points within the test system is shown in Figure 5 (see Appendix B). The injection system utilized for this effort is shown in Figure 8.

Table 6. Coagulant and Antiscalant Injection Concentrations for Conventional RO System.

Injection	Chemical	Batch Concentration	Feed Rate (at batch concentration)	Feed Water Concentration
Coagulant	Filtermate C150	1.07 ml/gal	25 ml/min	0.4 ppm
Antiscalant	Hypersperse AF 150	13.3 ml/gal	25 ml/min	5 ppm

RO System

The RO systems used for this effort were standard packaged units purchased from Applied Membranes in San Marcos, California. The components were comprised of standard features, and include:

- TFC membranes – 2 each 2.5" x 40" Filmtec High Rejection
- FRP membrane housings
- Nickel-aluminum-bronze high pressure pumps
- Permeate and concentrate flow meters
- Low and high pressure shutoff
- Stainless steel back pressure control valve
- High pressure relief valve
- Liquid filled stainless steel pressure gauges
- Cartridge filter housing with 5-micron element
- Filter in/out pressure gauges
- Antiscalant and coagulant injection ports
- Pulsation dampener
- Hour meter
- System controller with indicator lights and controls

During the test period, the RO elements were operated at an average constant flux rate of 10 gallons per square foot per day (gfd), and are shown in Figure 9 (see Appendix B).

4.2 SWISS Intake System

The concept RO system was operated using the SWISS as intake and pretreatment all in one without the benefit of media prefiltration for removal of suspended solids (see Figure 10, Appendix B). The well screen selected for the SWISS during Task 1 (Selection of candidate wellpoints for the SWISS) was the filter mesh screen HQ06 manufactured by Hydroquest (see Table 4). This screen was hydraulically jetted approximately 15 feet below the seafloor and connected to the SWISS intake piping (see Figure 11). The test system utilized antiscalant and bio-fouling control injection systems. A schematic representation of this test system is provided in Figure 12 (see Appendix B).

The seawater intake pump drew water up from the SWISS without the use of a strainer or media filtration. Major elements of the test System were limited to (1) antiscalant and bio-fouling control injections, (2) cartridge filter, and (3) RO system.

Cartridge filter

A cartridge filter was installed in the RO feed line just upstream of the high-pressure pump on the RO skid. The cartridge filter used was a standard single element, 5-micron, 20-inch housing, manufactured by Eden Equipment Company, PN XL1-FP005-PCL-20. For the RO feed water flow rate of 5.0 gpm, the loading rate for the filter element is calculated at 2.5 gpm per 10-inch element length.

Chemical injection

The SWISS RO system was operated using antiscalant and bio-fouling control injections. The antiscalant utilized was *Hypersperse AF 150* and produced by Argo Scientific of San Marcos, California. The bio-fouling control agent was a proprietary liquid RO antibacterial pretreatment. Table 7 presents the specific chemicals used, batch concentration, chemical feed rate, and feed water concentration for each injection point. The locations of injection points within the test system are shown in Figure12 (see Appendix B).

Table 7. Antiscalant and Antibacterial Injection Concentrations for SWISS RO System.

Injection	Chemical	Batch Concentration	Feed Rate (at batch concentration)	Feed Water Concentration
Antibio-fouling	Antibacterial	26.6 ml/gal	25 ml/min	10 ppm
Antiscalant	Hypersperse AF 150	13.3 ml/gal	25 ml/min	5 ppm

RO System

The RO system used for this effort was a standard package unit purchased from Applied Membranes in San Marcos, California. The unit was comprised of standard features, and identical to the unit described in paragraph 4.1 above. During the test period, the RO elements were operated at an average constant flux rate of 10 gfd.

4.3 Instrumentation

The following paragraphs describe the instruments and associated specifications used to measure and collect operational data.

Pressure Measurements

All pressure and vacuum measurements were made using 316 SS gauges having a dial diameter of 2 ½ to 6 inches and an accuracy of ½ % of full scale.

Flow Measurement

All flow measurements were performed using in-line, direct reading rotometers having an accuracy of 3% of full scale. Calibration was performed using a timed volume technique.

Turbidity

Turbidity measurements were performed using a Hach 1720D Low Range Turbidimeter and AquaTrend Interface system. This unit is an in-line system that provides the sensitivity to accurately track turbidity levels down to 0.001 NTU. It is capable of measuring turbidity from 0.001 to 100.0 NTU with accuracy at 2% of full scale.

Silt Density Index

The SDI apparatus utilized the 0.45 um, 47 mm diameter MF-Millipore membrane filters. This system was designed to accurately maintain filter pressure at 30 psi during the test run. The SDI apparatus is shown in Figure 13 (see Appendix B).

Conductivity

Conductivity measurements were achieved using a YSI conductivity/salinity meter, Model 34, having an accuracy of 0.5% full scale.

ORP

ORP measurements were made using a portable platinum band-sensing electrode, manufactured by Cole-Parmer. This unit has a range of –50 to +1050 mV with an accuracy of 5mV.

pH

The pH meter utilized was a portable, handheld unit having an accuracy of 0.01 units, manufactured by Cole-Parmer.

DO

Dissolved oxygen measurements were accomplished using a Chemetrics Model I-2002 colorimeter.

5.0 TEST RESULTS

Performance data achieved during the test and evaluation period was reduced and is presented in chart form in the following figures. These include:

Figure 15 – Salt Transport
Figure 16 – Membrane Differential Pressure
Figure 17 – Turbidity Comparison
Figure 18 – Water Transport Comparison
Figure 19 – Dissolved Oxygen and ORP
Figure 20 – Water Temperature Comparison
Figure 21 – Silt Density Index Comparison
Figure 22 – SWISS Vacuum
Figure 23 – Cartridge Filter Differential Pressure

5.1 Raw Feedwater Characteristics

The test systems were operated together from June 1999 through August 1999 using raw seawater from the open ocean intake and from the SWISS simultaneously. The feedwater characteristics measured for each of the intake systems during the test period are summarized in Table 8.

Table 8. Feedwater Characteristics Summary.

Parameter / System	Open Ocean Intake	SWISS
Temperature (C)	15.4 – 18.9	16.3 – 17.6
Turbidity (NTU)	0.492 – 1.204	0.055 - 0.132
SDI	15.19 – not measurable	1.69 – 2.81
ORP (mV)	45 - 140	5 – 105
Dissolved Oxygen (mg/L)	5.8 – 8.0	1.0 – 5.1
pH	8.08 – 8.42	7.80 – 8.05

Temperature

Temperature readings for the open ocean intake and SWISS remained approximately the same with the greatest variations occurring with the open ocean system. Readings for the SWISS tended to remain more straight line during the test period. It can be seen in Figure 20 that the open ocean temperature was sometimes greater than the SWISS and sometimes lower than the SWISS. The open ocean intake is more susceptible to ambient conditions (wind, tides, currents, temperatures) than the SWISS. For the short test conducted in this study, the average temperatures for the open ocean and the SWISS were 16.7 and 17.0 °C respectively. Because of the effect of temperature on RO operating pressure (at constant flux), it would be interesting to conduct a test over one year to observe whether lower RO operating pressures are achieved with the SWISS because of a higher average temperature than an open ocean system.

Turbidity

Significant differences between the two intake systems are obvious in terms of feedwater turbidity shown in Figure 17. Average turbidity of the open ocean intake was 0.750 NTU with a standard deviation of 0.201, while the average turbidity for the SWISS was 0.075 NTU with a standard deviation of 0.021. The red tide condition that occurred at 400 operating hours was responsible for the highest turbidity measured during the test, which also corresponded with the elevated water temperatures at the time. The red tide condition had no impact on the SWISS water's turbidity. The influence of local weather and ocean conditions on the quality of the water will have impacts on the operation of the plant in order for the plant to maintain good water quality to the reverse osmosis system. These impacts could include requirements for varying coagulant dose and lowering loading rates which all increase the complexity of the design and operation of a desalination plant.

Silt Density Index

SDI measurements are shown in Figure 21. The SDI for the conventional open ocean intake could only be measured by performing a 5-minute test. During certain time periods where the line is discontinuous, the SDI pad plugged before the 5 minute test could be completed. In contrast, the SWISS intake system provided a consistently low SDI of approximately 2.46 throughout the test. As in the turbidity data, local conditions have a significant affect on the SDI for open ocean intakes compared to the SWISS system. The red tide condition that occurred at 400 operating hours created an immeasurable SDI and also elevated the SDI of the RO feed. The red tide condition had no impact on the SWISS.

General Mineral Analysis

Appendix C presents the results of the general mineral analyses performed for the raw water for the open ocean intake and the SWISS system. Ion ratios (ion to overall TDS) for most of the compounds were very similar for both system raw waters. The results show that the only significant difference in the water quality is the greater iron and manganese concentrations in the SWISS intake system (0.14 mg/liter versus non-detect for iron, and 0.070 mg/liter versus 0.030 mg/liter for manganese). Because of the likelihood of the growth of iron reducing bacteria in the RO system, the antibacterial was dosed at 10 mg/liter for the SWISS system in order to prevent the growth of iron bacteria in the system. The 10 mg/liter dose concentration recommended by the manufacturer was injected in the well by inserting a ¼-inch OD tube down the suction line of the SWISS intake. This dose appeared to be effective as minimal growth was observed at the clear rotometers and on the cartridge filters. No specific tests were done to detect the presence or quantify the number of bacteria in the system.

ORP, pH and Dissolved Oxygen

Figure 19 shows the dissolved oxygen and ORP measurements for both the open ocean intake and the SWISS. As shown in the chart, the ORP tracks the dissolved oxygen levels with the open ocean having a higher DO and ORP than the SWISS intake. The average DO and ORP for the open ocean intake water was 7.1 mg/L and 90 mV respectively. The average DO and ORP for the SWISS was 2.6 mg/L and 29 mV respectively. The lower DO concentrations for the SWISS indicate the presence of aerobic bacteria within the porous strata surrounding the wellscreen as they remove DO from the raw seawater. The lower pH of the SWISS intake water shown in Figure 150 also signifies the presence of aerobic bacteria as the bacteria respire carbon dioxide, which lowers pH. It is this presence that required the use of the antibacterial to inhibit the growth of these bacteria in the RO system. The lower pH may have a beneficial effect on RO systems, which operate at 40 to 50% recovery by reducing acid or antiscalant requirements for calcium carbonate scale control.

5.2 Open Ocean Intake with Conventional Pretreatment: System Performance

The RO system used with the open ocean intake and the conventional pretreatment system performed as expected during the 85-day test period. There were no unusual operational events, very little RO element fouling occurred, and there were not excessive media filter backwashes or cartridge filter changeouts required. No RO membrane cleanings were required.

Pretreatment System Performance

Figures 3 and 7 show the turbidities and SDI measurements for the feedwater to the reverse osmosis system. The average RO feed turbidity was 0.094 NTU with a standard deviation 0.078. The average turbidity removal by the pretreatment system was 86.4% with a standard deviation of 6.4%. The average RO feed SDI was 4.71 with a standard deviation of 1.42. Except for an anomaly at 400 operating hours where the raw seawater turbidity increased due to red tide conditions, the RO feed turbidities and SDI's were very stable as would be expected from a conventional, well designed pretreatment system. The SDI was below the maximum of 5 recommended by RO membrane manufacturers throughout most of the test.

During the 85-days operating period, the media filter was backwashed 6 times and the cartridge filter did not require changing. The average backwash frequency was once every 14 days. The total coagulant consumed was 509 ml.

RO System Performance

Figure 18 shows the water transport coefficient (calculated using the solution diffusion model) for the RO elements installed on the conventional system. Over the 85-day test period, the water transport remained essentially constant for both elements with only minor fluctuations. The stable water transport indicated that very little fouling was occurring and therefore membrane cleaning was not required. The membrane differential graph in Figure 16 also shows that the feed/brine channel of the RO membranes experienced very little fouling and indicated no requirement for membrane cleaning.

Figure 15 shows the salt transport (calculated using the solution diffusion model) over the test period being stable, indicating no degradation of the membrane over the test period. Overall, the RO system performed as expected with conventional pretreatment operating at conservative loading rates.

5.3 SWISS Intake: System Performance

The RO system used with the SWISS performed as expected during the test period. There were no unusual operational events, very little RO element fouling occurred, and excessive cartridge filter changeouts were not required. No RO element cleanings were required.

SWISS Performance

Figure 22 shows the measured vacuum across the SWISS wellscreen operating at a constant flowrate of 5 gpm. The vacuum remained relatively constant over the first 600 hours and then showed some erratic variation. The reason for the variation is unknown. Overall, the vacuum showed no steady increase, which would signify fouling or plugging of the wellscreen or formation.

Pretreatment System Performance

Figures 17 and 21 show the turbidities and SDI measurements for the feedwater to the reverse osmosis system. The average turbidity was 0.075 NTU with a standard deviation of 0.021. The average turbidity removal by the cartridge filter was 16.3% with a standard deviation of 11.2 %. The low turbidity removal by the cartridge filter shows that it was performing very little particle removal, as the SWISS intake water was very high quality. As mentioned earlier the average SDI of the SWISS intake water was only 2.46. After the cartridge filter the average SDI was 1.97 with a standard deviation of 0.80. This shows that the cartridge filters are really not necessary from a particulate removal standpoint and function more as a safety device to remove debris that may be shed from the pipe walls during startup or operation. Another feature to point out on Figure 21, is that the SWISS system was not affected by the red tide condition as was the conventional system at 400 operating hours.

During the 85-day operating period, the cartridge filter was changed 5 times. The cartridge filter changeout frequency was once every 17 days. This was due completely to iron bacteria being drawn from the well onto the cartridge filter. The total antibacterial consumption was 3.36 gallons.

RO System Performance

Figure 18 shows the water transport coefficient (calculated using the solution diffusion model) for the RO elements installed on the SWISS system. Over the 85-day test period, the water transport remained essentially constant and comparable to the conventional system's RO elements. The stable water transport indicated that very little fouling was occurring and therefore membrane cleaning was not required. The membrane differential graph in Figure 16 was also very comparable to the conventional system's RO elements indicating that the feed/brine channel of the RO membranes experienced very little fouling with no requirement for membrane cleaning.

Figure 15 shows the salt transport (calculated using the solution diffusion model) over the test period being comparable to the conventional system's RO elements. Though there appears to be some increase between 400 and 700 operating hours, the salt transport did level off close to the initial performance. The salt transport for the elements was very similar to that for the conventional system's RO elements, which indicates little degradation of the membrane over the test period.

Overall, the RO system performed as expected when provided with a high quality feedwater of low turbidity and SDI. Bio-growth potential was minimized with the use of a proprietary antibacterial. As discussed earlier, the antibacterial addition was required given the iron and manganese concentrations, and the lower DO levels, which indicated biological activity in the strata surrounding the SWISS wellscreen.

6.0 DISCUSSION OF RESULTS

RO System Performance

The previous discussions presented the data for both RO systems; one operating using an open ocean intake water source and the other using the SWISS as a water source. Each system was operated at the same average flux of 10 gfd. As discussed previously, both RO systems operated very similar with no significant fouling or membrane degradation. Cleaning of the RO elements was not required for either system. The water and salt transport, and membrane differential pressure for each system were within 8.9%, 3.4%, and 2.6% respectively. These percentages can be considered insignificant given the variations in new membrane performance.

RO Feedwater Quality

Previous discussions presented the measured temperatures, turbidities, SDI, ORP, DO, pH, and general mineral analysis. The Table 9 summarizes the water quality differences between the RO feedwater for the two systems.

Table 9. RO Feedwater Comparison.

Parameter	Average		Standard Deviation		Range	
	Open Ocean	SWISS	Open Ocean	SWISS	Open Ocean	SWISS
Temperature (°C)	16.8	17.0	1.1	0.4	15.4 – 18.9	16.3 – 17.6
Turbidity (NTU)	0.094	0.061	0.078	0.014	0.054 – 0.332	0.036 – 0.078
SDI	4.71	1.97	1.42	0.80	3.73 – 9.56	0.89 – 4.47
ORP (mV)	90	29	24.5	29	45 – 140	5 – 105
DO (mg/L)	7.1	2.6	0.8	1.4	5.8 – 8.0	1.0 – 5.1
pH	8.31	7.95	0.09	0.08	8.08 – 8.42	7.80 – 8.05
Fe (ppb)	ND	140	-	-	-	-
Mn (ppb)	30	70	-	-	-	-

From the above table it can be seen, that except for the Fe and Mn concentrations, the water quality to the RO system from the SWISS with just cartridge filter pretreatment would be considered better than that for the open ocean intake system with coagulant addition, multimedia filtration, and cartridge filtration. This initial research effort showed that the SWISS is capable of providing as high or better quality feed water than the conventional pretreatment equipment and techniques.

The differences in the standard deviations and the ranges in the measured water quality parameters do show the susceptibility of an open ocean intake to the local weather and ocean conditions compared to the SWISS system. This dependence on local weather and ocean conditions due identify the need for a more complex design and operation of a conventional plant compared to one that operates on a SWISS system.

Performance Summary

The results of this initial effort have been highly successful. The level of filtration that is created with the SWISS design is equivalent to a deep bed slow sand filter and therefore provides filtration of particles down to 1 to 10 micron size range. The quality of raw water directly exiting the SWISS is, in many ways, superior to RO feed water pretreated with conventional systems. It effectively eliminates the need for costly media pretreatment and associated capital and O&M costs for water treatment facilities. Figure 14 illustrates the effect the SWISS intake had on aquatic growth within process equipment as compared to a conventional open water intake system. With the conventional intake system, the flowmeter was almost completely covered after only 800 hours of service and unusable due to growth, while the SWISS intake flowmeter remained clean and functional.

Figure 14-a. Open Water Intake Flowmeter.

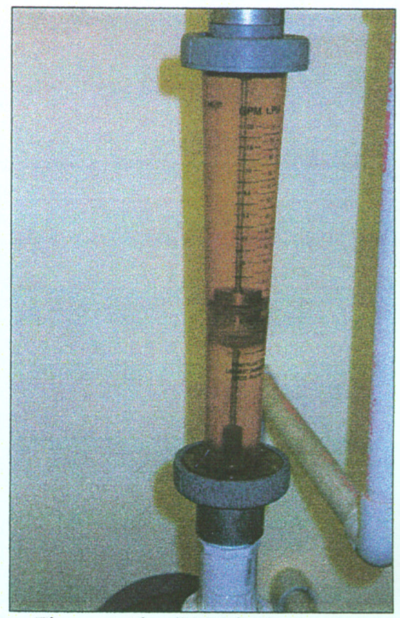


Figure 14-b. SWISS Flowmeter.

7.0 COST COMPARISON

The ultimate objective of this initial research effort was to demonstrate that a reduction by 20-32% in initial capital expenditure costs of SWRO facilities can be achieved using an advanced intake/pretreatment concept termed the SWISS. The basis for this cost comparison is taken from cost reports presented by Wright, as well as Shields (1996), and current SWISS capital costs prepared by The Source Group (Evensen, 1999). Wright (1996) has compiled intake costs for a number of intake alternatives having a water supply capacity range of 0.5 to 8 MGD. Shields and Moch (1966) present SWRO capital and operating costs associated with six different facilities. The Source Group (Evensen, 1999) presents initial design criteria for the SWISS, as well as, capital costs associated with its construction and installation (see Appendix D).

The overall costs associated with complex conventional pretreatment systems usually range from 20 to 30% of the total SWRO facility costs. In addition, costs associated with open ocean intake systems will often be 10% or more of the total SWRO facility costs. Table 10 presents capital cost data extracted from Wright, as well as Shields and Moch (1996). Capital costs of open ocean intakes, process equipment, and total capital costs for three facilities (Mediterranean Sea, Red Sea, and Arabian Gulf) have been extracted from the work performed by Shields and Moch (1996). The composite costs compiled by Wright (1996) for surface intake structures are also included. Projected pretreatment costs have been calculated at 20%.

Table 10. Typical Capital Costs.

Function	Med. Sea 6 MGD (2) $K	Red Sea 12 MGD (2) $K	Arabian Gulf 6 MGD (2) $K	Surface Intake 1 MGD (1) $K	Averages
Intake	1,850	3,250	2,350	540	-
Process equipment	13,700	23,800	16,700	-	-
Total direct capital costs	19,650	36,650	24,650	-	-
Projected pretreatment costs – (20%)	3,930	7,330	4,930	-	-
Intake costs scaled to 1 MGD	416	439	529	540	481
Pretreatment costs scaled to 1 MGD	665	611	822	-	696

As part of this initial research effort, The Source Group prepared initial design criteria for the upscale SWISS and prepared capital cost estimates associated with the construction and installation of a 1 MGD system. Table 11 presents a summary of these costs for a very modest entrance velocity of 0.02 ft/sec and a more tailored rate of 0.05 ft/sec. Based on results of testing, it is anticipated that an entrance velocity between 0.02 and 0.05 ft/sec will be used for future SWISS designs, depending on local geology. Table 12 presents a cost comparison between three selected locations analyzed by Shields and Moch (1996) using conventional intake and pretreatment systems and projected costs for those same locations if the SWISS were incorporated into the design.

Table 11. SWISS Capital Cost Summary for 1 MGD.

Velocity (ft/sec)	SWISS Installation ($K)	Material ($K)	Total ($K)
0.02	210	27	237
0.05	84	10.8	94.8

Table 12 presents more detailed cost data extracted from Shields and Moch (1996) for the same three facilities, and then projects these same cost categories for two different velocity SWISS (0.02 and 0.05 ft/sec) intakes if incorporated into the design.

Table 12. SWISS Cost Comparison for Three Locations - (0.02 and 0.05 ft/sec).

Function/Location	Med. Sea	Med. Sea w/ SWISS	Med. Sea w/ SWISS	Red Sea	Red Sea w/ SWISS	Red Sea w/ SWISS	Arabian Gulf	Arabian Gulf w/ SWISS	Arabian Gulf w/ SWISS
Direct Capital		(0.02 ft/sec)	(0.05 ft/sec)		(0.02 ft/sec)	(0.05 ft/sec)		(0.02 ft/sec)	(0.05 ft/sec)
RO modules	3,600	3,600	3,600	8,600	8,600	8,600	5,100	5,100	5,100
Site Development	500	500	500	1,000	1,000	1,000	500	500	500
Intake	1,850	1,422	569	3,250	2,840	1,138	2,350	1,422	569
Process equipment	13,700	9,770	9,770	23,800	16,470	16,470	16,700	11,770	11,770
Sub Total	*19,650*	*15,292*	*14,439*	*36,650*	*28,914*	*27,208*	*24,650*	*18,792*	*17,939*
Indirect Capital									
Const. Interest	983	765	722	1,833	1,446	1,361	1,233	940	897
Contingency	1,572	1,223	1,155	2,932	2,313	2,177	1,972	1,503	1,435
A&E fees	3,341	2,600	2,455	6,231	4,916	4,626	4,191	3,195	3,050
Working capital	983	766	722	1,833	1,446	1,361	1,233	940	897
Sub Total	*6,879*	*5,353*	*5,055*	*12,829*	*10,121*	*9,524*	*8,629*	*6,578*	*6,280*
TOTAL CAPITAL	**26,529**	**20,645**	**19,493**	**49,479**	**39,035**	**36,731**	**33,279**	**25,370**	**24,218**
Projected savings		*22.2%*	*26.5%*		*21.1%*	*25.8%*		*23.8%*	*27.2%*

In summary, the cost comparison presented in Table 12 indicates a projected savings of 21.1 to 27.2% for the three facilities with a SWISS designed at two different entrance velocities of 0.02 and 0.05 ft/sec.

Microfiltration Pretreatment Systems

The cost analysis shown in this report is based upon the use of media filtration as pretreatment to an SWRO facility. Current trends in SWRO facility design, however, appear to be moving towards the use of microfiltration technology for pretreatment. As a result, the following cost information provides a summary of projected savings in Total Capital Costs when microfiltration is incorporated into an SWRO process design.

- Costs associated with microfiltration technologies are usually about 30% higher than conventional media filtration equipment.
- When microfiltration is incorporated in to the process design, pretreatment costs increase from 20% to about 25% of Total Direct Capital costs.
- The projected savings in Total Capital Costs increases by 4-5% over the savings presented in Table 12 when the SWISS is compared with microfiltration pretreatment.

8.0 CONCLUSIONS

1. The quality of RO feedwater coming from the SWISS (after biocide addition and 5-micron cartridge filtration) is superior in several ways compared to that exiting an open ocean intake and conventional pretreatment equipment (after polymer chemical addition, multimedia filtration and 5-micron cartridge filtration). This is evidenced by the data shown in Table 8 with the following feedwater characteristics:
    - Average turbidity measurement of the conventional open-ocean intake system was 0.750 NTU, while the average turbidity measurement of the SWISS was only 0.075 NTU. This is an order of magnitude less for the SWISS and reflects the fact that it acts as a slow sand filter with greatly superior filtration performance.
    - The range of SDI readings for the conventional open-ocean intake was 15.19 to not-measurable for a ***5-minute*** SDI measurement, while the average SDI reading of the SWISS raw water was 2.25 for a ***15-minute*** SDI measurement (and only 1.97 after cartridge filtration). Clearly, the feedwater coming from the SWISS is significantly less fouling over long-term operation of RO membranes, as compared to membranes fed from an open-ocean intake.
    - The average dissolved oxygen reading for the conventional open-ocean intake was 7.1, while the average dissolved oxygen reading for the SWISS was 2.6. The lower dissolved oxygen levels observed with the SWISS indicates that state-of-the-art polymeric membranes should experience longer life compared to membranes fed from an open-ocean intake, due to reduced oxidation.

2. The results of this initial research effort clearly indicate that polymer chemical addition and media filtration are not required as pretreatment to RO membranes systems when a SWISS is installed as the seawater intake structure. The SWISS satisfies the requirements of both seawater intake and pretreatment filtration simultaneously, while providing higher quality feedwater than that of open-ocean takes and conventional pretreatment techniques.

3. The subsequent reduction of pretreatment equipment will result in a total capital cost savings of between 21.1 and 27.2%, depending on intake flow velocities and desalination facility location.

9.0 RECOMMENDATIONS

A SWISS should be installed using HDD techniques and operated as the intake for a seawater RO facility. This evaluation should document RO membrane performance and process operation and maintenance characteristics over an extended period of time, such as one year.

10.0 REFERENCES

Evensen, J., "Evaluation of Well Materials and Installation Techniques", The Source Group, 1999 (included in Appendix D)

Shields, C. P., and I. Moch, "Evaluation of Global Seawater Reverse Osmosis Capital and Operating Costs", Technical Proceedings American Desalting Association, 1996 Biennial Conference & Exposition, pp 44-60.

Wright, Robert, "Pretreatment Cost Evaluation of Surface-Water Versus Alternative Intake Systems for Seawater Membrane Treatment Plants", 1996

Figure 15

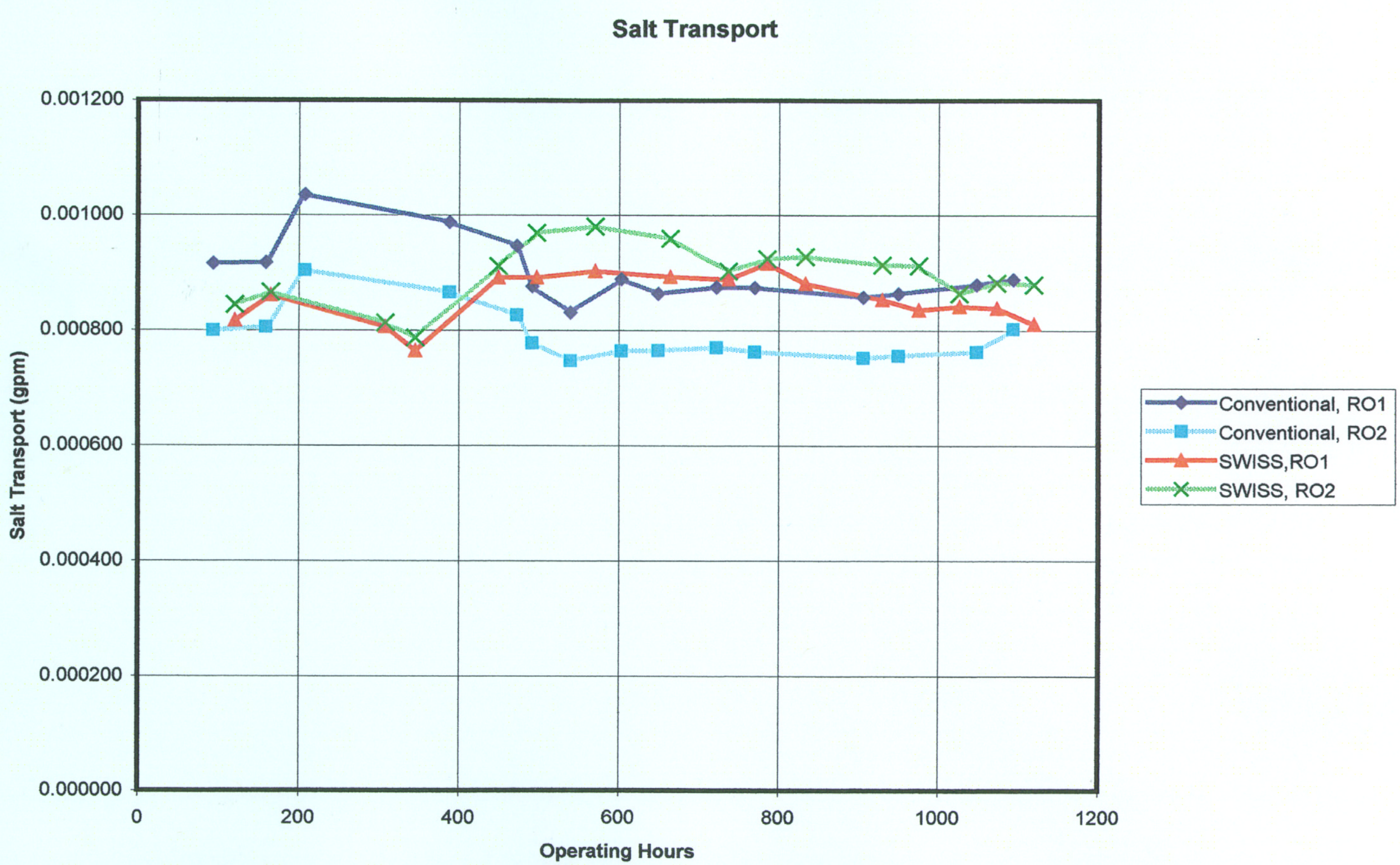

Salt Transport
Salt Transport (gpm)
0.001200
0.001000
0.000800
0.000600
0.000400
0.000200
0.000000
0
200
400
600
800
1000
1200
Operating Hours
Conventional, RO1
Conventional, RO2
SWISS,RO1
SWISS, RO2

Figure 16

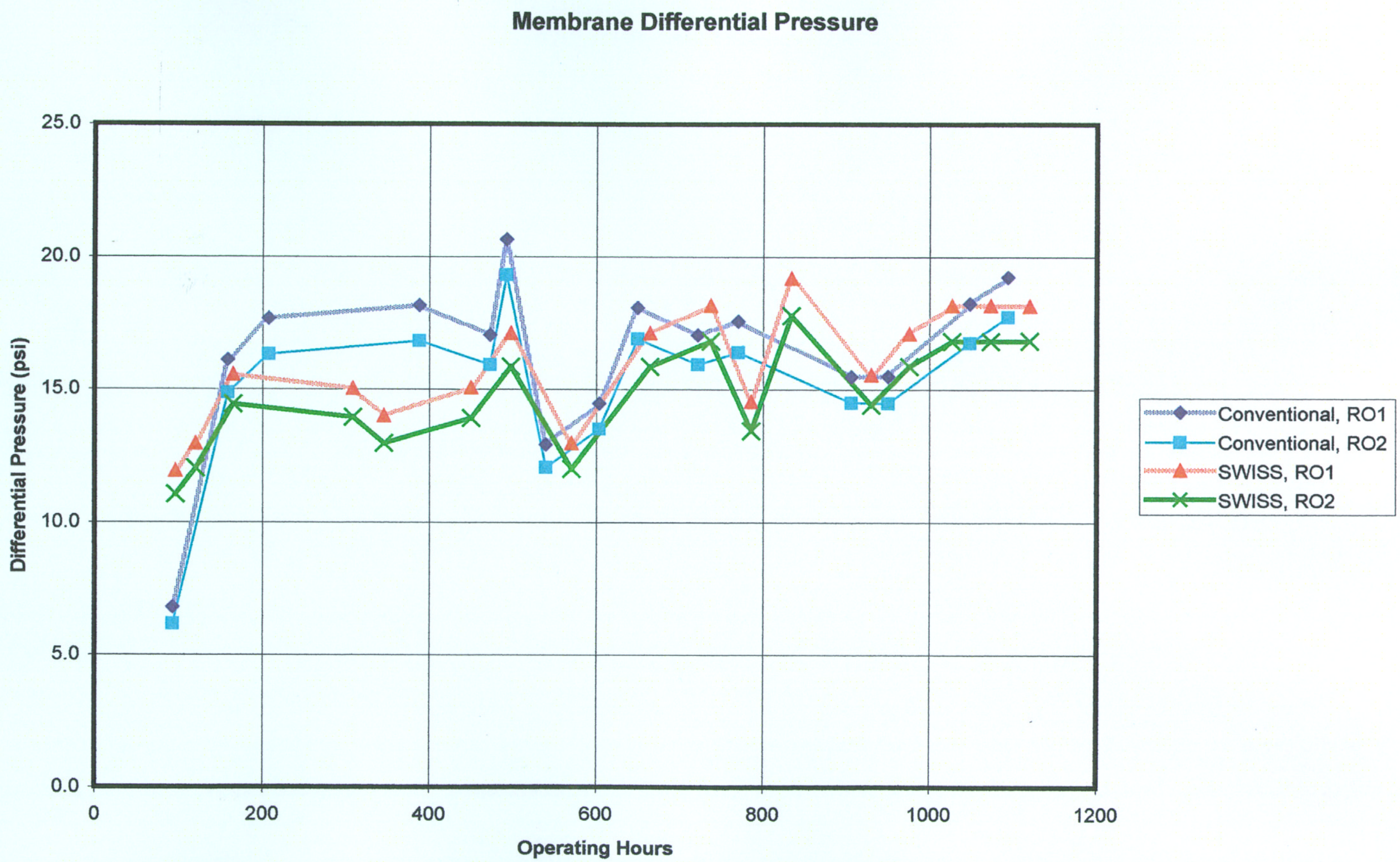

Membrane Differential Pressure
Differential Pressure (psi)
25.0
20.0
15.0
10.0
5.0
0.0
0
200
400
600
800
1000
1200
Operating Hours
Conventional, RO1
Conventional, RO2
SWISS, RO1
SWISS, RO2

Figure 17

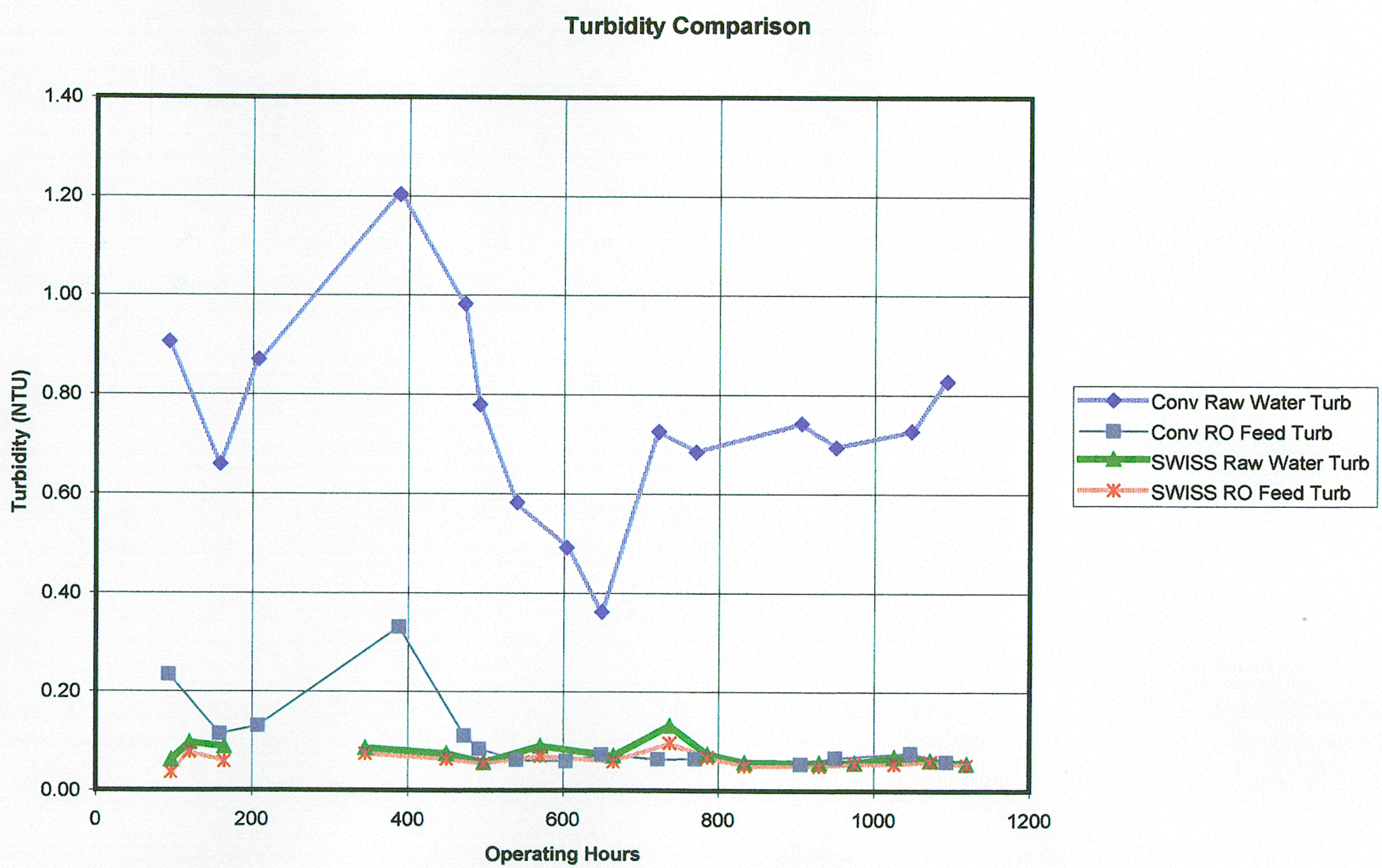

Turbidity Comparison
Turbidity (NTU)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
200
400
600
800
1000
1200
Operating Hours
Conv Raw Water Turb
Conv RO Feed Turb
SWISS Raw Water Turb
SWISS RO Feed Turb

Figure 18

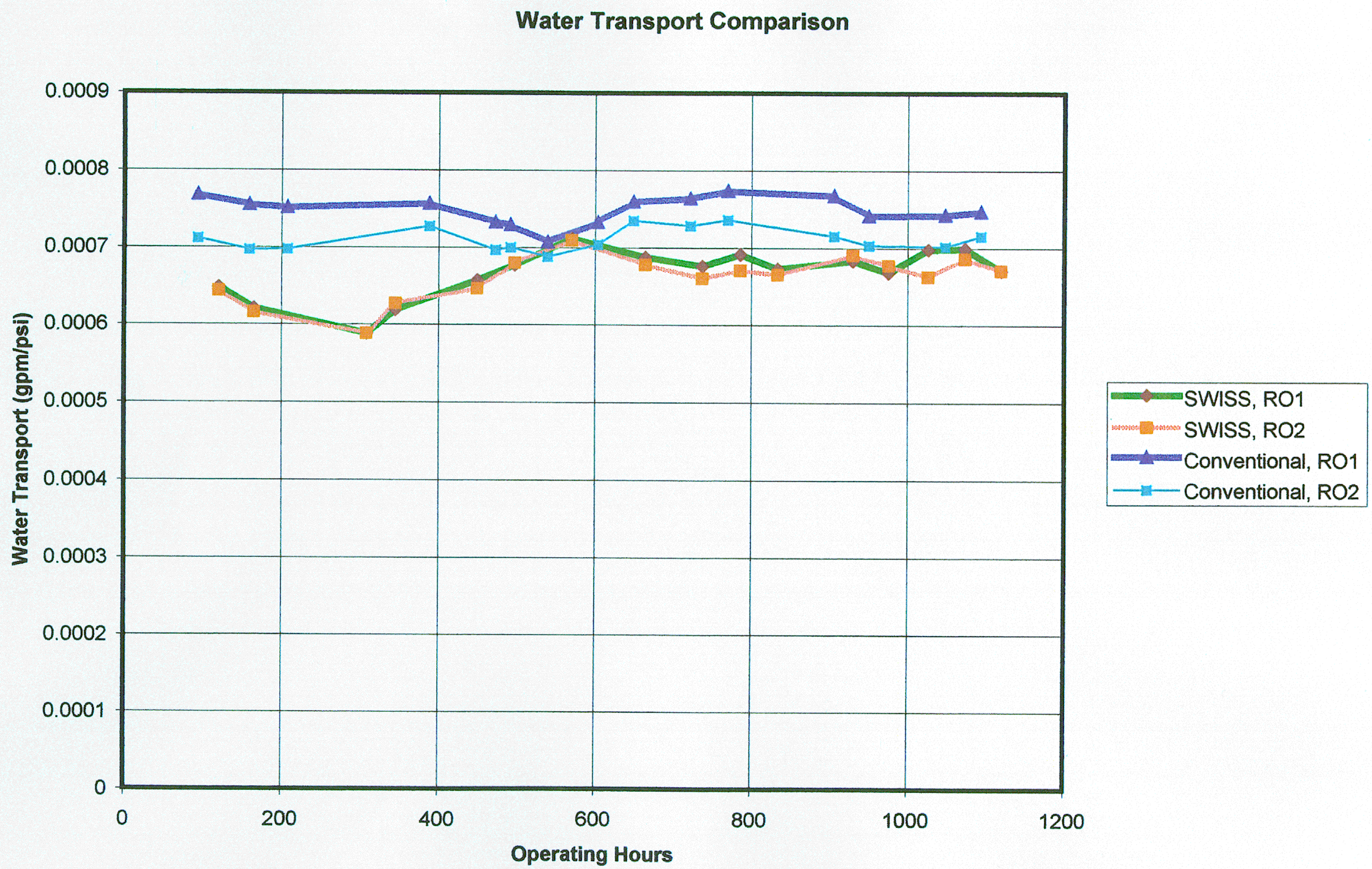

Water Transport Comparison
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Water Transport (gpm/psi)
0
200
400
600
800
1000
1200
Operating Hours
SWISS, RO1
SWISS, RO2
Conventional, RO1
Conventional, RO2

Figure 19

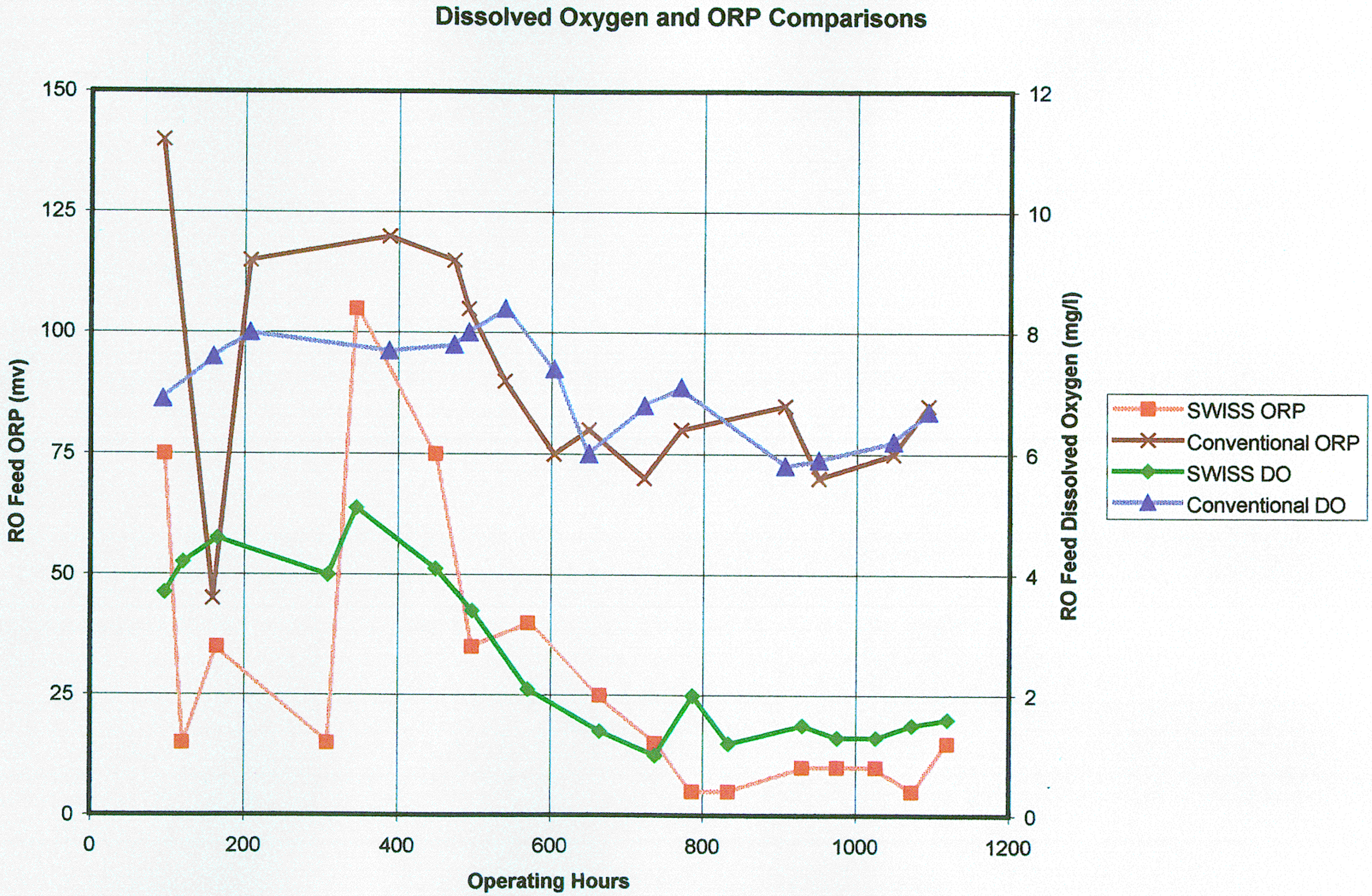

Dissolved Oxygen and ORP Comparisons
RO Feed ORP (mv)
RO Feed Dissolved Oxygen (mg/l)
Operating Hours
0
25
50
75
100
125
150
0
2
4
6
8
10
12
0
200
400
600
800
1000
1200
SWISS ORP
Conventional ORP
SWISS DO
Conventional DO

Figure 20

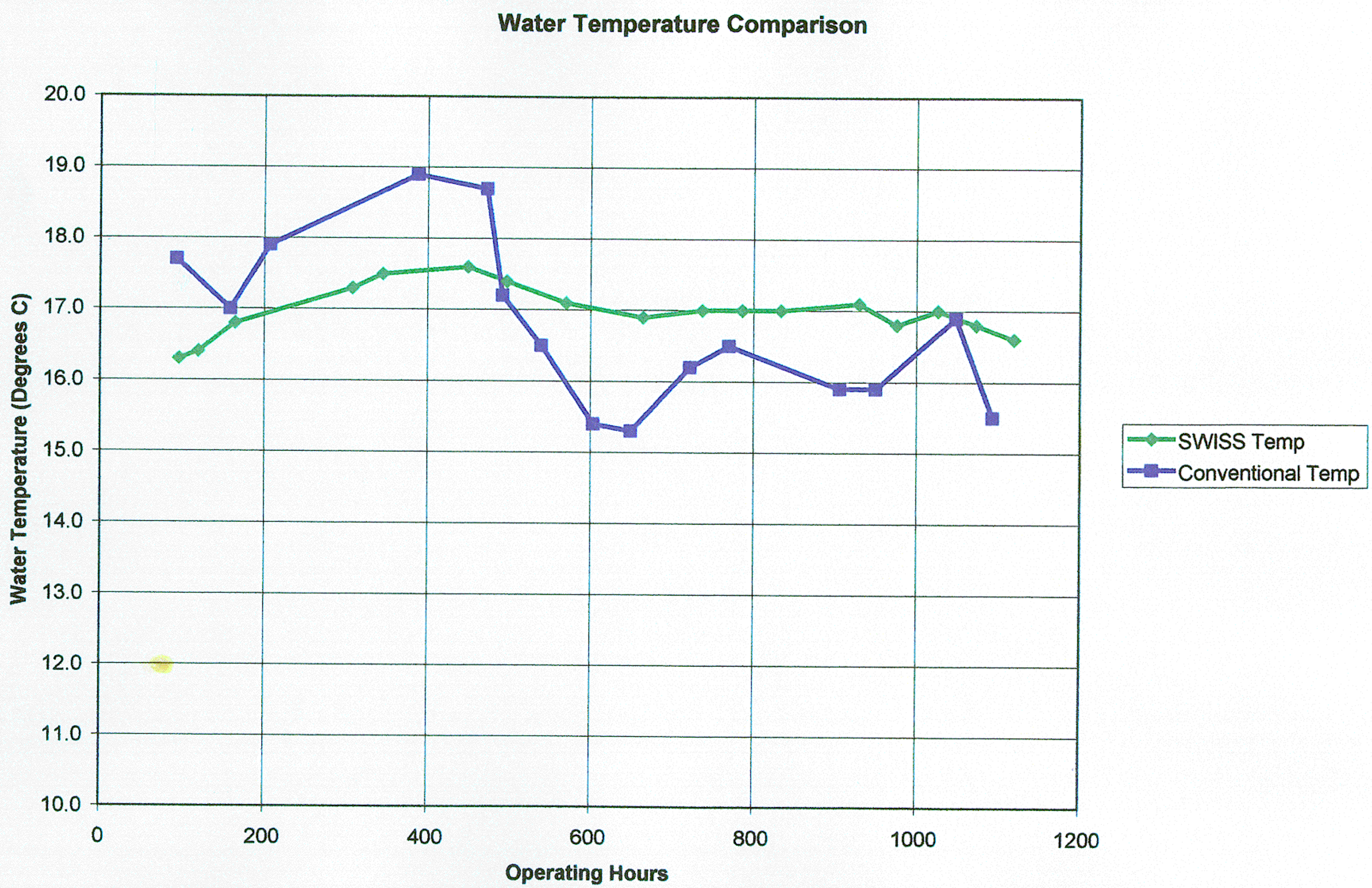

Water Temperature Comparison
Water Temperature (Degrees C)
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
0
200
400
600
800
1000
1200
Operating Hours
SWISS Temp
Conventional Temp

Figure 21

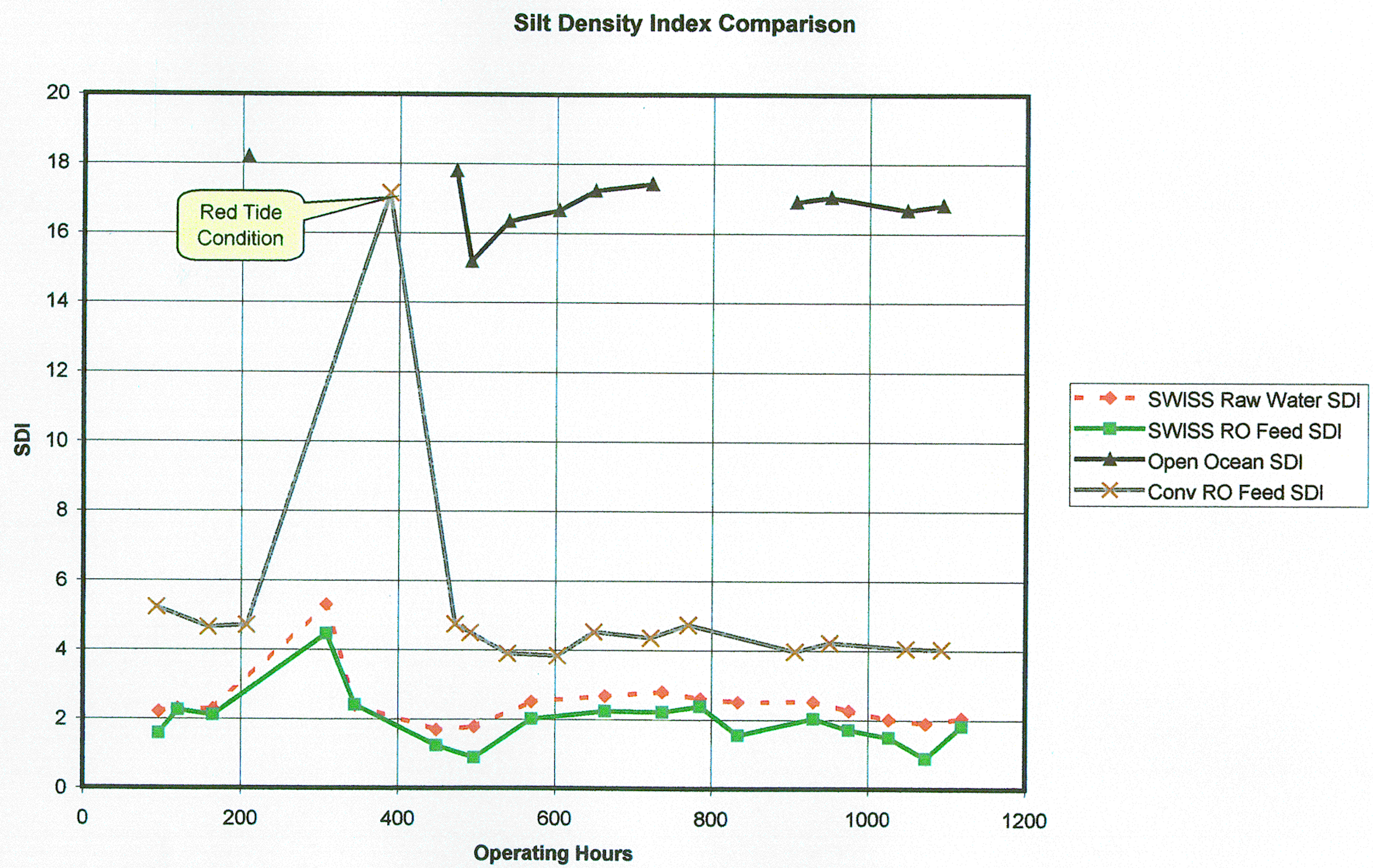

Silt Density Index Comparison
SDI
Operating Hours
Red Tide Condition
SWISS Raw Water SDI
SWISS RO Feed SDI
Open Ocean SDI
Conv RO Feed SDI
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200

Figure 22

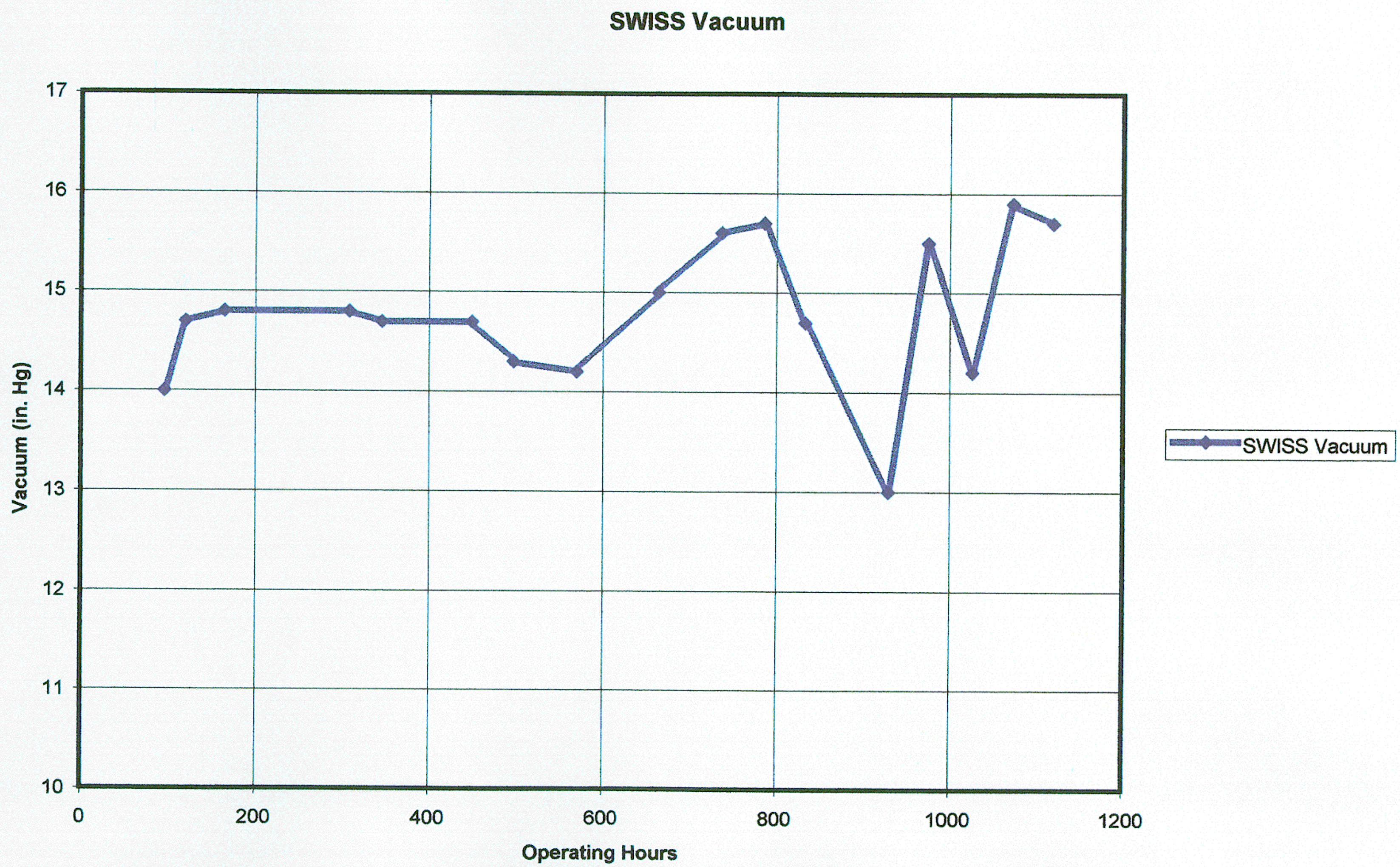
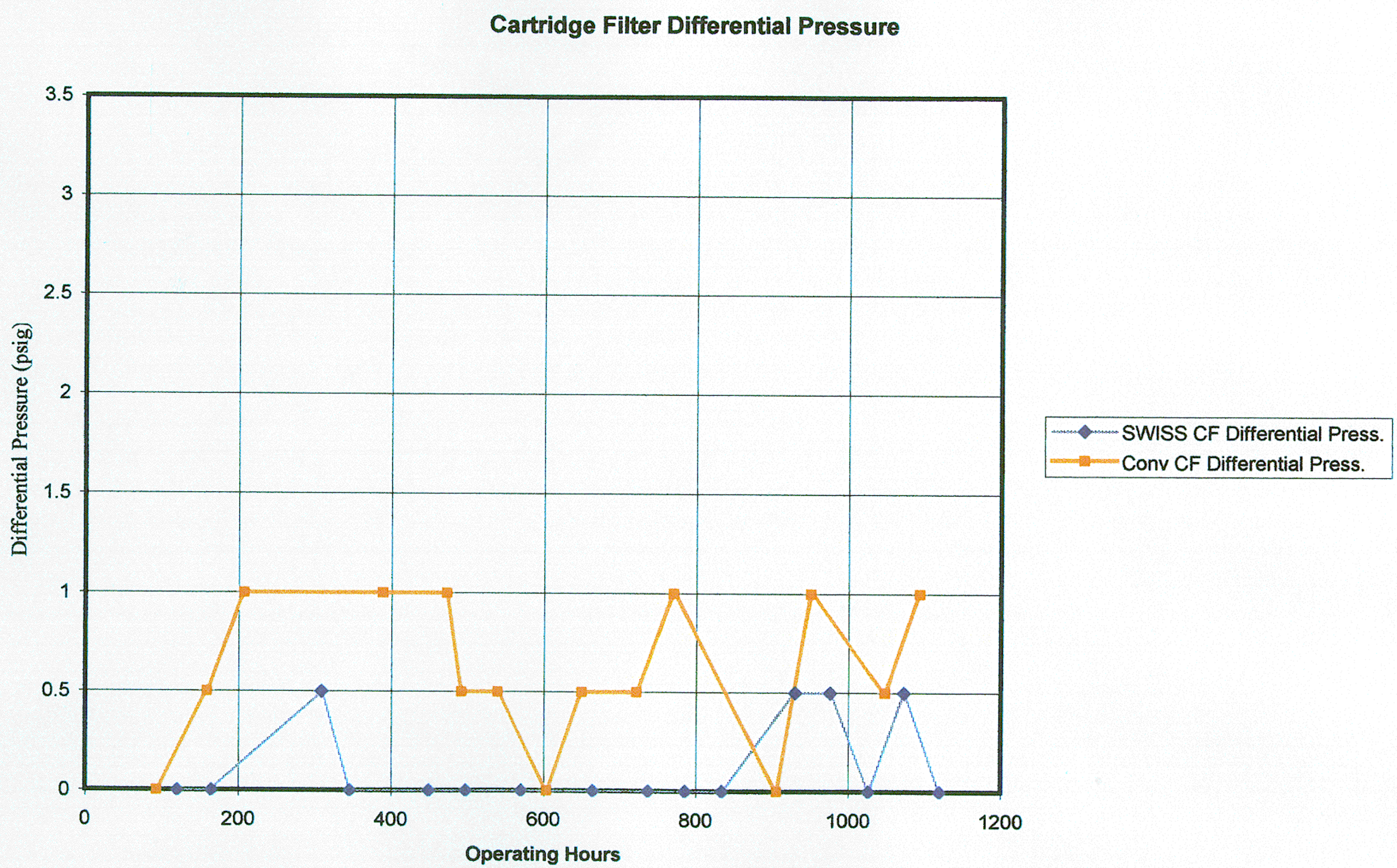

SWISS Vacuum
Vacuum (in. Hg)
17
16
15
14
13
12
11
10
0
200
400
600
800
1000
1200
Operating Hours
SWISS Vacuum

Figure 23


Cartridge Filter Differential Pressure
Differential Pressure (psig)
3.5
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000
1200
Operating Hours
SWISS CF Differential Press.
Conv CF Differential Press.

APPENDIX A

SAMPLE DATA SHEET

DATA SHEET

Desalination Research and Development Program
Cost Reduction Study

Conventional RO System			Well Point RO System		
Date:	Op. Time:		Date:	Op. Time:	
Time:	Operator:		Time:	Operator:	
Turbidity (NTU)			Turbidity (NTU)		
Raw Water			Raw Water		
MMF Out			RO Feed		
RO Feed			Permeate		
Pressure (psig)			Pressure (psig)		
MMF In			WP Vacuum (in. Hg)		
CF In			CF In		
CF Out			CF Out		
RO Feed			RO Feed		
Brine			Brine		
Flow (gpm)			Flow (gpm)		
Raw Water			Raw Water		
Permeate			Permeate		
Brine			Brine		
Timed Flow (gpm)			Timed Flow		
Brine			Brine		
Permeate 1			Permeate 1		
Permeate 2			Permeate 2		
Conductivity (umhos)			Conductivity (umhos)		
RO Feed (umhos)			RO Feed (umhos)		
Permeate 1 (umhos)			Permeate 1 (umhos)		
Permeate 2 (umhos)			Permeate 2 (umhos)		
Brine (umhos)			Brine (umhos)		
SDI			SDI		
Raw Water (5 min)			Well Point (15 min)		
CF In (15 min)			RO Feed (15 min)		
RO Feed (15 min)					
Chloride (mls titrant)			Chloride (mls titrant)		
RO Feed			RO Feed		
Brine			Brine		
pH			pH		
RO Feed			RO Feed		
Dissolved Oxygen (mg/l)			Dissolved Oxygen (mg/l)		
RO Feed			RO Feed		
ORP (mv)			ORP (mv)		
RO Feed			RO Feed		
Temperature (C)			Temperature (C)		
Permeate 1			Permeate 1		

NOTES:

APPENDIX B

TEST SYSTEM FIGURES

Figure 5. Open Ocean Intake.

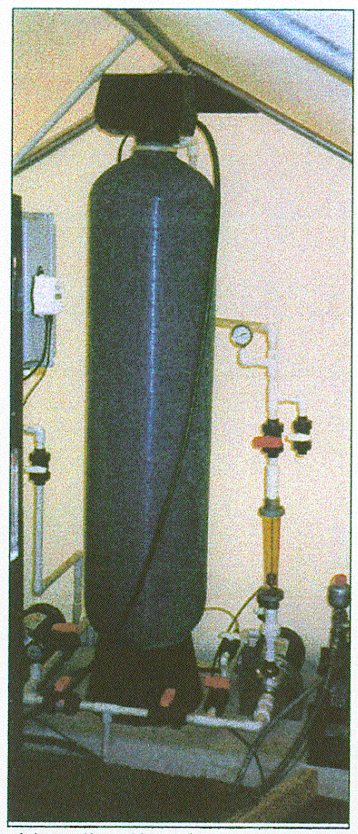


Figure 7. Multimedia Filter for Convention RO System.

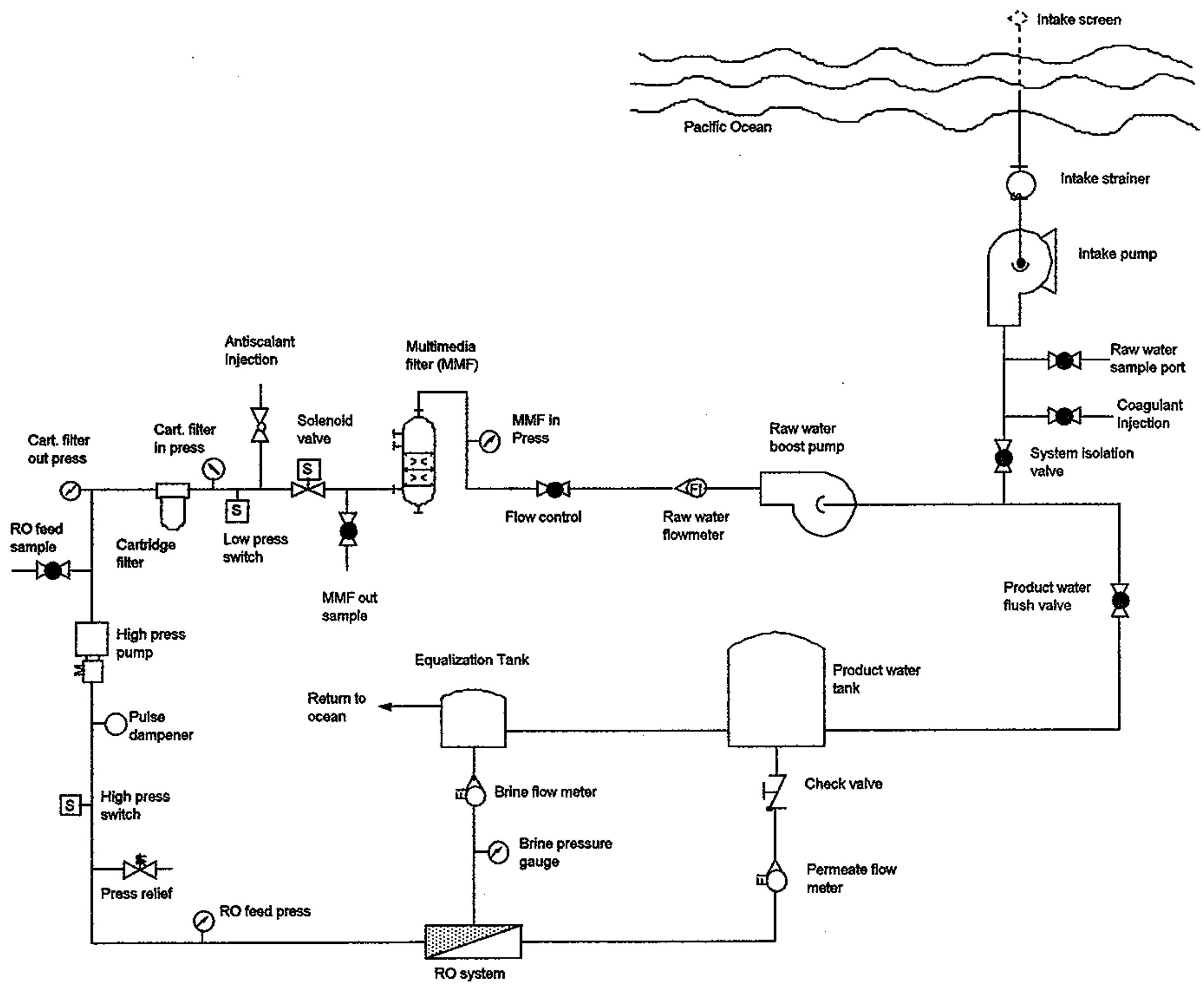


Figure 6. Open Ocean Intake Test System Schematic.

Figure 8. Chemical Injection System.

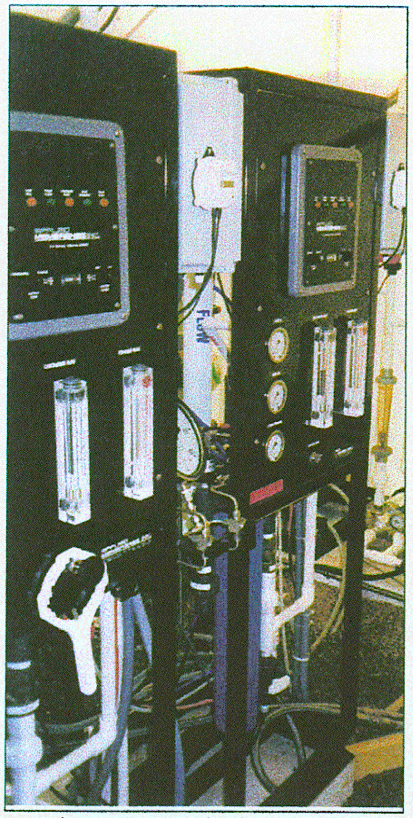


Figure 9. Testbed RO Units.

Figure 10a. SWISS Intake Piping.

Figure 10b. SWISS Intake.

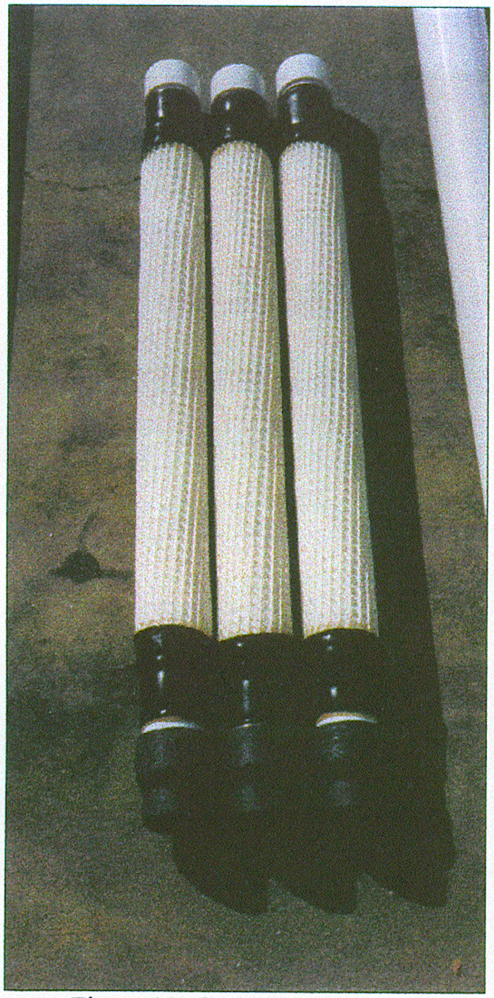


Figure 11. SWISS Wellscreen.

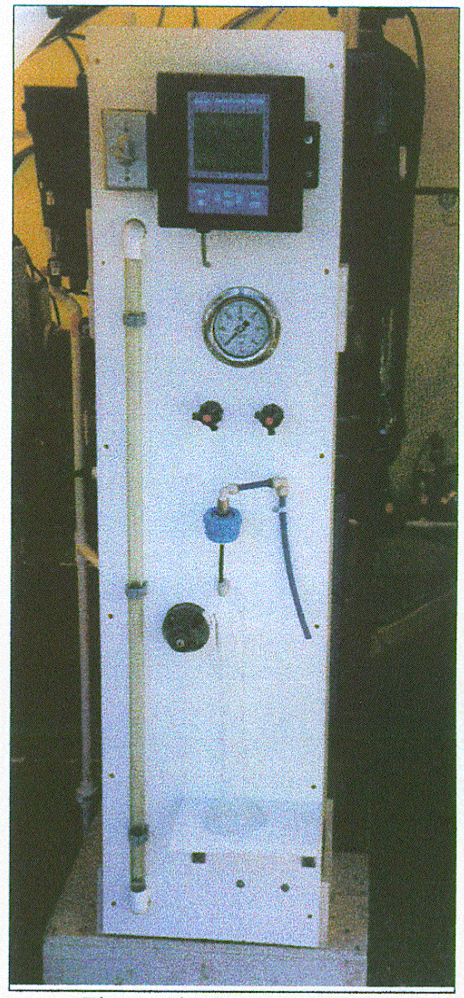


Figure 13. SDI Apparatus.

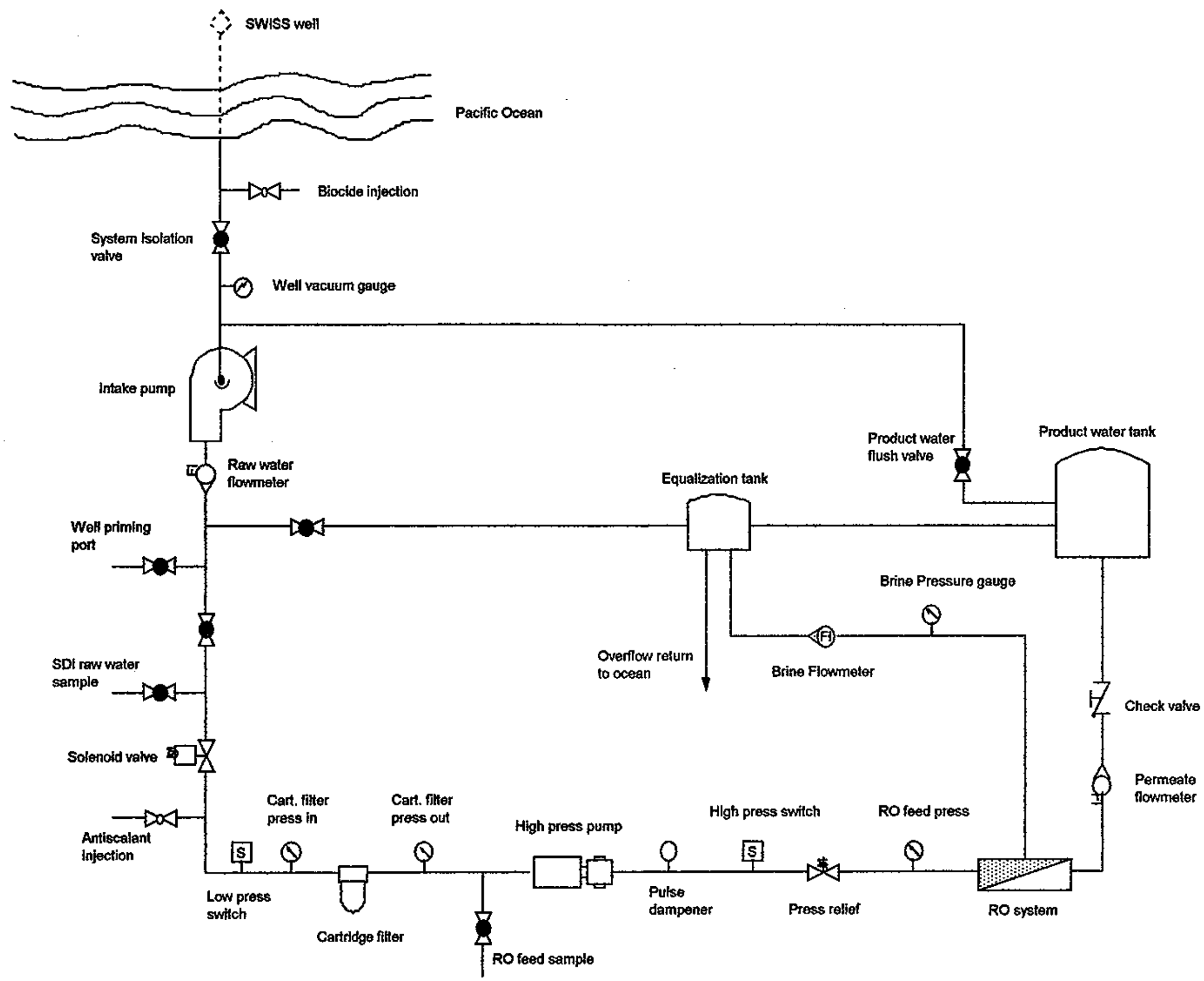


Figure 12. SWISS Test System Schematic.

APPENDIX C

GENERAL MINERAL ANALYSES

ENVIRONMENTAL

ANALYTICAL CHEMISTS

September 13, 1999 LAB No: SP 907157-1

Pacific Research Group
162 Fraser Lane
Ventura, CA 93001

Sampled : August 19, 1999
Received : August 19, 1999
Completed : August 25, 1999

Sample Site: 562310-A
Description: 562310-A

Sample type: Surface Water

General Mineral Analytical Results

CONSTITUENT		METHOD	UNITS	DLR	RESULTS	MCL
Total Hardness	($CaCO_3$)		mg/L	7	5710	
Calcium	(Ca)	200.7	mg/L	2	358	(a)
Magnesium	(Mg)	200.7	mg/L	10	1170	(a)
Potassium	(K)	200.7	mg/L	10	390	(a)
Sodium	(Na)	200.7	mg/L	50	10300	(a)
Total Cations			meq/L		572	
Total Alkalinity	($CaCO_3$)		mg/L	10	120	
Hydroxide	(OH)	2320B	mg/L	10	ND	(a)
Carbonate	(CO_3)	2320B	mg/L	10	ND	(a)
Bicarbonate	(HCO_3)	2320B	mg/L	10	140	(a)
Sulfate	(SO_4)	4110B	mg/L	100	2500	500 (b)
Chloride	(Cl)	4110B	mg/L	200	17500	500 (b)
Nitrate	(NO_3)	4110B	mg/L	2	ND	45
Nitrite	(NO_2)	4110B	mg/L	1.5	ND	3.3
Nitrate as N	(NO_3-N)	4110B	mg/L	0.5	ND	10
Nitrite as N	(NO_2-N)	4110B	mg/L	0.5	ND	1
Fluoride	(F)	4110B	mg/L	20	ND	1.4-2.4(c)
Total Anions			meq/L		548	

ND = Not Detected greater than or equal to the DLR. DLR = Detection Limit for Reporting purposes
MCL = Maximum Contaminant Level (California Health & Safety Code, Title 22)
mg/L = Milligrams Per Liter (ppm) meq/L = Milliequivalents Per Liter
(a) Not specifically restricted. Value obtained does relate to both E.C. and TDS values.
(b) Upper limit, Mineralization - Secondary Drinking Water Standards.
(c) Dependent on Annual Average of Maximum Daily Air Temperature.

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September 13, 1999

LAB No: SP 907157-1

Pacific Research Group

Sampled : August 19, 1999

Sample Site: 562310-A
Description: 562310-A

Sample type: Surface Water

General Mineral Analytical Results

CONSTITUENT		METHOD	UNITS	DLR	RESULTS	MCL
Aggressiveness Index		Calc.	---	0.1	12.8	
Langlier Index (Corrosivity)				0.1	0.7	
pH		4500-H B		---	7.8	
E.C.		2510B	umhos/cm	1	50600	1600 (b)
TDS (Residue at 180°C)		2540C	mg/L	510	34700	1000 (b)
TDS (by Summation)		Calc.	mg/L	1	32400	
MBAS		5540C	mg/L	0.1	0.1	0.5
Boron	(B)	200.7	mg/L	0.1	4.3	
Copper	(Cu)	200.7	ug/L	50	ND	1000
Iron	(Fe)	200.7	ug/L	50	ND	300
Manganese	(Mn)	200.7	ug/L	30	30	50
Zinc	(Zn)	200.7	ug/L	100	ND	5000

ND = Not Detected greater than or equal to the DLR. DLR = Detection Limit for Reporting purposes
MCL = Maximum Contaminant Level (California Health & Safety Code, Title 22)
ug/L = Micrograms Per Liter (ppb) mg/L = Milligrams Per Liter (ppm)
(b) Upper limit, Mineralization - Secondary Drinking Water Standards.

FGL ENVIRONMENTAL

Kurt Wilkinson, B.S.
QA Director

KW:kdm

ENVIRONMENTAL

ANALYTICAL CHEMISTS

September 13, 1999

LAB No: SP 907157-1

Pacific Research Group
162 Fraser Lane
Ventura, CA 93001

RE: Inorganic Analysis

Sample Site: 562310-A
Description: 562310-A
Sampled by : Robert Lovo
Type of Sample: Surface Water

Sampled : August 19, 1999
Received : August 19, 1999
Completed : September 2, 1999
QA/QC ID# : 90715701-

Analytical Results

CONSTITUENT	METHOD	UNITS	DLR	RESULTS
Silica	200.7	mg/L	2	ND

DLR = Detection Limit for Reporting Purposes. ND = Not Detected at or above the DLR.
ug/L = Micrograms Per Liter (ppb) mg/L = Milligrams Per Liter (ppm) mg/kg = Milligrams Per Kilogram
♦ = DLR adjusted because of dilutions, concentrations, or limited sample.
Preservatives: (1) HNO_3 pH < 2 Containers: (a) Plastic

If you have any questions, please call.

FGL ENVIRONMENTAL

Kurt Wilkinson, B.S.
QA Director

KW:kdm

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Mobile: 559/737-2399

ENVIRONMENTAL

ANALYTICAL CHEMISTS

September 13, 1999

LAB No: SP 907157-2

Pacific Research Group
162 Fraser Lane
Ventura, CA 93001

Sampled : August 19, 1999
Received : August 19, 1999
Completed : August 25, 1999

Sample Site: 562310-B
Description: 562310-B

Sample type: Surface Water

General Mineral Analytical Results

CONSTITUENT		METHOD	UNITS	DLR	RESULTS	MCL
Total Hardness	($CaCO_3$)		mg/L	7	5870	
Calcium	(Ca)	200.7	mg/L	2	358	(a)
Magnesium	(Mg)	200.7	mg/L	10	1210	(a)
Potassium	(K)	200.7	mg/L	10	410	(a)
Sodium	(Na)	200.7	mg/L	50	9700	(a)
Total Cations			meq/L		550	
Total Alkalinity	($CaCO_3$)		mg/L	10	130	
Hydroxide	(OH)	2320B	mg/L	10	ND	(a)
Carbonate	(CO_3)	2320B	mg/L	10	ND	(a)
Bicarbonate	(HCO_3)	2320B	mg/L	10	150	(a)
Sulfate	(SO_4)	4110B	mg/L	100	2300	500 (b)
Chloride	(Cl)	4110B	mg/L	200	19600	500 (b)
Nitrate	(NO_3)	4110B	mg/L	2	ND	45
Nitrite	(NO_2)	4110B	mg/L	30.0	ND	3.3
Nitrate as N	(NO_3-N)	4110B	mg/L	0.5	ND	10
Nitrite as N	(NO_2-N)	4110B	mg/L	10	ND	1
Fluoride	(F)	4110B	mg/L	20	ND	1.4-2.4(c)
Total Anions			meq/L		603	

ND = Not Detected greater than or equal to the DLR. DLR = Detection Limit for Reporting purposes
MCL = Maximum Contaminant Level (California Health & Safety Code, Title 22)
mg/L = Milligrams Per Liter (ppm) meq/L = Milliequivalents Per Liter
(a) Not specifically restricted. Value obtained does relate to both E.C. and TDS values.
(b) Upper limit, Mineralization - Secondary Drinking Water Standards.
(c) Dependent on Annual Average of Maximum Daily Air Temperature.

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FAX: 559/734-8435
Mobile: 559/737-2399

September 13, 1999 LAB No: SP 907157-2

Pacific Research Group Sampled : August 19, 1999

Sample Site: 562310-B
Description: 562310-B Sample type: Surface Water

General Mineral Analytical Results

CONSTITUENT		METHOD	UNITS	DLR	RESULTS	MCL
Aggressiveness Index		Calc.	---	0.1	12.7	
Langlier Index (Corrosivity)				0.1	0.6	
pH		4500-H B		---	7.6	
E.C.		2510B	umhos/cm	1	50900	1600 (b)
TDS (Residue at 180°C)		2540C	mg/L	510	34400	1000 (b)
TDS (by Summation)		Calc.	mg/L	1	33700	
MBAS		5540C	mg/L	0.1	ND	0.5
Boron	(B)	200.7	mg/L	0.1	4.1	
Copper	(Cu)	200.7	ug/L	50	ND	1000
Iron	(Fe)	200.7	ug/L	50	140	300
Manganese	(Mn)	200.7	ug/L	30	70	50
Zinc	(Zn)	200.7	ug/L	100	ND	5000

ND = Not Detected greater than or equal to the DLR. DLR = Detection Limit for Reporting purposes
MCL = Maximum Contaminant Level (California Health & Safety Code, Title 22)
ug/L = Micrograms Per Liter (ppb) mg/L = Milligrams Per Liter (ppm)
(b) Upper limit, Mineralization - Secondary Drinking Water Standards.

FGL ENVIRONMENTAL

Kurt Wilkinson, B.S.
QA Director

KW:kdm

ENVIRONMENTAL

ANALYTICAL CHEMISTS

September 13, 1999 LAB No: SP 907157-2

Pacific Research Group
162 Fraser Lane
Ventura, CA 93001

RE: Inorganic Analysis

Sample Site: 562310-B
Description: 562310-B
Sampled by : Robert Lovo
Type of Sample: Surface Water

Sampled : August 19, 1999
Received : August 19, 1999
Completed : September 2, 1999
QA/QC ID# : 90715702-

Analytical Results

CONSTITUENT	METHOD	UNITS	DLR	RESULTS
Silica	200.7	mg/L	2	7

DLR = Detection Limit for Reporting Purposes. ND = Not Detected at or above the DLR.
ug/L = Micrograms Per Liter (ppb) mg/L = Milligrams Per Liter (ppm) mg/kg = Milligrams Per Kilogram
♦ = DLR adjusted because of dilutions, concentrations, or limited sample.
Preservatives: (1) HNO3 pH < 2 Containers: (a) Plastic

If you have any questions, please call.

FGL ENVIRONMENTAL

Kurt Wilkinson, B.S.
QA Director

KW:kdm

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ENVIRONMENTAL

ANALYTICAL CHEMISTS

September 13, 1999

LAB No: SP 907157-3

Pacific Research Group
162 Fraser Lane
Ventura, CA 93001

Sampled : August 19, 1999
Received : August 19, 1999
Completed : August 25, 1999

Sample Site: 562310-C
Description: 562310-C

Sample type: Surface Water

General Mineral Analytical Results

CONSTITUENT		METHOD	UNITS	DLR	RESULTS	MCL
Total Hardness	($CaCO_3$)		mg/L	7	5690	
Calcium	(Ca)	200.7	mg/L	2	353	(a)
Magnesium	(Mg)	200.7	mg/L	10	1170	(a)
Potassium	(K)	200.7	mg/L	10	400	(a)
Sodium	(Na)	200.7	mg/L	50	10400	(a)
Total Cations			meq/L		576	
Total Alkalinity	($CaCO_3$)		mg/L	10	120	
Hydroxide	(OH)	2320B	mg/L	10	ND	(a)
Carbonate	(CO_3)	2320B	mg/L	10	ND	(a)
Bicarbonate	(HCO_3)	2320B	mg/L	10	140	(a)
Sulfate	(SO_4)	4110B	mg/L	100	2500	500 (b)
Chloride	(Cl)	4110B	mg/L	200	19400	500 (b)
Nitrate	(NO_3)	4110B	mg/L	2	ND	45
Nitrite	(NO_2)	4110B	mg/L	30.0	ND	3.3
Nitrate as N	(NO_3-N)	4110B	mg/L	0.5	ND	10
Nitrite as N	(NO_2-N)	4110B	mg/L	10	ND	1
Fluoride	(F)	4110B	mg/L	20	ND	1.4-2.4(c)
Total Anions			meq/L		602	

ND = Not Detected greater than or equal to the DLR. DLR = Detection Limit for Reporting purposes
MCL = Maximum Contaminant Level (California Health & Safety Code, Title 22)
mg/L = Milligrams Per Liter (ppm) meq/L = Milliequivalents Per Liter
(a) Not specifically restricted. Value obtained does relate to both E.C. and TDS values.
(b) Upper limit, Mineralization - Secondary Drinking Water Standards.
(c) Dependent on Annual Average of Maximum Daily Air Temperature.

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September 13, 1999

Pacific Research Group

Sample Site: 562310-C
Description: 562310-C

LAB No: SP 907157-3

Sampled : August 19, 1999

Sample type: Surface Water

General Mineral Analytical Results

CONSTITUENT		METHOD	UNITS	DLR	RESULTS	MCL
Aggressiveness Index		Calc.	---	0.1	13.0	
Langlier Index (Corrosivity)				0.1	0.9	
pH		4500-H B		---	8.0	
E.C.		2510B	umhos/cm	1	51200	1600 (b)
TDS (Residue at 180°C)		2540C	mg/L	680	35000	1000 (b)
TDS (by Summation)		Calc.	mg/L	1	34400	
MBAS		5540C	mg/L	0.1	ND	0.5
Boron	(B)	200.7	mg/L	0.1	4.4	
Copper	(Cu)	200.7	ug/L	50	ND	1000
Iron	(Fe)	200.7	ug/L	50	ND	300
Manganese	(Mn)	200.7	ug/L	30	30	50
Zinc	(Zn)	200.7	ug/L	100	ND	5000

ND = Not Detected greater than or equal to the DLR. DLR = Detection Limit for Reporting purposes
MCL = Maximum Contaminant Level (California Health & Safety Code, Title 22)
ug/L = Micrograms Per Liter (ppb) mg/L = Milligrams Per Liter (ppm)
(b) Upper limit, Mineralization - Secondary Drinking Water Standards.

FGL ENVIRONMENTAL

Kurt Wilkinson, B.S.
QA Director

KW:kdm

Analytical Chemists

September 13, 1999

Inorganic Quality Assurance Report for sample: 907157

Pacific Research Group
162 Fraser Lane
Ventura, CA 93001

Actual sample results are contained in the accompanying analytical report(s).

Constituent	BATCH ID	Method	Units	BLANK QA/QC DLR	BLANK QA/QC Result	BLANK QA/QC NOTE	CALIBRATION QA/QC Type	CALIBRATION QA/QC Conc.	CALIBRATION QA/QC % REC	CALIBRATION QA/QC AR	CALIBRATION QA/QC NOTE	METHOD QA/QC Type	METHOD QA/QC Conc.	METHOD QA/QC % REC	METHOD QA/QC % REC	METHOD QA/QC AR	% DIF	RAV	NOTE
Calcium	4A203	200.7	mg/L		N/A				N/A			MS	51.00	104	108	75-125	2.4	20.0	
Magnesium	4A203	200.7	mg/L		N/A				N/A			MS	51.00	107	108	75-125	1.0	20.0	
Potassium	4A203	200.7	mg/L		N/A				N/A			MS	51.00	105	104	75-125	0.9	20.0	
Sodium	4A203	200.7	mg/L		N/A				N/A			MS	51.00	110	108	75-125	0.7	20.0	
Boron	4A203	200.7	mg/L		N/A				N/A			MS	5.100	104	106	75-125	1.3	20.0	
Copper	4A203	200.7	ug/L		N/A				N/A			MS	1020	105	104	75-125	0.4	20.0	
Iron	4A203	200.7	ug/L		N/A				N/A			MS	5100	104	105	75-125	1.6	20.0	
Manganese	4A203	200.7	ug/L		N/A				N/A			MS	1020	104	105	75-125	1.4	20.0	
Zinc	4A203	200.7	ug/L		N/A				N/A			MS	1020	103	105	75-125	1.9	20.0	
Total Alkalinity	1A 2A	2320B	mg/L		N/A		CCV	236	95.8	90-110		Dup	119	N/A	N/A	N/A	2.7	6.5	
Hydroxide	1A 2A	2320B	mg/L		N/A				N/A			Dup	0.000	N/A	N/A	N/A	0.0	20.0	
Carbonate	1A 2A	2320B	mg/L		N/A				N/A			Dup	0.000	N/A	N/A	N/A	0.0	20.0	
Bicarbonate	1A 2A	2320B	mg/L		N/A				N/A			Dup	145	N/A	N/A	N/A	2.7	6.5	
Sulfate	0B215	4110B	mg/L		N/A		LCS	100.0	97.9	90-110		MS	1000	100	101	80-120	0.4	20.0	
Chloride	5B215	4110B	mg/L		N/A		LCS	50.00	108	90-110		MS	500.0	103	102	82-130	0.8	13.6	
Nitrate	0B215	4110B	mg/L		N/A		LCS	40.00	98.6	90-110		MS	400.0	101	101	86-124	0.5	13.7	
Nitrite as N	0B215	4110B	mg/L		N/A		LCS	30.00	98.9	90-110		MS	300.0	99.8	100	86-113	0.6	10.5	
Fluoride	5B215	4110B	mg/L		N/A		LCS	5.000	93.8	90-110		MS	50.00	93.2	93.8	69-131	0.6	11.5	
pH	0A 2B	4500-H B	units		N/A		CCV	8.00	99.6	95-105		Dup	7.22	N/A	N/A	N/A	0.1	1.4	
E. C.	1A 2A	2510B	umhos/cm	1.0	0.5		CCV	1000	99.4	95-105		Dup	50600	N/A	N/A	N/A	0.2	0.8	
TDS	1A 2A	2540C	mg/L	40	ND		LCS	1000	98.3	89-111		Dup	1510	N/A	N/A	N/A	0.3	15.8	

FGL ID = 19990819 ND => Not Detected at above DLR. DLR => Detection Limit for Reporting purposes. N/A => Not Applicable NOTE => See note indicated below.
An explanation of QA terms is provided on the reverse side of this page.

Table continued next page .....

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Page 2

September 13, 1999 **INORGANIC Quality Assurance Report for sample: 907157**

Quality Assurance Cont'd.

Constituent	BATCH ID	Method	Units	BLANK QA/QC DLR	Result	NOTE	CALIBRATION QA/QC Type	Conc.	% REC	AR	NOTE	METHOD QA/QC Type	Conc.	% REC	% REC	AR	% DIF	MAV	NOTE
MBAS	2A 2A	5540C	mg/L	0.10	0.01		LCS	0.500	110	78-116		MS	0.500	82.4	95.0	52-138	12.1	9.0	410
Silica	14A203																		

FGL ID = 19990819 ND => Not Detected at above DLR. DLR => Detection Limit for Reporting purposes. N/A => Not Applicable NOTE => See note indicated below.
An explanation of QA terms is provided on the reverse side of this page.

Notes:

410 Relative Percent Difference (RPD) not within Maximum Allowable Value (MAV). Data was accepted based on the LCS or CCV recovery.

FGL ENVIRONMENTAL, INC.

Kurt Wilkinson, B.S., QA Director

KW:kdm

APPENDIX D

SWISS INITIAL DESIGN CRITERIA AND CAPITAL COSTS
THE SOURCE GROUP

EVALUATION OF WELL MATERIALS AND INSTALLATION TECHNIQUES

Horizontal Well Pilot Program, Port Hueneme, California

Dear Mr. Lovo:

The Source Group, Inc. (TSG) is pleased to provide this evaluation of various well/casing materials and drilling techniques to be used for horizontal seawater intake wells at the Naval Base in Port Hueneme, California. Information for the recommendations contained herein are based on discussions with you and your affiliates, results from the short-term pilot study, and in conjunction with our experience in the field of horizontal directional drilling. The formulation of our opinions focus on meeting the future objectives for installing a cost effective seawater intake well. The horizontal well will have a suitable design to be used for either desalinization or aquaculture. This report presents the well design parameters derived from the pilot study, which tested a modified design approach for the installation of seawater intakes.

1.0 RESEARCH OBJECTIVE

The objective of the short-term pilot study was to test the performance of selected well materials and evaluate their applicability for potential use in a large-scale horizontal well application. A total of five types of well/filter material were considered for the pilot test program. Of the five products, two of them showed the greatest promise for the large-scale application. The premise for the field program was to initiate the study using what we believed would be the best-suited well product. If that product was unable to function at the required performance level, then the product considered to be the next most feasible was to be tested.

In support of the research premise and design objective presented above, TSG prepared an evaluation of well materials followed by well design specifications and construction parameters specific to installing large-scale horizontal wells. These topics are discussed in the following paragraphs.

1.1 Study Premise

Seawater intake design for desalination and aquaculture facilities can be improved through the use of horizontal well drilling technology combined with the use of specially designed well materials. A seawater intake system installed below the sea floor could allow for the production of seawater that is free from the organic and inorganic (including silt and clay material) particulate debris which is normally produced from standard open-water intake designs. The particulate-free water produced will allow for greatly extended well and system operating life in addition to a significant reduction in water filtration maintenance costs. To accommodate the goals of the pilot study, the wide array of commercially available well products were considered.

2.0 MATERIALS EVALUATION

Evaluation of well materials for use as a horizontal seawater intake considered four major design criteria as follows: 1) chemical compatibility; 2) installation feasibility; 3) flow capacity; and 4) life expectancy. Due to the nature of the intended study, the criteria of chemical compatibility combined with installation feasibility serve to screen out most standard well materials. Based on our review, we were able to reduce the number of feasible product candidates to five. Each of these five products would require different well designs, based on their respective materials, slot/pore properties, and strength (Table 1, attached). In order of expected performance, the products are described as follows:

2.1 Hydroquest® Filtermesh Well Screens

This material consists of a base pipe wrapped by coarse and finer mesh materials. Design can be customized to all standard sizes and can be constructed of either PVC or HDPE base pipes. HDPE has superior qualities that include flexibility, low reactivity (virtually inert), and longevity; however, the machine cut slots are not as precise as a PVC product. Overall, either pipe composition is well suited for horizontal well installations. The entrance velocity for this type of design is based primarily upon the fine mesh and to a lesser extent on the base pipe used in its construction. Based on our sieve data showing a 50 to 60% retained grain size of 0.0071 inches, we proposed the use of HQ 06 fine mesh which has an open area of 40% and an equivalent to 0.006 slot width.

It has recently been discovered that the Hydroquest® product is no longer commercially available. The manufacturer that originally produced this product has been acquired by another company that ultimately discontinued this product line. It is unlikely that this product can be used in the large-scale application.

2.2 US Filters Schumafilter Well Screens

The Schumafilter™ consists of a porous polyethylene material that acts both as a sand pack and the well screen. The Schumafilter is, as the name implies more of a filter type product, but appears to be well-suited for this application due to the large open area of the design. The key in using this material is to design the large-scale well so that the entrance velocity through the materials does not exceed that prescribed maximum for the adjacent formation materials. Based on the sieve data obtained from one sand sample, we propose the use of Schumafilter screen with an average pore size of 200 μm. The average particle pass size for this screen is 80 μm.

2.3 Titan EnviroFlex

This material is similar to the Hydroquest® except that the base pipe forms the outside layer in this system. The interior of the base pipe is fitted with either a non-woven geotextile or porous polyethylene filter. This material is available with circular holes, vertical machined slots, or horizontal machined slots. Similar to the Hydroquest®, it is also available in HDPE and PVC as well as steel. The main difference in this product is that the base pipe controls the entrance velocities. It is our opinion that the total open area may be closer to the sum of open area of the internal liner directly adjacent to the openings in the base pipe.

2.4 Machine Slotted Well Screen (Custom Design)

The fourth design represents an experimental method to allow an inner well screen that can be removed for maintenance. This design will utilize inner and outer sections of machine slotted well screen. The inner material was constructed of flexible HDPE well screen with large slots and resulting open area, wrapped in a porous filter mesh similar to the above designs. The difference with this design is that the inside HDPE pipe was removable from the well for cleaning/replacement of the filter mesh.

For test materials 2, 3, and 4, the well design based on entrance velocity is primarily controlled by the properties of the base pipe, with interference from exterior filter mesh material. TSG originally proposed to utilize a filter mesh material equivalent to the Hydroquest® HQ 06 for this pilot test.

2.5 Plastic V-Wire Screen

The last type of test well will utilize PVC VEE-WIRE® or equivalent well screen. This type of well screen is constructed by wrapping plastic v-shaped wires around ribs that run the length of the pipe. There are significant advantages to this type screen configuration. The primary advantage of the type of product is the greater percentage of open area relative to equally sized machine slotted screen greater than 0.010 inches (In the finer slot sizes, the relative width of the v-wires cause the percentage of open area to be quite small). The other advantages include better capacity for well development due to the geometry of the slot openings, which ultimately increased the well efficiency. Lastly, this type of screen characteristically offers greater longevity as a result of the maximized open area and slot geometry. This screen, however, has limited flexibility and tensile strength. These limitations may be overcome by material and/or structural modifications.

Table 2 (attached) summarizes flow capacity information for various well diameters and materials. Final well design for the pilot test can be modified in accordance with the depths of the vertical wells and the available diameters.

3.0 HORIZONTAL WELL INSTALLATION

3.1 Horizontal Directional Drilling

Horizontal Directional Drilling (HDD) was introduced into the construction industry during the mid 1980s. The technology was adopted from the petroleum exploration industry and has been scaled down to accommodate the installation of utility pipelines, ducting, cables, and wells. The advantages offered by this technology versus conventional trench installation techniques include: 1) minimized surface disturbance/impacts; 2) reduction in the quantity of excavated material; 3) achievement of greater depths; 4) accuracy of conduit placement; 5) safer working conditions; and 6) backfill and compaction of open trenches is eliminated.

In most applications, the borehole is initiated at grade by drilling into the ground at a low angle relative to a horizontal datum. Depending on the scale of the operation, bend radius of the drill stem or conduit materials, and/or the design parameters, the trajectory of the drilling can be remotely controlled to accommodate the desired depth or position. In other settings, the borehole can be drilled into a slope or wall, enabling the orientation to be established at the initiation of the hole. Drilling can be accomplished by either rotary, percussion, or jetting techniques. Typically, rotary drilling or percussion is used in rock or densely consolidated material, whereas, jetting is performed predominantly in unconsolidated materials. Rotary drilling utilizes mechanical cutting tips in conjunction with drilling fluids/muds to advance the drill string. The circulating drilling fluids/muds are used to stabilize the borehole, cool and lubricate the cutting tip, and to remove the drill cuttings from the drill hole. In an application where the drilled media is soft or unconsolidated, high pressure water can be jetted from the drill tip to cut through the porous material.

With the exception of an air-cutting tool, the borehole is usually stabilized with drilling muds or engineered fluids. The design or the drilling fluid is developed to maintain the integrity of the open hole, while keeping the drilling equipment from becoming lost in the borehole. Conductor or carrier casings are also commonly used during drilling. These types of casings are used to hold the borehole open as well as to significantly improve the driller's ability to circulate the drilling fluids. For example, during the installation of Schumafilter material, the manufacturer recommends the use of such a carrier casing. For this application, the carrier casing is solid HDPE pipe that is installed in the borehole as it is drilled. Once the borehole is completed, the Schumafilter product is inserted into the carrier casing and then both are flooded with the completion solution. The carrier casing is then removed, allowing the completion solution to flow into the annulus.

3.2 Well Installation

Numerous well installation techniques can be employed for the placement of well screen and casing. For shallow and many small-scale applications, the borehole is advanced from the ground surface, drilled horizontally for the desired distance, then drilled upward and surfaced. This technique yields two openings to the borehole that can be accessed for the installation of the final product. In this double aperture technique, the well product or conduit is usually fed into the exit hole and pulled back into position by the drilling rig.

The other most common techniques involves drilling a hole that is terminated at the prescribed depth and position. In this setting, the well product or conduit is either pushed into position (short runs) or is installed by connecting the leading tip to a thrust tool and pulling the product into position by pushing the thrust rod. Once the desired position is achieved, the mechanical connection at the leading end is released and the thrust rod is removed.

3.3 Well Development

Well development is used to both remove the residual drilling fluids/muds and to increase the yield of the well. The removal of the drilling fluids/muds is critical for maximizing the productivity of the well and to prevent those residuals from being pumped from the well during subsequent operations. The principle objective of developing a well in natural formation material is to remove up to 50 to 60 percent of the fine-grained formation material that resides in close proximity to the well screen. Hence, the remaining material is coarser-grained adjacent to the well and is graded (percentage of fine sediment increases away from the well), yielding a significantly more productive well. For a well where a filter pack is installed, the goal is virtually the same as that of a naturally developed well. In either case, the objective is to remove as much of the fine material that could clog the openings in the well screen.

Well development can be accomplished by hydrojetting and pumping, surging and pumping, and/or simple bailing. During development, the fines are pulled into the well casing and removed from the well. It is good practice to monitor turbidity during development and to collect as much of the recovered sediment to document the completeness of the undertaking.

4.0 LARGE-SCALE DESIGN PARAMETERS

The purpose of this section is to outline the design parameters for two large-scale wells; a 1 million gallon per day well and a 10 million gallon per day well. In general terms, the objectives for designing a good water supply well include maximized production rates and longevity, optimized water quality, with minimized costs. For the purpose of this report, TSG prepared the following example well design. Due to the fact that the Hydroquest® product is not currently available, the design herein is based on commercially available Schedule 40, PVC, VEE-WIRE® well screen.

The example well design is based on the results from of the sieve analysis performed on a sample collected from the shallow marine sediment, located directly off shore at Port Hueneme. At the laboratory, the sample was dried, reduced to grain sized-material, and subsequently passed through a set of Tyler mesh screens. The analysis was performed by Goode Core Analysis Service, located in Bakersfield, California. The results of the sieve analysis were presented in both tabular and graphical formats (Analysis report attached).

The information revealed by the sieve analysis shows that the sediment sample is predominantly fine- to very fine-grained sand. The information also shows that less than 50 percent of the sample, by weight, is coarser than the fine-grained sand range (approximately 0.0078 inches). This indicates that after development of a conventional well screen with a slot size of 0.010 inches, approximately 70 percent of the sedimentary particles that are within close proximity to the screen will be developed out of the formation and extracted from the well. If the slot size were reduced, the effective open area would also be reduced to the extent that the well would be inefficient or simply too long and ultimately economically infeasible to install.

Based on the flow requirements of 1 million gallons per day with an intake velocity of 0.01 feet per second, a standard design using 6-inch diameter VEE-WIRE® well screen would require an aggregate screen length of approximately 1,700 feet. However, if the intake flow velocity were increased to 0.05 feet per second, the aggregate length of the well would only be in the order of 340 feet.

The cost of materials for horizontal wells of 1,700 feet and 340 feet well would be approximately $54,000 and $10,800, respectively. For those same wells, the horizontal directional drilling, well installation, and development costs would be approximately $420,000 and $84,000, respectively. For wells capable of producing as much as 10 million gallons per day, the incremental cost increase is almost directly proportional to the aggregate length of well screen. Specifically, multiple horizontal wells can be installed from the same origin and simply manifolded together to meet those high production requirements.

5.0 PILOT STUDY FINDINGS AND RESULTS

The objective of this study revealed critical information regarding the mechanisms involved in the material selection, technology alternatives, and potential costs for the installation and operation of a large-scale horizontal seawater intake well. The design parameters developed from this study can be applied to the construction of large-scale wells that are capable of producing 10 million gallons (or greater) per day of sediment-free seawater. These types of wells have excellent applicability in the aquaculture industry or for supplies to desalination plants.

This investigation and field pilot study produced the following findings:

- The field pilot study produced the expected and ultimately favorable results.
- As anticipated, the Hydroquest® well screen performed effectively, with extremely low sediment production and no measurable pressure drop during the 1,000-hour term of the test. These positive results meant that the other well products need not be tested in the same manner.
- Horizontal directional drilling offers the necessary technology for installing wells that are capable of having very low intake velocities. Achieving these low velocities will be imperative to meet the objective of long-term operation without silt fouling.
- The cost of these wells may appear to be relatively large; however, they offer the significant benefits of extremely long operational life spans. Hence, the actual long-term costs of these wells are low when maintenance, downtime, and replacement expenses are considered.

We sincerely appreciate the opportunity to be of service on this important project. If you have any questions or comments, please feel free to call us at any time.

Sincerely,
The Source Group, Inc.

Paul D. Horton, R.G., C.HG
Principal Hydrogeologist

James M. Evensen, Jr., R.G., C.HG
Principal Hydrogeologist

Attachments: Table 1. Well Design Data
Table 2. Well Product Cost Comparison
Sieve Analysis

TABLE 1

WELL DESIGN DATA FOR
1 MILLION GALLON PER DAY HORIZONTAL WELL
PACIFIC RESEARCH GROUP, PORT HUENEME, CALIFORNIA

Well Material	Diameter		Open Area		Intake Velocity = 0.01 ft/sec		Intake Velocity = 0.05 ft/sec		Intake Velocity = 0.1 ft/sec	
	Outside (in)	Inside (in)	Percent	Per Foot (ft²)	Flow Capacity (gpm/ft)	Length (ft)	Flow Capacity (gpm/ft)	Length (ft)	Flow Capacity (gpm/ft)	Length (ft)
Schumafilter 200 μm pore (1)	2.95	2.36	36.0%	0.018	0.08	8408	0.41	1682	0.83	841
Schumafilter 200 μm pore (1)	4.92	3.94	36.0%	0.031	0.14	5037	0.69	1007	1.38	504
Schumafilter 200 μm pore (1)	7.09	5.91	36.0%	0.046	0.21	3358	1.03	672	2.07	336
Hydroquest (2)	2.38	2.00	40.0%	0.017	0.08	8930	0.39	1786	0.78	893
Hydroquest (2)	4.50	4.00	40.0%	0.035	0.16	4465	0.78	893	1.56	446
Hydroquest (2)	6.63	6.00	40.0%	0.052	0.23	2977	1.17	595	2.33	298
Hydroquest (2)	8.63	8.00	40.0%	0.069	0.31	2232	1.56	446	3.11	223
Hydroquest (2)	10.75	10.00	40.0%	0.087	0.39	1786	1.95	357	3.89	179
EnviroFlex (3)	2.38	2.00	3.5%	0.002	0.01	102055	0.03	20411	0.07	10205
EnviroFlex (3)	4.50	4.00	2.7%	0.002	0.01	65984	0.05	13197	0.11	6598
EnviroFlex (3)	6.63	6.00	2.5%	0.003	0.01	47626	0.07	9525	0.15	4763
EnviroFlex (3)	8.63	8.00	2.4%	0.004	0.02	37208	0.09	7442	0.19	3721
EnviroFlex (3)	10.75	10.00	2.1%	0.005	0.02	34018	0.10	6804	0.20	3402
PVC/HDPE, Machine Slot (4)	2.38	2.00	3.5%	0.002	0.01	102055	0.03	20411	0.07	10205
PVC/HDPE, Machine Slot (4)	4.50	4.00	2.7%	0.002	0.01	65984	0.05	13197	0.11	6598
PVC/HDPE, Machine Slot (4)	6.63	6.00	2.5%	0.003	0.01	47626	0.07	9525	0.15	4763
PVC/HDPE, Machine Slot (4)	8.63	8.00	2.4%	0.004	0.02	37208	0.09	7442	0.19	3721
PVC/HDPE, Machine Slot (4)	10.75	10.00	2.1%	0.005	0.02	34018	0.10	6804	0.20	3402
SCH 40 PVC, V-Wire (5)	2.60	2.00	9.9%	0.051	0.23	3013	1.15	603	2.31	301
SCH 40 PVC, V-Wire (5)	4.62	4.00	7.7%	0.081	0.36	1922	1.81	384	3.62	192
SCH 40 PVC, V-Wire (5)	6.61	5.75	6.0%	0.092	0.41	1689	2.06	338	4.11	169
SCH 40 PVC, V-Wire (5)	8.62	7.50	7.6%	0.150	0.67	1032	3.37	206	6.73	103

Notes:
1. Schumafilter percent open area is based upon a reported value for the 200μm pore material.
2. Intake flow velocity for the Hydroquest is based upon the filter fabric with an open area percentage larger than that of the PVC screen. This product is currently unavailable.
3. Intake flow velocity for the EnviroFlex is based upon open area percentage of the external well screen.
4. The PVC/HDPE, Machine Slot screen specifications are based on 0.010 slot opening calculated based upon using schedule 40 pipe and the specifications listed below.
5. SCH 40 PVC, V-Wire screen specifications are based on using a Johnson 10 slot screen. Values for open area are reported by Johnson and not calculated in this spreadsheet.
6. The surface area of a cylinder is calculated as ..... pi x d x L, where r is the radius and l is the length of the cylinder.

CALCULATION OF THE OPEN AREA OF STANDARD MACHINE SLOTTED PVC WELL SCREEN

	Outside Dia. (inches)	Inside Dia (inches)	Rows of Slots	Slot Length (inches)	Slot Width (inches)	Slots per Row Foot	Slot Spacing	Open Area (in²/ft)	Open Area (ft²/ft)	Surface Area ft² per foot inside	Open Area Percent
Various Screen Diameters	2.38	2.00	3	1.5	0.01	80	1/8th inch	3.6	0.025	0.087	0.288
	4.50	4.00	6	1.5	0.01	80	1/8th inch	7.2	0.050	0.260	0.192
	6.63	6.00	5	1.9	0.01	80	1/8th inch	7.6	0.053	0.520	0.101
	8.63	8.00	6	2.35	0.01	80	1/8th inch	11.28	0.078	0.867	0.090
	10.75	10.00	7	2.4	0.01	80	1/8th inch	13.44	0.093	1.301	0.072

TABLE 2

WELL PRODUCT COST COMPARISON MATRIX
PACIFIC RESEARCH GROUP
PORT HUENEME, CALIFORNIA

WELL PRODUCT	PILOT STUDY (5K to 15K gpd)				LARGE-SCALE INTAKE (1 MM gpd)			
	SIZE		DOLLARS PER FOOT		SIZE		DOLLARS PER FOOT	
	Diameter (in)	Length (ft)	PVC	HDPE	Diameter	Length	PVC	HDPE
Schumafilter® 200 μm pore	2.00	5.00	35.00		6.00	850.00	55.00	
Hydroquest® (Bedrock)	2.00	5.00	22.11	23.59	6.00	750.00	44.00	46.00
EnviroFlex® (Titan)	2.00	5.00	19.25	20.55	6.00	750.00	34.88	36.90
Machine Slotted Screen	2.00/1.00	5.00	2.09	2.38	6.00/4.00	1500.00	16.54	21.88
Plastic V-Wire Screen	2.00	5.00	7.22	N/A	6.00	2800.00	31.69	N/A

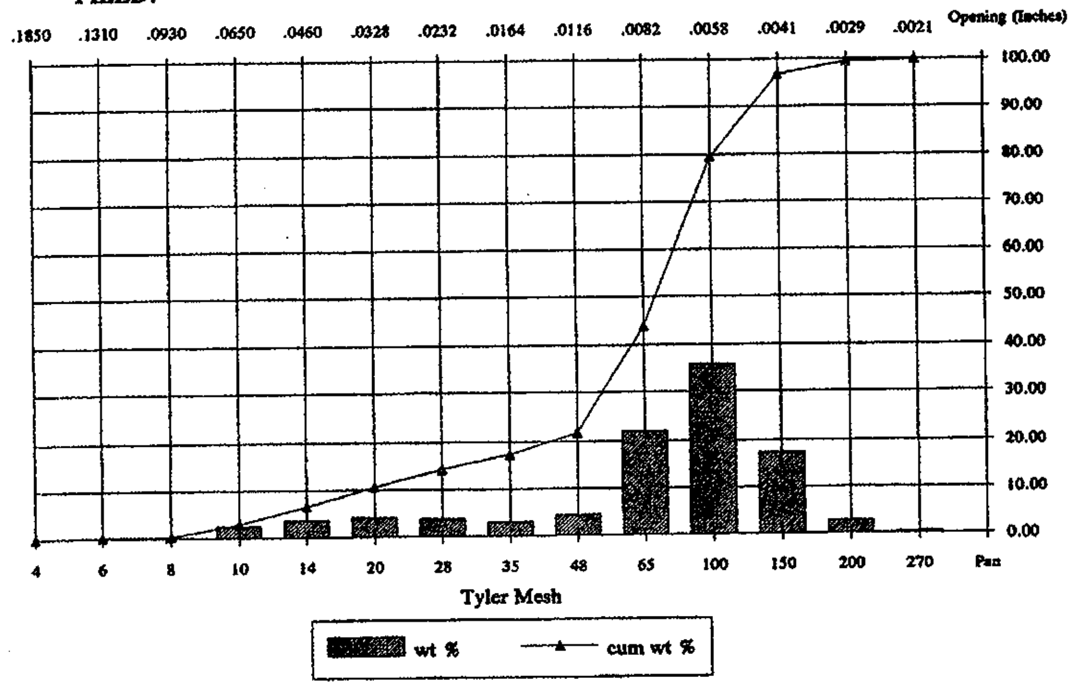
Notes:
1. Schumafilter is only available in polyethylene.
2. Prices on EnviroFlex are quoted on a per project basis.

GOODE CORE ANALYSIS SERVICE

Company: The Source Group, Inc.
WELL:
FIELD:

SIEVE ANALYSIS

FILE NO: 98575
DEPTH: Sea Floor
SAMPLE ID:



Sieve Analysis Tabular Data

Tyler Mesh	Opening Inches	Sample Weight	Percent Total	Cumulative % Weight
4	.1850	0.00	00.00	00.00
6	.1310	0.09	00.21	00.21
8	.0930	0.07	00.18	00.38
10	.0650	1.03	02.48	02.87
14	.0460	1.50	03.60	06.47
20	.0328	1.70	04.09	10.56
28	.0232	1.56	03.75	14.31
35	.0164	1.25	03.01	17.32
48	.0116	1.83	04.41	21.73
65	.0082	9.16	22.02	43.74
100	.0058	14.86	35.72	79.46
150	.0041	7.19	17.28	96.74
200	.0029	1.13	02.73	99.47
270	.0021	0.17	00.41	99.88
Pan		0.05	00.12	100.00
	Totals	41.60	100.0	

Percent Retained	Opening Inches
10	0.0346
20	0.0135
30	0.0103
40	0.0088
50	0.0078
60	0.0071
70	0.0064
80	0.0057
90	0.0048