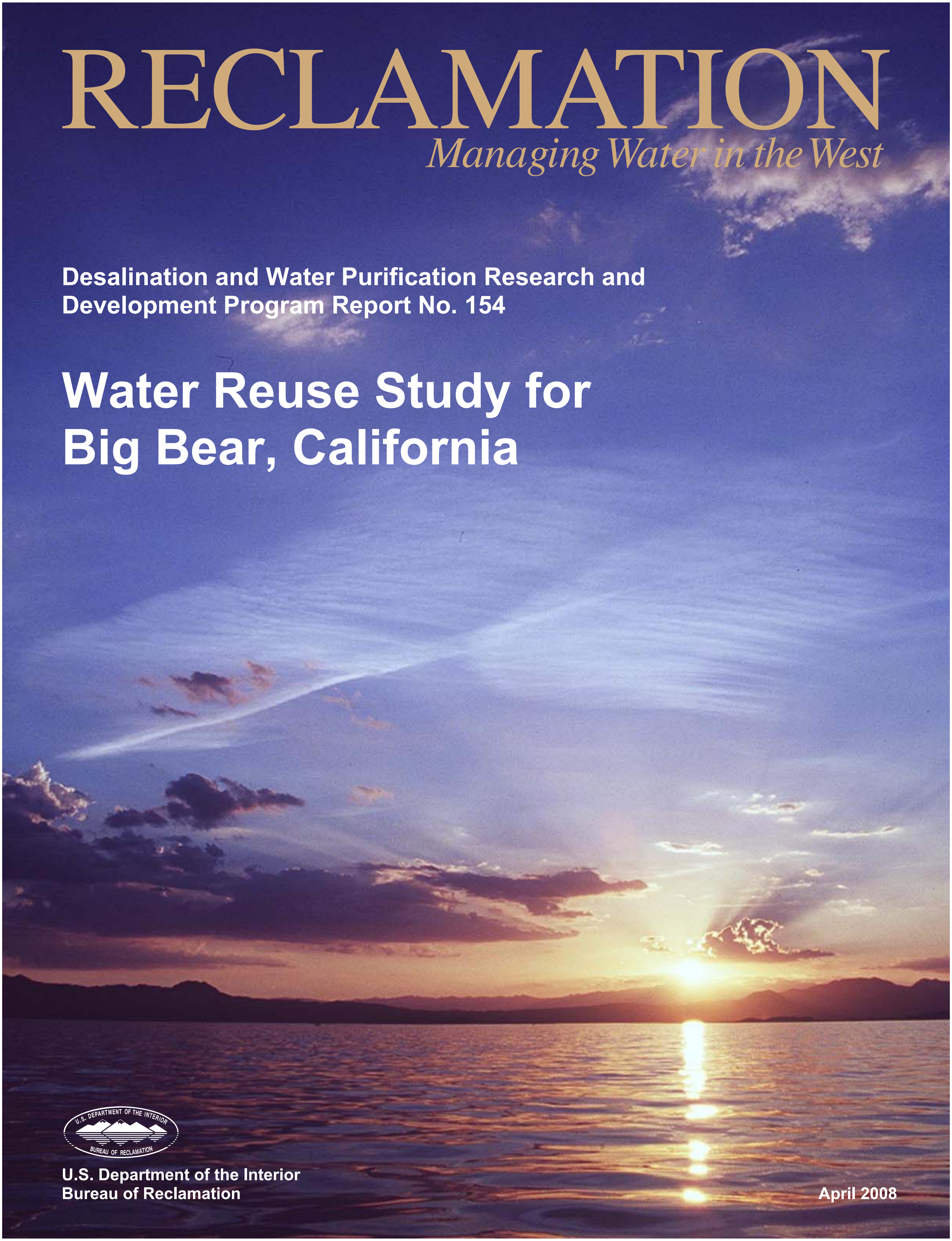
RECLAMATION

Managing Water in the West



Desalination and Water Purification Research and Development Program Report No. 154

Water Reuse Study for Big Bear, California

U.S. Department of the Interior
Bureau of Reclamation

April 2008

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Reverse osmosis (RO) and nanofiltration (NF) were tested using microfiltered municipal wastewater for producing water for irrigation and wetlands habitat. Vibratory shear enhanced processing (VSEP®) was tested for high recovery of RO concentrate. NF concentrate had the best quality for irrigation. Product water from both NF and RO would be pure enough for wetland augmentation. Maximum recovery possible with the VSEP® process was 93.5%. Cost estimates and preliminary design are provided for a 1-million-gallon-per-day ultrafiltration (UF)/RO and UF/NF system.

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Prepared for
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by

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U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water and Environmental Services Division
Water Treatment Engineering Research Team
Denver, Colorado

April 2008

MISSION STATEMENTS

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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.

Disclaimer

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Acronyms

BBARWA	Big Bear Area Regional Water Authority
Ca	calcium
CIP	clean-in-place
da	dalton
DBP	disinfection byproducts
DHS	California Department of Health and Safety
dS/m	decisiemens per meter
EC_w	electrical conductivity
EPA	U.S. Environmental Protection Agency
ft^2	square feet
gal/d	gallons per day
gfd	gallons per square foot per day of membrane
hr-sq m	hour-square meter
in	inch
kPa	kilopascal
m	meter
m^2	square meter
m^3/day	cubic meters per day
MCL	maximum contaminant levels
MF	microfiltration
MFL	magnetic flux leakage
Mg	magnesium
mgd	million gallons per day
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm	millimeter
mol/L	mole per liter
mrem/yr	millirem per year
mS/cm	microsiemens per centimeter
MTBE	methyl tertiary butyl ether
Na	sodium
NF	nanofiltration

Acronyms (continued)

NSF	National Science Foundation
NTU	nephelometric turbidity unit
pCi/L	picocuries per liter
ppm	parts per minute
psi	pounds per square inch
Reclamation	Bureau of Reclamation
RO	reverse osmosis
SAR	sodium absorption ratio
SCCWRRS	Southern California Comprehensive Water Reclamation and Reuse Study
SDI	silt density index
S/cm	siemens per centimeter
TDS	total dissolved solid
TIN	total inorganic nitrogen
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
UF	ultrafiltration
USGS	U.S. Geological Survey
VSEP®	vibratory shear enhanced separation process
WWTP	waste water treatment plant
°C	degrees Celsius
°F	degrees Fahrenheit
µg/L	micrograms per liter
µm	micrometer
µS/cm	microsiemens per centimeter
%	percent

1.0 Executive Summary

As water supplies in the West continue to be strained due to drought and increasing demand, water use prioritization and reuse have become important in the management of this valuable resource. To address this issue in southern California, a partnership has been formed of many southern California water utilities and regulatory agencies. This study has been undertaken as a part of the overall Southern California Comprehensive Water Reclamation and Reuse Study (SCCWRRS) to identify ways to treat municipal waste water to meet secondary water requirements such as habitat maintenance, crop irrigation, and construction water.

The Bureau of Reclamation (Reclamation) Southern California Area Office, in partnership with the Big Bear Area Regional Water Authority (BBARWA) and the Reclamation Science and Technology Research Office, joined resources to test microfiltration (MF) followed by nanofiltration (NF) and reverse osmosis (RO) to determine the qualities of water produced from the secondary effluent of the BBARWA Waste Water Treatment Plant (WWTP). The MF system was purchased by BBARWA. A 6-gallon-per-minute NF/RO system was provided by the Reclamation Water Treatment Engineering and Research Group. The unit had been built for the Port Hueneme Water Reuse Demonstration Plant, but they needed the room for expansion of their processes.

For the first year, the system was loaded with "loose" NF membrane with salt rejection of 60-70 percent (%) depending on the makeup of the feed water. The system was operated with a slight pH adjustment for most of the year with no problem. Operating pressure was 60 pounds per square inch (psi). The inorganic water analysis showed that the product water met the U.S. Environmental Protection Agency (EPA) and California Department of Health Services requirements for infiltration into drinking water aquifers. Organic analysis was not performed at this time.

During the second year, RO membranes were installed into the system with salt rejection of 99%, water recovery of 75%, and operating pressures of 130 psi. Operation during this year was more sporadic than the NF operation, mainly because of other activities at the WWTP. This water met the infiltration water quality requirements and also EPA drinking water quality specifications.

The concentrate from both the NF and the RO had low sodium absorption ratios of 1.7 and 3.7, respectively, with conductivities of 1.6 and 2.35 decisiemens per meter, respectively. These values are well within the range of Food and Agriculture Organization irrigation water guidelines for crops. The boron level in the RO concentrate was 470 micrograms per liter (µg/L) which is high for sensitive crops. The NF concentrate boron concentration was only 146 µg/L.

Design parameters and comparative cost estimates are provided for ultrafiltration (UF)/NF and UF/RO systems to produce 1 million gallons per day of product water. The costs are very close at $3.5 million for construction cost and $1.4 million annual cost. The NF option is $100 thousand more in capital cost and $100 thousand per year less in operation and maintenance cost. However, there may be further cost savings in operating without chemical adjustments that are not reflected in the cost model.

During the final year of testing, CH2M Hill operated the system to obtain data for design of a full-scale plant. Operating data and water analysis data from that period are included in this report. During the last month of testing, a vibratory shear enhanced separation (VSEP®) process was tested to maximize recovery from the system. With the 1-gallon-per-minute unit, it was possible to attain 97.7% overall recovery from the RO/VSEP® process. Since the objective of the original project was to provide water for aquatic habitat and for irrigation with the concentrate, the VSEP® process is not included in the design and cost estimate.

2.0 Background and Introduction

Water utilities and regulatory agencies of southern California have formed a partnership with the Southern California Area Office of the Bureau of Reclamation (Reclamation) to complete a Comprehensive Water Reclamation and Reuse Study. The study, authorized by the Title XVI Water Reuse and Recycling Program, was organized into Phase IA, Phase IB, and Phase II.

- During Phase IA, the cost-sharing partners, along with Reclamation, developed an extensive database of existing and potential recycled water demands and supplies, land use, environmental assets, and local water and waste water agency recycling plans.
- During Phase IB, planning tools were developed with which to analyze the data and evaluate the benefits of regional water recycling strategies.
- During Phase II, the cost-sharing partners opened the planning process to all southern California water and waste water agencies, to work together in partnership using the tools and database developed in Phase I.
- The product of Phase II of the Southern California Comprehensive Water Reclamation and Reuse Study (SCCWRRS) was the generation of a list of 34 short-term projects for implementation by 2010, as well as the development of a long-term regional recycling strategy for projects through 2040.

The short-term projects, which were developed with the assistance of over 80 local agencies, have a total potential yield of approximately 451,500 acre-feet per year of additional recycled water. One of these projects was a water reuse pilot study with Big Bear Area Regional Waste Water Authority.

2.1 Big Bear Area Description

The Big Bear Valley is located in the San Bernardino Mountains (see figure 1). The Valley has a population of approximately 26,200 residents on a full- and part-time basis. The area is continuing to grow and experiences approximately 50 to 100 new sewer line connections per year. The service area for the Big Bear Area Regional Wastewater Authority (BBARWA) includes the entire Big Bear Valley (79,000 acres). BBARWA serves three separate collection systems: the city of Big Bear Lake, representing approximately 62 percent (%) of the total flow; the Big Bear City Community Services District, representing approximately 34% of the total flow; and the county of San Bernardino Service Area 53B, representing approximately 4% of the total. Each underlying agency maintains and operates its own waste water collection system and delivers waste water to the agency's interceptor system for transport to the regional plant (see figure 2).

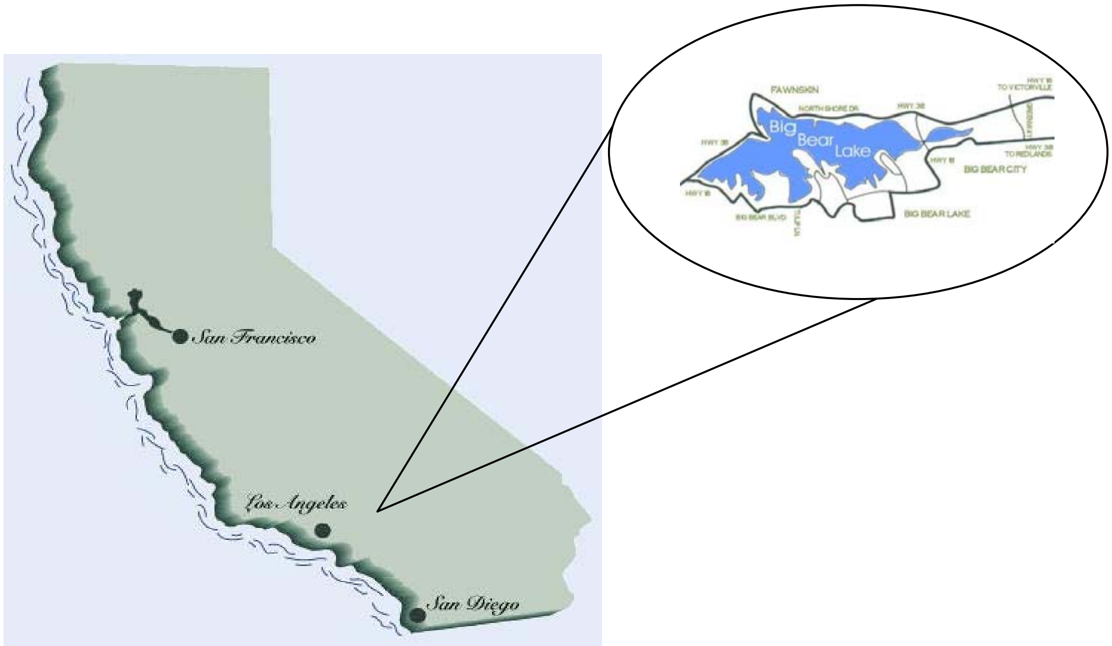

Figure 1. Regional View of Big Bear Area.

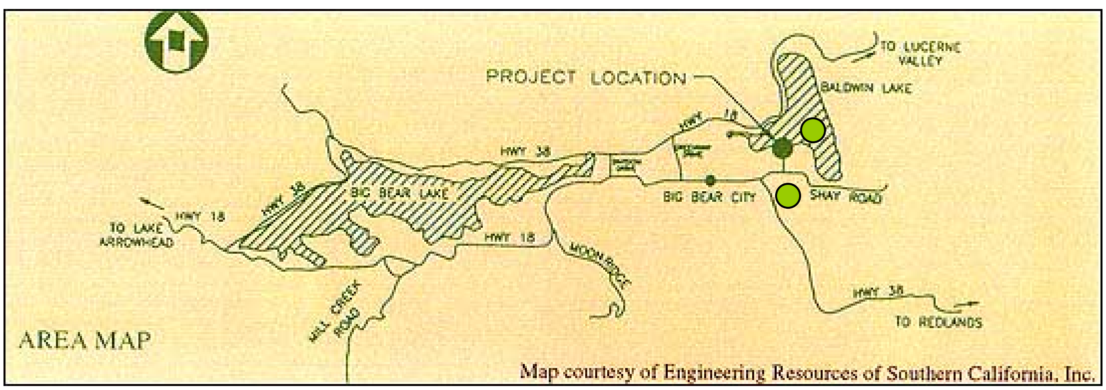

Figure 2. BBARWA Service Area Showing the Waste Water Treatment Plant and Stickleback Fish Environment.

The local water resources are limited, and there is no water available for import. To meet the increasing needs of the community, BBARWA has been investigating other ways to augment the current ground water supplies in a reliable, long-term, and locally controlled manner. Recycled waste water from BBARWA Waste Water Treatment Plant (WWTP) was suggested as one alternative for augmenting the current water supply in the area. From 2003 to 2006, BBARWA tested systems for advanced treatment of effluent from the waste water treatment plant to produce recycled water for beneficial use in the Big Bear Valley.

2.2 Current Waste Water Treatment Process

The BBARWA WWTP, diagramed in figure 3, is an oxidation ditch, activated sludge process with a process design capacity of 4.9 million gallons per day (mgd) that currently treats an average flow of 2.2 mgd. The secondary treatment at design capacity (4.9 mgd) produces 2,000 acre-feet per year of treated water for disposal. The secondary effluent is piped to the Lucerne Valley where it is used for the irrigation of alfalfa to feed livestock. Solids from the facility are either composted or incinerated. The plant has consistently achieved total nitrogen and all other effluent discharge requirements (CH2MHill 2004).

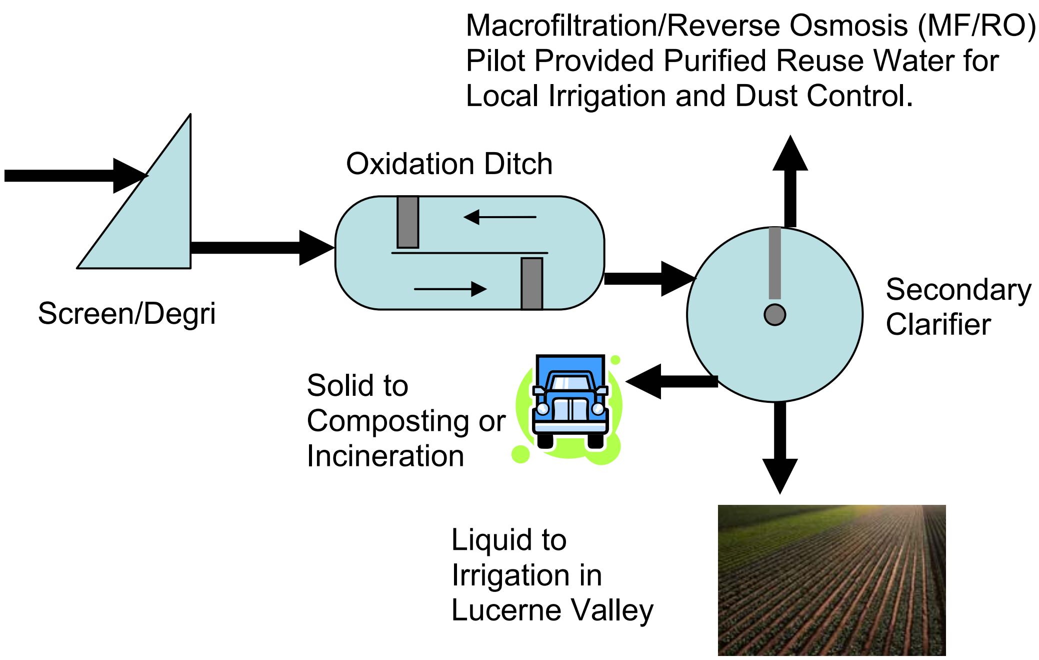

Figure 3. BBARWA Waste Water Treatment System.

2.3 Recycled Water Use in Big Bear

During the course of the study, BBARWA operated a small-scale recycling program via three permits. This recycling program allows distribution of recycled water for construction, irrigation, and other permitted activities.

Within this program, BBARWA had approximately 139 accounts of various types. Irrigation users comprise the largest number of accounts, but they use significantly smaller amounts of water than construction users. In 2004, over 11 acre-feet of recycled water was sold, with only 12 % supplied to irrigation users. Irrigation use currently is permitted via a valley-wide permit, where recycled water is delivered to individual homeowners via trucks and distributed from onsite holding tanks.

2.4 Study Objectives

The two objectives for the water reuse project are:

1) To determine the appropriate level of treatment to produce water conducive to wildlife habitat and/or irrigation of high value crops, while maintaining a useful concentrate stream for feed crop irrigation.

2) To evaluate treatment technologies to define parameters that would be needed to develop a cost estimate and design a full-scale system.

2.4.1 Level of Treatment

The concern with using waste water effluent for aquatic habitat is the concentration of pharmaceuticals and other household products that are more hazardous to aquatic species than to humans. These compounds are called "emerging contaminants" and include steroids, nonprescription drugs, insect repellents, detergent metabolites, disinfectants, plasticizers, fire retardants, and several other widely used compounds. Kolpin and co-authors from the United State Geological Survey (USGS) (2002) analyzed samples from 139 sites across the country likely to be exposed to municipal, industrial, or agricultural waste water. They found members of these top seven categories of compounds in over 60% of the streams tested. While not regulated at this time, there is evidence that this class of contaminants affects the endocrine system of fish in very low doses and may have synergistic effects when combined.

Another concern for high value food crops is the presence of pathogenic bacteria and virus that could become incorporated or imbedded in the produce making it unfit for consumption without severe sterilization, which would harm the food value of the crop. Therefore, it is necessary to use a good barrier technology with disinfection to ensure that the product water will be safe to use on valuable food crops.

Finally, the concentrate must retain value for irrigating feed crops for livestock. That is the current use of the waste water system effluent from the Big Bear Valley. The ranchers are dependant on this source of water to supplement other sources of irrigation water.

2.4.2 Evaluation of Nanofiltration (NF) and RO Product Water Quality

NF membrane performance was compared to RO membrane performance to find which level of separation would be required to meet the treatment objectives. NF membrane separation is specified as a percent rejection of magnesium chloride and can vary widely depending on what other ions are present. If the quality is acceptable, the low-pressure NF membranes would save on pumping energy.

2.4.3 Concentrate Minimization

In the event that concentrate would not be required for irrigation, the vibratory shear enhanced processing (VSEP®) process was tested to determine the maximum recovery attainable. It uses either NF or RO flat sheet membrane in stacks that are vibrated during the separation process. The vibration energy helps keep scale and particulate buildup from forming on the membrane surface.

3.0 Methods and Equipment

Microfiltration, reverse osmosis, and ultraviolet (UV) disinfection units were installed and tested at the BBARWA WWTP from August 2004 to April 2006. Figure 4 is a schematic diagram of the advanced water treatment pilot system, illustrating the major processes and approximate flow rates through the different stages of the system.

3.1 Microfiltration Unit

The Memcor 3M10C microfiltration unit was used during this pilot test. This unit model has three M10C hollow fiber membrane cartridges. See table 1 for the MF M10C membrane specifications. The membranes have a nominal pore size of 0.2 microns and are intended to remove particulate material, including protozoa and bacteria. The water flow through the membranes follows an outside-in path, meaning that pressurized feed water is introduced to the outside surface of the fiber, and filtrate water is collected on the inside of the fiber.

3.1.1 Pretreatment

The BBARWA secondary effluent has relatively low iron, manganese, aluminum, and arsenic concentrations and does not require pretreatment prior to MF for successful operation of the system. No pretreatment was necessary for removing organic carbon. Chloramines were added to the feedwater prior to the MF system to minimize biological growth. The MF membranes are not tolerant to chlorine; however, they can withstand exposure to chloramines. Aqueous ammonia and sodium hypochlorite were added to the MF feed to produce chloramines. The target dose was 1.0 to 2.0 milligrams per liter (mg/L) as a continuous feed to the system.

3.1.2 Operation

The Memcor 3M10C has two modes of operation: filtration and backflush. During the filtration mode, product water is generated and suspended materials collect on the outside of the membrane fiber. This unit only operates in a dead-end mode meaning that there is no feed water recirculation. As the suspended solids collect on the membrane surface, the pressure difference between the outside of the fiber and the inside increases. When a sufficient increase in transmembrane pressure occurs, the system requires a backwash to remove suspended solids from the membranes surface, by pushing water in an inside-out flow configuration to re-move the solids. See figure 5 for a schematic diagram of the Memcor 3M10C microfiltration unit and table 1 for specifications of the unit. The MF unit flux was 33 gallons per square foot per day (gfd) of membrane and operated at 70% recovery.

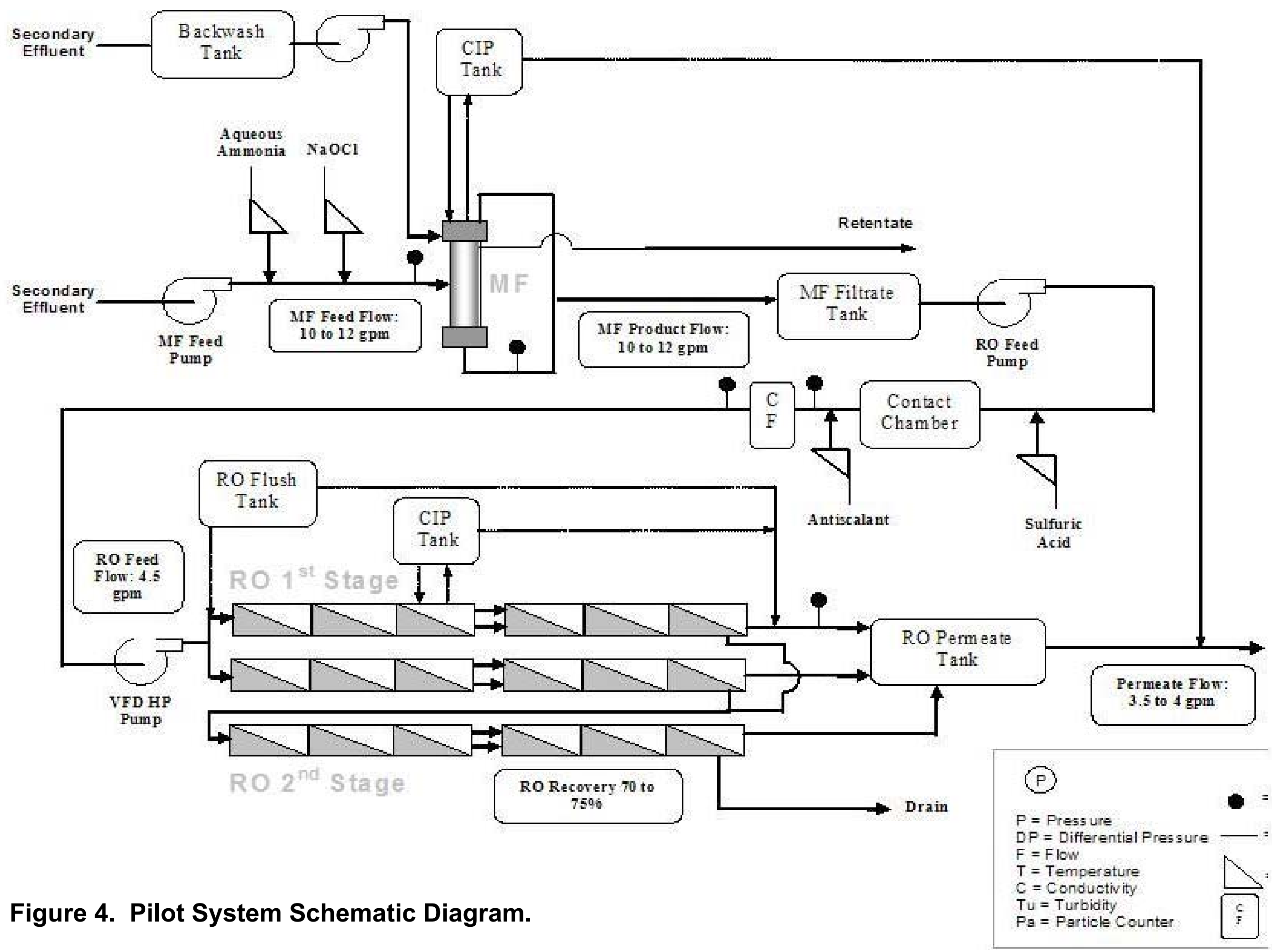

Figure 4. Pilot System Schematic Diagram.

Table 1. MF 3M10C Membrane Specifications[1]

Characteristic	Units	Value
Membrane manufacturer		US Filter Memcor Products
Membrane Model/Commercial Designation		M10C
Operating modes		Continuous microfiltration (CMF)
Approximate size of membrane module	in (m)	45.5 (1.157) long x 4.7 (0.119) dia
Active membrane area	ft^2 (m^2)	360.7 (33.52)
Number of fibers per module		20,000
Number of modules (operational)		3
Inside diameter of fiber	mm	0.25
Outside diameter of fiber	mm	0.55
Approximate length of fiber	in (m)	38.1 (0.970)
Flow direction		Outside-in
Nominal molecular weight cutoff	Daltons	N/A
Absolute molecular weight cutoff	Daltons	N/A
Nominal membrane pore size	Micron	0.2
Membrane material/construction		Polypropylene/hollow fiber
Membrane surface characteristics		Hydrophobic
Membrane charge		Slightly negative at neutral pH
Design operating pressure	psi (bar)	22 (1.5)
Design flux at design pressure	gfd (1/hr-sq m)	25 gfd typical (42.5)
Maximum transmembrane pressure	psi (bar)	29 (2.0)
Standard testing pH		6.8
Standard testing temperature	degrees Fahrenheit (°F) (degrees Celsius [°C])	68 (20)
Acceptable range of operating pH values		2-13
Maximum permissible turbidity	NTU	500
Continuous chlorine/oxidant tolerance		0.01 mg/L free chlorine 5 mg/L chloramine 0.01 mg/L potassium Permanganate Avoid ozone 0.01 mg/L chlorine dioxide

[1] in = inch; m = meter; ft^2 = square foot; m^2 = square meters; mm = millimeter; psi = pounds per square inch; hr-sq m = hour-square meter; NTU = nephelometric turbidity unit.

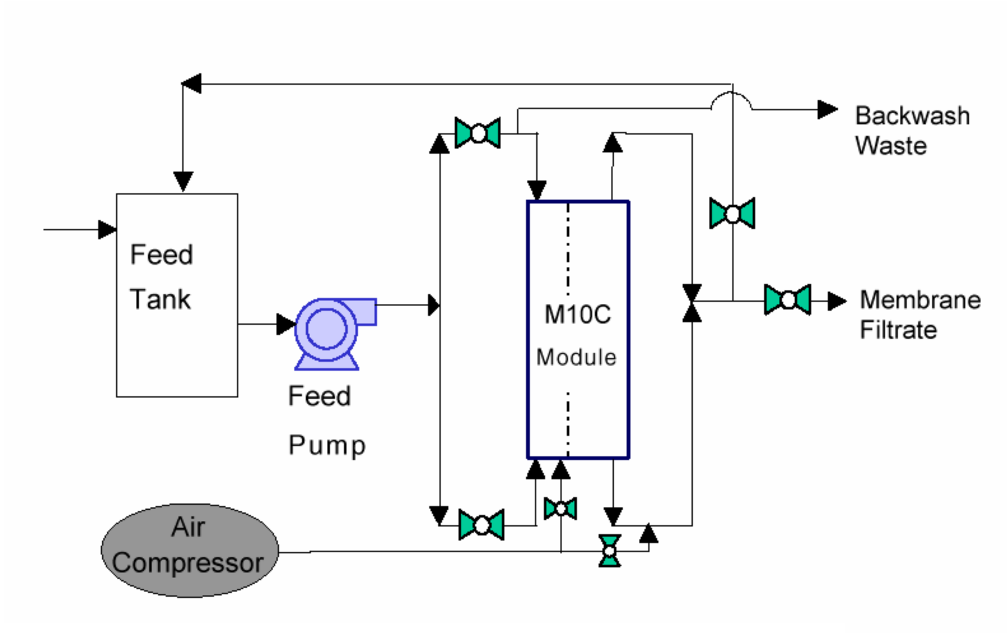

Figure 5. Schematic of the Memcor 3M10C MF Unit (National Science Foundation [NSF], 2003).

Figure 6. Photo of the 3M10C MF Unit (NSF, 2003).

3.2 Reverse Osmosis/Nanofiltration System

The RO/NF system for this testing consists of chemical metering/injection systems for the addition of antiscalant and acid, a contact chamber for acid mixing, a 5-micrometer (μm) cartridge filter, a variable speed, multistage centrifugal pump, and six pressure vessels each holding three membranes. Figure 7 is a diagram of the equipment and plumbing, and figure 8 is a photograph of the unit at its original home at the Port Hueneme Demonstration Plant in California. Figure 9 is a diagram of the instrumentation to monitor the performance of the membranes; including pressure, conductivities, temperature, and flow rates and an Allen-Bradley SLC-5/03 used to control the membrane system and provide safeguards against operational conditions that would damage the unit. WaterEye, a data acquisition program developed by Perlorica, is used to upload data to a remote Web site that can be accessed through a password-secure Web site.

The skid holds 18 2.5- by 40-inch membrane elements in a split 2-1 array with 6 elements in each complete vessel. To save space however, the vessels are split in half with three elements in each one.

The system has a maximum feed flow of 6 gallons per minute with the possibility of 75–80% recovery. As the unit was designed to treat fairly low total dissolved solid (TDS) water from the California State Water Project, the Goulds Model 1SVD multistage centrifugal pump has a maximum pressure of 280 pounds per square inch (psi) when pumping the full 6 gallons per minute. To operate half capacity the pressure will be only 70 psi.

Instrumentation included with the system is listed in table 2. An Allen Bradley SLC 3 is used to control the variable frequency drive to maintain either constant product flow or constant pressure, monitor sensors, and to shut down the system if the supply of feed water should run out or the pressure gets too high.

Table 2. Instrumentation for the RO/NF System

Parameter	Raw Water	Feed	Interstage	Concentrate	Permeate
Flow		X		X	X
Temperature	X	X			
Pressure		X	X	X	
pH	X	X			X
Conductivity	X		X	X	X
Turbidity	X				

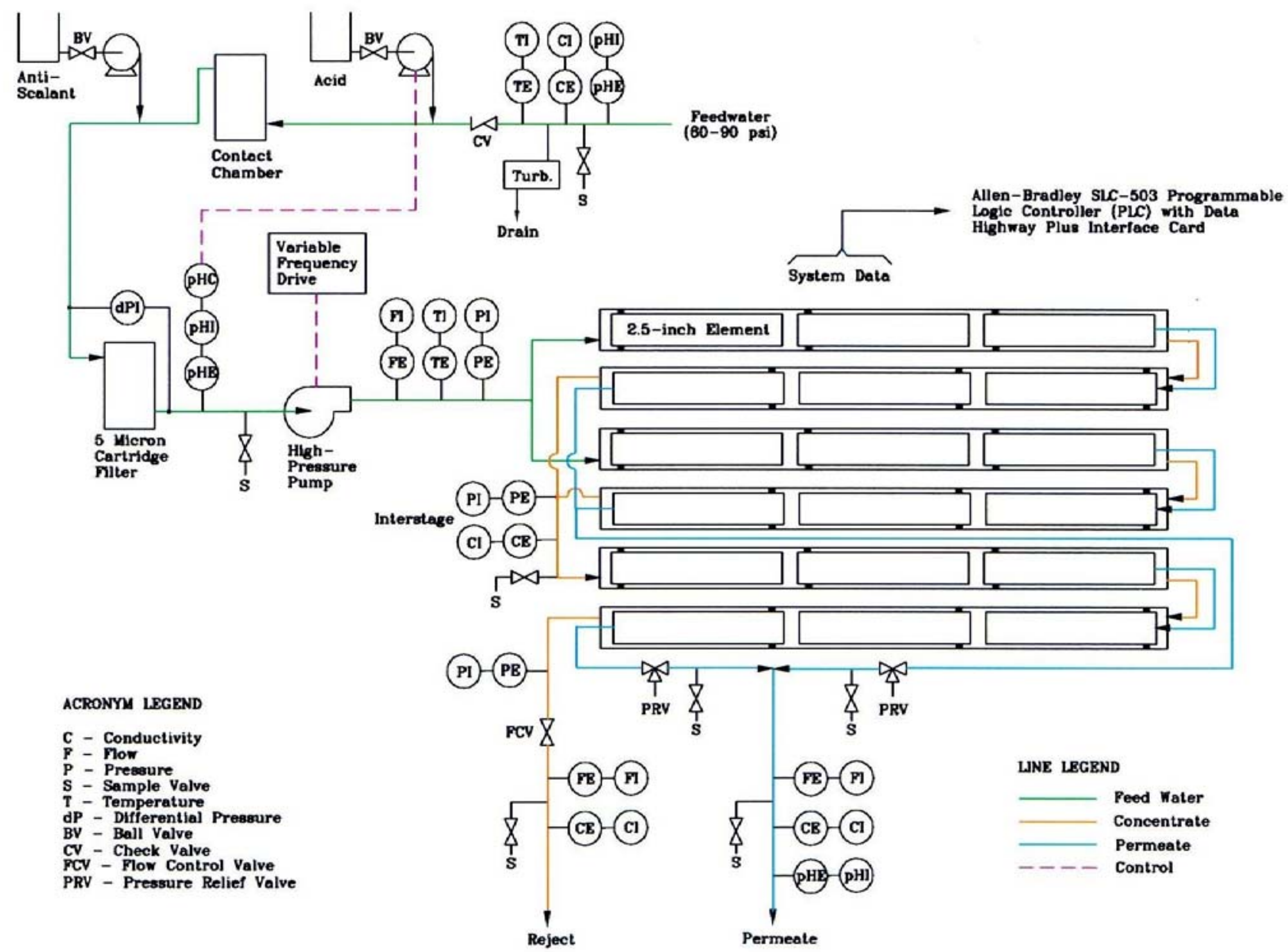

Figure 7. RO/NF Test Skid Diagram.

Figure 8. Reclamation RO/NF Test Skid.

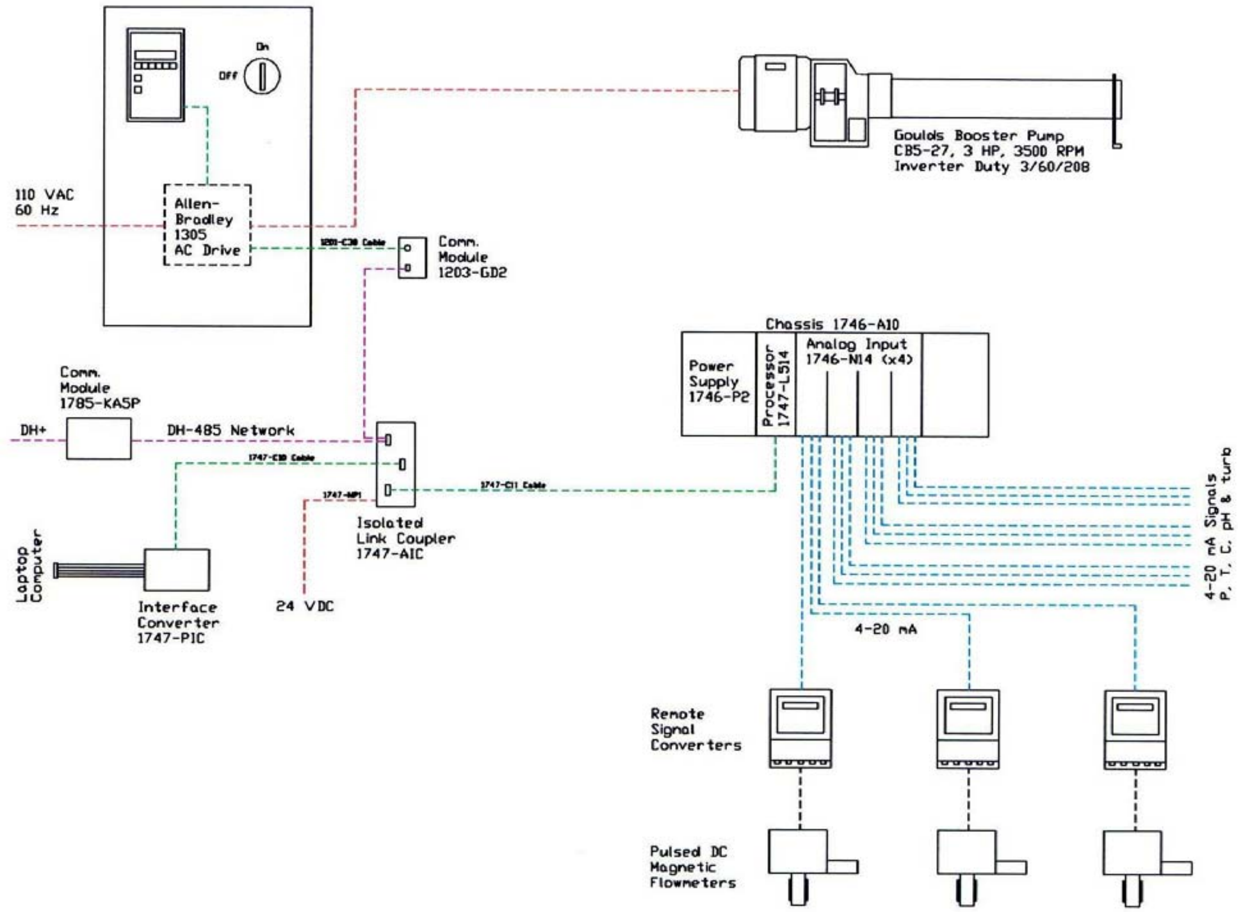

Figure 9. Data Acquisition and Control System.

Data was automatically recorded into an Excel spreadsheet during the first 2 years of testing. An Excel macro was developed to copy data from the SLC-503 each 15 minutes through RSLinx, a Rockwell Software communications program. The operators were required to save the file and start a new one each day. When CH2M Hill took over, a DSL line was provided to the test facility to allow data monitoring online through WaterEye service. WaterEye provides autonomous remote monitoring of processes (Perlorica, 2003). Their RO normalization and cleaning projection software was developed under a cooperative agreement through Reclamation's Desalination and Water Purification Research Program.

3.2.1 Data Collection and Analysis

During the first 2 years of testing, the operators periodically would e-mail the saved data sheets. Invalid data points where the system was off, or in the midst of starting, were discarded. Still the record was exceedingly large. If the "start recording" button was pushed more than once, then dual recording periods would be set in motion. The data point collected near the top of the hour was used for presentation purposes.

WaterEye provides a relatively stable data recording service, collecting data every 15 minutes. The higher frequency is good for detecting problems but creates a huge amount of data to fit onto a graph. Here again, data where the system was off, or in the midst of starting, were discarded. Then the data was sorted by minute and hour to select the point collected at the top of the hour at even hours for presentation purposes. Setting rules for data thinning creates an unbiased, manageable data set.

Differential Pressure

$$\Delta P_1 = P_f - P_i \qquad (1)$$

$$\Delta P_2 = Pi - Pc \qquad (2)$$

Where P is pressure, subscript 1 is for the first stage, two for the second, "f" for feed, "i" for interstage, and "c" for concentrate.

Average Osmotic Pressure

$$\pi = \left(\frac{(C_f + C_c)}{2} - C_p \right) * RT \qquad (3)$$

Where C is the concentration in mole per liter (mol/L) of the "f" feed, "c" concentrate, and "p" product, R is the universal gas constant, 8.314 L bar $K^{-1}mol^{-1}$, and T is the temperature in K. The result is the average osmotic pressure in kilopascals (kPa), then converted to psi for this report to maintain consistency of units.

Net Driving Pressure

$$NDP = \frac{(P_f + P_c)}{2} - \pi - P_p \qquad (4)$$

Temperature Correction Factor

$$\mathrm{TCF} = e^{\left[2640*\left(\frac{1}{298.15} - \frac{1}{(273.15+T)}\right)\right]} \qquad (5)$$

Normalized Permeate Flow

$$NPF = \left(\frac{NDP_o}{NDP_i}\right) * \left(\frac{TCF_i}{TCF_o}\right) * F_p \qquad (6)$$

Where subscript "o" is the initial stable value and "i" is the value at time "i."

Conversion from Conductivity to Concentration (mol/L)

The feed and product water analyses completed during the project were used to determine the conversion factor from conductivity to concentration. The concentrate concentration was determined by mass balance using the target recovery rate. Table 3 lists the ionic concentrations used for this analysis. Detailed analyses are provided in the "Results" section.

Table 3. Conversion Factors from Conductivity to Concentration

	Concentration (mg/L)	Conductivity (µS/cm)[1]	Concentration (mol/L)	Conversion Factor (mol*cm)/(µS*L)
Secondary Effluent	425	790	1.42×10^{-2}	1.80×10^{-5}
NF Permeate	384	470	9.49×10^{-3}	2.02×10^{-5}
Calculated NF Concentrate	499	1,145	1.81×10^{-2}	1.58×10^{-5}
RO Permeate	18	25	5.51×10^{-4}	2.20×10^{-5}
Calculated RO Concentrate	1,500	2,475	4.76×10^{-2}	1.92×10^{-5}

[1] µS/cm = microsiemens per centimeter.

Specific Flux, or productivity per unit area and pressure, was not calculated since the system was not optimized for high productivity, but for low chemical use.

3.2.2 NF Membranes

Since the RO/NF system was designed for relatively low pressure, and because the TDS of the Big Bear waste water effluent is quite low, the initial round of pilot testing was conducted with NF membranes following the MF process. The benefits to using NF membranes rather than RO membranes are the reduced operating pressure and the preservation of mineral content in the product water.

Since NF membranes do not have as high a rejection rate for mono-valent ions as RO membranes, it is possible to pass more bicarbonate to the product stream and lessen the requirement for stabilization.

A NF membrane may also pass more of the organic pharmaceuticals and personal care products, but funding was not provided for detailed organic analyses of the NF permeate. Eighteen 2.5-inch-diameter NF-270 Filmtec elements were installed into the two-one membrane array with six elements in each vessel. The split vessel configuration is shown in figure 7; the specifications for the elements are in table 4.

Table 4. Specifications for the NF Membranes[1]

Parameter	Units	Value
Manufacturer		Dow FilmTec
Model Type		NF270
Membrane Chemistry		Polyamide
Construction		Spiral Wound
Applications		Specific Ion Selectivity
Permeate Flow	gal/d (m^3/day)	750 (2.8)
Nominal Rejection		40-60% for $CaCl_2$, >97% $MgSO_4$
Membrane Area	ft^2 (m^2)	28 (2.6)
Typical Operating Pressure	psi (kPa)	130 – 300 (900 – 2,000)
Maximum Operating Pressure	psi (kPa)	600 (4,100)
Maximum Operating Temperature	ºF (ºC)	113 (45)
Maximum Cleaning Temperature	ºF (ºC)	113 (45)
Maximum Continuous Free Chlorine	mg/L	<0.1
Allowable pH – Continuous Operation		3 - 10
Allowable pH – Short Term Operation		1 - 12
Maximum Differential Pressure per Element	psi (kPa)	15 (100)
Maximum Differential Pressure per Vessel	psi (kPa)	50 (340)
Maximum Feed Turbidity	NTU	0.1
Maximum Feed SDI (15 minute)		3
Feed Spacer Thickness	mil (mm)	28 (0.71)
Maximum Number of Elements per Vessel		6

[1] gal/d = gallons per day; m^3/day = cubic meters per day; SDI = silt density index.

3.2.3 RO Membranes

To compare mineral and organic content of the product water when treated with NF to that produced with RO membrane, the second testing session was conducted with high rejection RO membrane. The Fluid Systems® TFC® HR 2.5-inch tape-wrapped membranes were used in this pilot testing (specifications in table 5). These membranes were recommended by Koch for treating waste water effluent. Again, 18 elements were installed in the split-vessel two-one array.

Table 5. Fluid Systems® TFC® HR RO Membrane Specifications

Parameter	Units	Value
Manufacturer		Koch Fluid Systems
Model Type		2540 HR
Membrane Chemistry		Proprietary Thin Film Composite Polyamide
Construction		Spiral wound with tape outerwrap
Applications		High rejection for brackish water treatment
Permeate Flow	gfd (m^3/day)	750 (2.8)
Nominal Rejection		99.4
Membrane Area	ft^2 (m^2)	27.0 (2.5)
Typical Operating Pressure	psi (kPa)	200–450 (1,380–3,105)
Maximum Operating Pressure	psi (kPa)	600 (4,140)
Maximum Operating Temperature	ºF (ºC)	113 (45)
Maximum Cleaning Temperature	ºF (ºC)	113 (45)
Maximum Continuous Free Chlorine	mg/L	< 0.1
Allowable pH – Continuous Operation		4– 1
Allowable pH – Short-term Operation		2.5–11
Maximum Differential Pressure per Element	psi (kPa)	10 (69)
Maximum Differential Pressure per Vessel	psi (kPa)	60 (414)
Maximum Feed Turbidity	NTU	1
Maximum Feed SDI (15 minutes)		5
Feed Spacer Thickness	mil (mm)	31 (0.8)
Maximum Number of Elements per Vessel		6

3.2.4 Cleaning System

A clean-in-place (CIP) system was used to conduct chemical cleaning of the membrane unit. Typically, when the temperature normalized, permeate flow rate through the membrane system drops by 15% from the initial value, salt pressure increases by 25%, or differential pressure across any stage of the system increases by 50%, membrane cleaning is required.

The CIP system used with this unit is shown in figure 10. It consists of a chemical storage tank, an immersion heater, and hoses with the necessary fittings to attach to the ends of two pressure vessels. The CIP system is capable of cleaning two pressure vessels at a time (each vessel holds three elements).

3.2.5 Chemical Addition

The RO/NF system is capable of injecting acid and/or antiscalant. Projections run on the feed water with Nalco's Permacare Global software recommended a slight decrease in pH from 7.8 to 6.9 to achieve a safe 50% recovery without adding antiscalant. Alternatively, we could use 5.40 mg/L of PC-391, an antiscalant from Nalco. The waste water treatment plant already had acid on hand and preferred to

Figure 10. Cleaning Skid with Mix Tank, Heater, Circulation Pump, Cartridge Filter, and Instrumentation.

lower the pH rather than use antiscalant. There was concern about the lingering presence of the antiscalant in the concentrate. Using only acid would give us the worse case scenario for treatment and the best case for preserving options for using the concentrate.

3.3 Vibratory Shear Enhanced Processing – VSEP®

A common issue with membrane treatment is disposal of the concentrate or brine. One of the alternatives for brine disposal that was investigated is the vibrational separation process called VSEP® illustrated in figure 11. In this process, flat sheets of membranes are arranged in stacks. The membrane disk stack is then oscillated above a torsion spring that moves the stack back and forth approximately 7/8 of an inch.

The feed slurry moves at a low flow rate through the membrane stack. A shear action is created by vigorously vibrating the membrane disks in a direction tangent to the faces of the membrane. The shear produced by the membrane's vibration prevents solids and foulants from depositing on the membrane surface. Because particles are not blocking the active membrane surface, approximately 3 to 10 times more throughput is possible compared to conventional cross flow membrane systems.

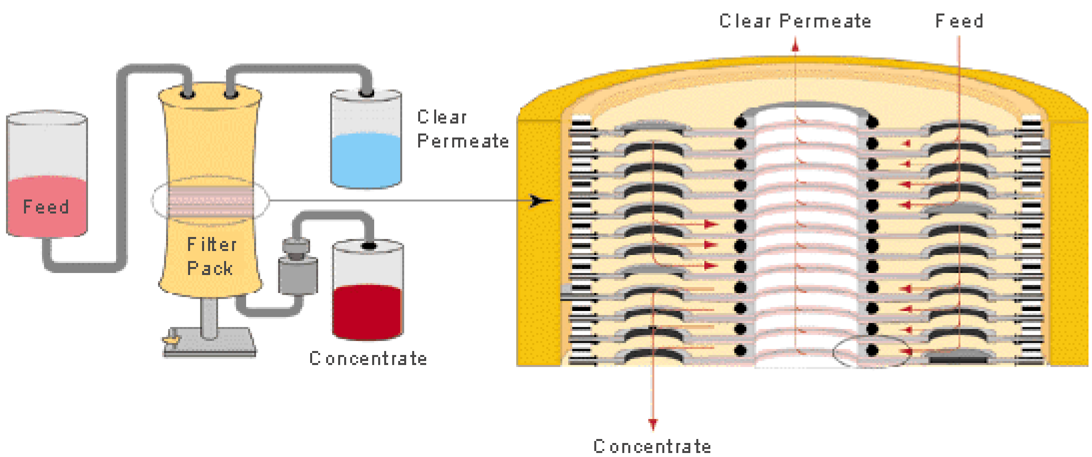

Figure 11. VSEP® System Schematic Diagram (New Logic, 2006).

A high-pressure pump supplies the energy for the VSEP® unit which can handle operating pressures up to 1,000 psi. While higher pressures generate higher permeate flow rates, more energy is consumed. Additionally, higher temperatures can also be employed to achieve a higher flux and a lower operating pressure.

The VSEP® LP model, used in this pilot testing, contains a "filter pack" of flat sheet membrane disks with a total active area of 16.9 ft^2. The feed to the unit is pumped with a positive displacement pump. The feed pressure to the unit can be regulated by adjusting the pump speed. The permeate recovery rate is adjusted by manipulating the automated back pressure regulator on the concentrate outlet, which limits the reject flow from the system. Because of the unique design of the VSEP® unit (vibrational shear within the filter), the concentrate flow rate can actually be held at zero for several minutes, followed by a concentrate purge for a few seconds. This allows for high recovery rates and stable permeate flux rates.

An RO membrane (Fluid Systems® TFC®) was used in the VSEP® unit to achieve maximum concentration of the RO concentrate stream and to obtain the highest possible quality of product water from the VSEP®. Nanofiltration membranes were also evaluated (Fluid Systems® NF-90). See table 6 for membrane properties. If the NF permeate stream was of high enough quality, operation with NF membranes would allow for high flux and recovery rates at lower operating pressures as compared with the RO membranes. The VSEP® Series LP model was used for this pilot test. The unit was used in slipstream mode for the majority of the testing, meaning that some of the RO concentrate was fed continuously to the VSEP® unit and the both the permeate and concentrate streams were discharged from the system.

Table 6. Membranes Used in VSEP® Process[1]

Membrane	Pore Size	NaCl % rej	Composition	Ph Tol	Maximum Temperature	Chlorine Tolerance
LFC	30 da	99.5%	Thin Film Composite	2.5~11.5	60 ºC	<0.1 ppm
NF-90	90 da	90.0%	Thin Film Composite Polyamide	3~10	70 ºC	<0.1 ppm

[1] ppm = parts per minute; da = dalton.

3.4 Equipment Operation

The Memcor microfiltration unit was installed and operated entirely by the BBARWA staff as needed for the local water re-use program or to supply the RO/NF system. The RO/NF system was delivered to Big Bear and installed by Reclamation staff in November 2003. The BBARWA operators were trained on the RO/NF system and operated the system for the duration of the testing period. Table 7 gives the details of various phases of operation.

Table 7. Operations Schedule

<table>
<tr><th>Year</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>2003</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Renovation</td><td colspan="2">Set up at Big Bear</td><td>NF</td></tr>
<tr><td>2004</td><td colspan="3">NF</td><td colspan="4">Shut Down</td><td>NF</td><td colspan="4">RO</td></tr>
<tr><td>2005</td><td colspan="4">RO</td><td colspan="4">Shut Down</td><td colspan="4">New RO, CH2M Hill Operation</td></tr>
<tr><td>2006</td><td>Fouling/ Clean</td><td colspan="2">RO</td><td>VSEP®</td><td colspan="8">Shut Down</td></tr>
</table>

The system was shut down during the spring and early summer to avoid the high runoff period. Demand for the reuse water for construction and irrigation was low at that time of year.

In September 2005, CH2M Hill began another phase of pilot testing funded by BBARWA to provide data for a full-scale design. The equipment was modified at that time to replace some sensors that had failed, permeate pressure gauges were installed, and the PLC was connected to a DSL line so that WaterEye could be used to monitor the data. CH2M Hill wrote the test protocol and managed the testing of the equipment from November 2005 to the conclusion of the testing in April 2006.

3.5 Water Analysis

For the initial phase of testing, an inorganic water analysis was performed on the waste water plant effluent and the NF product water. It was not feasible to get pharmaceutical analyses at this time. After the RO membranes were installed, the RO product was analyzed for inorganic and organic composition. Two wells in the area were also sampled for comparison as potential supplemental fish habitat water. In the latter phase of the testing, more comprehensive water quality analyses were conducted by CH2M Hill on RO product water.

3.6 Performance Criteria

3.6.1 Water Treatment Objectives

The advanced water treatment system is intended to treat secondary waste water effluent for potential ground water aquifer recharge, and/or aquatic habitat. For ground water recharge, the product is required to meet primary and secondary U.S. Environmental Protection Agency (EPA) drinking water standards listed in table 8. The concentrate from the advanced water treatment system may be used for irrigation purposes. For irrigation or for aquatic habitat, the water must meet the California Department of Health and Safety (DHS) Title 22 recycled water quality requirements.

Table 8. EPA Drinking Water Standards[1]

Inorganic Constituent (µg/L)	Maximum Contaminant Levels (MCLs)				
	California Department of Health Services		Environmental Protection Agency Limits		Regional Water Quality Board Limits
	Primary MCL	Secondary MCL	EPA Primary MCL	EPA Secondary MCL	
Aluminum	1,000	200		50 to 200	200
Antimony	6		6		6
Arsenic	50		50		50
Asbestos	7 MFL		7 MFL		7 MFL
Barium	1,000		2,000		1,000
Beryllium	4		4		4
Cadmium	5		5		5
Chloride		250 mg/L		250 mg/L	10
Chromium (total)	50		100		50
Color		15 units		15 units	15 units
Copper	1,300	1,000	1,300	1,000	1,000
Corrosivity		Noncorrosive		Noncorrosive	Noncorrosive
Cyanide	150		150		150
Fluoride	2,000		2,000		2,100

Table 8. EPA Drinking Water Standards[1] (continued)

Inorganic Constituent (µg/L)	Maximum Contaminant Levels (MCLs)				
	California Department of Health Services		Environmental Protection Agency Limits		Regional Water Quality Board Limits
Iron		300		300	300
Lead	15		15		50
Manganese		50		50	50
Mercury, inorganic	2		2		2
Nickel	100				45
Odor		3 threshold units		3 threshold units	3 threshold units
pH				6.5 to 8.5	6.0 to 9.0
Radioactivity, Gross Alpha	15 pCi/L		15 pCi/L		15 pCi/L
Radioactivity, Gross Beta	50 pCi/L		4 mrem/yr		Zero
Radium-226 + Radium-228	5 pCi/L		5 pCi/L		5 pCi/L
Selenium	50		50		5
Silver		100		100	50
Specific Conductance (EC)		900 umhos/cm			
Strontium-90	8 pCi/L				8 pCi/L
Sulfate		250 mg/L	500 mg/L	250 mg/L	20 mg/L
Thallium	2		2		2
Total Dissolved Solids		500 mg/L		500 mg/L	300 mg/L
Total Hardness as $CaCO_3$					225 mg/L
Total Nitrogen (TN)	5,000				
	10,000				
Tritium	20,000 pCi/L				20,000 pCi/L
Turbidity		5 NTU	1.0/0.5/0.1 NTU		5 NTU
Uranium	20 pCi/L		20 pCi/L	Zero	20 pCi/L
Zinc		5,000		5,000	5,000

[1] MFL = magnetic flux leakage; µg/L = microgram per liter; pCi/L = picocuries per liter; mrem/yr = millirem per year.

3.6.2 Sodium Absorption Ratio

The odium absorption ratio (SAR) is a calculation of the suitability for a water source for irrigation (figure 12). The equation for the calculation is:

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{+2}]+[Mg^{+2}]]}{2}}} \qquad (7)$$

The concentrations of sodium (Na), calcium (Ca), and magnesium (Mg) are in milli-equivalents per liter. When irrigation water has high SAR values, above three, then much more control is needed in controlling salt accumulation. Water with high SAR can be used if enough water is applied to wash the salts down below the root zone of the crops.

The SAR and electrical conductivity (EC_w) of the water must be considered together to determine the probably affect of using the water for irrigation. When the source water has a higher conductivity, then there is a greater potential for salt damage at lower SAR levels. EC_w is normally expressed as decisiements per meter (dS/m) which is the same as siemens per centimeter (S/cm). Conductivity is reported in this document as microsiemens per centimeter (mS/cm).

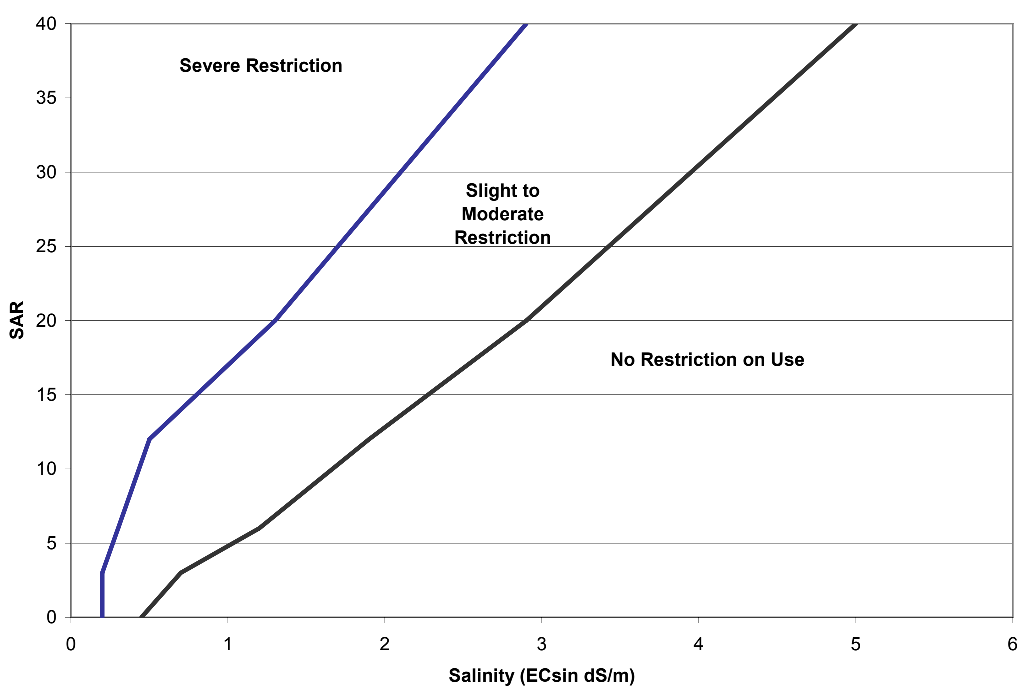

Figure 12. Suitability of Water for Irrigation. From data in Ayers and Westcot, 1994.

4.0 Results and Discussion

4.1 Secondary Effluent Water Quality

Table 9 lists the WWTP secondary effluent quality from January to June 2004.

Table 9. Secondary Effluent Quality January 2004 to June 2004

Parameter	Unit	Detection Limit	Average	Minimum	Maximum	Standard Deviation
Alkalinity	mg/L	3.0	238	193	278	29.2
Ammonia – N	mg/L	0.01	1.46	0	9	1.8
Antimony	mg/kg[1]	6.0	ND			
Arsenic	mg/L	2.0	ND			
Beryllium	mg/L	1.0	ND			
BOD_5	mg/L	4.0	4.99	4	42	5.20
Boron	mg/L		0.24	0.10	0.56	0.12
Cadmium	µg/L	1.0	ND			
Calcium	mg/L	1.0	67	59	72	5.83
Chloride	mg/L	1.0	42.6	19	56	7.73
Copper	mg/L	20	ND			
Conductivity	µS/cm	1.0	687	363	1,157	70.6
Flouride	mg/L	0.1	0.50	0.20	0.87	0.18
Iron	mg/L	0.02	0.09	0.02	0.35	0.10
Lead	µg/L	10	ND			
Magnesium	mg/L	1.0	22.4	19	26	2.06
Manganese	mg/L	0.010	0.027	0.01	0.061	0.013
Mercury	µg/L	1.0	ND			
Methyl tertiary Butyl Ether (MTBE)	µg/L	3	ND			
Nickel	µg/L	10.0	ND			
Nitrate-N	mg/L	0.2	3.32	0.01	16.2	3.23
Nitrite-N	mg/L	0.1	0.30	0.01	1.68	0.28
Orth-Phosphate P	mg/L	0.1	1.32			
pH		1.0	7.84	7.84		
Selenium	mg/L	5.0	ND			
Silver	mg/L	10.0	ND			
Sodium	mg/L	1.0	57.4	28.0	74.0	12.84

Table 9. Secondary Effluent Quality January 2004 to June 200 (continued)

Parameter	Unit	Detection Limit	Average	Minimum	Maximum	Standard Deviation
Sulfate	mg/L	0.5	34.8	24.9	41.4	4.9
Suspended Solids	mg/L	1.0	9.1	1.0	206	24.0
Temperature	ºF		55.0	40.6	70.5	7.0
Thallium	mg/L	1.0	ND			
Total Inorganic Nitrogen (TIN)	mg/L		5.7	0.7	18.9	3.7
Total Kjeldahl Nitrogen (TKN)	mg/L	0.5	3.0	1	7.4	1.9
Total Chromium	mg/L	1.0	ND			
Total Dissolved Solids	mg/L	10	409	229	481	51.5
Total Nitrogen	mg/L		7.6	2.8	12.7	3.2
Total Phosphorous	mg/L	0.5	1.7	0.06	3.6	1.0

[1] mg/kg = milligrams per kilogram.

4.2 NF and RO Performance During Qualitative Testing

The following sections describe the product water quality and performance during operation of the initial NF and RO membranes.

4.2.1 Product Water Quality

Table 10 lists the product water quality along with representative feed water obtained from the initial testing with the NF and RO membranes. Organo-chlorine pesticides, herbicides, fumigants, carbamates, semivolatile and volatile organic compounds were all nondetect in the water sources and WWTP effluent. As can be seen from this table, the NF-270 membranes did not provide significant removal of inorganic constituents. The NF product did not meet the nitrate standard for drinking water, and the total organic carbon (TOC) level is still high for drinking, considering that it comes from waste water effluent; but it would be suitable for irrigation or wetlands habitat. It may not be appropriate for aquatic habitat; without the pharmaceutical and personal care product analysis, we cannot be certain that this water would be healthy for fish.

One interesting result was the high aluminum in the RO product, but not the NF product. Poly-aluminum chloride is used as a stabilizer for the secondary effluent, but it is added after the MF system intake. Apparently at the time of this sampling, it was added ahead of the RO sample collection point.

Table 10. NF and RO Product Water Analysis from Initial Testing

Analyte	Method	Secondary Effluent January – June 2004	NF Product Sept. 2004	RO Product Oct. 2004
Color (Color Units)	SM 2120B	20*	0	0
Odor (T.O.N.)	SM 2150	64*	0	0
Turbidity	EPA 180.1	1.7*	NM	NM
Bicarbonate (mg/L)	SM 2320 B	300	180	7.3
Carbonate (mg/L)	SM 2320 B	ND	ND	ND
Total Alkalinity (mg/L)	SM 2320 B	240	150	6.0
Calcium (mg/L)	EPA 200.7	61	47	ND
Chloride (mg/L)	EPA 300.0	46	45	ND
Flouride (mg/L)	SM 4500F C	0.3	0.3	ND
Hydroxide (mg/L)	SM2320 B	ND	ND	ND
Magnesium (mg/L)	EPA 200.7	26	11	ND
Nitrate (mg/L as Nitrogen)	EPA 300.0	15.3	33	ND
Nitrite (mg/L as Nitrogen)	SM 1200NO2 B	3.3*	ND	ND
Kjeldahl Nitrogen (mg/L)	EPA 351.2	5.7	7.5	NM
pH	SM 4500H+ B	7.8	7.8	ND
Potassium (mg/L)	EPA 200.7	13	12	ND
Sodium (mg/L)	EPA 200.7	59	59	ND
Sulfate (mg/L)	EPA 300.0	36	14	ND
Specific Conductance (µS/cm)	SM2510	740	470	7
Total Dissolved Solids (mg/L)	SM2540 C	420	280	ND
Total Hardness (mg/L)	EPA 200.7	240	120	ND
Perchlorate (µg/L)	EPA314.0	ND	ND	ND
Cyanide (mg/L)	SM4500CN F	ND	ND	ND
Bromide (mg/L)	EPA 300.0	0.064	ND	ND
Foaming Agents (mg/L)	SM 5540C	ND	ND	ND
Total Organic Carbon (mg/L)	SM5310B	6.5	1.1	ND
Aluminum (µg/L)	EPA 200.7	ND	ND	56
Antimony (µg/L)	EPA 200.8	ND	ND	ND
Arsenic (µg/L)	EPA 200.8	ND	ND	ND
Barium (µg/L)	EPA 200.8	ND	ND	ND
Beryllium (µg/L)	EPA 200.8	ND	ND	ND
Cadmium (µg/L)	EPA 200.8	ND	ND	ND
Boron (µg/L)	EPA 200.7	240	280	ND
Total Chromium	EPA 200.8	ND	ND	ND
Copper (µg/L)	EPA 200.8	ND	ND	ND
Iron (µg/L)	EPA 200.7	43	ND	ND
Lead (µg/L)	EPA 200.8	ND	ND	ND
Manganese (µg/L)	EPA 200.8	13	ND	ND
Mercury (µg/L)	EPA 200.8	ND	ND	ND
Nickel (µg/L)	EPA 200.8	ND	ND	ND

Table 10. NF and RO Product Water Analysis from Initial Testing (continued)

Analyte	Method	Secondary Effluent Jan. -June 2004	NF Product Sept. 2004	RO Product Oct. 2004
Selenium (µg/L)	EPA 200.8	ND	ND	ND
Strontium (µg/L)	EPA 200.8	NM	150	ND
Silver (µg/L)	EPA 200.8	ND	ND	ND
Thallium (µg/L)	EPA 200.8	ND	ND	ND
Total Silica (mg/L)	EPA 200.7	22	NM	ND
Zinc (µg/L)	EPA 200.8	57	ND	ND

[1] NM = not measured; ND = not detected; * = data was not collected in 2004, so 2002 value was used.

4.2.2 Sodium Absorption Ratio

Table 11 lists the calculated values of SAR and EC for the secondary WWTP effluent and the NF and RO product and concentrate. Because the NF membrane used in this study has a very low rejection of sodium, the product water actually has a higher SAR than the feed. This same result is expected for NF membranes, in all situations due to the low rejection of monovalent ions and higher rejection of divalent ions for NF membranes. This is because the calcium and magnesium are reduced, but the sodium concentration is much the same as the feed water. Consequently, the NF concentrate has a lower SAR—it is enriched with calcium and magnesium.

The RO product is depleted of minerals and would be good to use for cleaning salt out of the soil if it must be used for irrigation. There are much more valuable uses for the RO product if it would be socially acceptable. Figure 13 shows where these results fall on the SAR/EC diagram in figure 12. Both concentrate waters are actually acceptable for irrigation with no reduction in rate of infiltration, while the secondary effluent and the NF product waters would result in a moderate reduction in infiltration rate. The RO product would result in a severe reduction in infiltration rate.

Table 11. SAR and EC of Various Water Options

Water Source	SAR	EC (dS/m)	Boron Concentrate
Secondary Waste Water Effluent	1.85	0.620	240 µg/L
NF Product	2.01	0.400	280 µg/L
NF Concentrate	1.73	1.600	146 µg/L
RO Product	Not Applicable	0.010	135 µg/L
RO Concentrate	3.71	2.350	470 µg/L

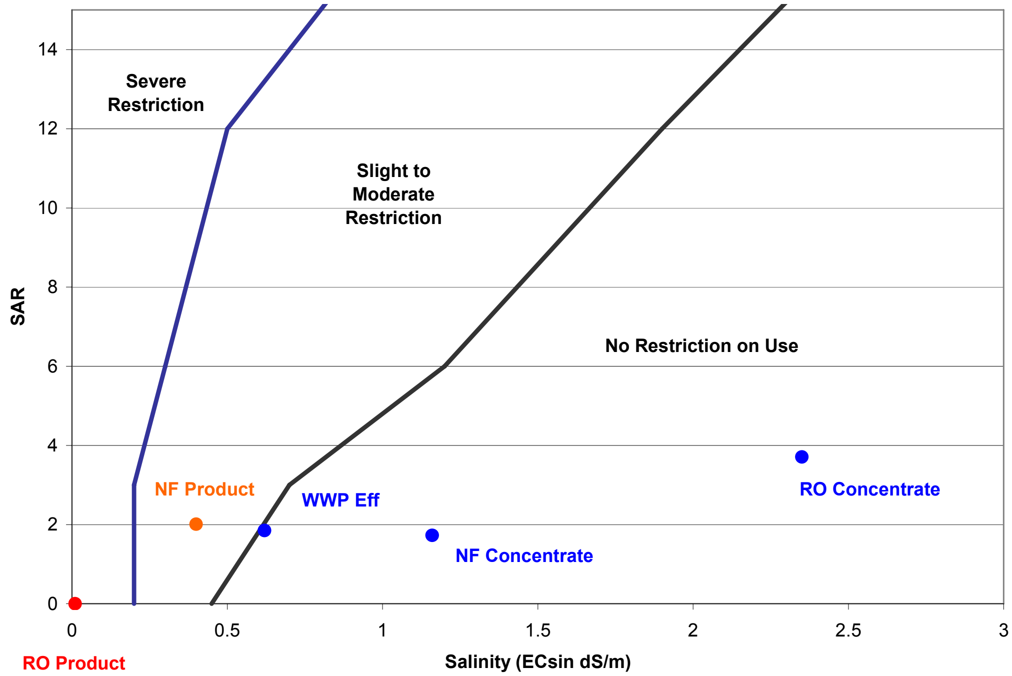

Figure 13. Expanded SAR/EC Diagram with Pilot Results.

Boron concentration in all of the water sources is in the healthy range for most plants. The FAO publication, *Water Quality for Agriculture* (Ayers and Westcot, 1994), says that plants need some boron—but only a small amount. The 0.2 mg/L in the secondary effluent and NF product could be beneficial, but five times that amount could be toxic. Table 12 lists the tolerance level of various crops from Ayers and Westcot (1994). All the water sources listed in table 10 meet the requirements for very sensitive crops.

Table 12. Crop Tolerance to Boron in Irrigation Water

Tolerance Level	Range of Boron Concentration	Crops
Very Sensitive	<0.5 mg/L	Lemon, blackberry
Sensitive	0.5–0.75 mg/L	Avocado, grapefruit, orange, apricot, peach, cherry, plum, persimmon, fig, grape, walnut, pecan, cowpea, onion
Sensitive	0.75–1.0 mg/L	Garlic, sweet potato, wheat barley, sunflower, mung bean, sesame, lupine, strawberry, jerusalem artichoke, kidney bean, lima bean, peanut
Sensitive	1.0–2.0 mg/L	Red pepper, pea, carrot, radish, potato, cucumber
Moderately Tolerant	2.0–4.0 mg/L	Lettuce, cabbage, celery, turnip, kentucky bluegrass, oats, maize, artichoke, tobacco, mustard, sweet clover, squash, muskmelon
Tolerant	4.0–6.0 mg/L	Sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugarbeet
Very Tolerant	60–15.0 mg/L	Cotton, asparagus

4.2.3 NF Operational Data

There were no operational challenges associated with the NF operation. Variations in feed and concentrate flows are the result of feed tank level variation throughout the day. Minimal fouling was observed with these membranes. After a monthlong shutdown after Christmas 2003, the system was flushed with NF product water for a few days to rinse out residual concentrate. After that, the feed tank to the system was kept full—as is apparent from the slightly higher and more stable feed flow rate.

After the flushing period at the end of February 2003, the system was operated at a slightly higher flow rate and recovery without adversely affecting operation. In fact, rejection was improved from 60% to 65%. During March 2004, the acid feed pump failed; but the increase in pH also did not have a negative effect on performance (figure 15). When the pump was replaced, the pH was a bit lower which, again, improved rejection from 65% to 70%. This is probably due to off gassing of some of the carbon dioxide that was passing through the membrane. See figures 14-23.

4.2.4 Initial RO Operational Data

Operation with RO membranes was not as consistent as with the NF membrane (figures 24-29). This could be due to many factors—other activities at the WWTP, the higher recovery rate, or the difference in salt passage, which can cause scaling or fouling problems. Scaling may have been a factor as within a month of changing to RO membrane; the differential pressure, shown in figure 26, for the second stage increased from 15 psi to 70-80 psi. The system was not cleaned during this time, and it was operated only periodically. Operators were instructed to perform a fast flush on the system if it would be shut down for more than a day.

4.3 Long-term RO Performance

At the end of September 2005, CH2M Hill took over the pilot testing. The RO membranes were replaced, further instrumentation added, and the DSL line was installed. Figures 30-36 depict the performance from restart to the end of the study on May 1, 2006. During the time from November 28 to January 8, significant membrane fouling occurred. This fouling was evident by a decrease in feed flow and normalized permeate flow, and an increase in differential pressure and operating pressure. Chemical cleaning using acid and caustic was not successful in restoring the membrane performance.

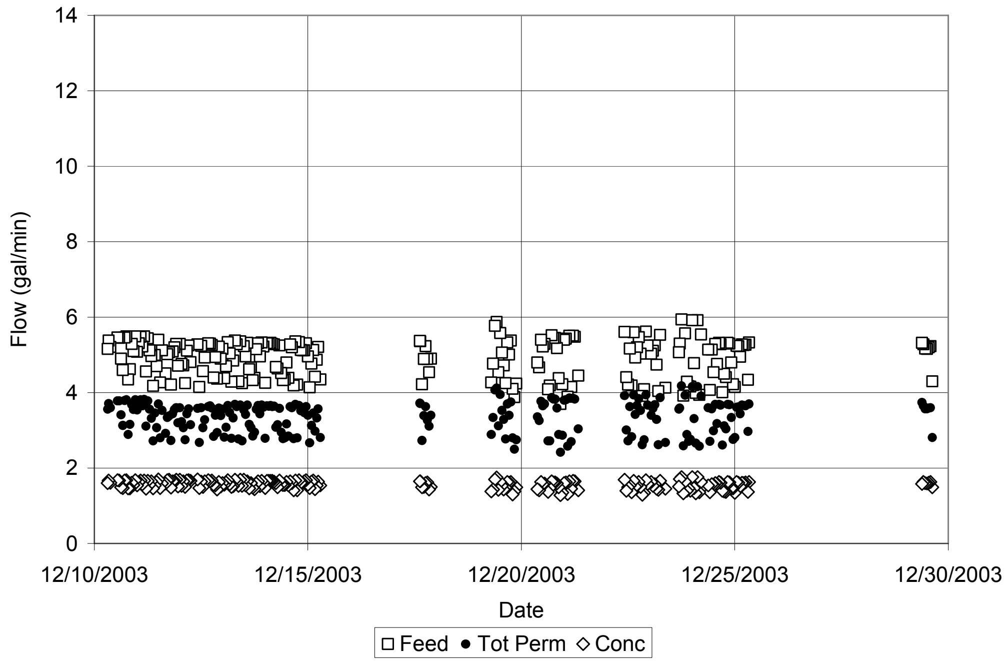

Figure 14. NF Operational Flows in December 2003.

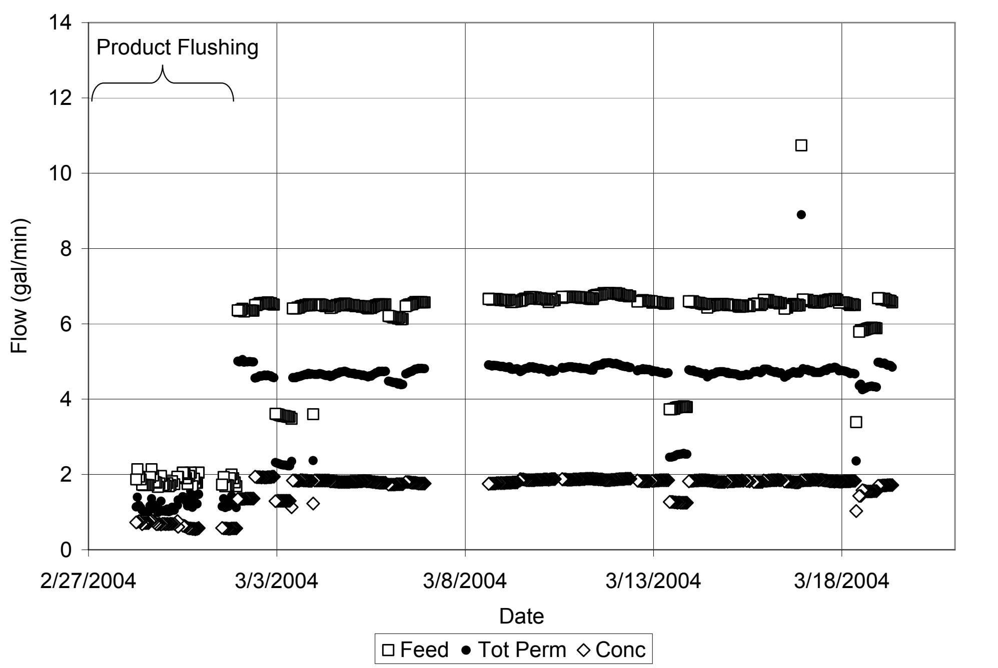

Figure 15. NF Operational Flows During Spring of 2004.

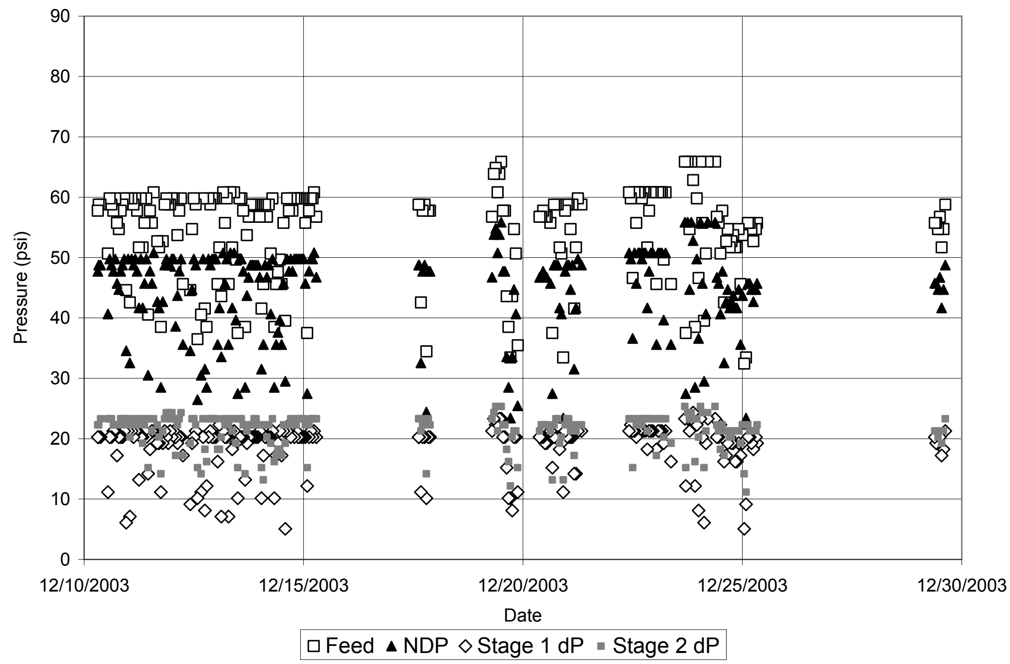

Figure 16. NF System Pressure at Startup.

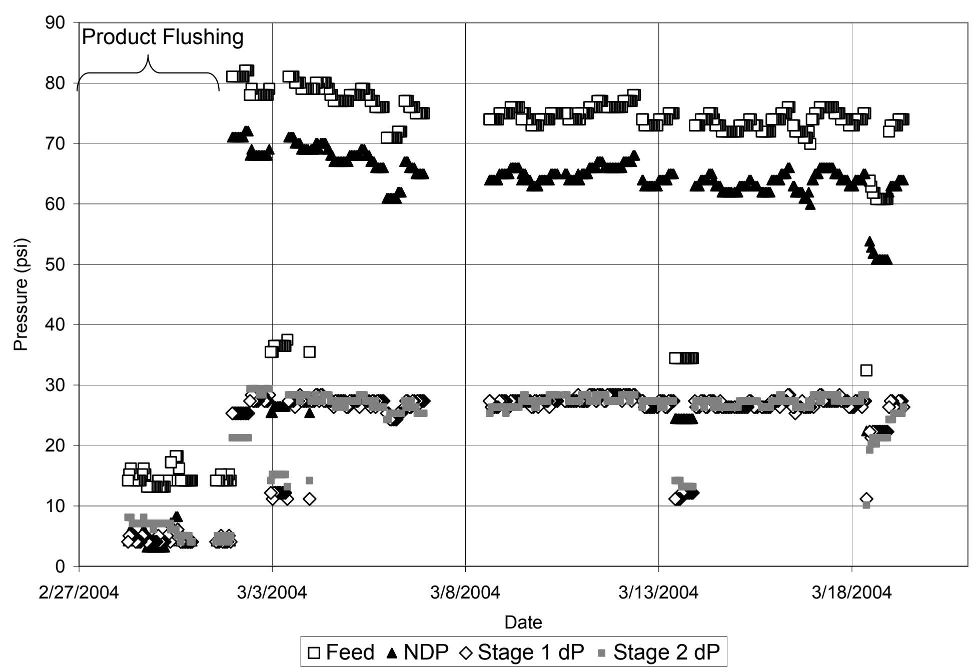

Figure 17. NF System Pressure During Spring of 2004.

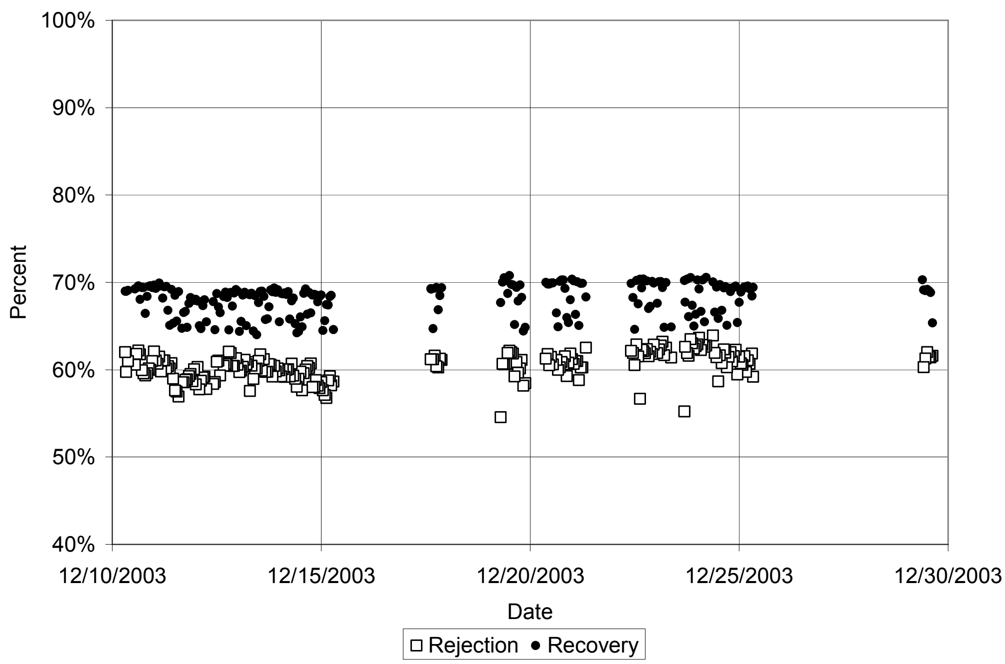

Figure 18. Recovery and Rejection Using NF270 Membrane.

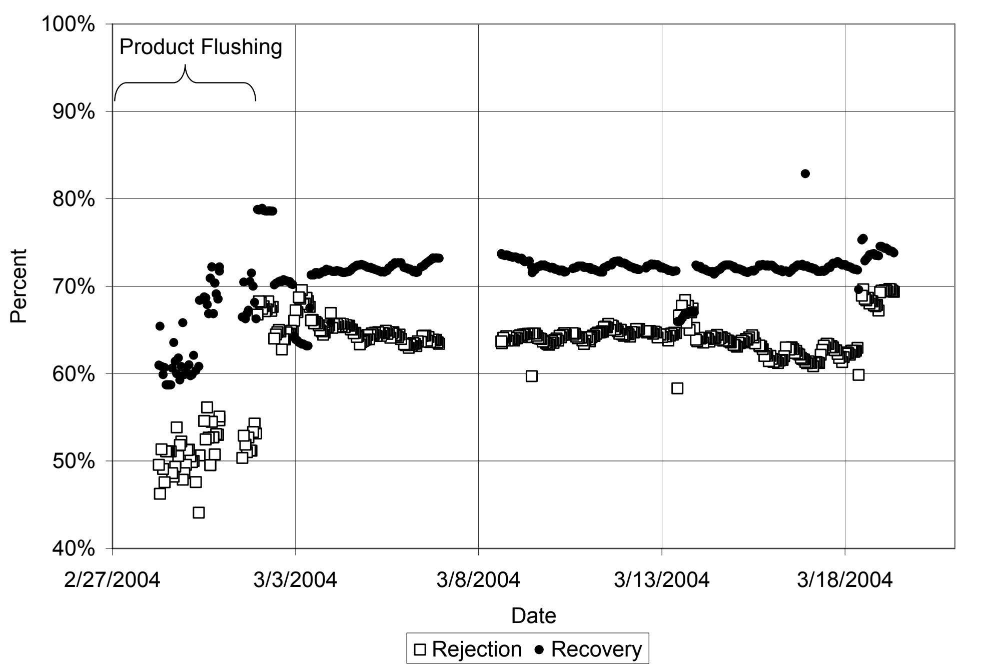

Figure 19. Recovery and Rejection Using NF270 Membrane – Spring of 2004.

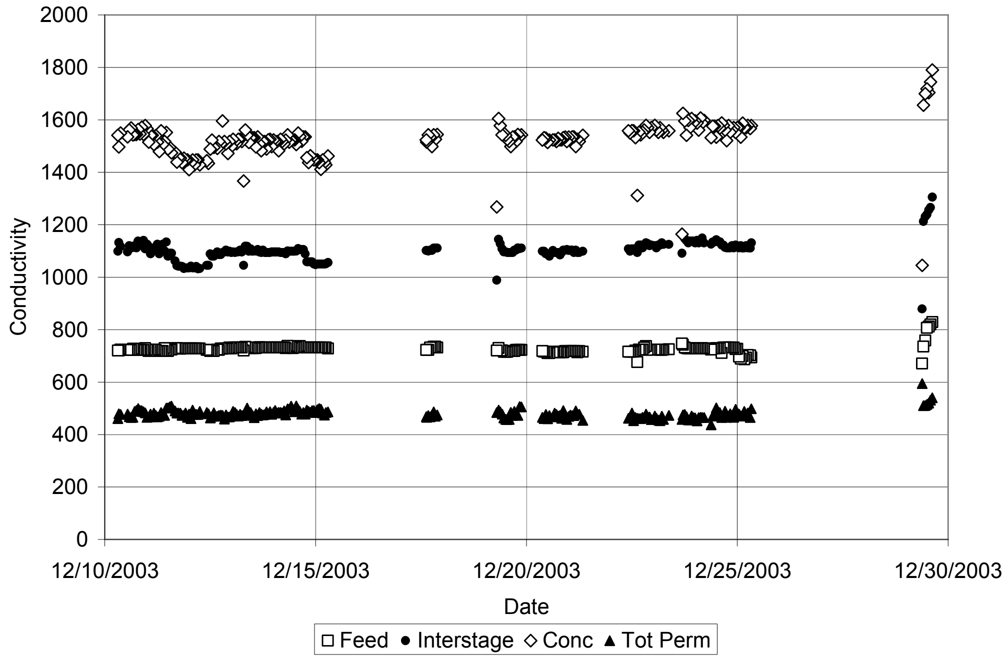

Figure 20. NF System Conductivities at Startup.

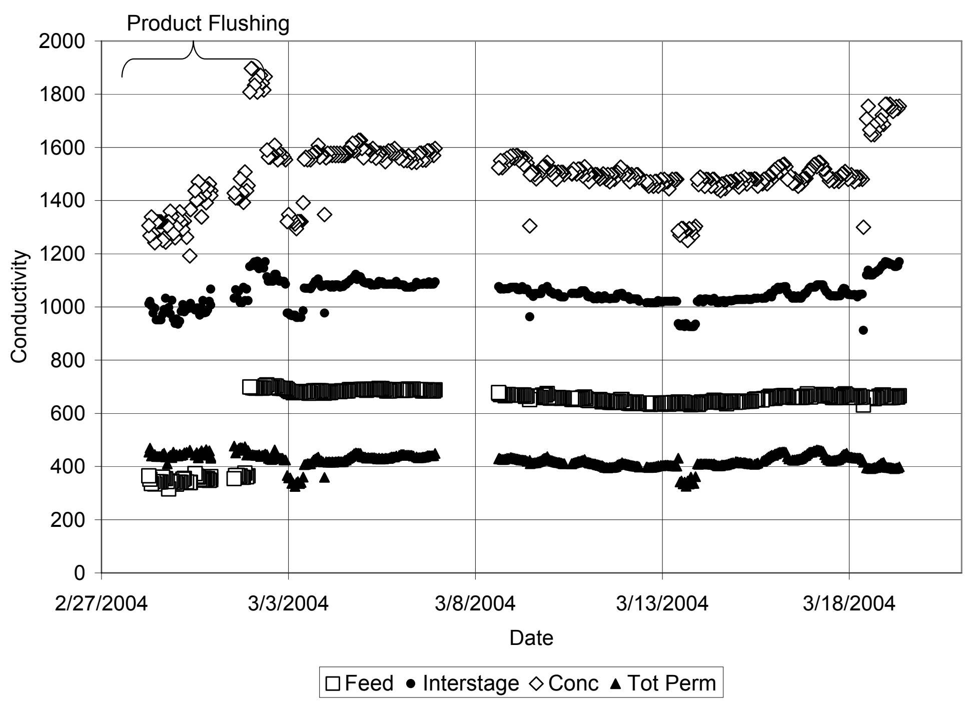

Figure 21. NF System Conductivities During Spring of 2004.

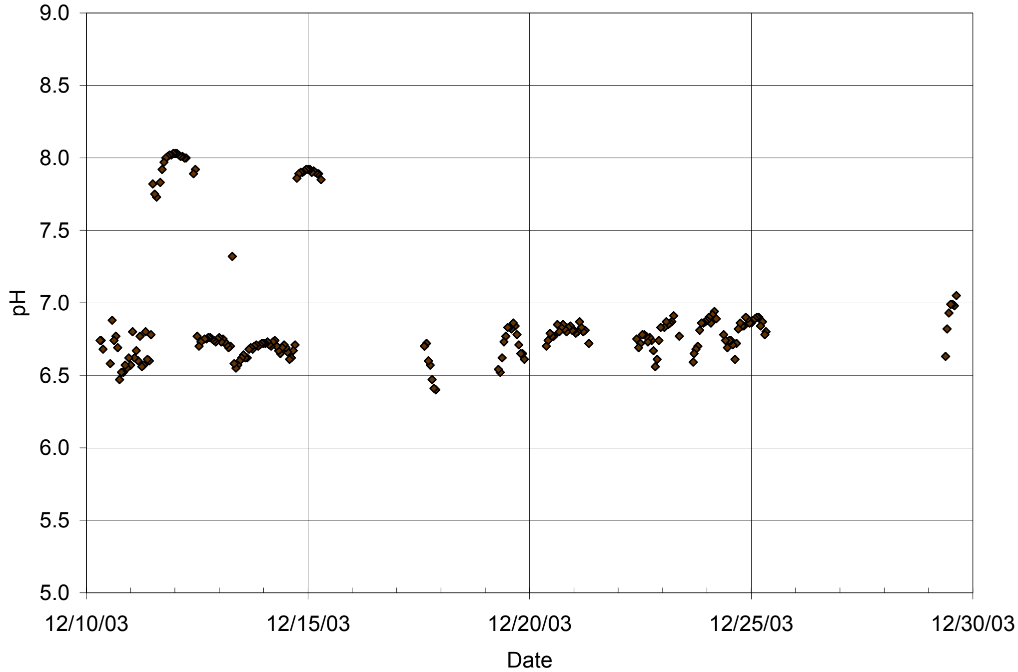

Figure 22. Feed pH at Startup with Acid Feed.

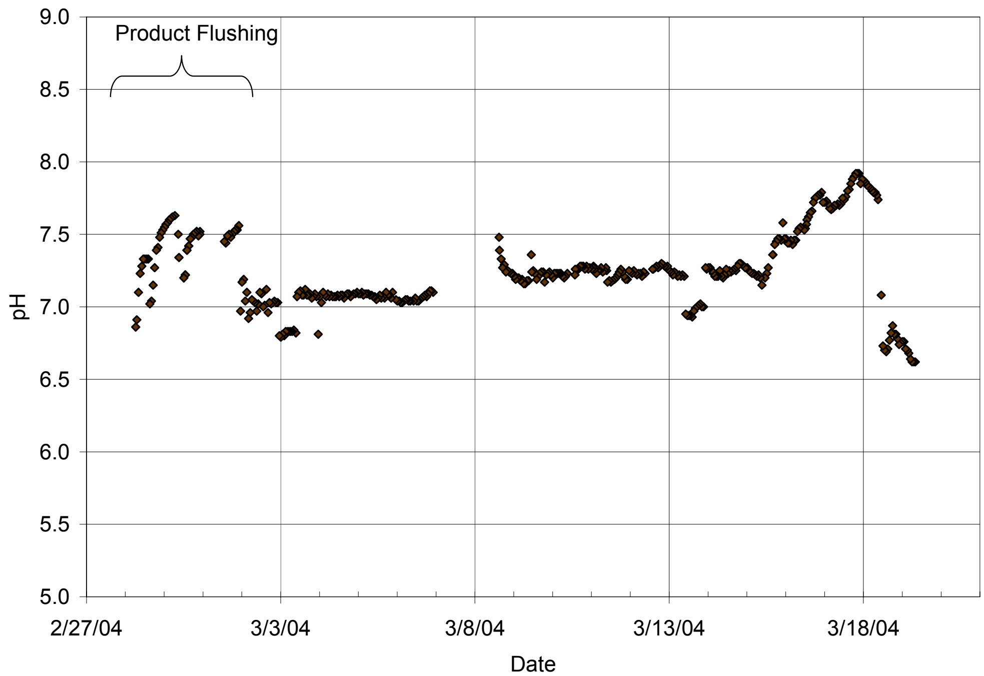

Figure 23. Feed pH During Spring 2004.

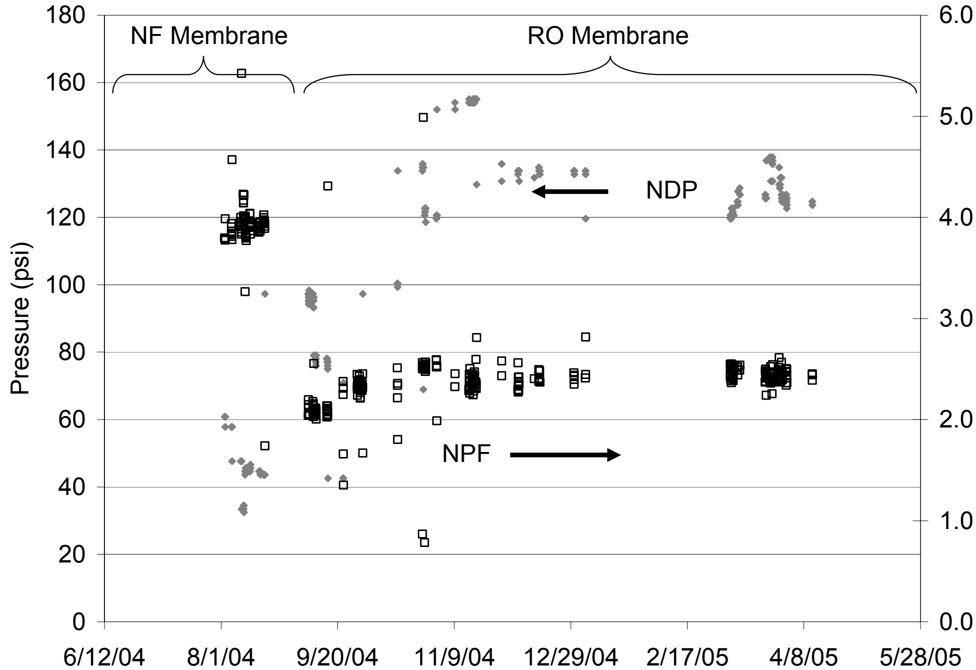

Figure 24. Net Driving Pressure and Normalized Permeate Flow.

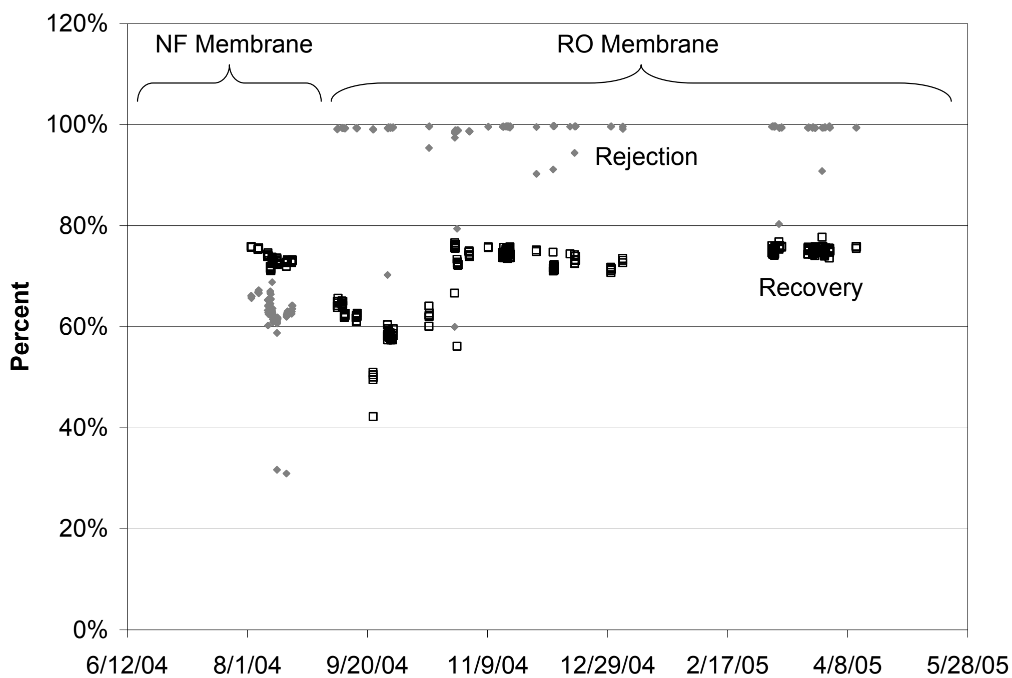

Figure 25. Rejection and Recovery.

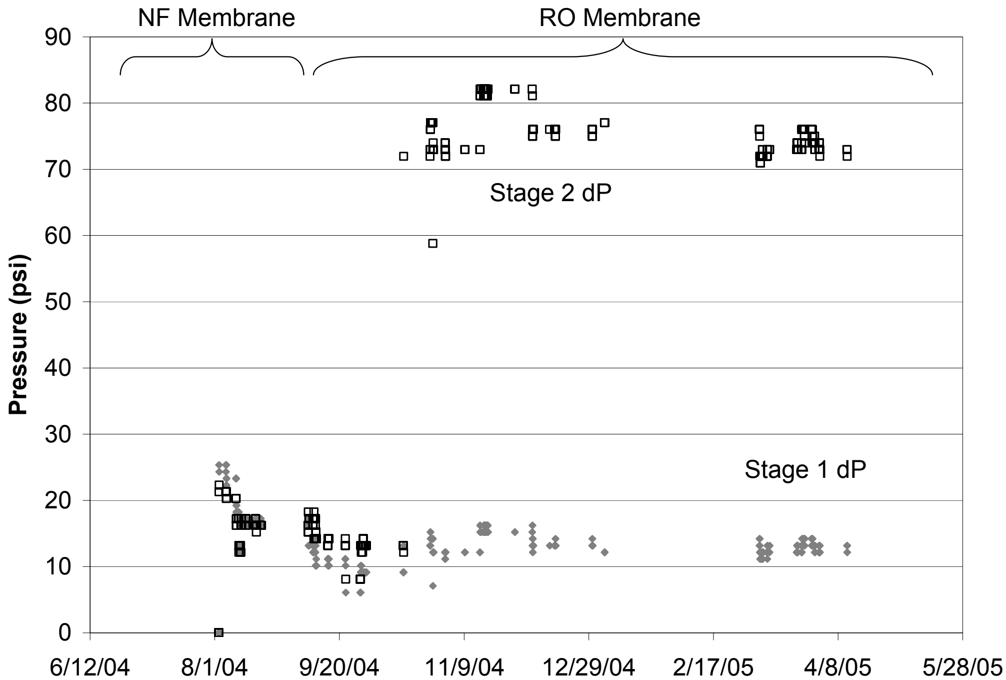

Figure 26. Differential Pressure.

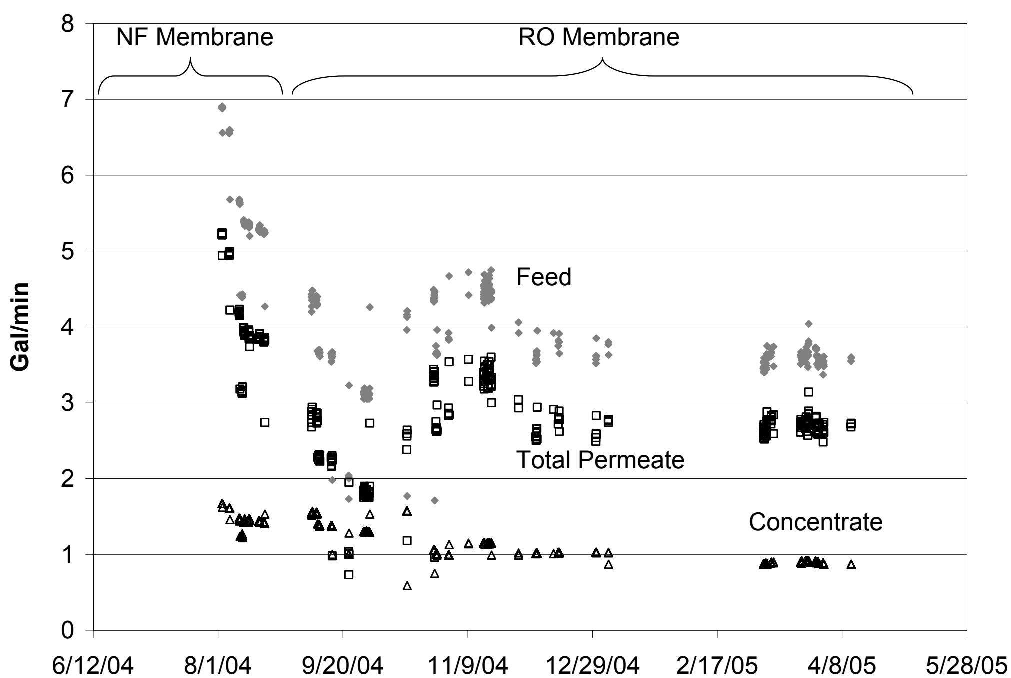

Figure 27. Feed, Concentrate, and Permeate Flows.

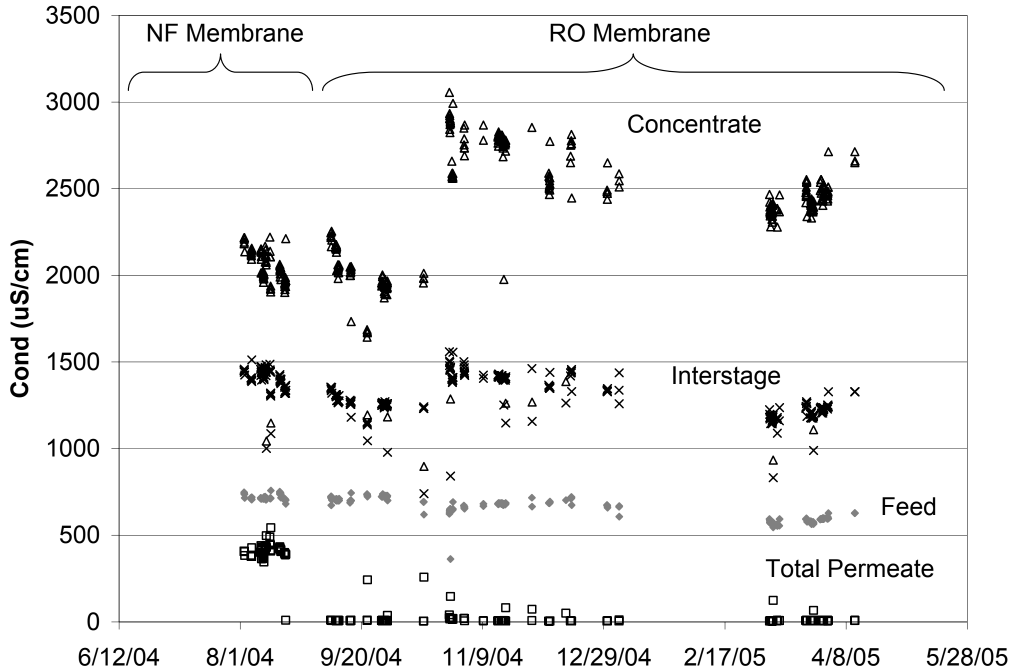

Figure 28. Feed, Concentrate, and Permeate Conductivities.

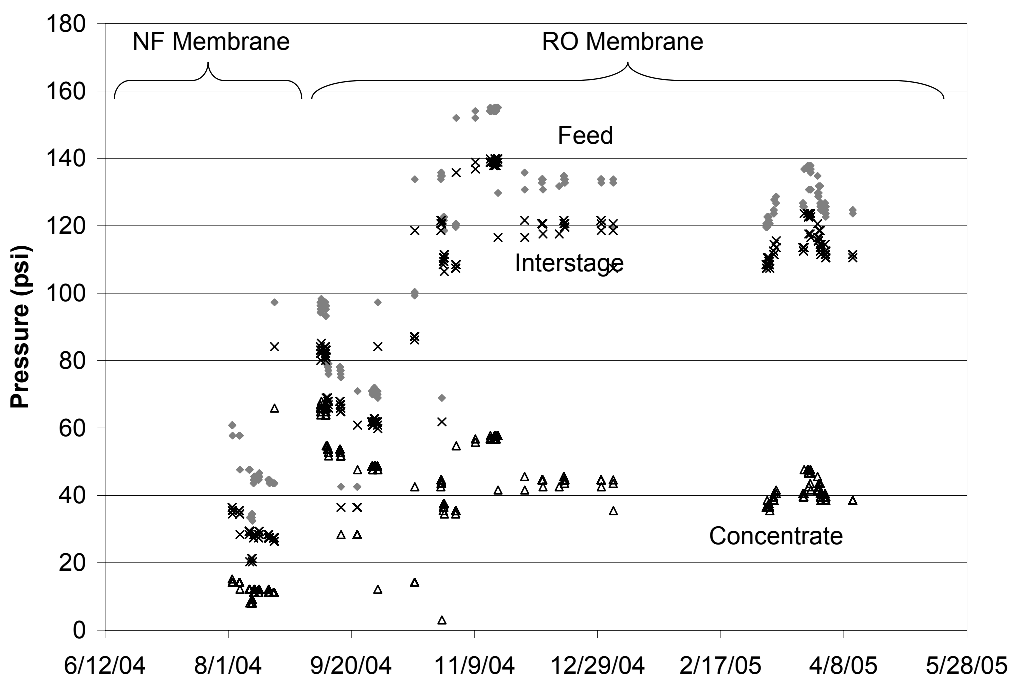

Figure 29. System Pressures.

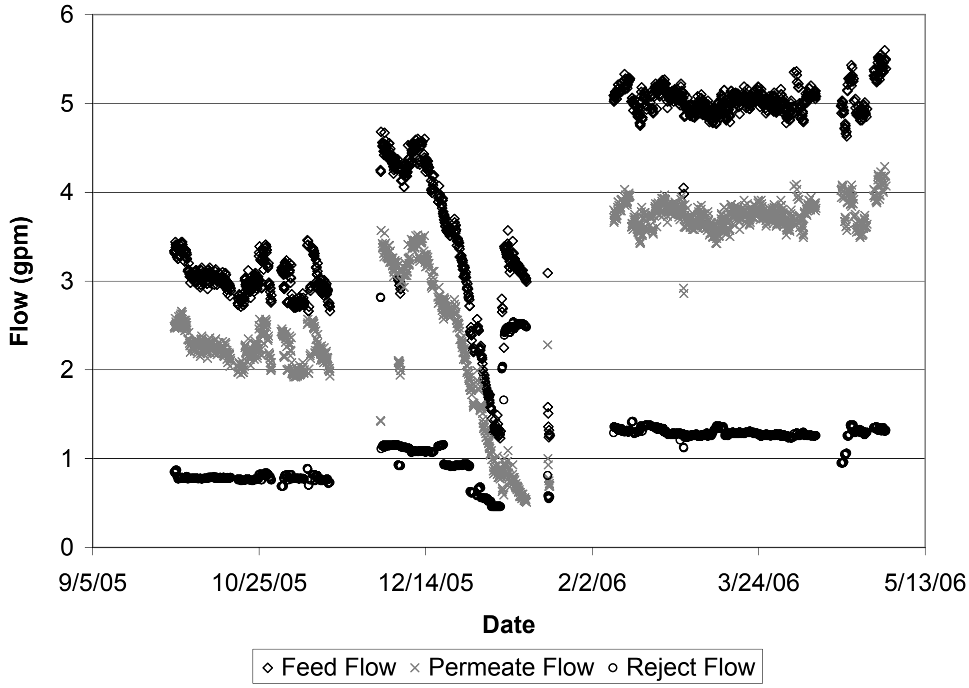

Figure 30. RO System Flows.

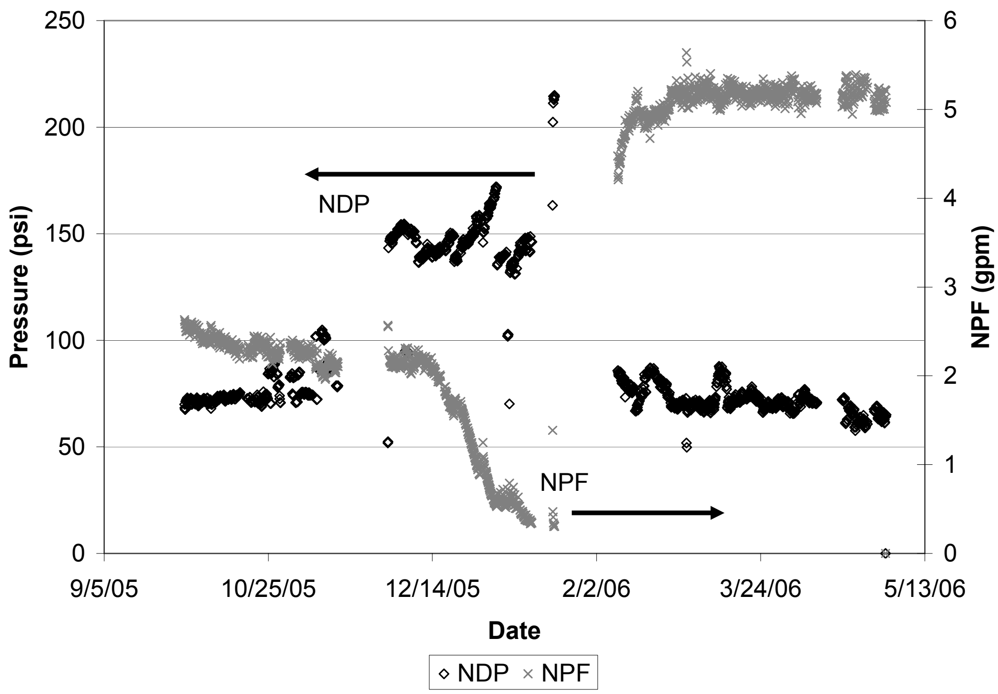

Figure 31. RO Pressure and Temperature Normalized Permeate Flow and Net Driving Pressure.

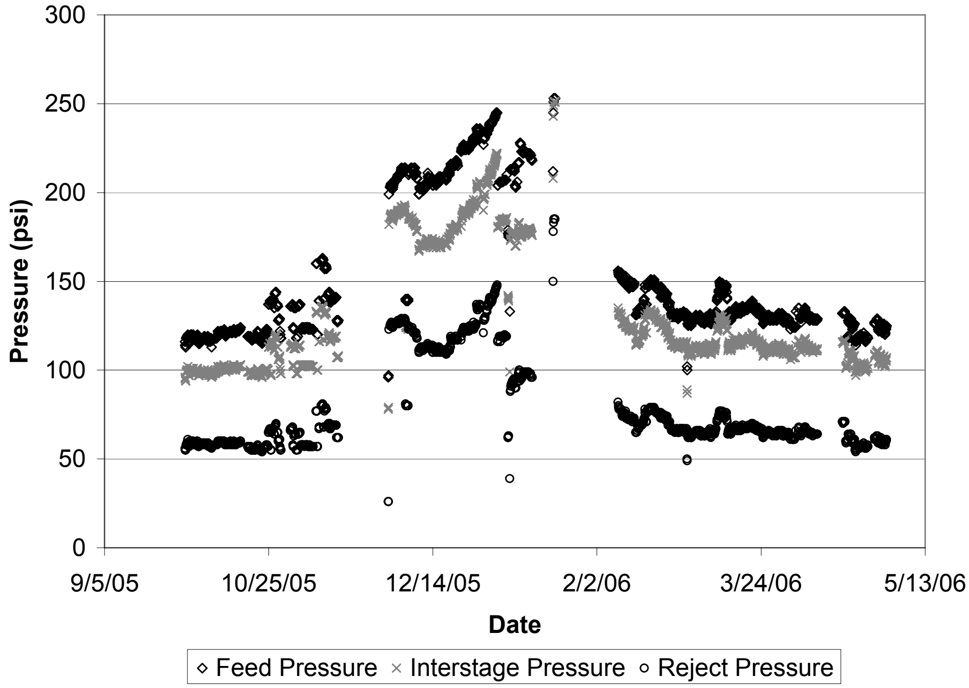

Figure 32. RO System Pressures.

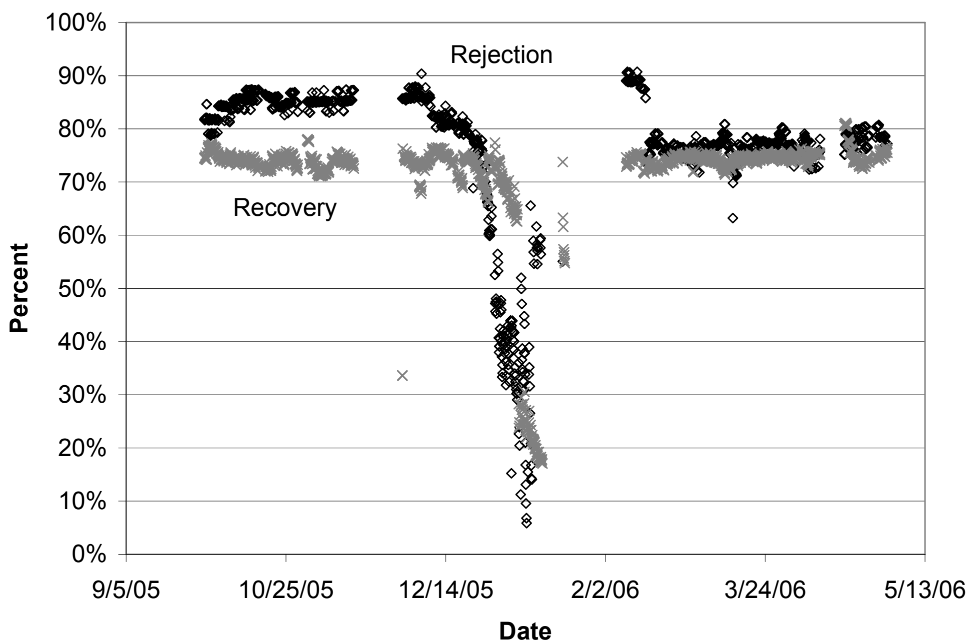

Figure 33. RO Rejection and Recovery.

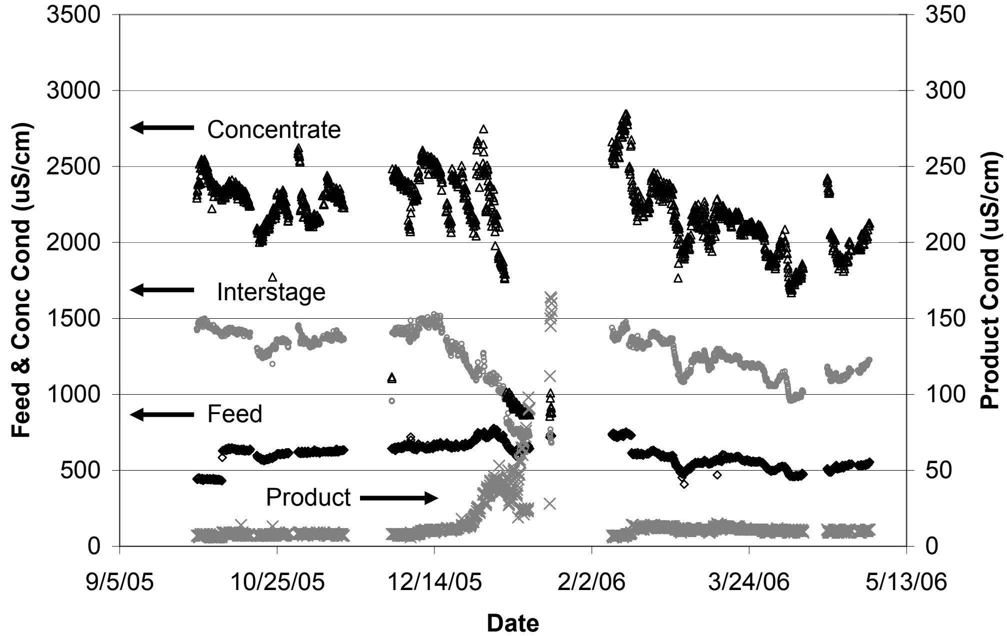

Figure 34. RO System Conductivities.

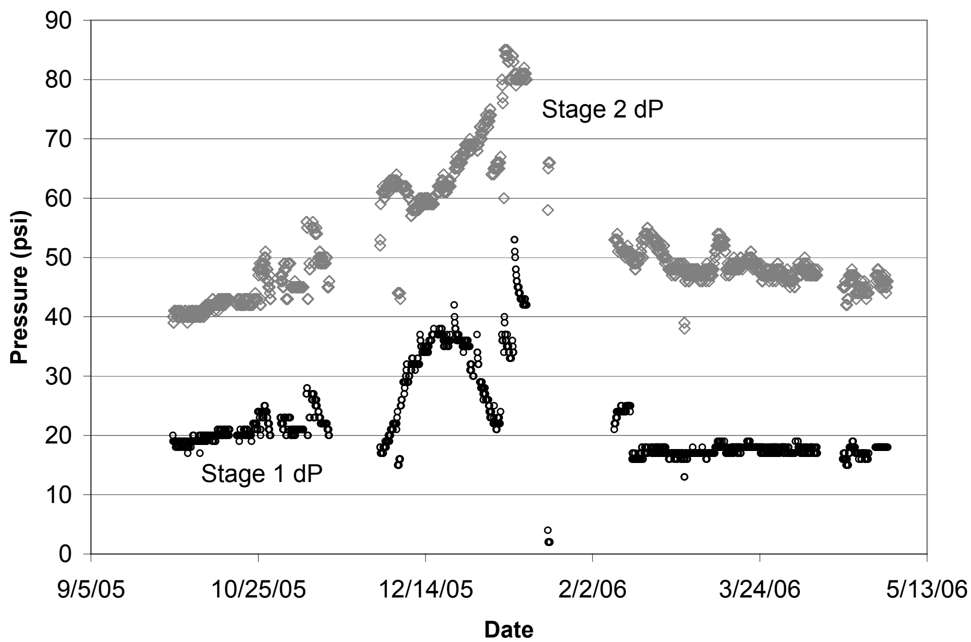

Figure 35. RO System Differential Pressures.

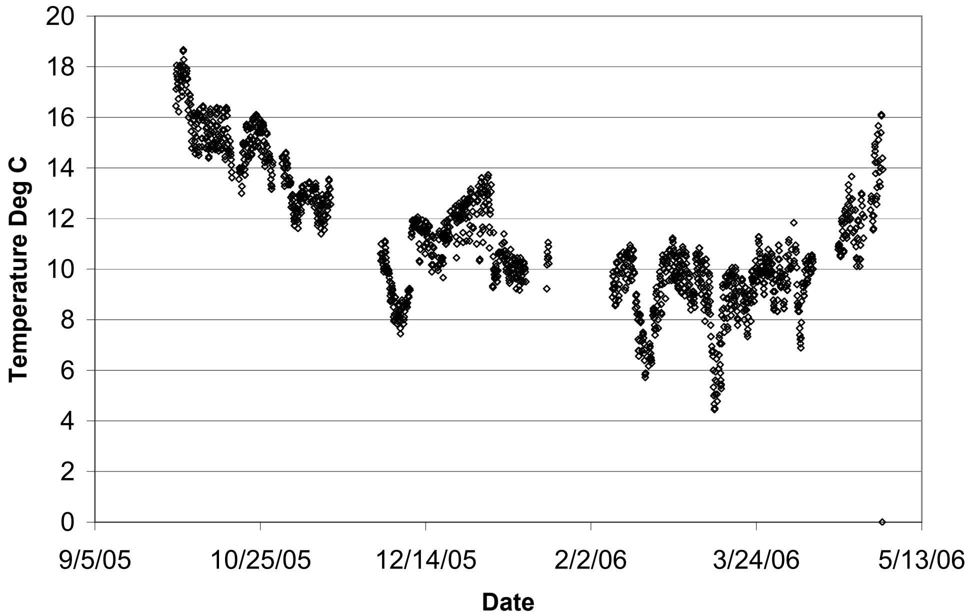

Figure 36. RO System Temperature.

The irreversible fouling was due to corrosion of a chemical mixing tank that fed the RO system. When changing the membranes, large rust particles were found in the feed end of the system. Since the chemical feed injection point is after the cartridge filters, all the corrosion particles ended up at the front end of the membranes. The chemical feed tank was replaced with one of compatible material, the membranes were replaced, and operation continued much more smoothly.

4.3.1 Product Water Quality

The RO permeate from this testing was of much higher quality than the DHS Ground Water Recharge (GWR) Title 22 recycled water criteria and Regional Water Quality Control Board (RWQCB) requirements for inorganic and general compounds. The RO product, as expected, is also corrosive, indicated by a negative Langelier Saturation Index (LSI) value. In full-scale operation, the RO product water would require stabilization. The RO feed, permeate, and concentrate water quality is described below in table 13.

Table 13. RO Product Water Quality

Parameter	Unit	Detection Limit	RO Feed	RO Permeate	RO Concentrate	CDHS and RWQCB MCLs for Title 22 GWR
Aluminum (dissolved)	mg/L	50	ND	ND	ND	
Aluminum (total)	mg/L	50	ND	ND	ND	200 (200)
Antimony	mg/L	6.0	ND	ND	ND	6.0 (6.0)
Arsenic	mg/L	2.0	ND	ND	2.0	50 (50)
Asbestos	MFL	0.2	ND	ND	ND	7.0 (7.0)
Boron	mg/L	5.0	240	135	470	1,000 (750)
Cadmium	mg/L	1.0	ND	ND	ND	5.0 (5.0)
Chromium (total)	mg/L	10	ND	ND	ND	50 (50)
Copper	mg/L	50	ND	ND	ND	1,300 (1,000)
Iron (dissolved)	mg/L	100	ND	ND	ND	
Iron (total)	µg/L	100	ND	ND	110	300
Lead	µg/L	5.0	ND	ND	ND	15 (50)
Manganese (dissolved)	µg/L	20	ND	ND	37	
Manganese (total)	µg/L	20	24	ND	74	50 (50)
Mercury	µg/L	1.0	ND	ND	ND	2.0 (2.0)
Nickel	µg/L	10	ND	ND	ND	100
Silver	µg/L	10	ND	ND	ND	100 (50)
Thallium	µg/L	1.0	ND	ND	ND	2
Vanadium	µg/L	3.0	ND	ND	ND	50
Zinc	µg/L	50	ND	ND	130	5,000 (5,000)
Alkalinity (as $CaCO_3$)	mg/L	5.0	270	5.8	965	
Total Phosphorus	mg/L P	0.02	6.2	0.24	22.5	
Soluble Orthophosphate	mg/L P	0.02	1.5	0.024	5.8	
Total Hardness (as $CaCO_3$)	mg/L	5.0	250	ND	910	
Total Organic Carbon	mg/L	0.3	5.8	ND	23	1.0
TDS	mg/L	5	435	20	1,550	500 (300)
pH		0	7.7	7.1	7.65	6.0-9.0
Specific Conductance	µS/cm	10	740	11	2,450	900
Nitrite+Nitrate as N	mg/L N	0.04	3.4	0.26	12.4	See TN raw
Ammonia as N	mg/L N	0.1	2.1	0.31	7.3	See TN raw
TKN	mg/L N	0.4	2.8	0.51	9.7	See TN raw
Total Nitrogen	mg/L N	NA	6.2	0.77	20.9	10
Turbidity	NTU	0.01	0.2	0.05	0.75	0.5/0.2 (5)
Apparent Color	CU	3.0	15	ND	50	

Table 13. RO Product Water Quality (continued)

Parameter	Unit	Detection Limit	RO Feed	RO Permeate	RO Concentrate	CDHS and RWQCB MCLs for Title 22 GWR
Odor Threshold	TON	1.0	ND	ND	ND	3.0 (3.0)
UV Transmittance	%	0	74	97.9	–	
Ammonium	mg/L	0.1	2.7	0.40	9.4	See TN raw
Barium	µg/L	100	ND	ND	ND	1,000 (1,000)
Berylium	µg/L	1.0	ND	ND	ND	
Calcium	mg/L	1.0	63.0	ND	230	
Magnesium	mg/L	1.0	25.0	ND	ND	
Potassium	mg/L	1.0	14.0	ND	53	
Sodium	mg/L	1.0	60	1.9	210	
Strontium	µg/L	20	285	ND	980	
Bicarbonate	mg/L	5.0	340	5.8	1,200	
Carbonate	mg/L	5.0	ND	ND	ND	
Chloride	mg/L	1.0	53.5	2.4	200.0	250 (50)
Fluoride	mg/L	0.10	0.25	ND	0.84	2.0 (2.1)
Hydroxide	mg/L	5.0	ND	ND	ND	
Nitrate	mg/L	0.13	15.6	1.2	56.5	
Soluble Ortho Phosphate	mg/L	0.02	4.5	0.072	17.5	
Sulfate	mg/L	0.5	40.0	ND	155	250 (20)
Cyanide	µg/L	100	ND	ND	ND	150 (150)
Selenium	µg/L	5.0	ND	ND	ND	5.0 (5.0)
Silica	mg/L	0.5	26.0	0.57	94	
Strontium-90	pCi/L	2.0	ND	ND	ND	8.0 (8.0)
Total Alpha	pCi/L	3.0	–	ND	5.5	15 (15)
Total Beta	pCi/L	4.0	–	ND	42	50 (50)
Uranium	pCi/L	2.0	–	ND	5.1	20 (20)

Table 14 summarizes the concentrations of disinfection byproducts (DBPs) in the RO feed, product and reject. Ammonia and chlorine were added to the RO feed to prevent biological fouling.

Table 15 describes the regulated organics concentrations in the RO feed, permeate, and reject. Only toluene, methyl mercury, and foaming agents were detected in the RO feed. These compounds were not detected in the RO product; therefore, the RO system successfully satisfies the Title 22 criteria for GWR for synthetic and volatile organics compounds.

Table 14. Disinfection Byproducts

Paramter	Unit	Detection Limit	RO Feed	RO Permeate	RO Reject	DHS and RWQCB MCLs for Title 22 GWR
Bromate	µg/L	5.0	ND	ND	ND	10
Chloramines	mg/L	0.1	1.52	1.41	0.58	4.0
Chlorine Dioxide	mg/L	0.24	ND	ND	ND	0.8
Chlorate	mg/L	0.2	ND	ND	ND	1.0
Bromodichloromethane	µg/L	0.5	ND	ND	ND	80
Bromoform	µg/L	0.5	ND	ND	ND	80
Chloroform	µg/L	0.5	0.8	ND	3.0	80
Dibromochloromethane	µg/L	0.5	ND	ND	ND	80
Monochloroacetic acid	µg/L	2.0	ND	ND	5.1	60
Dichloroacetic acid	µg/L	1.0	6.5	ND	21.0	60
Trichloroacetic acid	µg/L	1.0	ND	ND	2.8	60
Monobromoacetic acid	µg/L	1.0	ND	ND	ND	60
Dibromoacetic acid	µg/L	1.0	ND	ND	ND	60

Table 15. Regulated Organics

Paramter	Unit	Detection Limit	RO Feed	RO Permeate	RO Reject	CDHS and RWQCB MCLs for Title 22 GWR
Atrazine	µg/L	0.05	ND	ND	ND	1.0 (1.0)
Bentazon	mg/L	2	ND	ND	ND	18
Benzo(a)anthracene	mg/L	0.05	ND	ND	ND	0.1
Benzene	mg/L	0.5	ND	ND	ND	5.0 (1.0)
Benzopyrene	µg/L	0.02	ND	ND	ND	0.2
gamma-BHC (Lindane)	µg/L	0.2	ND	ND	ND	0.2 (0.3)
Carbofuran	µg/L	5	ND	ND	ND	18 (18)
Carbon tetrachloride	µg/L	0.5	ND	ND	ND	0.5 (0.5)
Chlordane	µg/L	0.1	ND	ND	ND	0.1
Chlorobenzene	µg/L	0.5	ND	ND	ND	70 (100)
2,4-D	µg/L	10	ND	ND	ND	70 (70)
Dalapon	µg/L	10	ND	ND	ND	200 (200)
Dibromochloropropane (DBCP)	µg/L	0.01	ND	ND	ND	0.2 (0.2)
1,1-Dichloromethane	µg/L	0.5	ND	ND	ND	NSL

Table 15. Regulated Organics (continued)

Paramter	Unit	Detection Limit	RO Feed	RO Permeate	RO Reject	CDHS and RWQCB MCLs for Title 22 GWR
1,2-Dibromoethane	µg/L	0.5	ND	ND	ND	0.05
1,2-Dichlorobenzene	µg/L	0.5	ND	ND	ND	600 (600)
1,4-Dichlorobenzene	µg/L	0.5	ND	ND	ND	5 (5)
1,1-Dichloroethane	µg/L	0.5	ND	ND	ND	5 (5)
1,2-Dichloroethane	µg/L	0.5	ND	ND	ND	0.5 (5)
1,1-Dichloroethylene	µg/L	0.5	ND	ND	ND	6 (6)
cis-1,2-Dichloroethylene	µg/L	0.5	ND	ND	ND	6 (70)
trans-1,2-Dichlorethylene	µg/L	0.5	ND	ND	ND	10 (10)
1,2-Dichloropropane	µg/L	0.5	ND	ND	ND	5 (5)
1,3-Dichloropropene	µg/L	0.5	ND	ND	ND	0.5 (0.5)
Di (2-ethylhexyl) adipate	µg/L	0.6	ND	ND	ND	400
Di (2-ethylehexyl) phthalate	µg/L	0.6	ND	ND	ND	4
Dinoseb	µg/L	2	ND	ND	ND	7 (7)
Diquat	µg/L	0.4	ND	ND	ND	20 (20)
Endothal	µg/L	20	ND	ND	ND	100 (100)
Endrin	µg/L	0.1	ND	ND	ND	2
Epichlorohydrin	µg/L	0.4	ND	ND	ND	NSL
Ethlybenzene	µg/L	0.5	ND	ND	ND	700 (700)
Foaming Agents (MBAs)	mg/L	0.02	0.1	ND	0.31	0.5 (0.5)
Glyphosate	µg/L	25	ND	ND	ND	700 (700)
Heptachlor	µg/L	0.01	ND	ND	ND	0.01
Heptachlor epoxide	µg/L	0.01	ND	ND	ND	0.01 (0.01)
Hexachlorobenzene	µg/L	0.5	ND	ND	ND	1 (1)
Hexachlorocyclopen-tadiene	µg/L	1	ND	ND	ND	50 (50)
Methoxychlor	µg/L	10	ND	ND	ND	30 (30)
Methyl t-butyl ether (MTBE)	µg/L	0.3	ND	ND	ND	13 (5)
Methyl Mercury	µg/L	0.025	0.095	ND	0.129	
Oxamyl	µg/L	20	ND	ND	ND	50 (50)
Pentachlorophenol	µg/L	0.2	ND	ND	ND	1 (1)
Picloram	µg/L	1	ND	ND	ND	500 (500)

Table 15. Regulated Organics (continued)

Paramter	Unit	Detection Limit	RO Feed	RO Permeate	RO Reject	CDHS and RWQCB MCLs for Title 22 GWR
Polychlorinated biphenyls	µg/L	0.5	ND	ND	ND	0.5 (0.5)
Simazine	µg/L	0.05	ND	ND	ND	4 (4)
Styrene	µg/L	0.5	ND	ND	ND	100 (100)
2,3,7,8-TCDD	µg/L	5	ND	ND	ND	0.03 (0.03)
1,1,2,2-Tetrachlorethane	µg/L	0.5	ND	ND	ND	1 (1)
Tetrachlorethylene	µg/L	0.5	ND	ND	ND	5 (5)
Thiobencarb	µg/L	0.2	ND	ND	ND	70
Toluene	µg/L	0.5	2.4	ND	8	150 (150)
Toxaphene	µg/L	1	ND	ND	ND	3
2,4,5-TP	µg/L	1	ND	ND	ND	50 (50)
1,2,4-Trichlorobenzene	µg/L	0.5	ND	ND	ND	5 (70)
1,1,1-Trichlorethane	µg/L	0.5	ND	ND	ND	200 (200)
1,1,2-Trichloroethane	µg/L	0.5	ND	ND	ND	5 (3)
Trichlorethylene	µg/L	0.5	ND	ND	ND	5 (5)
Trichlorofouromethane	µg/L	5	ND	ND	ND	150 (150)
1,1,2-Trichloro-1,2,2-triflouroethane	µg/L	10	ND	ND	ND	1,200 (1,200)
Vinyl chloride	µg/L	0.5	ND	ND	ND	0.5 (0.5)
Xylene	µg/L	0.5	ND	ND	ND	1,750 (1,750)

Table 16 shows the concentrations of a number of organic chemicals that do not have MCLs but have heath-based advisory levels called “action levels.” All measured parameters were below the detection level in the RO feed, except for boron. The RO membranes accomplished 49% removal efficiency. Still the feed, permeate, and reject concentrations of boron were all below the action level.

4.4 VSEP® Performance

During the month of April 2006, New Logic Research, Inc, conducted pilot testing of VSEP® technology in Big Bear. The VSEP® was used to treat the concentrate water from the RO unit. Initial testing was conducted using the LFC three membrane and NF-90. As can be seen in the following figures and explanation, the LFC membrane was found to be the least prone to fouling and provided excellent salt rejection.

Table 16. Action-Level Chemicals

Paramter	Unit	Detection Limit	RO Feed	RO Permeate	RO Reject	CDHS and RWQCB MCLs for Title 22 GWR
Boron	µg/L	5	240	135	470	1,000
n-Butylbenzne	µg/L	0.5	ND	ND	ND	260
sec-Butylbenzene	µg/L	0.5	ND	ND	ND	260
tert-Butylbenzene	µg/L	0.5	ND	ND	ND	260
Carbon disulfide	µg/L	0.5	ND	ND	ND	160
Chlorate	µg/L	0.1	0.064	ND	0.31	0.8
2-Chlorotoluene	µg/L	0.5	ND	ND	ND	0.14
4-Chlorotoluene	µg/L	0.5	ND	ND	ND	0.14
Dichlorodifluoromethane	µg/L	0.5	ND	ND	ND	1,000
1,4-Dioxane	mg/L	0.002	ND	ND	ND	0.003
Ethylene glycol	mg/L	0.2	ND	ND	ND	14
Formaldehyde	µg/L	0.2	ND	ND	ND	100
Isopropylbenzene	µg/L	0.5	ND	ND	ND	770
Methyl-isobutyl-ketone	µg/L	0.5	ND	ND	ND	120
Naphthalene	µg/L	0.5	ND	ND	ND	17
N-Nitrosodiethyamine	ng/L	2	ND	ND	ND	10
N-Nitrosodimethylamine	ng/L	2	ND	ND	ND	10
N-Nitrosodi-n-propylamine	ng/L	2	ND	ND	ND	10
Perchlorate	µg/L	4	ND	ND	ND	6.0
n-Propylbenzene	µg/L	0.5	ND	ND	ND	260
Tertiary butyl alcohol	µg/L	2	ND	ND	ND	12
1,2,3-Trichloropropane	µg/L	0.005	ND	ND	ND	0.005
1,2,4-Trimethylbenzene	µg/L	0.5	ND	ND	ND	330
1,3,5-Trimethylbenzene	µg/L	0.5	ND	ND	ND	330
Vanadium	µg/L	3	ND	ND	ND	50

4.4.1 Product Water Quality

During the 2-week testing of the VSEP® technology in Big Bear, the main objective was to optimize the hydraulic conditions and to find stable operating conditions. Observing the product water quality was not the primary concern. However, using the rejection provided by the manufacturer in the membrane specifications sheet, the overall total dissolved solids concentration of the VSEP® product water can be calculated. The LFC RO membrane has a rejection of 99.5%, and the TDS of the feed to the VSEP® unit is 1,500 mg/L. This results in an estimated product concentration of 7.5 mg/L. Additionally, one data point was collected for operation with the LFC membrane; the measured TDS concentration was 4.0 mg/L.

When the VSEP® product water is combined with the RO product water, the RO/VSEP® system recovery is 93.5%, and the RO/VSEP® system product water quality is 15 mg/L and 96.5% salt rejection.

4.4.2 Operational Data

Figure 37 shows the data collected during operation of the VSEP® unit. Data from both NF and RO membrane operation is shown.

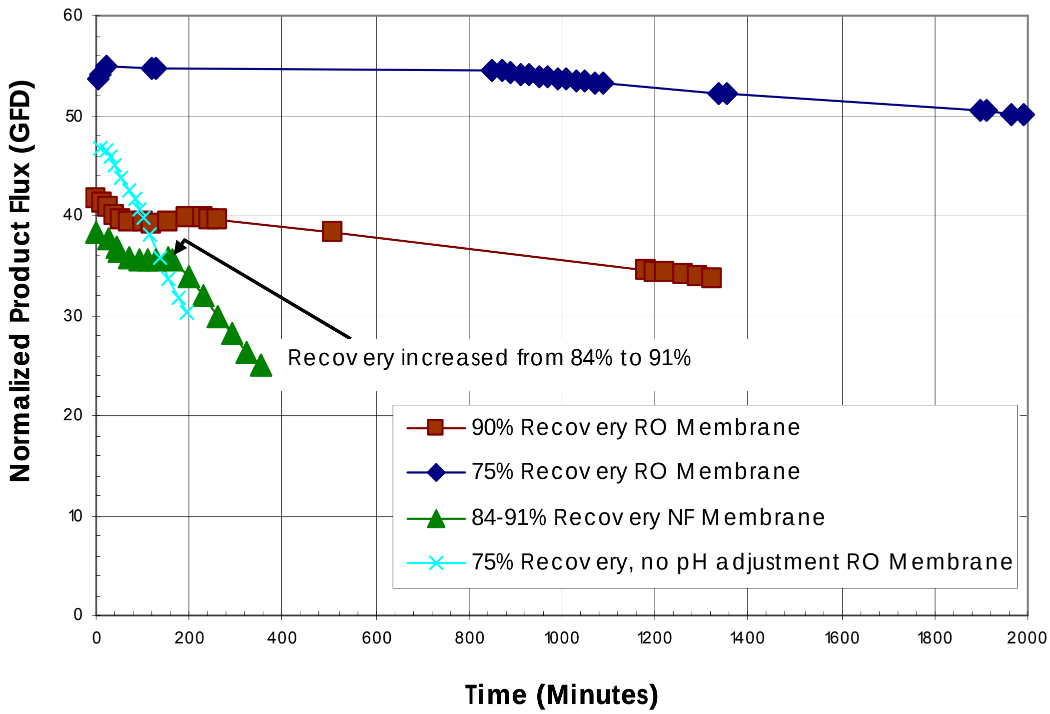

Figure 37. VSEP® Recovery.

4.4.3 Cleaning

Chemical cleaning of the VSEP® is conducted for the same reasons as for traditional spiral wound membranes. While VSEP® can prevent colloidal fouling of the membrane and can reduce polarization of rejected materials at the membrane surface, it cannot avoid fouling caused by chemical bonding. The cleaning procedure used during this testing was a two-part process. The steps in sequence were NLR 404 acid cleaning followed by NLR 505 caustic cleaning.

The procedure was based on previous experience by New Logic with similar applications. The cleaners were used in a 3% by volume solution. The estimated cleaning frequency is twice per week. Further pH optimization may also result in a lower cleaning efficiency.

5.0 Plant Design and Economic Analysis

A preliminary, subappraisal level cost estimate was developed for a 1-mgd advanced water treatment system with the same unit processes as the RO pilot system using WTCost©, a commercially available cost estimating routine. To develop this preliminary cost estimate, a number of assumptions were made which are listed in table 18. The treatment system capital costs were developed using the permeate water quality data obtained from the pilot testing and the assumption that the final plant size would generate 1 mgd of product water. The following pieces of equipment were included in the estimate: chloramination injecttion system, antiscalant injection system, acid injection system, ultrafiltration, reverse osmosis, including high-pressure pumps, UV post disinfection, and product water stabilization. Capital and annual costs are itemized in table 20.

Cost indexes used to update the cost assumptions to current dollars were obtained from the Engineering News Record Economics Web site (http://www.enr.com/features/coneco/subs/recentindexes.asp) and are listed in table 17.

Table 17. Cost Indexes – October 2006[1]

Engineering News Record Cost Index	October 2006	Used For
Construction Cost	7,882.53	Manufactured and electrical equipment
Wage Rate $/hr	41.16	Labor (operating the plant)
Building Cost	4,431.26	Housing
Skilled Labor	7,415.98	Excavation and site work
Materials	2,607.79	Piping, valves, and maintenance materials
Cement (%/ton)	94.28	Concrete
Steel ($/CWT)	39.41	Steel
Electricity ($/kWHr)	0.07	Power
Interest Rate (%)	6	On construction and bond money
Amortization (years)	30	For bond period

[1] $/hr = dollars per hour; %/ton = percent per ton; $/CWT = dollars per hundred weight; $/kWHr = dollars per kilowatthour.

The RO scenario assumes that the product will be used for high value purposes, while the concentrate will be used for irrigation. This estimate does not include the VSEP® technology, as it was understood that some water does need to be provided for agriculture. Alternatively, a low recovery NF system with no chemical feed pretreatment or post-treatment could be used to provide concentrate for agriculture and product for wetlands development and infiltration. These scenarios are outlined in tables 18 and 19 with cost estimates in tables 20 and 21.

Actually, though the NF system is operated at a lower pressure with no chemical feed pretreatment or post-treatment, the capital and annual costs are slightly higher than the RO system. This is due to the higher feed flow which necessitates larger pumps and piping. The power costs are lower, but only by $100 thousand per year. The labor costs may be high. These scenarios assume 6 staff days per day for both the RO and UF systems. These could be the same people who are operating the WWTP.

Table 18. Design Parameters for 1-mgd UF/RO System

Component	Design Parameter	Value
RO System	Nominal Feed Flow, mgd	1.33
	Recovery	75%
	Planned Operation, hours per day	24
	Plant Availability	95%
	Operating Temperature	19 °C
Pretreatment	Chloramine Addition, mg/L	1.0 to 2.0
	Antiscalant Addition, mg/L	0.5
	Acid Addition (97% H_2SO_4), mg/L	7.0
	Microfiltration Flowrate, gallons per minute (gpm)	975
Desalting Units	Number of Trains	2
	Number of Vessels	16
	Number of Membrane Elements	96
	Nominal Operating Pressure, psi	140
Product Delivery	Nominal Product Flow, gallons per day (gpd)	1,000,000
Concentrate Volume	Nominal Reject Flow, gpd	333,000
Power	Power Requirement, kW*hr/year	500,000

Table 19. Design Parameters for 1-mgd UF/NF System

Component	Design Parameter	Value
NF System	Nominal Feed Flow, mgd	1.55
	Recovery	65%
	Planned Operation, hours per day	24
	Plant Availability	95%
	Operating Temperature	19 °C
UF System	Microfiltration Flowrate, gpm	975
Desalting Units	Number of Trains	2
	Number of Vessels	16
	Number of Membrane Elements	96
	Nominal Operating Pressure, psi	100
Product Delivery	Nominal Product Flow, gpd	1,000,000
Concentrate Volume	Nominal Reject Flow, gpd	550,000
Power	Power Requirement, kW*hr/year	324,000

Table 20. Unit Process Costs UF/RO (October 2006 $)

Equipment	Capital Cost ($)	Annual O&M[1] Cost ($/yr)
Chloramine Injection	37,000	38,000
Ultrafiltration Units	1,120,000	166,000
Antiscalant Feed System	43,000	9,000
Acid Feed System	17,500	3,000
Zinc Polyphosphate (2 mg/L)	42,500	10,000
Elements at $450 per Element	43,000	5,000
Vessels/trains at $3,000 per Vessel	48,000	0
Cartridge Filters	19,000	9,000
Membrane Cleaning Equipment (and Chemicals)	70,000	18,000
Forwarding and High-Pressure Pumps	64,000	4,000
Instrumentation and Controls	164,000	0
Contractor Engineering and Training	60,000	0
Process Piping	95,000	0
Yard Piping	70,000	0
Electrical Cost	130,000	0
Sitework at $55 per 1,000 Gallons	70,000	0
Building	230,000	454,000
UV System	20,000	50,000
Indirect Costs	1,107,000	250,000
Labor		408,000
Electricity		46,000
Total Direct Costs	**3,450,000**	**1,470,000**

[1] O&M = operation and maintenance.

Table 21. Unit Process Costs UF/NF (October 2006 $)

Equipment	Capital Cost ($)	Annual O&M Cost ($/yr)
UF System	1,324,000	182,000
Elements at $450 per Element	43,000	5,000
Vessels/Trains at $3,000 per Vessel	48,000	0
Cartridge Filters	21,000	9,000
Membrane Cleaning Equipment (and Chemicals)	70,000	8,000
Forwarding and High-Pressure Pumps	50,000	2,400
Instrumentation and Controls	164,000	0
Contractor Engineering and Training	61,000	0
Process Piping	108,000	0
Yard Piping	78,000	0
Electrical Cost	130,000	0
Sitework at $55 per 1,000 Gallons	70,000	0
Building	230,000	387,000
UV System	20,000	50,000
Indirect Costs	1,127,000	255,000
Labor		408,000
Electricity		35,700
Total Direct Costs	**3,544,000**	**1,342,100**

6.0 Conclusions

6.1 Potential for Agricultural Irrigation or Aquatic Habitat

Both the concentrate from the NF membrane and the RO membrane are suitable to use for irrigation of crops or landscaping. The NF concentrate had a lower SAR than the secondary effluent which suggests that these loose NF membranes can be used to improve waste water effluent for high value crops while also creating a higher value NF product stream that may be suitable for wildlife habitat. Since the NF product and concentrate were not analyzed for pharmaceuticals, we cannot say for sure if they would be suitable for aquatic habitat. It would be worthwhile to find out. The NF product did meet all the requirements for ground water infiltration.

6.2 NF Versus RO

The NF membrane was much easier to maintain than the RO membrane. With waste water reclamation projects such as this, operating costs can be reduced by operating at a lower recovery and rejection as with the NF membrane system. Since more of the bicarbonate passes through the membrane, there is little problem with scale formation. The operating pressure is lower; thus, the power cost will be lower. Operating between 60% and 70% recovery kept the system clean for the whole year, even with frequent down periods. When the acid feed pump failed, the higher pH did not cause a decline in performance—probably because of the very low bicarbonate rejection. The difference in cost was only $100,000 per year. The capital costs are $100,000 more for NF than the RO system with chemical pretreatment. However, there may be much greater cost savings the avoiding chemical use than are reflected in the cost model.

The RO membrane operation period was much more erratic than the NF period. Since they were not run at the same time, it is impossible to say whether the operators were less attentive to the system during that time, or if there were changes in the WWTP operation that influenced performance. Acid feed was required during this time to prevent carbonate or phosphate scaling. This did create issues with procuring acid, keeping the chemical feed tank supplied and the pH sensors calibrated.

Both systems produced water that meets the criteria for infiltration into a drinking water aquifer. The NF concentrate would be better suited for irrigation than the RO concentrate, but both were acceptable according to FAO guidelines. The RO product was, of course, superior in quality to the NF product; but that could be overkill if it is only going to be used for wetlands development. The treatment facility would need to find an economically attractive use for the RO product.

6.3 Concentrate Minimization

The VSEP® system was very effective in recovering additional high quality water from the RO concentrate. The overall recovery of the RO/ VSEP® system was 97.7% with the VSEP® operating at 85% recovery and the RO system temporarily operating at 85% recovery. This assumes that appropriate antiscalant dosing and pH adjustment would be implemented to attain 85% recovery of the RO system on a long-term basis. In this situation, however, the concentrate will be used for irrigation; and so, there is no need to further concentrate the residuals.

7.0 References

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