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DARE COUNTY REGIONAL R.O. PLANT
KILL DEVIL HILLS, NORTH CAROLINA

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EVALUATION OF POTENTIAL TRAIN CAPACITY INCREASE

April 21, 1995

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DARE COUNTY REGIONAL R.O. PLANT

KILL DEVIL HILLS, N.C.

EVALUATION OF POTENTIAL TRAIN CAPACITY INCREASE BY ADDING MEMBRANE AREA

1.0 INTRODUCTION

The Dare County Regional Reverse Osmosis Plant was placed into operation in the early fall of 1989, at initial feed pressures of between 265 psig and 270 psig. The typical average feed water quality at that time was approximately 2200 ppm TDS.

The plant basis of design provided for the initial operation, estimated to be between 5 and 10 years, was based on hydrogeologic projections of feedwater quality deterioration. A plant with permeate production of 850,000 gpd at 75% recovery, blended with 150,000 gpd bypassed raw water, for an RO unit production of 1 mgd of product at 500 ppm (approximately 850 micromhos) specified. The system was designed to achieve this performance with a feedwater with TDS of 4500 ppm. The permeate conductivity at the start of operations was approximately 120 micromhos, while the blended quality set point was established at 750 micromhos. At this setting, the blending ration was at or very close to the design of 15%.

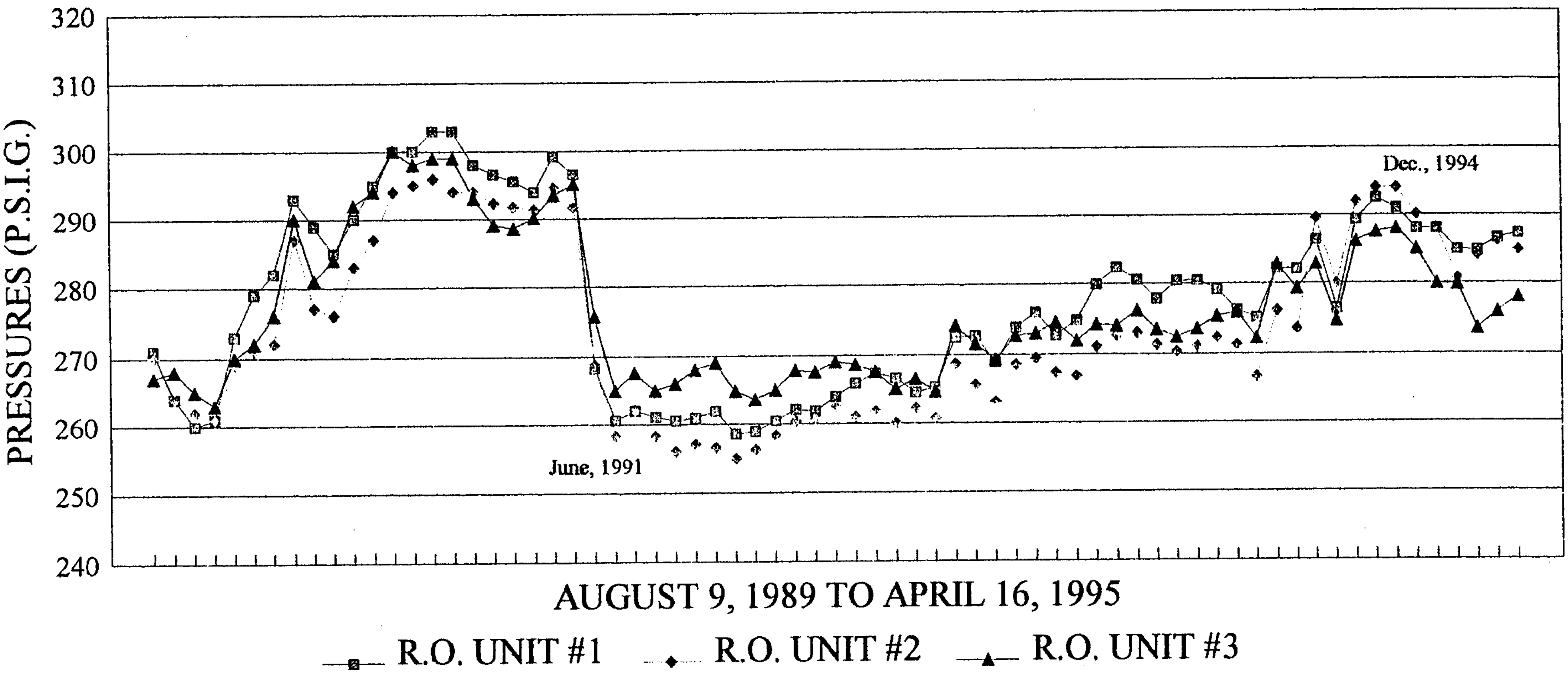
The time frame assumed for the initial basis of design was adopted after the groundwater consultant predicted a worsening of water quality in the pumped zone of the wellfield due to seawater intrusion. It was anticipated that as water quality worsened, the feed pressure would be increased to compensate for increasing osmotic pressure. At the same time the salt passage, while increasing with increasing feedwater TDS, would still permit adequate blending. The next generation of membranes, when installed as expected in the mid-1990's, would, through superior salt rejection and increased productivity relative to applied net driving pressure, restore the design output of the three initial trains at a feed pressure within the capability of the existing Afton feed pumps.

Figure 1 is a chart produced by the Dare County Water Department. It describes feed pressure vs. elapsed time, and demonstrates clearly the rapid rise in feed pressure for all three RO units during the initial 16-to-18 months of operation. During this time, the plant was operated at full capacity during the summer months, and at about 50% the rest of the year. After an initial decline in feed pressure, there was another rapid increase, due in large part to iron fouling of the membranes. This fouling material was successfully removed by cleaning, with a resulting drop in feed pressure, although not back to values of the initial three months of operation. This adjustment occurred because in addition to fouling, there had been a significant increase in the wellwater TDS during this time frame, a trend which continued until revised wellfield operating procedures stabilized the feedwater at a TDS of about 3700 ppm. At the end of 1990, a decision was made to replace the second stage membranes with the Hydranautics CPA-2 model, based on an analysis and recommendation by Rostek Services, Inc. This membrane, at the time, demonstrated superior flux and salt rejection characteristics, compared to other available products. Modeling the proposed hybrid system indicated a reduction in feed pressure of over 10%, and the potential restoration of the initial blending ratio and design production.

The new second stage membranes were installed in June of 1991, and the result was dramatic, as can be seen in Figure 1. Since then, there has been an upward trend in feed pressure, in spite of routine cleaning and a well-managed wellfield. It would appear that the first stage elements are nearing the end of their useful life, and that, combined with a relatively stable but gradually increasing feedwater TDS has caused the feed pump discharge pressure to increase to a value very close to its maximum. Continuation of this trend will result in reduction in plant output; reduced blending (and thus a change in stability); and increased water production cost. It also means that the fourth unit may need to be installed earlier than anticipated, not necessarily for expansion, but to make up for lost production of the initial installation.

FEED PRESSURES

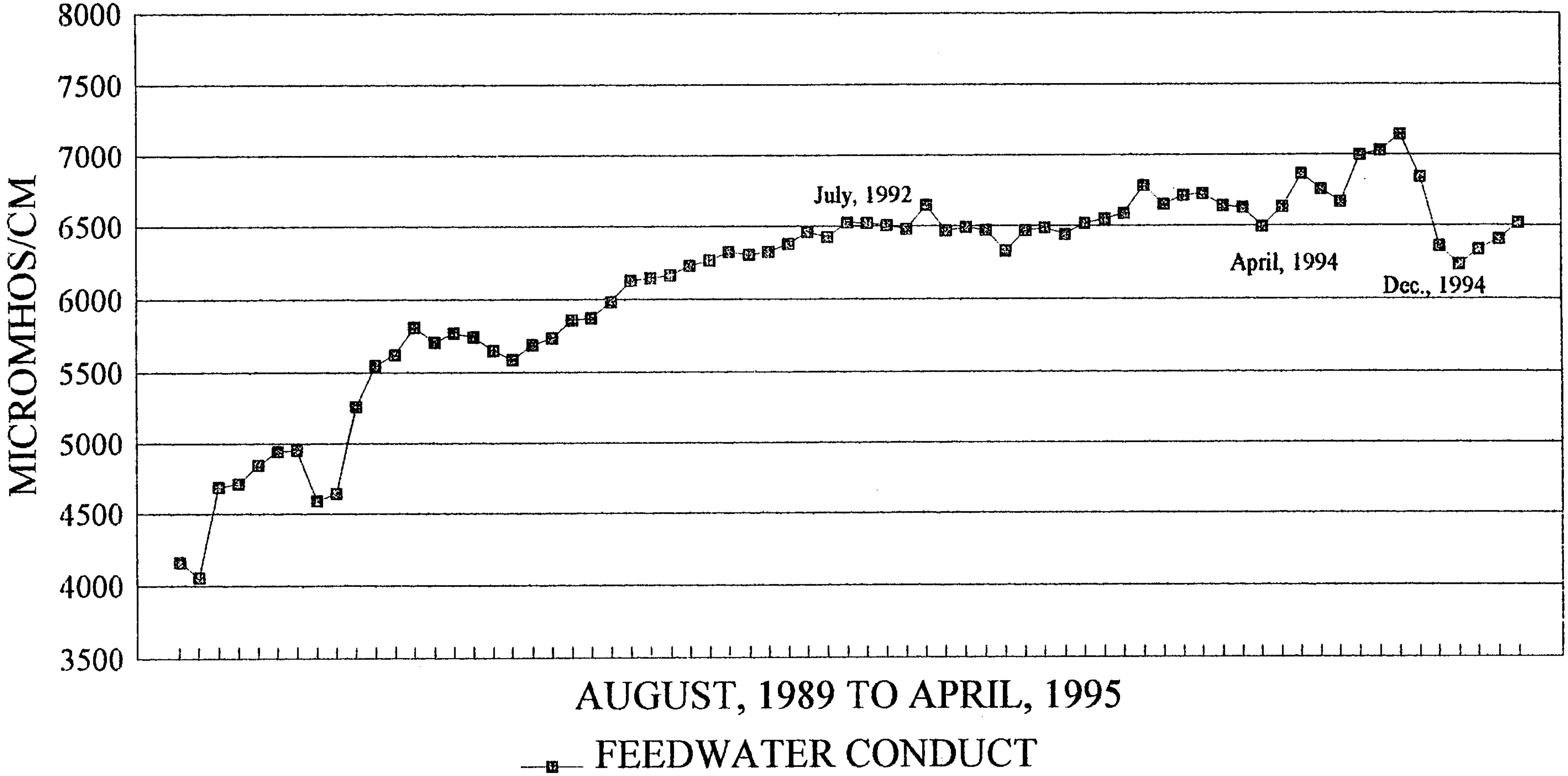
R.O. UNITS #1, #2 & #3



Notice distinct drop in Feed Pressure after installation of new second pass membranes - June, 1991.
Second distinct drop in Feed Pressure after start-up of new R.O. wells #9 & #10 - Dec., 1994.

REVERSE OSMOSIS RAW WATER CONDUCTIVITY

MONTHLY AVERAGES OF DAILY READINGS



July, 1992 - R.O. raw water withdrawals reduced. April, 1994 - R.O. at 60 % distribution again.
December, 1994 - Start-up of new Wells #9 & #10.

When the second stage membranes were changed in 1991, 162 cleaned Fluid Systems TFCL elements were removed. Some were treated with sodium metabisulphite solution, and double-bagged. All but 44 of those elements (18 were moved to the first stage, 24 were sold, 2 were autopsied) remain at the plant. Because of the current condition of the plant, the addition of 3 pressure vessels (loaded with these membranes) to each RO unit may extend the useful life of all the first stage elements, thus delaying major capital expenditures. The addition of pressure vessels would also permit the future installation of additional new membranes, particularly in the first stage. The additional membrane area would benefit the County, either by increasing the unit production of each train, or by reducing the feed pressure. Either way, the cost of water production would decline.

To formally evaluate the options available to the County, Boyle Engineering Corporation was asked to perform this study. To best cover the various options, several membrane configurations were developed, and the ability of the existing plant infrastructure to support these configurations was examined. The procedures and results are described in the sections following.

2.0 FEEDWATER QUALITY

Since the second stage membrane exchange in 1991, the wellfield that provides feedwater to the plant has been carefully managed to minimize the increase in feedwater TDS. Concurrently, further groundwater studies were conducted which concluded that the increased TDS was not occurring as a result of seawater intrusion, but because of upconing. Since the aquifer is stratified, the denser water is at lower elevations, and this higher TDS water was, and to some extent still is, being induced into the pumped zone of each of the original six wells.

The groundwater study further concluded that additional wells should be constructed at some distance from the existing wellfield. This action would reduce the stress on the existing wellfield, and by providing a source of lower TDS water, control and perhaps halt the steady increase in feedwater TDS.

Two new wells have been constructed, and are now in operation. The water quality is similar to, if not slightly better than the original water quality from the first six wells. Because these wells are now available, the feedwater quality coming into the RO plant will be derived from three existing wells and one new well, on a rotating basis. Mr. Robert Oreskovich, the department director, has developed a management strategy which precludes the use of the two new wells together, and rotates the use of the six old wells in such a way as to minimize pumping stress on that part of the aquifer. Given the adoption of this strategy, and with the very real possibility that the reduced pumpage from the original wellfield may actually result in an improvement in feedwater quality with time, it was agreed that the design feedwater quality for this study would be based on a combination of the three original wells with the worst water quality and one new well. This worst-case combination was tested with three trains, operating data collected, and samples of feed and permeate taken and analyzed. Based on this test, the analysis used for membrane projections in this study is:

Cations		Anions	
Calcium	50.3 ppm	Bicarbonate	268.0 ppm
Magnesium	84.9 ppm	Sulphate	196.0 ppm
Sodium	1363.7 ppm	Chloride	2200.0 ppm
Potassium	65.8 ppm	Fluoride	0.2 ppm
		Nitrate	0.6 ppm

Other	
Silica (as $Si0_2$)	11.2 ppm
pH	8.1
Temperature	20°C
TDS	4242 ppm

Because barium and strontium sulphate scale potential has always been very low, analysis for these ions was not performed, and they are not included on the list. Similarly, although iron is present, the recorded concentrations have always been less than 1 ppm, and that is not expected to change.

The original plant design included the addition of acid, not for carbonate scale control, but for the generation of carbon dioxide in the feedwater. This gas is transferred to the permeate. Without the need for a decarbonator, the carbon dioxide remains in the blended water. The addition of caustic soda raises the pH, by reacting with the carbon dioxide and creating additional bicarbonate alkalinity, which helps stabilize the finished water. The same approach to post-treatment stabilization has been taken in this study.

The finished water goal assumed for this study is 450 ppm TDS after caustic soda addition. This is roughly equivalent to a 750 micromhos conductivity. To achieve this quality, the blended product water, prior to post-treatment, must be about 400 ppm TDS, and this value was established as the design point for this study.

3.0 MEMBRANE ARRANGEMENTS

3.1 Approach

As discussed in the Introduction, the existing Dare County RO Plant as installed consisted of three parallel RO units, each arranged in a 21:9 array, with Fluid Systems 8821LP TFCL membrane elements. Those elements still in service in the first stage are now approaching six years old. When the second stage membranes were changed in June 1991, an additional vessel was added to the first stage. Therefore, today's array is 22:9, and the second stage membranes are approaching four years old. They are Hydranautics 8040-LSY-CPA2 membranes.

Because the plant is currently a hybrid in terms of membranes (70% TFCL, 30% CPA2), an approach had to be developed to assess the performance of an expanded array, using the current membrane mix. To do this, the Hydranautics membrane performance model "RODES" was used. The version utilized was 4.1, since this version contains a subroutine which allows the "creation" of a membrane other than the Hydranautics models. By using this version, the Fluid Systems TFCL membrane data could be inserted into the model, and the performance of the hybrid arrangement simulated.

A second consideration that directly affected the modeling of expanded train performance with existing membranes is the question of membrane age. After consideration of the impact of age on the results of the modeling, the following averages were selected for Runs 1, 2 and 3.

Run 1:	Average membrane age	=	4 years
	Salt passage increase	=	1.5%
Run 2:	Average membrane age	=	3.8 years
	Salt passage increase	=	1.4%
Run 3:	Average membrane age	=	3.4 years
	Salt passage increase	=	1.3%

3.2 Discussion of Results

As proposed, Runs 1, 2 and 3 were to model an expanded productivity for an RO unit, by adding vessels and using TFCL membranes on hand. However, a second set of Runs 1-3 was prepared, using 850,000 gpd as the permeate output, so that the impact on feed pressure could be studied. Thus, from the performance perspective, Runs 1, 2 and 3 can be used to assess the viability of either increased production, or reduced feed pressure. Details of the performance projection runs can be found in Appendix 1.

Table 1 shows the membrane arrays on which computer projections were based, while Table 2 shows the results of the computer projections. The shaded area in the permeate quality column represent the results of the simulations made with the existing hybrid membrane system. While the simulation predicted feed pressure at a reasonable level of confidence, the permeate quality results should not be considered valid. The current permeate quality produced during the test runs with design feedwater, ______ ppm TDS should be reproducible in the expanded array. Meanwhile, the permeate quality projected for runs 4,5, 6 and 7 reflect today's improved membrane performance. In fact, these values may even be somewhat conservative, and better quality is anticipated, providing for additional blending flexibility.

Even more exciting to contemplate is the next generation of membranes, one example of which is currently under test in small scale at the Kill Devil Hills facility. Based on the initial results of this test, future membrane replacement may permit operation at higher permeate flow than 1 mgd, at a higher recovery than 75%, and with a resultant permeate conductivity less than 100 micromhos.

Table 1.

Membrane Conditions For Each Run

Run No.	Membrane Array	Membrane Age	SPF	Flux Decline Coefficient	Permeate mgd	Temperature deg	Recovery %	Feedwater pH
1-A	25:9	4	1.5	-0.03	0.85	20	75	7.0
1-B	25:9	4	1.5	-0.03	1.00	20	75	7.0
2-A	25:10	3.8	1.4	-0.03	0.85	20	75	7.0
2-B	25:10	3.8	1.4	-0.03	1.00	20	75	7.0
3-A	25:10	3.4	1.3	-0.03	0.85	20	75	7.0
3-B	25:10	3.4	1.3	-0.03	1.00	20	75	7.0
4	25:10	3	1.2	-0.03	1.00	20	75	7.0
5	25:10	3	N/A	N/A	1.00	20	75	7.0
6	25:10	3	N/A	0.85*	1.00	20	75	7.0
7	25:10	3	1.3	-0.025	1.00	20	75	7.0

* Indicates fouling factor for Dow "Rosa" projection.

Table 2.

Output From Computer Projections

Model Run #	RO Vessel Array	Permeate Flow, mgd	No. of Elements per Unit	Membrane Feed Pressure psig	Permeate Quality, ppm TDS	Permeate Quality, ppm CaH	Permeate Quality, ppm M Alk
1-A	25:9	0.85	204	262.80	258	1.80	19.50
1-B	25:9	1.00	204	294.60	218	1.50	16.60
2-A	25:10	0.85	210	256.10	231	1.60	17.50
2-B	25:10	1.00	210	286.70	197	1.30	14.90
3-A	25:10	0.85	210	255.70	205	1.40	15.50
3-B	25:10	1.00	210	286.20	273	1.20	13.20
4	25:10	1.00	210	256.40	117	0.80	8.90
5	25:10	1.00	210	260.00	59	0.30	5.40
6	25:10	1.00	210	264.20	90	1.50	5.20
7	25:10	1.00	210	270.60	101	0.90	6.90

4.0 FEED PUMP EVALUATION

The membrane feedwater is pressurized by three vertical turbine pumps. Each pump has six stages installed, with the capability of adding three stages. The motors currently installed are 250 HP, and power is provided through a variable frequency drive (VFD). (A fourth pump is a spare and not connected to the piping.)

The vendor pump curves from the O&M manual were checked against actual readings taken in the field. These readings were taken during plant operation with the well combination described earlier. Previous operating records were also reviewed as part of this performance evaluation. The comparison of pump performance data with the manufacturers curves showed a close match. Therefore, no adjustments to the curves were necessary for wear and tear on the pumps.

The Table 3 presents a summary of the pump performance requirements for the membrane runs evaluated.

Future runs (4, 5, 6, and 7) with current state-of-the-art membranes indicate that no pump modifications are required. However, the potential for adding additional stages was confirmed with the manufacturer. The results indicate that a 7th stage can be added for extra head requirements, if necessary. This feature provides for the possibility of increasing the capacity and the recovery of each unit in the future, and represents a safety factor for utilizing high rejection membranes with an increased feedwater TDS.

Table 3.

Membrane Feed Pump Performance Evaluation

Run #	Boost Pressure psi	Flow gpm	Head Ft of H_20	Pump Efficiency %	Pump hp
1A	250	787	577.5	82	140
1B	282	926	651.4	81	191
2A	243	787	561.3	82	136
2B	274	926	632.9	80	185
3A	243	787	561.3	82	136
3B	273	926	630.6	80	184
4	243	926	561.3	80	164
5	223	926	515	80	128
6	250	926	577.5	80	169
7	245	926	565.9	80	166

Table 4.

Feed Pump Modification Cost Estimate

Description	Quantity	Unit Cost	Cost
Disassemble Pump/Piping/Motor	3 each	1,250	$ 4,750
Shipment (round trip)	2	4,000	8,000
Shaft, Seal, Bearings and Stage	4 each	8,000	32,000
Assemble Piping/Pump/Motor	3 each	2,000	6,000
Miscellaneous (pump/motor separation, 4th pump - parts and supplies)			6,000
TOTAL:			**$56,750**

Table 4 presents a summary of probable cost for the pump modifications, as required.

5.0 ELECTRICAL SYSTEM

The electrical system for the RO facility is comprised of a 480/277 volt, three phase power system fed through a 2000 ampere main service entrance circuit breaker. The electrical load is distributed through a 480 volt switchboard manufactured by Westinghouse Electric Company. Five feeder circuit breakers are located in the switchboard to distribute the load. They include:

- - 400 Amp Circuit Breaker to each RO Feed Pump VFD (Typical 3)
- - 600 Amp Circuit Breaker to Motor Control Center (MCC) 2
- - 800 Amp Circuit Breaker to MCC1

The MCC1 feed also can be provided by a 750 kW standby generator which is interfaced to a 1600 Ampere Automatic Transfer Switch (ATS). MCC1 is utilized to provide power to the high service pumps, building lighting and HVAC, and utilization loads.

Each existing RO feed pump motor is rated at 250 HP, with a 1.10 service factor, and is controlled by VFD. The VFDs are manufactured by Siemens and have a rated input of 300 Amperes and a rated output of 285 amperes for the 250 HP motor. The drives are 6 pulse converter type drives with a bypass starter for full voltage operation in the event of a drive failure, and are preceded with isolation transformers. All systems are sized to accommodate the existing and future pump conditions, including a seventh stage. Therefore, no motor exchange or electrical modifications will be required.

6.0 CHEMICAL FEED SYSTEMS

Six chemicals are being utilized at the facility, two for RO feedwater, and four for finished water. The usage range of these chemicals was estimated by reviewing chemical consumption logs for several, randomly selected operating events over a period of approximately one year. These data are summarized in Table 5.

Table 5.

Chemical Usage Data

Chemical	Concentration Range (mg/L)	Use
Chlorine	3-6	6
Fluoride	0.85 - 0.95	1
Caustic Soda	15-25	25
Sulfuric Acid	10 - 20	20
Scale Inhibitor	3 - 5	20
Corrosion Inhibitor	4 - 7	7

For the purposes of this study, the higher, or more conservative, values were utilized.

The capacity of one chemical feed pump from each chemical feed system to handle the total plant flow was evaluated. The RO feed water and product water flows, based on membrane performance projections, will be 4.0 and 3.45 MGD respectively.

Table 6 presents a summary of the chemical feed system pump capacity evaluation. Since conservative assumptions were made in these evaluations, it appears as though adequate capacity exists in the chemical feed systems to support an expanded production.

Table 6.

Chemical System Evaluation

Chemical	Conc. mg/L	Receiving Flow mgd	Required lb/hr	Density lb/gal	Required gal/hr	Available gal/hr	Approx. Setting %
1. Chlorine	6	3.45	7.2	—	—	—	87
2. Fluoride	1	3.45	1.2	.8	0.14	0.55	25
3. Caustic	25	3.45	30	10.59	2.83	15	20
4. Sulfuric acid	40	4.0	55	15.3	3.63	9.7	37
5. Scale Inhibitor	4	4.0	5.6	10	56	0.72	78
6. Corrosion Inhibitor	7	3.45	8.4	9.4	0.9	6	15

7.0 INSTRUMENTATION AND CONTROL

7.1 Introduction

The existing instrumentation and control system for automatic operation of the RO facility was evaluated for system operation with respect to the potential for increased capacity. The evaluation of the instrumentation was limited to the concentrate and permeate flow measurement and control, and scale inhibitor flow measurement. The corrosion inhibitor instrumentation was not investigated as it was inoperable at the time of the investigation. The analytical instrumentation (conductivity, turbidity, etc.) and the pressure monitoring of the system was not evaluated as these parameters should remain in the operable range with respect to the increased capacity. The control system was investigated from an overview perspective to identify the general operation of the system and possibilities for expansion in the future. The investigation looked at the physical appearance of the instrumentation, the general architecture of the system, and the workable range of the instruments with relation to the proposed increase in system parameters.

7.2 Control System

The RO plant is controlled utilizing Allen Bradley Model 3/10 Programmable Logic Controllers (PLCs) configured in a redundant standby architecture. From interviewing the plant personnel the PLCs require manual switchover to the secondary unit, but the databases of each PLC are updated in a real time mode to prevent loss of data. Although the 3/10 PLCs are somewhat outdated in terms of current technology, they are supported by Allen Bradley and have a good record of being a reliable controller.

The PLCs are housed in a control console located, along with an I/O cabinet, in a central control room which has a window onto the RO process room. The operator interface to the system is via dual IBM personal computers (PC) operating an Advisor PC software package. The software package is also provided by Allen Bradley (A/B) and provides graphical representation of the process, data collection, alarm management, data logging and system parameter trending.

The PCs are IBM model 7532 computers with 640K RAM, 1.2 Mb Diskette Drive, 120 Mb Tape backup, and a hard drive for data storage. The monitor is an IBM model 7534 color monitor for operator viewing of the graphics. Each PC is connected to the PLC via a data highway interface module which provides direct connection and data transmission to and from the PLC. Again the current technology for PCs far exceeds the existing setup, but PCs are reliable as a unit and would not need to be upgraded for this expansion.

From the evaluation, the control system appears to be operable and in satisfactory condition and is only lacking in the sense that the system may be slow by comparison to today's standards, and that the technology cannot support current supervisory software programs. As previously mentioned the proposed increase in capacity will not dictate the requirement to modify this operable system.

A Turbitrol SCADA system resides in the same area as the RO plant control stations for monitoring and control of the water distribution system. At this time no interfacing of the two systems have been performed, but through discussions with the plant operational personnel this may be a viable option in the future. In addition, a plant control station is currently being constructed for an adjacent facility. In the future, this may require interfacing to the SCADA system and RO plant. Additional consideration should be made in the selection of the PLCs and plant process control software for that facility, to form an open system for connection of the RO plant, new treatment plant, and SCADA distribution network. At that time it is suggested that the RO control system be upgraded to conform with the latest technological standards which will enhance the operation of the system.

Due to the age of the plant control station equipment and software, and the rapid technology swings in the control systems market, it is unlikely that the PLCs and plant control software are expandable to any systems other than the RO process. If a system with greater capabilities and interfacing to other systems is required in the future, we suggest that the PLC and PC system be replaced. However, at this time, the RO process is functioning satisfactorily and the Advisor PC is providing the capabilities for set-point adjustment and manual control of the system for operation of the facility. Therefore, for the current study, the control and monitoring system of the RO process does not require any modifications.

The Allen Bradley 3/10 PLC is programmed in ladder logic using the 6200 series programming software from Allen Bradley. The ladder logic program is not accessible from the PC using the Advisor PC software. Therefore, any modifications required to the software for additional equipment, RO units, or fine tuning the system requires exiting the PC advisor system to edit or monitor the PLC ladder logic. However, with dual PCs capable of viewing the process software, one is available for this on line editing without disturbing the system operation. Software available in today's market can provide this background editing in a Windows environment.

7.3 Instrumentation

The only instrumentation of concern, related to the increased capacity upgrade of the system, is the flow instrumentation and control for the RO units, and the scale inhibitor flow meter.

Each RO unit has two flow meters; one for the permeate flow and one for the concentrate flow. The primary elements are venturi meters which create a pressure differential proportional to the flow through the element. The existing permeate element is calibrated to 1000 gpm for a pressure differential of approximately 172 inches of water. The existing concentrate flow element is calibrated to 500 gpm for a pressure differential of approximately 86 inches of water. Based on the estimated flow associated with modifying the membrane arrays, these elements will not require recalibration. Also, the pressure differential transmitters are Rosemount 1151 with the Smart option and have maximum calibration ranges of 750 and 150 inches of water, respectively. Therefore, even in the event that the flow exceeded the 1000 or 500 gpm limit, the transmitters would only require calibration based on the calculated differential from the primary flow element.

The scale inhibitor flow indicator and transmitter were investigated for the possibility of increasing the range of the unit. In that the transmitter and indicator can be calibrated to a maximum of 4000 cc/minute of continuous flow, calibration is not required and the flow system can remain intact.

The concentrate flow control valve, manufactured by Cashco, is rated for 280 gpm. At the design recovery ratio of 75%, a conversion to 1 mgd/unit of permeate production would result in a design concentrate flow of 231.5 gpm. This flow rate remains within the capability of the existing valve, although the internal trim may need to be changed. This conversion would be a minor field change, which could be accomplished by current maintenance personnel.

In summary, the instrumentation appears to be in satisfactory working order, with exception of the corrosion inhibitor flow meter and transmitter. The instrumentation can also meet the system requirements for the increased capacity. Modification and/or upgrading of the supervisory system is not necessary, nor is it recommended at this time.

8.0 COST ESTIMATES

Based on the evaluation of the infra structure supporting the membrane systems, as discussed in Sections 4 through 7, it is not expected that any modifications or upgrades are required to support any membrane expansion. If at some future date a seventh pump stage is desired, an opinion of the cost to accomplish that at the suppliers factory has been included. This cost is obviously based on 1995 dollars.

The expansion of the membrane units to a 25:10 array involves the purchase and installation of 4 additional vessels per unit: the necessary hardware, piping and valves to install these vessels, and the purchase of 6 Hydranautics CPA2 membrane elements per unit.

A complication is the disappearance of the Fluid Systems vessels currently installed from the market. Because of the design of the high pressure connections, and the type of connection device used, it was necessary to have rigid feed and brine ports in the end plugs. Since this vessel design is no longer available, neither is this type of end plug. Since end plugs with a floating port design must of necessity be used, it will be necessary to change from flexible connections between the manifolds and vessels to a rigid connection for the new vessels. It is estimated that this change will increase the cost of installation of each vessel by about $3000.

In summary, the opinion of cost to expand the membrane arrays is as follows:

12 new pressure vessels @ $1500	$18,000
Installation of new vessels @ $750	9,000
18 new CPA2 membranes @ $750	13,500
Miscellaneous supplies, O-rings, connectors, etc.	2,500
Total Estimated Cost:	$43,000

Run 2 would appear to be the most cost effective modification, since Run 3 infers the purchase of 50 new TFCL membranes per unit. This option is more of an intermediate step between expansion, and 100% membrane replacement, if and when that step appears appropriate.

From Table 2, it can be seen that the membrane feed pressure for the high flow option is about 287 psig. This can be compared to the current plant feed pressure of about 292 psig average, and obviously is not significantly lower. However, it is predicted that given the increase in membrane capacity, and maintenance of the current blending ration, a 10% to 15% increase in finished water production capability can be achieved.

Based on the 5th Annual Report of the Regional Water System, the unit cost of production at the RO plant in FY94 was $1.58/kgal of product water. Of this total, approximately $1.07/kgal could be considered "fixed" cost, not dependent on the volume of water produced. If 10% more water could be produced, this fixed cost, on a unit basis, would be reduced to about $0.96/kgal, and the total cost reduced to $1.47/kgal. This difference, on an annual basis, is about $60,000, based on an increased production.

Appendix 1.

Scope of Study