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Desalination and Water Purification Research and Development Program Report No. 108

Volume Reduction of High-Silica RO Concentrate Using Membranes and Lime Treatment

University of Texas at El Paso

Agreement No. 02-FC-81-0835-Task F

U.S. Department of the Interior
Bureau of Reclamation

February 2005

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
March 2004

2. REPORT TYPE
Technical

3. DATES COVERED *(From - To)*
October 2002 – December 2003

4. TITLE AND SUBTITLE
Volume Reduction of High-Silica RO Concentrate Using Membranes and Lime Treatment

5a. CONTRACT NUMBER
02-FC-81-0835-Task F

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Anthony J. Tarquin

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Civil Engineering
The University of Texas at El Paso
El Paso, Texas

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Denver Federal Center
P.O. Box 25007
Denver, CO 80225

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
Report No. 108

12. DISTRIBUTION / AVAILABILITY STATEMENT
Available from National Technical Information Service, Operations Division, 5285 Port Royal Rd, Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Two processes were studied to investigate ways to reduce the volume of silica-saturated reverse osmosis reject concentrate: (1) Nanofiltration of the concentrate (for removing hardness) followed by reverse osmosis treatment of the nano permeate, and (2) lime treatment of the concentrate (for removing silica) followed by reverse osmosis of the lime-treated water. Results showed that the membrane processes could reduce the concentrate volume by up to 55 percent, but at recoveries greater than this, membrane fouling was observed.

Lime treatment of the concentrate was shown to be very effective for removing silica, with the overall process described as a first-order reaction. However, no silica removal occurs until the lime dosage exceeds the lime-equivalent of the alkalinity. Lime treatment was shown to be more cost effective than the best "throw-away" option of deep-well injection. At a lime dosage of 750 mg/L, there would be a net savings of $1.6 million per year compared to injection, and 5 million gallons per day (0.218 cubic meters per second) of project water would be produced at a cost of $1.43 per thousand gallons ($0.375 per cubic meter).

15. SUBJECT TERMS
desalting, desalination, reverse osmosis, nanofiltration, silica, silica removal, lime treatment, alkalinity, nano permeate, nano concentrate

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Anthony Tarquin
a. REPORT	b. ABSTRACT	c. THIS PAGE		43	19b. TELEPHONE NUMBER *(include area code)* 915-747-6915

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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Bureau of Reclamation
Technical Service Center
Environmental Resources Team
Water Treatment Engineering and Research Group
Denver, Colorado

February 2005

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Acknowledgements

This project was made possible through funding provided by the U.S. Bureau of Reclamation under solicitation No. 02-FC-81-0757 – Task F – Concentrate Issues.

Their continuous moral support and offers of laboratory support are truly appreciated.

El Paso Water Utilities provided financial assistance, physical facilities, and personnel for constructing buildings, doing plumbing and electrical work, and maintaining equipment.

Special thanks also go to GE-Osmonics for providing two pilot plants, filters, and all of the membranes used throughout the study.

Finally, this project would not have been completed without the unwavering help of individuals at all levels of El Paso Water Utilities and UTEP students who devoted most of their waking hours to completing this investigation.

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Executive Summary

As more and more communities face projected shortages in long-term water supplies, they are increasingly considering desalting as an option to help alleviate the water supply shortage. For inland communities that undertake large projects, disposal of the brine concentrate can present a major problem. In the Southwestern United States, the presence of silica in the groundwater exacerbates the brine concentrate problem because it limits the extent to which water can extracted from the brackish water supply, resulting in the generation of even larger volumes of waste concentrate. This project was undertaken to investigate ways to reduce the volume of silica-saturated reverse osmosis reject concentrate.

Two processes were studied in this investigation: (1) nanofiltration of the concentrate (for removing hardness) followed by reverse osmosis treatment of the nano permeate, and (2) lime treatment of the concentrate (for removing silica) followed by reverse osmosis of the lime-treated water.

The results showed that the membrane processes could reduce the concentrate volume by up to 55 percent, but at recoveries greater than this, membrane fouling was observed. This is probably because the nanofiltration pre-treatment step did not remove all of the hardness from the concentrate, resulting in silica precipitation in the subsequent reverse osmosis (RO) process when the silica concentration in its reject stream reached about 300 milligrams per liter (mg/L).

Lime treatment of the concentrate was shown to be very effective for removing silica, with the overall process described as a first-order reaction. However, no silica removal occurs until the lime dosage exceeds the lime-equivalent of the alkalinity.

In this study, lime treatment was shown to be more cost-effective than the best "throw-away" option of deep-well injection. At a lime dosage of 750 mg/L, there would be a net savings of $1.6 million per year compared to injection, and 5 million gallons per day (0.218 cubic meters per second) of project water would be produced at a cost of $1.43 per thousand gallons ($0.375 per cubic meter).

1. Introduction

El Paso Water Utilities, in partnership with Fort Bliss (a U.S. Army installation), has committed to build the largest inland reverse osmosis (RO) desalting plant in the United States. The plant will treat 18 million gallons per day (MGD) (0.79 cubic meters per second [m^3/s]) of brackish groundwater and produce 27.5 MGD (1.2 m^3/s) of product water after blending.

A problem faced by any inland water desalting facility is what to do with the brine solution that is generated as reject water in the reverse osmosis process. This problem is exacerbated when the raw water supply contains substances such as silica that could foul membranes if the reject water is concentrated too much. This is the case in the city of El Paso, where the brackish groundwater contains silica at an average concentration of 25-30 milligrams per liter (mg/L). At this concentration, recovery of product water will be limited to about 80-85 percent (%) because above this value, silica will precipitate, fouling the membranes. The 80-85% recovery rate will generate more than 3 MGD of brine concentrate that will have to be disposed of or concentrated in some way.

Lab-scale studies conducted by GE-Osmonics had shown that it might be possible to recover between 65% and 90% of the silica-saturated brine concentrate through appropriate combinations of existing processes (CDM, 2002). The purpose of this project was to verify the laboratory scale studies with pilot scale systems and obtain meaningful data that could be used in the design of a full-scale membrane-based brine-concentrate treatment system.

2. Conclusions and Recommendations

Based on the results of this study, the following conclusions and recommendations can be made with reasonable certainty:

1. The membrane processes of nanofiltration followed by reverse osmosis can be used to recover a significant portion of the water from silica-saturated RO brine, but the volume recoverable is limited by both the concentration of calcium and the concentration of silica in the nano permeate. In this study, the maximum overall recovery that was achieved using only membranes was about 55%, with the maximum silica concentration reaching about 300 mg/L at a hardness concentration of around 500 mg/L.

2. Silica removal from nanofiltration and RO concentrates via lime precipitation appears to be a first-order reaction of the general equation:

$$C = Co10^{-kL}$$

Where:	C	=	Silica concentration remaining, mg/L
	Co	=	Initial silica concentration, mg/L
	k	=	Rate Constant
	L	=	Lime dosage, mg/L

For the concentrates used in this project, the k values ranged from 0.0027 to 0.0064.

3. Hardness can have a major effect on precipitation of silica from silica-saturated brines. At high pH values, even very low concentrations of hardness can facilitate rapid precipitation of silica. Hardness also affects silica precipitation during lime treatment of brine concentrates. In general, the higher the concentration of hardness in the brine, the greater the silica removal per mg/L of lime.

4. Alkalinity has a significant effect on silica removal via lime precipitation. Results in this study show that there is essentially no silica removal at lime concentrations lower than the lime-equivalent of the alkalinity. However, silica is removed on essentially a one-for-one basis with lime at incremental lime dosages above the alkalinity equivalent concentration of lime when the silica concentration is greater than 200 mg/L. Thus, degassing of the brine prior to treatment with lime reduces the lime dosage required for a given amount of silica removal in direct proportion to the reduction in the alkalinity.

5. When silica is assumed to be the only parameter limiting recovery of the brackish water from RO concentrate, the lime-softening process is very cost effective when compared to either pond evaporation or deep-well injection. For example, any lime dosage above 350 mg/L would result in a lower annual cost for disposing of the RO concentrate than would deep-well injection, while at the same time producing additional project water. For example, at a lime dosage of 750 mg/L in degassed RO concentrate, the net annual savings would be over $1.6 million per year (the expected cost for injecting the 3 MGD of concentrate). This assumes that 80% of the concentrate would be recoverable through additional RO treatment after the silica concentration is reduced. The other 20% would be disposed of through evaporation ponds. Blending of this recovered water with brackish groundwater would result in an extra 5 MGD (0.218 m^3/s) of project water at a cost of approximately $1.43 per thousand gallons of produced water ($0.375/$m^3$).

6. Pilot studies should be conducted to determine which parameters are limiting recovery of the RO concentrate. In the economic evaluation conducted in this report, silica was assumed to be the limiting parameter. However, other parameters such as barium sulfate could limit the extent to which the brine could be concentrated and this would obviously affect the economics of the process. On the other hand, the maximum silica concentration used for determining water recovery during RO treatment of the lime-treated water was

140 mg/L. Since it is possible that a higher silica concentration could be feasible, additional pilot studies are warranted to investigate this possibility.

7. In addition to identifying the parameters that limit recovery of the brine, long-term pilot studies need to be conducted to accurately determine the operating parameters of the reverse osmosis system that would treat the lime-treated water. These parameters would include feed pressure, flux rate, operating pH, membrane type, etc. Again, this information is necessary for conducting accurate economic analyses.

8. Finally, since hardness has a significant effect on precipitation of silica under super-saturated conditions, it would be worthwhile to investigate the use of ion exchange for softening the water from the nanofiltration system and, possibly, for softening some of the water from the lime treatment process. This would allow for higher recovery of water in the RO process and, therefore, may be economically attractive.

3. Work Performed

This research project could be considered as consisting of two separate research projects embodied in one. This is because two completely different concepts regarding how the silica-saturated RO concentrate should be handled were investigated. The first concept that was tested involved using only membranes to concentrate the silica saturated brine. The membrane treatment scheme was based on the premise that by removing hardness from the brine using nano filtration, the silica concentration could be raised considerably above the normal saturation value without precipitating any of the silica in a subsequent reverse osmosis brine recovery unit. The second concept that was tested involved lime treatment of the concentrate to reduce its silica concentration so that additional water could be recovered from the concentrate through additional reverse osmosis treatment.

3.1 Membrane Studies

The membrane studies were conducted at the Montana Booster Station field site owned by El Paso Water Utilities. A 10 feet (’) x 14 feet (3.05 meters (m) x 4.27 m) building was constructed at the site to house the membrane units. As stated above, the membrane studies involved the use of nano filtration to remove hardness from the brine while allowing the silica to pass through the membrane with the permeate. The high-silica nano permeate was then subjected to RO treatment to recover some of the water from the softened brine. This resulted in further concentration of the silica in the brine. A schematic diagram of the process (as originally envisioned) is shown in figure 1.

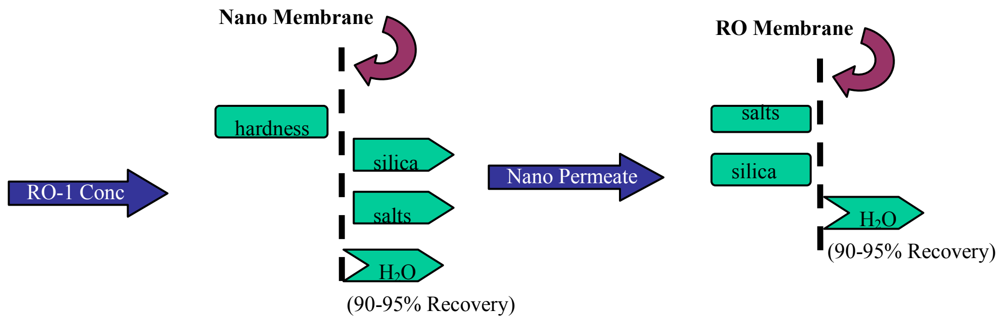

Figure 1 – Schematic of Membrane Processes.

The feed water to the nano filtration unit was RO concentrate (identified as RO-I concentrate) from a reverse osmosis pilot plant operated Camp, Dresser, & McKee Inc. The 25-gallons-per-minute (gpm) (0.095 m^3/min) pilot plant was operated at recovery rates ranging between 75% and 85%, producing about 4 gpm (0.015 m^3/min) of RO concentrate having a silica concentration ranging between 120 mg/L and 175 mg/L.

The RO-I concentrate was subjected to nano filtration using 4 inches (") (10.16 centimeters [cm]) diameter membranes in series in a four-vessel system that was provided by GE-Osmonics. This unit was operated at recovery rates ranging from 50% to 85%. The permeate from the nano system was treated using 2.5 ″ (6.35 cm) membranes in series in a three-vessel, six-membrane RO system (also provided by GE-Osmonics).

Samples were taken from the permeate and concentrate streams of each unit and were subjected to various physical and chemical tests including conductivity, temperature, pH, total hardness, calcium, chlorides, alkalinity, sulfates, silica, and TDS. Most of the analyses were conducted using HACH procedures, but silica was occasionally also analyzed using Inductively Coupled Plasma (ICP) to verify the HACH procedure and to measure silica that was in a non-monomeric form.

3.2 Lime Treatment Studies

The lime treatment studies involved batch experiments conducted at the lab scale, and continuous flow experiments conducted using pilot-scale equipment. The lab studies used water taken from four different streams: RO-I concentrate, nano permeate, nano concentrate, and RO-II concentrate. Some of the physical and chemical characteristics of each sample are shown in table A1 of appendix A.

The laboratory jar test procedure used one-liter samples in square containers of a Phipps & Bird jar test apparatus. The samples were treated with various concentrations of hydrated lime, $Ca(OH)_2$, ranging from 100 mg/L to 800 mg/L. After dosing, the samples were stirred for 30 minutes at 40 revolutions per minute (rpm), allowed to settle for 60 minutes, and then filtered through 9 cm, no. 25 fiberglass filters. Various physical and chemical analyses were performed on the filtrates, depending on the purpose of each particular trial run.

The pilot scale studies were conducted at the Montana Booster Station site, where a 12’ x 16’x 15’ (3.7 m x 4.9 m x 4.6 m) partially-enclosed structure was constructed to house the treatment units. The pilot plant equipment was leased from CDM Inc., and it included a pumping module, a three-tank flocculation unit, a tube settler for solids separation, and two 13’ (4 m) tall by 4” (10.2 cm) diameter mixed-media pressure filters. The units were capable of handling flows up to about 2 gpm (0.0075 m^3/min). Near the end of the project period, three 55-gallon (0.208 m^3) drums were added in series ahead of the flocculation unit to serve as CO_2 degasifiers.

A schematic diagram of the lime-treatment pilot plant is shown in figure 2.

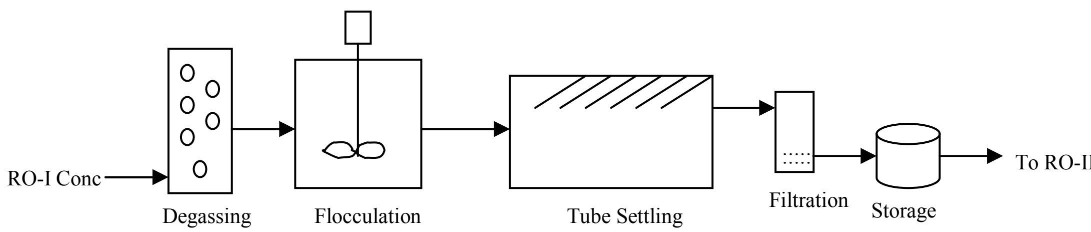

Figure 2 – Schematic of Lime Treatment Pilot Plant.

Degassing was accomplished in three-55 gallon (0.208 m^3) drums by injecting acid into the first drum and aerating the first two by passing compressed air at 2 CFM (0.057 m^3/min) through ½” (1.27 cm) PVC diffuser pipes (having 1/16” diameter holes) located in the bottom of the drums.

The three-compartment flocculator had a total volume of 70 gallons (0.265 m^3), yielding a theoretical detention time of 78 minutes at the average flow of 0.9 gpm (4.9 m^3/day) that was used during most of the lime-treatment studies. The flocculated solids were removed through a tube-settler and multi-media filter, with some of the treated water stored in a 500-gallon (1.89 m^3) tank for subsequent treatment by reverse osmosis to further concentrate the original RO-I reject.

The silica concentration in the treated water was measured daily, with other parameters measured intermittently as deemed necessary to understand the overall performance of the process.

4. Analysis of Results

4.1 Membrane Studies

When the membrane studies were first begun, unchlorinated *well water* was used as the source of supply to both membrane units (i.e., nano and RO) for the first few days to provide time for the investigators and El Paso Water Utility personnel to become familiar with the operating characteristics of the systems. The recovery rates on both the nano and RO units were set at about 75% and the systems performed well. When the source of supply was switched to RO-I concentrate, the feed pressure in the RO unit increased from 450 psi (3.1 MPa) to over 900 psi (6.2 Mpa) *overnight*. Therefore, it was obvious that the 75% recovery rates were too high, so the nano recovery rate was set back to 65% and the RO rate to 50%. The recovery rates were then gradually increased until the maximum short-term sustainable rates could be identified as discussed below.

A major complicating factor in this study was the changing characteristics of the concentrate that was the source of supply for the membrane systems. This occurred because the RO-I concentrate that was the supply for these systems was generated in another pilot plant that was operated to provide design information for the full-scale desalination facility. As such, changes were frequently made in that unit in recovery rates, membrane type, antiscalants, acid feed rate, etc. Each change resulted in generation of a somewhat different concentrate. Figure 3 is a plot of the changes in conductivity of the feed water to the nano unit that occurred during the project period (see Appendix A for data for all figures) and, as shown, the conductivity changed by a factor of more than three (i.e., 3,520 to 10,940 µS/cm). Similar changes occurred in other parameters of interest, including hardness, alkalinity, chlorides, etc., as shown by the raw data provided in tables B1 thru B9 of appendix B. The biggest change in quality occurred in April when a new groundwater source of supply was used for the project. Although these changes made it difficult to identify the maximum non-fouling operating conditions for either of our membrane systems, the results were obtained over equilibrium time periods that were sufficiently long to render them fairly reliable.

In addition to showing the quality of the feed water for 9 different parameters, tables B1 thru B9 show the results for samples collected at 12 different places within the two systems. These results were collected over a 7-month period of time, with operating conditions frequently being changed so that the maximum water recovery rates could be identified. Figure 4 shows the recovery rates tested for the nano and RO systems during that time and, as shown, fouling started when the recovery rate in the RO unit reached about 71% on 2/19. There was no apparent fouling at a 65% recovery rate, and since the recovery rate in the nano unit at that time was about 85%, the maximum overall recovery rate that was achieved for the membrane systems as a whole was about 55%. When the quality

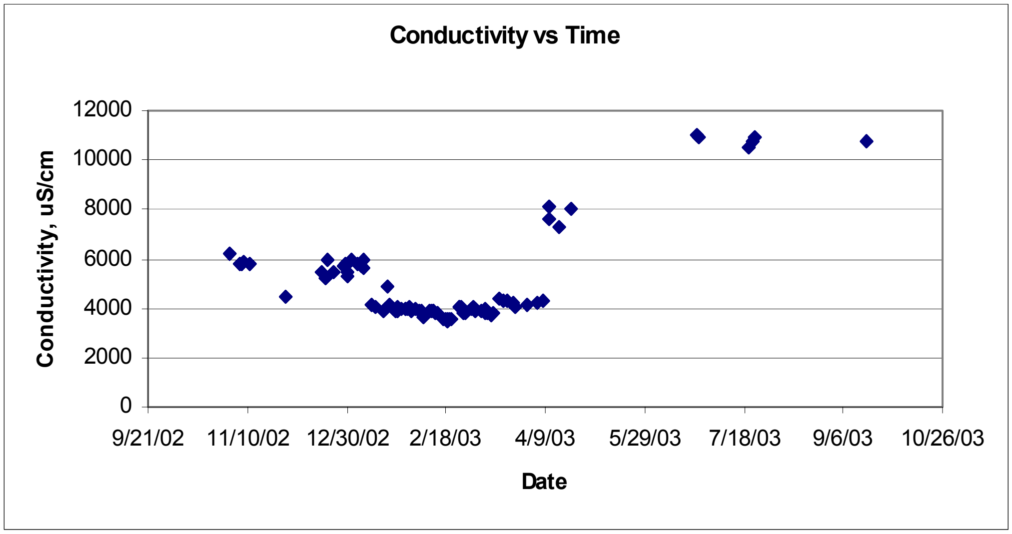

Figure 3 – Changes in Conductivity of Feed Water to Nano Unit.

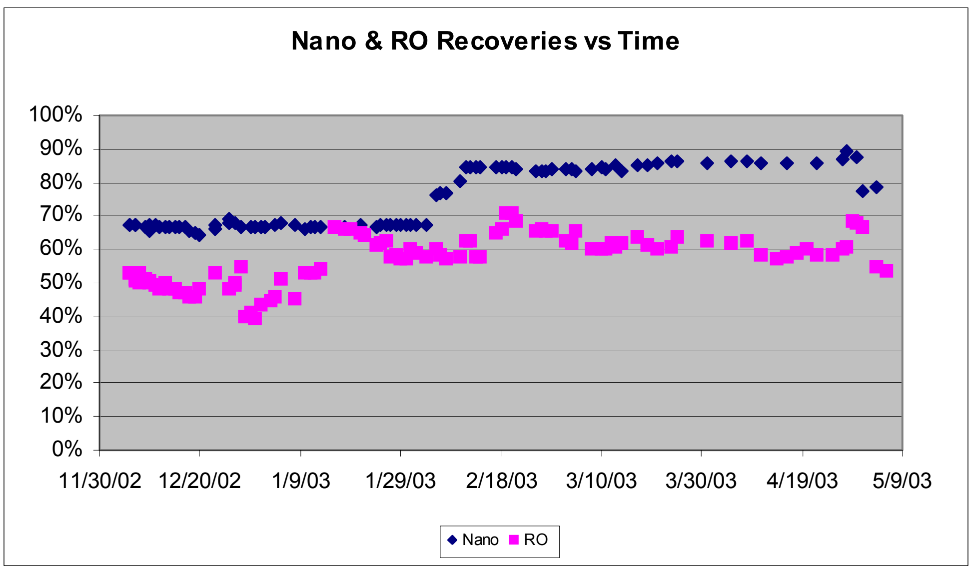

Figure 4 – Nano and RO Recovery Rates Tested During Membrane Studies.

of the feed water changed in April, the maximum overall sustainable recovery rate decreased to less than 50%, so lime treatment studies were begun.

4.2 Lime Treatment Studies – Laboratory

The first lab studies that were conducted regarding lime treatment focused on the effect of initial silica concentration on silica precipitation by lime. A stock solution of sodium meta-silicate ($Na_2SiO_3.2H_2O$) was used to make four standard solutions of silica having initial silica concentrations of 240 mg/L, 140 mg/L, 75 mg/L and 24.5 mg/L, respectively.

Each solution was treated with 500 mg/L of lime and then subjected to the jar test procedure described above. The results shown in figure 5 reveal that more silica is removed per mg/L of lime as the silica concentration in the water increases. This is expected of course because silica is very unstable in solutions having concentrations exceeding the silica saturation value (Iler, 1979).

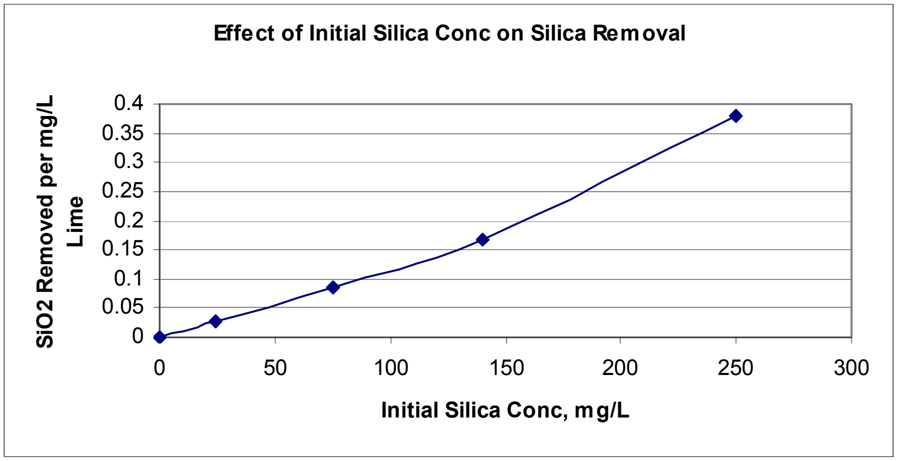

Figure 5 – Effect of Initial Silica Concentration on SiO2 Removal – 500 mg/L Lime

The effectiveness of lime for removing silica was determined through jar tests wherein the lime dosage was varied in four different silica-containing solutions: RO-I concentrate, nano permeate, nano concentrate, and RO-II concentrate. The data from these tests are shown in tables A5 and A6 of appendix A.

Figure 6 is a plot of silica removal versus lime dosage for RO-I concentrate and as the graph clearly shows, lime is very effective for removing silica from the concentrate. Silica removal appears to follow a first-order reaction as shown by the fairly good fit (R^2= 0.89) of the exponential equation.

$$C = 129 * e^{-0.0027L}$$

Where: C = Silica remaining, mg/L
L = Lime dosage in mg/L

This equation could be used to determine the lime dosage required to reduce the silica concentration to any level that would be desired.

Figures 7 shows the relationship between silica removal and lime dosage for the other three brine streams that were treated: nano permeate, nano concentrate, and RO-II concentrate.

The graphs for these brines are very similar to that of RO-I concentrate, with even higher correlation coefficients for the respective equations. With k values of 0.0027, 0.0044, 0.0046 and 0.0029 for RO-I concentrate, nano permeate, nano

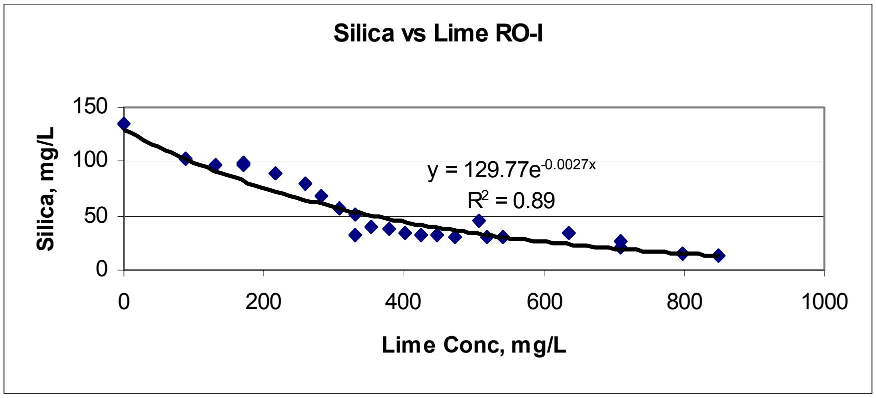

Figure 6 – Silica Remaining vs Lime Concentration for RO-I Concentrate.

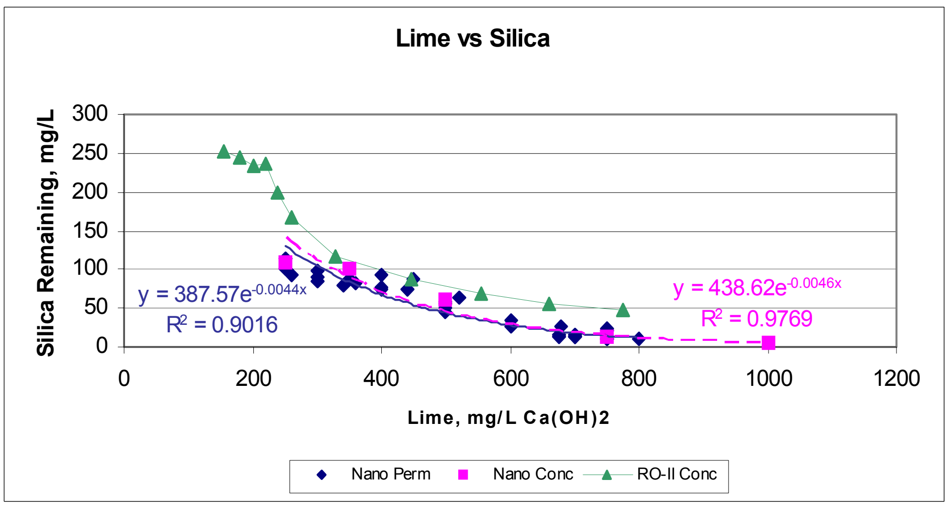

Figure 7 – Lime vs Silica for Nano Perm, Nano Concentrate, and RO-II Concentrate.

concentrate, and RO-II concentrate, respectively, it is fairly certain that silica removal via lime addition can be described as a first-order reaction with a k-value close to 0.004. However, it should be pointed out that these equations apply to lime dosages that are required to remove silica *and* satisfy the alkalinity, because lime reacts with alkalinity first, and then it reacts with the silica, as discussed later in this report.

The effect of *hardness* on silica precipitation was investigated by spiking pure silica standard solutions and nano permeate with various concentrations of $CaCl_2$. No attempt was made to control the pH, so some of the solutions had pH values as high as pH 11. The solutions were stirred for 10 minutes, filtered and then analyzed for silica. Figure 8 shows the results obtained when the hardness of the silica standards was increased by various amounts up to 15,000 mg/L using $CaCl_2$.

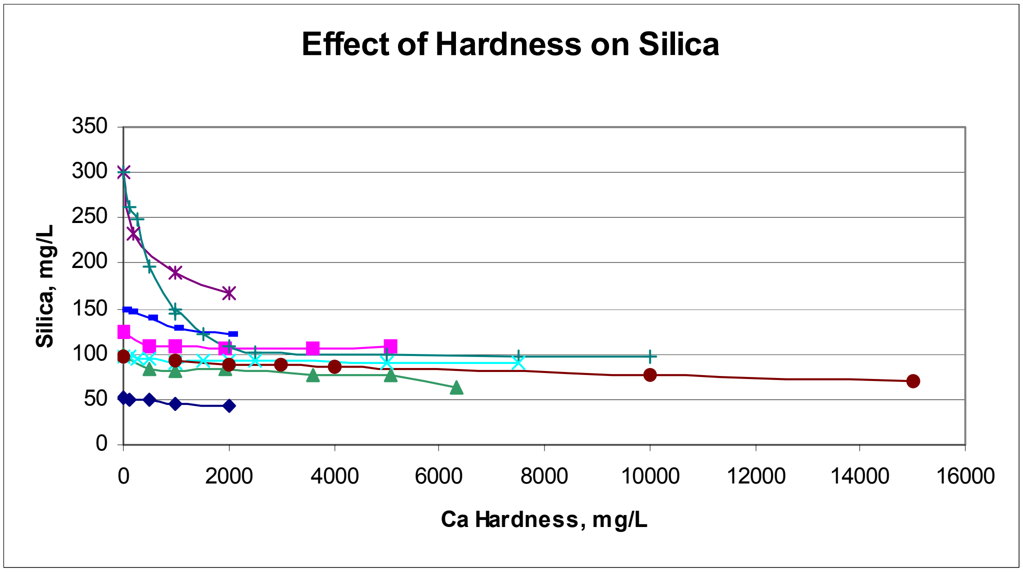

Figure 8 – Effect of Hardness on Silica Precipitation From Standard Silica Solutions.

The results show that for a given concentration of hardness, more silica precipitates as the concentration of silica is increased. This is similar to the results discussed previously wherein *lime* caused greater silica precipitation in silica standards having higher initial concentrations of silica (see figure 5).

To better quantify the effect of hardness and pH on silica precipitation, silica standards were prepared wherein the pH of the standards was adjusted to between pH 2 and pH 8. The results are shown in table 1 and they reveal that the monomeric silica concentration is affected by hardness and silica concentration, but the change is much less at these pHs than at higher pH values.

Table 1 – Effect of Hardness on Silica Precipitation at Various pH values

			Silica, mg/L at pH					
Hard, mg/L	2	4	6	8	2	4	6	8
0	141	143	160	155	241	246	250	212
1,000	130	138	147.5	145	225	229	227.5	188.5
2,000	127	132	140	134.5		209.5	218	189.5
3,000	117.5	130	129	134.5	204	208.5	212	175
4,000	110	129.5	128.5	133	208	200	203	175
5,000		120	123.5	130		196	188.5	169

These results indicate that calcium hardness can have a significant effect on silica precipitation, especially at the concentrations of silica that may be encountered in membrane concentrates generated at the higher recovery rates in RO systems.

This effect would be beneficial during lime treatment of brines for silica removal, but it would be detrimental during membrane treatment of high-silica, high-hardness brines.

To further evaluate the effect of hardness on silica precipitation during lime treatment of brines*, nano permeate* was spiked with different amounts of $CaCl_2$ and then treated with 500 mg/L of lime. The un-spiked permeate had a hardness of 230 mg/L and a silica concentration of 123 mg/L. The $CaCl_2$-spiked samples had hardness values of 600 mg/L, 650 mg/L, and 1250 mg/L. After treatment with 500 mg/L of lime, the silica concentration decreased to 30.9 mg/L in the un-spiked sample, but it decreased to less than 16 mg/L in each of the other three. These results, which are presented in figure 9, show that extra calcium hardness does have a small beneficial effect on silica removal in the lime treatment process.

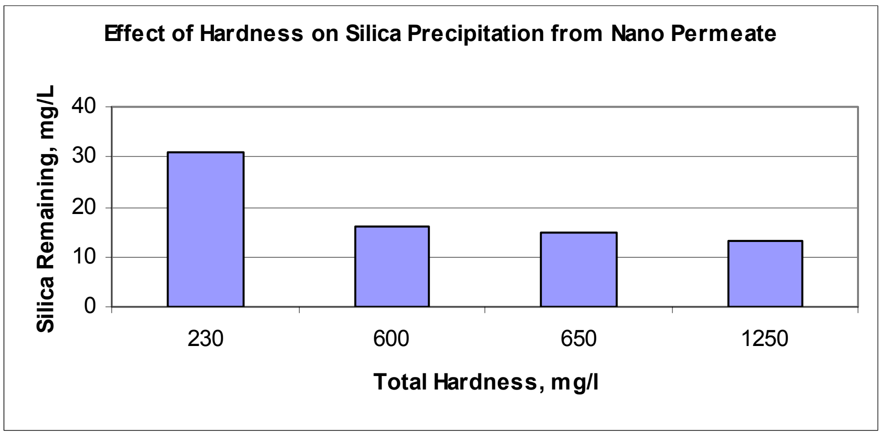

Figure 9 – Effect of Hardness on Silica Precipitation From Nano Permeate.

The final parameter investigated with respect to its effect on silica removal during lime treatment of brines was alkalinity. The alkalinity in RO-I concentrate, which had a silica concentration of 135 mg/L, was varied from zero to 1,560 mg/L either by adding sulfuric acid and degassing (by bubble aeration) or by adding sodium bicarbonate. After the alkalinity was adjusted, lime was added at a concentration of 500 mg/L and the jar test procedure was conducted. The results are in figure 10 and they reveal that alkalinity has a major effect on silica removal via lime precipitation. Specifically, the data show that there is essentially no silica removal at lime concentrations lower than the lime-equivalent of the alkalinity**.** This means that lime reacts with alkalinity first, and then it reacts with silica. Therefore, the lime dosage required to achieve a given amount of silica removal in a given brine solution is reduced on a *one-for-one basis* as the alkalinity of the solution is reduced.

Thus, for concentrates that have a significant amount of alkalinity, the lime dosage required for a given amount of silica removal could be reduced in direct proportion to any reduction in the alkalinity of the solution.

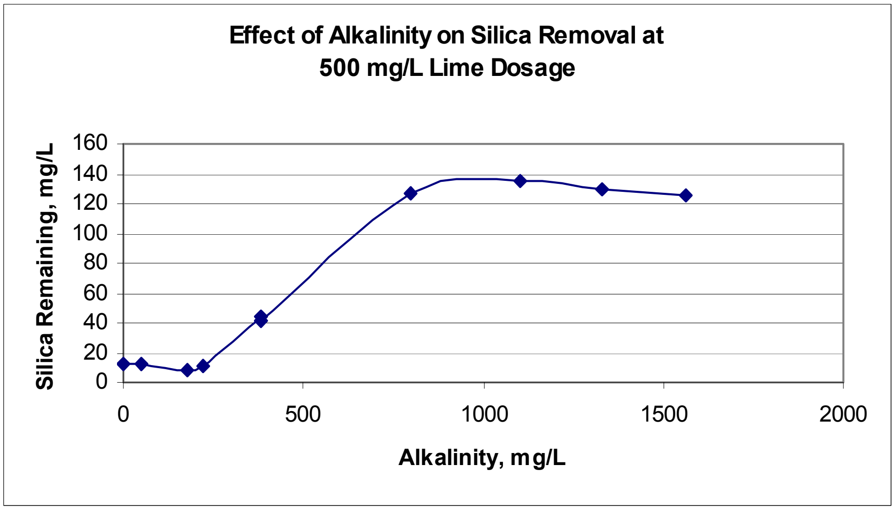

Figure 10 – Silica Remaining vs Alkalinity at 500 mg/L Lime Dosage.

To further demonstrate the effect of alkalinity reduction on silica removal via lime precipitation, the alkalinity of RO-I concentrate (initial silica concentration of 135 mg/L) was reduced from 380 mg/L to 150 mg/L, 80 mg/L, and 40 mg/L, respectively. The solutions were then dosed with various concentrations of lime and stirred using the jar test apparatus. The results are plotted in figure 11 and they clearly show that the curves are almost parallel, shifted by an amount equal to the lime equivalent of the alkalinity difference between the respective samples. Thus, there is a significant reduction in the amount of lime required to reach a specified silica concentration as the alkalinity of the solutions is reduced.

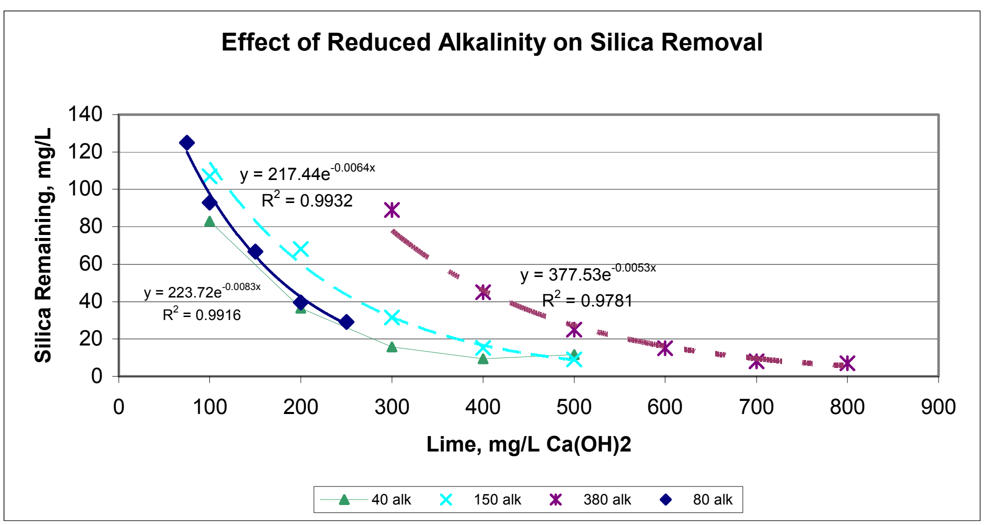

Figure 11- Silica Remaining vs Lime Dosage at Various Alkalinities.

For example, to reduce the silica concentration from 135 mg/L to 40 mg/L in RO-I concentrate, the lime dosage required would be approximately 425 mg/L if the alkalinity were 380 mg/L. However, if the alkalinity were reduced to 150 mg/L, the required lime dosage decreases to 260 mg/L and at 40 mg/L alkalinity, the lime dosage is less than 200 mg/L. Thus, removal of alkalinity by acidification and gasification reduces the lime required proportionately and, therefore, reduces the volume of sludge that must be handled and subsequently disposed of.

4.3 Lime Treatment Studies – Pilot Plant

pilot studies regarding lime precipitation were conducted in a continuous flow environment primarily to verify the trends identified in the batch-mode laboratory studies. Some of the water produced in the lime treatment pilot plant was treated through reverse osmosis to demonstrate the effectiveness of the silica reduction process. The recovery rate in those tests was limited to 60% because frequent changes in the operation of the lime-treatment pilot plant made it nearly impossible to predict the quality of the feed water to the RO-II system. Nevertheless, meaningful results were obtained as discussed in a later section of this report.

During the first 2 months of operation of the lime treatment plant, the silica concentration in RO-I concentrate was 135 mg/L. In the last month, the silica concentration was 165 mg/L because of a higher recovery rate in the CDM pilot plant.

The results from both time periods are plotted in figure 12 and, as shown, the data are very well represented by exponential equations. The K-values of 0.0044 and 0.0029 are similar to those found in the lab studies.

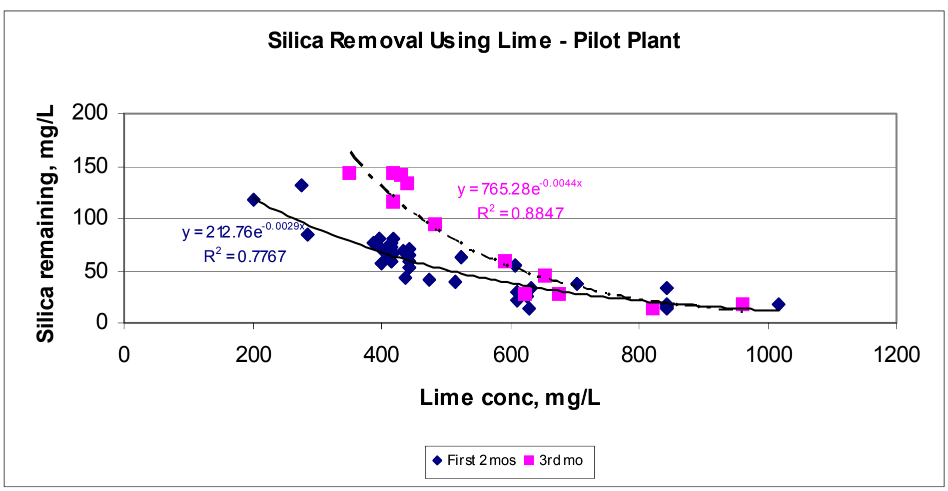

Figure 12 – Pilot Plant Results with Silica at 135 mg/L and 165 mg/L.

By removing the alkalinity from the influent concentrates through degassing, the curves would be shifted to the left because no lime would be consumed by the bicarbonates.

Figure 13 shows the results obtained when RO-I concentrates having silica concentrations of 135 mg/L and 165 mg/L, respectively, were degassed prior to lime treatment. The curves are shifted to the left by approximately 200-300 mg/L of lime, meaning less lime is required to execute a given amount of silica removal.

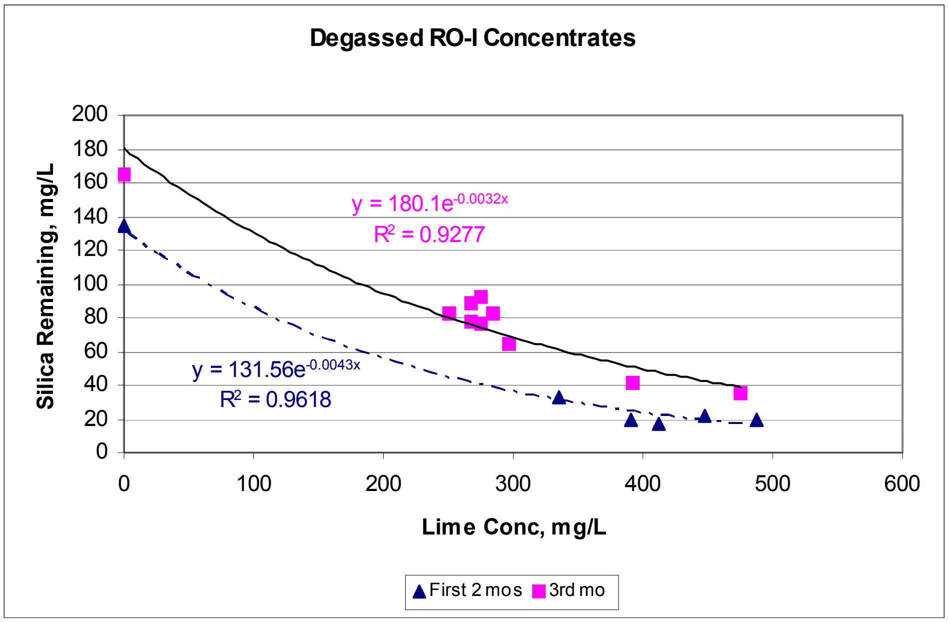

Figure 13 – Degassed Concentrates with Original Silica of 135 mg/L and 165 mg/L.

Theoretically, the curves would be shifted by an amount equal to the lime-equivalent of the alkalinity that is degassed. For example, if 500 mg/L of alkalinity is removed, the lime requirement would be reduced by [(500/50)*28], or 280 mg/L. Inspection of the two curves in figure 13 indicates that the concentrate having the lower initial silica concentration (i.e., 135 mg/L) was probably degassed better than the other one, as indicated by the value of each constant compared to their initial silica concentrations (135 versus 131.5 mg/L compared to165 versus 180 mg/L). This is probably because the concentrate having the higher silica also had a higher alkalinity (560 versus 380 mg/L) and the air compressors used for the degassing could not deliver enough air to complete the operation. In any case, the advantage of low alkalinity from the standpoint of reduced lime requirements is obvious. On the other hand, alkalinity removal through degassing leaves a higher calcium concentration in the water because calcium carbonate hardness is not removed by lime softening. Thus, the advantage of less lime and less sludge for a given silica removal must be weighed against the disadvantages of extra cost for degassing and higher osmotic pressure.

4.4 RO Treatment of Lime-Treated Water

Some of the lime-treated water was treated by reverse osmosis in an attempt to demonstrate that a significant percentage of the reduced-silica brine could be recovered. The RO system initially was operated at 50 % recovery, with the idea that the recovery rate would be increased after the reliability of the lime treatment system was established. However, operation of the lime treatment system proved to be so demanding that the RO system could not be operated at high recovery rates. The almost constant variations that were occurring in the lime treatment system due to influent water quality changes, component failures, or intentional changes in operating parameters made it almost impossible to know what the silica concentration in the feed water to the RO system was going to be. Therefore, the system generally had to be operated very conservatively to avoid possibly fouling the membranes from unexpected high concentrations of influent silica. In spite of these problems, the RO system was operated on a continuous basis for more than one month, with the highest recovery rate at 63 %. There was some fouling during the initial run because of high silica spikes and a relatively high flux rate (i.e.. 16 GPD/ft^2)(0.65 m^3/day-m^2), but after the membranes were cleaned, there was no other apparent fouling at any of the recovery rates tested, even though the silica concentration in the RO-II concentrate reached a value as has high as 220 mg/L on one occasion.

Thus, the lime treatment system did seem to satisfy the objective of rendering most of the RO-I concentrate recoverable, even though the RO system was not operated at the high levels of recovery that appear to be possible on the basis of the low silica concentrations achievable through the lime precipitation system.

The quality parameters of the RO-II feed water and of the product streams at a 57 % recovery rate are shown in table 2.

Table 2 – Water Quality Data for RO Treatment of Lime-Treated Water

	Cond	TDS	Hard	Cl	Alk	SO4	Silica
RO-II Feed	10,190	7,636	1,220	3,275	0	1,020	27
RO-II Perm	1,430	836	40	435	0	15	10
RO-II Conc	22,715	17,036	2,910	7,225	0	2,305	46

Although the TDS of 836 mg/L is below the desired maximum concentration of 1,000 mg/L, the 435 mg/L chloride concentration exceeds the Secondary Drinking Water standard of 250 mg/L. To overcome this problem, the RO-II permeate was collected in a separate tank and again treated in the RO system, with the second-pass product water identified as RO-III permeate. The permeate and concentrate streams during this treatment scheme were put back into the same tank to allow for continuous circulation of the RO-II feed water. The system was operated this way for 7 days at a recovery rate of about 80%, and the results are shown in table 3.

Table 3 – Water Quality Data for RO Treatment of RO-II Permeate

	Cond	TDS	Hard	Cl	Alk	SO4	Silica
RO-III Feed	1190	696	50	335	0	1	4
RO-III Perm	69	*	*	15	0	*	*
RO-III Conc	*	3020	200	1420	0	*	*

The quality of the second-pass RO permeate was very high, having a conductivity of only 69 µS/cm and a chloride concentration of 15 mg/L. This nearly-pure water is obviously perfect for blending, probably on a one-for-one basis, so that the product water volume from the entire process will possibly exceed the amount of concentrate that was originally brought in. This clearly helps make the process more attractive from an economic point of view, as discussed in the economic analysis section below.

5. Economic Analysis

In a previous section of this report, it was shown that the silica concentration remaining in the water after lime treatment could be reduced to essentially any value that is desired. However, the amount of lime required per mg/L of silica removed increases exponentially as the residual silica concentration decreases. Since silica is the parameter that limits the amount of water that could be removed through reverse osmosis in this project, the obvious question is "What is the most economical amount of silica that should be removed?"

To conduct an economic analysis such as this, it is necessary to assign values to all of the variables involved (interest rate, lives, first cost, blend ratio, water rates, percent recovery, etc) (Blank and Tarquin, 2002). The values used in this analysis are listed in Table C1of Appendix C.

The rationale for the analysis carried out here is based on the fact that only two things can be done with concentrate from a reverse osmosis process: (1) throw it away, or (2) recover all or some of it and throw the rest away. The only "throw-away" options that will be discussed here are pond evaporation and deep-well injection. However, five "recover" options are investigated, including membrane-only and lime treatment followed by reverse osmosis.

The costs for the two throw-away options were based on information obtained from a report prepared by CDM for El Paso Water Utilities (CDM, 2002). Total evaporation would require over 800 acres (3.24 square kilometers [km^2]) and would cost $2.7 million per year of which $25.4 million is for capital investment and $657,000 is for annual maintenance and operation. The capital investment cost is for land acquisition and site improvements, including, excavation, lining, fencing, piping, and pumping. The injection alternative calls for four injection wells and would require an initial investment cost of $9.7 million. Annual maintenance and operation is estimated to be $750,000. When the initial cost is amortized over a twenty-year period using an interest rate of 5.5% per year, the total equivalent annual cost comes to $1.56 million per year.

A description of the "recover" options along with the projected cost of the treated water is shown in table 4.

Table 4 – Description of Recover Options and Preliminary Costs

Option	Description	Cost, $/1,000 gallons
1	Treat RO-I conc w/Nano; treat Nano perm in RO-II; dispose of Nano & RO-II concentrates by evap	10.30
2	Treat RO-I conc w/Nano, treat Nano perm in RO-II; lime-trt RO-II conc, treat lime-trt'd RO-II conc in RO III, dispose Nano & RO-III conc by evap	4.89
3	Lime treat RO-I conc, treat lime-trt'd RO-I conc in RO-II, dispose of RO-II conc & lime sludge by evap	3.83
4	Lime treat RO-I conc, treat lime-trt'd RO-I conc in RO-II, lime-trt RO-II conc, treat lime-trt'd RO-II conc in RO III, evap RO-III conc	2.70
5	Treat RO-I conc w/Nano; lime treat Nano perm; treat lime trt'd Nano perm in RO II; dispose Nano & RO-II conc by evap	6.04

These preliminary calculations, which are based on a single concentration of lime (e.g., 500 mg/L) and a single RO recovery rate (e.g., 75%), show that Option 4 is the best of the five options. This option involves RO treatment of lime-treated RO-I concentrate, followed by RO treatment of lime-treated RO-II concentrate. The projected cost of the product water is $2.70 per thousand gallons ($0.713/$m^3$) prior to blending.

To get a better understanding of the costs associated with an alternative similar to this one, a more detailed analysis was conducted wherein the cost was calculated as a function of the volume of water recovered (based on the lime dosage). That is, the maximum allowable silica concentration was set at 140 mg/L. Then, the lime dosage was varied and the silica concentration remaining in the water was calculated per the regression equations developed for regular and degassed RO-I concentrate. On the basis of the silica concentration remaining, the recovery rate that would yield a silica concentration of 140 mg/L in RO-II concentrate was determined. The recovered RO permeate was then treated in RO-III (to reduce chlorides as discussed later) and then assumed to be blended with brine on a 1:1 volumetric basis, with the blended water assumed to be salable for $1.50 per thousand gallons ($0.4 /m^3).

Table 5 shows the values obtained when regular RO-I concentrate and degassed RO-I concentrate were treated with lime and then handled as described above. Note that a lime concentration of 0 mg/L is equivalent to total evaporation of the concentrate and in this case, that cost would be $2.7 million per year. The cost for deep-well injection of the concentrate would be $1.6 million per year as stated previously.

Table 5 – Net Cost of Lime-Treated Concentrate

	Regular RO-1 Concentrate			Degassed RO-1 Concentrate		
Lime, mg/L	SiO2 left,mg/L	max recov	netcost,$/yr	SiO2 left,mg/L	max recov	netcost,$/yr
0			$2,656,092			$2,656,092
100	159.4	0%	$3,993,986	130.7	7%	$3,282,891
200	119.3	15%	$2,786,983	94.9	32%	$2,210,653
300	89.2	36%	$1,894,835	68.9	51%	$1,444,031
400	66.8	52%	$1,238,326	50.0	64%	$899,382
500	50.0	64%	$758,175	36.3	74%	$515,964
600	37.4	73%	$410,021	26.4	81%	$249,660
700	28.0	80%	$160,662	19.2	86%	$68,431
800	20.9	85%	-$14,746	13.9	90%	-$50,993
900	15.7	89%	-$134,799	10.1	93%	-$125,515
1,000	11.7	92%	-$213,412	7.3	95%	-$167,412
1,200	6.6	95%	-$285,364	3.9	97%	-$186,558
1,500	2.7	98%	-$270,470	1.5	99%	-$127,032

The net cost per year values were obtained by subtracting the revenue received from the sale of the blended product water at $1.50 per thousand gallons ($0.4 /m^3) from the total cost of treatment.

Figure 14 is a plot of the net cost values from table 5 and it clearly shows that there is a significant cost advantage in lime treatment of the concentrate compared to either of the two throw-away options.

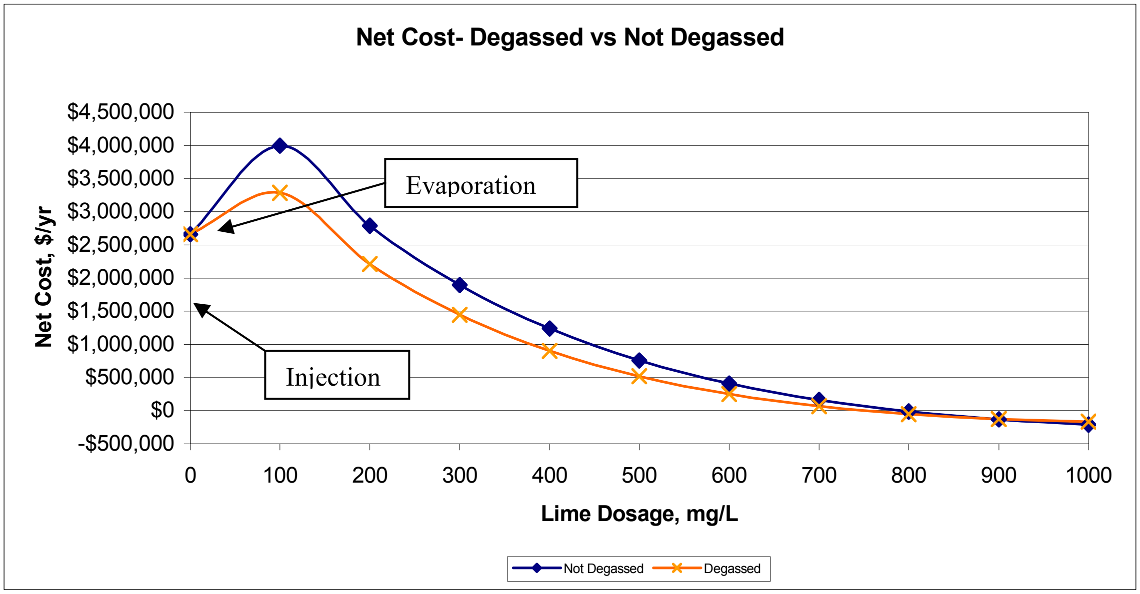

Figure 14 – Net Cost/yr for Treatment of Degassed and Regular RO-I Concentrate.

For regular RO-1 concentrate, any lime dosage above 200 mg/L would have a lower annual cost than evaporation and any dosage above 350 mg/L would yield a net cost lower than deep-well injection (the better of the throw-away options). At lime doses above 800 mg/L, there would be net income from the treatment processes, yielding an economic advantage of at least $1.6 million per year over deep-well injection while producing 5 MGD (0.218 m^3/s) of product water (with blending) from the project. The savings are even greater when the alkalinity is removed by degassing prior to lime treatment. For example, a lime dosage of 275 mg/L would yield a net cost equal to that of injection, but it would produce an extra 3 MGD (0.13 m^3/s) (with blending) of product water. At a lime dosage of 750 mg/L, there would be a net savings of $1.6 million compared to injection and the extra product water volume would be over 5 MGD (0.218 m^3/s). Thus, lime treatment of degasified RO-1 concentrate is clearly the best option for "disposing" of the high-silica brine concentrate.

This analysis assumed that silica was the only parameter that would limit recovery of the water through the reverse osmosis process (this value was set at 140 mg/L). However, it is possible that at recoveries above 63% (the maximum rate tested in this study), other parameters such as calcium or barium sulfate may limit the extent to which water can be recovered. On the other hand, the 140 mg/L limit on silica is probably lower than the concentration that could actually be reached without fouling the RO membranes. If so, this would render the alternatives even more attractive than indicated in the calculations above. Therefore, these results should be regarded as preliminary until they could be verified through membrane performance at the pilot plant level.

6. References

1. Blank, L. and Tarquin, A., *Engineering Economy*, Fifth Edition, McGraw – Hill, 2002

2. CDM, Inc, *Basis of Design Document, Brine Disposal*, prepared for El Paso Water Utilities, April, 2002..

3. Iler, Ralph K., *The Chemistry of Silica*, John Wiley & Sons, 1979.

Appendix A
Tables and Data for Figures in Report

Table A1 – Chemical Characteristics of Brine Concentrate Samples

Parameter	Nano Permeate			RO-I Conc	Nano Conc	RO-II Conc
	Sample 1	Sample 2	Sample 3			
Silica, mg/L	110	123	92	125	127	251
Alkalinity, mg/L	130	100	150	380	270	300
Total Hardness, mg/L	170	230	210	800	3,300	540
Ca Hardness, mg/L	160	170	180	620	2,100	460
pH	6.3	6.3	6.4	8.2	6.9	6.6
Conductivity, µS/cm	3,325	3,570	3,475	10,180	7,600	8,950

Table A2 – Conductivities During Project (Figure 3)

Date	Cond	Date	Cond	Date	Cond	Date	Cond
11/1/02	6,180	1/18/03	3,930	2/13/03	3830	3/13/03	3,730
11/6/02	5,770	1/19/03	3,940	2/14/03	3820	3/14/03	3,830
11/7/02	5,760	1/20/03	4,920	2/14/03	3810	3/17/03	4,370
11/8/02	5,880	1/21/03	4,100	2/17/03	3540	3/19/03	4,290
11/11/02	5,770	1/23/03	3,950	2/18/03	3590	3/21/03	4,300
11/29/02	4,450	1/24/03	3,920	2/19/03	3550	3/24/03	4,180
12/17/02	5,500	1/25/03	3,930	2/19/03	3500	3/25/03	4,020
12/19/02	5,190	1/25/03	4,020	2/20/03	3550	3/31/03	4,120
12/20/02	6,000	1/27/03	3,970	2/21/03	3520	4/5/03	4,250
12/23/02	5,500	1/29/03	3,950	2/25/03	4060	4/8/03	4,330
12/28/02	5,700	1/29/03	3,940	2/25/03	4090	4/11/03	7,600
12/29/02	5,800	1/30/03	3,950	2/26/03	4090	4/11/03	8,150
12/30/02	5,300	1/31/03	4,040	2/27/03	3820	4/16/03	7,300
12/31/02	5,500	2/1/03	3,880	2/28/03	3830	4/22/03	8,000
1/1/03	5,900	2/3/03	3,940	3/3/03	3990	6/24/03	11,000
1/2/03	6,000	2/5/03	3,920	3/4/03	4020	6/25/03	10,900
1/5/03	5,800	2/6/03	3,930	3/5/03	3990	7/21/03	10,500
1/7/03	5,740	2/7/03	3,650	3/5/03	3900	7/23/03	10,800
1/8/03	6,000	2/10/03	3,910	3/8/03	3890	7/23/03	10,740
1/8/03	5,660	2/11/03	3,900	3/10/03	3810	7/24/03	10,940
1/12/03	4,120	2/12/03	3,930	3/10/03	3950	9/18/03	10,780
1/14/03	4,040	2/12/03	3,890	3/11/03	3830		

Table A3 – Nano and RO Recoveries During Project (Figure 4)

Date	Nano	RO	Date	Nano	RO	Date	Nano	RO
11/25/02	68.4%	73.8%	1/8/03	67.4%	45.1%	3/11/03	84.1%	60.2%
11/26/02	68.4%	71.4%	1/10/03	66.1%	52.8%	3/12/03		62.2%
11/27/02	66.6%	71.4%	1/11/03	66.6%	53.1%	3/13/03	85.0%	60.8%
11/29/02	68.4%	71.8%	1/12/03	66.8%	53.1%	3/14/03	83.5%	61.9%
12/2/02	67.3%	67.8%	1/13/03	66.8%	53.9%	3/17/03	85.4%	63.8%
12/3/02	66.5%		1/16/03		66.9%	3/19/03	85.4%	61.2%
12/6/02	67.4%	70.6%	1/18/03	66.6%	65.9%	3/21/03	85.5%	60.2%
12/6/02	67.4%	53.0%	1/19/03		65.9%	3/24/03	86.1%	60.5%
12/6/02	67.4%	53.0%	1/21/03	67.4%	64.7%	3/25/03	86.1%	63.8%
12/7/02	67.4%	51.4%	1/22/03		64.1%	3/31/03	85.9%	62.3%
12/7/02	67.4%	51.4%	1/24/03	66.7%	61.5%	4/5/03	86.2%	61.7%
12/7/02	67.4%	50.7%	1/25/03	67.0%	61.7%	4/8/03	86.0%	62.6%
12/8/02		49.8%	1/26/03	67.0%	62.7%	4/10/03		
12/8/02		53.0%	1/27/03	67.0%	57.7%	4/11/03	85.6%	58.1%
12/9/02	66.5%	51.2%	1/28/03	67.0%	58.2%	4/14/03		57.1%
12/10/02	65.5%	50.7%	1/29/03	67.0%	56.9%	4/16/03	85.6%	57.7%
12/10/02	67.4%	50.0%	1/30/03	67.0%	57.0%	4/18/03		58.7%
12/11/02	67.4%	49.5%	1/31/03	67.0%	60.2%	4/20/03		60.2%
12/12/02	66.5%	48.5%	2/1/03	67.0%	58.7%	4/22/03	85.6%	58.1%
12/13/02	67.0%	50.2%	2/3/03	67.0%	57.5%	4/25/03		58.1%
12/14/02	67.0%	48.5%	2/5/03	76.1%	60.4%	4/27/03	87.0%	59.8%
12/15/02	67.0%	48.5%	2/6/03	76.8%	58.2%	4/28/03	89.5%	60.8%
12/16/02	66.5%	46.8%	2/7/03	76.9%	57.4%	4/29/03		68.2%
12/17/02	66.5%	47.1%	2/10/03	80.6%	57.5%	4/30/03	87.7%	67.6%
12/18/02	65.5%	45.7%	2/11/03	84.5%	62.2%	5/1/03	77.7%	66.7%
12/19/02	65.2%	45.7%	2/12/03	84.2%	62.2%	5/4/03	78.7%	54.9%
12/20/02	64.1%	48.4%	2/13/03	84.5%	57.7%	5/6/03		53.6%
12/23/02	66.0%		2/14/03	84.6%	57.8%	5/10/03	77.6%	51.4%
12/23/02	67.3%	52.8%	2/17/03	84.4%	64.6%	5/12/03	77.5%	51.9%
12/26/02	69.0%		2/18/03	84.5%	66.2%	6/2/03	82.5%	57.4%
12/26/02	68.1%	48.1%	2/19/03	84.5%	70.8%	6/5/03	74.2%	52.6%
12/27/02	67.8%	50.0%	2/20/03	84.5%	71.0%	6/18/03	55.5%	53.1%
12/27/02		49.7%	2/21/03	84.1%	68.6%	6/23/03		
12/28/02	66.7%	54.8%	2/25/03	83.4%	65.8%	6/24/03	52.5%	
12/29/02		39.8%	2/26/03	83.4%	65.8%	6/25/03	51.9%	47.5%
12/30/02	66.5%	41.2%	2/27/03	83.6%	65.6%	7/21/03	52.5%	48.5%
12/31/02	66.5%	39.4%	2/28/03	84.2%	65.4%	7/23/03	47.2%	50.5%
1/1/03	66.5%	43.2%	3/3/03	83.7%	62.4%	12/30/03		
1/2/03	66.5%		3/4/03	83.7%	62.0%		61.7%	54.5%
1/3/03		44.6%	3/5/03	83.5%	65.3%	1/6/2004		55.4%
1/4/03	67.0%	45.8%	3/8/03	84.1%	60.3%	1/7/2004		47.3%
1/5/03	67.8%	51.0%	3/10/03	84.3%	60.0%	1/9/2004	58.4%	49.1%

Table A4 – Effect of Initial Silica Concentration on Precipitation (Figure 5)

Init SiO2	Ratio
0	0
24.5	0.026
75	0.086
140	0.166
250	0.38

Table A5 – Silica Remaining vs Lime for RO-I Concentrate (Figure 6)

Lime	Silica
0	135
87	102
130	98
172	98
172	97
217	90
260	79
283	68
307	57
330	33
331	51
354	40
378	38
401	34
425	33
448	32
472	31
507	45
519	30
542	30
634	35
708	20
710	26
797	14
850	13

Table A6 – Lime Treatment of Nano Perm, Nano Conc, & RO Conc (Figure 7)

Lime	Nano Perm	Nano Conc	RO Conc
155	*	*	251
180	*	*	243
200	*	*	234
200	*	*	237
240	*	*	199
250	115	*	*
250	101	*	*
250	101	110	*
260	94	*	168
300	86	*	*
300	98	*	*
300	90	*	*
330	*	*	118
340	80	*	*
350	89	101	*
360	81	*	*
400	75	*	*
400	93	*	*
400	78	*	*
440	73	*	*
445	*	*	87
450	87	*	*
500	57	60	*
500	57	*	*
500	45	*	*
500	50	*	*
520	63	*	*
555	*	*	69
600	35	*	*
600	27	*	*
660	*	*	56
675	16	*	*
675	14	*	*
680	27	*	*
700	14	*	*
700	17	*	*
700	13	*	*
750	10	12	*
750	10	*	*
750	14	*	*
750	24	*	*
750	20	*	*
775	*	*	49
800	10	*	*
1000	*	5	*

Table A7 – Effect of Hardness on Silica Precipitation (Figure 8)

Hardness, mg/L	Silica Concentration, mg/L						
0	300	300	150	125	100	100	50
100	261	*	146	*	96	*	49
200	*	230	*	*	*	*	*
250	248	*	*	*	95	*	*
500	196	*	140	109	95	84	49
1000	144	189	129	108	91	81	46
1000	150	*	*	*	90	*	*
1500	122	*	*	*	93	*	*
2000	108	168	122	107	93	83	42
2500	102	*	*	*	92	*	*
4000	*	*	*	105	*	77	*
5000	100	*	*	*	91	76	*
6000	*	*	*	110	*	63	*
7500	97	*	*	*	91	*	*
10000	98	*	*	*	*	*	*

Table A8 – Effect of Hardness on Silica Precipitation from Nano Permeate (Figure 9)

Hardness	Silica
230	30.9
600	15.9
650	15
1250	13.3

Table A9– Effect of Alkalinity on Silica Removal at 500 mg/L Lime (Figure 10)

Alk	Silica
0	12.7
50	12.3
180	8.8
220	10.6
380	44.7
380	41.3
800	127.5
1100	135.5
1330	130
1560	126

Table A10 – Effect of Reduced Alkalinity on Silica Removal at Various Lime Dosages (Figure 11)

	Silica (mg/l) at Stated Alkalinity (mg/L)			
Lime, mg/L	380	150	80	40
0	125	125	125	125
75	*	*	125	*
100	*	107	103.9	96.4
150	*	*	83.2	*
200	*	68	74.2	54.6
250	*	*	54.7	*
300	89	31.5	*	23
400	45	15.3	*	13.4
500	25	9.1	*	11.3
600	15	*	*	*
700	8	*	*	*
800	7	*	*	*

Table A11 – Pilot Plant Lime Treatment Studies – 135 mg/L Silica (Figure 12)

Date	Lime	Silica
8/13	400	57
8/13	201	118
8/14	444	59.4
8/18	437	44
8/20	474	42
8/20	285	85
8/22	388	77
8/23	400	71
8/24	405	71
8/25	410	62
8/26	415	69
8/27	420	66
8/28	435	69
9/1	608	54
9/2	523	62
9/3	416	73
9/4	397	80
9/5	397	80
9/10	705	38
9/11	444	65
9/12	444	53
9/14	444	70.2
9/17	842	18.4
9/18	842	33.5
9/19	842	16.3
9/20	842	14.6
9/23	629	13.8
9/24	1016	17.3
9/26	419	81
9/29	414	76
9/30	415	58.7
10/1	275	132
10/1	516	40
10/2	632	33
10/4	626	26
10/6	612	21
10/6	612	29.7

Table A12 – Pilot Plant Lime Treatment Studies – 165 mg/L Silica (Figure 12)

Date	Lime	Silica
11/1	653	46
11/2	623	28
11/3	593	59
11/19	419	116
11/19	432	142
11/20	440	133
11/20	350	143
11/21	484	95
11/21	675	27
11/22	823	14
11/16	419	144
11/16		
11/17		
11/18	962	18

Table A13 – Degassed Concentrate – 135 mg/L Silica (Figure 13)

Date	Lime	Silica
10/15	0	135
10/16	0	135
10/16	448	21.6
10/17	488	20
10/17	390	20
10/18	412	16.7
10/19	335	33

Table A14 – Degassed Concentrate – 165 mg/L Silica (Figure 13)

Date	Lime	Silica
11/3	0	165
11/4	0	165
11/4	393	41
11/5	475	35
11/7	275	92
11/8	268	78
11/9	275	76
11/10	267	88
11/12	284	82
11/13	250	82
11/15	297	64

Appendix B
Raw Water Analysis Data

Table B1 - Chlorides

Date	nano Raw	nano Feed	nano Perm	nano 1	nano 3	nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm 3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
1-Nov-02	1975		1275			2175								
6-Nov-02	1750		1350	1950	1800	2300								
7-Nov-02	1950		1500	2000	2000	2050								
8-Nov-02	1815		1390	1935	2100	2140								
11-Nov-02	2125		1575			2175								
17-Dec-02	1738		1250			1515	1070				28	1724		
19-Dec-02	1372		1168			1708	1139				44	1796		
2-Jan-03	1675		1450	1900	1975	2075	1400	100	100	100	150	2050		
2-Jan-03	1700		1650	1900	2150	2300	1600	0	20	30	30	2400		
3-Jan-03	1600		1300	1850	1900	2050	1350	150	100	100	100	2050		
6-Jan-03	1550	1600	1300	1700	1750	1800								
7-Jan-03	1250	1400	1100	1350	1500	1400	1300				45	2175		
8-Jan-03														
8-Jan-03	1550	1650	1350	1650	1900	1850	1350				35	2100		
14-Jan-03	900	900	750	1000	1000	1050	1225				20	1775		
18-Jan-03	800	950	800	950	950	1000	1400				35	2075		
19-Jan-03														
20-Jan-03	975	1100	875			1200	1400				50	2100		
22-Jan-03			900				1500				75	2025		
23-Jan-03	1000	1100	875	1150	1175	1250	1225				50	2075		
25-Jan-03			900				1575				75	2100		
29-Jan-03			900				1575				75	1975		
1-Feb-03							750				50	1950		
6-Feb-03	975	1100	925	1100		1175	875				50	1875		
10-Feb-03	975	1150	950	1175		1300								
12-Feb-03	950	1075	950			1300	975				25	2125		
14-Feb-03	975	1100	925			1200	900				30	2000		
17-Feb-03							850				30	2200		
19-Feb-03	875	1000	825			1075	800				25	2575		
25-Feb-03	1100	1225	1025			1375	1100				35	2775		
5-Mar-03	1050	1225	965	1225		1300								
10-Mar-03	1000	1175	950			1275					30	2200		
17-Mar-03	1150	1175	1050			1775	1100				30	2600		
6-Apr-03	1175	1250	1020	1325	1575	1850	1000				35	2700		
11-Apr-03	2175	2225	2050			3450	2025				70	4625		
3-Jun-03	1600	1625	1450			2275					45	3325		
5-Jun-03	1325	1300	1150			1750						2950		
17-Jun-03												2125		
18-Jun-03	1325	1400	1200			1600	1225				180	2050		
24-Jun-03	3150	3075	2725			3475					330	4550		
21-Jul-03	2925	3000	2500			3525					210	2025		
23-Jul-03	3200	3150	3750			3500					355	4500		
18-Sep-03	3325						3275				435	7225	3270	3125
24-Sep-03	2375						2550				210	5775	2475	2600

Blue numbers represent Dr T's analyses
Violet numbers represent Aide's analyses

Table B2 -Total Hardness

Date	nano Raw	nano Feed	nano Perm	nano 1	nano 3	nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
1-Nov-02	900		40			1100								
6-Nov-02	800		150	1200	1400	1600								
7-Nov-02	800		60	1220	1350	1650								
8-Nov-02	880		110	1450	1850	1510								
11-Nov-02	900		120			1525								
26-Nov-02							5	0	0	0	0	15		
27-Nov-02							20	0	0	0	0	60		
30-Nov-02							10	0	0	0	0	40		
17-Dec-02	900		150			1400								
17-Dec-02	900		180			1900	80				30	130		
18-Dec-02														
19-Dec-02	800		200			1900	50				0	80		
2-Jan-03	800		200	1450	1800	2000	210	0	0	0	0	330		
2-Jan-03	900		200	1500	1800	2000	200	0	0	0	0	325		
3-Jan-03	820		210	1550	2000	2100	210	0	0	0	0	330		
6-Jan-03	820	1420	200	1500	1750	2050								
7-Jan-03	860	1200	200	1400	1600	1750	200				5	330		
8-Jan-03	800	1350	210	1450	1750	1950	180				0	290		
14-Jan-03	580	800	190	950	1250	1400	180				0	290		
15-Jan-03	580	950	150			1400					5	280		
16-Jan-03											10	390		
18-Jan-03	550	850	160	1000	1200	1300	240				10	380		
20-Jan-03	580	1000	150			1450	260				0	400		
22-Jan-03			150				250				0	350		
23-Jan-03	540	1000	160	1050	1300	1400	240				20	340		
25-Jan-03			160				290				0	360		
29-Jan-03			150				310				0	340		
1-Feb-03							160				10	360		
6-Feb-03	680	1280	200	1360		1840	200				0	400		
10-Feb-03	500	1420	190	1550		2100								
12-Feb-03	580	1750	160			2800	170				0	380		
14-Feb-03	560	1750	170			2650	220				0	430		
17-Feb-03							180				0	460		
17-Feb-03							180				0	480		
19-Feb-03	520	1600	180			2450	190				0	590		
25-Feb-03	580	1500	190			2950	190				0	540		
5-Mar-03	560	1700	200			2450								
10-Mar-03	580	1750	200			2600	200				0	460		
17-Mar-03	620	640	160			3300	200				10	460		
6-Apr-03	640	650	210	750	1800	3150	220				20	470		
11-Apr-03	1080	1150	310			5750	320				10	710		
3-Jun-03	950	1000	310			4100					30	680		
5-Jun-03	700	750	950			2550						650		
17-Jun-03												480		
18-Jun-03	821	777	244			1443	244				33	433		
24-Jun-03	1865	1665	522			2720					22	899		
21-Jul-03	1499	1443	500			2498					33	777		
23-Jul-03	1499	1499	433			2387					11	810		
18-Sep-03	1530						1220				40	2910	1210	1210
24-Sep-03	1200						1020				40	4200	960	1000
26-Sep-03	1340												1180	
30-Dec-03		1900	617			4000					5	1375		
7-Jan-04		1800	600											

Blue numbers represent Dr T's analyses

Violet numbers represent Aide's analyses

Table B3 - Calcium Hardness

Date	nano Raw	nano Feed	nano Perm	nano 1	nano 3	nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
17-Dec-02	600		160			1400	70				20	100		
19-Dec-02	680		180			1680	40				0	70		
2-Jan-03	600		170	1150	1350	1500	180	0	0	0	0	290		
2-Jan-03	700		180	1200	1300	1500	180	0	0	0	0	280		
3-Jan-03	580		180	1150	1350	1450	190	0	0	0	0	300		
6-Jan-03	580	1000	180	1000	1200	1350								
7-Jan-03	600	950	160	900	1100	1200	180	0	0	0	0	300		
8-Jan-03	600	1020	180	1120	1200	1350	170	0	0	0	10	260		
8-Jan-03	600	1020	180	1120	1200	1350	170	0	0	0	10	260		
14-Jan-03	420	650	130	850	1000	1100	180				0	290		
15-Jan-03	460	650	140			900		5				260		
16-Jan-03								5				340		
16-Jan-03								5				340		
18-Jan-03	420	650	140	700	900	950	210				10	330		
20-Jan-03	440	700	120			900	220				0	330		
22-Jan-03			130				240					320		
23-Jan-03	280	800	140	700	900	950	220				0	300		
25-Jan-03			140				260				0	330		
29-Jan-03			140				270				0	310		
1-Feb-03							140				0	340		
6-Feb-03	400	800	140	900		1150	150				0	330		
10-Feb-03	400	1320	160	1400		1900								
12-Feb-03	480	1400	140			2150	140				0	320		
14-Feb-03	420	1200	160			1750	160				0	370		
17-Feb-03							160				0	400		
19-Feb-03	420	1300	170			2150	160				0	500		
25-Feb-03	440	1200	170			1950	70					460		
5-Mar-03	400	1150	140	1250		2200								
10-Mar-03	480	1200	160			2100					0	370		
17-Mar-03														
6-Apr-03	520	500	180	650	1250	2400	190				0	420		
11-Apr-03	920	500	280			4250	290					640		
3-Jun-03	800	750	280			4000					0	620		
5-Jun-03	650	650	250			2100						550		
17-Jun-03												410		
18-Jun-03	666	666	200			1166	200				22	366		
24-Jun-03	1554	1332	444			2442					11.1	777		
21-Jul-03	2003.6	2003.6	366.3			2053.6					0	677		
23-Jul-03	1276.5	1221	399.6			2164.5					11.1	721.5		

Table B4 - Alkalinity

Date	Nano Raw	Nano Feed	Nano Perm	Nano 1	Nano 3	Nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
1-Nov-02	400		150			500								
6-Nov-02	380		300	480	650	700								
7-Nov-02	260		120	300	400	410								
8-Nov-02	390		180	480	560	600								
11-Nov-02	480		210			730								
30-Nov-02							250	15	15	20	10	750		
17-Dec-02	300		200			540	200				30	760		
19-Dec-02	240		250			780	240				10	240		
2-Jan-03	340		210	520	600	660	230				10	340		
2-Jan-03	360		220	540	620	640	220				0	340		
3-Jan-03	380		230	540	640	680	230				10	360		
6-Jan-03	340	460	210	500	560	600								
7-Jan-03	360	420	180	460	520	560	200				10	340		
8-Jan-03	320	440	190	460	540	580	200				10	330		
14-Jan-03							210				0	310		
18-Jan-03	280	360	120	400	440	440	350				30	370		
20-Jan-03	260	300	150			750	250				10	370		
22-Jan-03			160				260				20	380		
23-Jan-03	300	360	170	380	460	480	260				10	390		
25-Jan-03			180				310				10	400		
29-Jan-03			160				300				10	380		
1-Feb-03							160				10	380		
6-Feb-03	300	320	150	350		620	155				10	350		
10-Feb-03	300	340	160	350		450								
12-Feb-03	200	150	70			200	70				20	120		
14-Feb-03	300	300	160			400	180				20	340		
17-Feb-03							150				20	390		
19-Feb-03	280	350	160			400	160				20	480		
25-Feb-03	240	250	110			300	120				20	300		
5-Mar-03	200	250	100	200		250								
10-Mar-03	260	250	70			250					20	220		
17-Mar-03	310	110	80			260	90				20	180		
6-Apr-03	260	250	150	250	450	600	150				10	370		
11-Apr-03	220	200	60			300	90				20	190		
4-Jun-03	500	250	150			600					20	390		
5-Jun-03	450	300	250			550						400		
17-Jun-03												430		
18-Jun-03	440	150	80			150	90				60	110		
24-Jun-03	420	400	140			300					20	240		
21-Jul-03	450	287	130			300					10	240		
23-Jul-03	380	200	120			440					30	250		
18-Sep-03	380						0				0	0	50	20

Table B5 - Conductivity

Date	Nano Raw	Nano Feed	Nano Perm	Nano 1	Nano 3	Nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
1-Nov-02	6180		3590			7050								
6-Nov-02	5770		3650	6610	7140	7560								
7-Nov-02	5760		3820	6740	7270	7630								
8-Nov-02	5880		3960	6700	7080	7500								
11-Nov-02	5770		3820			7410								
27-Nov-02							4350	50	75	190	100	12500		
29-Nov-02	4450		3200			6500								
17-Dec-02	5500		4500	7500	8000	8200	4550	75	151	165	182.5	7500		
19-Dec-02	5190		4000			7050	4040				120.6	6420		
20-Dec-02	6000		4600	7700	8000	8100	4450	70	138	160		7500		
23-Dec-02	5500		4150			8100								
28-Dec-02	5700		4450	7500	8100	8500	3250	40	49	50		5250		
29-Dec-02	5800		4440	7500	8200	8500	4300	60	70	93		6900		
30-Dec-02	5300		4300	7100	7800	8000	4200	52	61	88		6500		
31-Dec-02	5500		4400	7300	8000	8000	4370	59	69	82		6800		
1-Jan-03	5900		4620	7500	8100	8500	4600	58	73	101		7200		
2-Jan-03	6000		4550	7700	8200	8500	4520	65	80	108		7400		
3-Jan-03							4510				84	7160		
5-Jan-03	5800	7100	4500	6900	8000	8300	4480	52	70	93	70	7200		
7-Jan-03	5740	6870	4420	7170	7540	8020								
8-Jan-03	6000	7250	4550	7800	8100	8600	4600	58	76	105	75	7800		
8-Jan-03	5660	6790	4390	7030	7710	8050	4390	84	75	133	89	7070		
11-Jan-03		4960	3190	5200	5800	5900	3850	48	55	73	61	5500		
12-Jan-03	4120	5100	3160	5300	5950	6050	3890	48	58	78	62	5500		
14-Jan-03	4040	4750	3000	5100	5500	5790	4390	84	75	133	89	7070		
18-Jan-03	3930	4930	3050	5100	5500	5900	4600	59	75	107	78	7000		
19-Jan-03	3940	4900	3030	5100	5500	5600	4580	62	85	118	80	7100		
20-Jan-03	4920	3980	3000			5780	4760				112	7020		
21-Jan-03	4100	5100	3200	5300	5900	6000	5010	93	112	129	110	7650		
22-Jan-03						2980	4680				98	6770		
23-Jan-03	3950	4850	2980	5090	5480	5620	4610	75	94	148	93	6660		
24-Jan-03	3920	4900	3080	5100	5400	5800	5600	102	128	174	120	7300		
25-Jan-03	3930	4950	3120	5100	5600	5800	5700	105	128	169	128	7200		
25-Jan-03	4020	5020	3110	5100	5600	5900	5800	102	130	175	125	7500		
25-Jan-03			2990				5220	126	156	170	110	6820		
27-Jan-03	3970	4990	3080	5100	5600	5750	5400	98	124	155	122	5950		
29-Jan-03	3950	4990	3110	5100	5500	5800	5400	92	119	154	112	6950		
29-Jan-03	3940	5110	2940	4910	5380	5610	4790	98	123	183	130	6520		
30-Jan-03	3950	4980	3110	5050	5500	5800	5700	97	122	138	119	7000		
31-Jan-03	4040	4900	3000	5050	5700	5800	3020	70	110	102	95	7300		
1-Feb-03	3880	4830	3030	5050	5400	5750	3050	59	118	120	96	6900		
1-Feb-03							2770	66	119	158	110	6510		
3-Feb-03	3940	4910	3070	5100	5600	5900	3030	41	71	112	67	7100		
5-Feb-03	3920	5400	3100	5700	6200	6400	3100	46	90	127	75	7100		
6-Feb-03	3930	5400	3170	5800	6200	6500	3170	52	92	145	73	7400		
7-Feb-03	3650	5100	2950	5200	5900	6050	2930	51	79	138	65	6700		
10-Feb-03	3910	5800	3220	6000	6750	7000	3300	52	83	150	73	7200		
11-Feb-03	3900	6050	3270	6300	7000	7250	3290	51	98	155	79	7650		
12-Feb-03	3930	6300	3170	6800	7400	7900	3160	53	102	176	83	7400		
12-Feb-03	3890	5970	3020			7620	3020				76	6830		
13-Feb-03	3830	6000	3190	6250	7000	7250	3150	50	88	160	78	7200		
14-Feb-03	3820	6000	3180	6300	7000	7200	3190	49	88	162	78	7200		
14-Feb-03	3810	5670	3040			7160	3080				76	6750		
17-Feb-03	3540	5700	2905	6000	6800	6950	2900	49	106	166	93	7900		
17-Feb-03							2790				68	7390		
18-Feb-03	3590	5800	2975	6050	6850	7000	2990	51	99	158	83	8400		
19-Feb-03	3550	5800	2990	6050	6800	7000	2990	56	106	169	88	9900		
19-Feb-03	3500	5280	2770			6550	2810				76	8740		
20-Feb-03	3550	5600	2950	6000	6600	7000	2950	51	99	146	81	9600		
21-Feb-03	3520	5300	2990	5700	6200	6500	2980	43	81	138	63	9200		
25-Feb-03	4060	5820	3280			7210	3320				100.9	8950		
25-Feb-03	4090	6100	3430	6650	7150	7450	3400	65	138	309	130	9900		
26-Feb-03	4090	6150	3480	6700	7150	7400	6100	86	146	280	130	9900		
27-Feb-03	3820	5900	3160	6150	6900	7100	5700	72	120	223	104	9050		
28-Feb-03	3830	5900	3200	6200	6900	7150	5850	73	119	223	106	9050		
3-Mar-03	3990	6200	3370	6500	7200	7350	6000	73	112	192	97	9300		
4-Mar-03	4020	6100	3330	6650	7100	7500	5600	79	100	213	101	8900		
5-Mar-03	3990	6100	3300	6500	7050	7300	6000	85	132	289	118	9300		
5-Mar-03	3900	5860	3110			7220								
8-Mar-03	3890	6000	3220	6400	7200	7500	3320	77	95	134	101	8000		
10-Mar-03	3810	5950	3175	6200	7000	7250	3150	73	85	126	92	7500		
10-Mar-03	3950	6050	3130			7560					93	7540		
11-Mar-03	3830	6000	3130	6200	7050	7300	3170	72	87	129	95	7600		
13-Mar-03	3730	5900	3130	6250	6900	7200	3180	71	87	133	97	7700		
14-Mar-03	3830	6000	3220	6600	7300	7600	3250	80	93	142	102	7850		
17-Mar-03	4370	4500	3570	5000	7000	9100	3580	77	98	132	103	8350		
19-Mar-03	4290	4450	3450	4950	7000	9050	3430	72	86	122	95	8000		
21-Mar-03	4300	4470	3400	4970	7000	9000	3450	77	94	142	101	8300		
24-Mar-03	4180	4230	3390	4770	6700	9100	3470	82	89	134	97	8200		
25-Mar-03	4020	4200	3280	4640	6800	8900	3340	77	90	138	97	8200		
31-Mar-03	4120	4300	3380	4800	6700	8600	3430	73	101	144	102	8700		
5-Apr-03	4250	4400	3480	4900	6900	8800	3550	63	87	147	98	8600		
8-Apr-03	4330	4490	3590	4970	7000	9100	3650	99	118	158	103	9000		
11-Apr-03	7600	7800	6500	8800	11700	14800	6500	153	239	280	231	14600		
11-Apr-03	8150	8160	6630			15810	6560				228	15120		
16-Apr-03	7300	7700	6200	8500	11400	14100	6300	163	221	219	221	13800		
22-Apr-03	8000	8100	6700	9100	12300	15000	6700	170	261	327	255	15000		
5-Jun-03	5460	5490	4170			8950						10300		
17-Jun-03												7500		
18-Jun-03	5400	5600	4240	6100	7200	7100	4300	510	680	720	690	7700		
24-Jun-03	11000	11100	9000	11700	13200	13200	9400	910	1030	1320	1230	14500		
25-Jun-03	10900	11200	9000	11900	13200	13200	9400	850	1150	1250	1180	14900		
21-Jul-03	10500	10800	83600	11500	13000	13300	8700	510	780	900	800	14700		
23-Jul-03	10800	10800	8900	11700	12900	12800	9300	1030	1120	1420	1320	14700		
23-Jul-03	10740	10820	8260			13280					730	14750		
24-Jul-03	10940	10950	8710			12900					1230	14620		
18-Sep-03	10780						10190				1430	above rang	10190	10080
30-Dec-03		11800	9800	12700	14600	14800					740	20100		
6-Jan-04		11700	9300			14800					690	20200		
7-Jan-04		11500	9700			15200					520	18400		
9-Jan-04		11700	9500			14300					560	17000		

Blue numbers represent Dr T's analyses
Violet numbers represent Aide's analyses
Green numbers represent Yanet analyses
Black numbers represent Gautam analyses

Table B6 - pH

Date	Nano Raw	Nano Feed	Nano Perm	Nano 1	Nano 3	Nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
11/1/02	7.37		7.27			7.77								
11/6/02	8.02		7.48	8.86	8.04	7.84								
11/7/02	7.41		6.87	7.29	7.33	7.35								
11/8/02	6.49		6.7	7.01	6.85	5.6								
11/10/02														
11/11/02	6.2		6			6.1								
12/12/02	7.2		7.04	7.38	7.45	7.4	7.2	5.95	6.06	6.05		7.27		
12/17/02	7.6		7.29	7.25	7.28	7.33	7.08	5.54	5.85	5.81	6	7.21		
12/19/02	8.1		7.86			8.17	7.99				6.61	8.01		
12/20/02	7.46		7.28	7.58	7.6	7.63	7.35	5.6	5.88	5.88		7.42		
12/28/02	7.07		6.88	7.24	7.31	7.28	7.22	5.57	5.64	5.47		7.25		
12/29/02	7.05		6.92	7.24	7.29	7.31	7.05	5.58	5.41	5.48		7.1		
12/30/02	7.44		7.25	7.57	7.58	7.61	7.4	5.67	5.59	5.69		7.43		
12/31/02	7.21		7.08	7.39	7.45	7.46	7.23	5.55	5.49	5.58		7.27		
1/1/03	7.4		7.2	7.53	7.54	7.56	7.33	5.51	5.52	5.6		7.39		
1/2/03	7.29		7.1	7.43	7.48	7.5	7.3	5.58	5.54	5.58		7.37		
1/2/03														
1/3/03	7.52		7.22			7.68								
1/5/03	7.25	7.43	7.12	7.43	7.48	7.47	7.24	5.57	5.51	5.55	5.51	7.31		
1/7/03	7.82	7.82	7.75	7.87	7.81	7.94								
8-Jan-03	7.17	7.36	7.01	7.36	7.4	7.41	7.17	5.52	5.48	5.5	5.44	7.29		
8-Jan-03	7.55	7.63	7.32	7.75	7.72	7.83	7.72	6.38	5.72	6.71	6.08	7.78		
11-Jan-03	7.77	7.89	7.57	7.88	7.91	7.91	7.35	5.75	5.68	5.68	5.72	7.46	No acid feed	
12-Jan-03	6.75	6.95	6.62	6.97	7.07	7.07	6.85	5.24	5.23	5.29	5.26	6.95	at CDM RO plant	
14-Jan-03	7.57	7.71	7.45	7.76	7.76	7.83	7.6	6.44	5.82	5.84	5.97	7.74		
18-Jan-03	7.3	7.46	7.11	7.43	7.47	7.47	7.38	5.12	5.13	5.29	5.14	7.38		
19-Jan-03	7.15	7.33	7	7.33	7.36	7.39	7.16	5.12	5.15	5.3	5.12	7.3		
21-Jan-03	7.09	7.25	6.95	7.25	7.29	7.3	7.18	5.18	5.21	5.5	5.26	7.21		
23-Jan-03	6.75	7.23	7	7.27	7.17	7.39	7.69	5.25	5.52	5.51	5.54	7.77		
24-Jan-03	7.21	7.36	7.02	7.34	7.43	7.41	7.38	5.29	5.32	5.51	5.32	7.32		
25-Jan-03	7.22	7.35	7.02	7.36	7.39	7.41	7.24	5.25	5.28	5.49	5.32	7.35		
25-Jan-03			7.65				7.73	6.06	7.17	6.84	6.47	7.9		
26-Jan-03	7.22	7.42	7.07	7.37	7.43	7.42	7.4	5.27	5.35	5.6	5.36	7.35		
27-Jan-03	7.23	7.4	7.05	7.39	7.43	7.44	7.39	5.25	5.31	5.48	5.29	7.38		
28-Jan-03	7.41	7.57	7.19	7.55	7.55	7.54	7.52	5.78	5.86	6.11	5.88	7.46		
29-Jan-03	7.24	7.38	7.05	7.39	7.42	7.45	7.33	5.21	5.33	5.49	5.26	7.31		
29-Jan-03	7.43	7.55	7.13	7.84	7.88	7.59	7.55	6	5.73	6	5.74	7.59		
30-Jan-03	7.25	7.45	7.11	7.42	7.45	7.47	7.37	5.25	5.32	5.42	5.34	7.34		
31-Jan-03	7.3	7.49	7.02	7.46	7.52	7.52	7.25	5.21	5.3	5.59	5.25	7.45		
1-Feb-03	7.29	7.45	7.06	7.43	7.47	7.48	7.23	5	5.29	5.35	5.21	7.41		
1-Feb-03							7.08	5.39	5.42	6.12	5.65	7.68		
3-Feb-03	7.26	7.42	7.05	7.39	7.47	7.49	7.18	4.82	5.06	5.35	5.07	7.39		
5-Feb-03	7.21	6.68	6.33	6.64	6.69	6.7	6.41	4.39	4.68	5	4.68	6.73		
6-Feb-03	7.35	6.72	6.4	6.72	6.79	6.8	6.57	4.44	4.81	5.17	4.72	6.8		
7-Feb-03	7.47	6.84	6.43	6.79	6.85	6.86	6.54	4.39	4.64	5.17	4.66	6.86		
10-Feb-03	7.33	6.72	6.39	6.72	6.78	6.76	6.73	4.32	4.7	5.09	4.58	6.7		
11-Feb-03	7.53	6.79	6.44	6.75	6.81	6.81	6.53	4.36	4.71	5.16	4.63	6.82		
12-Feb-03	6.88	6.21	5.93	6.16	6.23	6.23	5.95	4.4	4.78	5.11	4.63	6.2		
12-Feb-03	7.25	6.57	6.36			6.59	6.37				5.37	6.77		
13-Feb-03	7.31	6.69	6.4	6.67	6.75	6.75	6.44	4.49	4.83	5.2	4.67	6.71		
14-Feb-03	7.33	6.72	6.39	6.69	6.76	6.77	6.45	4.5	4.81	5.19	4.68	6.77		
14-Feb-03	7.85	7.51	6.58			6.86	7.2				5.35	7		
17-Feb-03	7.31	6.7	6.4	6.7	6.75	6.75	6.46	4.42	4.8	5.12	4.71	6.83		
17-Feb-03							6.55				5.39	6.93		
18-Feb-03	7.26	6.69	6.36	6.64	6.69	6.72	6.48	4.41	4.76	5.01	4.66	6.78		
19-Feb-03	7.39	6.73	6.42	6.7	6.76	6.79	6.47	4.47	4.81	5.21	4.78	6.88		
19-Feb-03	7.12	6.59	6.18			6.61	6.38				5.11	6.68		
20-Feb-03	7.42	6.77	6.45	6.75	6.81	6.8	6.48	4.48	4.86	5.11	4.65	6.89		
21-Feb-03	7.44	7.66	7.3	7.66	7.69	7.69	7	4.73	5.08	5.58	5.03	7.36		
25-Feb-03	7.2	6.56	6.09			6.52	6.34				5.05	6.57		
25-Feb-03	7.33	6.61	6.31	6.6	6.65	6.67	6.42	4.65	5.01	5.44	4.98	6.68		
26-Feb-03	7.29	6.56	6.27	6.56	6.6	6.61	6.57	4.62	4.96	5.4	4.89	6.64		
27-Feb-03	7.3	6.6	6.32	6.59	6.68	6.66	6.65	4.68	5.05	5.47	4.93	6.77		
28-Feb-03	7.33	6.63	6.35	6.6	6.71	6.71	6.69	4.63	5	5.48	4.98	6.72		
3-Mar-03	7.38	6.69	6.37	6.66	6.71	6.71	6.71	4.67	5.05	5.57	4.9	6.81		
4-Mar-03	7.36	6.71	6.41	6.66	6.71	6.74	6.65	4.69	5	5.67	4.91	6.72		
5-Mar-03	7.37	6.35	6.07	6.3	6.37	6.37	6.38	4.69	4.98	5.71	4.94	6.5		
5-Mar-03	7.23	6.26	5.92	6.26		6.13								
8-Mar-03	7.44	6.46	6.21	6.43	6.48	6.49	6.27	5.1	5.28	5.45	5.28	6.49		
10-Mar-03	7.3	6.4	6.17			6.5					5.4	6.5		
10-Mar-03	7.46	6.45	6.21	6.42	6.46	6.47	6.29	5.12	5.33	5.48	5.3	6.51		
11-Mar-03	7.45	6.49	6.2	6.42	6.48	6.5	6.34	5.36	5.37	5.41	5.33	6.48		
13-Mar-03	7.41	6.6	6.36	6.56	6.6	6.64	6.48	5.22	5.37	5.48	5.4	6.7		
14-Mar-03	7.39	6.44	6.15	6.4	6.46	6.47	6.33	5.3	5.36	5.47	5.35	6.52		
17-Mar-03	7.39	6.25	6.09	6.24	6.43	6.49	6.23	5.29	5.39	5.43	5.36	6.41		
19-Mar-03	7.46	6.34	6.12	6.27	6.48	6.52	6.26	5.21	5.36	5.35	5.37	6.48		
21-Mar-03	7.4	6.25	6.09	6.26	6.41	6.48	6.33	5.29	5.4	5.44	5.32	6.41		
24-Mar-03	7.47	6.3	6.1	6.32	6.48	6.56	6.33	5.42	5.4	5.52	5.39	6.44		
25-Mar-03	7.33	6.19	5.99	6.22	6.32	6.39	6.27	5.3	5.36	5.45	5.37	6.44		
31-Mar-03	8.07	6.73	6.54	6.7	6.91	6.98	6.66	5.35	5.47	5.58	5.52	6.66		
5-Apr-03	7.32	6.92	6.7	6.68	7.05	7.12	6.78	5.29	5.5	5.71	5.55	7.09		
8-Apr-03	7.46	6.59	6.4	6.56	6.75	6.8	5.59	5.46	5.45	5.36	5.78	5.83		
11-Apr-03	7.35	6.44	6.23	6.38	6.53	6.62	6.27	5.25	5.4	5.51	5.46	6.47		
11-Apr-03	7.39	6.51	6.37			6.75	6.56				5.74	6.69		
16-Apr-03	7.51	6.54	6.31	6.43	6.6	6.67	6.44	5.13	5.26	5.41	5.48	6.6		
22-Apr-03	7.36	6.39	6.26	6.42	6.55	6.61	6.41	5.16	5.3	5.48	5.45	6.47		
5-Jun-03	8.1	7.36	6.6			6.96						7.03		
17-Jun-03												7.35		
18-Jun-03	8.04	5.98	5.83	5.94	6.01	6.02	5.85	5.61	5.7	5.63	5.61	5.95		
24-Jun-03	7.97	6.45	6.24	6.37	6.43	6.42	6.34	5.71	5.72	5.75	5.7	6.36		
25-Jun-03	7.97	6.41	6.2	6.34	6.42	6.41	5.55	5.66	5.68	5.65	6.31	6.36		
21-Jul-03	7.86	6.5	6.23	6.38	6.48	6.46	6.33	5.43	5.57	5.55	5.61	6.39		
23-Jul-03	7.69	6.51	6.24	6.35	6.44	6.44	6.38	5.69	5.71	5.79	5.77	6.5		
23-Jul-03	8.13	6.95	6.75			6.64					5.82	8.21		
24-Jul-03	7.79	6.48	6.35			6.52					5.61	6.84		
18-Sep-03	7.7						4.5				8.3	3.5	9.8	9.4
30-Dec-03		6.06	5.88	6.02	6.12	6.13					5.27	6.24		
6-Jan-04		6.04	5.84			6.2					5.27	6.22		
7-Jan-04		5.87	5.75			6.07					5.2	5.98		
9-Jan-04		6.34	6.09			6.27					5.7	6.38		

Blue numbers represent Dr T's analyses
Violet numbers represent Aide's analyses

Table B7 - Sulfates

Date	Nano Raw	Nano Feed	Nano Perm	Nano 1	Nano 3	Nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
1-Nov-02	293		20			338								
6-Nov-02	356		31	477	583	592								
7-Nov-02	548		118	834	978	936								
8-Nov-02	454		98	700	1244	806								
11-Nov-02	380		124			804								
27-Nov-02							4.2	3.6	3.2	3.2	3.2	7.8		
30-Nov-02							15	3.9	2.8	2.2	2.4	16		
6-Jan-03	685	1275	0	1320	1605	1645								
7-Jan-03	750	1145		1295	1555	1595	0				0	0		
8-Jan-03	870	1335	0	1440	1715	1885	0.1							
14-Jan-03	140	995	0	1105	1275	1405	0							
18-Jan-03	548	800	8	876	1012	1046	0							
22-Jan-03			0.1				0.9							
23-Jan-03	410	1150	0.3	1310	1405	1575	0							
25-Jan-03			0.7				0.4							
29-Jan-03	650	1060	0	1125	1320	1415	0.2					0		
1-Feb-03							0							
5-Feb-03			0			1675								
7-Feb-03	20	1610	0.4			2180								
6-Feb-03	80	1465	0.4	1590		2005	0.4				0.2	0.2		
10-Feb-03	285	1780	20	1985		2465								
12-Feb-03	870	2350	0.3			3415	0.2				0.1	0.4		
12-Feb-03	920	2320	0			3285	0							
14-Feb-03	605	2060	20			2870	0.3				0	0.2		
17-Feb-03							0.2				0	0		
19-Feb-03	455	2515	1.2			3525	0.2				0.1	0.3		
25-Feb-03	362	1870	0.4			2650	0.3				0.2	0.4		
5-Mar-03	462	2725	0.2			3725								
10-Mar-03	367	2205	4.6			3030					4.5	4.7		
17-Mar-03	483	1040	0.2			4900	0.3				0.3	0.4		
6-Apr-03	377	2050	0.5			2540	0				0	0		
11-Apr-03	945	995	0.1			4950	0.8				0.2	0.6		
17-Apr-03	714	772	2.9			> 4000								
3-Jun-03	596	1195	0.9			5800					0.5	1.1		
18-Jun-03	358	150	34.5			1800	30.2/30.4				1.1/0.5	46.9/46.9		
24-Jun-03	1000	1290	38.8			2000					0	63.2		
21-Jul-03	1075	1255	22.7			2065					0.3	20		
23-Jul-03	1415	1480	30.9			2015					1.2	78.5		
18-Sep-03	1945						1020				15	2305	995	1180
24-Sep-03	890						975				0.7	3195	855	890

Red numbers represent Bhaskar analyses

Green numbers represent Yanet analyses

Table B8 - Silica

Date	Nano Raw	Nano Feed	Nano Perm	Nano 1	Nano 3	Nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil	Tank 3
1-Nov-02	131.5		107			143								
6-Nov-02	129		105.5	135	145.5	149.5								
7-Nov-02	167		139	160	166	171								
8-Nov-02	170		174	194	180	226								
11-Nov-02	186		152			214								
25-Nov-02	137		124.5	152	159.5	163.5	130	15.9	25.2	31	22	131		
25-Nov-02							140					410		
26-Nov-02	140		129	157	167.5	170	120	3.7	5.4	12.3	7.4	120.4		
26-Nov-02							137							
27-Nov-02	130		119.5	150	152	153.5	120	4.8	9.5	9.5	7.6	110		
27-Nov-02												387		
30-Nov-02	125		123.5	145.5	155	155.5	120	5.3	7.5	12	9.1	110		
30-Nov-02							142							
2-Dec-02	110		122.5	144.5	153.5	161.5	120				11.5	101		
3-Dec-02	126.5		111	145	147.5	152								
17-Dec-02	125.5		116.5			143.5	115.5				8.1	187.5		
18-Dec-02	128		117.5			145.5	115				7.9	186		
2-Jan-03	131		119	142	147.5	157.5	125.5				14.5	210.5		
6-Jan-03	131	147.5	112	147	148	155	97.5				4.6	139		
7-Jan-03	131	153	123.5			163	129				4.7	208.5		
8-Jan-03	128	141	117	130.5	136.5	155	132					178.5		
14-Jan-03	120	126	112	131	132	129	139	15.5	15.8	17	15.8	193		
15-Jan-03	120	125	111			133	137				16.5	195	47% recovery	
18-Jan-03	116	124	113	127	135	135	155	20	20.2	22.1	20.8	248		
20-Jan-03	104.5	110	90.5			108	104.5				8.1	146		
22-Jan-03			120				155				8.5	100		
23-Jan-03			145				157	4.5	7.5	9.5	3	144		
25-Jan-03			95.6				160.4	6.6	7.2	8.5	8.1	154		
29-Jan-03	112.4	103.2	100	113.2	118	122.4	168.8	5.2	7	9.1	6.8	214.8		
1-Feb-03							101	5	7.1	10	6.6	215		
5-Feb-03			107.5			136								
6-Feb-03	104	120	101.2	120		120.8	100				4.5	220		
7-Feb-03	97	110	94			115								
10-Feb-03	105.5	115	98.5	117.5		121								
11-Feb-03	108	116	102.5			132.5								
12-Feb-03	100.5	121.5	103			117	100				5	241.5		
14-Feb-03	103.5	114.5	98			119.5	96				3.9	213		
17-Feb-03							99				4.3	266.5		
19-Feb-03	99.5	109.5	95			122	91.5				2.4	310.5		
20-Feb-03							97				3.3	297.5		
25-Feb-03	91	112	91			108.5	87.5				8.3	251.5		
3-Mar-03														
10-Mar-03	102.5	109	96.5			111.5					3.2	227		
17-Mar-03	104	96	94.5			127	97				4.1	229.5		
6-Apr-03	97	93.5	92.5	102	118	130.5	93.5				3.9	222		
11-Apr-03	86.5	88.5	81			91.3	82				4.2	199.5		
3-Jun-03	140	134	129			170					6.5	262		
5-Jun-03	131	132	136			156					136	242.5		
17-Jun-03												202		
18-Jun-03	130.5	127	113.5			138	115.5				26.3	202/194		
24-Jun-03	130.5	133.5	119.5			138					19	187		
21-Jul-03	138.5	127.5	113.5			154.5					14.5	199		
23-Jul-03	132	133.5	113.5			142.5					19	202.5		
19-Sep-03	141.5						27				10	45.5	27.5	39
24-Sep-03	105						26.5				4.1	104	17.5	15.5

Blue numbers represent ICP analyses
Red numbers represent Bhaskar analysis
Green numbers represent Yanet analyses.

Table B9 - Total Dissolved Solids (TDS)

Date	Nano Raw	Nano Feed	Nano Perm	Nano 1	Nano 3	Nano Conc	RO Feed	RO Perm1	RO Perm2	RO Perm3	RO Tperm	RO Conc	Lime fil Eff	Tank 3
1-Nov-02	4306		2254			5744								
6-Nov-02	3894		2194	4640	5204	5548								
7-Nov-02	3890		2136	4602	5108	5338								
8-Nov-02	3898		2260	4546	5020	5248								
11-Nov-02	3914		2374			5390								
12-Nov-02														
26-Nov-02	3755		2470	5430	6155	6485								
27-Nov-02	3805		2495	5500	6155	6560	2500	40	56	104	68			
28-Nov-02														
29-Nov-02														
30-Nov-02	4170		2645	5745		6850	2550	16	56	52	52			
1-Dec-02														
2-Dec-02	3150		2860	5935	6570	6725	2665	85	295	260	210	1305		
3-Dec-02	3960		2685	5585	6250	6525								
7-Jan-03	3800	4953	2567	5237	5893	6130	2580				30	4240		
8-Jan-03														
8-Jan-03	3763.3	4943.3	2593.3	5120	5796.6	5873.3	2556.6					4290		
14-Jan-03	2580	4423	1720	3510	3860	4193.3	2170				40	3266.6		
15-Jan-03	2628	3464	1812			4304	2272				40	3324		
18-Jan-03	2452	3320	1780	3600	3984	3994	2816					4440		
20-Jan-03	2685					4317	2920							
22-Jan-03			1620				2450				40	4020		
23-Jan-03	2476	3280	1825	3444	3876	4088	2772	8	28	40	124	4116		
25-Jan-03			1928				3476	153	182	524	270	4528		
29-Jan-03	2596	3324	1792	3552	3960	4172	3244	80	92	108	148	4048		
1-Feb-03								16	40	52	56	4056		
5-Feb-03		1680				4596								
6-Feb-03	2448	3808	1708	4084		5144	1696				288	4148		
7-Feb-03	2408	4284	1956			5408								
10-Feb-03	2536	4252	1832			5544								
11-Feb-03	2636	4800	1856			6364								
12-Feb-03	2528	4908	1884			7040	1756				20	4516		
14-Feb-03	2292	4276	1568			6088	1536				8	3916		
17-Feb-03							76.2324				52.4453	4504		
19-Feb-03	2428	4300	1740			5836	1792				92	5828		
25-Feb-03	2884	4952	2268			6580	2260				84	6320		
5-Mar	2556	4684	1936	5064		6292								
10-Mar-03	2356	4392	1844			6300					48	4600		
19-Mar-03	3200	3152	2332			7832	2116				152	5032		
6-Apr-03	2784	2800	2096	3124	4864									
3-Jun-03	4016	4012	3930			10400					160	7350		
5-Jun-03	3390	3552	2400			6932						6280		
18-Jun-03	3124	3600	2596			4988	2610				650	3540		
24-Jun-03	7856	7860	5788			9872					972	9724		
23-Jul-03	6600	6764	4572			9308					300	8828		
18-Sep-03	8148						7636				836	17036	7484	7508
24-Sep-03	5484						5316				320		5028	5164

Blue numbers represent Dr T's analyses

Red numbers represent Janet/Bhaskar data entry

Green numbers represent Yanet analyses

Table B10 - Pilot Plant Operating Conditions

	Nano						RO						
Date	Feed press	Final press	perm flow	Conc flow	Recvry	Temp	Feed press	Final press	Perm flow	Conc flow	Recvry	Recycle flow	Temp
11/25/02	130	110	2.6	1.2	68.4%	22	305	275	1.55	0.55	73.8%		24
	78	48	1.55	6.5		22	65	35	0	3.3			23.75
	System on City water feed;Concentrate valve was closed and recycle was half open. Nano stareted at 0845 hrs anc												
	and stopped at 1610 hrs. RO unit started at 1500 hrs and stopped at 1610 hrs												
11/26/02	135	115	2.6	1.2	68.4%	21	300/340	280/310	1.50	0.60	71.4%		24/23
	80	48	1.6	6.5		21	70	< 30	0.00	2.86			23
11/27/02	128	109	2.55	1.28	66.6%	21	330	300	1.50	0.60	71.4%		22.5/23
	79	47	1.55	6.5			70	< 30	0.00	2.86			24
11/29/02	139	119	2.6	1.2	68.4%	21	320/400	305/363	1.27	0.50	71.8%		25/27
11/30/02	78	47	1.55	6.5		22	70	< 30	0.00	2.86			23.5
12/2/02	139	119	2.68	1.3	67.3%	20/23	475/925	450/873	0.80	0.38	67.8%		24/26
	Nano Unit was left running.						70	< 30	0.00	2.99			26
12/3/02	126	109	2.58	1.3	66.5%	23							
12/6/02	132	113	2.48	1.2	67.4%	19	400		1.42	0.59	70.6%		
12/6/02	132	113	2.48	1.2	67.4%	19	310	285	1.14	1.01	53.0%		
12/6/02	132	113	2.48	1.2	67.4%	19	310	285	1.14	1.01	53.0%		
12/7/02	132	113	2.48	1.2	67.4%	19	310	285	1.07	1.01	51.4%		
12/7/02	132	113	2.48	1.2	67.4%	19	320	298	1.07	1.01	51.4%		
12/7/02	132	113	2.48	1.2	67.4%	19	325	300	1.04	1.01	50.7%		
12/8/02							340	310	1.00	1.01	49.8%		
	Nano Unit was left running.						Flush started @ 1100 hrs and stopped @ 1600 hrs						
	Ion exchange connected between Nano and RO						340	318	1.14	1.01	53.0%		
12/9/02	122	105	2.38	1.2	66.5%	23	355	330	1.06	1.01	51.2%		
	RO unit was switched to Raw because tank level went down to @ 100 gallons @ 1815 hrs and put back on Perm @ 2100 hrs												
12/10/02	122	104	2.28	1.2	65.5%		360	330	1.04	1.01	50.7%		
	Cartridge filters changed on Nano												
	128	110	2.38	1.15	67.4%		380	340	1.01	1.01	50.0%		
	14" of water in RO permeate tank @ 1230hrs; 14 1/4" @ 1330hrs. Looks like there is a small amount of oil on surface in brine												
	Check CDM inflow for oil and let me know what u find out. Switched to raw on RO @ 1800 hrs tank level 12", full @ 2300 hrs												
12/11/02							380	340	0.99	1.01	49.5%		
	128	109	2.38	1.15	67.4%		380	343	0.99	1.01	49.5%		
12/12/02	128	109	2.38	1.2	66.5%		383	342	0.95	1.01	48.5%		
12/13/02	128	110	2.33	1.15	67.0%	24	390	345	1.02	1.01	50.2%		24
	Shut down RO @ 0908 hrs to change pressure gauges, put new ones in and started @ 0912 hrs.												
	Shut nano @ 0932 hrs to install plumbing for acid injection anc valve for pH sampling. Start back up @ 0940 hrs.												
12/14/02	128	110	2.33	1.15	67.0%		395	350	0.95	1.01	48.5%		
12/15/02	125	108	2.33	1.15	67.0%		400	360	0.95	1.01	48.5%		
	Flush started on RO @ 1530 hrs and stopped @ 1630 hrs,Pressure down by @ 5 psi. timed flows RO 230 sec												
	for 5 gal @ 1.3 gpm ;rotometer displays 1.2 gpm.												
	RO perm 150 sec for 5 gal @ 0.94 gpm rotometer displays 0.97.												
12/16/02	128	108	2.28	1.15	66.5%	23.5	402	360	0.89	1.01	46.8%		
12/17/02	127	108	2.28	1.15	66.5%	24	405	360	0.90	1.01	47.1%		26
12/18/02	128	110	2.18	1.15	65.5%	22	410	380	0.85	1.01	45.7%		24
12/19/02	127	109	2.15	1.15	65.2%		440	400	0.85	1.01	45.7%		
12/20/02	125	108	2.18	1.22	64.1%		430	385	0.91	0.97	48.4%		
12/23/02	135	115	2.43	1.25	66.0%								
	Above readings r when Nano was started after a 2 hour chemical flush.												
	150	143	2.8	1.36	67.3%		390	342	1.04	0.93	52.8%		
	Above readings r after moving yellow valve to completely closed position. Discharge pressure 160 psi.												
	RO started @ 1445 hrs after chemical flush and placing 2 IO tanks in series.												
12/26/02	150	140	3.18	1.43	69.0%								
	After taking readings moved recycle valve on Nano to reduce flows. Also changed												
	valve at bottom of RO to reduce perm and conc flow.												
	135	121	2.78	1.3	68.1%		280	240	0.78	0.84	48.1%		
12/27/02	130/125	111/105	2.63	1.25	67.8%	21	380	340	0.00				
	Moved recycle valve on Nano to adjust flows. RO tank had feed water since 2 days temp of water was 12												
	adjusted recycle valve on RO to get new value since perm was reading 0												
							425	380	0.76	0.76	50.0%		15
	Adjusted recycle valve on RO to get perm to 0.8. After adjustments and temp changes readings r noted below.												
	Mass balance: perm 0.8 and conc 1.1. Hardness feed to RO = 40 mg/l.												
							315		0.82	0.83	49.7%		18
12/28/02	123	107	2.5	1.25	66.7%	22.5	305	260	0.92	0.76	54.8%		
12/29/02							280		0.78	1.18	39.8%		24
	Found water on floor; discovered that tee from ion exchange was leaking badly;												
	Knob "push for service" was in wrong position (not in service) took ion exchange units out of circulation.												
	Pressure feed to RO was 315 psi with perm flow 1 gpm. Changed concentrate valve to lower perm flow												
	to 0.82 and conc to 1.4 temp was 24 pressure went down to 280 psi.												
12/30/02	123	107	2.38	1.2	66.5%	22.5	280	230	0.80	1.14	41.2%		23
	Changed cartridge filters on Nano.												
12/31/02	129	111	2.48	1.25	66.5%	22	280	230	0.82	1.26	39.4%		24
	RO is at 36% recovery. RO feed hardness 200 mg/l and RO conc hardness 320 mg/l. Perfect mass balance.												
1/1/03	128	110	2.48	1.25	66.5%	22	280	222	0.83	1.09	43.2%		24.2
1/2/03	128	110	2.48	1.25	66.5%	22							
1/3/03							315	260	0.95	1.18	44.6%		25
	Changed RO permeate flow rate from 0.88 gpm to 1 gpm.Also changed conc flow rate from 1.3 gpm to 1.4 gpm.												
1/4/03	128	110	2.48	1.22	67.0%	23	305	260	0.98	1.16	45.8%		26
1/5/03	128	111	2.48	1.18	67.8%	22	315	260	1.03	0.99	51.0%		24
1/6/03	Perm flow in Nano down a bit; everything else the same.												
1/8/03	128	110	2.48	1.2	67.4%	23	315	260	0.97	1.18	45.1%	0	25
		Everything looks good; Changed RO recovery rate to 50%(after collecting samples) and											
	started to recirculate to increase xflow velocity (1.0 perm, 1.0 conc,1.0 recirc)												

(Continued Pilot Plant Operating Conditions)													
1/9/03													
	Plant down due to power outage; both systems were flushed and restarted; perm in RO was set at 1gpm, CDM recovery lowered from												
1/10/03	129	110	2.38	1.22	66.1%	22.5	305	250	0.94	0.84	52.8%	1	25
1/11/03	128	110	2.43	1.22	66.6%	22	308	255	0.94	0.83	53.1%	0.99	25
	Out of acid on CDM feed.												
1/12/03	129	110	2.45	1.22	66.8%	22	305	250	0.95	0.84	53.1%	0.95	25.5
1/13/03	128	110	2.45	1.22	66.8%	23	310	255	0.96	0.82	53.9%	0.95	25.5
1/15/03	RO set to 66% recovery perm 1.0 conc 0.5 recycle 1.0; temp 24.												
1/16/03	128	110	2.43			22	320	270	0.95	0.47	66.9%	>1.0	24.5
	Pressure observed from yesterday to today; seems that RO behaves better during the day than at night.												
	The perm flow seems to drop and pressure increases at night over a 3 degree increase in temp, so is												
	it possible that silica precipitates at lower night temp?												
1/18/03	126	109	2.43	1.22	66.6%	22	323	275	0.91	0.47	65.9%	>1.0	24
	Pressure is definitely increasing and perm flow reducing each day. Did 15 minute flush; pressure												
	still slightly over 320 after resetting perm flow to 0.97gpm.												
1/19/03	127	109	2.38	1.22		22	327	279	0.91	0.47	65.9%	>1.0	24.5
	Press up a little from yesterday, perm lower. Started power flush at 1115 hrs will continue till Gautam turns it back on in pm												
1/21/03	122	102	2.48	1.2	67.4%	22	278	223	0.77	0.42	64.7%	>1.09	26
1/22/03	123	103	2.48			22	280	230	0.75	0.42	64.1%	>1.0	26
1/24/03	125	108	2.48	1.24	66.7%	21.5	270	220	0.67	0.42	61.5%	1.55	26
1/25/03	125	108	2.48	1.22	67.0%	21	276	220	0.66	0.41	61.7%	1.55	
1/26/03	125	107	2.48	1.22	67.0%	21.5	275	222	0.64	0.38	62.7%	1.55	26.5
	Pressure up slightly from yesterday; Permeate slightly down; changed conditions to 0.7 flux, 0.5 conc, 2.0 recycle												
1/27/03	128	108	2.48	1.22	67.0%	21	281	225	0.64	0.47	57.7%	2.05	26
1/28/03	128	109	2.48	1.22	67.0%	21	282	225	0.64	0.46	58.2%	2.05	25.5
1/29/03	125	107	2.48	1.22	67.0%	22	282	225	0.62	0.47	56.9%	2.05	26.5
	All readings seem to be the same as yesterday												
1/30/03	126	108	2.48	1.22	67.0%	21.5	282	225	0.61	0.46	57.0%	2.05	26
	Everything looks good;All readings seem to be the same as yesterday												
	RO feed pressure increased to 478 (was 460 at start a few days ago)												
1/31/03	128	109	2.48	1.22	67.0%	21.5	297	255	0.64	0.42	60.2%	0	25
	Stopped recycle flow last night at 7:30 pm; kept perm @0.68/0.638 and conc @0.5/0.422; readings this morning same												
2/1/03	128	109	2.48	1.22	67.0%	21.5	298	255	0.61	0.43	58.7%	0	24.5
	All readings look the same as yesterday												
2/3/03	127	108	2.48	1.22	67.0%	22	465	425	0.92	0.68	57.5%	0	24.5
	RO system was changed Saturday night to increase flux, same recovery rate (i.e.59%) as before												
2/4/03	Acid feed was set up today; began feeding acid and lowered nano feed pH to 6.7;												
	RO feed pressure increased to 478 (was 460 at start a few days ago)												
2/5/03	128	110	2.48	0.78	76.1%	22.5	485	425	0.90	0.59	60.4%	0	25
	Recovery in nano unit was changed to 76%; all readings above were taken after recovery rate was changed												
2/6/03	128	111	2.48	0.75	76.8%	22	490	450	0.87	0.63	58.2%	0	24
	Nano readings look good; RO pressure up slightly and permeate down slightly												
2/7/03	129	111	2.47	0.74	76.9%	21	500	465	0.85	0.63	57.4%	0	23
	RO pressure up, perm down, but temp is lower; nano recovery rate changed to 80 % after samples were collected												
2/10/03	130	112	2.45	0.59	80.6%	22	497	462	0.85	0.63	57.5%	0	24.2
	RO readings about the same over last several days; nano recovery changed to 84% after samples were collected												
2/11/03	130	112	2.45	0.45	84.5%	23	490	455	0.86	0.52	62.2%	0	25.5
	Slime in nano feed hose all gone. It may be due to fast forward flush done 2 days ago. All nano and RO values look good.												
2/12/03	131	113	2.42	0.45	84.2%	22.5	490	455	0.86	0.52	62.2%	0	25
	RO readings same as yesterday; not sure about nano;pH of conc from CDM low (6.88); therefore, all of our pH's are lower												
2/13/03	130	113	2.45	0.45	84.5%	22.5	497	460	0.85	0.62	57.7%	0	25
	Readings on both units look good (no changes); RO elbow broke; flushed system for about 2 hrs w/city water												
2/14/03	130	112	2.45	0.45	84.6%	22	502	466	0.86	0.63	57.8%	0	25
	RO pressure a little high; may be due to readjustment of conc valve because of leak repair												
2/17/03	130	112	2.4	0.44	84.4%	22	525	495	0.87	0.48	64.6%	0	25
	RO recovery rate raised to 64%												
2/18/03	129	111	2.4	0.44	84.5%	23	522	492	0.88	0.45	66.2%	0	26.5
	All pressures and permeate rates look good												
2/19/03	129	111	2.4	0.44	84.5%	22.5	545	518	0.89	0.37	70.8%		
	RO recovery changed to 70% last night at same permeate rate												
2/20/03	129.5	112	2.38	0.44	84.5%	22	565	535	0.85	0.35	71.0%	0	25
	RO pressure is 20 psi higher; may be due to 1.5 degree colder temp; need to check silica balance												
2/21/03	129	112	2.33	0.44	84.1%	22	578	550	0.81	0.37	68.6%	0	25
	RO press higher,perm lower; nano perm also lower; pH feed to nano way too high;												
	acid feed not working; will flush all membranes												
2/25/03	130	112	2.38	0.47	83.4%	22	555	525	0.82	0.43	65.8%		
	RO system was down from Saturday thru Monday morning because of leak;System was restarted at 64%												
	recovery; will start recirculating at 1.0 gpm in RO tonight												
2/26/03	130	112	2.37	0.47	83.4%	23	580	545	0.84	0.44	65.8%	1	26.5
	There is no advantage (from pressure point of view) for recirculating; therefore will discontinue in next day or so												
2/27/03	129	112	2.4	0.47	83.6%	22	590	552	0.82	0.43	65.6%	1	26
	Pressure in RO up from yesterday; may try flushing tomorrow if pressure increases												
2/28/03	129	111	2.5	0.47	84.2%	22	590	555	0.81	0.43	65.4%	1	26.5
	RO pressure same as yesterday; nano good												
3/3/03	128	111	2.38	0.47	83.7%	22	610	577	0.70	0.42	62.4%	1.04	27
	RO pressure higher, perm lower; flushed RO systerm for 15 minutes; didn't appear to do any good												
3/4/03	128	110	2.38	0.46	83.7%	22.5	620	590	0.77	0.47	62.0%	1	26.5
	Flushed RO system for 4 hrs; pressures and flow rates improved, but not back to original,clean membrane												
	values; lowered pH in nano feed from 6.7 to 6.4												
3/5/03	128	110	2.35	0.46	83.5%	22	615	580	0.77	0.41	65.3%	1	27
	Flushed RO system for 15 mins;didn't seem to help												
3/6/03	Flushed RO system for 12 hours; feed pressure still too high; will do chemical cleaning tomorrow;												
	RO conc rotometer stuck; cleaned salt build-up from stem												

(Continued Pilot Plant Operating Conditions)													
3/7/03	Did chemical flush from 1 AM to 9 AM; changed cartridge filter in nano (previous change was on 12/31/02)												
	restarted nano at 3 PM, RO at 8 PM												
	Set flow conditions similar to 2/1/03; RO feed pressure lower than before by 40 psi; chemical cleaning worked great!!												
	pH of 1:100 dilution of high flux cleaning solution is 3.55												
3/8/03	132	118	2.47	0.47	84.1%	22	255	208	0.70	0.46	60.3%	0	26
	All pressures and flows look good; pH readings on perm look like those on 2/1/03 when												
	flow conditions were similar; other pH values lower because of acid feed												
3/10/03	134	118	2.47	0.46	84.3%	22	245	205	0.67	0.45	60.0%	0	25
	All systems look good; RO recovery rate at 60%												
3/11/03	135	119	2.5	0.47	84.1%	22	245	205	0.68	0.45	60.2%	0	25.5
3/12/03	135	118	2.43			23	245	205	0.74	0.45	62.2%	0	27
	Acid feed line was leaking; flushed membranes and then shut down both systems												
3/13/03	135	118	2.58	0.46	85.0%	22	245	205	0.72	0.46	60.8%	0	26
3/14/03	136	120	2.48	0.49	83.5%	24	245	202	0.73	0.45	61.9%	0	27
	Stopped recirculation in nano unit; kept same conditions as before: perm = 2.5 gpm and conc = 0.45 gpm												
3/17/03	131	126	2.52	0.43	85.4%	22.5	242	202	0.67	0.38	63.8%	0	25.5
3/19/03	132	128	2.5	0.43	85.4%	22	243	203	0.62	0.39	61.2%	0	24
3/21/03	131	127	2.52	0.43	85.5%	23	245	205	0.69	0.46	60.2%	0	26
3/24/03	131	127	2.6	0.42	86.1%	24	245	202	0.70	0.46	60.5%	0	26
	All systems look good												
3/25/03	130	127	2.6	0.42	86.1%	25	243	202	0.67	0.38	63.8%	0	27
	Acid feed valve came apart;Gautam put it back together w/o the spring; Ralph will replace when new valves arrive												
3/31/03	130	125	2.53	0.41	85.9%	22	250	205	0.72	0.44	62.3%	0	26
	System was down on 28th because CDM cleaned their membranes; pH from CDM unit is high												
4/5/03	133	129	2.52	0.40	86.2%	22	255	218	0.68	0.42	61.7%	0	25
4/8/03	132	128	2.58	0.42	86.0%	22	255	218	0.68	0.41	62.6%	0	24
	Nano unit was off line, apparently all night; don't know why												
4/9/03	Switched to new well 72 today; cond is 2320 (about twice as high as old wells)												
4/10/03							258		0.60				
4/11/03	135	130	2.47	0.42	85.6%	23	258	220	0.61	0.44	58.1%	0	26
4/14/03							255		0.60	0.45	57.1%		
4/16/03	135	131	2.45	0.41	85.6%	23	255	218	0.59	0.43	57.7%	0	25.5
4/18/03			2.48				258		0.64	0.45	58.7%		
4/20/03			2.48				257	210	0.65	0.43	60.2%		
4/22/03	133	130	2.42	0.41	85.6%	24	255	218	0.59	0.43	58.1%	0	27
4/25/03			1.88						0.61	0.44	58.1%		
	Flushed both units for 6 hrs;												
4/27/03			2.4	0.36	87.0%		242		0.76	0.51	59.8%		
4/28/03	142	138	2.31	0.27	89.5%	24.5	248	205	0.67	0.43	60.8%	0	29
	Nano recovery rate was changed to about 90% last night; RO recovery low at 56%												
4/29/03	150	145	2				243	205	0.73	0.34	68.2%		
	Flushed nano w/city water												
4/30/03	135	131	2.43				241	0.76					
			2.14	0.30	87.7%		245	205	0.71	0.34	67.6%		
5/1/03	133	129	2.26	0.65	77.7%		245		0.68	0.34	66.7%		
5/2/03			2.28				245		0.64				
5/4/03	136	131	2.22	0.60	78.7%		245	205	0.62	0.51	54.9%		
5/6/03			2.14	0.56					0.59	0.51	53.6%		
5/8/03			2.08				250		0.60				
5/10/03	137	132	2.1	0.61	77.6%				0.55	0.52	51.4%		
5/12/03	138	132	2.14	0.62	77.5%		250	210	0.55	0.51	51.9%		
	Adjusted bottom valve on RO for THM test						500	460	1.22	0.55	68.9%		
5/13/03	170	155	2.4				530	200	1.14				
5/13/03			2.9	0.60	82.8%				0.57	1.10	34.2%		
5/13/03	169	162	2.7	0.60	81.8%		540	510	1.05	0.57	64.8%		
	Flushed with city waterfor 2 hrs; didn't help												
5/14/03							560		0.99	0.40	71.2%		
	Flushed w/city water for 1 hr: no apparent change												
5/16/03			2.72	0.60	81.9%		495		0.95	0.55	63.3%		
5/17/03	172	167	2.28				520		0.85				
	Flushed nano;changed nano conc valve to get perm to 1.5 gpm; nano feed cond =8100												
5/17/03	166	160	2.79	0.74	79.0%		505	470	0.86	0.49	63.7%		
5/18/03			2.3	0.84	73.2%		530		0.84	0.40	67.7%		
	Acid feed hasn't been working for several days--air lock												
5/19/03			2.72	0.54	83.4%								
5/20/03	169		2.63	0.48			490		0.65	0.28	69.9%		
							440		0.53	0.57	48.3%		
	Conducted Geosmin test today;readjusted RO to 440 psi												
5/21/03	Did chemical cleaning in nano and RO units												
6/2/03			2.28	0.48	82.5%		265		0.97	0.72	57.4%		
	Nano is down (from 6/4/03 yesterday)												
6/5/03	153	148	2.1	0.73	74.2%	24.5	270	230	0.91	0.82	52.6%	0	29
6/18/03	83	78	1.77	1.42	55.5%	23	95	50	0.43	0.38	53.1%	0	27
	Acid was re-started and lowered to 6.0; new RO membranes appear to be fouling even												
	though recovery is at 49%; flow is still from wells 500; well 72 will be re-started in next few days												
6/23/03	84	79	1.69			24	140	95	0.59				29
	pH of nano feed is about 6.4;												
6/24/03	85	80	1.69	1.53	52.5%	24.5	145	95	0.57			0	29
	Both perm flows lower than yesterday; nano recovery is about 54% and RO is about 44%												
6/25/03	83	79	1.66	1.54	51.9%	24	143	95	0.58	0.64	47.5%	0	28
	Both perm flows about same as yesterday;King Lee antiscalant feed was started yesterday at 30 ppm to nano unit												
7/21/03	143	138	1.58	1.43	52.5%	24.5	180	120	0.83	0.88	48.5%	0	28.5
	Nano definitely fouling; must reduce recovery from 64%(on 7/18) to about 50%: RO may be OK at about 50%												
7/23/03	90	85	1.7	1.90	47.2%	25	140	90	0.50	0.49	50.5%	0	29.5
	Nano recovery at 47%; pressure way down; RO recovery at 46%												
12/30/03	The results from here on are for new RO System												
	108	102	2.09	1.3	61.7%	22	246	230	0.60	0.50	54.5%		
1/6/2004	113	108	2.1			22	245	228	0.62	0.5	55.4%		
1/7/2004	115	110	2.1			22	238	219	0.7	0.78	47.3%		
1/9/2004	108	102	2.02	1.44	58.4%	22.5	240	222	0.83	0.86	49.1%		

Appendix C
Other Data

Table C1 – Values Used in Economic Analysis

Item	Value
initial RO-I conc volume, gpd	3,000,000
Lime cost, $/lb	0.0462
Interest rate, %	5%
Evap rate, in/yr	50
Liner cost, $/sq ft	0.75
Liner life, yrs	20
Excavation, $/cu yd	$3.00
Fence, $/LF	$10.00
Flow storage, mos	5
Excavation amortization time, yrs	20
Sludge density, lbs/cu ft	70
Sludge disposal cost(pickup, hauling, disp), $/cu yd	5.88
Reactor/Clarifier, $	$560,000
Lime silo/feeder, $	$130,000
Thickener/press, $	$250,000
Sand filter, $	$600,000
Equipment life, yrs	20
Recovery of lime-softn'd water,%	95%
Water selling price,$/1000 gal	$1.50
Blending ratio(total vol/RO perm)	2
RO capital cost, $/MGD	$480,000
RO operating press, psi	200
Power cost, $/kw-hr	$0.08
Pump & Motor efficiency, %	70%
Buildings, $	$250,000
Membrane cost, $/80 sq ft	$400
Membrane life, yrs	3
Membrane life RO, yrs	5
Flux, gpd/sq ft	10
RO-III flux,gpd/sq ft	25
H_2SO_4 cost, $/lb	$0.06
H_2SO_4 dosage, lbs acid/MG/mg/L alk	8.47
Alkalinity to be removed, mg/L	330
Lime equiv of alk removed, mg/L	185