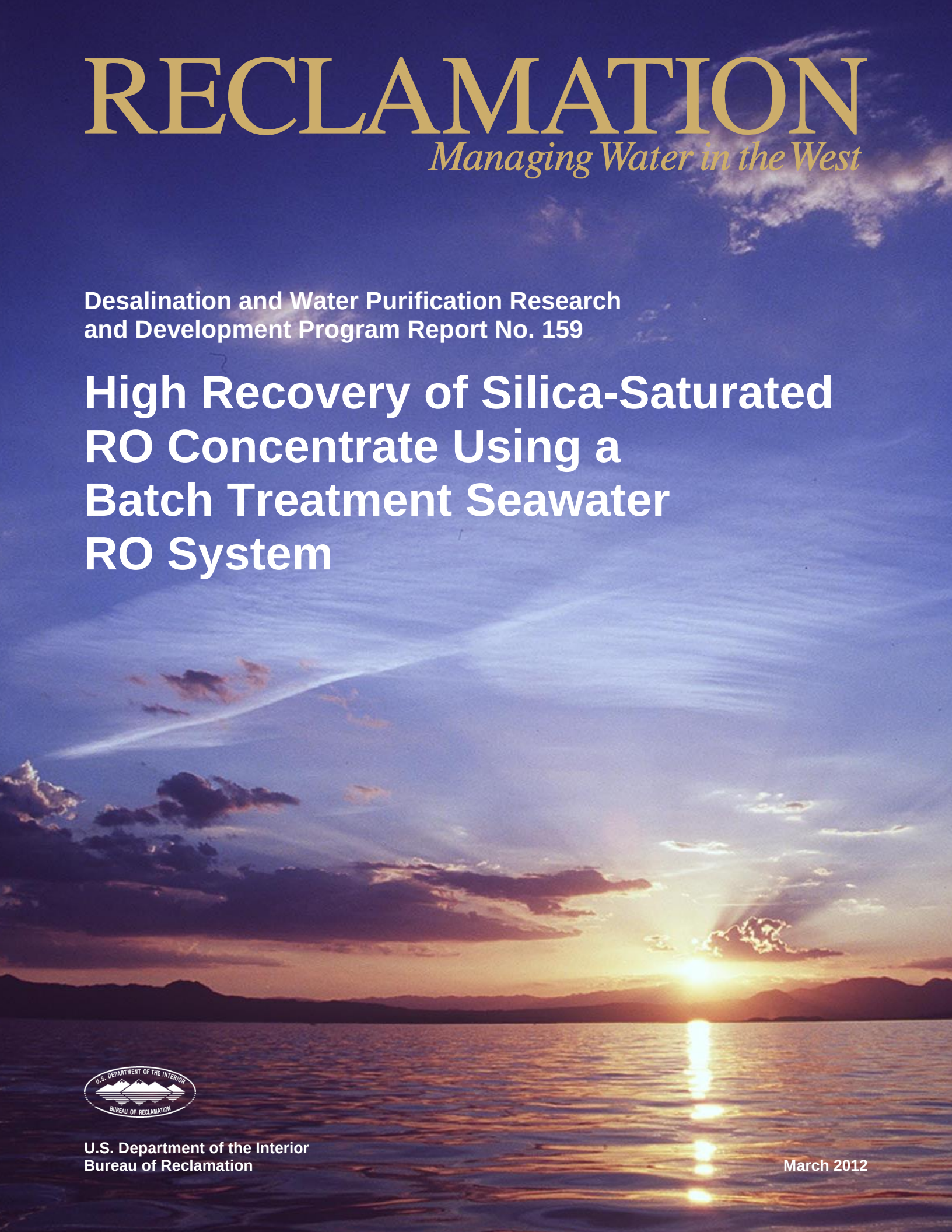
RECLAMATION

Managing Water in the West

Desalination and Water Purification Research and Development Program Report No. 159

High Recovery of Silica-Saturated RO Concentrate Using a Batch Treatment Seawater RO System



U.S. Department of the Interior
Bureau of Reclamation

March 2012

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
March 15, 2012	Final	June 2010 – March 2012

4. TITLE AND SUBTITLE
High Recovery of Silica-Saturated RO Concentrate Using a Batch Treatment Seawater RO System

5a. CONTRACT NUMBER
Agreement No. R10AP81217

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Dr. Anthony Tarquin

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Civil Engineering
University of Texas at El Paso
El Paso, TX 79968

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of the Interior, Bureau of Reclamation
Technical Service Center, Environmental Services Division
Water Treatment Engineering and Research Group, 86-68230
PO Box 25007, Denver, CO 80225-0007

10. SPONSOR/MONITOR'S ACRONYM(S)
BOR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
DWPR Report No. 159

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTE
Report can be downloaded from Reclamation Web site:
www.usbr.gov/pmts/water/publications/reports.html

14. ABSTRACT

The main objective of this project was to evaluate the performance of a batch-treatment seawater RO system on RO concentrates. The first part of the project involved spiking concentrate from the KBH Desalting Plant with various salts and then treating the spiked concentrate using the concentrate enhanced recovery reverse osmosis (CERRO) process in a seawater reverse osmosis unit. In the second part, the equipment was moved to the BGNDRF site in Alamogordo, NM, to test the process on brackish groundwater that is primarily made up of $CaSO_4$. Various antiscalants were evaluated in laboratory studies. The results showed that regardless of which salt was added to the KBH silica-saturated concentrate, recoveries of at least 80% were achievable using the batch-treatment CERRO process. The results from testing at the BGNDRF site showed that the maximum recovery achievable using the CERRO process with an antiscalant concentration of 5 ppm was 68%. When the antiscalant concentration was increased to 20 ppm, the recovery went up to 76%. Spiking the raw water or RO concentrate with 10,000 mg/L of sodium chloride resulted in total recovery of over 86%.

15. SUBJECT TERMS
RO Concentrate Recovery, Batch Treatment, Silica, Induction Time, Calcium Sulfate Precipitation, CERRO

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	a. THIS PAGE		108	John Walp
U	U	U			19b. TELEPHONE NUMBER *(Include area code)* 303-445-2871

Desalination and Water Purification Research and Development Program Report No. 159

High Recovery of Silica-Saturated RO Concentrate Using a Batch-Treatment Seawater RO System

Prepared for the Bureau of Reclamation Under Agreement No. R10AP81217

by

Anthony J. Tarquin

MISSION STATEMENTS

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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

Disclaimer

The views, analyses, recommendations, and conclusions in this report are those of the authors and do not represent official or unofficial policies or opinions of the U.S. Government, and the United States takes no position with regard to any findings, conclusions, or recommendations made. As such, mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

Acknowledgements

This project was made possible through the Desalination and Water Purification Program, U.S. Bureau of Reclamation under Agreement No. R10AP81217.

El Paso Water Utilities provided funding, physical facilities, and personnel for a variety of tasks including equipment installation, plumbing and electrical work, equipment maintenance/replacement, and extensive laboratory analytical services. Without the unwavering support of many, many individuals at all levels in the Utility, we would have had no chance of accomplishing the objectives of this project.

Special thanks goes to Randy Shaw and all other personnel at the Brackish Groundwater National Desalination Research Facility for their continued willingness to help and eagerness to satisfy everyone conducting research at the site.

Finally, this project would not have been completed without the steadfast help of the undergraduate and graduate students at the University of Texas – El Paso, who devoted many of their waking hours to completing this investigation, especially Guillermo Delgado, Isaac Campos, and Shaddy Castillo.

ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
%	percent
µS	microSiemens
µS/cm	microSiemens per centimeter
BGNDRF	Brackish Groundwater National Desalination Research Facility
CERRO	concentrate enhanced recovery reverse osmosis
EPWU	El Paso Water Utilities
g	grams
gal	gallons
gal/d	gallons per day
gal/m	gallons per minute
HERO	high efficiency reverse osmosis
IWQL	International Water Quality Laboratory
KBH	Kay Bailey Hutchison Desalting Plant
lb/in^2	pounds per square inch
M	moles per liter
mg/L	milligrams per liter
Mgal/d	million gallons per day
mL	milliliters
mL/m	milliliters per minute
mS	milliSiemens
NTU	Nephelometric Turbidity Units
OPUS	optimized pretreatment and unique separation
ppm	parts per million
QA/QC	quality assurance/quality control
Reclamation	Bureau of Reclamation
RO	reverse osmosis
SPARRO	Slurry Precipitation and Recycle Reverse Osmosis
SWRO	sea water reverse osmosis
TDS	total dissolved solids
UTEP	University of Texas – El Paso
VSEP	Vibratory Shear Enhanced Processing
ZDD	Zero Discharge Desalination

CONTENTS

Page

Appendices

Tables

Figures

EXECUTIVE SUMMARY

This project is an outgrowth of previous pilot-scale projects that were funded by the Bureau of Reclamation, El Paso Water Utilities, the Texas Water Development Board, and the WateReuse Foundation. The pilot plant results from those studies showed that several methods could be used to recover a significant amount of water from silica-saturated reverse osmosis (RO) concentrate. The methods studied included nanofiltration followed by second-pass RO, lime treatment followed by second-pass RO, Vibratory Shear Enhanced Processing (VSEP), batch-treatment seawater RO (SWRO), and continuous-flow SWRO. The batch treatment SWRO process was the most successful, reaching recoveries of over 90 percent (%) of the concentrate from the Kay Bailey Hutchison (KBH) Desalting Plant in El Paso, Texas. The main objective of this project was to evaluate the performance of a batch-treatment SWRO system on concentrates that are different from those at the KBH Desalting Plant and are representative of feedwaters at other locales. Therefore, the first part of the project involved spiking the concentrate from the KBH Desalting Plant with various concentrations of sodium chloride (NaCl), sodium sulfate (Na_2SO_4), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$) and then treating the spiked concentrate using the concentrate enhanced recovery reverse osmosis (CERRO) process in a SWRO unit. In the second part of the project, the SWRO equipment was moved to the Brackish Groundwater National Desalination Research Facility (BGNDRF) site in Alamogordo, New Mexico, to test the process on brackish groundwater that is primarily made up of calcium sulfate. The performance of various antiscalants was evaluated in laboratory studies at the same time the studies were conducted at the BGNDRF site.

The results from the spiked concentrate studies showed that regardless of which salt was added to the KBH silica-saturated concentrate, recoveries of at least 80% of the concentrate were achievable using the batch-treatment CERRO process. Because the concentrate from the KBH Desalting Plant was generated in a desalting process operated at 80% recovery, the total recovery of water from the combined RO and CERRO processes was at least 94%, regardless of which salt was used in spiking the concentrate.

Test results from the BGNDRF site, using brackish water that was primarily made up of calcium sulfate, showed that the maximum total recovery achievable using the RO and CERRO processes with an antiscalant concentration of 5 parts per minute (ppm) was 68%. When the antiscalant concentration was increased to 20 ppm, the total recovery went up to 76%. Spiking the raw water or RO concentrate with 10,000 milligrams per liter of sodium chloride resulted in total recovery of over 86%.

The laboratory evaluation of antiscalants revealed a significant difference in the performance of products that claimed to be effective for controlling calcium sulfate precipitation. For the best performing antiscalant, the induction period

increased as the antiscalant dosage increased, albeit at a decreasing rate of increase (up to about 30 ppm). The increase in the induction period is important in a batch-treatment process because more water can be recovered before precipitation begins. An economic analysis of incremental recoveries and incremental costs showed that the optimum dosage of antiscalant would be between 9 and 10 ppm, based on the results of the laboratory studies. Although adding sodium chloride to the concentrate effectively enhanced total water recovery from high-calcium sulfate water, the economic analysis clearly showed it would not be economically feasible.

Overall, this project showed that the CERRO batch-treatment process is a very effective method for achieving high recovery of water from silica-saturated or calcium sulfate-saturated RO concentrates, resulting in a significant reduction in the concentrate volume requiring further treatment or ultimate disposal.

BACKGROUND

El Paso Water Utilities (EPWU), in partnership with Fort Bliss (a United States Army installation), owns and operates the largest inland brackish groundwater reverse osmosis (RO) desalting plant in the United States. The Kay Bailey Hutchison (KBH) Desalting Plant produces 27.5 million gallons per day (Mgal/d) (1.205 cubic meters per second) of drinking water when operating at full capacity.

A problem faced by any inland water desalting facility is determining what to do with the concentrated brine solution generated in the RO process. The problem is exacerbated when the raw water supply contains substances that could foul membranes if an excessive amount of permeate is extracted from the brackish feedwater. This is the situation in El Paso, Texas, 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 75 percent (%) (if no antiscalants are used) because above this value, silica will precipitate and foul the membranes. Because the KBH Desalting Plant uses an antiscalant, the plant is operated at a recovery of 80%, which results in a concentrate volume of about 3.5 Mgal/d with a silica concentration of 125 mg/L. At the present time, the concentrate is disposed of via injection wells located 23 miles (37 kilometers from the plant.

According to two different studies (Tarquin, A., 2005; Tarquin, A., 2006) funded by the Bureau of Reclamation (Reclamation), it appears economically feasible to recover up to 85% of the RO concentrate using either Vibratory Shear Enhanced Processing (VSEP) or a seawater reverse osmosis system (SWRO) known as concentrate enhanced recovery reverse osmosis (CERRO). The studies revealed that at concentrate recoveries in the 85-90% range, calcium sulfate, not silica, is the primary precipitant in the batch-treatment CERRO process. This project was undertaken to evaluate the effectiveness of the CERRO process on concentrates that have different combinations of salts than those present in KBH concentrate. Of particular interest was evaluating the CERRO process on water at the Brackish Groundwater National Desalination Research Facility (BGNDRF) site because of the high concentration of calcium sulfate in the groundwater there.

CONCLUSIONS AND RECOMMENDATIONS

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

1. The batch-treatment CERRO process is an effective method for recovering up to 88% of the water from brackish-water RO concentrates, even if they are saturated with silica.

2. Concentrate recoveries of at least 80% can be achieved using the batch-treatment CERRO process on KBH concentrate that is spiked with up to 5,000 mg/L of sodium chloride, sodium sulfate, calcium chloride, or magnesium chloride.

3. There is a significant difference in performance among the different brands of antiscalants that claim to be effective for retarding calcium sulfate precipitation. Based on a laboratory study of seven different calcium sulfate precipitation-inhibiting antiscalants, it appears that a laboratory evaluation of antiscalant performance could provide valuable guidance in selecting the best antiscalant and in determining the appropriate dosage. The results obtained from the study show that Pretreat Plus 0400 increases the calcium sulfate induction time as the antiscalant concentration is increased up to about 30 parts per million (ppm). This is an important consideration in determining the optimum recovery in a batch-treatment SWRO process.

4. Water recovery from calcium sulfate-saturated RO concentrate can be significantly increased by adding sodium chloride to RO concentrate before beginning the batch-treatment CERRO process, or by raising the antiscalant concentration above 5 ppm. However, while high doses of antiscalant appear to be cost effective for increasing water recovery in the batch-treatment process, adding sodium chloride is not cost effective at all.

5. Additional studies should be conducted at the pilot scale level to more accurately identify the most effective antiscalant for calcium sulfate control in high-sulfate waters, as well as to determine the most economical dosage to use in the CERRO batch-treatment process.

6. Investigations should be conducted regarding harvesting salts from the superconcentrate produced at the end of the CERRO batch-treatment process. Emphasis should be placed on the economics of recovering calcium sulfate using the Slurry Precipitation and Recycle Reverse Osmosis (SPARRO) process, Zero Discharge Desalination (ZDD) process, lime precipitation, or other procedure deemed effective.

7. The effect of adding sodium chloride to RO concentrate to increase total recovery of water from the RO concentrate should be quantified. Particular attention should be given to systems that have a sodium chloride recovery component as part of the process.

8. Studies should be undertaken to develop cost-effective methods for enhancing evaporation or other final disposal techniques for the superconcentrate generated in the CERRO batch-treatment process. As more and more inland communities consider RO to solve critical water supply problems, the need for economical ways to handle the final concentrate volume is becoming more and more acute.

9. Procedures for precipitating salts from the final concentrate should be investigated with the concept of recirculating the reduced total dissolved solids (TDS) supernatant back through the CERRO batch-treatment process for additional recovery of water, while at the same time decreasing the volume of concentrate requiring final disposal.

SUMMARY OF LITERATURE

Silica

In its combined form, silicon is the most abundant element, besides oxygen, in the earth's crust. As such, it is a common constituent of groundwater in areas that have sandy soils. The chemistry of silica (SiO_2) is so unique, it can be considered both a pollutant (i.e., reactive silica) and a pollutant remover (i.e., activated silica). Processes for removing silica have been known for many years because silica presents a big problem when it is present in water used to produce high-pressure steam (it precipitates as a glassy deposit on turbine blades). In more recent history, silica has also been a big problem in RO systems because if it is allowed to reach saturation, it precipitates on the RO membranes and fouls them (Ning, 2002; Semiat, 2001; Sheikholeslami and Bright, 2002; Amjad et al., 1997). There are ways to deal with this problem, however (Ning, R., 2006), and this project is directed toward demonstrating one of those ways at the pilot plant level.

There are three general ways to deal with high silica waters in RO systems: (1) create and operate a treatment system wherein the silica will not precipitate, (2) remove the silica before it reaches the RO membrane, and (3) pretreat the feedwater in a way that will significantly increase the solubility of the silica in the brine solution. This project investigated only the first method for preventing silica scaling or fouling in RO systems.

As shown in table 1, the solubility of silica increases exponentially with pH, exceeding 1,000 mg/L when the pH rises above 11. Aquachem's brine concentration process (i.e., high efficiency reverse osmosis [HERO]) employs hardness removal and a high pH environment to prevent membrane fouling by silica. NA System's optimized pretreatment and unique separation (OPUS) process also employs hardness removal for silica control.

Table 1.—Solubility of silica versus pH

pH	Solubility of SiO_2 at 25 °C (mg/L)
6-8	120
9	138
9.5	180
10	310
10.6	876
>11	1,000

Note: °C = degrees Celsius.

The chemistry of silica in water is quite complex, but it has long been known that silica precipitates rather slowly in cold water, especially in the absence of hardness, heavy metals, or excess magnesium oxide (Nordell, 1961). In the form of sodium silicate, silica is very stable in solution, even at concentrations well above 2,000 mg/L. However, silica will precipitate under the highly saline conditions of NaCl concentrations exceeding about 30,000 mg/L (Ueda, 2003), although data is lacking regarding the rate of polymerization and precipitation (i.e., induction period) of silica from brackish water undergoing RO treatment. Previous studies conducted at the KBH Desalting Plant showed that rapid batch-processing times and a low pH environment enable recoveries that result in silica concentrations exceeding 900 mg/L without fouling the membranes. This is achieved by keeping the batch processing time less than the induction period of silica and other compounds that are present at supersaturated concentrations. Mickley and Coury (1982) investigated the concept of "time to polymerization" and found that at 500 mg/L of soluble silica, precipitation begins at 60 minutes. In order to improve silica management practices in geothermal plants, Burton et al. (2003) developed models for quantifying the effects of sodium, pH, and temperature on silica polymerization. They concluded that lowering the pH increases the induction time prior to polymerization and decreases the polymerization rate. They also point out that by adding chemical inhibitors, overall reaction rates can be retarded such that the fluid moves beyond scale-sensitive plant facilities before scale precipitates. The concepts of low pH, chemical inhibitors, and induction time considerations form the basis for successful implementation of the batch treatment CERRO process.

Calcium Sulfate

Calcium sulfate scale formation on the membrane surface can be homogeneous or heterogeneous. In the homogeneous process, ions of opposite charge cluster together in large groups to form nuclei, which ultimately give way to the growth and formation of crystalline precipitates. In heterogeneous precipitation, nuclei associate with suspended or colloidal particles in solution and precipitate on the membrane surface. In the past decades, several studies were performed to identify the nature of the homogeneous and heterogeneous precipitation of calcium sulfate. Cameron (1901) studied the effect of various electrolytes (i.e., sodium chloride, sodium sulfate, calcium chloride, and magnesium chloride) on calcium sulfate solubility and found that all, except calcium chloride, increased the solubility at certain concentrations of the salts.

In a batch treatment system such as the CERRO process, in addition to the concentration of the salts themselves, the induction period is extremely important because of its relationship to the batch processing time. Sarig and Mullin (1982) reported that induction periods for the precipitation of calcium sulfate were insensitive to calcium sulfate concentration, suggesting that the nucleation process was heterogeneous. Lancia et al. (1999) found that the induction period for homogeneous nucleation of calcium sulfate decreased when either temperature or supersaturation increased. Alimi et al. (2003) found that the induction period was strongly dependent on the solution supersaturation and temperature, with the activation energy decreasing with increasing supersaturation and temperature. Shih et al. (2005) found that calcium sulfate scale development was affected by the formation of crystals on the membrane surface and suggested that research is needed on the impact of surface topology and chemistry on surface crystallization of mineral salts. In addition, a number of studies have demonstrated that calcium sulfate scaling on membranes is controlled by both surface/heterogeneous crystallization and by deposition of bulk materials (Mi and Elimelech, 2010). According to Mi and Elimelech (2010), calcium sulfate scaling on a polyamide membrane was dominated by heterogeneous/surface crystallization, while calcium sulfate scaling of a cellulose acetate membrane was dominated by bulk crystallization and subsequent particle deposition.

A number of techniques have been studied and tested for preventing calcium sulfate scaling in membrane systems. Water softening (via chemical treatment and/or ion exchange) has been used for many years and is an important step in both the HERO and OPUS processes for high product recovery in RO systems. Pomerantz et al. (2006) had success in preventing calcium sulfate scaling by reversing the flow to RO process trains, thereby replacing the supersaturated brine in the last membrane element with unsaturated feed flow before the induction time was reached. A small-scale unit was operated for 22 hours under reverse

flow conditions with a calcium saturation index of 5.4 without fouling the last element. Corbett et al. (2003) evaluated electromagnetic technology for calcium sulfate control and concluded that neither a magnetic device nor a high-voltage capacitance device was effective in preventing calcium sulfate scaling at 91% water recovery. Corbett et al. (2003) also concluded that adding 2 mg/L of sodium hexametaphosphate to RO feed water successfully prevented scale at recoveries of 93%. The addition of proprietary antiscalants is perhaps the most common method of calcium sulfate control in RO systems. Antiscalants interfere with precipitation reactions through threshold inhibition (keeping sparingly soluble salts in solution), crystal modification (interrupting the electric balance necessary for crystal growth), or dispersion (imparting anionic charges on crystals to keep them separated) (Avista Technologies, 2008). In evaluating different types of antiscalants, Amjad (1985) concluded that formulated polyelectrolytes were the most effective, with the induction period affected by the antiscalant molecular weight, its concentration, and the nature of the functional groups.

CONCENTRATE CHARACTERIZATION

This project was carried out at two different sites: the KBH Desalting Plant in El Paso, Texas, and the BGNDRF site in Alamogordo, New Mexico. There is a considerable difference in the chemical characteristics of the water at each site, as discussed below.

KBH Concentrate

Concentrate from the KBH Desalting Plant served as the raw water source for the first part of this project, wherein various salts were added to the KBH concentrate to simulate concentrates that would be generated from groundwater that is different from that found in the El Paso area. Table 2 shows the characteristics of the KBH concentrate. Notable characteristics for 2010 are TDS at 12,763 mg/L, silica at 145 mg/L, calcium at 722 mg/L, and sulfates at 1,410 mg/L, as indicated in the column marked “Average.”

The proprietary antiscalant Pretreat Plus Silica, from King Lee Technologies, is added to the feedwater to the KBH Desalting Plant at a dosage of 4 mg/L. Therefore, the concentration of the antiscalant in the KBH concentrate should be approximately 20 mg/L, based on an average KBH Desalting Plant recovery of 80%.

Table 2.—KBH concentrate characteristics during 2010

Parameter	Parameter Value		
	Minimum	Average	Maximum
Chloride	4,040	6,099	10,100
Sulfate	1,020	1,410	2,260
Alkalinity (as $CaCO_3$)	130	397	477
Specific conductance	20,700	20,565	28,800
Iron	0.06	0.16	0.41
Hardness	540	2,490	4,330
Manganese	0.14	0.21	0.34
Phosphate	0.1	0.17	0.96
pH	7.6	8.0	8.0
Calcium	716	722	1,220
Potassium	61	78	89
Magnesium	146	191	260
Sodium	2,710	3,412	4,440
Silica	36.7	145	187
TDS	9,750	12,763	17,900
Temp	22.1	26.0	26.6

Note: All values are in mg/L, except electroconductivity microSiemens per centimeter (µS/cm), pH (pH units), and temperature (°C).

BGNDRF Well 2 Water

Table 2 shows the characteristics of the raw water at well 2 of the BGNDRF site. Concentrate was produced by passing the raw water through an RO unit that was operated up to 50% recovery. Therefore, the feedwater to the batch treatment SWRO unit had approximately twice the concentration of the constituents shown in table 3. The most notable characteristic is the extremely high sulfate concentration averaging 3,300 mg/L which, when concentrated via 50% recovery in the RO unit, is nearly 5 times greater than the amount in the KBH concentrate. Also, the silica concentration, even at 50% recovery, is only about one-third as high as it is at the KBH site. Therefore, calcium sulfate, rather than silica, was the most significant parameter of concern at the BGNDRF site.

Table 3.—Raw water characteristics of Well 2 at BGNDRF site

Parameter	Sample Date	
	3/15/2011	8/22/2011
Alkalinity, total (as $CaCO_3$)	250	250
Bromide	0.5	0.41
Chloride	590	650
Fluoride	0.32	0.26
Nitrogen, nitrate (as N)	7.4	8.3
pH	7.32	7.65
Phosphorus, total (as P)	0.018	0.032
Specific conductance	5,800	6,100
Sulfate	3,200	3,400
TDS	5,320	5,900
Calcium	550	550
Iron (total)	0.06	0.02
Magnesium	340	340
Potassium	2.9	2.6
Silica	24	23
Sodium	670	720
Strontium	7.5	8.8
Hardness (as $CaCO_3$)	2,700	2,600
Organic carbon, total	1	1.3

Note: All values are in mg/L, except electroconductivity microSiemens per centimeter (µS/cm), and pH (pH units).

WORK PERFORMED AND DESCRIPTION OF SYSTEMS

The main goal of this research project was to show that a high percentage (up to 90%) of the water in silica-saturated RO concentrates can be economically recovered in a batch-treatment SWRO system using the CERRO process. This was accomplished previously using concentrate from EPWU's KBH Desalting Plant, but this time, the challenge was to show that the same process could be used on RO concentrates that have different proportions of inorganic salts than those in the KBH concentrate, thereby extending its applicability to regions beyond El Paso. This was accomplished in two ways: (1) by spiking KBH concentrate with different types of inorganic salts, including sodium chloride,

sodium sulfate, calcium chloride, and magnesium chloride; and (2) by conducting tests at the BGNDRF site in Alamogordo, New Mexico, using raw water, which is quite different from the water in El Paso, due to its high concentration of calcium sulfate. While the Alamogordo studies were being carried out, a laboratory evaluation of several antiscalants thought to inhibit calcium sulfate precipitation was completed. The results of that evaluation are presented in the "Laboratory Antiscalant Test Procedure and Results" section of this report.

Pilot Studies at KBH Desalting Plant

The studies involving chemically spiked RO concentrate were carried out in the research laboratory at the KBH Desalting Plant. The pilot plant was a small, manually operated, batch-treatment SWRO unit (purchased from Crane Environmental) that had a single 2-1/2-inch-diameter, 20-inch-long, FILMTEC SW30-2521 SWRO membrane. A batch-treatment process was used because it affords an opportunity to achieve extraordinarily high recoveries by using **batch processing times that are shorter than the induction time** of the compound that precipitates first (in this case, calcium sulfate). In general, the batch processing time needed to be about 1 hour, depending on the final concentration of the precipitant. Figure 1 is a schematic diagram of the test system, and figure 2 is a photograph of it.

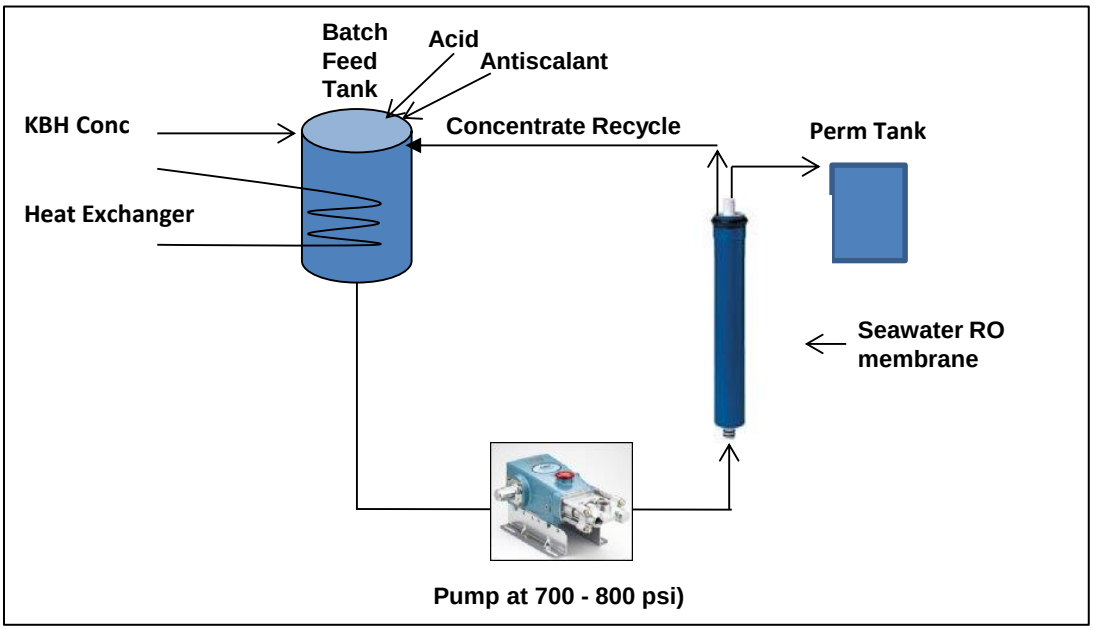


Figure 1.—Schematic of SWRO batch-treatment system.

Figure 2.—SWRO unit used for conducting tests at KBH Desalting Plant.

Most of the chemical analyses included in this report were performed at the International Water Quality Laboratory (IWQL) of El Paso Water Utilities. After samples were collected at the research site (i.e., KBH Desalting Plant research laboratory), a chain of custody form was filled out, and the samples were transported to the IWQL within 2 hours. The quality assurance/quality control (QA/QC) procedures associated with the test results are contained in section 23 of EPWU's Quality Manual (EPWU, 2011). Additional samples were collected for analysis in the laboratories of the Civil Engineering Department at The University of Texas - El Paso (UTEP). Those samples were analyzed using ion chromatography or wet chemical techniques of the HACH Chemical Company. The UTEP tests not only provided "instant feedback" about the test run from which they were taken, but also the precipitated solids that were analyzed, via x-ray diffraction or electron microscopy, to determine the composition of the precipitate. It should be noted that the HACH procedure for silica determination measures only reactive silica; thus, after silica begins to polymerize, the HACH colorimetric procedure will measure only the monomeric silica that remains. Total silica could be determined using Inductively Coupled Plasma or by digesting the samples prior to analysis, but those techniques were not used in this project; therefore, some mass balances for silica show a silica deficiency in the product waters.

Pilot Studies at BGNDRF Site

The pilot system used at the BGNDRF site was similar to the small pilot-scale unit used at the KBH Desalting Plant site, except that it is fully automated and has extensive data-logging capability. Figure 3 is a photo showing the SWRO unit.

The SWRO unit has two 2-1/2-inch pressure vessels that are 20 inches long. Concentrate that was generated in a dedicated RO unit (operated at about 50% recovery) was pumped into the batch feed tank, which is connected to the high-pressure pump (Cat Model 2SF35SEEL). Sulfuric acid and the antiscalant for sulfate control were automatically added to the feed tank via positive displacement chemical feed pumps (Prominent Type CNPA Concept Plus). Data were logged at 1-minute intervals for pH, conductivity, flow rate, pressure, etc. Table 4 shows a sample printout of the data.

In addition to the data-logged information, samples of the feedwater and permeate were collected at 5-minute intervals during the test run so the feedwater samples could be immediately analyzed for turbidity, pH, and conductivity. The feedwater samples were returned to the feed tank immediately after the measurements were taken. The permeate samples were composited according to permeate flow for later analysis at the lab. Immediately after a batch was finished, the membrane was flushed with feedwater or permeate to remove the highly concentrated concentrate from the membrane to prevent possible fouling by one or more of the supersaturated compounds in the concentrate.

All samples for analysis were transported back to El Paso on the day the test was conducted, and they were delivered to the IWQL the following day, except the samples kept for analysis at the UTEP labs. The typical analyses included anions/cations, silica, TDS, pH, and conductivity. Other ions and compounds were measured when deemed necessary.

Figure 3.—Automated SWRO unit used at BGNDRF site.

Table 4.—Sample printout of data from automated SWRO unit

Date/time	Temper-ature (°C)	pH	Flows (gal/m)			Conductivity			Pressure (lb/in^2)		Permeate total (gal)	Set recovery (%)	Actual recovery (%)	Batch size (gal)
			Feed	Permeate	Concen-trate	Tank (mS)	Permeate (µS)	Concen-trate (mS)	Feed	Concen-trate				
4/6/2011 11:46	26.3	4.5	0.0	0.0	0.0	0.0	100	2.7	0	0	0.0	70	0	0.0
4/6/2011 11:47	26.3	4.6	5.0	0.0	0.0	10.1	100	2.7	0	0	0.0	70	0	4.5
4/6/2011 11:48	26.3	5.2	5.0	0.0	0.0	13.1	100	2.7	0	0	0.0	70	0	9.5
4/6/2011 11:49	26.3	5.6	5.1	0.0	0.0	13.6	100	2.7	0	0	0.0	70	0	14.5
4/6/2011 11:50	26.4	3.8	5.0	0.0	0.0	14.2	100	2.7	0	0	0.0	70	0	19.4
4/6/2011 11:51	26.4	4.3	0.0	0.0	0.0	14.4	100	2.6	0	0	0.0	70	0	20.3
4/6/2011 11:52	26.4	3.9	0.0	0.0	0.0	14.4	100	2.6	0	0	0.0	70	0	20.3
4/6/2011 11:53	26.4	3.9	0.0	0.0	0.0	15.0	100	2.6	0	0	0.0	70	0	20.3
4/6/2011 11:54	26.4	3.7	0.0	0.0	1.8	14.4	92	2.4	718	714	0.0	70	0	20.3
4/6/2011 11:55	26.1	3.9	0.0	0.7	2.7	15.0	351	21.2	818	815	0.6	70	0	20.3
4/6/2011 11:56	26.2	3.9	0.0	0.7	2.7	14.7	344	21.9	828	820	1.1	70	6	20.3
4/6/2011 11:57	26.4	3.9	0.0	0.7	2.7	15.8	329	22.5	826	824	1.8	70	9	20.3
4/6/2011 11:58	26.6	4.0	0.0	0.7	2.7	16.3	319	23.2	833	826	2.3	70	12	20.3
4/6/2011 11:59	26.7	4.0	0.0	0.7	2.7	17.2	314	23.8	832	832	3.0	70	15	20.3
4/6/2011 12:00	26.9	4.0	0.0	0.7	2.7	17.4	302	24.6	841	833	3.5	70	18	20.3
4/6/2011 12:01	27.2	4.1	0.0	0.7	2.7	18.5	295	25.3	846	836	4.2	70	20	20.3
4/6/2011 12:02	27.4	4.1	0.0	0.7	2.7	19.0	288	26.2	848	837	4.8	70	23	20.3
4/6/2011 12:03	27.6	4.1	0.0	0.7	2.7	19.8	278	27.1	844	840	5.3	70	26	20.3
4/6/2011 12:04	27.8	4.2	0.0	0.7	2.7	20.4	271	28.0	852	844	5.9	70	29	20.3
4/6/2011 12:05	27.9	4.2	0.0	0.7	2.7	21.1	266	29.0	849	847	6.6	70	32	20.3
4/6/2011 12:06	28.2	4.2	0.0	0.7	2.7	22.8	258	30.0	850	848	7.2	70	35	20.3
4/6/2011 12:07	28.4	4.2	0.0	0.7	2.7	23.9	253	31.2	858	851	7.8	70	38	20.3
4/6/2011 12:08	28.7	4.2	0.0	0.7	2.7	24.4	251	32.4	862	853	8.4	70	41	20.3
4/6/2011 12:09	28.9	4.2	0.0	0.7	2.7	25.7	280	33.5	845	840	8.9	70	44	20.3
4/6/2011 12:10	29.2	4.3	0.0	0.7	2.7	27.1	278	34.8	851	844	9.6	70	47	20.3
4/6/2011 12:11	29.5	4.3	0.0	0.7	2.7	28.9	275	36.4	854	850	10.1	70	50	20.3
4/6/2011 12:12	29.7	4.3	0.0	0.7	2.8	30.6	275	37.9	847	838	10.8	70	53	20.3
4/6/2011 12:13	30.1	4.3	0.0	0.7	2.7	32.2	266	40.0	900	893	11.4	70	56	20.3
4/6/2011 12:14	30.3	4.3	0.0	0.7	2.7	33.8	271	41.8	880	874	11.9	70	59	20.3
4/6/2011 12:15	30.7	4.3	0.0	0.7	2.8	36.2	278	43.7	881	870	12.6	70	62	20.3
4/6/2011 12:16	21.0	4.4	0.0	0.7	2.8	38.6	283	45.9	887	876	13.1	70	65	20.3
4/6/2011 12:17	31.3	4.4	0.0	0.7	2.8	41.4	295	48.3	892	882	13.8	70	68	20.3
4/6/2011 12:19	31.6	4.4	0.0	0.0	0.0	0.0	83	48.4	0	0	0.0	70	0	0.0

mS = milliSiemens

DATA ANALYSIS

This section of the report includes the results of pilot-scale studies conducted at the KBH Desalting Plant and the BGNDRF test site. The results of a laboratory evaluation of antiscalants that affect calcium sulfate precipitation are also presented herein.

Pilot Plant Results at KBH Desalting Plant

As stated previously, the pilot studies conducted at the KBH Desalting Plant used RO concentrate from the plant that was spiked with various inorganic salts and then batch treated in the manually operated, SWRO unit. Different amounts of the following salts were added to KBH concentrate before the addition of acid and antiscalant: sodium chloride (NaCl), sodium sulfate (Na_2SO_4), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2 \cdot 6H_2O$). In this study, the primary reason the salts were added to KBH concentrate was to change its composition to simulate RO concentrates that would be generated in other parts of the country. Later, certain salts were discovered to have a beneficial effect on water recovery in RO systems. Cameron and Seidell (1901) studied the effect of the above-mentioned salts on the solubility of calcium sulfate and found that all of the salts, except calcium chloride, **increased** the solubility of calcium sulfate at certain concentrations of the salts. Previous studies at the KBH Desalting Plant showed calcium sulfate, not silica, was the precipitant of concern when recovering additional water from the concentrate; therefore, adding the salts **could potentially increase** the recovery of water from the spiked RO concentrate.

Most of the test runs were terminated before precipitation occurred because the small remaining feed volume was close to falling below the inlet suction point. Therefore, the data taken at the KBH site do not conclusively prove that adding some of the salts had a beneficial effect on total recovery. However, the addition of sodium chloride was shown to have a beneficial effect on total recovery at the BGNDRF site, as discussed later in this report.

Unspiked KBH Concentrate Results

This section presents the results of recovering water from unspiked KBH Desalting Plant RO concentrate to serve as a reference point for the spiked sample results. Table 5 shows the raw data from a typical run of the CERRO batch-treatment process.

Table 5.—Raw data from test using unspiked RO concentrate from KBH Desalting Plant

Antiscalant (mL)	H_2SO_4 (mL)	Salt added (g) / none	Permeate flush flow rate initial (mL/m)	Permeate flush flow rate final (mL/m)	Pressure flush (lb/in^2)	Operating pressure (lb/in^2)	Initial volume (gal)	Final volume measured (gal)	Recovery (%)	Date	
0.6	32		800	790	300	700	30	4.00		5/14/2010	
								Measured	87		

Time (m)	Permeate (mL/m)	Col (C) permeate conductivity (µS/cm)	Conc conductivity (µS/cm)	Feed conductivity (µS/cm)	Temperature (°C)	pH	Silica (mg/L)	Permeate mass col (C) * col (K)	Col (K) average permeate flow (mL/m)	Unit recovery	Total recovery
	1,220			18,150	24.7	3.7					0%
5	1,220	452	23,300	19,030	25.1	3.7		551,440	1,220	5%	5%
10	1,210	437	24,400	19,900	25.0	3.8		530,955	1,215	5%	11%
15	1,170	422	25,500	22,300	25.5	3.9		502,180	1,190	5%	16%
20	1,160	414	26,900	23,800	25.0	3.9		482,310	1,165	5%	21%
25	1,140	406	28,400	25,100	25.2	3.9		466,900	1,150	5%	26%
30	1,100	403	30,100	26,800	26.1	4.1		451,360	1,120	5%	31%
35	1,090	403	31,500	28,200	25.6	4.1		441,285	1,095	5%	36%
40	1,040	413	33,400	30,100	26.3	4.2		439,845	1,065	5%	41%
45	1,020	419	35,100	31,700	25.8	4.2		431,570	1,030	5%	45%
50	990	426	37,200	34,000	26.5	4.3		428,130	1,005	4%	50%
55	930	444	39,600	36,300	26.0	4.3		426,240	960	4%	54%
60	850	466	42,000	38,900	26.8	4.4	310,310,330	414,740	890	4%	58%
65	820	460	44,700	41,700	27.1	4.6		384,100	835	4%	61%
70	790	540	47,900	44,700	27.2	4.7		434,700	805	4%	65%
75	740	581	51,400	48,400	26.7	4.8		444,465	765	3%	68%
80	660	669	54,200	51,500	27.3	5.0		468,300	700	3%	71%
85	560	780	57,800	55,500	26.6	5.1		475,800	610	3%	74%
90	520	873	61,600	59,200	27.4	5.3		471,420	540	2%	76%
95	460	996	65,100	63,160	26.9	5.3		488,040	490	2%	79%
100	375	1178	68,400	66,400	27.3	5.7		491,815	418	2%	80%
105	325	1434	78,100	70,600	27.4	5.8		501,900	350	2%	82%
110	240	1660	75,200	73,500	27.7	5.9		468,950	283	1%	83%
115	200	2140	77,200	76,100	27.3	6.0	650,650,660	470,800	220	1%	84%
							Average permeate conductivity = 538				

Note: mL – milliliters, g = grams, mL/m = milliliters per minute

The top portion of table 5 shows the conditions for the test run. The permeate flush flow rates (initial and final) refer to the permeate flow rate at 300 lb/in^2 (2,067 kilopascal amperes) before and after the test run was executed to indicate whether or not the membrane got fouled during the run. The measured recovery is the recovery based on the measured volume of concentrate remaining at the end of the test run. This value would probably be slightly **higher** than the actual recovery because some water was taken for samples or otherwise lost during the test run. The total recovery shown in the last column table 5 was calculated by integrating the permeate flow rates recorded in the second column, which were obtained with a graduated cylinder and a stop watch.

Tables A1 through A8 in appendix A show the raw data from eight different test runs, and table 6 summarizes the data.

Table 6.—CERRO results using unspiked KBH RO concentrate

Date	Initial feed conductivity (µS/cm)	Final concentrate conductivity (µS/cm)	Average permeate conductivity (µS/cm)	Final pH	Final silica concentrate (mg/L)	Calculated recovery (%)
05/13/2010	18,650	80,400	550	6.0	703	86
05/14/2010	18,150	77,200	558	6.0	653	84
06/08/2010	21,100	79,800	1243	5.0	787	81
06/10/2010	21,500	82,800	951	5.2	-	85
06/16/2010	17,570	77,700	1167	4.6	747	86
06/23/2010	22,100	83,900	1335	4.5	690	87
10/01/2010	22,800	93,500	957	3.8	690	88
10/08/2010	22,300	81,800	1083	4.6	710	86

In general, the data show calculated recoveries from KBH concentrate were in the 85% range, with final reactive silica concentrations usually between 700 and 800 mg/L. For an initial silica concentration of 145 mg/L, the final values are in the expected range, indicating that little or no silica polymerization took place. The conductivity of the composited permeate from the CERRO process ranged from 550 to 1,335 µS/cm, with higher conductivities associated with lower pH values (due to the high equivalent conductance of hydrogen ions). Figure 4 shows the relationship between permeate conductivity and final feed pH for seven of the test runs using KBH concentrate (the test run on 10/1/2010 was not included because extra acid was added to the feedwater near the end of the run). In general, the graph shows that as pH decreases, conductivity increases. Previous research (Ning and Tarquin, 2010) showed that the TDS concentration of permeate from the SWRO process at 80% recovery of KBH concentrate was less than 165 mg/L at an electrical conductivity of 902 µS/cm. If the same ratio between permeate conductivity and TDS is applied here, the TDS of the permeate

would be less than 250 mg/L at the highest conductivity shown in table 6, indicating that the CERRO process was working very well.

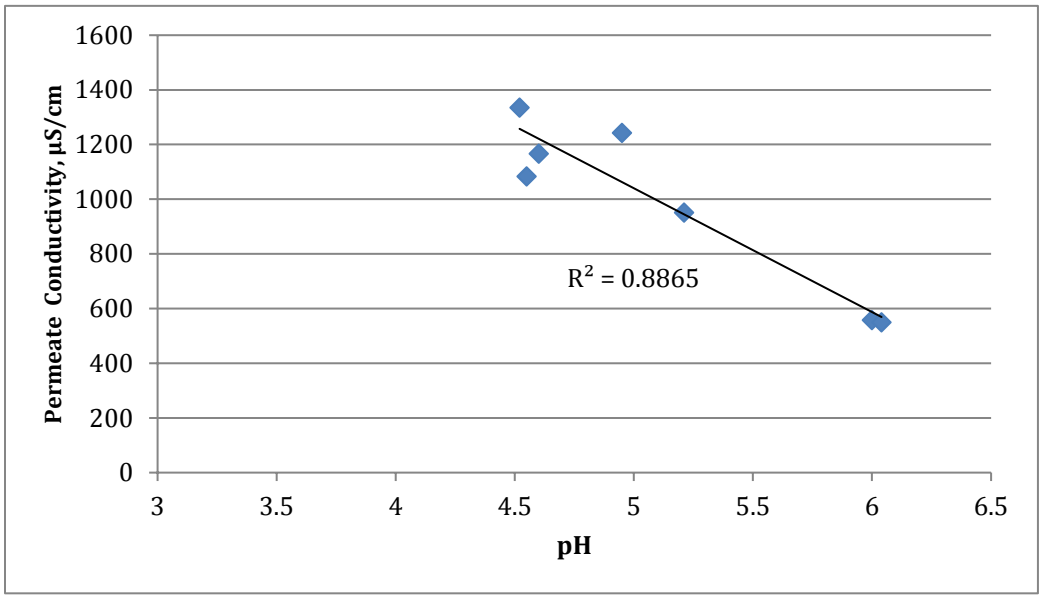


Figure 4.—Permeate conductivity versus pH.

KBH Concentrate Spiked with Various Salts

Table 7 summarizes the results of tests using KBH concentrate spiked with various salts, and tables A9 and A10 in appendix A present the raw data for samples spiked with sodium chloride. Tables A11-A15, A16-A22, and A23-A26 show the raw data for samples spiked with calcium chloride, sodium sulfate, and magnesium chloride, respectively. The results show that recoveries above 80% were achieved (with several in the high 80s), regardless of which salt was used as the spike, unless the process was stopped due to excess processing time or insufficient feed volume. Many of the reactive silica concentrations were lower than they should be, based on the recoveries attained, indicating that some silica polymerization had taken place, especially for magnesium chloride. Some of the polymerization may have occurred during the recovery process itself; however, most of it believed to have taken place between the time the process ended and the sample was analyzed. Figure 5 is plot of the conductivity and silica data from the test run conducted on August 17, 2010.

The graph shows that the silica concentration increased about the same as the conductivity, indicating that no silica polymerization took place during the process. When the final concentrate sample was reanalyzed each of the following 3 days, however, only the reactive silica concentration significantly decreased each day, as shown by the data in table 8 and the graph in figure 6. Thus, even though some silica polymerization occurred during the batch-treatment process, silica did not appear to be a problem from the standpoint of fouling or scaling because there was no apparent silica **precipitation.**

Table 7.—Summary of spiked RO concentrate results

Spike ID	Spike amount (mg/L)	Final silica (mg/L)	Final pH	Final concentrate conductivity (µS/cm)	Calculated recovery (%)	Test date
NaCl	5,000	420	4.4	80,500	71	07/06/2010
NaCl	5,000	530	4.6	87,200	79	07/09/2010
NaCl	4,227	–	4.6	54,300	82	12/10/2010
$CaCl_2$	1,000	663	4.6	85,900	83	07/20/2010
$CaCl_2$	3,000	600	5.0	84,900	81	07/22/2010
$CaCl_2$	5,000	–	5.2	80,600	68	08/02/2010
$CaCl_2$	5,000	553	4.8	88,700	83	08/06/2010
$CaCl_2$	5,200	441	4.9	–	81	12/17/2010
Na_2SO_4	2,500	647	4.6	84,200	84	08/11/2010
Na_2SO_4	2,500	660	4.9	82,600	82	08/17/2010
Na_2SO_4	5,000	570	4.4	78,900	78	08/27/2010
Na_2SO_4	5,000	–	3.9	71,200	85	11/12/2010
Na_2SO_4	5,000	620	4.3	86,600	88	11/19/2010
Na_2SO_4	2,350	–	–	81,400	80	06/14/2011
Na_2SO_4	5,000	–	–	76,000	91	06/16/2011
$MgCl_2*6H_2O$	2,500	605	4.5	80,000	84	09/17/2010
$MgCl_2*6H_2O$	4,400	265	4.4	78,000	80	09/24/2010
$MgCl_2*6H_2O$	5,300	365	5.8	97,700	83	11/05/2010
$MgCl_2*6H_2O$	5,000	382	5.2	86,500	91	12/21/2010

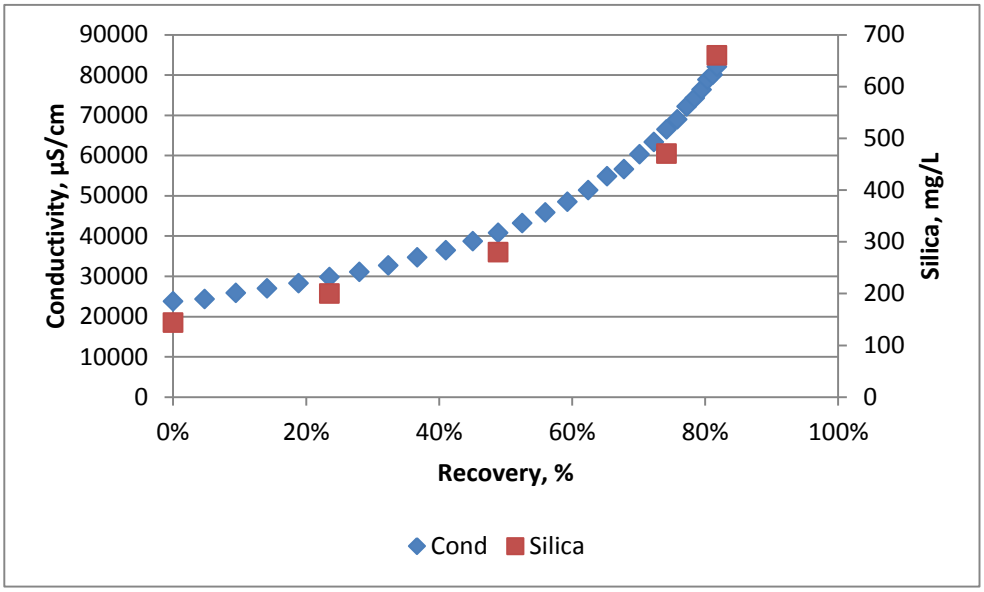


Figure 5.—Conductivity and silica versus recovery on August 17, 2010.

Table 8.—Results of final concentrate analysis on four consecutive days

Date	Hard	Ca	SO_4	Cl	TDS*0.5	SiO_2
8/17/10	12,250	8750	18,500	28,250	35,674	660
8/18/10	12,250	8750	18,940	30,500	35,671	363
8/19/10	11,750	8500	18,820	29,250	35,660	196
8/20/10	12,250	8500	18,540	28,000	35,647	170

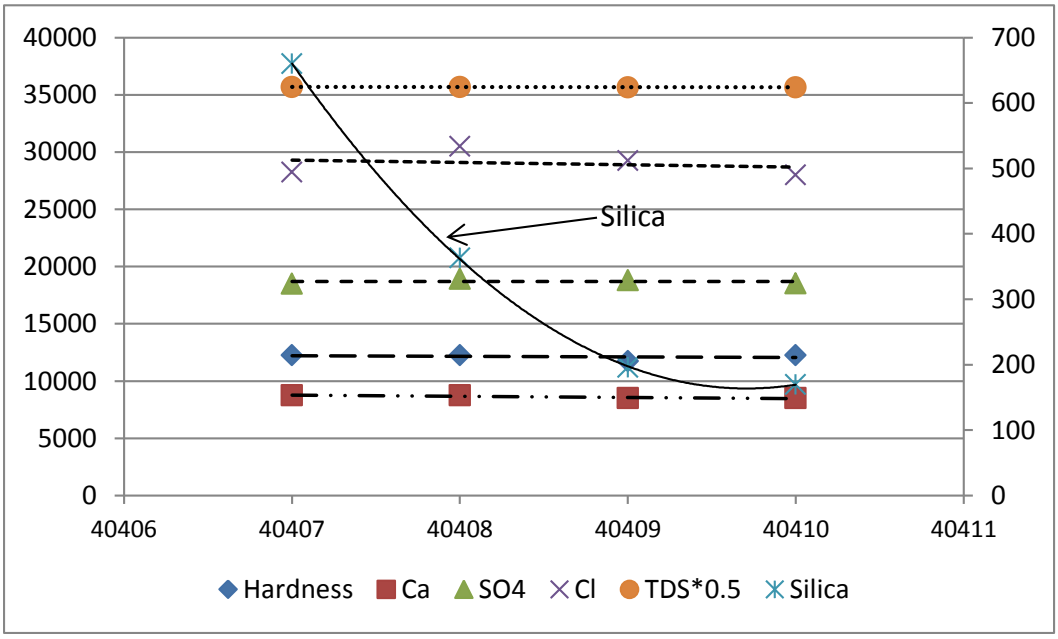


Figure 6.—Results of concentrate analyses conducted on four consecutive days.

Mass balances were conducted for selected test runs to verify the system recoveries. Table 9 shows the results obtained when KBH concentrate was spiked with 5,300 mg/L of $MgCl_2 \cdot 6H_2O$ before being treated in the SWRO unit to 83% recovery. The 80.7% recovery calculated from the mass balance shown in table 10 is lower than the 83% calculated from the permeate flows for the same reasons that the recovery of 87% based on the remaining concentrate volume is too high: because of water (and the concomitant mass) that was removed from the system during sampling or otherwise lost during the course of the test run. In any case, treatment was excellent, as shown by the high quality of permeate with a TDS concentration of 728 mg/L.

Table 9.—Results with 5,300 mg/L of $MgCl_2*6H_2O$ on November 5, 2010

Parameter (mg/L)	KBH concentrate before spiking	KBH concentrate spiked with 5,300 mg/L $MgCl_2*6H_2O$	Spiked concentrate after 83% recovery	SWRO permeate after 83% recovery
T hardness	2,730	5,280	26,800	56
Calcium	783	785	4,010	3
Magnesium	208	765	3,940	8
Potassium	85	89	468	5
Sodium	3,800	3,680	18,100	130
Chloride	6,880	8,500	43,700	521
Sulfate	1,610	1,970	10,400	23
TDS	14,200	16,500	78,000	728
Silica	32	31	123	365

Table 10.—Mass balance calculations for data from table 9

Parameter	Mass In	Permeate mass	Concentrate mass	Permeate + concentrate	Difference	% Difference
TH	599,544	5,111	588,340	593,452	6,092	-1%
Ca	89,137	458	88,032	88,490	647	-1%
Chlorides	965,175	47,722	959,346	1,007,068	-41,893	4%
Sulfates	223,694	2,088	228,311	230,400	-6,706	3%
TDS	1,873,575	66,683	1,712,334	1,779,017	94,558	-5%
K	10,106	458	10,274	10,732	-626	6%
Mg	86,866	687	86,495	87,182	-316	0%
Na	417,864	11,908	397,349	409,257	8,607	-2%
Silica	15,329	183	8,013	8,196	7,133	-4%
Recovery = 80.7%						

The total cycle time for treating the 30-gallon batch to 83% recovery was 150 minutes, which is too long. The silica concentration in the final feedwater **immediately after the treatment was stopped** was 365 mg/L, which is only about one-half of what it should be based on theoretical calculations. This indicates that silica polymerization was taking place during the test run. There was a slight decrease in permeate flow rate when the membrane was tested at the end of the run (using KBH permeate at 300 lb/in^2); therefore, as a precaution, the membrane was chemically cleaned using King Lee's silica cleaner, and the

system performed as usual during the next batch run. All succeeding test runs used batch sizes of 20 gallons or less to keep the batch processing time less than 90 minutes.

Pilot Plant Results at BGNDRF Site

This section contains the results of three different test-run conditions at the BGNDRF test site: (1) using raw water or RO concentrate (at 50% recovery) from Well 2 with an antiscalant concentration of 5 ppm (Pretreat Plus 0400), (2) using RO concentrate (50% recovery) spiked with 10,000 mg/L of sodium chloride and 5 ppm of antiscalant; and (3) using RO concentrate (50% recovery) treated with 20 ppm of antiscalant. The results from the tests are summarized in Table 11 and discussed later in separate sections of this report.

Table 11.—Summary of results from BGNDRF site

Date	Feedwater ID	Feedwater pretreatment	Total recovery (%)	Comments
Low-dose antiscalant				
6/23/2011	Raw well water	5 ppm antiscalant	67.0	
6/23/2011	Raw well water	5 ppm antiscalant	73.0	
8/4/2011	RO concentrate at 33% recovery	5 ppm antiscalant	68.5	
11/182011	RO concentrate at 50% recovery	5 ppm antiscalant	68	
12/13/2011	RO concentrate at 49% recovery	5 ppm antiscalant	67.4	
NaCl + low-dose antiscalant				
6/23/2011	Raw well water	5,000 mg/L NaCl	73++	Process reached. Preset endpoint.
6/23/2011	Raw well water	10,000 mg/L NaCl	79++	Process reached. Preset endpoint.
11/18/2011	RO concentrate at 50% recovery	10,000 mg/L NaCl	86.5	
High-dose antiscalant				
12/13/2011	RO concentrate at 49% recovery	20 ppm antiscalant	76.0	

Low-Dose Antiscalant Results

The low-dose antiscalant tests were conducted using either raw water taken directly from Well 2 or using Well 2 water that had been concentrated by up to about 50% before it was treated using the batch-treatment CERRO process. As shown in the top part of table 11, the total recovery of Well 2 water was about 68% whether the feedwater was **raw water from Well 2** or was Well 2 water that had been previously concentrated by up 50% in a pretreatment RO unit. The raw data from the five test dates, when a 5-ppm dose of antiscalant was applied, are shown in tables B1through B5 in appendix B. Tables C1 through C5 in appendix C show the data logs for those runs.

All testing conducted at the BGNDRF site involved taking turbidity measurements of the feedwater at approximately 5-minute intervals to quantitatively measure the time precipitation began. Figure 7 is a plot of recovery versus turbidity for the November 18, 2011, test run, which clearly shows precipitation started at between 30 and 35% recovery of the RO concentrate that was previously generated from 50% recovery of Well 2 water, yielding a total recovery of about 67%.

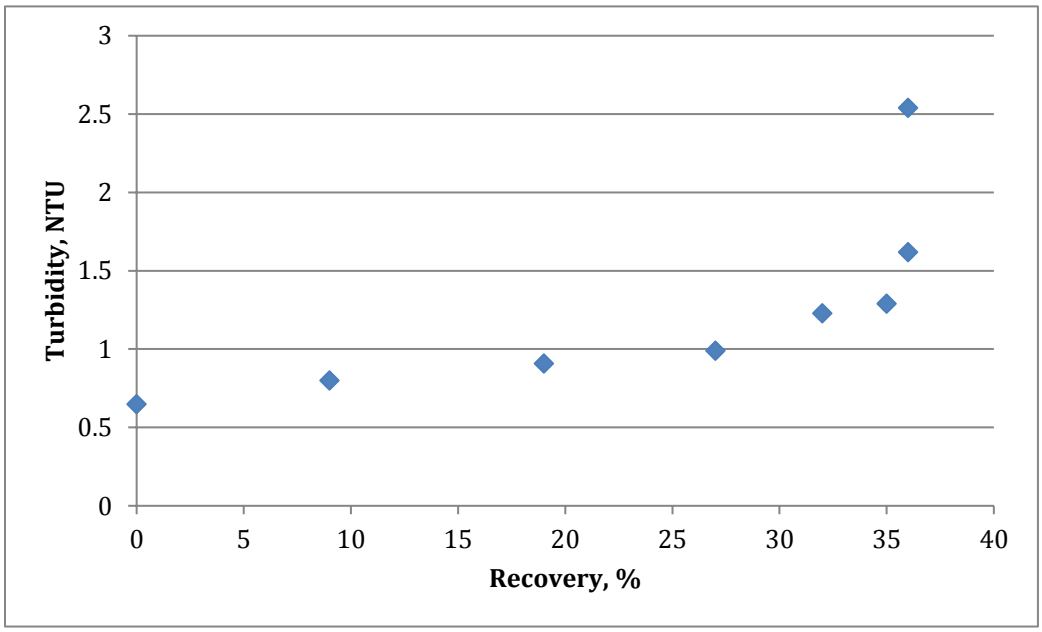


Figure 7.—Turbidity of feedwater versus recovery of RO concentrate.

Table 12 summarizes the chemical analyses from the November 18, 2001, test run. The permeate quality was excellent, with a TDS concentration of 124 mg/L, which would allow for some blending with raw well water. In a full-scale system, blending of permeate with raw well water would **lower the cost** of the total water produced from a groundwater desalting treatment system due to the lower cost of the blend water.

Table 12.—Summary of chemical analyses for test run on November 18, 2011

Parameter	Raw well water	RO concentrate at 50% recovery	SWRO permeate	SWRO final feed
Calcium	435	942	0	355
Magnesium	260	536	4	792
Sodium	687	1,398	12	2,050
Chloride	547	1,107	21	1,615
Fluoride	2.0	1.64	0	3.14
Nitrate	29	62	2	92
Sulfate	3,065	6,124	12	7,161
Conductivity	5,950	12,600	299	16,740
TDS	5,610	10,388	124	14,930

Note: All values in mg/L, except conductivity (µS/cm).

Table 13 shows the mass balance of the parameters measured in the raw well water and the final SWRO concentrate. There was a significant loss of mass in several of the parameters, most notably calcium, sulfate, and TDS, due primarily to precipitation of calcium sulfate. If all of the lost calcium is assumed to be in the form of calcium sulfate, it would produce a mass of 12,527 milligrams of calcium sulfate per liter of solution. A similar calculation for the lost sulfate would produce a mass of 11,813 milligrams of calcium sulfate per liter of solution, which is close to the value calculated from the calcium. The calculated loss of TDS is 12,453 mg/L of solution, showing that most of the lost mass was probably due to precipitation of calcium sulfate.

Table 13.—Mass balance for parameters from table 12 (raw water to SWRO final feed)

Parameter	Mass In	Permeate mass	Concentrate mass	Permeate + concentrate	Difference	% Difference
Conductivity	675,623	21,953	633,609	655,562	20,061	-3%
Calcium	50,643	379	13,437	13,815	36,828	-73%
Chlorides	63,474	2,354	61,128	63,482	-8	0%
Sulfates	355,071	871	271,044	271,914	83,156	-23%
TDS	637,016	5,299	507,190	512,489	124,527	-20%
Fluoride	227	76	119	195	33	-14%
Magnesium	30,091	106	29,977	30,083	8	0%
Sodium	79,712	379	77,593	77,971	1,741	-2%
Nitrate	3,407	189	3,482	3,671	-265	8%
Recovery = 66.7%						

Low-Dose Antiscalant with Sodium Chloride Results

Per the work of Cameron and Seidell (1901), certain salts have a significant effect on the solubility of calcium sulfate in aqueous solutions. Figure 8 is a plot of Cameron's data for sodium chloride. It shows that there is more than a three-fold increase in the solubility of calcium sulfate with increases in sodium chloride concentration up to about 80,000 mg/L. As mentioned earlier, however, silica tends to precipitate at sodium chloride concentrations that exceed 30,000 mg/L (Ueda, 2003).

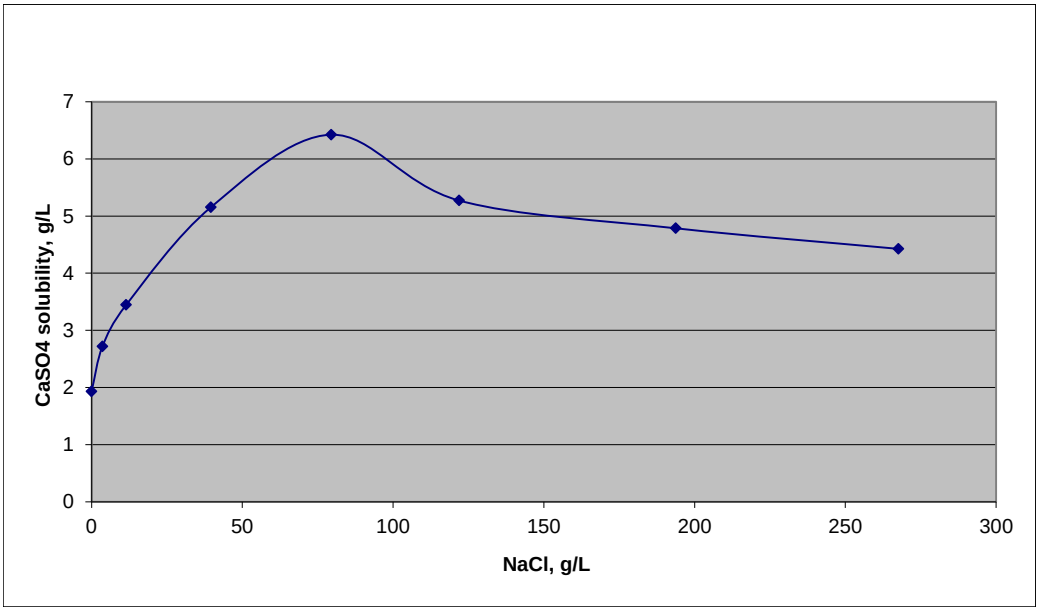


Figure 8.—Calcium sulfate solubility versus sodium chloride concentration, Cameron and Seidell (1901).

In order to evaluate the effect of sodium chloride addition on total system recovery in the batch-treatment CERRO process, test runs were conducted wherein raw water or RO concentrate from Well 2 water was spiked with 5,000 or 10,000 mg/L of sodium chloride. The raw data from the four test dates, when a 5-ppm dose of antiscalant was applied along with sodium chloride, are shown in tables B6 through B8 in appendix B. The data logs for those runs are shown in tables C6 through C8 in appendix C.

A summary of the chemical analyses from the November 18, 2011, test run with 5 ppm of antiscalant and 10,000 mg/L of sodium chloride is shown in table 14. The quality of the permeate was excellent, with a composited permeate concentration of 250 mg/L.

Table 14.—Summary of chemical analyses for November 18, 2011, test with 10,000 mg/L NaCl

Parameter	RO concentrate at 50% recovery before salt and acid	RO concentrate at 50% recovery after salt and acid	SWRO permeate	SWRO final feed
Calcium	942	906	3	667
Magnesium	536	538	2	1,785
Sodium	1,398	5,020	73	16,624
Chloride	1,107	6,734	127	22,165
Fluoride	1.6	2.6	0.1	6.2
Nitrate	62	61	4	206
Sulfate	6,124	6,510	14	15,675
Conductivity	12,600	27,300	–	68,300
TDS	10,388	20,735	250	58,772

Note: All values in mg/L, except conductivity (µS/cm).

Table 15 shows a mass balance of the parameters measured in the RO concentrate feedwater and the final SWRO concentrate. The 70% recovery of the **RO concentrate** that was generated from 50% recovery of Well 2 water yields a **total recovery** of 85%. In the two previous runs with sodium chloride-spiked water (performed on June 23, 2011), the recovery process automatically stopped at the preset recovery points of 75% and 80%, respectively, because they were set below the unexpectedly high recoveries that were reached.

As was true for the test run without the addition of sodium chloride, there was a significant loss of mass in the same parameters mentioned previously; most notably calcium, sulfate, fluoride, and TDS. Again, this was due primarily to precipitation of calcium sulfate (and minimally due to precipitation of calcium fluoride). If the unaccounted-for masses of calcium, sulfate, and fluoride are added together, they total 85% of the TDS loss, which is probably within the experimental error of the test results. In any case, most of the unaccounted-for mass is certainly due to precipitation of calcium sulfate.

Table 15.—Mass balance for test run with 10,000 mg/L NaCl added to RO concentrate

Parameter	Mass in	Permeate mass	Concentrate mass	Permeate + concentrate	Difference	% difference
Conductivity	3,099,915	47,691	2,326,640	2,374,331	725,585	-23%
Calcium	102,876	238	22,721	22,960	79,916	-78%
Chlorides	764,646	10,095	755,051	765,145	-500	0%
Sulfates	739,211	1,113	533,969	535,082	204,129	-28%
TDS	2,354,459	19,871	2,002,068	2,021,939	332,520	-14%
Fluoride	290	10	212	221	68	-24%
Magnesium	61,090	159	60,806	60,965	125	0%
Sodium	570,021	5,802	566,297	572,099	-2,078	0%
Nitrate	6,927	318	7,017	7,335	-409	6%
Recovery = 70.0%						

High-Dose Antiscalant Results

The high-dose antiscalant test was conducted using water from Well 2 that had been concentrated to 49% before it was treated using the batch-treatment CERRO process. Table 16 summarizes the chemical analyses from the December 13, 2011, test run. The quality of the permeate was excellent, with a TDS concentration of 70 mg/L.

Table 16.—Summary of chemical analyses for December 13, 2011, test with 20-ppm antiscalant

Parameter	Raw water, Well 2	RO concentrate at 49% recovery	SWRO permeate	SWRO final feed
Calcium	521	1,029	7	471
Magnesium	279	556	3	1,190
Sodium	665	1,302	14	2,743
Chloride	622	1,196	43	2,472
Fluoride	2.3	2.8	0.3	4.9
Nitrate	26	53	6	106
Sulfate	3,148	6,012	25	9,717
Silica	26	48	2	103
Conductivity	5,960	12,600	100	21,300
TDS	5,610	10,999	70	18,192

Note: All values in mg/L, except conductivity (µS/cm).

The mass balance using Well 2 raw water parameters, as well as the final SWRO concentrate presented in table 17, show that the **total recovery** was 76%, which is a 9% improvement over the recovery obtained when using an antiscalant concentration of 5 ppm. It is, however, 10% below the 86% recovery obtained

when the water was treated with 5 ppm of antiscalant **and** spiked with 10,000 mg/L of sodium chloride.

Table 17.—Mass balance for December 13, 2011, test with 20-ppm antiscalant

Parameter	Mass in	Permeate mass	Concentrate mass	Permeate + concentrate	Difference	% Difference
Conductivity	675,623	25,081	576,437	601,518	74,105	-11%
Calcium	59,160	626	12,747	13,373	45,787	-77%
Chloride	70,628	3,754	66,899	70,653	-25	0%
Sulfate	357,455	2,145	262,969	265,114	92,342	-26%
TDS	640,990	8,649	492,326	500,974	140,015	-22%
Nitrate	2,976	476	2,869	3,344	-368	12%
Magnesium	31,680	277	32,205	32,481	-801	3%
Sodium	75,511	1,176	74,233	75,409	101	0%
Silica	2,930	173	2,787	2,960	-31	1%
Fluoride	257	28	132	159	97	-38%
Recovery = 76.2%						

As was true for most of the test runs discussed previously, there was a significant loss of mass in calcium, sulfate, fluoride, and TDS. As before, the lost mass is due to precipitation of calcium sulfate. In this case, the lost calcium and sulfate masses accounted for 99% of the total loss in TDS.

Laboratory Antiscalant Test Procedure and Results

Antiscalant Test Procedure

Since calcium sulfate appears to be the constituent that limits water recovery at both the Alamogordo test site and the KBH Desalting Plant in El Paso, a decision was made to perform bench-scale testing of scale inhibitors, a procedure manufacturers recommended was effective to combat calcium sulfate precipitation. Seven different antiscalants were obtained from four different suppliers as follows:

Antiscalant	Supplier
A-104	American Water Chemicals
MDC-760	GE
Pretreat Plus 400	King Lee Technologies
Trisen 3150	Trisen Corporation
Trisen 4150	Trisen Corporation
Trisen 6150	Trisen Corporation
Trisen 7150	Trisen Corporation

Raw water from Well 2 at the BGNDRF site was used as the test solution. The pH was reduced to 3.5 to simulate pilot plant operating conditions. Two hundred and fifty milliliters of the water were treated with 0 (control) and various concentrations of antiscalant. The water was then dosed with sodium sulfate and calcium chloride stock solutions to yield equivalent calcium sulfate additions of 0.01 mole per liter (M) to 0.1 M (to simulate various recoveries in the SWRO unit). The solutions were continuously stirred on a magnetic mixer, and samples were withdrawn at 5-minute intervals and tested for turbidity. During initial testing, all of the antiscalants were tested at a dosage of 0.8 ppm with an equivalent calcium sulfate addition of 0.03 M. After the initial test, certain antiscalants were selected for further testing at higher antiscalant dosages and calcium sulfate additions. Tables D1 through D8 in appendix D present the data from all of the tests that were conducted.

Antiscalant Test Results

As shown in figure 9, the results from the 0.8-ppm test run reveal a significant difference in the effectiveness of the antiscalants. If the time required for the control solution to reach a turbidity of 2 NTU is arbitrarily selected as the time at which the antiscalant failed, four of the antiscalants failed within 10% of that time. According to these results, some of the antiscalants were no more effective at the low antiscalant dosage of 0.8 ppm than no treatment at all (this underscores the importance of antiscalant testing in any membrane desalting project). On the other hand, at least one of the antiscalants (i.e., A-104) that performed poorly at the 0.8-ppm concentration performed much better than the control at 2 ppm with a higher concentration of calcium sulfate. Pretreat Plus 0400 is the antiscalant used in the pilot studies at the KBH Desalting Plant and the BGNDRF test site, and it performed equal to or better than all of the other antiscalants at the initial dosages and calcium sulfate concentrations tested. It was, therefore, the only antiscalant evaluated at the higher concentrations (i.e., above 5 ppm) and at the higher calcium sulfate levels (i.e., up to 0.1 M).

In order to determine the effect of antiscalant concentration on induction time, raw water from Well 2 was first treated with Pretreat Plus 0400 at concentrations of 1 ppm to 6 ppm (in 1-ppm increments) and then dosed with 0.05 M calcium chloride and sodium sulfate solutions. The solutions were continuously stirred on a magnetic mixer, and turbidity was measured at 5-minute intervals. Figure 10 shows the effect of antiscalant concentration on calcium sulfate precipitation time. The graph clearly shows that the induction time increases as the concentration of antiscalant is increased, and the increase is significant. For example, if a turbidity of 1 NTU is arbitrarily used to indicate the end of the induction period, the time increases from approximately 40 minutes at an antiscalant concentration of 1 ppm to approximately 330 minutes at 6 ppm. This phenomenon has far-reaching implications in a batch treatment process because total water recovery is directly

proportional to the length of the batch processing time (i.e., water recovery in a batch treatment process can continue as long as the onset of precipitation is delayed).

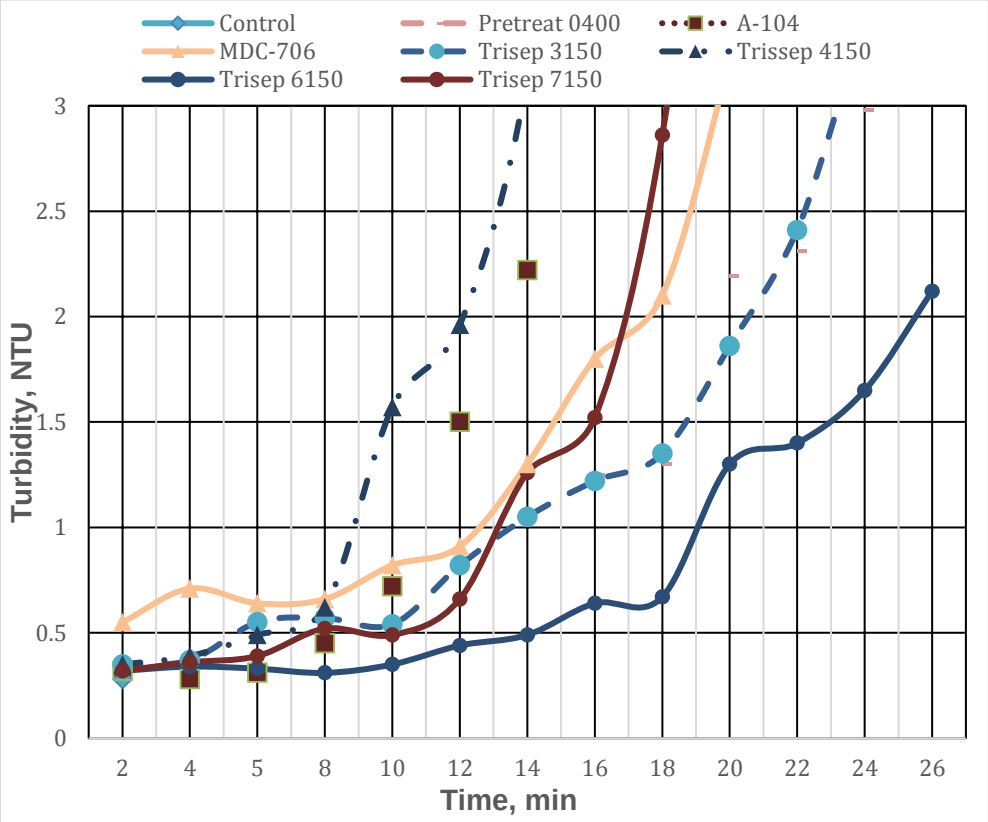


Figure 9.—Turbidity versus time at antiscalant concentration of 0.8 ppm with addition of 0.03M $CaSO_4$.

The data generated in the induction-time experiments were used to obtain a crude estimate of total water recovery as a function of antiscalant concentration in the batch treatment process. This relationship would be useful in establishing the optimal water recovery from the standpoint of incremental product-water cost.

The 3,300-mg/L concentration of sulfate (i.e., 0.034 M) in the raw water was used as the basis for calculating total recovery. This means that if 0.034 M calcium sulfate **were added** to the water during the antiscalant experiments, it would represent a recovery of 50%, because the sulfate concentration would have doubled. Similarly, if 0.068 M calcium sulfate were added, the recovery would be calculated as 67%, etc. The calcium sulfate dose (i.e., simulated recovery) that resulted in a turbidity of 2 NTU in 60 minutes (i.e., the approximate batch processing time) at a given antiscalant concentration was then plotted against that antiscalant concentration to show its effect on total recovery from the batch

treatment system. The results, plotted in figure 11, show a significant increase in recovery as a function of antiscalant dosage, but the rate of increase decreases rather rapidly beyond a dosage of about 5 ppm (i.e., diminishing returns). Nevertheless, as mentioned above, the longer the cycle time, the greater the recovery; thus, total recovery can be increased by increasing the induction time via an increase in antiscalant concentration. The economics of doing so are briefly discussed below.

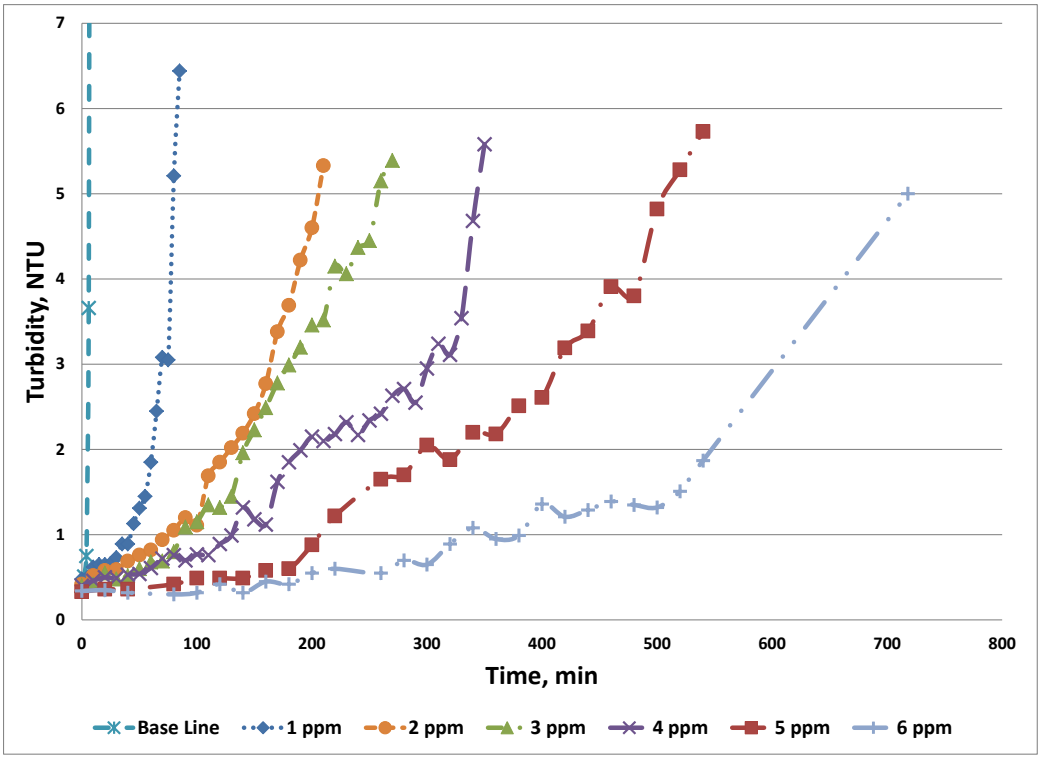


Figure 10.—Effect of antiscalant concentration on induction time at 0.05M $CaSO_4$.

It is interesting to note that the recoveries calculated from the regression equation compare rather well with the actual recoveries obtained in the pilot plant. For example, the predicted **total recovery** of Well 2 water at a 5-ppm dosage of antiscalant is 64.3%. The recovery obtained in the pilot plant tests at the BGNDRF site was 68%. Similarly, the respective values for a 20-ppm dosage are 77.9% predicted versus 76% actual. It appears, therefore, that a laboratory evaluation of antiscalant performance could provide valuable guidance in selecting the best antiscalant and in determining the appropriate dosage.

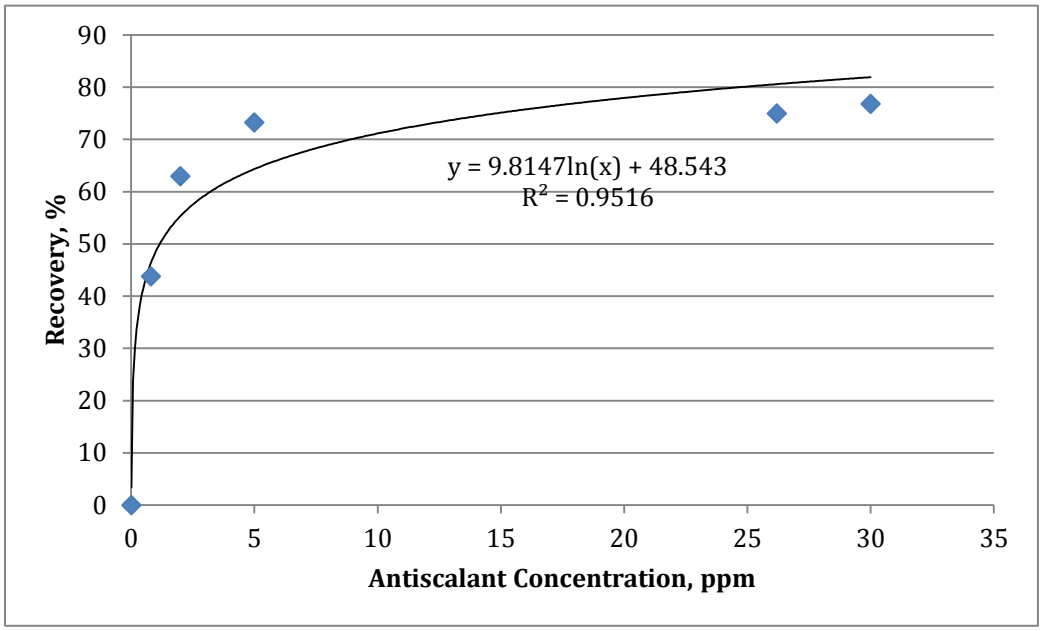


Figure 11.—Predicted SWRO recovery versus antiscalant concentration.

ECONOMIC CONSIDERATIONS

In order to determine the cost effectiveness of achieving enhanced recovery via the use of high-dose antiscalants or sodium chloride addition to the feedwater, an economic evaluation was conducted that considered only the extra cost of the additives versus the extra revenue from the sale of the additionally recovered water. A more robust evaluation would also consider cash flows associated with operating cost, capital cost, final concentrate disposal, blending, etc. Such an evaluation would be highly dependent on the type of final concentrate disposal employed. In any case, the procedures discussed here can be applied to whatever method of final concentrate disposal is ultimately involved.

Antiscalant Optimization

The economic evaluation for sodium chloride, which appears later in this report, was based on the results obtained at the BGNDRF site for an assumed feedwater flow of 1 Mgal/d. According to the pilot plant results, approximate total recoveries of 68% and 76% can be achieved with antiscalant doses of 5 ppm and 20 ppm, respectively. Other assumptions are that water recovery without antiscalant would be 60%, water is sold for $2.50 per thousand gallons (a relatively low value), and the cost of antiscalant is $1.25 per pound. If an antiscalant dosage of 5 ppm increased the recovery from 60% to 68%, the extra volume of permeate would be 80,000 gallons per day (gal/d). The revenue from

that water would be $200. The cost of the antiscalant would only be $52.13. Clearly, a 5-ppm dose of antiscalant is cost effective. For the 20-ppm dose, the recovery would increase from 68% to 76%. The cost of the extra 15 ppm of antiscalant is $156.38. The extra 8% increase in water recovery would result in an extra 80,000 gallons of water, which would generate an extra $200 in revenue, which is $43.62 greater than the cost of the antiscalant, rendering the 20-ppm antiscalant dosage also cost effective **when incrementally compared to the 5-ppm dosage**.

However, a dosage of 20 ppm might not be justifiable if pilot plant data were available for a 10-ppm dosage of antiscalant. For example, if pilot plant data had shown that the recovery at 10 ppm was 72% (which is 4% higher than the 68% recovery at 5 ppm of antiscalant), the incremental revenue of $100 (from 4% more water) would more than offset the incremental cost of $52.13 for the additional 5 ppm of antiscalant. However, when increasing antiscalant from 10 ppm to 20 ppm, the additional recovery of 4% (i.e., from 73% to 76%) would yield an incremental income of $100, which would not be enough to offset the $104.26 incremental cost of the antiscalant, rendering the 10-ppm dosage the optimal one. The breakeven cost would occur when a 2.4-ppm antiscalant dosage increased the recovery by 1% (i.e., if an extra antiscalant dosage of 2.4 ppm increased the recovery by more than 1%, the extra dosage would be cost effective, and vice versa). Stated another way, the cost for 1 ppm of antiscalant is $10.43 per day (based on the water flow and antiscalant cost assumed above). The extra amount of water required to recover that cost is 4,170 gal/d (again based on the daily water volume and water selling price assumed above). The 4,170-gal/d volume represents a required extra recovery of 0.417% per day. Thus, breakeven occurs when an extra antiscalant dosage of 1 ppm increases the recovery by 0.417%. For the equation shown in figure 11, the breakeven point occurs between dosages of 24 and 25 ppm. Therefore, the optimal dosage for the data shown in figure 11 (based only on antiscalant cost and water-selling price) would be 24 ppm.

Please note that these calculations do not account for costs associated with final concentrate disposal. It is possible that increased antiscalant concentration would also increase the final disposal cost. This is unlikely, however, when final concentrate will be disposed of through pond evaporation and **all costs** (i.e., capital and operating) have been taken into account, as well as blending. A higher antiscalant dosage would probably be economically attractive because of the revenue from the blend water and the reduced costs of pond construction, lining, fencing, etc. In any case, these results show that for **batch-treatment** SWRO systems, it would be prudent to undertake studies to determine the best performing antiscalant and the optimal antiscalant dosage (or other treatment regimen) that will optimize the design of the system.

Sodium Chloride Evaluation

As discussed in "Low-Dose Antiscalant with Sodium Chloride Results" section of this report, adding 5,000 or 10,000 mg/L of sodium chloride to the raw water or concentrate from Well 2 significantly increases the total water recovery from the batch treatment system. The calculations below are based on a total recovery of 86% when 10,000 mg/L of sodium chloride were added to RO concentrate generated from 50% recovery of raw water from Well 2. The extra pumping cost due to the increased osmotic pressure from the salt is based on 1 lb/in^2 per 100 mg/L of salt, a 75% pumping efficiency, and $0.08 per kilowatthour electricity cost. Salt cost is assumed at $0.10 per pound.

Increasing recovery from 68% to 86% produces 180,000 gal/d of extra water volume. At a sale price of $2.50 per thousand gallons, an incremental revenue of $450 per day would be produced. The cost of the salt would be $4, 170 per day (10,000*1*0.5*8.34*0.10). When the higher pumping cost is added (about $77 per day), the cost for salt treatment of the RO concentrate becomes almost 10 times the amount of the incremental revenue, without considering the burden and cost of handling nearly 21 tons of salt every day. Thus, even if some cost savings would result from a smaller volume of final concentrate for disposal, adding sodium chloride to RO concentrate to increase calcium sulfate solubility does not appear viable for increasing water recovery from raw water having a high concentration of calcium sulfate.

BIBLIOGRAPHY

Ahmed, Z., 1999. "A New Antifoulant for Controlling Silica Fouling in Reverse Osmosis Systems," *UltraPure Water*, Vol. 16, No. 2, February.

Alimi, F., H. Elfil, and A. Gadri, 2003. "Kinetics of the Precipitation of Calcium Sulfate Dihydrate in a Desalination Unit," *Desalination*, 157, 9-16.

Amjad, Z., 1985. "Applications of Antiscalants to Control Calcium Sulfate Scaling in Reverse Osmosis Systems," *Desalination*, 54, 263-276.

Amjad, Z., J. Zibrida, and R.W. Zuhl, 1997. *A New Antifoulant for Controlling Silica Fouling in Reverse Osmosis Systems*, Lubrizol Advanced Materials, Inc., Cleveland, Ohio.

Avista Technologies, 2008. *Antiscalant Technical Data Sheet*, Avista Technologies, Inc., San Marcos, CA.

Badruk, M., and I. Matsunaga, 2001. "Experimental Results of Silica Removal from Simulated Solutions of Geothermal Brine of Kizildere Field, Turkey," *Geothermics*, Vol. 30, 561-570.

Betz Laboratories, Inc., 1991. *Betz Handbook of Industrial Water Conditioning.*

Burton, E.A., W.L. Bourcier, A. Wallace, C.J. Burton, and R. Leif, June, 2003. *Silica Scale Management: Lowering Operating Costs through Improved Scale Control, and Adding Value by Extracting Marketable By-Products*, U.S. Department of Energy, Office of Technical Information, Oak Ridge, TN.

Cameron, F., and A. Seidell, 1901. "Solubility of Gypsum in Aqueous Solutions of Certain Electrolytes," *Journal of Physical Chemistry*, 5, 643-653.

Comb, L., 2001. *A Study of Silica and RO*, Osmonics, Inc., December.

Corbett, B.E., C.D. Moody, and D. Michael, 2003. *Evaluation of Reverse Osmosis Scaling Devices at High Recovery*, U.S. Department of the Interior, Bureau of Reclamation, Advanced Water Treatment Program, Report No. 91, March.

EPWU, 2011. *Quality Manual*, Section 23: "Quality of Test Results," *International Water Quality Laboratory*, pp. 157-173, El Paso Water Utilities.

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

Kedem, O., and G. Zalmon, 1997. "Compact Accelerated Precipitation Softening (CAPS) as a Pre-treatment for Membrane Desalination. I. Softening by NaOH," *Desalination,* Vol. 113, 65.

Lancia, A., D. Musmarra, and M. Prisciandaro, 1999. "Measuring Induction Period for Calcium Sulfate Dihydrate Precipitation," *AIChE Journal*, 45, 390-397.

Masariva, Alexandra, D. Meyerstein, N. Daltrophe, and O. Kedem, 1997. *Compact Accelerated Precipitation Softening (CAPS) as a Pre-treatment for Membrane Desalination, II. Lime Softening with Concomitant Removal of Silica and Heavy Metals*, Desalination, V113, 73-84.

Mi, B., and M. Elimelech, 2010. "Gypsum Scaling and Cleaning in Forward Osmosis: Measurements and Mechanisms," *Environmental Science and Technology, 44*, 2022-2028.

Mickley, M., and G. Coury, 1982. *Parameters of Silica Scaling in Reverse Osmosis Systems*, WSIA J.

Moreno-Cardenas, Inc., and CDM, Inc., 2002. *Basis of Design Document for Brine Disposal – East Side Groundwater Desalination Facility*, April.

Ning, R., 2002. "Discussion of Silica Speciation, Fouling, Control, and Maximum Reduction," *Desalination*, 151, 67-73.

Ning, R.Y., A. Tarquin, M. Trzcinski, and G. Patwardhan, 2006. "Recovery Optimization of RO Concentrate from Desert Wells," *Desalination*, Vol. 201, Issues 1-3, pp. 315-322. Available at: http://www.sciencedirect.com/science/article/pii/S0011916406011763.

Ning, R., and A. Tarquin, 2010. "Crystallization of Salts from Super-Concentrate Produced by Tandem RO Process," *Desalination and Water Treatment,* No. 16, pp. 238-242.

Ning, R., A. Tarquin, and J. Balliew, 2010. "Seawater RO Treatment of RO Concentrate to Extreme Silica Concentrations," *Desalination and Water Treatment*, 22, 286-291.

Nordell, E., 1961. *Water Treatment for Industrial and Other Uses*, 2nd Edition, Reinhold Publishing Corporation.

Pomerantz, N., Y. Ladizhansky, E. Korin, M. Waisman, N. Daltrophe, and J. Giron, 2006. "Prevention of Scaling of Reverse Osmosis Membranes by 'Zeroing' the Elapsed Nucleation Time. Part 1. Calcium Sulfate," *Industrial Engineering Chemical Research*, 45, 2008-2016.

Sarig, S., and J.W. Mullin, 1982. "Effect of Trace Impurities on Calcium Sulfate Precipitation," *Journal of Chemical Technology and Biotechnology*, 32, 525-531.

Semiat, R., I. Sutzkover, and D. Hasson, 2001. "Technique for Evaluating Silica Scaling and its Inhibition in RO Desalting," *Desalination.* Vol. 140, Issue 2, November 1, pp. 181-193.

Sheikholeslami, R., 2000. *Study of the Formation and Inhibition of Silica Scales in RO Desalting*, available at: http://www.medrc.org/index.php/component/k2/item/320-final-research-reports.

Sheikholeslami, R., and J. Bright, 2002. "Silica and Metals Removal by Pretreatment to Prevent Fouling of Reverse Osmosis Membranes," *Desalination*, 143, 255-267.

Shih, W-Y., A. Rahardianto, A., R.W. Lee, and Y. Cohen, 2005. "Morphometric Characterization of Calcium Sulfate Dihydrate (Gypsum) Scale on Reverse Osmosis Membranes," *Journal of Membrane Science*, 252, 253-263.

Tarquin, A., 2005. *Volume Reduction of High-Silica RO Concentrate Using Membranes and Lime Treatment*, U.S. Department of the Interior, Bureau of Reclamation, DWPR Report No. 108.

Tarquin, A., 2006. *Cost Effective Volume Reduction of Silica-Saturated RO Concentrate*," U.S. Department of the Interior, Bureau of Reclamation, DWPR Report No. 125.

Tarquin, A., 2010. *High Tech Methods to Reduce Concentrate Volume Prior to Disposal*, Texas Water Development Board, Final Report, Contract No. 0704830769, 2010.

Ueda, A., 2003. "Silica Removal from Mokai, New Zealand, Geothermal Brine by Treatment with Lime and a Cationic Precipitant," *Geothermics*, Vol. 32, Issue 1, 47-61, February.

APPENDICES

Appendix A Tables

Table *Page*

Appendix A

Table A1: Raw Data - KBH Concentrate – Unspiked – 5/13/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	51		860	800,800,810	300	700	30	3.80		5/13/2010		
	Acid was not concentrated							Measured	87			
Time, min	Perm, ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0	1130	***509***	18650	18650	23.9	3.96						0%
5	1160	***509***	22800	18820	23.7	3.98			582805	1145	5%	5%
10	1100	***509***	24000	19870	23.7	4.03			575170	1130	5%	10%
15	1080	509	25100	22500	24.1	4.09			554810	1090	5%	15%
20	1070	***519***	26200	23300	24	4.11			557925	1075	5%	20%
25	1060	***519***	27500	24500	24.4	4.18			552735	1065	5%	24%
30	1040	***519***	28700	26000	24.5	4.2			544950	1050	5%	29%
35	1020	529	30800	26860	24.2	4.25			544870	1030	5%	33%
40	1010	***529***	31600	28700	25.6	4.27			536935	1015	4%	38%
45	950	***529***	33400	30500	25.6	4.32			518420	980	4%	42%
50	950	***529***	35200	32100	25.7	4.43			502550	950	4%	46%
55	910	529	37800	34100	25.5	4.45			491970	930	4%	50%
60	870	***587***	39400	36600	26.7	4.59			522430	890	4%	54%
65	830	***587***	42500	39000	26.3	4.64			498950	850	4%	58%
70	800	***587***	44900	41400	26	4.68			478405	815	4%	62%
75	760	645	48100	44600	26.4	4.86			503100	780	3%	65%
80	710	***872***	51000	47200	26.1	4.97			640920	735	3%	68%
85	630	***872***	53900	51100	26	5			584240	670	3%	71%
90	580	***872***	57200	54800	26.4	5.12			527560	605	3%	74%
95	530	***872***	61200	58600	26	5.26			483960	555	2%	76%
100	440	***872***	64500	62500	26.5	5.62			422920	485	2%	79%
105	400	1099	68600	65800	26.3	5.66			461580	420	2%	80%
110	350		71400	69100	26.4	5.8			0.0	375	2%	82%
115	310		75400	73900	26.2	5.82			0.0	330	1%	84%
120	260		77500	76300	26.8	6.03	690,690,730		0.0	285	1%	85%
125	213		80400	79700	28.8	6			0.0	236.5	1%	86%
								Avg Perm Cond	**549.9**			
Bold italicized perm cond values are estimated												

Table A2: Raw Data - KBH Concentrate – Unspiked – 5/14/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	32		800	790	300	700	30	4.00		5/14/2010		
								Measured	87			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				18150	24.7	3.7						0%
5	1220	452	23300	19030	25.1	3.72			275720	1220	5%	5%
10	1210	437	24400	19900	25	3.8			530955	1215	5%	11%
15	1170	422	25500	22300	25.5	3.88			502180	1190	5%	16%
20	1160	414	26900	23800	25	3.91			482310	1165	5%	21%
25	1140	406	28400	25100	25.2	3.93			466900	1150	5%	26%
30	1100	403	30100	26800	26.1	4.07			451360	1120	5%	31%
35	1090	403	31500	28200	25.6	4.08			441285	1095	5%	36%
40	1040	413	33400	30100	26.3	4.18			439845	1065	5%	41%
45	1020	419	35100	31700	25.8	4.2			431570	1030	5%	45%
50	990	426	37200	34000	26.5	4.3			428130	1005	4%	50%
55	930	444	39600	36300	26	4.32			426240	960	4%	54%
60	850	466	42000	38900	26.8	4.4	310,310,330		414740	890	4%	58%
65	820	460	44700	41700	27.1	4.55			384100	835	4%	61%
70	790	540	47900	44700	27.2	4.67			434700	805	4%	65%
75	740	581	51400	48400	26.7	4.84			444465	765	3%	68%
80	660	669	54200	51500	27.3	4.98			468300	700	3%	71%
85	560	780	57800	55500	26.6	5.13			475800	610	3%	74%
90	520	873	61600	59200	27.4	5.33			471420	540	2%	76%
95	460	996	65100	63160	26.9	5.34			488040	490	2%	79%
100	375	1178	68400	66400	27.3	5.65			491815	417.5	2%	80%
105	325	1434	71800	70600	27.4	5.75			501900	350	2%	82%
110	240	1660	75200	73500	27.7	5.88			468950	282.5	1%	83%
115	200	2140	77200	76100	27.3	6	650,650,660		470800	220	1%	84%
								Avg Perm Cond	**558.4**			

Table A3: Raw Data - KBH Concentrate – Unspiked – 6/8/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	32		800	790	300	700	30	3.14		6/8/2010		
								Measured	90			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				21100								0%
5	1220	1403	23800	21700	26.9	3.21			855830	1220	5%	5%
10	1185	1355	25700	22500	26.9	3.25			1629388	1202.5	5%	11%
15	1180	1325	26200	24100	26.7	3.32			1566813	1182.5	5%	16%
20	1160	1265	28400	25500	27.2	3.38			1480050	1170	5%	21%
25	1140	1202	29500	26900	27.4	3.34			1382300	1150	5%	26%
30	1080	1182	31600	28700	27.4	3.51			1312020	1110	5%	31%
35	1080	1149	33100	30200	27.3	3.59			1240920	1080	5%	36%
40	1050	1069	35400	32300	27.4	3.68			1138485	1065	5%	40%
45	1020	999	37500	34100	27.4	3.67			1033965	1035	5%	45%
50	994	952	40200	36700	27.5	3.86	300,310,310		958664	1007	4%	49%
55	960	940	43700	39500	27.2	3.96			918380	977	4%	54%
60	790	969	46500	46100	29.2	4.13			847875	875	4%	58%
65	770	1051	48700	46100	27.5	4.15			819780	780	3%	61%
70	700	1090	52500	49200	27.7	4.28			801150	735	3%	64%
75	640	1190	55900	52800	27.6	4.37			797300	670	3%	67%
80	570	1365	59000	56660	27.5	4.46			825825	605	3%	70%
85	520	1220	63000	60600	27.6	4.56			664900	545	2%	72%
90	460	1290	66400	64300	27.7	4.64			632100	490	2%	74%
95	370	1760	69300	67600	27.7	4.72			730400	415	2%	76%
100	310	1900	71900	70600	28	4.8			646000	340	1%	78%
105	260	2300	75300	74300	28.1	4.87			655500	285	1%	79%
110	220	2620	78100	76800	28.3	4.92			628800	240	1%	80%
115	165	3200	79800	78900	28.4	4.95	810,780,760		616000	192.5	1%	81%
								Avg Perm Cond	**1243.1**			

Table A4: Raw Data - KBH Concentrate – Unspiked – 6/10/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	31			770	300	700	30	3.33		6/10/2010		
								Measured	89			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				21500	25.7	3.77						0%
5	1160	830	25100	22200	25.4	3.67			481400	1160	5%	5%
10	1160	802	25800	23000	25.6	3.71			930320	1160	5%	10%
15	1130	797	27100	24300	25.9	3.77			912565	1145	5%	15%
20	1120	742	27900	25000	26.2	3.83			834750	1125	5%	20%
25	1100	739	29700	26700	26.4	3.88			820290	1110	5%	25%
30	1100	718	31200	28200	26.6	3.97			789800	1100	5%	30%
35	1080	709	32800	29800	26.5	4.05			772810	1090	5%	35%
40	1040	669	34900	31600	27.0	4.14			709140	1060	5%	39%
45	1000	667	36800	33700	27.1	4.24			680340	1020	4%	44%
50	980	667	39200	35800	27.3	4.30			660330	990	4%	48%
55	940	700	41400	38200	27.4	4.45			672000	960	4%	52%
60	910	697	44200	40700	27.2	4.59			644725	925	4%	57%
65	810	740	46500	43800	27.8	4.70	310,320,320		636400	860	4%	60%
70	780	834	50000	46900	28.1	4.82			663030	795	4%	64%
75	710	961	53000	49700	27.8	4.92			715945	745	3%	67%
80	645	1083	57000	53600	28.0	5.03			733733	677.5	3%	70%
85	575	1252	59600	57500	28.5	5.13			763720	610	3%	73%
90	520	1469	63500	60800	28.5	5.18			804278	547.5	2%	75%
95	455	1745	66700	64600	28.4	5.23			850688	487.5	2%	77%
100	400	1510	70300	67900	28.3	5.18			645525	427.5	2%	79%
105	320	1770	73300	71100	28.3	5.24			637200	360	2%	81%
110	265	2190	75700	72600	28.4	5.24			640575	292.5	1%	82%
115	215	2510	77700	76700	28.0	5.22			602400	240	1%	83%
120	175	3140	80200	78500	28.7	5.24			612300	195	1%	84%
125	145	3720	82800	81600	28.9	5.21			595200	160	1%	85%
								Avg Perm Cond	**950.6**			

Table A5: Raw Data - KBH Concentrate – Unspiked – 6/16/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	30		800	780	300	700	30	4.57		6/16/2010		
								Measured	85			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				17570	25.7	3.19						0%
5	1210	1330	22300	18750	26.0	3.22			804650	1210	5%	5%
10	1210	1302	23300	19720	26.4	3.26			1575420	1210	5%	11%
15	1200	1242	24500	22200	26.4	3.32			1496610	1205	5%	16%
20	1180	1186	25900	23100	26.2	3.37			1411340	1190	5%	21%
25	1170	1144	27100	24300	26.4	3.44			1344200	1175	5%	26%
30	1130	1082	28600	25800	26.2	3.50			1244300	1150	5%	31%
35	1110	1029	30400	27500	26.6	3.58			1152480	1120	5%	36%
40	1070	986	32100	28900	26.6	3.66			1074740	1090	5%	41%
45	1040	930	34000	30700	27.0	3.75	270,270,260		981150	1055	5%	46%
50	1030	929	36500	33300	26.6	3.84			961515	1035	5%	50%
55	940	923	39900	35700	26.8	3.95			909155	985	4%	55%
60	900	892	40800	38300	26.6	4.03			820640	920	4%	59%
65	850	855	44200	41200	27.4	4.16			748125	875	4%	63%
70	800	901	47400	44300	26.7	4.26			743325	825	4%	66%
75	760	1134	50800	47800	26.8	4.36			884520	780	3%	70%
80	640	1078	54800	51800	27.0	4.43			754600	700	3%	73%
85	590	1516	58500	55200	26.9	4.49			932340	615	3%	75%
90	510	1382	61900	59600	26.7	4.52			760100	550	2%	78%
95	450	1651	66000	63500	26.7	4.55			792480	480	2%	80%
100	380	1929	69300	66900	26.9	4.58			800535	415	2%	82%
105	320	1710	72800	71000	27.6	4.58			598500	350	2%	83%
110	270	2210	75400	74400	28.1	4.61			651950	295	1%	85%
115	320	2810	77700	77300	28.6	4.60	750,740,750		828950	295	1%	86%
								Avg Perm Cond	**1167.3**			

Table A6: Raw Data - KBH Concentrate – Unspiked – 6/23/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	30		800	780	300	700	30	3.92		6/23/2010		
								Measured	87			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				22100	25.6	3.06						0%
5	1160	1180	25300	22600	25.4	3.14			684400	1160	5%	5%
10	1130	1140	26500	23600	25.5	3.19			1305300	1145	5%	10%
15	1100	1639	27400	24700	25.6	3.23			1827485	1115	5%	15%
20	1120	1485	28800	26200	25.9	3.28			1648350	1110	5%	20%
25	1100	1413	30100	27500	26	3.34			1568430	1110	5%	25%
30	1060	1313	31400	29300	26	3.41			1418040	1080	5%	30%
35	1040	1270	33200	30600	26.4	3.47			1333500	1050	5%	34%
40	1030	1185	35200	32300	26.4	3.54			1226475	1035	5%	39%
45	1000	840	36800	34100	26.5	3.63			852600	1015	4%	43%
50	960	830	38800	35000	26.7	3.7			813400	980	4%	48%
55	920	790	40600	38100	26.6	3.81	300,290,300		742600	940	4%	52%
60	880	1020	43700	40600	27	3.93			918000	900	4%	56%
65	800	1060	45700	43200	27	4.02			890400	840	4%	59%
70	760	1050	48600	45400	27.1	4.13			819000	780	3%	63%
75	730	1082	51800	48600	27.2	4.25			806090	745	3%	66%
80	680	1221	54500	52200	27.3	4.32			860805	705	3%	69%
85	610	1256	57900	55500	27.2	4.37			810120	645	3%	72%
90	530	1575	60900	58200	27.7	4.43			897750	570	3%	75%
95	480	1210	64100	61700	27	4.47			611050	505	2%	77%
100	440	1420	67100	64700	27.2	4.5			653200	460	2%	79%
105	320	1800	69600	68200	26.8	4.52			684000	380	2%	80%
110	320	1950	72800	71200	26.5	4.52			624000	320	1%	82%
115	260	2390	75000	73600	26.9	4.54			693100	290	1%	83%
120	220	2610	77600	76500	27.1	4.54			626400	240	1%	84%
125	185	3010	80100	79300	27.3	4.52			609525	202.5	1%	85%
130	145	3450	81400	81000	27.2	4.52			569250	165	1%	86%
135	120	4430	83100	83500	27.4	4.52			586975	132.5	1%	86%
140	102	5040	83900	84700	27.8	4.52	710,670,690		559440	111	0%	87%
								Avg Perm Cond	**1335.3**			

Table A7: Raw Data - KBH Concentrate – Unspiked – 10/1/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	30				300	800	30	3.00		10/1/2010		
								Measured	90			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				22,800	25.3	3.84						0%
5	1,360	514	26,600	23,100	24.8	4.06			349520	1360	6%	6%
10	1,400	467	28,300	29,000	29.9	4.07			644460	1380	6%	12%
15	1,340	499	29,900	25,600	25.2	4.11			683630	1370	6%	18%
20	1,340	517	31,400	27,400	25.6	4.18			692780	1340	6%	24%
25	1,320	494	33,400	29,600	25.7	4.24			657020	1330	6%	30%
30	1,300	538	35,600	31,800	26.3	4.33			704780	1310	6%	36%
35	1,240	594	37,800	34,100	26.7	4.41			754380	1270	6%	41%
40	1,200	584	40,800	36,600	27	4.5			712480	1220	5%	47%
45	1,180	619	43,200	39,600	27.1	4.59			736610	1190	5%	52%
50	1,080	669	46,700	42,700	27.1	4.79			755970	1130	5%	57%
55	1,020	749	50,300	46,700	27.8	4.94			786450	1050	5%	61%
60	940	904	54,400	50,700	28.1	5.1			885920	980	4%	66%
65	860	1,000	58,900	54,000	28.1	5.28			900000	900	4%	70%
70	760	1,186	62,600	59,100	28.6	5.56			960660	810	4%	73%
75	640	1,423	67,400	64,300	29.2	5.78			996100	700	3%	76%
80	560	1,666	71,900	68,800	20.8	6			999600	600	3%	79%
85	440	1,660	76,300	73,700	30	6.27			830000	500	2%	81%
90	356	2,020	80,000	78,000	30.1	6.34			803960	398	2%	83%
95	312	2,342					*		782228	334	1%	84%
100	232	3,490	86,800	86,400	31	3.73			949280	272	1%	86%
105	180	3,880	89,300	88,400	30.7	3.78			799280	206	1%	87%
110	132	4,590	91,400	90,000	30.7	3.78			716040	156	1%	87%
115	112	6,120	93,300	93,000	30.4	3.81			746640	122	1%	88%
120	92	7,030	94,300	93,500	31.7	3.83	690,690,690		717060	102	0%	88%
								Avg Perm Cond	957			
Notes:												
*About 30 additional drops of acid were added at this point because the pH was deemed too high.												
Precipitation was seen in final sample												

Table A8: Raw Data - KBH Concentrate – Unspiked – 10/8/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g)	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		None										
0.6	30				300	800	30	3.75		10/8/2010		
								Measured	88			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				22,300	24.8	3.1						0%
5	1,360	1,155	25,300	22,200	24.8	3.2			785400	1360	6%	6%
10	1,360	1,111	26,400	23,700	25.6	3.24			1510960	1360	6%	12%
15	1,340	1,110	27,900	24,900	25.9	3.32			1498500	1350	6%	18%
20	1,340	1,017	29,400	25,300	25.8	3.35			1362780	1340	6%	24%
25	1,320	975	31,000	28,300	26.4	3.43			1296750	1330	6%	30%
30	1,300	951	33,500	29,900	26.7	3.54			1245810	1310	6%	35%
35	1,280	885	35,800	32,100	27.2	3.64			1141650	1290	6%	41%
40	1,240	859	38,400	34,700	27.6	3.59			1082340	1260	6%	47%
45	1,200	833	41,200	37,600	28.2	3.82			1016260	1220	5%	52%
50	1,140	833	44,000	40,900	28.2	3.99			974610	1170	5%	57%
55	1,080	877	47,600	44,500	29.2	4.11			973470	1110	5%	62%
60	1,020	918	52,100	48,300	29.2	4.22			963900	1050	5%	67%
65	920	1,037	57,200	53,700	29.8	4.41			1005890	970	4%	71%
70	780	1,244	61,700	57,400	29.7	4.41			1057400	850	4%	75%
75	680	1,445	66,900	63,300	29.9	4.48			1054850	730	3%	78%
80	560	1,862	71,700	68,600	30	4.54			1154440	620	3%	81%
85	460	1,590	75,700	73,200	30.5	4.53			810900	510	2%	83%
90	400	2,010	81,100	77,800	30.6	4.54			864300	430	2%	85%
95	150	2,570	83,300	81,800	30.7	4.55	700,710,720		706750	275	1%	86%
								Avg Perm Cond	1083.3			

Table A9: Raw Data - KBH Concentrate Spiked with 5000 mg/L NaCl – 7/6/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
		NaCl										
0.6	30	5000 mg/L	800	790	300	700	30	7.50		7/6/2010		
								Measured	75			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				30,000	26.3	2.98	150					0%
5	1,000	1,960	36,000	32,400	26.4	3			980000	1000	4%	4%
10	1,000	1,940	37,400	33,300	26.6	3.05			1940000	1000	4%	9%
15	940	1,890	39,100	35,400	27.1	3.1			1833300	970	4%	13%
20	920	1,740	40,400	37,100	27.3	3.15			1618200	930	4%	17%
25	920	1,660	42,000	38,300	27.5	3.2			1527200	920	4%	21%
30	900	1,540	43,500	40,000	27.5	3.25			1401400	910	4%	25%
35	880	1,520	44,700	41,800	27.7	3.25			1352800	890	4%	29%
40	800	1,490	46,700	43,100	27.8	3.38			1251600	840	4%	33%
45	800	1,430	48,800	46,100	27.9	3.46			1144000	800	4%	36%
50	780	1,839	51,100	46,600	2.82	3.55			1452810	790	3%	40%
55	700	1,895	52,700	49,500	28.5	3.63			1402300	740	3%	43%
60	680	1,796	53,800	52,200	28.7	3.72	300, 300, 280		1239240	690	3%	46%
65	640	1,430	57,300	54,500	28.8	3.8			943800	660	3%	49%
70	610	1,823	58,700	56,200	29.9	3.89			1139375	625	3%	52%
75	570	1,879	61,000	58,800	29.4	3.97			1108610	590	3%	54%
80	500	1,530	63,000	60,900	29.4	4.06			818550	535	2%	57%
85	480	1,590	65,600	63,200	29.6	4.14			779100	490	2%	59%
90	440	1,520	68,000	64,900	30.1	4.2			699200	460	2%	61%
95	410	1,830	70,200	67,800	30.2	4.27			777750	425	2%	63%
100	336	2,110	78,100	68,900	30.3	4.31			787030	373	2%	64%
105	312	2,310	72,700	71,000	30.2	4.33			748440	324	1%	66%
110	292	2,910	75,000	73,300	30.5	4.34			878820	302	1%	67%
115	260	2,910	76,600	75,300	30.5	4.37			803160	276	1%	68%
120	216	3,180	78,700	76,600	30.9	4.38			756840	238	1%	69%
125	192	3,700	77,600	77,000	30.9	4.42			754800	204	1%	70%
130	164	4,330	80,500	79,800	31.2	4.41	420,420,420		770740	178	1%	71%
								Avg Perm Cond	1836.4			
Note: Process stopped at 130 min (time)												

Table A10: Raw Data - KBH Concentrate Spiked with 5000 mg/L NaCl – 7/9/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) NaCl	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	568	800	800	300	700	30	5.50		7/9/2010		
								Measured	82			

Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				23,500	25.5	3.09	150,150,160					0%
5	1,080	1,490	29,500	24,900	25.9	3.08			804600	1080	5%	5%
10	1,100	1,929	31,100	27,100	26.5	3.12			2102610	1090	5%	10%
15	1,100	1,904	32,100	28,900	26.6	3.17			2094400	1100	5%	14%
20	1,080	1,823	33,100	30,300	27.0	3.23			1987070	1090	5%	19%
25	1,040	1,748	34,600	31,700	27.6	3.3			1852880	1060	5%	24%
30	1,020	1,634	36,800	33,500	27.8	3.37	240,240,250		1683020	1030	5%	28%
35	980	1,607	37,800	35,100	28.0	3.44			1607000	1000	4%	33%
40	960	1,502	40,500	36,800	28.5	3.52			1456940	970	4%	37%
45	940	1,418	42,500	39,100	28.5	3.61			1347100	950	4%	41%
50	910	1,404	45,200	41,100	29.0	3.7			1298700	925	4%	45%
55	840	1,366	47,700	44,100	29.2	3.79	270,270,290		1195250	875	4%	49%
60	800	1,411	49,500	47,500	29.5	3.91			1157020	820	4%	53%
65	760	1,140	54,100	50,200	30.0	4.02			889200	780	3%	56%
70	680	1,531	55,700	53,100	29.5	4.06			1102320	720	3%	59%
75	620	1,190	59,500	57,000	31.1	4.22			773500	650	3%	62%
80	500	1,470	63,200	60,900	31.1	4.28	340,350,350		823200	560	2%	65%
85	460	1,650	66,700	64,800	31.6	4.34			792000	480	2%	67%
90	400	1,920	69,500	67,500	31.0	4.33			825600	430	2%	69%
95	360	2,280	72,000	71,100	31.8	4.43			866400	380	2%	70%
100	340	2,570	74,100	73,200	32.5	4.41			899500	350	2%	72%
105	275	2,910		75,300	32.6	4.45			894825	307.5	1%	73%
110	236	3,580	77,800	77,300	32.7	4.44			914690	255.5	1%	74%
115	180	3,990	78,900	79,900	32.9	4.45			829920	208	1%	75%
120	172	5,040	81,700	81,300	33.1	4.48			887040	176	1%	76%
125	152	5,400	82,200	82,600	33.6	4.67			874800	162	1%	77%
130	140	6,040	82,000	82,800	33.8	4.5			881840	146	1%	77%
135	120	6,740	84,900	86,000	33.6	4.52			876200	130	1%	78%
140	92	7,767	85,400	86,000	35	4.49			823302	106	0%	79%
145	86	7,980	86,500	87,700	34.2	4.37			710220	89	0%	79%
150	80	9,540	87,200	87,500	34.9	4.59	520,530,530		791820	83	0%	79%
								Avg Perm Cond	1945.0			

Table A11: Raw Data - KBH Concentrate Spiked with 1000 mg/L $CaCl_2$ – 7/20/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $CaCl_2$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	113.5	800	810	300	700	30	-		7/20/2010		
								Measured				
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				23100	26.2	3.27	150,160,150					0%
5	1,200	1,320	27,300	24,400	26.7	3.21			792000	1200	5%	5%
10	1,200	1,534	28,200	25,400	26.8	3.26			1840800	1200	5%	11%
15	1,140	1,612	29,600	26,600	27.4	3.33			1886040	1170	5%	16%
20	1,140	1,412	31,200	28,300	26.8	3.5			1609680	1140	5%	21%
25	1,100	1,325	32,500	29,300	28.4	3.46			1484000	1120	5%	26%
30	1,080	1,278	33,900	31,100	28.5	3.52			1393020	1090	5%	30%
35	1,060	1,244	35,700	33,000	28.4	3.61			1331080	1070	5%	35%
40	1,040	1,210	38,800	34,700	29.2	3.63			1270500	1050	5%	40%
45	1,000	1,134	40,600	37,100	28.9	3.85			1156680	1020	4%	44%
50	960	1,127	42,700	38,800	29.5	3.82	240,250,270		1104460	980	4%	49%
55	920	1,150	45,500	42,000	29.6	4.02			1081000	940	4%	53%
60	880	1,102	48,300	44,700	30.1	4.05			991800	900	4%	57%
65	820	1,168	51,500	48,400	29.6	4.2			992800	850	4%	60%
70	740	1,238	54,500	51,300	30.7	4.32			965640	780	3%	64%
75	680	1,389	58,200	54,400	30.8	4.47			986190	710	3%	67%
80	620	1,693	61,700	58,800	31.3	4.54			1100450	650	3%	70%
85	540	1,765	65,200	61,800	31.8	4.6			1023700	580	3%	72%
90	480	2,050	68,700	65,500	32.0	4.63			1045500	510	2%	75%
95	376	2,340	71,100	68,400	32.1	4.63			1001520	428	2%	77%
100	324	2,430	72,300	71,200	32.1	4.68			850500	350	2%	78%
105	280	2,600	76,800	74,600	32.4	4.66			785200	302	1%	79%
110	228	3,290	78,500	76,600	32.2	4.68			835660	254	1%	81%
115	192	3,810	79,900	78,100	32.2	4.61			800100	210	1%	81%
120	156	4,380	81,900	80,300	32.7	4.65			762120	174	1%	82%
125	132	5,320	83,200	82,500	32.2	4.62			766080	144	1%	83%
130	112	4,910	85,900	84,400	33.3	4.64	650,670,670		599020	122	1%	83%
								Avg Perm Cond	1546			
Notes:												

Table A12: Raw Data - KBH Concentrate Spiked with 3000 mg/L $CaCl_2$ – 7/22/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $CaCl_2$	Flush Flow Rate Initial (ml/min)	Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	34	340	800	790	300	700	30			7/22/2010		
								Measured				
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0		Perm		Perm 26,300	25.6	3.54	160,160,160					0%
5	1,100	1,017	29,700	26,900	25.9	3.6			559350	1100	5%	5%
10	1,080	1,028	31,000	28,200	26.0	3.66			1120520	1090	5%	10%
15	1,070	943	32,400	29,300	26.2	3.73			1013725	1075	5%	14%
20	1,060	921	34,100	31,000	26.5	3.82			980865	1065	5%	19%
25	1,030	927	35,200	32,400	26.7	3.87			968715	1045	5%	24%
30	1,020	880	37,000	33,900	27.2	3.97			902000	1025	5%	28%
35	980	876	38,700	35,500	27.3	3.99			876000	1000	4%	33%
40	960	901	40,900	37,700	27.7	4.14			873970	970	4%	37%
45	940	789	43,000	39,700	27.6	4.24			749550	950	4%	41%
50	900	819	45,200	41,500	28.0	4.33	240,250,270		753480	920	4%	45%
55	860	898	47,400	42,200	28.5	4.44			790240	880	4%	49%
60	815	921	50,200	46,200	28.8	4.53			771338	837.5	4%	53%
65	755	964	52,300	48,900	29.2	4.62			756740	785	3%	56%
70	725	1,389	53,300	51,700	29.1	4.67			1027860	740	3%	59%
75	680	1,258	57,700	55,100	29.6	4.94			883745	702.5	3%	62%
80	610	1,339	60,100	57,300	29.9	4.84			863655	645	3%	65%
85	550	1,438	63,600	60,300	30.4	4.89			834040	580	3%	68%
90	500	1,797	65,300	63,700	30.2	4.91			943425	525	2%	70%
95	430	1,480	68,800	66,600	30.9	4.95			688200	465	2%	72%
100	390	1,820	71,800	69,900	31.0	4.95			746200	410	2%	74%
105	330	2,180	74,000	72,500	31.4	4.95			784800	360	2%	76%
110	272	2,480	75,800	72,900	31.6	4.95			746480	301	1%	77%
115	232	3,030	78,800	76,600	31.6	4.96			763560	252	1%	78%
120	204	3,770	80,800	78,000	32	4.98			821860	218	1%	79%
125	164	4,220	82,400	80,300	32.2	4.98			776480	184	1%	80%
130	140	4,840	83,500	81,900	32.4	4.98			735680	152	1%	80%
135	112	4,490	82,600	83,600	32.2	4.98			565740	126	1%	81%
140	96	6,350	86,500	84,900	32.8	4.97	600,600,600		660400	104	0%	81%
								Avg Perm Cond	1275			
Notes:												
Precipitation occurred												

Table A13: Raw Data - KBH Concentrate Spiked with 5000 mg/L $CaCl_2$ – 8/2/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $CaCl_2$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	568	800	800	300	700	30	7.50		8/2/2010		
								Measured	75%			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0	1,160				27.0	3.1	130,130,130					0%
5	1,160	1,870	27,400	1,870	27.5	3.11			2169200	1160	5%	5%
10	1,160	1,795	28,900	1,795	27.7	3.16			2082200	1160	5%	10%
15	1,160	1,764	30,300	1,764	28.5	3.23			2046240	1160	5%	15%
20	1,150	1,665	31,800	1,665	28.7	3.31			1923075	1155	5%	20%
25	1,140	1,531	33,200	1,531	29.2	3.38			1752995	1145	5%	25%
30	1,120	1,448	35,400	1,448	29.6	3.45			1636240	1130	5%	30%
35	1,110	1,333	37,500	1,333	29.8	3.54			1486295	1115	5%	35%
40	1,050	1,218	40,200	1,218	30.3	3.67			1315440	1080	5%	40%
45	1,030	1,185	42,200	1,185	30.8	3.31			1232400	1040	5%	45%
50	980	1,170	45,000	1,170	31.2	3.95	250,240,240		1175850	1005	4%	49%
55	940	1,113	48,400	1,113	31.2	4.12			1068480	960	4%	53%
60	880	1,102	51,300	1,102	31.3	4.29			1002820	910	4%	57%
65	800	1,067	54,200	1,067	31.8	4.42			896280	840	4%	61%
70	740	1,299	58,500	1,299	32.2	4.57			1000230	770	3%	64%
75	680	1,365	60,900	1,365	32.1	4.71			969150	710	3%	68%
80	560	1,565	65,500	1,565	31.5	4.73			970300	620	3%	70%
85	460	1,510	68,400	1,510	30.6	4.8			770100	510	2%	73%
90	406	1,530	71,400	1,530	30.5	4.87			662490	433	2%	74%
95	376	1,840	74,200	1,840	31.4	4.87			719440	391	2%	76%
100	324	2,260	75,900	2,260	32.0	4.99			791000	350	2%	78%
105	268	2,760	77,500	2,760	32.8	5.06			816960	296	1%	79%
110	224	3,000	78,500	3,000	32.1	5.15			738000	246	1%	80%
115	164	3,470	80,600	3,470	32.7	5.17			673180	194	1%	81%
								Avg Perm Cond	1465			
Notes:												
Precipiation on bottom of the tank; water very clear												

Table A14: Raw Data - KBH Concentrate Spiked with 5000 mg/L $CaCl_2$ – 8/6/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $CaCl_2$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	568	800	810	300	700	30	5.00		8/6/2010		
								Measured	83%			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				23100	22.4	3.01	120,120,140					0%
5	1,120		28,900	25,600	25.1	3.04				1120	5%	5%
10	1,110		30,100	26,800	25.8	3.19				1115	5%	10%
15	1,080		31,100	27,800	26.5	3.18				1095	5%	15%
20	1,080		32,700	29,200	26.6	3.25				1080	5%	19%
25	1,060		33,900	30,600	26.9	3.32				1070	5%	24%
30	1,040		35,400	32,100	27.2	3.42				1050	5%	29%
35	1,020		37,600	33,600	27.8	3.48				1030	5%	33%
40	1,000		39,500	35,300	28.2	3.58				1010	4%	38%
45	990		41,700	37,800	28.8	3.68				995	4%	42%
50	960		44,300	40,400	29	3.78				975	4%	46%
55	910		46,600	42,900	29.5	3.9	210,220,230	Rec 50%		935	4%	51%
60	860		48,600	45,700	29.9	4.02				885	4%	54%
65	820		53,200	49,000	31	4.18				840	4%	58%
70	760		55,800	51,800	30.9	4.29				790	3%	62%
75	700		58,900	55,100	31.2	4.42				730	3%	65%
80	600		62,200	58,600	31.8	4.55				650	3%	68%
85	555		65,400	62,300	31.7	4.64				577.5	3%	70%
90	500		68,700	65,600	32.3	4.71				527.5	2%	73%
95	440		71,700	68,900	32.7	4.78				470	2%	75%
100	360		74,000	73,100	32.6	4.85				400	2%	76%
105	312		77,500	75,400	34	4.88				336	1%	78%
110	232		80,300	77,800	33.7	4.89				272	1%	79%
115	192		81,900	80,300	34.3	4.89				212	1%	80%
120	164		83,000	79,500	34.7	4.89				178	1%	81%
125	136		84,800	83,600	35.1	4.88				150	1%	81%
130	116		85,400	84,600	35.4	4.88				126	1%	82%
135	112		87,600	86,500	36.1	4.87				114	1%	82%
140	92		88,700	87,400	36.7	4.84	560,550,550			102	0%	83%
Notes:												
A certain amount of precipitate was found in the sample before it was analyzed												

Table A15: Raw Data - KBH Concentrate Spiked with 5200 mg/L $CaCl_2$ – 12/17/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $CaCl_2$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.4	15.5	286	800	800	300	800	14.5	1.69		12/17/2010		
								Measured	88			
Dehydrated Calcium Chloride												
Time, min	Perm, ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Silica Notes	Perm Cond for Mass Balance	avgperm	Unit Recvry	Tot recvry
0				14070	24.3	3.68						0%
5	1,240	877	18,800	16,990	24.2	3.72			543740	1240	11%	11%
10	1,180	750	21,600	18,720	24.8	3.82			907500	1210	11%	22%
15	1,140	754	23,300	21,900	25.4	4.01			874640	1160	11%	33%
20	1,100	765	26,600	24,700	26.3	4.2			856800	1120	10%	43%
25	1,020	828	28,200	25,000	26.7	4.43			877680	1060	10%	53%
30	940	943	31,900	29,900	27.5	4.63			924140	980	9%	62%
35	800	1,131	37,500	35,900	27.9	4.75			983970	870	8%	70%
40	640	1,494	40,100	38,500	28	4.86			1075680	720	7%	76%
45	500	1,906	45,900	43,700	28.8	4.89			1086420	570	5%	81%
								Avg Perm Cond	950			
Notes:												
Wrong conductivity; meter not working properly												
12.01 gal of perm collected												

Table A16: Raw Data - KBH Concentrate Spiked with 2500 mg/L Na_2SO_4 – 8/11/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	31	284	800	800	300	700	30	3.86		8/11/2010		
								Measured	87%			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				22200	26.50	3.57	126,122,126					0%
5	1,220		25,700	23,300	26.60	3.58			0.0	1220	5%	5%
10	1,200		27,300	24,400	26.90	3.65			0.0	1210	5%	11%
15	1,160		28,600	25,500	27.00	6.72			0.0	1180	5%	16%
20	1,140		30,100	26,800	27.20	3.77			0.0	1150	5%	21%
25	1,120		31,200	28,600	27.30	3.83	180,180,180	Recv 25%	0.0	1130	5%	26%
30	1100		33600	30100	27.30	3.94			0.0	1110	5%	31%
35	1,060		35,200	31,500	27.60	3.93			0.0	1080	5%	36%
40	1,020		36,900	33,800	27.80	4.06			0.0	1040	5%	40%
45	1,000		39,400	35,900	28.20	4.13			0.0	1010	4%	45%
50	940		41,000	37,800	28.70	4.18	220,250,260	Recv 50%	0.0	970	4%	49%
55	900		44,100	40,400	28.40	4.27			0.0	920	4%	53%
60	880		46,500	42,600	28.80	4.34			0.0	890	4%	57%
65	800		49,600	45,700	28.90	4.39			0.0	840	4%	61%
70	740		52,300	48,900	28.90	4.45			0.0	770	3%	64%
75	690		53,700	52,300	29.10	4.49			0.0	715	3%	67%
80	615		58,500	55,500	29.60	4.53			0.0	652.5	3%	70%
85	560		61,400	59,100	29.40	4.57			0.0	587.5	3%	73%
90	490		65,300	62,300	29.70	4.58	440,450,460	Recv 75%	0.0	525	2%	75%
95	420		68,300	66,000	29.90	4.60			0.0	455	2%	77%
100	320		70,200	69,200	29.80	4.61			0.0	370	2%	78%
105	280		72,900	71,800	29.30	4.65			0.0	300	1%	80%
110	240		75,300	74,400	29.30	4.63			0.0	260	1%	81%
115	200		78,100	76,800	30.00	4.64			0.0	220	1%	82%
120	172		79,800	78,900	29.70	4.64			0.0	186	1%	83%
125	152		80,900	80,700	29.60	4.66			0.0	162	1%	83%
130	88		82,000	82,100	29.70	4.61			0.0	120	1%	84%
135	104		84,200	83,300	29.90	4.60	650,650,640		0.0	96	0%	84%
Notes:												
Precipitation occurred @135 min.												
From lab analysis: Precipitation was found												

Table A17: Raw Data - KBH Concentrate Spiked with 2500 mg/L Na_2SO_4 – 8/17/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	31	284		800	300	700	30	4.88		8/17/2010		
								Measured	84%			

Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp. C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				23700	24.9	3.69	144,144,148					0%
5	1,080	893	27,500	24,300	24.8	3.78			482220	1080	5%	5%
10	1,040	927	28,400	25,800	25.2	3.8			982620	1060	5%	9%
15	1,100	933	29,300	26,900	25.4	3.85			998310	1070	5%	14%
20	1,060	833	31,500	28,200	25.7	3.9			899640	1080	5%	19%
25	1,040	824	32,800	29,700	25.8	3.96	175,200,200	25% Recv	865200	1050	5%	24%
30	1,000	791	34,300	31,000	26	4.03			806820	1020	4%	28%
35	990	778	35,900	32,600	26.2	4.08			774110	995	4%	32%
40	980	772	37,800	34,600	26.4	4.12			760420	985	4%	37%
45	960	774	40,100	36,400	26.5	4.19			750780	970	4%	41%
50	900	806	41,800	38,600	26.9	4.25			749580	930	4%	45%
55	830	836	43,500	40,700	26.9	4.34			723140	865	4%	49%
60	800	846	46,200	43,100	27.1	4.45			689490	815	4%	52%
65	780	900	49,000	45,800	27.2	4.52	280,280,290	50% Recv	711000	790	3%	56%
70	740	989	51,200	48,400	27.3	4.58			751640	760	3%	59%
75	680	1,145	54,500	51,300	27.6	4.65			812950	710	3%	62%
80	600	1,241	56,800	57,800	27.6	4.69			794240	640	3%	65%
85	560	1,360	59,900	56,500	27.7	4.75			788800	580	3%	68%
90	510	1,507	63,300	60,200	28	4.77			806245	535	2%	70%
95	460	1,775	65,900	63,300	28.2	4.81	470,470,480	75% Rec	860875	485	2%	72%
100	404	1,590	67,900	66,400	28.4	4.83			686880	432	2%	74%
105	328	1,870	71,600	68,900	28.7	4.84			684420	366	2%	76%
110	316	2,040	73,600	72,100	28.7	4.82			656880	322	1%	77%
115	244	2,390	75,800	74,200	28.9	4.84			669200	280	1%	78%
120	224	3,390	77,700	76,300	29.1	4.84			793260	234	1%	79%
125	180	3,790	80,100	78,800	29.5	4.88			765580	202	1%	80%
130	156	3,980	81,300	80,000	29.4	4.86			668640	168	1%	81%
135	140	5,420	82,600	82,000	29.7	4.86	650,660,670		802160	148	1%	82%
								Avg Perm Cond	1145			

Notes:

Precipitation occurred @135 min.

Table A18: Raw Data - KBH Concentrate Spiked with 5000 mg/L Na_2SO_4 – 8/27/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	564		800	300	700	30	4.88		8/27/2010		
								Measured	84			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				24,500	25.2	3.2	160,160,150					0%
5	1,080	2,850	28,800	25,500	24.9	3.34			1539000	1080	5%	5%
10	1,060	1,037	29,500	26,800	25.1	3.38			1109590	1070	5%	9%
15	1,040	1,016	31,200	27,800	25.3	3.43			1066800	1050	5%	14%
20	1,020	989	32,200	29,300	25.3	3.44			1018670	1030	5%	19%
25	1,000	960	33,900	30,600	25.6	3.5			969600	1010	4%	23%
30	980	943	35,300	32,300	25.7	3.58			933570	990	4%	27%
35	960	978	37,400	34,100	26.1	3.69			948660	970	4%	32%
40	940	985	34,100	36,000	26.3	3.64			935750	950	4%	36%
45	900	1,008	40,700	37,700	26.6	3.8			927360	920	4%	40%
50	860	981	42,800	39,700	26.7	3.87			863280	880	4%	44%
55	820	1,006	45,006	42,000	26.6	3.93			845040	840	4%	48%
60	800	1,019	47,800	44,600	26.9	4	270,270,250		825390	810	4%	51%
65	760	1,042	49,700	47,100	26.3	3.99			812760	780	3%	55%
70	680	1,117	52,600	49,600	27.2	4.08			804240	720	3%	58%
75	660	1,280	55,200	52,300	27.4	4.17			857600	670	3%	61%
80	570	1,358	58,000	55,100	27.3	4.23			835170	615	3%	63%
85	530	1,582	61,000	5,800	27.7	4.26			870100	550	2%	66%
90	500	1,630	63,800	60,700	27.7	4.28			839450	515	2%	68%
95	440	1,892	66,700	63,200	27.9	4.3			889240	470	2%	70%
100	400	1,540	69,100	66,500	28.2	4.32			646800	420	2%	72%
105	350	1,760	72,100	69,100	28.5	4.34			660000	375	2%	74%
110	320	2,050	73,000	71,500	28.8	4.35	470,470,470		686750	335	1%	75%
115	280	2,220	75,000	73,900	28.9	4.35			666000	300	1%	76%
120	180	2,440	77,000	75,800	29.4	4.37			561200	230	1%	77%
125	204	4,140	78,900	76,800	29.5	4.37	570,580,560		794880	192	1%	78%
								Avg Perm Cond	1264			
Notes:												

Table A19: Raw Data - KBH Concentrate Spiked with 5000 mg/L Na_2SO_4 – 11/12/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.4	15	284		820	300	800	15	2.43		11/12/2010		
								Measured	84			

Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				24200	25.4	3						0%
5	1,320	1,162	27,100	24,700	25.2	3.01			766920	1320	12%	12%
10	1,260	1,696	29,700	27,000	26	3.06			2187840	1290	11%	23%
15	1,240	1,703	33,300	30,000	26.6	3.14			2128750	1250	11%	34%
20	1,200	1,695	37,400	34,500	27.8	3.24			2067900	1220	11%	45%
25	1,100	1,692	42,400	39,400	28.2	3.35			1945800	1150	10%	55%
30	1,020	1,693	48,300	45,900	29	3.47			1794580	1060	9%	64%
35	880	1,755	55,600	53,600	29.5	3.64			1667250	950	8%	73%
40	700	1,907	63,100	61,800	30.1	3.69			1506530	790	7%	80%
45	520	1,600	71,200	69,800	30.7	3.89			976000	610	5%	85%
								Avg Perm Cond	1628			

Notes:

Concentrate precipitated immediately after test was stopped

12.53 gallons of permeate captured

Test ended at 0:46:46

Table A20: Raw Data - KBH Concentrate Spiked with 5000 mg/L Na_2SO_4 – 11/19/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.4	15	268		820	300	800	15	1.56		11/19/2010		
								Measured	90			
Time, min	Perm, ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Silica Notes	Perm Cond for Mass Balance	avgperm	Unit Recvry	Tot recvry
0				24500	24.2	3.42	140,140,150					0%
5	1,260	1,055	30,000	26,500	24.8	3.53			664650	1260	11%	11%
10	1,200	1,007	32,800	29,100	25.2	3.56			1238610	1230	11%	22%
15	1,180	1,002	35,900	32,300	25.9	3.62			1192380	1190	10%	32%
20	1,100	1,022	39,900	36,100	26.5	3.64			1165080	1140	10%	42%
25	1,020	1,060	44,100	40,600	27.1	3.79	260,270,280	at 24:51	1123600	1060	9%	52%
30	960	1,131	49,500	45,800	28	4.00			1119690	990	9%	61%
35	860	1,290	56,000	52,500	28.7	4.10			1173900	910	8%	69%
40	700	1,588	63,900	60,100	29.6	4.21			1238640	780	7%	75%
45	540	1,550	71,100	68,900	30.1	4.21			961000	620	5%	81%
50	380	2,050	76,600	75,500	32	4.30			943000	460	4%	85%
55	260	3,060	86,600	82,100	33	4.31	630,630,610		979200	320	3%	88%
								Avg Perm Cond	1247			
Notes:												
Precipitation found at the end												
12.8 gal of permeate collected												
Ended @ 00:58:25												

Table A21: Raw Data - KBH Concentrate Spiked with 2350 mg/L Na_2SO_4 – 6/14/2011

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	20	190	820	820	300	700	21.4	1.63		6/14/2011		
								Measured	92			

Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp. C	pH	Turbidity	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0		773	0	21,300	22.3	4.17	0.270					0%
5	1,040	455	24,000	21,400	22.6		0.200		236600	1040	6%	6%
10	1,040	459	26,500	22,800	22.9		0.280		477360	1040	6%	13%
15	1,020	440	28,500	25,300	23.9		0.200		453200	1030	6%	19%
20	1,020	454	30,900	27,900	24.3		0.240		463080	1020	6%	25%
25	1,000	478	32,900	30,200	23.9		0.240		482780	1010	6%	32%
30	980	515	35,400	31,800	24.3		0.220		509850	990	6%	38%
35	920	587	38,100	35,200	25.3		0.200		557650	950	6%	44%
40	900	630	41,000	38,400	26.1		0.150		573300	910	6%	49%
45	840	736	45,000	42,100	26.8		0.190		640320	870	5%	55%
50	760	900	49,400	44,900	29.2		0.230		720000	800	5%	60%
55	700	1,036	53,200	51,300	29.2		0.170		756280	730	5%	64%
60	570	1,349	59,000	56,600	29.3		0.180		856615	635	4%	68%
65	500	1,538	63,200	61,300	29.3		0.200		822830	535	3%	71%
70	400	2,020	68,000	66,800	29.9		0.230		909000	450	3%	74%
75	340	2,650	73,100	72,000	29.9		0.300		980500	370	2%	76%
80	260	3,270	77,300	76,300	30.7		0.350		981000	300	2%	78%
85	220	4,130	81,400	79,800	30.1		0.580		991200	240	1%	80%
							0.920					
Notes:	The turbidity values were high at end of the run					Precip	1.130					
	Precipitation						1.630	Avg Perm Cond	912			
							1.750					
							2.200					

Table A22: Raw Data - KBH Concentrate Spiked with 5000 mg/L Na_2SO_4 – 6/16/2011

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) Na_2SO_4	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.5	15.5	284		820	300	700	15	1.55		6/16/2011		
								Measured	90%			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	Turbidity	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0	1180			21,700	25.5	3.9						0%
5	1,160	591	28,500	26,000	27		0.240		691470	1170	10%	10%
10	1,160	613	30,900	28,400			0.270		711080	1160	10%	21%
15	1,060	660	34,400	30,700	26.6		0.500		732600	1110	10%	30%
20	1,080	674	37,500	33,600	28.5		0.260		721180	1070	9%	40%
25	1,020	775	41,100	37,100	29		0.260		813750	1050	9%	49%
30	940	821	45,800	42,200	2.9		0.200		804580	980	9%	58%
35	860	965	51,000	47,500	30.4		0.240		868500	900	8%	66%
40	760	1,172	56,200	53,700	31.4		0.170		949320	810	7%	73%
45	630	1,466	62,800	60,500	31.7		0.150		1018870	695	6%	79%
50	510	1,881	70,600	67,200			0.250		1072170	570	5%	84%
55	410	2,420		73,600	34.2		0.500		1113200	460	4%	88%
58							1.380					
59							1.840					
60							3.210	Avg Perm Cond	881			
62							6.430					

Table A23: Raw Data - KBH Concentrate Spiked with 2500 mg/L $MgCl_2 \cdot 6H_2O$ – 9/17/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $MgCl_2*6H_2O$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	284		840	300	700	30	4.88		9/17/2011		
								Measured	84%			
Time, min	Perm, ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Silica Notes	Perm Cond for Mass Balance	avgperm	Unit Recvry	Tot recvry
0				23,100	26	3.03						0%
10	1,140	1,170	28,100	24,600	26.7	3.15			666900	1140	10%	10%
20	1,140	1,164	30,700	27,300	27.3	3.25			1326960	1140	10%	20%
30	1,100	1,148	33,800	30,200	27.7	3.38			1285760	1120	10%	30%
40	1,040	1,051	37,300	33,900	28	3.55			1124570	1070	9%	39%
50	960	1,011	41,800	37,900	28.4	3.74			1011000	1000	9%	48%
60	860	1,018	46,400	42,700	28.5	3.99			926380	910	8%	56%
70	780	1,094	51,500	48,500	28.8	4.21			897080	820	7%	63%
80	640	1,313	57,900	55,000	29.2	4.38			932230	710	6%	70%
90	520	1,290	65,100	61,800	29.2	4.46			748200	580	5%	75%
100	400	1,770	70,300	68,700	29.5	4.5			814200	460	4%	79%
110	280	2,400	77,000	74,700	29.8	4.53			816000	340	3%	82%
120	180	3,660	80,000	79,200	29.9	4.52			841800	230	2%	84%
								Avg Perm Cond	1260			
Notes:												
Metallic Calcium was added to the SWRO concentrate at CE lab. Calcium reacted with the salts in the water producing precipitation.												

Table A24: Raw Data - KBH Concentrate Spiked with 5000 mg/L $MgCl_2 \cdot 6H_2O$ – 9/24/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $MgCl_2*6H_2O$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	500		840	300	700	30	5.80		9/24/2011		
								Measured	81%			

Time, min	Perm, ml/min	Perm cond	conc cond	feed cond	temp, C	pH	silica	Silica Notes	Perm Cond for Mass Balance	avgperm	Unit Recvry	Tot recvry
0				21,800	26.4	2.53						0%
5	1,160								0	1160	5%	5%
10	1,160	1,930	27,100	24,100	26.6	2.62			2238800	1160	5%	10%
15									0	1160	5%	15%
20	1,140	1,800	29,700	26,500	27.4	2.74			1026000	1140	5%	20%
25									0	1140	5%	25%
30	1,120	1,630	33,300	29,600	27.6	2.85			912800	1120	5%	30%
35									0	1120	5%	35%
40	1,060	1,580	36,900	33,300	28.5	2.97			837400	1060	5%	40%
45									0	1060	5%	45%
50	980	1,880	41,000	37,600	29.5	3.19			921200	980	4%	49%
55									0	980	4%	53%
60	840	1,923	47,100	43,600	28.3	3.36			807660	840	4%	57%
65									0	840	4%	61%
70	780		53,300	49,100	29.4	3.66			0	780	3%	64%
75									0	780	3%	67%
80	600								0	600	3%	70%
85									0	600	3%	73%
90	405								0	405	2%	75%
95									0	405	2%	76%
100	310		71,900	71,900	31.6	4.33			0	310	1%	78%
105									0	310	1%	79%
110	190		78,000	78,000	33.2	4.38			0	190	1%	80%
								Avg Perm Cond	692			

Notes:

Table A25: Raw Data - KBH Concentrate Spiked with 5300 mg/L $MgCl_2 \cdot 6H_2O$ – 11/5/2010

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $MgCl_2*6H_2O$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.6	30	605		770	300	800	30	3.92		11/5/2010		
								Measured	87%			

Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	Turbidity	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				26,800	25.7	3.54						0%
5	1,220	928	32,000	27,900	25.5	3.55			566080	1220	5%	5%
10	1,260	905	33,300	29,400	26.2	3.62			1122200	1240	5%	11%
15	1,220	880	35,100	30,900	26.7	3.68			1091200	1240	5%	16%
20	1,220	879	37,300	32,500	26.9	3.66			1072380	1220	5%	22%
25	1,180	829	39,500	34,400	27.7	3.82			994800	1200	5%	27%
30	1,160	826	42,400	37,400	28.6	3.89			966420	1170	5%	32%
35	1,120	857	44,100	38,900	28.5	3.99			976980	1140	5%	37%
40	1,080	865	46,800	41,900	27.7	3.99			951500	1100	5%	42%
45	1,000	905	49,000	44,400	28.3	4.1			941200	1040	5%	47%
50	940	956	52,500	47,300	28.2	4.15			927320	970	4%	51%
55	880	1,024	55,100	50,600	28.4	4.26			931840	910	4%	55%
60	860	1,260	55,800	54,300	28.5	4.27			1096200	870	4%	59%
65	740	1,360	62,200	57,800	28.8	4.4			1088000	800	4%	62%
70	660	1,456	65,000	61,000	29.5	4.46			1019200	700	3%	65%
75	620	1,607	69,200	65,100	29.5	4.51			1028480	640	3%	68%
80	520	1,911	72,200	68,700	29.5	4.6			1089270	570	3%	71%
85	460	1,910	75,900	72,800	29.9	4.74			935900	490	2%	73%
90	376	2,450	79,600	77,200	29.4	4.72			1024100	418	2%	75%
95	320	2,220	82,200	79,700	30.1	4.88			772560	348	2%	76%
100	272	2,890	85,500	82,400	30.2	4.97			855440	296	1%	77%
105	240	3,270	87,600	85,200	30.5	5.11			837120	256	1%	79%
110	176	4,070	88,100	87,300	30.4	5.21			846560	208	1%	79%
115	152	5,220	90,700	89,000	30.5	5.29			856080	164	1%	80%
120	124	5,870	92,600	90,900	31.1	5.28			810060	138	1%	81%
125	96	6,010	93,800	92,400	30.4	5.53			661100	110	0%	81%
130	84	6,630	95,000	93,400	31.2	5.68			596700	90	0%	82%
135	74	7,590	95,200	94,100	31.2	5.71			599610	79	0%	82%
140	62	8,210	96,400	95,000	31.2	5.74			558280	68	0%	82%
145	58	8,750	95,800	96,200	31.2	5.78			525000	60	0%	83%
150	48	11,200	97,700	96,900	30.6	5.75	360,370		593600	53	0%	83%
								Avg Perm Cond	1445			

Notes:

Concentrate did not precipitate 72hrs after the sample was taken

Silica values were very low; membrane fouled??

Table A26: Raw Data - KBH Concentrate Spiked with 5000 mg/L $MgCl_2 \cdot 6H_2O$ – 12/21/10

Antiscalant (ml)	H_2SO_4 (ml)	Salt Added (g) $MgCl_2*6H_2O$	Perm Flush Flow Rate Initial (ml/min)	Perm Flush Flow Rate Final (ml/min)	Pressure Flush (psi)	Operating Pressure (psi)	Initial Vol (gal)	Final Vol Measured (gal)	Recovery %	Date		
0.4	15	284		780	300	800	15	1.32		12/21/2010		
								Measured	91%			
Time, min	Perm ml/min	Perm cond	conc cond	feed cond	temp, C	pH	Turbidity	Notes	Perm Mass	Avg perm flow	Unit Recvry	Tot recvry
0				22,700	25.7	3.63						0%
5	1,380	460	28,400	24,400	25.6	3.84			317400	1380	12%	12%
10	1,340	463	31,900	26,900	27.3	3.85			629680	1360	12%	24%
15	1,300	498	35,900	30,700	27.8	3.99			657360	1320	12%	36%
20	1,240	560	-	33,900	28.5	4.07			711200	1270	11%	47%
25	1,100	660	45,500	45,100	29.2	4.28			772200	1170	10%	57%
30	940	806	52,800	48,800	30.6	4.4			822120	1020	9%	66%
35	800	1,040	59,300	56,100	31	4.54			904800	870	8%	74%
40	640	1,440	67,700	64,500	31.7	4.62			1036800	720	6%	80%
45	540	2,910	75,800	72,900	32.5	4.77			1716900	590	5%	85%
50	300	3,270	82,500	80,400	33.2	4.96			1373400	420	4%	89%
55	160	4,050	86,500	85,500	34.7	5.2			931500	230	2%	91%
								Avg Perm Cond	1014			
Notes:												
Final Permeate vol =		13 gal										

Appendix B Tables

Table *Page*

Appendix B

Table B1: Test Run 1 at BGNDRF Site with 5 ppm Antiscalant – 6/23/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
0	0.7			20		75

Note: Set point recovery not reached

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	Avgperm	Unit Recvry	Tot Recvry
0	0.7	6500	0	2.5	0.6	0%	670			0%
5	0.7	7,780	9,040	2.48	0.4	15%	672	0.7	18%	18%
10	0.7	9,260	10,740	2.4	0.38	29%	682	0.7	18%	35%
15	0.7	12,010	13,330	2.4	1	44%	680	0.7	18%	53%
20	0.7	16,580	17,880	2.4	0.6	58%	722	0.7	18%	70%
22	0.4			2.4	7	67%		0.55	6%	76%

Notes:

System stopped at 67% recovery due to high pressure

Precipitation occurred during test

Table B2: Test Run 2 at BGNDRF Site with 5 ppm Antiscalant – 6/23/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
0	0.7			30		80

Note: Set point recovery not reached

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	Avgperm	Unit Recvry	Tot Recvry
0	0	6670	0	4.12	0.50	0%	606			0%
5	0.7	7,730	9,080	4.22	0.40	13%	580	0.35	6%	6%
10	0.7	8,230	1,060	4.12	0.35	20%	588	0.7	12%	18%
15	0.7	9,620	11,280	4.17	0.34	30%	593	0.7	12%	29%
20	0.7	10,970	12,990	4.23	0.35	40%	592	0.7	12%	41%
25	0.7	13,230	15,580	4.28	0.29	50%	598	0.7	12%	53%
30	0.7	16,950	19,050	4.37	0.63	60%	617	0.7	12%	64%
32	0.63	n/a	n/a	n/a	0.75	64%	637	0.665	4%	69%
35	0.56	22,100	22,860	4.46	1.24	69%	683	0.595	6%	75%
37	0.35	n/a	n/a	n/a	1.43	72%	761	0.455	3%	78%
38	0.26	n/a	24,400	4.5	1.67	73%	798	0.305	1%	79%

Notes:

Permeate flow was low at the end of the run

Test was stopped at about 71% recovery

Precipitation was present at the end of the run

Table B3: Test Run at BGNDRF Site with 5 ppm Antiscalant – 8/4/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
0	0.7			30		95

Note: Set point recovery not reached

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	Avgperm	Unit Recvry	Tot Recvry
0	0.52	8000	9,320	3.3	0.58	see	710			0%
5	0.52		9,760	3.35	0.36	system	720	0.52	9%	9%
10	0.48		10,430	3.3	0.41	log	713	0.5	8%	17%
15	0.46		11,080	3.3	0.34		715	0.47	8%	25%
20	0.4		11,660	3.33	0.44		679	0.43	7%	32%
25	0.39		12,450	3.34	0.44		690	0.395	7%	39%
30	0.36		13,160	3.37	0.53		701	0.375	6%	45%
35	0.32		13,830	3.36	0.57		710	0.34	6%	51%
40	0.26		14,540	3.5	0.55		734	0.29	5%	55%
45	0.18		15,280	3.46	0.78		752	0.22	4%	59%
49	0.12		15,480	3.44	0.91		780	0.15	2%	61%
51	0.1		15,540	3.44	0.82		790	0.11	1%	62%
54	0.07		15,690	3.45	0.91		800	0.085	1%	63%
56	0.05		15,810	3.45	1.65		810	0.06	0%	63%
58	0.04		15,780	3.46	1.68		820	0.045	0%	63%
60	0.03		15,880	3.46	1.53		822	0.035	0%	64%
62	0.02		15,870	3.48	2.15		820	0.025	0%	64%
64	0.01				2.41	53%	829	0.015	0%	64%

Notes:

Well 2 conductivity 6,200 microS/cm; Primary RO conc. Conductivity 8000 microS/cm

Permeate conductivity: 1196 microS/cm; Permeate pH: 3.14

pH meter calibrated with pH 4 & pH 7 buffers

Conductivity meter calibrated 10,0000 microS/cm

The pH meter and the conductivity meter of the system are not working properly

Table B4: Test Run at BGNDRF Site with 5 ppm Antiscalant – 11/18/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
0	0.69	0.69	520	30	17-18	90
Note: Set point recovery not reached					36%-40% recovery	

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	Avgperm	Unit Recvry	Tot Recvry
0	0.69	750	11,550	3.69	0.65	see	20.5			0%
5	0.69	780	12,390	3.76	0.80	system	21	0.69	12%	12%
10	0.6	777	13,470	3.68	0.91	log	21.5	0.645	11%	22%
15	0.43	765	14,490	3.77	0.99		22.4	0.515	9%	31%
20	0.31	820	15,490	3.8	1.23		23.1	0.37	6%	37%
25	0.15	820	16,150	3.86	1.29		24.1	0.23	4%	41%
30	0.08	820	16,610	3.88	1.62		25.3	0.115	2%	43%
35	0.04	835	16,740	3.91	2.54	36%	26.1	0.06	1%	44%

Notes:

System stopped at 38 minutes due to low permeate flow (0.03 gpm)

Final concentrate volume = 17 gallons (36% recovery); does not include the recovery from RO

Turbidity of the final concentrate after 1 hour 85.8 NTU. There was precipitation present

RO system was working at 50% recovery approximately.

Well #2 conductivity 6000 microS/cm

Table B5: Test Run at BGNDRF Site with 5 ppm Antiscalant – 12/13/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
0	0.69	0.69	620	30		90%

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	Avgperm	Unit Recvry	Tot Recvry
0	0.6			3.84	1.09		712			0%
5	0.6	12,310		3	1.10		800	0.6	10%	10%
10	0.51	12,980		3.08	0.98	18%	728	0.555	9%	19%
15	0.45	13,990		3.02	2.15	27%	762	0.48	8%	27%
20	0.34	14,760		3.05	1.78	32%	768	0.395	7%	34%
25	0.22	15,380		3.07	3.31	35%	815	0.28	5%	39%
27	0.15	15,781		3.06	11.80	36%	841.0	0.185	1%	40%

Notes:

Table B6: Test Run at BGNDRF Site - 5000 mg/L NaCl in Raw Well 2 Water – 6/23/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
326						
NaCl	0.7			20		75

Note: Set point recovery was reached

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	Avgperm	Unit Recvry	Tot Recvry
0	0	8500	0	n/a	3	0%	n/a			0%
5	0.7	11,350	13,580	2.29	4	14%	n/a	0.35	9%	9%
10	0.6	13,900	16,260	2.3	4.1	29%	n/a	0.65	16%	25%
15	0.7	18,000	20,320	2.36	5	43%	n/a	0.65	16%	41%
20	0.6	25,600	27,160	2.37	3.7	58%	n/a	0.65	16%	58%
25	0.6	36,400	40,700	2.4	7	71%	n/a	0.6	15%	73%

Notes:

Permeate flow = 0.7- 0.6 until end of test

Table B7: Test Run at BGNDRF Site – 10,000 mg/L NaCl in Raw Well 2 Water – 6/23/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
NaCl						
1148	0.7			32		80

Note: Set point recovery was reached

Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	avgperm	Unit Recvry	Tot recvry
0		23500	0	3.9	2.9	0%	665			0%
5	0.6	25,800	28,000	4.08	3.7	10%	602	0.6	9%	9%
10	0.58	28,000	30,040	4.07	3.5	18%	605	0.59	9%	19%
15	0.55	29,900	32,430	4.2	4.1	26%	608	0.565	9%	27%
20	0.53	33,100	35,160	4.35	4.2	35%	615	0.54	8%	36%
25	0.51	36,000	38,390	4.46	4.2	43%	631	0.52	8%	44%
30	0.46	40,100	42,050	4.61	4.2	50%	628	0.485	8%	52%
35	0.42	43,800	46,200	4.69	5.1	57%	638	0.44	7%	58%
40	0.38	48,600	50,600	4.81	4.5	62%	649	0.4	6%	65%
45	0.35	53,200	55,240	4.83	5.0	68%	670	0.365	6%	70%
50	0.3	59,300	60,950	4.9	6.6	72%	692	0.325	5%	75%
55	0.25	63,900	67,350	4.89	6.0	76%	714	0.275	4%	80%
60	0.19	70,000	73,060	4.88	6.1	78%	733	0.22	3%	83%
62	0.17				8.7	79%	746	0.18	1%	84%

Notes:

No precipitation occurred during treatment.

Table B8: Test Run at BGNDRF Site – 10,000 mg/L NaCl in RO Conc – 11/18/2011

Salt Added, g NaCl	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %
1150	0.69	0.69	480	30	8.00	80%

Note: Set point recovery not reached 73% recovery

Time, min	Perm Flow Gal/min	Pressure, psi	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	avgperm	Unit Recvry	Tot recvry
0	0.58	760	27,300	3.76	0.72	see	19.2			0%
5	0.55	750	29,100	4.04	1.12	system	19.81	0.565	9%	9%
10	0.52	760	30,800	3.94	1.21	log	20.5	0.535	9%	18%
15	0.51	765	33,600	3.99	1.35		21.2	0.515	9%	27%
20	0.51	785	36,100	4.02	1.21		22	0.51	9%	35%
25	0.48	790	39,800	4.19	0.96		23	0.495	8%	44%
30	0.47	800	43,500	4.34	1.12		24.0	0.475	8%	52%
35	0.43	820	48,800	4.41	1.55		25.3	0.45	8%	59%
40	0.36	778	52,900	4.62	1.21		26.5	0.395	7%	66%
45	0.31	780	58000	4.67	1.49		27.6	0.335	6%	71%
50	0.26	820	63,500	4.91	2.61		29.3	0.285	5%	76%
55	0.15	870	68,300	5.04	7.3	73%	30.6	0.205	3%	79%

Notes:

Initial Volume 29 gallons + 1 gallon of water with 1150 grams of NaCl

System was stopped at 1 hr due to high pressure, high turbidity and low permeate flow

Acid dosage was set to 3.9 mL per gallon (25% acid)

Solids remained in solution longer than run with no salt

Table B9: Test Run at BGNDRF Site – 20 ppm Antiscalant in RO Conc – 12/13/2011

Salt Added, g	Flush Flow Rate Initial, gpm	Flush Flow Rate Final, gpm	Pressure Flush, psi	Initial Volume, gal	Final Vol Measured, gal	Recovery set pt, %				
0	0.69	0.69	620	30	14.1	90%				
Note: Set point recovery not reached					53% recovery					
20 ppm antiscalant										
Time, min	Perm Flow Gal/min	Feed Cond	Conc. Cond	pH	Turbidity	Datalogged Recovery	Pressure	avgperm	Unit Recvry	Tot recvry
0	0.59	10990		3.34	1.01	0%	699			0%
5	0.58	11,500		3.38	2.09	10%	697	0.585	10%	10%
10	0.57	12,470		3.38	1.77	17%	695	0.575	10%	19%
15	0.55	13,390		3.4	1.25	25%	699	0.56	9%	29%
20	0.53	14,610		3.31	1.16	33%	705	0.54	9%	38%
25	0.48	16,160		3.35	1.47	41%	728	0.505	8%	46%
30	0.37	17,710		3.45	1.20	48%	772	0.425	7%	53%
35	0.23	18720		3.41	1.71	51%	810	0.3	5%	58%
40	0.1	19,670		3.48	2.68	53%	803	0.165	3%	61%
43	0.06	19860		3.45	3.98	53%	822	0.08	1%	62%
45	0.04	21300		3.45	4.80	53%	831	0.05	0%	62%
Notes:										
30 gallon batch (2.3 mL of antiscalant equivalent to 20 ppm)										

Appendix C Tables

Table *Page*

Appendix C

Table C1 – Data Log for 6/23/2011- 5 ppm Antiscalant in Raw Water from Well 2 – 1st Run

Date	Temp (C)	pH	Cond (mS/cm)	Recovery (%)	Cond (mS/cm)	Totalizer (Gal)	Flow (GPM)	Flow (GPM)	Cond (uS/cm)	Press (psi)	Flow (GPM)	Press (psi)	Target (%)	Size (Gal)
6/23/2011 12:08	25.50	0.00	3.41	0	19.24	0.00	0.00	0.00	459	0	6.20	0	75	5.67
6/23/2011 12:09	25.39	0.00	2.86	0	19.19	0.00	0.00	0.00	459	0	6.18	0	75	11.81
6/23/2011 12:10	25.28	0.00	3.74	0	19.19	0.00	0.00	0.00	459	0	6.12	0	75	17.91
6/23/2011 12:11	25.17	0.00	2.86	0	19.19	0.00	0.00	0.00	459	0	0.00	0	75	20.46
6/23/2011 12:12	25.56	0.00	2.86	0	10.06	0.10	2.65	0.70	649	718	0.00	713	75	20.46
6/23/2011 12:13	28.17	0.00	2.86	3	8.25	0.70	2.64	0.70	683	726	0.00	724	75	20.46
6/23/2011 12:14	28.44	0.00	2.86	6	8.25	1.30	2.69	0.70	686	692	0.00	680	75	20.46
6/23/2011 12:15	28.67	0.00	3.74	9	8.45	1.90	2.72	0.70	695	671	0.00	666	75	20.46
6/23/2011 12:16	28.83	0.00	3.74	12	8.74	2.50	2.72	0.70	705	674	0.00	666	75	20.46
6/23/2011 12:17	29.00	0.00	4.73	15	8.99	3.10	2.72	0.70	717	678	0.00	667	75	20.46
6/23/2011 12:18	29.22	0.00	4.73	18	9.33	3.70	2.73	0.70	734	673	0.00	667	75	20.46
6/23/2011 12:19	29.44	0.00	4.29	21	9.67	4.30	2.71	0.70	752	671	0.00	668	75	20.46
6/23/2011 12:20	29.61	0.00	5.28	24	9.96	4.90	2.73	0.70	769	677	0.00	669	75	20.46
6/23/2011 12:21	29.89	0.00	5.06	27	10.45	5.50	2.72	0.70	800	674	0.00	671	75	20.46
6/23/2011 12:22	30.11	0.00	6.38	30	10.89	6.10	2.72	0.70	827	673	0.00	667	75	20.46
6/23/2011 12:23	30.33	0.00	6.16	33	11.28	6.70	2.73	0.70	854	671	0.00	666	75	20.46
6/23/2011 12:24	30.61	0.00	6.93	36	11.77	7.30	2.74	0.70	881	676	0.00	669	75	20.46
6/23/2011 12:25	30.89	0.00	6.71	39	12.26	7.90	2.74	0.70	913	680	0.00	679	75	20.46
6/23/2011 12:26	31.17	0.00	8.03	42	12.99	8.50	2.74	0.70	947	681	0.00	673	75	20.46
6/23/2011 12:27	31.50	0.00	9.13	44	13.58	9.10	2.74	0.70	979	680	0.00	677	75	20.46
6/23/2011 12:28	31.83	0.00	9.13	47	14.41	9.70	2.76	0.70	1025	688	0.00	681	75	20.46
6/23/2011 12:29	32.17	0.00	10.12	50	15.29	10.30	2.75	0.70	1069	687	0.00	684	75	20.46
6/23/2011 12:30	32.56	0.00	11.44	53	16.26	10.90	2.76	0.70	1108	699	0.00	693	75	20.46
6/23/2011 12:31	32.94	0.00	11.77	56	17.29	11.50	2.79	0.70	1157	710	0.00	704	75	20.46
6/23/2011 12:32	33.39	0.00	13.09	59	18.27	12.10	2.81	0.70	1206	728	0.00	721	75	20.46
6/23/2011 12:33	33.89	0.00	14.74	62	19.44	12.70	2.88	0.65	1255	749	0.00	739	75	20.46
6/23/2011 12:34	34.44	0.00	16.83	65	20.42	13.26	2.92	0.57	1289	842	0.00	832	75	20.46

Conc rm Feed Feed Feed Co

Table C2 – Data Log for 6/23/2011- 5 ppm Antiscalant in Raw Water from Well 2 – 2nd Run

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
6/23/2011 16:02	30.06	0.00	0.00	0	0.78	0.00	0.00	0.00	459	0	0.00	0	80	0.00
6/23/2011 16:03	29.06	0.00	2.64	0	0.78	0.00	0.00	0.00	398	0	6.26	0	80	5.70
6/23/2011 16:04	28.22	0.00	2.86	0	0.78	0.00	0.00	0.00	459	0	6.24	0	80	11.87
6/23/2011 16:05	27.61	0.00	4.29	0	0.73	0.00	0.00	0.00	410	0	6.20	0	80	18.02
6/23/2011 16:06	27.22	0.00	2.86	0	0.73	0.00	0.00	0.00	446	0	6.11	0	80	24.12
6/23/2011 16:07	26.94	0.00	3.74	0	0.73	0.00	0.00	0.00	454	0	1.08	0	80	30.21
6/23/2011 16:08	26.56	0.00	3.74	0	0.73	0.00	0.00	0.00	459	0	0.00	0	80	30.22
6/23/2011 16:09	30.06	0.00	3.74	2	8.50	0.60	2.68	0.70	112	611	0.00	602	80	30.22
6/23/2011 16:10	30.28	0.00	3.74	4	8.45	1.20	2.73	0.70	112	593	0.00	585	80	30.22
6/23/2011 16:11	30.39	0.00	3.74	6	8.60	1.80	2.72	0.70	112	592	0.00	586	80	30.22
6/23/2011 16:12	30.50	0.00	4.29	8	8.79	2.40	2.74	0.70	112	583	0.00	576	80	30.22
6/23/2011 16:13	30.56	0.00	4.29	10	8.99	3.00	2.74	0.70	112	582	0.00	577	80	30.22
6/23/2011 16:14	30.67	0.00	4.29	12	9.18	3.60	2.74	0.70	129	590	0.00	580	80	30.22
6/23/2011 16:15	30.72	0.00	4.29	14	9.33	4.20	2.74	0.70	144	591	0.00	582	80	30.22
6/23/2011 16:16	30.78	0.00	4.29	16	9.52	4.80	2.73	0.70	146	588	0.00	581	80	30.22
6/23/2011 16:17	30.89	0.00	4.29	18	9.82	5.40	2.75	0.70	146	583	0.00	578	80	30.22
6/23/2011 16:18	31.00	0.00	5.06	20	10.01	6.00	2.74	0.70	144	592	0.00	580	80	30.22
6/23/2011 16:19	31.11	0.00	5.06	22	10.26	6.60	2.74	0.70	144	591	0.00	580	80	30.22
6/23/2011 16:20	31.22	0.00	5.06	24	10.45	7.20	2.75	0.70	144	592	0.00	583	80	30.22
6/23/2011 16:21	31.33	0.00	5.61	26	10.79	7.80	2.75	0.70	144	588	0.00	582	80	30.22
6/23/2011 16:22	31.44	0.00	5.61	28	11.04	8.40	2.75	0.70	144	593	0.00	582	80	30.22
6/23/2011 16:23	31.61	0.00	6.38	30	11.28	9.00	2.75	0.70	141	594	0.00	583	80	30.22
6/23/2011 16:24	31.72	0.00	6.93	32	11.53	9.60	2.76	0.70	141	584	0.00	580	80	30.22
6/23/2011 16:25	31.89	0.00	6.93	34	11.92	10.20	2.76	0.70	141	592	0.00	582	80	30.22
6/23/2011 16:26	32.00	0.00	6.71	36	12.26	10.80	2.76	0.70	136	586	0.00	581	80	30.22
6/23/2011 16:27	32.11	0.00	6.93	38	12.60	11.40	2.76	0.70	141	589	0.00	582	80	30.22
6/23/2011 16:28	32.22	0.00	7.48	40	12.99	12.00	2.75	0.70	136	592	0.00	583	80	30.22
6/23/2011 16:29	32.33	0.00	7.70	42	13.38	12.60	2.76	0.70	136	591	0.00	584	80	30.22
6/23/2011 16:30	32.44	0.00	8.25	44	13.87	13.20	2.77	0.70	136	588	0.00	587	80	30.22
6/23/2011 16:31	32.56	0.00	9.13	46	14.21	13.80	2.78	0.70	136	589	0.00	587	80	30.22
6/23/2011 16:32	32.67	0.00	9.35	48	14.80	14.40	2.76	0.70	134	603	0.00	595	80	30.22
6/23/2011 16:33	32.83	0.00	9.57	50	15.34	15.00	2.79	0.70	134	599	0.00	595	80	30.22
6/23/2011 16:34	33.00	0.00	10.45	52	15.87	15.60	2.78	0.70	134	604	0.00	599	80	30.22
6/23/2011 16:35	33.17	0.00	11.00	54	16.56	16.20	2.79	0.70	134	609	0.00	604	80	30.22
6/23/2011 16:36	33.33	0.00	11.44	56	17.29	16.80	2.79	0.70	131	616	0.00	607	80	30.22
6/23/2011 16:37	33.50	0.00	12.32	58	17.97	17.40	2.79	0.70	134	616	0.00	608	80	30.22
6/23/2011 16:38	33.67	0.00	13.09	60	18.80	18.00	2.80	0.70	134	616	0.00	614	80	30.22
6/23/2011 16:39	33.89	0.00	14.19	62	19.58	18.60	2.82	0.70	134	622	0.00	621	80	30.22
6/23/2011 16:40	34.06	0.00	15.51	64	20.46	19.20	2.83	0.70	136	637	0.00	626	80	30.22
6/23/2011 16:41	34.22	0.00	16.28	66	21.29	19.80	2.86	0.69	136	638	0.00	635	80	30.22
6/23/2011 16:42	34.50	0.00	17.16	68	22.03	20.40	2.91	0.64	141	656	0.00	653	80	30.22
6/23/2011 16:43	34.72	0.00	18.48	69	22.71	20.95	2.95	0.57	141	688	0.00	679	80	30.22
6/23/2011 16:44	34.94	0.00	19.03	71	23.25	21.42	3.03	0.47	148	721	0.00	709	80	30.22
6/23/2011 16:45	35.28	0.00	20.13	72	23.64	21.78	3.12	0.35	156	761	0.00	750	80	30.22
6/23/2011 16:46	35.50	0.00	20.90	73	23.74	22.02	3.20	0.25	166	798	0.00	789	80	30.22

Table C3 – Data Log for 8/14/2011- 5 ppm Antiscalant in 33% RO Concentrate Feed

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
8/4/2011 11:33	23.67	0.00	0.00	0.00	2.83	0.00	0.00	0.00	26	0	0.00	0	95	0.00
8/4/2011 11:34	23.72	0.00	6.38	0.00	2.93	0.00	0.00	0.00	26	0	6.20	0	95	6.03
8/4/2011 11:35	23.72	0.00	5.61	0.00	2.98	0.00	0.00	0.00	26	0	6.07	0	95	12.16
8/4/2011 11:36	23.72	0.00	5.06	0.00	3.13	0.00	0.00	0.00	26	0	6.12	0	95	18.23
8/4/2011 11:37	23.72	0.00	4.29	0.00	3.22	0.00	0.00	0.00	26	0	6.14	0	95	24.28
8/4/2011 11:38	23.72	0.00	4.73	0.00	3.32	0.00	0.00	0.00	26	0	4.54	0	95	30.28
8/4/2011 11:40	23.72	0.00	4.29	0.00	3.47	0.00	0.00	0.00	26	0	0.00	0	95	30.30
8/4/2011 11:41	25.17	0.00	4.29	2.00	9.33	0.55	2.97	0.63	131	671	0.00	662	95	30.30
8/4/2011 11:42	25.44	0.00	4.73	4.00	9.47	1.15	2.97	0.60	104	674	0.00	669	95	30.30
8/4/2011 12:03	24.44	0.00	0.00	0.00	9.47	1.15	0.00	0.00	21	0	0.00	0	95	0.00
8/4/2011 12:04	24.44	0.00	0.00	0.00	9.43	0.00	0.00	0.00	21	0	0.00	0	95	0.00
8/4/2011 12:05	24.44	0.00	0.00	0.00	9.47	0.00	0.00	0.00	21	0	0.00	0	95	0.00
8/4/2011 12:06	24.39	0.00	0.00	0.00	9.47	0.00	0.00	0.00	21	0	0.00	0	95	0.00
8/4/2011 12:07	24.39	0.00	6.71	0.00	9.47	0.00	0.00	0.00	21	0	6.26	0	95	5.99
8/4/2011 12:08	24.33	0.00	5.28	0.00	9.47	0.00	0.00	0.00	21	0	6.18	0	95	12.13
8/4/2011 12:09	24.39	0.00	5.28	0.00	9.47	0.00	0.00	0.00	21	0	6.17	0	95	18.25
8/4/2011 12:10	24.33	0.00	4.73	0.00	9.47	0.00	0.00	0.00	21	0	6.12	0	95	24.34
8/4/2011 12:11	24.33	0.00	4.29	0.00	9.47	0.00	0.00	0.00	21	0	0.84	0	95	30.39
8/4/2011 12:13	24.33	0.00	4.29	0.00	9.47	0.00	0.00	0.00	21	0	0.00	0	95	30.40
8/4/2011 12:14	25.22	0.00	4.73	1.00	9.33	0.43	2.99	0.58	290	692	0.00	687	95	30.40
8/4/2011 12:15	25.44	0.00	5.06	3.00	9.52	0.91	2.99	0.56	271	705	0.00	695	95	30.40
8/4/2011 12:16	25.67	0.00	4.73	5.00	9.57	1.39	3.02	0.54	288	700	0.00	699	95	30.40
8/4/2011 12:17	25.78	0.00	5.06	6.00	9.72	1.87	3.02	0.53	280	709	0.00	704	95	30.40
8/4/2011 12:18	25.89	0.00	5.06	8.00	9.77	2.35	3.03	0.52	275	716	0.00	706	95	30.40
8/4/2011 12:19	26.00	0.00	5.06	9.00	9.96	2.83	3.05	0.50	271	695	0.00	693	95	30.40
8/4/2011 12:20	26.11	0.00	5.06	11.00	10.01	3.31	3.04	0.50	271	707	0.00	694	95	30.40
8/4/2011 12:21	26.28	0.00	6.16	12.00	10.16	3.79	3.03	0.49	268	697	0.00	697	95	30.40
8/4/2011 12:22	26.39	0.00	6.16	14.00	10.31	4.27	3.05	0.48	288	702	0.00	699	95	30.40
8/4/2011 12:23	26.50	0.00	6.16	16.00	10.40	4.75	3.05	0.48	288	710	0.00	703	95	30.40
8/4/2011 12:24	26.67	0.00	6.16	17.00	10.55	5.20	3.06	0.47	283	705	0.00	702	95	30.40
8/4/2011 12:25	26.78	0.00	6.16	18.00	10.70	5.60	3.07	0.47	283	709	0.00	705	95	30.40
8/4/2011 12:26	26.89	0.00	6.38	20.00	10.79	5.96	3.06	0.47	283	710	0.00	707	95	30.40
8/4/2011 12:27	27.06	0.00	6.16	21.00	10.94	6.32	3.06	0.46	280	718	0.00	709	95	30.40
8/4/2011 12:28	27.17	0.00	6.38	22.00	11.04	6.68	3.07	0.46	283	716	0.00	710	95	30.40
8/4/2011 12:29	27.33	0.00	6.71	23.00	11.18	7.04	3.06	0.45	283	716	0.00	711	95	30.40
8/4/2011 12:30	27.50	0.00	6.38	24.00	11.28	7.40	3.07	0.45	283	720	0.00	714	95	30.40
8/4/2011 12:31	27.67	0.00	6.93	26.00	11.48	7.76	3.07	0.45	280	726	0.00	717	95	30.40
8/4/2011 12:32	27.78	0.00	6.93	27.00	11.62	8.12	3.07	0.44	283	728	0.00	717	95	30.40
8/4/2011 12:33	27.94	0.00	6.93	28.00	11.67	8.48	3.12	0.41	288	678	0.00	675	95	30.40
8/4/2011 12:34	28.06	0.00	6.93	29.00	11.87	8.84	3.11	0.40	293	683	0.00	677	95	30.40
8/4/2011 12:35	28.22	0.00	7.70	30.00	11.97	9.20	3.13	0.39	293	686	0.00	675	95	30.40
8/4/2011 12:36	28.39	0.00	6.93	31.00	12.11	9.56	3.12	0.39	295	688	0.00	677	95	30.40
8/4/2011 12:37	28.50	0.00	7.70	33.00	12.21	9.92	3.13	0.39	295	686	0.00	677	95	30.40
8/4/2011 12:38	28.67	0.00	8.03	34.00	12.36	10.28	3.13	0.38	295	682	0.00	679	95	30.40
8/4/2011 12:39	28.83	0.00	8.25	35.00	12.60	10.64	3.13	0.39	295	688	0.00	682	95	30.40
8/4/2011 12:40	29.00	0.00	8.25	36.00	12.70	11.00	3.15	0.38	295	693	0.00	682	95	30.40
8/4/2011 12:41	29.17	0.00	9.13	37.00	12.84	11.36	3.15	0.37	295	688	0.00	684	95	30.40
8/4/2011 12:42	29.33	0.00	9.13	39.00	13.09	11.72	3.15	0.37	295	692	0.00	686	95	30.40
8/4/2011 12:43	29.50	0.00	8.25	40.00	13.14	12.08	3.14	0.36	300	696	0.00	687	95	30.40
8/4/2011 12:44	29.61	0.00	8.80	41.00	13.33	12.40	3.17	0.36	300	702	0.00	693	95	30.40
8/4/2011 12:45	29.83	0.00	8.80	42.00	13.48	12.64	3.14	0.35	300	695	0.00	694	95	30.40
8/4/2011 12:46	30.00	0.00	8.80	42.00	13.63	12.88	3.16	0.34	300	704	0.00	697	95	30.40
8/4/2011 12:47	30.17	0.00	9.35	43.00	13.87	13.12	3.17	0.33	300	706	0.00	699	95	30.40
8/4/2011 12:48	30.33	0.00	9.13	44.00	13.97	13.36	3.16	0.32	302	714	0.00	704	95	30.40
8/4/2011 12:49	30.50	0.00	9.35	45.00	14.11	13.60	3.16	0.31	302	714	0.00	706	95	30.40
8/4/2011 12:50	30.72	0.00	9.57	46.00	14.21	13.84	3.19	0.30	302	719	0.00	709	95	30.40
8/4/2011 12:51	30.89	0.00	9.57	46.00	14.46	14.08	3.18	0.29	302	724	0.00	713	95	30.40
8/4/2011 12:52	31.11	0.00	9.57	47.00	14.60	14.32	3.23	0.28	302	726	0.00	717	95	30.40
8/4/2011 12:53	31.28	0.00	10.45	48.00	14.70	14.56	3.23	0.26	305	731	0.00	722	95	30.40
8/4/2011 12:54	31.44	0.00	10.45	49.00	14.85	14.80	3.23	0.25	305	734	0.00	726	95	30.40
8/4/2011 12:55	31.61	0.00	11.44	49.00	14.95	15.04	3.24	0.23	307	738	0.00	730	95	30.40
8/4/2011 12:56	31.83	0.00	11.00	50.00	15.09	15.16	3.26	0.22	307	746	0.00	735	95	30.40
8/4/2011 12:57	32.06	0.00	11.00	50.00	15.19	15.28	3.26	0.21	307	753	0.00	740	95	30.40
8/4/2011 12:58	32.22	0.00	11.44	51.00	15.29	15.40	3.29	0.19	312	749	0.00	745	95	30.40
8/4/2011 12:59	32.44	0.00	11.44	51.00	15.34	15.52	3.28	0.17	312	761	0.00	750	95	30.40
8/4/2011 13:00	32.61	0.00	11.00	51.00	15.53	15.64	3.30	0.16	317	746	0.00	738	95	30.40
8/4/2011 13:01	32.83	0.00	11.44	52.00	15.58	15.76	3.31	0.14	319	748	0.00	741	95	30.40
8/4/2011 13:02	33.00	0.00	11.99	52.00	15.63	15.88	3.33	0.13	319	774	0.00	769	95	30.40
8/4/2011 13:03	33.17	0.00	11.77	53.00	15.68	16.00	3.33	0.11	324	786	0.00	773	95	30.40
8/4/2011 13:04	33.39	0.00	11.77	53.00	15.78	16.01	3.36	0.10	327	791	0.00	779	95	30.40
8/4/2011 13:05	33.56	0.00	11.99	53.00	15.82	16.01	3.33	0.09	332	793	0.00	783	95	30.40
8/4/2011 13:06	33.78	0.00	11.77	53.00	15.82	16.01	3.36	0.08	339	801	0.00	788	95	30.40
8/4/2011 13:07	33.89	0.00	11.77	53.00	15.87	16.01	3.36	0.07	344	797	0.00	791	95	30.40
8/4/2011 13:08	34.11	0.00	11.99	53.00	15.92	16.01	3.36	0.06	354	806	0.00	796	95	30.40
8/4/2011 13:09	34.22	0.00	11.99	53.00	15.92	16.01	3.38	0.05	363	808	0.00	799	95	30.40
8/4/2011 13:10	34.39	0.00	12.32	53.00	15.92	16.01	3.39	0.05	192	811	0.00	802	95	30.40
8/4/2011 13:11	34.50	0.00	12.32	53.00	15.92	16.01	3.38	0.04	185	810	0.00	807	95	30.40
8/4/2011 13:12	34.67	0.00	12.32	53.00	16.02	16.01	3.38	0.04	178	820	0.00	809	95	30.40
8/4/2011 13:13	34.78	0.00	12.32	53.00	16.02	16.01	3.39	0.03	170	819	0.00	809	95	30.40
8/4/2011 13:14	34.89	0.00	12.32	53.00	16.02	16.01	3.39	0.03	161	815	0.00	810	95	30.40
8/4/2011 13:15	34.94	0.00	11.99	53.00	16.02	16.01	3.40	0.02	161	816	0.00	812	95	30.40
8/4/2011 13:16	35.00	0.00	12.32	53.00	16.02	16.01	3.41	0.02	161	819	0.00	814	95	30.40
8/4/2011 13:17	35.06	0.00	12.32	53.00	16.02	16.01	3.41	0.02	156	828	0.00	815	95	30.40
8/4/2011 13:18	35.11	0.00	12.87	53.00	16.07	16.01	3.40	0.01	156	828	0.00	815	95	30.40
8/4/2011 13:19	35.11	0.00	12.87	53.00	16.07	16.01	3.40	0.01	156	825	0.00	816	95	30.40

Table C4 – Data Log for 11/18/2011- 5 ppm Antiscalant in 50% RO Concentrate Feed

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
11/18/2011 13:28	19.22	0.00	0.00	0	2.25	0.00	0.00	0.00	9	0	0.00	0	90	0.00
11/18/2011 13:29	19.28	0.00	11.44	0	2.25	0.00	0.00	0.00	9	0	6.10	0	90	5.55
11/18/2011 13:30	19.28	0.00	9.13	0	2.25	0.00	0.00	0.00	9	0	6.08	0	90	11.62
11/18/2011 13:31	19.28	0.00	9.13	0	2.25	0.00	0.00	0.00	9	0	6.11	0	90	17.64
11/18/2011 13:32	19.28	0.00	9.57	0	2.25	0.00	0.00	0.00	7	0	6.03	0	90	23.62
11/18/2011 13:33	19.28	0.00	8.80	0	2.25	0.00	0.00	0.00	9	0	6.05	0	90	29.57
11/18/2011 13:34	19.33	0.00	8.03	0	2.25	0.00	0.00	0.00	7	0	0.00	0	90	30.08
11/18/2011 13:35	20.56	0.00	9.35	1	13.68	0.25	2.80	0.69	207	779	0.00	775	90	30.08
11/18/2011 13:36	21.06	0.00	8.25	3	13.72	0.85	2.80	0.69	180	800	0.00	795	90	30.08
11/18/2011 13:37	21.22	0.00	9.13	5	14.07	1.45	2.79	0.69	166	810	0.00	807	90	30.08
11/18/2011 13:38	21.39	0.00	9.13	7	14.31	2.05	2.79	0.69	153	824	0.00	819	90	30.08
11/18/2011 13:39	21.56	0.00	8.80	9	14.60	2.65	2.78	0.69	141	857	0.00	851	90	30.08
11/18/2011 13:40	21.67	0.00	9.35	11	14.85	3.25	2.80	0.69	131	852	0.00	842	90	30.08
11/18/2011 13:41	21.83	0.00	10.12	13	14.95	3.85	2.85	0.69	124	808	0.00	801	90	30.08
11/18/2011 13:42	22.00	0.00	10.12	15	15.14	4.45	2.87	0.69	129	819	0.00	809	90	30.08
11/18/2011 13:43	22.17	0.00	11.00	17	15.38	5.05	2.89	0.69	124	818	0.00	815	90	30.08
11/18/2011 13:44	22.28	0.00	10.12	19	15.58	5.65	2.88	0.68	119	832	0.00	824	90	30.08
11/18/2011 13:45	22.44	0.00	11.44	21	15.87	6.25	2.92	0.66	117	843	0.00	834	90	30.08
11/18/2011 13:46	22.67	0.00	11.99	23	16.17	6.85	2.91	0.64	112	847	0.00	840	90	30.08
11/18/2011 13:47	22.83	0.00	11.77	25	16.41	7.45	2.83	0.69	112	985	0.00	976	90	30.08

Table C5 – Data Log for 12/13/2011- 5 ppm Antiscalant in 49% RO Concentrate Feed

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
12/13/2011 16:57	18.50	0.00	0.00	0	12.75	0.00	0.00	0.00	39	0	0.00	0	90	0.00
12/13/2011 16:58	18.56	0.00	0.00	0	12.75	0.00	0.00	0.00	39	0	5.94	0	90	5.91
12/13/2011 16:59	18.61	0.00	0.00	0	12.75	0.00	0.00	0.00	39	0	5.99	0	90	11.84
12/13/2011 17:09	19.06	0.00	0.00	0	12.75	0.00	0.00	0.00	39	0	0.00	0	90	0.00
12/13/2011 17:10	19.06	0.00	7.48	0	12.75	0.00	0.00	0.00	39	0	6.02	0	90	5.42
12/13/2011 17:11	19.11	0.00	8.25	0	12.75	0.00	0.00	0.00	39	0	5.94	0	90	11.36
12/13/2011 17:12	19.11	0.00	7.48	0	12.75	0.00	0.00	0.00	39	0	5.96	0	90	17.24
12/13/2011 17:13	19.17	0.00	9.13	0	12.70	0.00	0.00	0.00	39	0	5.91	0	90	23.58
12/13/2011 17:14	19.17	0.00	9.13	0	12.70	0.00	0.00	0.00	39	0	5.82	0	90	29.41
12/13/2011 17:15	19.17	0.00	7.70	0	12.65	0.00	0.00	0.00	36	0	0.00	0	90	30.39
12/13/2011 17:16	17.94	0.00	7.48	0	11.53	0.13	3.19	0.38	483	486	0.00	480	90	30.39
12/13/2011 17:17	15.94	0.00	8.03	2	12.16	0.53	3.05	0.54	148	633	0.00	624	90	30.39
12/13/2011 17:18	16.06	0.00	9.57	4	12.75	1.07	2.98	0.60	144	722	0.00	711	90	30.39
12/13/2011 17:19	16.17	0.00	8.25	5	12.84	1.67	2.99	0.60	131	715	0.00	714	90	30.39
12/13/2011 17:20	16.28	0.00	9.13	7	13.09	2.15	2.92	0.61	129	729	0.00	718	90	30.39
12/13/2011 17:21	16.44	0.00	9.13	9	13.33	2.70	2.94	0.64	380	784	0.00	774	90	30.39
12/13/2011 17:22	16.67	0.00	9.35	11	13.63	3.30	2.96	0.59	600	795	0.00	788	90	30.39
12/13/2011 17:23	16.83	0.00	10.12	13	13.87	3.88	2.95	0.60	368	805	0.00	798	90	30.39
12/13/2011 17:24	17.00	0.00	9.35	15	13.82	4.42	3.03	0.53	378	726	0.00	719	90	30.39
12/13/2011 17:25	17.17	0.00	10.12	16	13.97	4.90	3.05	0.52	385	727	0.00	723	90	30.39
12/13/2011 17:26	17.33	0.00	10.45	18	14.16	5.38	3.05	0.52	385	735	0.00	727	90	30.39
12/13/2011 17:27	17.50	0.00	10.45	19	14.31	5.86	3.04	0.51	380	735	0.00	730	90	30.39
12/13/2011 17:28	17.67	0.00	10.45	21	14.46	6.34	3.05	0.50	378	736	0.00	734	90	30.39
12/13/2011 17:29	17.83	0.00	11.00	22	14.70	6.78	3.06	0.49	393	745	0.00	739	90	30.39
12/13/2011 17:30	18.00	0.00	10.67	24	14.95	7.29	3.06	0.48	393	745	0.00	741	90	30.39
12/13/2011 17:31	18.17	0.00	11.00	25	15.09	7.67	3.06	0.46	393	757	0.00	745	90	30.39
12/13/2011 17:32	18.39	0.00	11.44	26	15.19	8.03	3.09	0.46	390	773	0.00	762	90	30.39
12/13/2011 17:33	18.61	0.00	11.00	28	15.38	8.36	3.09	0.44	388	789	0.00	777	90	30.39
12/13/2011 17:34	18.78	0.00	11.77	29	15.43	8.75	3.09	0.42	388	797	0.00	786	90	30.39
12/13/2011 17:35	19.00	0.00	11.99	30	15.58	9.11	3.13	0.38	398	761	0.00	753	90	30.39
12/13/2011 17:36	19.22	0.00	12.32	31	15.68	9.47	3.15	0.36	400	765	0.00	761	90	30.39
12/13/2011 17:37	19.39	0.00	11.99	32	15.82	9.72	3.16	0.33	400	778	0.00	770	90	30.39
12/13/2011 17:38	19.61	0.00	12.32	33	15.87	9.98	3.17	0.31	400	787	0.00	778	90	30.39
12/13/2011 17:39	19.83	0.00	12.32	34	15.92	10.22	3.22	0.29	402	802	0.00	790	90	30.39
12/13/2011 17:40	20.06	0.00	12.32	34	16.02	10.46	3.21	0.26	405	807	0.00	800	90	30.39
12/13/2011 17:41	20.28	0.00	12.87	35	16.02	10.66	3.23	0.23	410	825	0.00	810	90	30.39
12/13/2011 17:42	20.50	0.00	12.32	36	16.07	10.79	3.26	0.20	412	832	0.00	822	90	30.39
12/13/2011 17:43	20.72	0.00	13.09	36	16.07	10.91	3.29	0.17	422	844	0.00	831	90	30.39
12/13/2011 17:44	20.94	0.00	13.64	36	16.07	11.03	3.32	0.14	429	853	0.00	843	90	30.39

Table C6 – Data Log for 6/23/2011- 5,000 mg/L NaCl in Raw Water from Well 2

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
6/23/2011 11:04	22.00	0.00	0.00	0	0.29	0.00	0.00	0.00	7	0	0.00	0	60	0.00
6/23/2011 11:05	22.00	0.00	17.38	0	0.29	0.00	0.00	0.00	7	0	6.27	0	60	4.68
6/23/2011 11:06	22.00	0.00	10.12	0	0.29	0.00	0.00	0.00	7	0	6.15	0	60	11.34
6/23/2011 11:07	22.00	0.00	6.16	0	0.29	0.00	0.00	0.00	7	0	6.10	0	60	17.44
6/23/2011 11:08	22.00	0.00	4.29	0	0.29	0.00	0.00	0.00	7	0	0.00	0	60	20.51
6/23/2011 11:09	22.00	0.00	5.28	0	1.03	0.05	2.93	0.63	495	832	0.00	824	60	20.51
6/23/2011 11:10	26.06	0.00	5.06	3	13.33	0.65	2.73	0.69	1401	718	0.00	713	60	20.51
6/23/2011 11:11	26.56	0.00	6.38	6	12.70	1.20	2.75	0.69	1333	704	0.00	699	60	20.51
6/23/2011 11:12	26.78	0.00	6.38	9	12.94	1.80	2.75	0.70	1330	703	0.00	697	60	20.51
6/23/2011 11:13	26.94	0.00	6.71	12	13.33	2.45	2.74	0.70	1342	704	0.00	699	60	20.51
6/23/2011 11:14	27.17	0.00	7.48	15	13.72	3.05	2.74	0.70	1364	708	0.00	696	60	20.51
6/23/2011 11:15	27.39	0.00	7.70	18	14.16	3.60	2.76	0.70	1379	704	0.00	698	60	20.51
6/23/2011 11:16	27.56	0.00	8.80	20	14.70	4.20	2.76	0.70	1406	709	0.00	699	60	20.51
6/23/2011 11:17	27.78	0.00	8.80	24	15.29	4.85	2.74	0.69	1430	710	0.00	700	60	20.51
6/23/2011 11:18	28.11	0.00	9.35	26	15.87	5.45	2.74	0.69	1474	712	0.00	702	60	20.51
6/23/2011 11:19	28.28	0.00	10.12	29	16.56	6.00	2.75	0.70	1521	709	0.00	703	60	20.51
6/23/2011 11:20	28.56	0.00	10.12	32	17.29	6.60	2.75	0.70	1552	713	0.00	705	60	20.51
6/23/2011 11:21	28.78	0.00	11.00	35	18.02	7.20	2.77	0.69	1594	708	0.00	704	60	20.51
6/23/2011 11:22	29.11	0.00	11.99	38	18.95	7.85	2.76	0.70	1635	714	0.00	706	60	20.51
6/23/2011 11:23	29.39	0.00	13.09	41	19.78	8.45	2.78	0.70	1694	694	0.00	693	60	20.51
6/23/2011 11:24	29.67	0.00	13.42	44	20.81	9.00	2.79	0.70	1748	687	0.00	686	60	20.51
6/23/2011 11:25	29.94	0.00	15.51	47	22.03	9.60	2.79	0.70	1804	696	0.00	689	60	20.51
6/23/2011 11:26	30.33	0.00	16.28	50	23.25	10.25	2.79	0.70	1858	700	0.00	691	60	20.51
6/23/2011 11:27	30.72	0.00	17.71	53	24.66	10.85	2.81	0.70	1907	699	0.00	696	60	20.51
6/23/2011 11:28	31.06	0.00	19.03	56	26.32	11.40	2.81	0.70	1980	708	0.00	702	75	20.51
6/23/2011 11:29	31.50	0.00	20.90	59	27.99	12.00	2.81	0.70	2041	713	0.00	706	75	20.51
6/23/2011 11:30	31.89	0.00	22.99	61	29.99	12.60	2.82	0.70	2114	723	0.00	712	75	20.51
6/23/2011 11:31	32.39	0.00	25.74	64	32.28	13.20	2.84	0.70	2192	730	0.00	721	75	20.51
6/23/2011 11:32	32.94	0.00	27.83	67	34.92	13.80	2.85	0.67	2280	741	0.00	732	75	20.51
6/23/2011 11:33	33.56	0.00	31.90	70	37.80	14.40	2.88	0.63	2370	750	0.00	746	75	20.51
6/23/2011 11:34	34.17	0.00	35.09	73	40.54	14.96	2.93	0.58	2451	780	0.00	770	75	20.51

Table C7 – Data Log for 6/23/2011- - 10,000 mg/L NaCl in Raw Water from Well 2

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
6/23/2011 14:37	24.50	0.00	0.00	0	0.49	0.00	0.00	0.00	7	0	0.00	0	80	0.00
6/23/2011 14:38	24.44	0.00	25.07	0	0.54	0.00	0.00	0.00	7	0	6.19	0	80	5.69
6/23/2011 14:39	24.44	0.00	7.69	0	0.49	0.00	0.00	0.00	7	0	6.16	0	80	11.87
6/23/2011 14:40	24.39	0.00	34.32	0	0.54	0.00	0.00	0.00	7	0	6.18	0	80	18.02
6/23/2011 14:41	24.39	0.00	25.74	0	0.63	0.00	0.00	0.00	7	0	6.17	0	80	24.15
6/23/2011 14:42	24.33	0.00	21.45	0	0.54	0.00	0.00	0.00	7	0	0.46	0	80	30.25
6/23/2011 14:44	24.28	0.00	19.80	0	0.54	0.00	0.00	0.00	7	0	0.00	0	80	30.26
6/23/2011 14:45	28.39	0.00	20.13	2	27.40	0.53	2.90	0.69	295	637	0.00	626	80	30.26
6/23/2011 14:46	28.94	0.00	20.35	4	26.86	1.13	2.95	0.62	295	596	0.00	589	80	30.26
6/23/2011 14:47	29.00	0.00	20.90	6	27.30	1.73	2.95	0.61	302	597	0.00	591	80	30.26
6/23/2011 14:48	29.17	0.00	21.45	8	27.59	2.33	2.93	0.61	295	596	0.00	592	80	30.26
6/23/2011 14:49	29.28	0.00	22.22	10	27.89	2.93	2.94	0.61	295	603	0.00	595	80	30.26
6/23/2011 14:50	29.39	0.00	21.67	12	28.38	3.52	2.96	0.60	366	605	0.00	598	80	30.26
6/23/2011 14:51	29.44	0.00	22.55	14	28.77	4.09	2.94	0.59	368	606	0.00	600	80	30.26
6/23/2011 14:52	29.56	0.00	22.99	15	29.26	4.64	2.95	0.60	363	611	0.00	602	80	30.26
6/23/2011 14:53	29.61	0.00	23.87	17	29.60	5.13	2.96	0.59	361	611	0.00	602	80	30.26
6/23/2011 14:54	29.72	0.00	24.09	19	30.04	5.61	2.98	0.57	361	604	0.00	598	80	30.26
6/23/2011 14:55	29.83	0.00	24.42	20	30.43	6.09	2.99	0.57	356	606	0.00	597	80	30.26
6/23/2011 14:56	29.89	0.00	24.97	22	30.92	6.57	2.98	0.57	354	606	0.00	599	80	30.26
6/23/2011 14:57	30.00	0.00	25.19	23	31.45	7.05	2.99	0.57	351	609	0.00	600	80	30.26
6/23/2011 14:58	30.11	0.00	25.74	25	31.79	7.53	2.99	0.56	351	606	0.00	600	80	30.26
6/23/2011 14:59	30.22	0.00	26.84	26	32.43	8.01	2.99	0.55	349	610	0.00	601	80	30.26
6/23/2011 15:00	30.28	0.00	26.51	28	32.87	8.49	3.00	0.55	351	609	0.00	601	80	30.26
6/23/2011 15:01	30.44	0.00	27.61	30	33.41	8.97	3.01	0.54	349	615	0.00	605	80	30.26
6/23/2011 15:02	30.50	0.00	27.83	31	33.99	9.45	3.01	0.54	349	614	0.00	607	80	30.26
6/23/2011 15:03	30.61	0.00	28.93	33	34.58	9.93	3.00	0.53	351	616	0.00	607	80	30.26
6/23/2011 15:04	30.72	0.00	29.48	34	35.12	10.41	3.02	0.53	351	615	0.00	606	80	30.26
6/23/2011 15:05	30.83	0.00	29.81	36	35.70	10.89	3.01	0.52	354	613	0.00	607	80	30.26
6/23/2011 15:06	30.94	0.00	30.58	38	36.34	11.37	3.01	0.51	356	615	0.00	608	80	30.26
6/23/2011 15:07	31.06	0.00	30.80	39	37.07	11.85	3.00	0.53	356	629	0.00	621	80	30.26
6/23/2011 15:08	31.22	0.00	32.45	41	37.75	12.33	3.01	0.51	356	633	0.00	622	80	30.26
6/23/2011 15:09	31.33	0.00	33.22	42	38.39	12.81	3.02	0.51	363	636	0.00	624	80	30.26
6/23/2011 15:10	31.44	0.00	33.55	44	39.02	13.29	3.03	0.50	368	634	0.00	625	80	30.26
6/23/2011 15:11	31.56	0.00	33.77	46	39.76	13.77	3.05	0.50	376	636	0.00	629	80	30.26
6/23/2011 15:12	31.72	0.00	34.87	47	40.49	14.25	3.05	0.49	380	634	0.00	631	80	30.26
6/23/2011 15:13	31.83	0.00	35.09	49	41.27	14.73	3.04	0.49	390	635	0.00	633	80	30.26
6/23/2011 15:14	31.94	0.00	36.19	50	41.95	15.21	3.06	0.47	400	632	0.00	629	80	30.26
6/23/2011 15:15	32.11	0.00	36.96	51	42.64	15.57	3.08	0.45	417	627	0.00	620	80	30.26
6/23/2011 15:16	32.28	0.00	38.39	53	43.42	15.93	3.06	0.44	429	631	0.00	622	80	30.26
6/23/2011 15:17	32.39	0.00	38.61	54	44.15	16.29	3.05	0.44	441	631	0.00	625	80	30.26
6/23/2011 15:18	32.56	0.00	39.93	55	45.08	16.65	3.07	0.43	454	633	0.00	628	80	30.26
6/23/2011 15:19	32.67	0.00	40.48	56	45.86	17.01	3.09	0.43	471	640	0.00	629	80	30.26
6/23/2011 15:20	32.83	0.00	42.68	57	46.69	17.37	3.07	0.42	485	642	0.00	632	80	30.26
6/23/2011 15:21	33.00	0.00	43.23	59	47.62	17.73	3.09	0.41	503	641	0.00	634	80	30.26
6/23/2011 15:22	33.17	0.00	44.55	60	48.60	18.09	3.10	0.41	524	651	0.00	641	80	30.26
6/23/2011 15:23	33.33	0.00	45.32	61	49.47	18.45	3.09	0.39	544	651	0.00	639	80	30.26
6/23/2011 15:24	33.50	0.00	46.42	62	50.35	18.81	3.10	0.39	568	653	0.00	643	80	30.26
6/23/2011 15:25	33.67	0.00	48.07	63	51.33	19.17	3.12	0.38	588	658	0.00	647	80	30.26
6/23/2011 15:26	33.83	0.00	48.51	65	52.31	19.53	3.12	0.37	617	658	0.00	648	80	30.26
6/23/2011 15:27	34.06	0.00	49.94	66	53.28	19.89	3.11	0.36	647	662	0.00	652	80	30.26
6/23/2011 15:28	34.22	0.00	51.26	67	54.36	20.25	3.11	0.35	673	665	0.00	657	80	30.26
6/23/2011 15:29	34.39	0.00	53.13	68	55.48	20.49	3.14	0.34	705	665	0.00	661	80	30.26
6/23/2011 15:30	34.61	0.00	53.90	69	56.46	20.73	3.15	0.34	739	679	0.00	668	80	30.26
6/23/2011 15:31	34.78	0.00	56.10	69	57.68	20.97	3.15	0.33	771	681	0.00	673	80	30.26
6/23/2011 15:32	35.00	0.00	56.65	70	58.66	21.21	3.16	0.32	813	680	0.00	675	80	30.26
6/23/2011 15:33	35.22	0.00	57.97	71	59.88	21.45	3.15	0.31	857	690	0.00	681	80	30.26
6/23/2011 15:34	35.44	0.00	59.29	72	61.05	21.69	3.14	0.31	901	696	0.00	685	80	30.26
6/23/2011 15:35	35.61	0.00	60.61	72	62.17	21.93	3.18	0.29	949	698	0.00	691	80	30.26
6/23/2011 15:36	35.89	0.00	62.04	73	63.44	22.17	3.18	0.29	1008	707	0.00	696	80	30.26
6/23/2011 15:37	36.11	0.00	64.13	74	64.66	22.41	3.18	0.28	1059	711	0.00	700	80	30.26
6/23/2011 15:38	36.33	0.00	65.23	75	65.74	22.65	3.18	0.27	1113	713	0.00	706	80	30.26
6/23/2011 15:39	36.56	0.00	66.55	76	66.91	22.89	3.19	0.25	1181	718	0.00	709	80	30.26
6/23/2011 15:40	36.83	0.00	68.20	76	68.13	23.13	3.20	0.24	1257	722	0.00	713	80	30.26
6/23/2011 15:41	37.06	0.00	69.52	77	69.30	23.33	3.21	0.23	1345	727	0.00	718	80	30.26
6/23/2011 15:42	37.28	0.00	71.39	77	70.53	23.45	3.22	0.22	1430	732	0.00	720	80	30.26
6/23/2011 15:43	37.50	0.00	73.59	78	71.75	23.57	3.20	0.21	1533	734	0.00	726	80	30.26
6/23/2011 15:44	37.78	0.00	74.58	78	72.82	23.69	3.22	0.19	1643	734	0.00	730	80	30.26
6/23/2011 15:45	38.06	0.00	76.23	79	73.99	23.81	3.22	0.18	1760	738	0.00	731	80	30.26
6/23/2011 15:46	38.33	0.00	77.88	79	75.12	23.93	3.24	0.17	1899	743	0.00	738	80	30.26
6/23/2011 15:47	38.61	0.00	79.42	79	76.19	24.05	3.23	0.16	2048	749	0.00	739	80	30.26

Table C8 – Data Log for 11/18/2011- - 10,000 mg/L NaCl in 50% RO Concentrate Feed

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
11/18/2011 16:26	20.94	0.00	0.00	0	5.67	0.00	0.00	0.00	7	0	0.00	0	90	0.00
11/18/2011 16:27	20.89	0.00	8.25	0	5.86	0.00	0.00	0.00	7	0	6.20	0	90	5.64
11/18/2011 16:28	20.94	0.00	8.25	0	6.06	0.00	0.00	0.00	7	0	6.12	0	90	11.73
11/18/2011 16:29	20.89	0.00	33.55	0	6.30	0.00	0.00	0.00	7	0	6.05	0	90	17.77
11/18/2011 16:30	20.89	0.00	26.51	0	6.50	0.00	0.00	0.00	7	0	5.98	0	90	23.78
11/18/2011 16:31	20.94	0.00	22.55	0	6.64	0.00	0.00	0.00	7	0	0.02	0	90	29.24
11/18/2011 16:32	20.89	0.00	22.22	0	6.79	0.00	0.00	0.00	7	0	0.00	0	90	29.24
11/18/2011 16:33	19.83	0.00	22.22	1	29.11	0.42	3.00	0.58	476	760	0.00	756	90	29.24
11/18/2011 16:34	19.94	0.00	22.55	3	29.60	0.90	3.01	0.56	393	751	0.00	746	90	29.24
11/18/2011 16:35	20.06	0.00	22.77	5	30.09	1.38	3.00	0.55	388	756	0.00	750	90	29.24
11/18/2011 16:36	20.22	0.00	23.87	6	30.48	1.86	3.00	0.55	380	758	0.00	751	90	29.24
11/18/2011 16:37	20.39	0.00	23.87	8	30.96	2.34	2.99	0.54	378	759	0.00	751	90	29.24
11/18/2011 16:38	20.50	0.00	23.87	10	31.31	2.82	3.00	0.54	376	759	0.00	756	90	29.24
11/18/2011 16:39	20.61	0.00	23.87	11	31.79	3.30	3.00	0.54	380	767	0.00	757	90	29.24
11/18/2011 16:40	20.83	0.00	24.42	13	32.28	3.78	3.00	0.53	434	765	0.00	759	90	29.24
11/18/2011 16:41	20.94	0.00	24.97	15	32.72	4.26	3.01	0.53	434	766	0.00	759	90	29.24
11/18/2011 16:42	21.11	0.00	25.74	16	33.16	4.74	3.01	0.52	429	761	0.00	754	90	29.24
11/18/2011 16:43	21.22	0.00	26.29	18	33.65	5.22	3.01	0.52	434	761	0.00	754	90	29.24
11/18/2011 16:44	21.39	0.00	26.51	19	34.09	5.70	3.02	0.52	429	764	0.00	756	90	29.24
11/18/2011 16:45	21.61	0.00	27.61	21	34.58	6.18	3.01	0.52	429	760	0.00	755	90	29.24
11/18/2011 16:46	21.67	0.00	28.16	23	35.21	6.66	3.03	0.52	429	758	0.00	757	90	29.24
11/18/2011 16:47	21.89	0.00	28.38	24	35.65	7.14	3.02	0.51	429	766	0.00	755	90	29.24
11/18/2011 16:48	22.06	0.00	28.93	26	36.19	7.62	3.03	0.51	429	760	0.00	756	90	29.24
11/18/2011 16:49	22.22	0.00	29.26	28	36.83	8.10	3.03	0.50	429	762	0.00	760	90	29.24
11/18/2011 16:50	22.39	0.00	29.81	29	37.31	8.58	3.02	0.50	429	762	0.00	759	90	29.24
11/18/2011 16:51	22.61	0.00	30.58	31	38.00	9.06	3.01	0.50	434	771	0.00	764	90	29.24
11/18/2011 16:52	22.78	0.00	31.13	33	38.73	9.54	3.03	0.51	429	779	0.00	776	90	29.24
11/18/2011 16:53	23.00	0.00	31.90	34	39.37	10.02	3.01	0.51	434	782	0.00	778	90	29.24
11/18/2011 16:54	23.17	0.00	33.00	36	40.05	10.50	3.01	0.50	434	786	0.00	783	90	29.24
11/18/2011 16:55	23.39	0.00	33.22	38	40.73	10.98	3.02	0.50	437	793	0.00	781	90	29.24
11/18/2011 16:56	23.56	0.00	33.77	39	41.42	11.46	3.01	0.50	441	793	0.00	786	90	29.24
11/18/2011 16:57	23.78	0.00	34.87	41	42.15	11.94	3.02	0.49	446	790	0.00	781	90	29.24
11/18/2011 16:58	23.94	0.00	35.97	42	42.88	12.42	3.03	0.48	449	794	0.00	786	90	29.24
11/18/2011 16:59	24.17	0.00	36.52	44	43.71	12.90	3.03	0.48	454	795	0.00	787	90	29.24
11/18/2011 17:00	24.39	0.00	37.84	46	44.49	13.37	3.04	0.48	459	801	0.00	790	90	29.24
11/18/2011 17:01	24.61	0.00	37.84	47	45.32	13.81	3.03	0.47	461	798	0.00	792	90	29.24
11/18/2011 17:02	24.83	0.00	39.16	48	46.20	14.17	3.04	0.46	466	800	0.00	795	90	29.24
11/18/2011 17:03	25.06	0.00	39.93	50	47.08	14.53	3.05	0.46	476	810	0.00	798	90	29.24
11/18/2011 17:04	25.28	0.00	41.36	51	48.01	14.89	3.03	0.46	483	804	0.00	801	90	29.24
11/18/2011 17:05	25.56	0.00	41.36	52	48.89	15.25	3.04	0.45	490	815	0.00	806	90	29.24
11/18/2011 17:06	25.78	0.00	43.23	53	49.87	15.61	3.05	0.45	498	821	0.00	809	90	29.24
11/18/2011 17:07	26.00	0.00	45.10	55	50.79	15.97	3.06	0.44	510	817	0.00	806	90	29.24
11/18/2011 17:08	26.28	0.00	45.32	56	51.82	16.33	3.07	0.43	520	819	0.00	808	90	29.24
11/18/2011 17:09	26.50	0.00	46.64	57	52.80	16.69	3.07	0.43	532	822	0.00	812	90	29.24
11/18/2011 17:10	26.78	0.00	47.19	58	53.87	17.05	3.07	0.41	544	825	0.00	815	90	29.24
11/18/2011 17:11	27.06	0.00	48.51	60	54.51	17.41	3.11	0.37	583	779	0.00	776	90	29.24
11/18/2011 17:12	27.28	0.00	49.94	61	55.48	17.77	3.14	0.36	605	785	0.00	774	90	29.24
11/18/2011 17:13	27.56	0.00	51.26	62	56.46	18.13	3.15	0.36	620	787	0.00	778	90	29.24
11/18/2011 17:14	27.78	0.00	52.58	63	57.53	18.45	3.13	0.35	637	792	0.00	782	90	29.24
11/18/2011 17:15	28.11	0.00	53.90	64	58.51	18.69	3.14	0.34	659	787	0.00	778	90	29.24
11/18/2011 17:16	28.33	0.00	55.00	65	59.49	18.93	3.14	0.32	686	783	0.00	774	90	29.24
11/18/2011 17:17	28.61	0.00	56.65	66	60.56	19.17	3.16	0.31	715	780	0.00	775	90	29.24
11/18/2011 17:18	28.94	0.00	57.97	66	61.59	19.41	3.17	0.30	742	789	0.00	779	90	29.24
11/18/2011 17:19	29.22	0.00	59.29	67	62.76	19.65	3.17	0.30	756	796	0.00	793	90	29.24
11/18/2011 17:20	29.50	0.00	60.39	68	63.69	19.89	3.18	0.29	783	803	0.00	798	90	29.24
11/18/2011 17:21	29.78	0.00	61.16	69	64.76	20.13	3.17	0.28	808	811	0.00	802	90	29.24
11/18/2011 17:22	30.11	0.00	63.03	70	65.74	20.37	3.20	0.26	837	816	0.00	809	90	29.24
11/18/2011 17:23	30.44	0.00	64.68	70	66.86	20.61	3.20	0.25	866	825	0.00	814	90	29.24
11/18/2011 17:24	30.72	0.00	65.78	71	67.79	20.84	3.21	0.24	898	834	0.00	823	90	29.24
11/18/2011 17:25	31.06	0.00	66.55	72	68.62	20.96	3.22	0.22	930	833	0.00	829	90	29.24
11/18/2011 17:26	31.33	0.00	68.75	72	69.40	21.08	3.25	0.19	971	855	0.00	844	90	29.24
11/18/2011 17:27	31.72	0.00	69.19	73	70.04	21.20	3.27	0.17	1015	860	0.00	853	90	29.24
11/18/2011 17:28	31.94	0.00	71.39	73	70.57	21.32	3.28	0.14	1076	880	0.00	867	90	29.24
11/18/2011 17:29	32.22	0.00	71.94	73	70.62	21.36	3.32	0.09	1179	836	0.00	825	90	29.24
11/18/2011 17:30	32.44	0.00	72.71	73	70.96	21.36	3.34	0.08	1377	848	0.00	833	90	29.24

Table C9 – Data Log for 12/13/2011 – 20 ppm Antiscalant in 49% RO Concentrate Feed

Date	Temp (C)	pH	Tank Cond (mS/cm)	Recovery (%)	Conc Cond (mS/cm)	Perm Totalizer (Gal)	Conc Flow (GPM)	Perm Flow (GPM)	Perm Cond (uS/cm)	Feed Press (psi)	Feed Flow (GPM)	Conc Press (psi)	Recovery Target (%)	Batch Size (Gal)
12/13/2011 14:57	18.89	0.00	0.00	0	11.28	0.00	0.00	0.00	31	0	0.00	0	90	0.00
12/13/2011 14:58	18.89	0.00	6.38	0	11.43	0.00	0.00	0.00	31	0	6.12	0	90	6.07
12/13/2011 14:59	18.89	0.00	6.93	0	11.43	0.00	0.00	0.00	31	0	6.12	0	90	12.10
12/13/2011 15:00	18.94	0.00	8.25	0	11.43	0.00	0.00	0.00	31	0	6.07	0	90	17.61
12/13/2011 15:01	18.94	0.00	7.48	0	11.43	0.00	0.00	0.00	31	0	6.03	0	90	24.08
12/13/2011 15:02	18.94	0.00	7.70	0	11.38	0.00	0.00	0.00	31	0	5.88	0	90	29.51
12/13/2011 15:03	19.00	0.00	8.25	0	11.43	0.00	0.00	0.00	31	0	0.00	0	90	30.05
12/13/2011 15:04	17.61	0.00	7.48	1	11.97	0.19	2.89	0.69	229	757	0.00	746	90	30.05
12/13/2011 15:05	16.06	0.00	8.25	3	12.26	0.79	2.99	0.60	327	694	0.00	690	90	30.05
12/13/2011 15:06	16.06	0.00	8.03	5	12.41	1.38	3.00	0.59	319	694	0.00	689	90	30.05
12/13/2011 15:07	16.22	0.00	8.25	6	12.70	1.90	3.00	0.59	314	698	0.00	690	90	30.05
12/13/2011 15:08	16.33	0.00	8.03	8	12.89	2.38	2.99	0.59	312	700	0.00	698	90	30.05
12/13/2011 15:09	16.50	0.00	8.25	9	13.09	2.86	2.98	0.59	305	704	0.00	697	90	30.05
12/13/2011 15:10	16.67	0.00	10.12	11	13.33	3.34	2.98	0.58	305	699	0.00	691	90	30.05
12/13/2011 15:11	16.78	0.00	9.13	13	13.48	3.82	2.99	0.58	302	700	0.00	692	90	30.05
12/13/2011 15:12	16.89	0.00	9.35	14	13.72	4.30	2.98	0.58	329	703	0.00	693	90	30.05
12/13/2011 15:13	17.11	0.00	10.12	16	13.97	4.74	3.00	0.57	339	701	0.00	691	90	30.05
12/13/2011 15:14	17.28	0.00	9.35	18	14.11	5.26	3.01	0.56	339	689	0.00	686	90	30.05
12/13/2011 15:15	17.44	0.00	10.45	19	14.21	5.74	3.01	0.56	339	693	0.00	685	90	30.05
12/13/2011 15:16	17.61	0.00	9.35	21	14.55	6.22	3.01	0.56	336	695	0.00	687	90	30.05
12/13/2011 15:17	17.78	0.00	10.12	22	14.70	6.66	3.01	0.56	336	693	0.00	687	90	30.05
12/13/2011 15:18	17.94	0.00	11.00	24	14.95	7.18	3.00	0.56	336	694	0.00	687	90	30.05
12/13/2011 15:19	18.17	0.00	10.67	25	15.19	7.66	3.01	0.56	336	701	0.00	694	90	30.05
12/13/2011 15:20	18.33	0.00	11.44	27	15.43	8.14	3.01	0.55	336	698	0.00	694	90	30.05
12/13/2011 15:21	18.56	0.00	11.00	29	15.78	8.62	3.02	0.55	336	701	0.00	696	90	30.05
12/13/2011 15:22	18.72	0.00	11.77	30	16.02	9.10	3.02	0.54	336	709	0.00	699	90	30.05
12/13/2011 15:23	18.89	0.00	12.32	32	16.31	9.58	3.03	0.54	332	712	0.00	699	90	30.05
12/13/2011 15:24	19.11	0.00	11.77	33	16.56	10.02	3.03	0.53	332	708	0.00	700	90	30.05
12/13/2011 15:25	19.33	0.00	13.09	35	16.80	10.54	3.04	0.53	332	706	0.00	705	90	30.05
12/13/2011 15:26	19.50	0.00	13.42	37	17.14	11.02	3.04	0.52	332	719	0.00	708	90	30.05
12/13/2011 15:27	19.72	0.00	13.09	38	17.39	11.50	3.04	0.50	332	720	0.00	712	90	30.05
12/13/2011 15:28	19.94	0.00	13.42	40	17.73	11.94	3.05	0.49	332	721	0.00	716	90	30.05
12/13/2011 15:29	20.17	0.00	13.64	41	17.97	12.46	3.07	0.48	329	735	0.00	722	90	30.05
12/13/2011 15:30	20.39	0.00	13.64	43	18.27	12.88	3.06	0.46	329	735	0.00	728	90	30.05
12/13/2011 15:31	20.61	0.00	14.19	44	18.51	13.24	3.08	0.44	329	743	0.00	735	90	30.05
12/13/2011 15:32	20.89	0.00	14.96	45	18.71	13.60	3.09	0.43	329	755	0.00	744	90	30.05
12/13/2011 15:33	21.17	0.00	16.06	46	19.00	13.96	3.11	0.40	329	759	0.00	752	90	30.05
12/13/2011 15:34	21.39	0.00	16.06	48	19.19	14.32	3.13	0.38	329	771	0.00	761	90	30.05
12/13/2011 15:35	21.67	0.00	15.84	49	19.44	14.63	3.14	0.35	329	776	0.00	771	90	30.05
12/13/2011 15:36	21.89	0.00	16.28	49	19.58	14.87	3.18	0.32	329	789	0.00	782	90	30.05
12/13/2011 15:37	22.17	0.00	16.28	50	19.73	15.11	3.20	0.29	327	804	0.00	793	90	30.05
12/13/2011 15:38	22.44	0.00	17.38	51	19.83	15.35	3.24	0.26	329	814	0.00	803	90	30.05
12/13/2011 15:39	22.72	0.00	16.83	52	19.98	15.55	3.24	0.22	329	820	0.00	815	90	30.05
12/13/2011 15:40	23.00	0.00	17.71	52	20.07	15.67	3.26	0.19	336	833	0.00	826	90	30.05
12/13/2011 15:41	23.33	0.00	17.71	53	20.17	15.79	3.28	0.17	339	846	0.00	835	90	30.05
12/13/2011 15:42	23.61	0.00	17.71	53	20.17	15.91	3.32	0.13	349	794	0.00	788	90	30.05
12/13/2011 15:43	23.83	0.00	18.48	53	20.32	16.00	3.35	0.11	363	805	0.00	792	90	30.05
12/13/2011 15:44	24.11	0.00	18.48	53	20.32	16.00	3.36	0.10	373	807	0.00	799	90	30.05
12/13/2011 15:45	24.39	0.00	18.48	53	20.32	16.00	3.36	0.08	385	808	0.00	802	90	30.05
12/13/2011 15:46	24.67	0.00	18.48	53	20.42	16.00	3.37	0.07	398	811	0.00	808	90	30.05
12/13/2011 15:47	24.94	0.00	18.48	53	20.42	16.00	3.38	0.06	412	822	0.00	811	90	30.05
12/13/2011 15:48	25.17	0.00	18.48	53	20.46	16.00	3.40	0.05	434	830	0.00	815	90	30.05
12/13/2011 15:49	25.44	0.00	18.48	53	20.46	16.00	3.41	0.04	454	832	0.00	820	90	30.05
12/13/2011 15:50	25.61	0.00	18.26	53	20.42	16.00	3.40	0.04	214	831	0.00	821	90	30.05

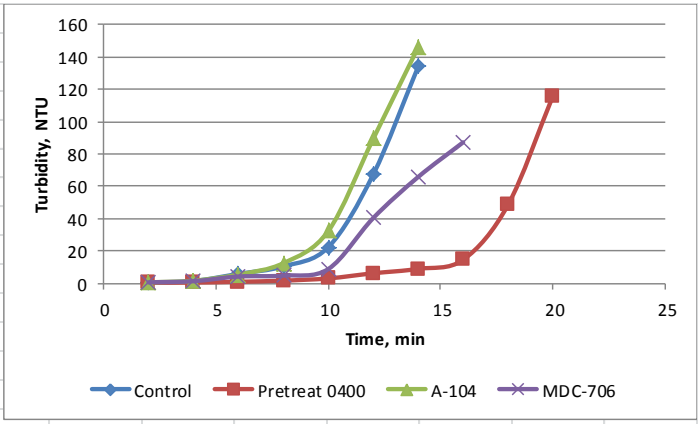
Appendix D Tables

Table *Page*

Appendix D

Table D1: Run 1 - Three Antiscalants at 0.8 ppm and 0.04 M $CaSO_4$ Addition

		Turbidity		
Time	**Control**	**Pretreat 0400**	**A-104**	**MDC-706**
2	0.48	0.45	0.64	0.64
4	1.48	0.51	1.66	1.35
6	5.86	0.98	5.48	4.24
8	10.5	1.7	12.48	4.81
10	22.4	3.07	32.4	8.88
12	67.35	6.25	89.4	40.4
14	134	8.97	146	65.8
16		14.6		87.2
18		48.6		
20		116		



Notes:

460 ml of Alamogordo Water were used

pH was adjusted to 3.94. It appears that pH does not change during reaction

Different amounts of $CaCl_2$ and $NaSO_4$ were added to Alamogordo water

A test with 10 ml of 1 M solution was made, but did not precipitate.

20 ml of 1 M solution of both compounds were added to 460 ml of Alamogordo water

Turbidity was appearing very fast when $NaSO_4$ was added

Table D2: Run 2 - Three Antiscalants at 0.8 ppm and 0.02 M $CaSO_4$ Addition

	Turbidity			
Time	Control	Pretreat 0400	A-104	MDC-706
2	0.71	0.65	0.39	0.64
4	1.2	0.63	0.38	0.66
6	1.05	0.61	0.46	0.62
8	1.37	0.65	0.45	0.68
10	1.52	0.63	0.45	0.67
12	1.67	0.62	0.48	0.62
14	2.59	0.61	0.52	0.68
16	3.38	0.62	0.57	0.59
18	3.55	0.64	0.69	0.65
20	4.99	0.68	0.72	0.66
22	7.18	0.64	1.06	0.69
24	10.5	0.65	0.89	0.72
26	10.9	0.6	0.85	0.75
28	12.4	0.73	0.98	0.78
30	16.9	0.71	1.05	0.75
32	21.5	0.68	1.24	0.71
34	24.8	0.71	1.18	0.72
36	28.6	0.89	1.31	0.8
38	38.4	0.88	1.52	0.84
40	43.38	0.75	1.45	0.79
42		0.75	1.49	0.82
44		0.73	1.64	0.95
46		0.89	1.75	0.92
48		0.97	1.68	0.91
50		1.05	1.72	1.05
52		1.14	1.69	1.09
54		1.21	1.72	1.2
56		1.18	1.72	1.18
58		1.2	1.68	1.32
60		1.15	1.94	1.28
70		1.25	1.98	1.54
80		1.54	2.13	1.86

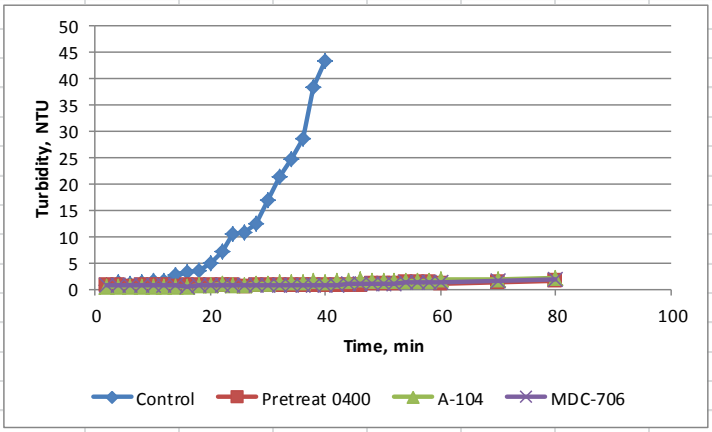


Table D3: Run 3 - Three Antiscalants at 0.8 ppm and 0.03 M $CaSO_4$ Addition

	Turbidity			
Time	**Control**	**Pretreat 0400**	**A-104**	**MDC-706**
2	0.71	0.41	0.65	0.43
4	1.66	0.44	0.61	0.4
6	3.2	0.56	1.2	0.39
8	6.61	0.64	1.88	0.49
10	12.4	0.59	5.54	0.59
12	26.3	0.95	8.46	0.52
14	46.5	1.05	13.3	0.54
16	69.3	1.16	21.4	0.56
18		1.41	35.9	0.62
20		1.48	56.8	0.89
22		1.54		0.92
24		1.88		1.02
26		2.09		1.16
28		2.22		1.35
30		3.5		1.91
32		3.42		2.23
34		3.84		2.41
36		4.24		3.54
38		4.94		4.15
40		6.44		4.84
42		6.99		5.25
44		8.03		6.84
46		9.52		10.3
48		10.8		14.6
50		12.3		22.3
52		14.1		35.4
54		15.3		66.3
56		16.5		89.9

Notes:

7.5 mL of 1M solution of CaCl2 and Na2SO4 were added to 235 mL of Alamogordo Water

pH 3.5

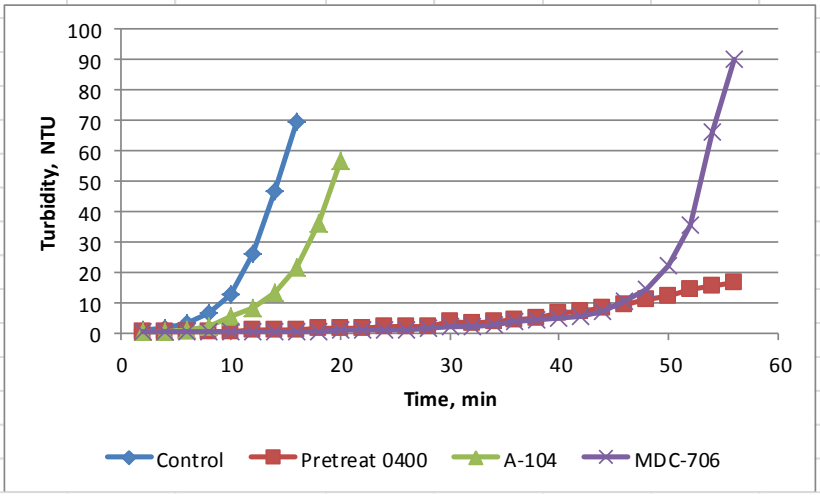


Table D4: Run 4 - Seven Antiscalants at 0.8 ppm and 0.03 M $CaSO_4$ Addition

	Turbidity							
Time	Control	Pretreat 0400	A-104	MDC-706	Trisep 3150	Trisep 4150	Trisep 6150	Trisep 7150
2	0.3	0.28	0.34	0.54	0.3	0.52	0.31	0.31
4	0.28	0.35	0.32	0.55	0.35	0.35	0.32	0.32
6	0.31	0.39	0.28	0.71	0.37	0.39	0.34	0.36
8	0.34	0.42	0.31	0.64	0.55	0.49	0.33	0.39
10	0.33	0.45	0.45	0.66	0.57	0.62	0.31	0.52
12	0.48	0.54	0.72	0.82	0.54	1.57	0.35	0.49
14	0.73	0.66	1.5	0.91	0.82	1.96	0.44	0.66
16	1.51	1.12	2.22	1.3	1.05	3.13	0.49	1.26
18	2.3	1.25	3.39	1.8	1.22	5.52	0.64	1.52
20	5.94	1.3	6.6	2.1	1.35	6.22	0.67	2.86
22	7.3	2.19	10.4	3.22	1.86	10.8	1.3	5.42
24	12.4	2.31	18.5	4.54	2.41	14.4	1.4	9.62
26	23.1	2.98	24.5	8.21	3.32	19.1	1.65	15.1
28	35.4	3.47	30.9	8.6	3.49	31.8	2.12	23.5
30	42	5.28	41.2	11.1	4.23	34.7	2.84	31.9
32		5.8		16.4	6.22		2.93	
34		6.42		24.2	7.89		3.57	
36		6.75		25.5	10.2		5.46	
38		7.27		38.1	11.2		5.72	
40		8.38		39.9	16.8		8.1	
42		10.1			21.2		8.54	
44		13.5			25.1		10.5	
46		15.2			31.7		16.1	
48		16.1			38.2		20.9	
50		22.8			49		35.2	
60		44.3						

Notes:

7.5 mL of 1M solution of $CaCl_2$ and Na_2SO_4 were added to 235 mL of Alamogordo Water

pH 3.5

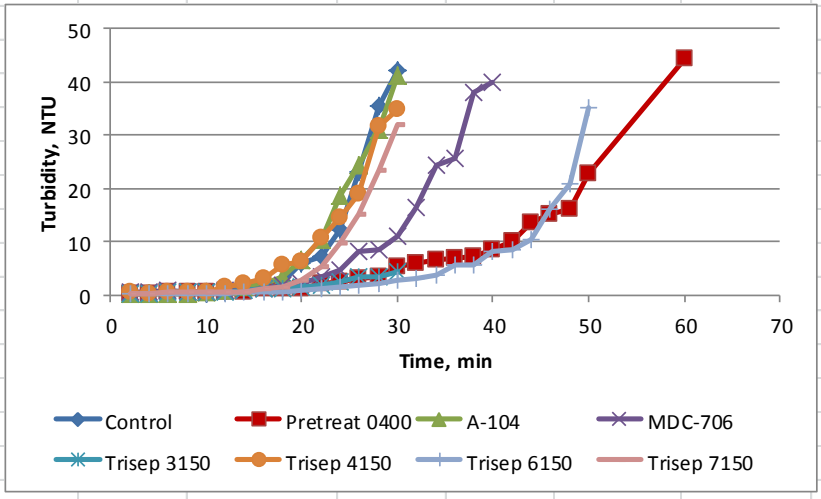


Table D5: Run 5 – Three Antiscalants at 2 ppm and 0.04 M $CaSO_4$ Addition

	Turbidity			Turbidity			Turbidity
Time	Control		Time	Pretreat 0400	Trisep 6150	Time	A-104
2	0.547		0	0.22	0.29	0	0.33
4	0.57		10	0.26	0.46	5	0.41
6	0.9		20	0.27	0.63	10	0.42
8	1.52		30	0.61	1.19	15	0.5
10	1.96		40	0.53	1.36	20	0.46
12	4.08		50	0.75	1.88	25	0.49
14	7.6		60	0.91	2.61	30	0.38
16	10.6		70	1.21	3.76	35	0.51
18	15.3		80	1.45	5.08	40	0.58
			90	1.91	6.41	50	0.71
			100	2.33	7.26	60	1.25
			110	2.55	8.65	90	4.5
			120	3.01	10.7	100	5.5
			130	3.48	11.5	110	7.31
			140	4.38	14.1	120	10.3
			150	5.51		130	17.5
			160	6.09			
			280	13.3			
			1100	3234			

Notes:
pH 3.5

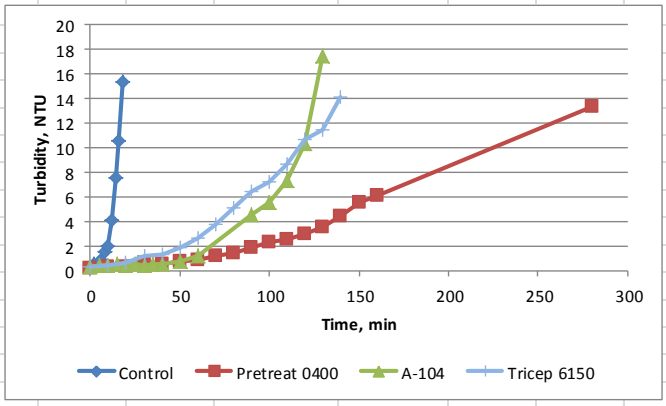


Table D6: Run 6 – Two Antiscalants at 5 ppm and 0.06 M $CaSO_4$ Addition

	Turbidity	
Time	**Pretreat 0400**	**Trisep 6150**
0	0.19	0.17
10	0.55	0.54
20	1.16	4.22
30	2.39	41.9
40	4.21	
50	7.8	
60	17	
70	21.9	

Notes:
pH 4.2

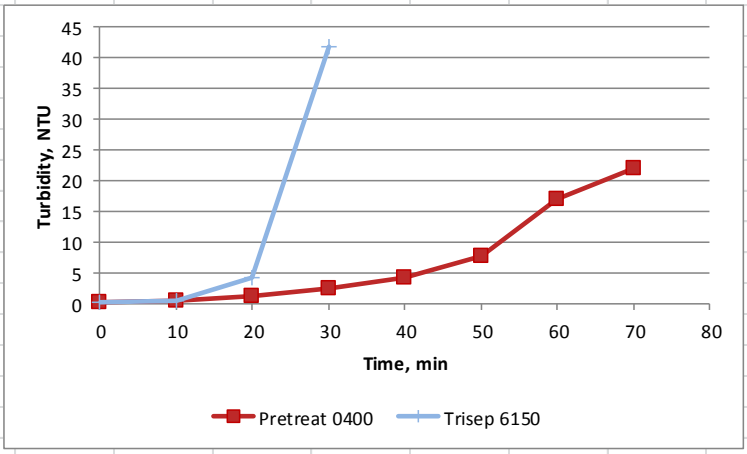


Table D7: Run 7 – Pretreat Plus 0400 at 1 to 6 ppm and 0.05 M $CaSO_4$ Addition

	Turbidity
Time	Control
2	0.51
4	0.75
6	3.66
8	20.5
10	

Time	1 ppm
0	0.48
5	0.5
10	0.62
15	0.65
20	0.65
25	0.66
30	0.73
35	0.89
40	0.89
45	1.13
50	1.31
55	1.45
60	1.85
65	2.45
70	3.08
75	3.05
80	5.21
85	6.44

	Turbidity		
Time	2 ppm	3 ppm	4 ppm
0	0.42	0.4	0.4
10	0.52	0.42	0.46
20	0.58	0.55	0.5
30	0.59	0.48	0.49
40	0.69	0.52	0.53
50	0.76	0.6	0.54
60	0.82	0.68	0.61
70	0.94	0.69	0.72
80	1.05	0.8	0.76
90	1.2	1.09	0.7
100	1.11	1.15	0.77
110	1.69	1.35	0.76
120	1.85	1.32	0.89
130	2.02	1.45	0.99
140	2.19	1.96	1.32
150	2.42	2.23	1.18
160	2.77	2.49	1.12
170	3.38	2.78	1.62
180	3.69	2.99	1.85
190	4.22	3.2	1.99
200	4.6	3.46	2.15
210	5.33	3.52	2.1
220		4.15	2.18
230		4.06	2.32
240		4.37	2.17
250		4.45	2.34
260		5.15	2.42
270		5.39	2.63

	Turbidity	
Time	5 ppm	6 ppm
0	0.33	0.34
20	0.36	0.35
40	0.36	0.32
80	0.42	0.3
100	0.49	0.32
120	0.49	0.42
140	0.49	0.32
160	0.58	0.45
180	0.6	0.42
200	0.88	0.55
220	1.22	0.6
260	1.65	0.55
280	1.7	0.7
300	2.05	0.65
320	1.88	0.89
340	2.2	1.08
360	2.18	0.95
380	2.51	0.99
400	2.61	1.36
420	3.19	1.21
440	3.39	1.29
460	3.91	1.39
480	3.8	1.35
500	4.82	1.32
520	5.28	1.51
540	5.73	1.87
718		5

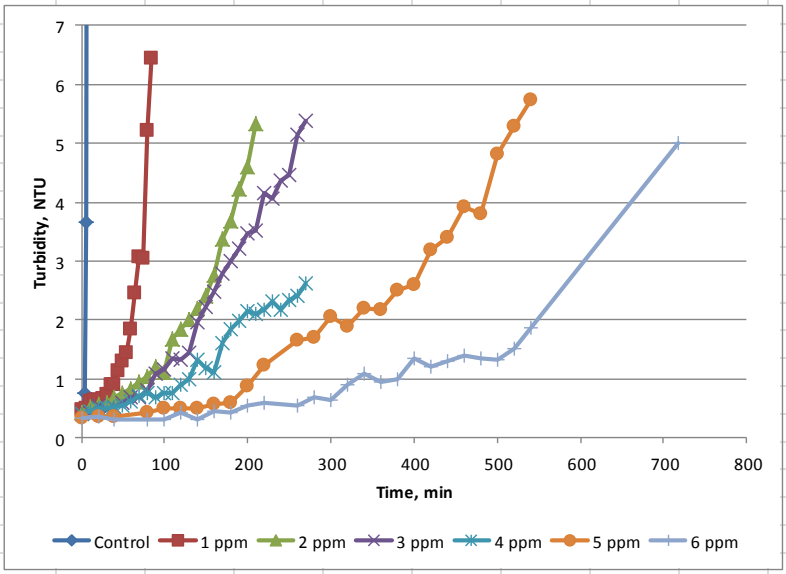


Table D8: Run 8 – Pretreat Plus 0400 at 5 to 30 ppm and 0.1 M $CaSO_4$ Addition

	Turbidity
Time	Control
0	0.41
2	50

	Turbidity	
Time	5 ppm	10 ppm
0	0.41	0.76
2	1.96	2.28
4	20.6	3.12
6		6.08
8		12.3

	Turbidity		
Time	15 ppm	20 ppm	30 ppm
0	0.47	0.41	0.41
5	0.66	0.42	0.41
10	1.78	0.49	0.42
15	10.3	0.64	0.51
20		0.85	0.59
25		1.02	0.84
30		1.25	0.95
35		1.59	0.99
40		1.89	1.12
45		1.9	1.32
50		2.09	1.35
55		2.25	1.69
60		2.71	1.72
65		3.12	2
70		3.45	2.3
75		4.08	2.7
80		4.6	2.8
85		5	3.62
90		5.8	3.89
95			4.62
100			4.89
105			5.38