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Coal Bed Natural Gas Produced Water Preliminary Pilot Plant Operation and Results

ConocoPhillips Well Site SAN JUAN 32-8 #237A

Malynda Aragon, Randy Everett, William Holub, Richard Kottenstette, Allan Sattler (Sandia National Laboratories)

and

ConocoPhillips, San Juan Operating Unit

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Abstract

Partnering with ConocoPhillips (CP), Biosphere Environmental (BEST), New Mexico State University (NMSU), and the US Department of Agriculture (USDA), Sandia National Laboratories is performing pilot studies at a coal bed natural gas (CBNG) pad site in the Four Corners Area near Navajo Dam, NM. This report covers the preliminary activities at the pilot site during 2007.

In the extraction of natural gas from coal-seam beds, there is a considerable amount of brackish water (water quality can range up to 60,000 mg/L TDS or higher) produced from a CBNG well. This produced water could pose environmental problems if untreated and is typically disposed of via injection wells or other disposal methods. The expenses for hauling off and disposing of produced water and could restrict the production of natural gas from coal beds. In this project, the produced water from the CBNG wells is desalinated to less than 1000 mg/L TDS.

Land application of two types of water (untreated and treated) and natural rainfall near the well site for rangeland and impaired riparian improvement is conducted by the NMSU Agriculture Science Center of Farmington and the USDA, Jornada Experimental Range, Las Cruces. This

work has been conducted with the approval and permits from of US Bureau of Land Management (BLM) and the NM Oil Conservation Division (OCD). Soil experiments using both treated and untreated produced water are applied to the existing rangeland grasses on the well/pad site.

Acknowledgements

This project would not have been possible without the generous collaboration of Frank McDonald, Biosphere Environmental, and Professor Rick Arnold of the Agricultural Sciences Center at Farmington. We gratefully acknowledge the partnership of Bob Wirtanen, Monica Johnson, Rebekah Miller; and Jimmy Bowman at ConocoPhillips who provided extensive site-work, an electrical generator, access to the coal bed derived water and safety provisions. Their professional staff and operators provided essential support to this project which could not have been completed without their professional and timely assistance.

The continuing support of David Borns, Mark Rigali, and John Merson at Sandia National Laboratories, as well as the continuing interest of and association with the U. S. Bureau of Land Management, Farmington, and the New Mexico Oil Conservation Division, Aztec in this endeavor is gratefully acknowledged.

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Acronyms and Abbreviations

AA	atomic absorption
BBL	US barrel, defined as 42 gallons
CBNG	coal bed natural gas
CP	ConocoPhillips
BPD	barrels per day
B.E.S.T.	Biosphere Sciences and Technologies
EIA	Energy Information Agency
gpm	gallons per minute
ICP, ICP-MS	inductively coupled plasma mass spectrometer
kwh	kilowatt hour
Mcf/d	1000 cubic feet per day
mg/L	milligrams per liter
μm	micrometer or micron
μg/L	micrograms per liter
μS/cm	microSiemens per centimeter (conductivity)
NMOCD	New Mexico Oil Conservation Division
NTU	nephelometric turbidity units
O&M	operations and maintenance
ppb	parts per billion
psi	pounds per square inch
PVC	polyvinyl chloride
RO	reverse osmosis
SNL	Sandia National Laboratories
SWD	salt water disposal facility
TOC	total organic carbon
TDS	total dissolved solids
TFC	thin film composite
TSS	total suspended solids
USBLM	U. S. Bureau of Land Management
USEPA	U.S. Environmental Protection Agency
USDA	U.S. Department of Agriculture

1. Introduction

1.1. Produced Water Background

Coal Bed Natural Gas (CBNG) accounted for over 10 percent of natural gas production in the U.S. in 2004 (EPA, 2008). Spurred by increased energy needs, environmental emission considerations, advantages of natural gas, and technology advances in exploration and production, CBNG production could easily double in the next 8-10 years, accounting for up to 20% of our total natural gas production. CBNG operators face increasing environmental problems and expense in hauling off and disposing of produced water (from $1-$5+/ barrel in the San Juan Basin) which has the potential of severely restricting the flow of natural gas. The aggregate water volumes from these gas wells, and the disposal and attendant environmental problems posed, are unprecedented. Operators relate that the problem of handling produced CBNG-water is very urgent.

Unlike some older established oil fields, CBNG fields like the San Juan and Raton Basins generally have relatively little infrastructure, especially when compared to other fields where complete gathering systems exist. In these relatively newer CBNG areas, desalination treatment of produced water may have to be done on a well pad by well pad basis, or by gathering the produced CBNG water from two or three adjacent pads. Therefore, more compact units may be more appropriate than larger desalination units.

CBNG produced water has a fairly consistent chemical signature, in that it has moderate to high levels of dissolved solids. The main dissolved constituent found in CBNG produced waters is bicarbonate, as well as higher levels of chloride and sodium. As described by Van Voast (2003), there is very little calcium or magnesium present in coal bed methane produced waters, which can be explained by the high bicarbonate levels; higher levels of bicarbonate lead to lowered solubility of calcium and magnesium.

1.2. San Juan Basin Wells

The San Juan Basin covers an area of about 7,500 square miles across the Colorado/New Mexico state line in the Four Corners region. Figure 1-1 (modified from EIA, 2004) shows the oil and gas mines in the region.

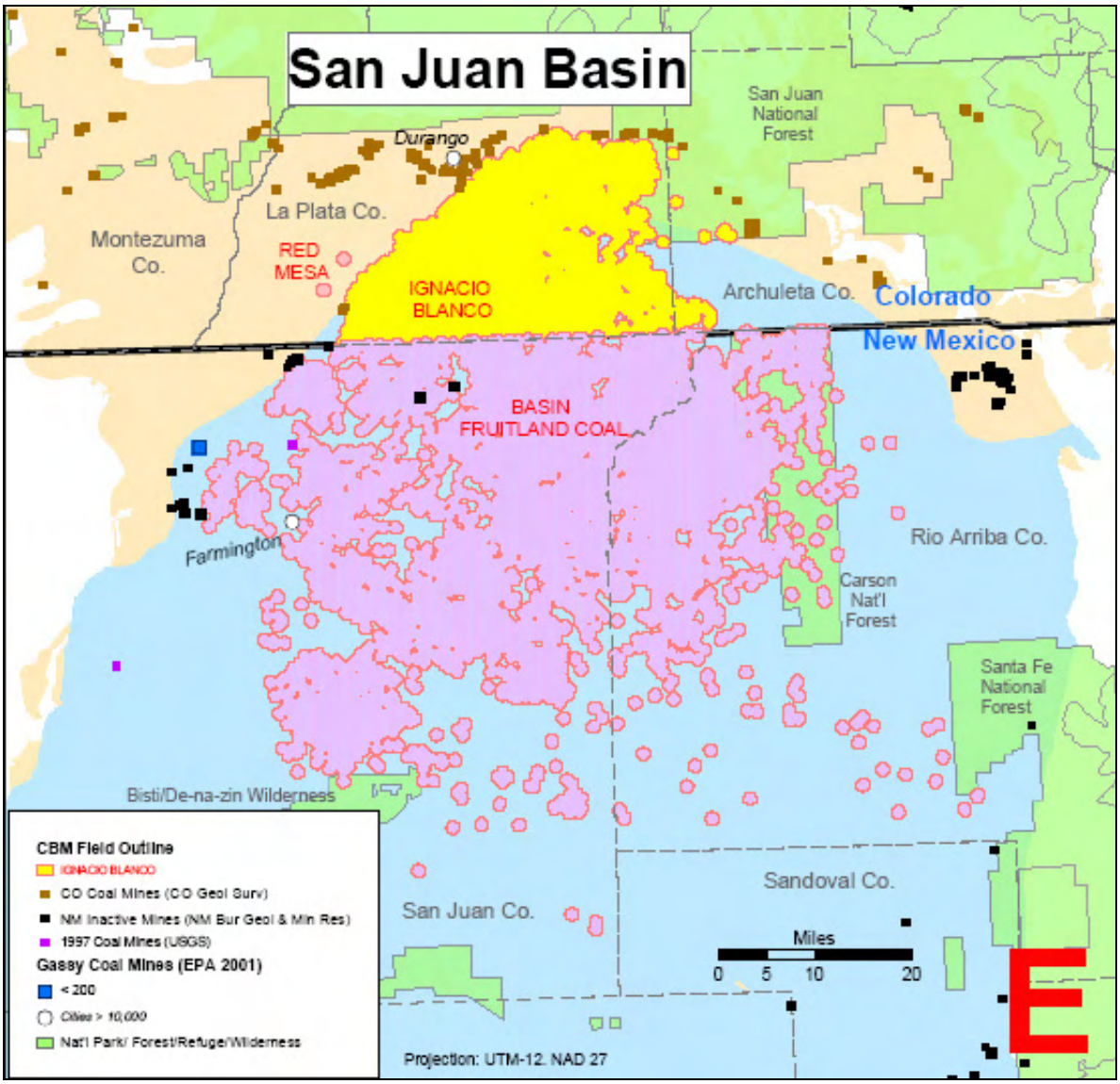

Figure 1-1. Overview Map of San Juan Basin, Colorado/New Mexico (source: EIA, 2004)

2. Objectives of the CBNG Produced Water Pilot Test

In this project, the produced water from CBNG wells was reclaimed (desalinated) and used for a short term rangeland improvement study. Some of the grasses near the pad of the ConocoPhillips San Juan Unit (Well) 32-8 #237 A were watered with treated and untreated water. The technology applied to bring CBNG produced water to a suitable standard for rangeland and riparian improvement depends both on the TDS and organic content of the particular CBNG produced water.

The technical challenge with respect to water treatment is to pre-treat the water for organic and other contaminants that will cause membrane fouling or scaling, as well as to remove coal fines prior to desalination. Membrane fouling and scaling can cause significant pressure increases and increase the amount of chemical cleaning required. The organic content of the produced water is designed to be lowered by membrane filtration. The pilot equipment was designed to remove

coal fines by cyclone/centrifuge separators and a settling tank. After the pretreatment the salt content was lowered by reverse osmosis.

3. Description of Pilot Test

3.1. Site Description

The pilot location is on ConocoPhillips SAN JUAN 32-8 #237A, which is located 500 ft off NM 511. The closest town is Bloomfield, NM and the site is approximately 11 miles past Navajo Dam. Figure 3-1 shows the approximate location of the pilot operation.

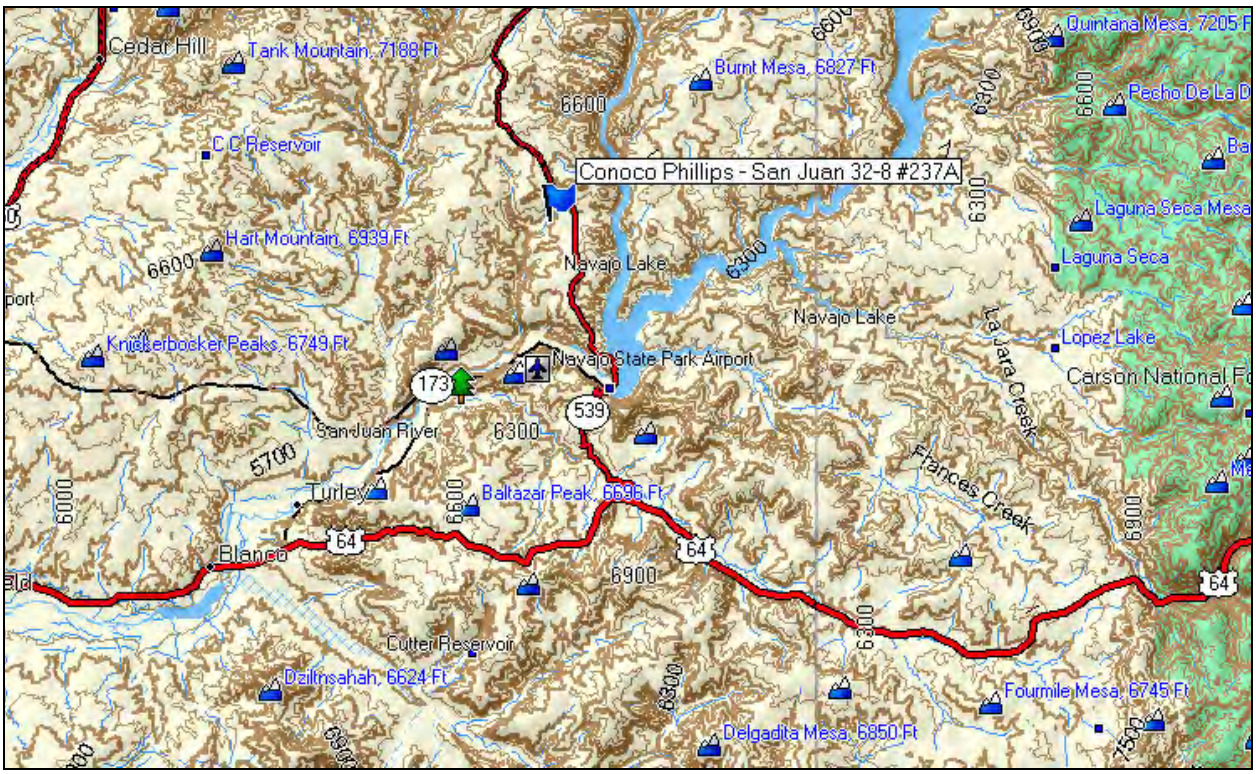

Figure 3-1. CBNG Produced Water Pilot Plant Location (PG Environmental, 2008)

Produced water from a single ConocoPhillips CBNG well is being utilized for this treatment pilot program. Natural gas and produced water are pumped from the Fruitland coal formation between 3183 feet and 3385 feet below the ground surface using a reciprocating piston pump. This mixture is sent to a gas-water separator, with the produced water going to a temporary storage tank. The water is normally drained from the storage tank and trucked away and is reinjected into the formation. The current gas production at this site is 220 Mcf/d. Water production from this well was approximately 15 to 37 BPD. Figure 3-2 shows the layout of the well site.

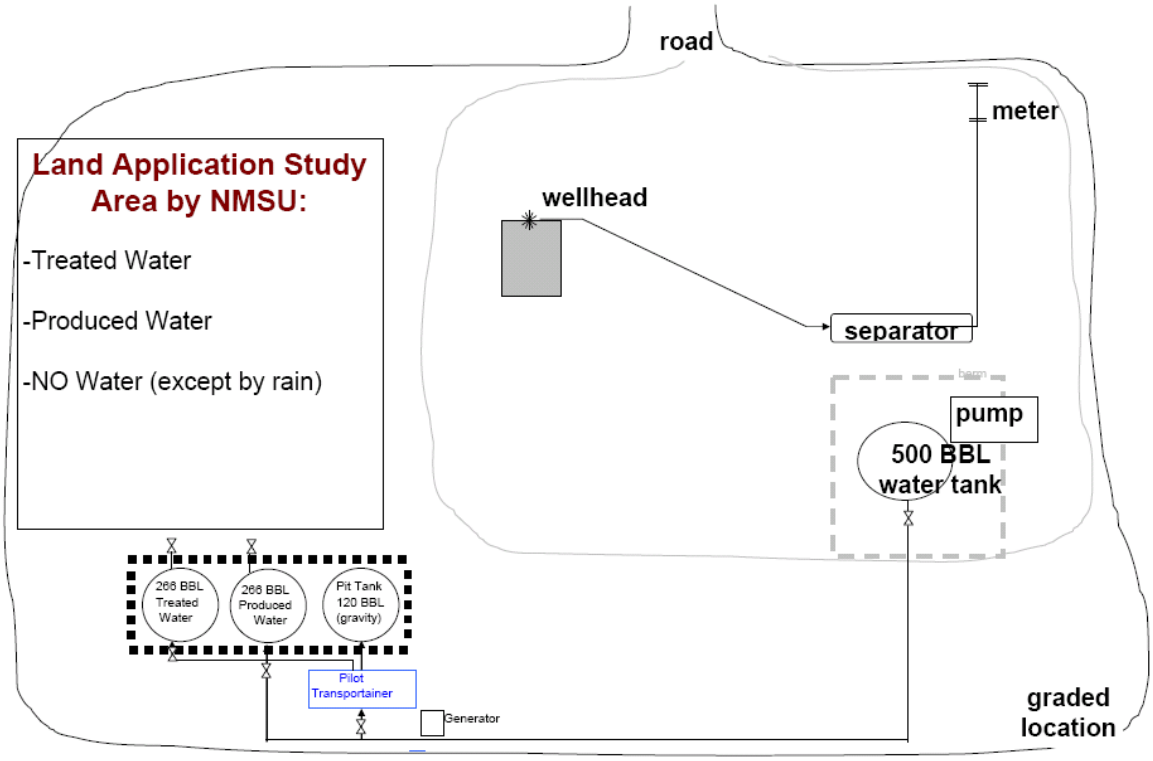

Figure 3-2. Pilot Site Diagram

Sandia pilot equipment is located on the ConocoPhillips well site and is located inside a 20-ft transportainer, owned by Sandia. The site has no electricity, so the pilot equipment was powered by a leased diesel generator for the duration of the pilot. ConocoPhillips provided produced water, site security, storage tanks, safety training and berming of critical areas. B.E.S.T. provided pilot operation and sampling. Figures 3-3 and 3-4 show the Sandia pilot equipment and the pilot site.

Figure 3-3. CBNG Well Site and Pilot Equipment

Figure 3-4. Generator, Transportainer and Treated, Untreated Water, and Concentrate Tanks on ConocoPhillips CBNG Well Pad

3.2. Pilot Plant Description

3.2.1. Pilot Test Design

ConocoPhillips provided raw (untreated) produced water to the Sandia pilot operation. This water was stored in the 500-BBL storage tank prior to being delivered the pilot. This water may have traces of constituents from the coal formation and/or from the mining process. The work, from 2/8/07-11/29/07, focused on testing a particulate removal system, along with membrane processes to produce water suitable for rangeland and riparian improvement.

3.2.2. Pilot Equipment and Treatment Equipment

The CBNG produced water pilot system is made up of the following modular components:

1. Raw water makeup system and water storage (ConocoPhillips equipment)
    a. 500-BBL produced water storage tank
    b. Piping to/from pilot equipment
    c. 266-BBL treated water storage tank
    d. 266-BBL raw produced water storage tank
    e. 120-BBL pit tank (for storage of pilot concentrate stream)
    f. Heat tape on water lines
    g. Berming of grasses and desalination equipment

2. Sandia Pilot Equipment
    a. Large Particulate Removal (settling tank, cyclone separators) to remove coal fines and other particulate matter that is 10-20 microns (μm) or larger
    b. Ultrafiltration to remove finer suspended matter, down to 0.01 μm (molecular weight cut-off of 20K-50K Daltons)
    c. Reverse Osmosis to remove dissolved matter (and remaining suspended matter)
    d. Data logging and controls system
    e. Pumps, tanks, filters, and treatment chemicals

3. Land Application Area, (3) 4000 ft^2 areas
    a. ~1/3 Natural area, no additional water added
    b. 1/3 Natural Area, Untreated produced water application
    c. 1/3 Natural Area ,Treated produced water application (TDS < 1,000 mg/L)

Figure 3-5 shows the flow diagram of the pilot equipment and Figures 3-6 a-d show the pieces of equipment themselves. Raw produced water from the 500-BBL storage tank was pumped into the pilot's settling tank (T-100). This tank has level control equipment installed to protect from over/under-filling. Water from T-100 was pumped through cyclone filters to remove larger suspended particles (designed for removal of 10-20 μm particles) and sent to the UF feed tank (T-200). Water from T-200 was fed to the 5-μm pre-filter, then through the UF itself to the RO feed tank (T-300). The final step is for the water to be pumped through the RO pre-filter and the RO itself to the permeate storage tank (T-400). T-400 was pumped to the ConocoPhillips treated water storage tank as it is filled (approximately every 35 gallons).

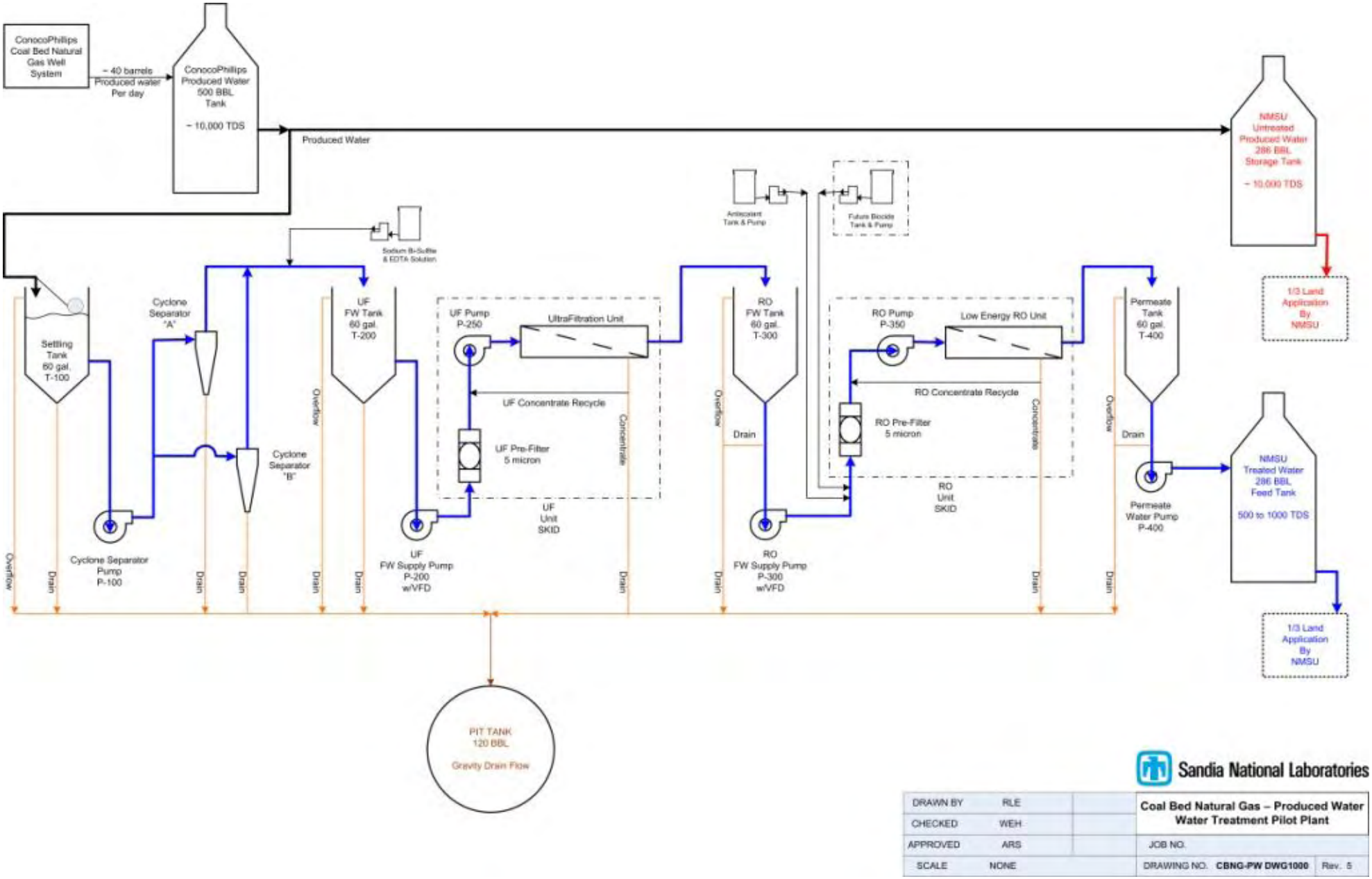

Figure 3-5. Pilot Flow Diagram

Figure 3-6a. T-100, Cyclone Filters, T-200

Figure 3-6b. Chemical Feed Tanks, UF System

Figure 3-6c. Chemical Feed Tank, T-300

Figure 3-6d. RO System, T-400

Figures 3-6 (a-d). Pilot Equipment Pictures

3.2.3. Treatment Process – Ultrafiltration and Reverse Osmosis

Ultrafiltration (UF) is a membrane process that separates particulate matter from water based on membrane pore size. The GE M-Series spiral wound UF membrane used in this pilot are characterized by a pore size of 0.01 μm with an approximate molecular weight cut-off of 20K-50K Daltons. Since the membrane is spiral wound, it is not able to be backwashed. The system was operated at a pressure of 160 psi.

Reverse Osmosis is a membrane process that removes dissolved species by overcoming the osmotic pressure of the feed stream with enough excess pressure to create a permeate stream. This occurs via diffusion, but the majority of all suspended and colloidal species remaining in the feed stream will also be removed (e.g. TOC, iron, etc.). The osmotic pressure of the feed water in this case is approximately 150 psi, which means more than 150 psi is required to produce permeate from the RO membrane. The more pressure applied, the more water

(and better quality) is produced. The GE AG4040 membranes used in this pilot operation are thin film composite (TFC) membranes that are designed for low energy (low pressure) brackish water desalination. The system was operated at a pressure of 270 psi.

3.3. Water Quality

Average produced water quality experienced during this pilot (February-December 2007) is presented in Tables 3-1 and 3-2. The water is brackish, with an average TDS (as calculated by summing of dissolved species present in water) of 14,500 mg/L. The TDS (gravimetric) is 10,700 mg/L on average. It is important to note that historical calculations for TDS and many publications would cite the TDS differently. The method used to measure TDS is to evaporate the water and weigh the solids leftover; this will cause about 50% of the bicarbonate to off gas, and therefore, not be counted. Many laboratories will reduce the calculated TDS if they sum all of the dissolved species by subtracting about 50% of the bicarbonate. It is most correct to sum up all dissolved species for membrane design, but both forms are shown here for completeness.

Table 3-1. CBNG Produced Water Composition

Analyte	Units	Avg Value
Specific Conductance	μS/cm	17,300
Total Dissolved Solids (@ 180 ^{o}C)	mg/L	10,700
TDS (sum of all dissolved species)	mg/L	14,500
pH	units	7.91
Temperature	^{o}C	16.2
Specific Gravity		1.00
Dissolved Oxygen	mg/L	5.30
Total Suspended Solids	mg/L	150
Anions		
Chloride	mg/L	2,087
Fluoride	mg/L	0.724
Nitrate, as N	mg/L	0.775
OrthoPhosphate, as P	mg/L	12.8
Total Phosphorous, as P	mg/L	13.0
Sulfate	mg/L	2.78
Silica	mg/L	9.88
Alkalinity		
Total, as $CaCO_3$	mg/L	6,380
Bicarbonate, as HCO_3	mg/L	7,790
Carbonate, as CO_3	mg/L	ND
Cations		
Hardness, as $CaCO_3$	mg/L	80.0
Aluminum	mg/L	<0.1
Arsenic	mg/L	<0.01
Boron	mg/L	2.65
Barium	mg/L	28.1
Copper	mg/L	<0.1
Calcium	mg/L	27.3
Iron	mg/L	0.405
Magnesium	mg/L	5.86
Manganese	mg/L	<0.1
Potassium	mg/L	22.8
Selenium	mg/L	ND
Sodium	mg/L	4,520

Table 3-2. Produced Water Organic Composition

Analyte	Units	Avg Value
Purgeable VOCs		
Benzene	µg/L	1.00
Ethylbenzene	µg/L	1.15
o-Xylene	µg/L	1.90
p/m-Xylenes	µg/L	6.90
Toluene	µg/L	39.0
Total BTEX	µg/L	50.0
Gasoline Range Organics	mg/L	ND
Diesel Range Organics	mg/L	ND
TOC	mg/L	17.7
Total Recoverable Petroleum Hydrocarbons	mg/L	ND
N-Hexane Extractable Material	mg/L	2.0

Similar to other CBNG produced waters, the main dissolved constituents are chloride, bicarbonate, and sodium. The elevated bicarbonate leads to significantly lowered calcium and magnesium solubility and thus this water, like most CBNG water, has extremely low calcium and magnesium content. CBNG produced waters are different from oil and gas produced waters in that they have minimal dissolved or emulsified organic constituents. The methanogenic microbes present in the formations anaerobically produce mostly methane, and reduce sulfur to a sulfide. This accounts for low sulfate content in the water as well. Although tests indicated that a small amount of VOCs were present in the water, it is unclear whether they were significant since he number of samples were small. This may be an indication of contamination during sampling or storage in the 500 BBL tank. We will attempt to investigate this in the next phase of the project.

3.4. Sampling Plan

A rigorous sampling plan was not created for this pilot operation. The raw (untreated) water was analyzed three times, the RO system twice, and the UF system once. Table 3-3 summarizes the analyses and methods performed by contract laboratories.

Table 3-3. Water Quality Sampling Plan

Parameter	Stream Sampled	Method Used (Envirotech[1])	Method Used (Assaigai)
Specific Conductance	Raw, UF (F,C,P), RO-all	EPA 600/4-79/020	EPA 120.1
Total Dissolved Solids (@ 180 ^{o}C)	Raw, UF (F,C,P), RO-all	EPA 600/4-79/020	EPA 160.1
TDS (summation of all dissolved species)	Raw, UF (F,C,P), RO-all	N/A	
pH	Raw, UF (F,C,P), RO-all	EPA 600/4-79/020	EPA 150.1
Temperature	Raw, UF (F,C,P), RO-all	EPA 600/4-79/020	Not analyzed
Specific Gravity	Raw, UF (F,C,P), RO-all	EPA 600/4-79/020	Not analyzed
Dissolved Oxygen	Raw, UF (F,C,P), RO-all	EPA 600/4-79/020	Not analyzed
Total Suspended Solids	Raw, UF (F, P), RO (all)	EPA 600/4-79/020	Not analyzed
Anions			
Chloride	Raw, RO (all)	EPA 600/4-79/020	EPA 300.0 (IC)
Fluoride	Raw, RO (all)	EPA 600/4-79/020	Not analyzed
Nitrate, as N	Raw, RO (all)	EPA 600/4-79/020	Not analyzed
OrthoPhosphate, as P	Raw, RO (all)	EPA 600/4-79/020	EPA 300.0 (IC)
Total Phosphorous, as P	Raw, RO (all)	EPA 600/4-79/020	SM 4500-P-B, D
Sulfate	Raw, RO (all)	EPA 600/4-79/020	EPA 300.0 (IC)
Silica	Raw, RO (all)	EPA 6010B	EPA 200.7 (ICP)
Alkalinity			
Total, as $CaCO_3$	Raw, RO (all)	EPA 600/4-79/020	Not analyzed
Bicarbonate, as HCO_3	Raw, RO (all)	EPA 600/4-79/020	EPA 310.1 (titration)
Carbonate, as CO_3	Raw, RO (all)	EPA 600/4-79/020	EPA 310.1 (titration)
Cations			
Hardness, as $CaCO_3$	Raw, RO (all)	EPA 600/4-79/020	SM 2340B (titration)
Aluminum	Raw, RO (all)	EPA 6010B	Not analyzed
Arsenic	Raw, RO (all)	EPA 6010B	EPA 200.8 (ICP-MS)
Boron	Raw, RO (all)	EPA 6010B	Not analyzed
Barium	Raw, RO (all)	EPA 600/4-79/020	Not analyzed
Copper	Raw, RO (all)	EPA 6010B	Not analyzed
Calcium	Raw, RO (all)	EPA 600/4-79/020	EPA 200.7 (ICP)
Iron	Raw, RO (all)	EPA 600/4-79/020	EPA 200.7 (ICP)
Magnesium	Raw, RO (all)	EPA 600/4-79/020	EPA 200.7 (ICP)
Manganese	Raw, RO (all)	EPA 6010B	Not analyzed
Potassium	Raw, RO (all)	EPA 600/4-79/020	EPA 200.7 (ICP)
Selenium	Raw, RO (all)	EPA 6010B	Not analyzed
Sodium	Raw, RO (all)	EPA 600/4-79/020	EPA 200.7 (ICP)
Purgeable VOCs		EPA 600/4-79/020	Not analyzed
Benzene	Raw, UF (F, P)	EPA 8021, 8260	EPA 8021B
Ethylbenzene	Raw, UF (F, P)	EPA 8021, 8260	EPA 8021B
o-Xylene	Raw, UF (F, P)	EPA 8021, 8260	EPA 8021B
p/m-Xylenes	Raw, UF (F, P)	EPA 8021, 8260	EPA 8021B
Toluene	Raw, UF (F, P)	EPA 8021, 8260	EPA 8021B
Total BTEX	Raw, UF (F, P)	EPA 8021, 8260	Not analyzed
Gasoline Range Organics	Raw, UF (F, P)	EPA 8015B	EPA 8015B
Diesel Range Organics	Raw, UF (F, P)	EPA 8015B	EPA 8015B
Total Organic Carbon	Raw, UF (F, P)	EPA 9060	EPA 9060
Total Recoverable Petroleum Hydrocarbons	Raw, UF (F, P)	EPA 8015B, 418.1	Not analyzed
N-Hexane Extractable Material	Raw, UF (F, P)	EPA 1664a	Not analyzed

[1]Envirotech used EPA Methods for Chemical Analysis of Water

4. Test Results

4.1. Operations

The pilot started producing water on 10/1/07 without the UF system in operation and a 5 μm cartridge filter was installed. Because we noticed that iron, turbidity and suspended solids levels after the 5 μm filter were higher than the RO manufacturers specifications we started using a 0.38 μm filter as the pre-filter on 10/17/07.

During the commissioning of the pilot equipment, the flow rates were optimized to maintain flow while minimizing on/off cycles of pumps and maintaining proper levels in the various tanks. Figure 4-1 summarizes the optimized flow rates and associated TDS and pH levels in each of the streams on 11/28/07 (these flow rates were utilized from 10/10/07 until the end of the pilot).

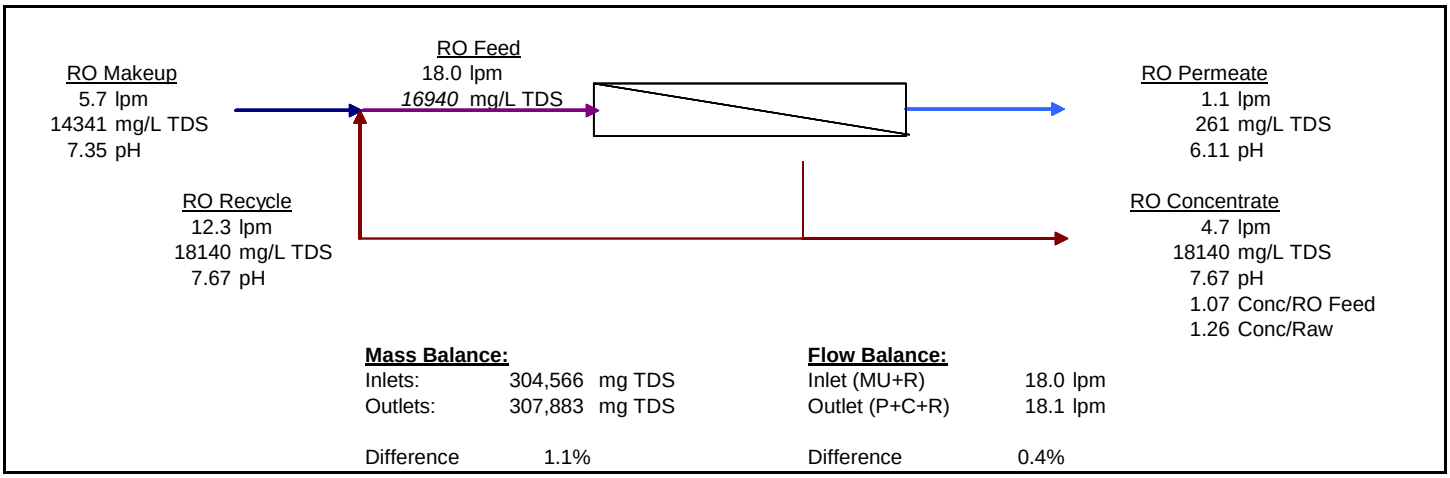

Figure 4-1. Reverse Osmosis Optimized Flow Rates and Mass Balance (on TDS)

The UF system was put into operation on 11/15/07. At that time, the pre-filter for the reverse osmosis system was changed back to a 1 μm size to minimize the pressure drop.

4.2. System Performance

4.2.1. Cyclone Filters & Settling Tanks

The original design utilizing a settling tank and cyclone filters was for the anticipated need for the removal of coal fines and other particulate matter greater than 10-20 μm in size. It became apparent during this test that there were very few coal fines or other particulate matter greater than 10-20 μm present. The cyclone filters were causing difficulties with flow balancing in the entire system and were removed on 11/13/07. Some particulate matter did settle in low flow areas such as tubing to pressure gauges. Since the pilot was not run for a long duration it is unclear if any particulates caused problems within the membrane systems (UF and RO).

4.2.2. Ultrafiltration System

The UF system was put into operation on 11/14/07 and was run for 4 days total. During phase 2 an extended period of operation is expected. The electronic datalogging equipment (flow metering) was not calibrated for the UF system so all flow data presented here are from the rotameters installed on the UF system. During operation only one sample was analyzed for organics on the UF streams; salt content was not analyzed since dissolved constituents are not removed with UF. Table 4-1 summarizes the single sample's analyses. Gasoline and diesel range organics, as well as total recoverable petroleum hydrocarbon data are not presented; all streams had non-detectable values.

Table 4-1. UF Performance Summary

	Units	Raw	UF Permeate	Removal Efficiency
Specific Conductance (@ 25°C)	μS/cm	16,500	16,400	N/A
Total Dissolved Solids (@ 180°C)	mg/L	12,200	11,800	N/A
TDS (calculation)	mg/L	14,953	14,341	N/A
pH	Units	7.35	7.58	N/A
Specific Gravity		1.0078	1.008	N/A
Dissolved Oxygen	mg/L	5.7	6	N/A
Total Suspended Solids	mg/L	150	150	0%
Benzene	μg/L	1.1	0.9	18%
Ethylbenzene	μg/L	0.5	0.6	0%
o-Xylene	μg/L	1.5	1.4	7%
p/m-Xylenes	μg/L	4	3.3	18%
Toluene	μg/L	83	53.4	36%
TOC	mg/L	30	30	0%
N-Hexane Extractable Material	mg/L	4	8	0%

This data would suggest that the UF may not have been performing well, or at least not consistently since TSS did not seem to be removed. However, it should be noted that all equipment was operated at sub-optimal conditions. Equipment was not operated continuously and in many cases was stagnant for multiple days. In addition, the design of the UF membrane (spiral wound) is such that is not able to be backwashed. A full scale system may be better served by an outside-inside UF system that can be backwashed on a regular frequency to minimize fouling by suspended solids. Finally, UF membranes will not remove any dissolved organic species, which may explain the low TOC removal.

Field data obtained during UF operation however, would suggest that the UF removed a significant amount of turbidity from the feed water. This significantly improved the water quality sent to the RO system. Table 4-2 summarizes the field data obtained during the UF operation. Turbidity was decreased by at least 68%, and the variation of removal efficiency was likely affected by the intermittent operation of the system.

Table 4-2. UF Field Data

	Parameter	Units	Inlet	Concentrate	Permeate
11/14/2007	Conductivity	μS/cm	17,840	17,930	17,940
	Temperature	C	16.5	17.1	17.4
	pH	units	7.4	7.4	7.4
	Turbidity	NTU	12.1	10.5	0.2
	Iron	mg/L	3.04	2.95	2.31
11/16/2007	Conductivity	μS/cm	17,900	18,010	18,100
	Temperature	C	14.2	14.8	14.4
	pH	units			
	Turbidity	NTU	17.9	16.3	1.08
	Iron	mg/L			
11/26/2007	Conductivity	μS/cm	18,010	18,180	18,130
	Temperature	C	11.1	10.3	10.5
	pH	units			
	Turbidity	NTU	8.57	11.5	2.94
	Iron	mg/L			
11/28/2007	Turbidity	NTU	15.6	18.4	4.91

4.2.3. Reverse Osmosis System

As mentioned previously, the RO system was operated without the UF system until 11/14/07. In addition, the system was operated intermittently and without a permeate flush or preservation during periods of inactivity. These conditions are sub-optimal, but are good for testing the worst case operational limits of the RO system itself.

Initially, the RO system was operated with a 5 µm pre-filter to remove particulate matter from the influent water. After some field data was gathered indicating higher than expected iron levels and turbidity levels above the RO membrane manufacturer's suggested levels, the pre-filter was changed to a 0.38 µm pre-filter in hopes of protecting the RO membrane as much as possible. Once the UF was in operation, a 1 µm pre-filter was installed. The filter was changed out a total of eight times.

Most species present in the feed water were removed by 98% or better by the reverse osmosis system. Some species such as TSS, silica, and sulfate, were removed to a lesser degree. It should be noted that only two sets of data were analyzed for the full suite of constituents. Of these, only one is somewhat accurate in its representation of the pilot operation as designed (UF & RO in operation). Removal results were all higher (more species removed) on the 10/9/07 sample. During phase 2 we hope to gather more data to better quantify the system performance. Table 5 summarizes the data obtained from laboratory testing. Figure 4.2 shows the desalination efficiency of the reverse osmosis system by way of conductivity measurements.

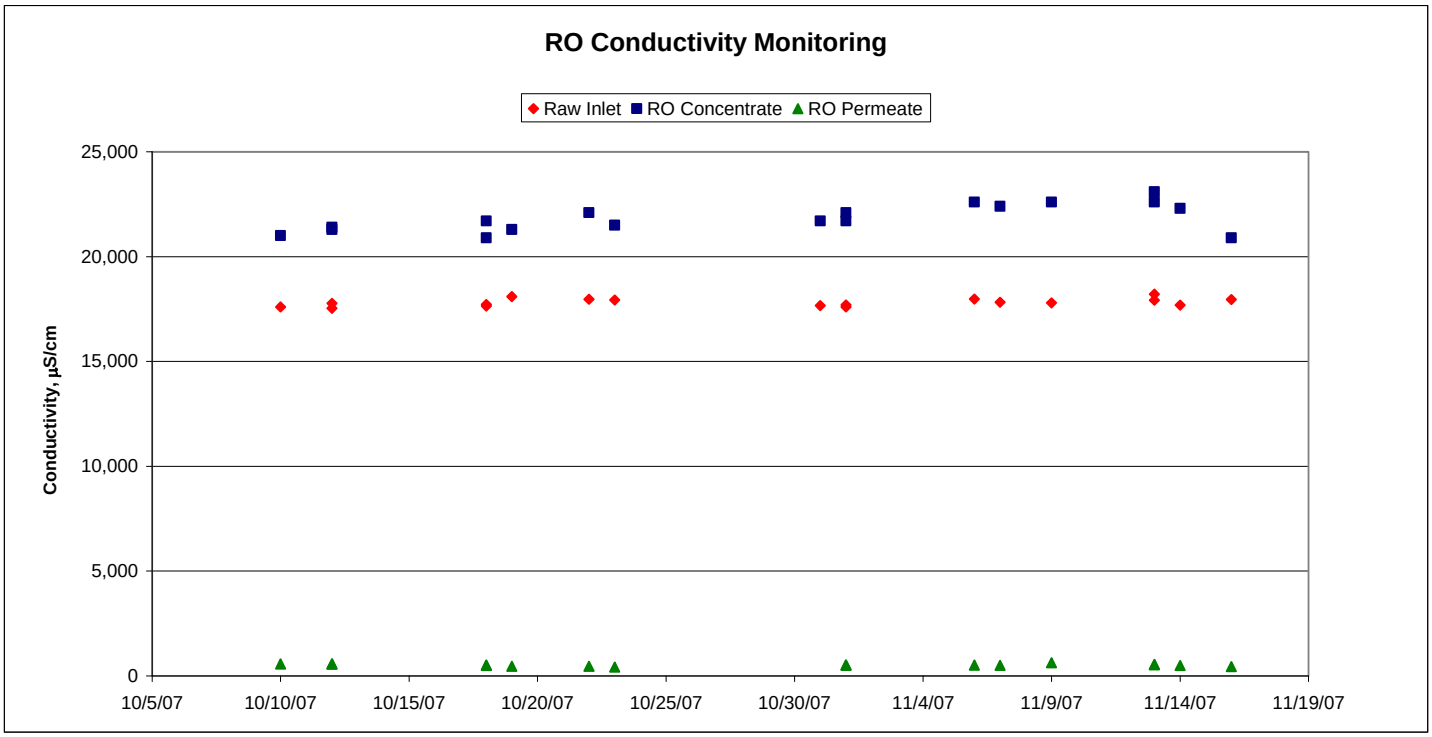

Figure 4.2. Conductivity Measurements – RO Streams

From mass balance calculations performed for each of the monitored constituents in the water streams, it is expected that some scaling (Ca, SiO_2, SO_4) and some fouling (organic, TSS) occurred within the RO membrane. Since the RO feed pump could not attain pressures higher than approximately 275 psi, increased net driving pressure and/or decreased normalized permeate flux would not be observed. Also, the pilot operation was not run for a long enough duration to see flux decline.

The RO system as installed at the pilot operated at a 6-8% efficiency across the single membrane stage (2 membranes in parallel) and 20-25% system efficiency (accounts for concentrate recycle). A full scale system would have more membrane surface area to attain higher efficiencies.

Table 4-3. Summary of RO Performance – Laboratory Analyses

	RO Concentration Factor (Conc/Raw)		RO Removal Eff	
Analyte	**10/9/07**	**11/28/07**	**10/9/07**	**11/28/07**
Specific Conductance (@ 25°C)	1.14	1.18	98%	98%
Total Dissolved Solids (@ 180°C)	1.11	1.22	98%	98%
TDS (calculation)	1.20	1.26	98%	98%
Total Suspended Solids	0.67	1.07	27%	53%
Chloride	1.06	1.48	98%	97%
Sulfate	1.00	0.67	100%	44%
Silica	1.10	0.76	97%	88%
Total	1.26	1.23	98%	99%
Bicarbonate	1.26	1.23	98%	99%
Hardness, as $CaCO_3$	0.80	0.93	100%	99%
Calcium	0.80	1.15	100%	98%
Iron	3.96	1.68	96%	74%
Magnesium		0.21		100%
Potassium	0.90	1.26	100%	99%
Sodium	1.19	1.09	98%	98%

There were two sets of field analyses where the UF and RO systems were in operation. From this data one can see a marked improvement in turbidity removal when the UF is operational. Figures 4-2 & 4-3 show the turbidity removal with and without the UF system. Appendix B contains all field and analytical data for the pilot operations.

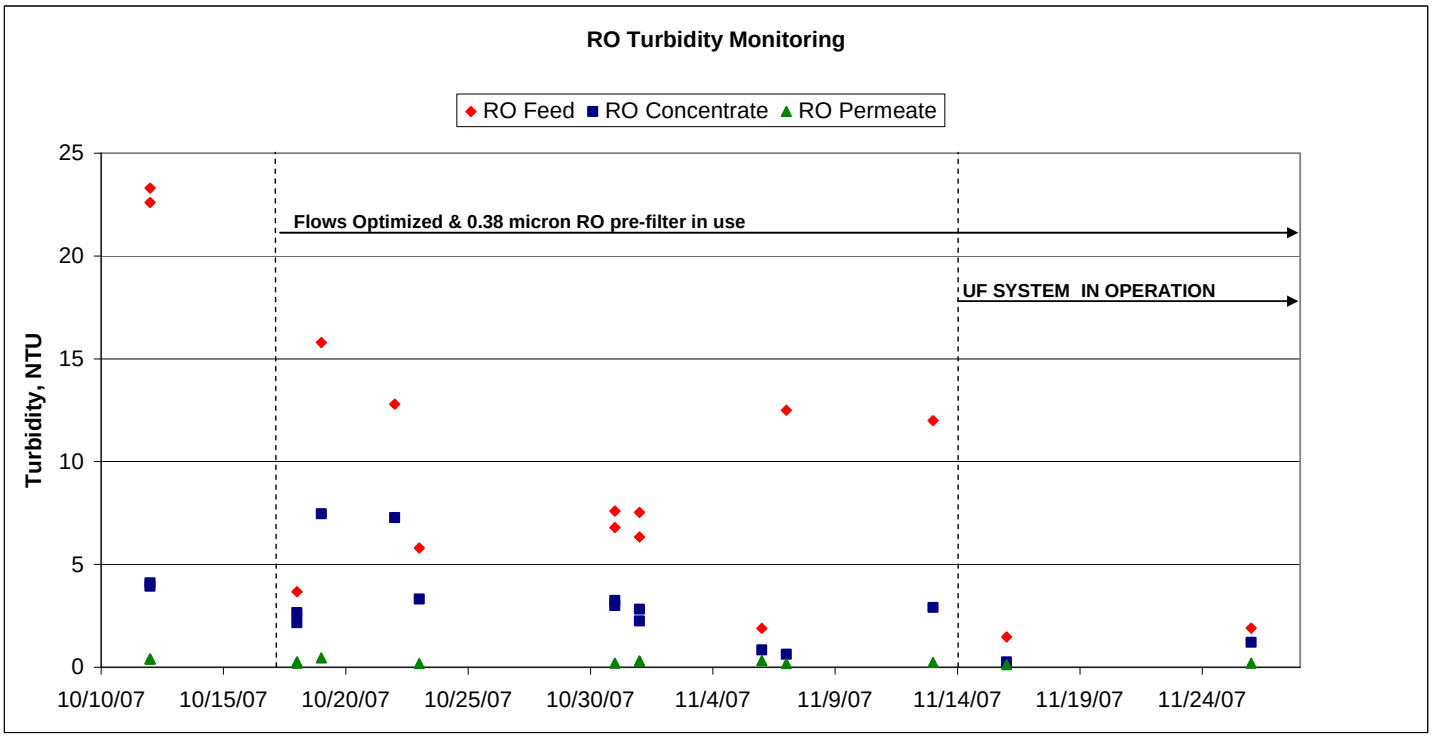

Figure 4-3. Turbidity Removal – Reverse Osmosis System

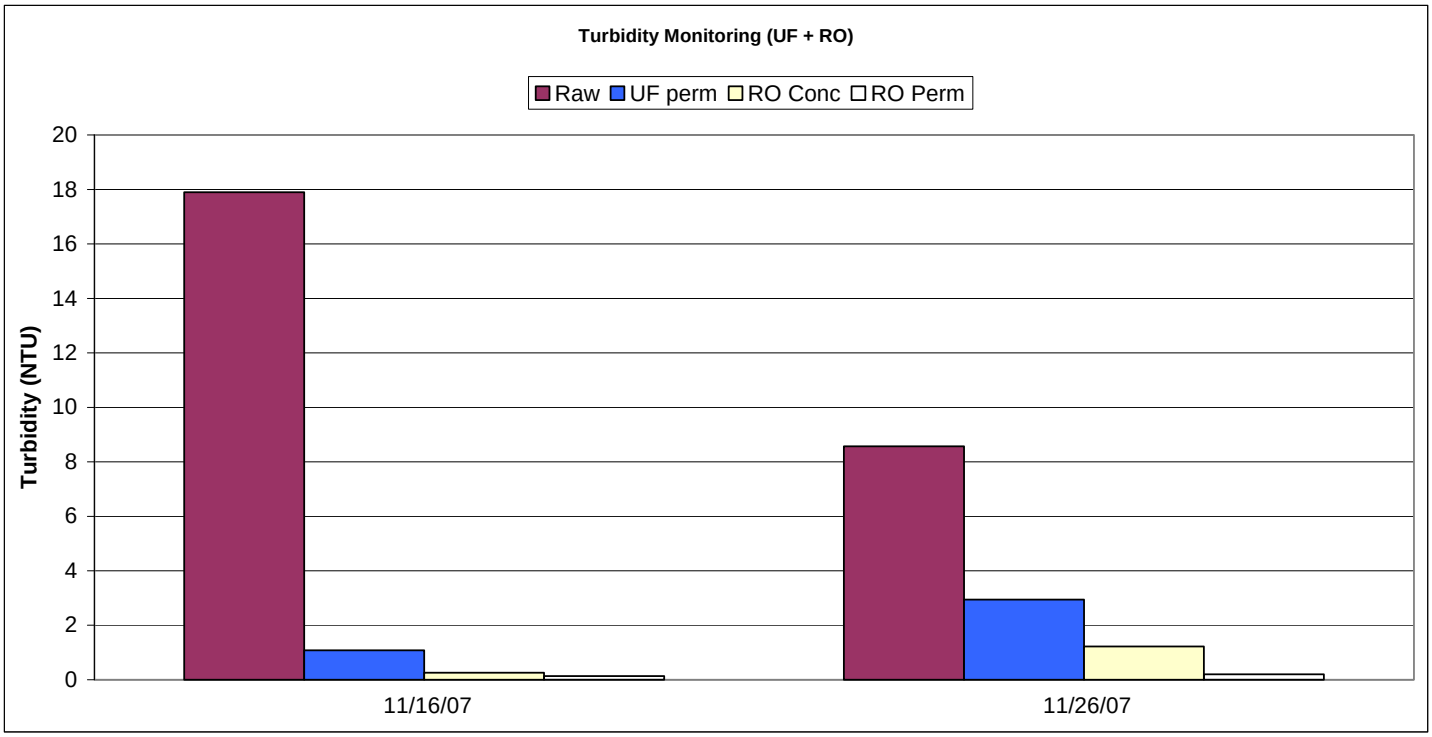

Figure 4-4. Turbidity Reduction – UF and RO systems

4.3. Land Application of Water by NMSU/USDA

Rangelands in the San Juan Basin of New Mexico are a potentially large reservoir for carbon, both in terms of the available oil and gas and in terms of a potential for carbon sequestration. In addition, the rangelands have ecological value as providing food, fiber, opportunities for recreation, wildlife habitat, and sustainable watersheds. However, land degradation associated with historical and current land use and management has threatened the stability of these landscapes. The barriers to achieving their potential lie primarily in the limited growing conditions (erratic precipitation) and reduced capacity for recovery (historical damage and ongoing disturbance). Increasing carbon storage while maintaining or increasing the value of other ecosystem services in arid rangelands requires a strategic approach to reestablish watershed functions. Stabilizing arid landscapes requires both enhancing existing vegetation and reintroducing woody plant species along riparian areas and reestablishing native grasses and shrubs in upland areas. The limiting factor in both cases is water availability, primarily the distribution in time and space.

A reliable source of water of sufficient quality for agricultural irrigation could provide the necessary base for the reestablishment of native vegetation with a host of environmental benefits. The technical challenges include: 1) selecting appropriate species for revegetation, 2) distribution and application of water to enhance germination and 3) protection of establishing from grazing (native and domestic grazers). Information to select appropriate species and guide resource allocation for restoration is critical for the cost:benefit analysis. These decisions must be guided by existing and potential soil, vegetation and landscape conditions. We are currently characterizing (soils, vegetation, geomorphology, ecological site descriptions) the La Manga Canyon watershed to provide this information. In addition to current conditions, we are constructing chronosequences of soil and vegetation change and building predictive models of landscape scale potential. Using this information will inform the decisions necessary to select the appropriate species and critical sites to increase the chances of landscape stabilization.

Approximately 1.81 inches of produced water and 0.68 inches of treated water were applied to ConocoPhillips 237A. Dates were October 24 and November 23 for produced water application and November 23 for treated

water application. Figure 4-4 shows irrigation performed on 10/24/07. Below is a summary of all activities performed by the USDA and NMSU.

1. Took soil samples from both non-treated and treated area before water was applied. Dates are 10-24-07 and 11-23-07 for non-treated and treated produced water.
2. Applied non-treated produced water on 10-24-07 and 11-23-07. Treated area was approximately 4500 square feet with approximately 60 barrels of non-treated produced water applied at each date for a total of 120 barrels.
3. Applied treated water on 11-23-07. Treated area was approximately 4500 square feet with approximately 45 barrels of treated water applied.

Figure 4-5. Land Application of Untreated Produced Water

5. Discussion and Conclusions

The Fall 2007 CBNG produced water desalination pilot effectively showed a proof of concept for low energy reverse osmosis treatment of the water. There were variations in the influent water quality (TOC, organics, turbidity, iron) throughout the pilot operation, and more samples would be required for a full quantification of the results. However, using a single reverse osmosis membrane in sub-optimal conditions (high fouling-tendency, single membrane, and most of the time without the benefit of an ultra filtration membrane), good quality water was produced for the rangeland/riparian improvement study.

5.1. Water Treatment Cost Estimates

Understanding the energy consumption for membrane processes is critical to understanding the maintenance and operations (M&O) budget. It is not totally infeasible to scale up from our pilot to a full scale operation, as there are many factors that are totally different. For example the pilot pumps are not high efficiency, full scale would have high efficiency pumps. In addition, there are many things that could be done at full scale that are not attainable in this size of a pilot (e.g. energy recovery).

Using data from the Desalting Handbook for Planners (2003, Bureau of Reclamation), electrical consumption is estimated to be at least 2.25 kwh/m^3 (0.36 kwh/BBL) of permeate. If one extrapolates using the standard reverse osmosis curve from figure 7-8 in the handbook, to 14,000 mg/L TDS, the number is more like 2.75-3.00 kwh/m^3 (0.43-0.48 kwh/BBL) of permeate. Using the data in figure 7-9, it is estimated that 600-625 psi would be required for 14,000 mg/L TDS removal using standard reverse osmosis systems. Both of these estimates assume 75% recovery. Generally speaking, approximately 30% of a desalination facility's cost will be in the pressure required to pump water.

5.2. Future Work

5.2.1. Experimental Plan – CBNG Produced Water Desalination Pilot, Phase 2

It is anticipated that a "Phase 2" pilot will be performed during 2008. This pilot will build on lessons learned from the "Phase 1" operations summarized in this report. The system will likely test the efficacy of using nanofiltration membranes. The pilot itself will actually expand on the 2007 pilot operations and will use reverse osmosis membranes for lower pressure operations, and will retain the ultrafiltration skid for particulate and suspended organics removal. Sandia pilot equipment will be located on the same ConocoPhillips well site used in the 2007 pilot demonstrations.

The goal of this pilot operation again is to demonstrate low pressure/low energy desalination of CBNG produced water. The treated water, raw produced water, and natural rainfall will be applied again to separate sections of native grasses to study the effects for rangeland and riparian repair by NMSU and the USDA, Jornada as before. This phase of the pilot operaton will produce 1-2 gpm of permeate with a TDS less than 1000 mg/L (most likely below 530 mg/L). Professor Rick Arnold, from NMSU's Agricultural Science Center at Farmington, has indicated that the lack of troublesome dissolved species (Na, Ca, Mg) combined with a low TDS (less than 1000 mg/L) should provide good quality water for rangeland and riparian studies.

The proposed pilot operation flow diagram is summarized in Figure 5-1. Raw CBNG produced water will be sent to an ultrafiltration system (UF), which will remove most of the particulate matter and larger molecular weight organic matter. The UF filtrate will be dosed with an antiscalant (for scale protection) and fed directly to a reverse osmosis system (RO). The RO is comprised of three membranes in series and will require approximately 330 psi of pressure for desalination. The RO can also be operated with only two membranes for lower feed pressure and lower permeate production with similar water quality in the permeate stream. Finally, the potential for nanofiltration (NF) with the produced water may be tested towards the end of the pilot operation by changing out RO membranes for NF membranes.

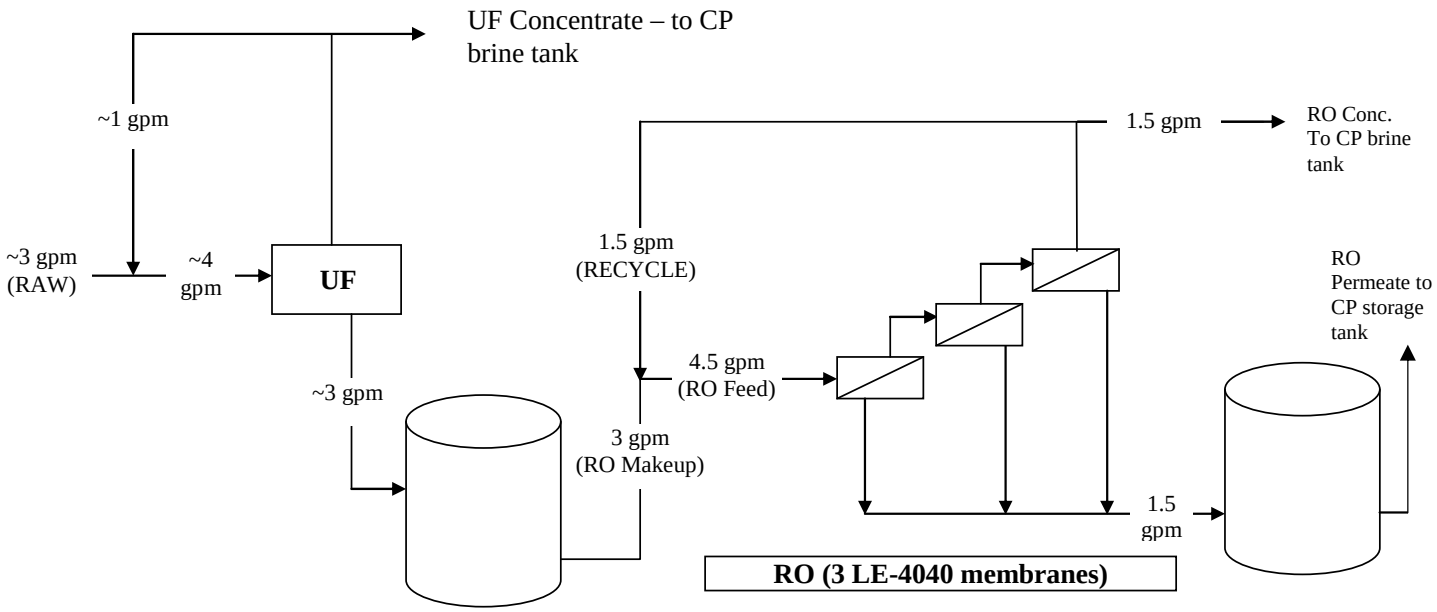

Figure 5-1. Water Treatment Pilot Equipment Flow Diagram

5.2.2. Desalination at a Salt Water Disposal (SWD) Site

For 2009 and beyond, additional pilot operations utilizing desalination and other treatment technologies at a ConocoPhillips SWD is envisioned. This would be on a larger scale than the current pilot operations described in this report and the challenges would be greater. Water at a SWD will have more dissolved and emulsified organic constituents, as well as other contaminants that will require other modes of treatment (e.g. iron). This may require more elaborate pretreatment processes.

Permitting requirements for the alternative use of water on a larger scale must also be factored into pilot operation plans. The use of treated water for impaired riparian area improvement and revegetation of disturbed areas may require some hauling of the processed water.

6. References

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Appendix A – CBNG Produced Water Pilot Plant Logs

Table A-1. Summary of Field Activities and Notes

Event Date or Trip	Specific Date	Description of Work Performed
02/08/07		PW Sample from 500BBL Tank to Assaigai
03/07/07 – 03/08/07		Initial trip w/Team to Western Environmental Management in Carlsbad
3/16/07		1st meeting with SNL Electrical Engineer
03/28/07 – 03/29/07		ConocoPhillips HSE Training & Site Visit
04/20/07		1st SNL-CP-BEST Meeting in Farmington 30th St. Office
05/15/07		B&D To Finish on Transportainer
05/21/07		Cancelled Transportainer Pickup– Electrical Systems must be inspected and Electrical TWD's in place.
08/01/07		Transportainer picked up
08/16/07		Transportainer delivered to site
08/27/07		Electrical Safety Document approved
09/05/07 – 09/07/07		
	090/5/07	Transported equipment with rental Truck
	09/06/07	Installation of Water Treatment Equipment
	09/07/07	Installation of Water Treatment Equipment
09/11/07 – 09/14/07		
	09/11/07	Installation of Process Piping & Data Acquisition System
	09/12/07	Installation of Process Piping & DAS Generator being installed by CP, Initial Electrical Tests Roust-About crew working on grass field berms, Pilot inspection by CP
	09/13/07	Electrical Troubleshooting by CP Final install of main equipment Starting to hydro-test system Continued work on DAS & Controls
	09/14/07	Electrical and system troubleshooting Repair of leaks DAS & Controls
09/17/07 – 09/21/07		
	09/17/07	Ji working on DAS & Controls
	09/18/07	Ji working on DAS & Controls
	09/19/07	DAS Tank & Pump Hydro test Change out membranes On UF & RO Units UF switched AK for MW series cartridges. RO switched AK-LE for the AG series cartridges. UF Unit could not be put in service. The existing housing end caps will not accept the MW membrane cartridges. MW cartridge has female ends. Ordered adapters.
	09/20/07	Programming DAS Startup on equipment motors, pumps, tank check leaks Pressures and flows
	09/21/07	Check and calibrate Echo Switches
09/27/07 – 09/28/07		

Event Date or Trip	Specific Date	Description of Work Performed
	09/27/07	Replace pressure switches Installed new adapters for UF Unit to accept M-Series Membranes UF Unit could not be in service. The existing housing is not long enough. No one indicated that the MW Series membranes also needed longer housing to hold cartridge. New housing on order. 30 day lead time from factory Repair T-300 Leak Finish checking EchoSwitches Seal holes in transportainer
	09/28/07	Bypass & equalizing line between T-200 & T-300 Found leak on one of the RO end caps. Found manufacturing defect in housing where O-ring seals. Replaced the housing with the one short housing from the UF Unit. ½" piping inside T-100 to diffuse water splash, eliminates cavitations at low tank level. Found roof leaking from recent rains. Will purchase roof coat to seal screw holes in roof.
10/01/07 – 10/03/07		
	10/01/07	System Startup Calibration of DAS components Main PW 500BBL Tank is operating at 10'. Jimmy Bowman to reset. Only getting 2.5 to 3.0 gpm to the inlet of T-100. As per WEM: Both E4 and LE-E4 units, the TOMCO pump must operate with a total of 5 gpm through pump. Total flow equals, concentrate flow out + recycle flow + permeate flow out. Maximum pressure outputs from TOMCO pumps UF 130 psi + suction pressure RO 245 psi + suction pressure Primary pressure to RO operating at 270psi yielding Permeate output around 0.3 gpm. Set Auto-Flush Timers for manual operation with 10 to 15 minute flush at system startup, 2 to 3 hours of continuous operation and final just before unit shutdown. System is not designed to use permeate for flush. Autoflush timer just increases flow through membrane.
	10/02/07	System Startup Calibration of DAS Analytical Testing
10/8/07 – 10/12/07		
	10/08/07	Operating RO DAS
	10/09/07	Operating RO DAS Set of samples taken for Envirotech
	10/10/07	Operating RO ES&H Walk Through with SNL safety personnel
	10/11/07	Operate RO Recalibrate T-200

Event Date or Trip	Specific Date	Description of Work Performed
		Cleanup inside of Transportainer Tour with SNL & CP Managers Notes from B.E.S.T. We need to test for Barium & Lead. CP has PW chemical concentration re-injection limits. What are those limits? CP had to send SWD pre-filters to hazardous waste facility. Also Frank recommended when we present our data to use some graphical plots.
	10/12/07	Operate RO Seal holes top of Transportainer
10/17/07 – 10/19/07		
	10/17/07	RO Operation RO Performance Testing and Analysis with SNL project engineer
	10/18/07	RO Operation Training DAS-PC Interface
	10/19/07	500BBL PW Tank level re-adjusted to 15 feet we can now get ~ 5 gpm flow to T-100, tank does not run dry now. With this extra flow Frank started filling the PW-Untreated NMSU 286BBL Tank. RO Operation
10/23/07		Tour with EPA, OCD, & BLM
10/24//07		1st addition of PW-Untreated by NMSU
10/31/07		RO Operation by Frank Filters clogging fast – Iron residuals high ~2 mg/L
11/01/07		RO Operation by Frank
11/13/07 – 11/15/07		
	11/13/07	Cyclone separators taken out of service.
	11/14/07	RO Operation Frank showed us the RO pre-filters. Filters have a lot of iron precipitate being removed. New Conductivity Sensors UF Rebuild – Used new longer membrane housing. UF still out of service – Found brass fittings (factory install) leaking. Fittings were cracked. Went to town to find fittings. ABB Drive
	11/15/07	Repair leak on UF Calibrate VFD UF startup. UF finally in service Operate UF & RO
11/27/07 – 11/29/07		
	11/27/07	2nd Watering by NMSU for PW-Untreated 1st Watering by NMSU for Treated PW
	11/28/07	Last Envirotech Sample Also took sample of PW for GAB Winterizing of Pilot
	11/29/07	Pilot shut down until Spring ‘08

Appendix B – Water Chemistry Measurements

Table B-1. Field Test Results

FIELD TEST RESULTS				UF			RO			
				Inlet	CONC	PERM	Makeup	FW	CONC	PERM
10/10/2007	17:25	Conductivity	µS/cm				17,600		21,000	572
10/10/2007	17:25	Temperature	C				22.2		25.5	25.5
10/10/2007	17:25	pH	units				7.54		7.6	6.34
10/10/2007	17:25	Turbidity	ntu							
10/10/2007	17:25	Iron	mg/L							
10/12/2007	9:30	Conductivity	µS/cm				17,770		21,400	560
10/12/2007	9:30	Temperature	C				16.9		18.1	18.1
10/12/2007	9:30	pH	units				7.5		7.7	6.3
10/12/2007	9:30	Turbidity	ntu				22.6		3.94	0.41
10/12/2007	9:30	Iron	mg/L							
10/12/2007	12:45	Conductivity	µS/cm				17,540		21,300	582
10/12/2007	12:45	Temperature	C				21.1		24.2	24.1
10/12/2007	12:45	pH	units				7.7		7.7	6.4
10/12/2007	12:45	Turbidity	ntu				23.3		4.1	0.4
10/12/2007	12:45	Iron	mg/L							
10/18/2007	10:00	Conductivity	µS/cm				17,640	17,830	20,900	494
10/18/2007	10:00	Temperature	C				15.3	15.2	18	17.4
10/18/2007	10:00	pH	units				7.3	7.5	7.5	6.2
10/18/2007	10:00	Turbidity	ntu				13.5	3.68	2.17	0.27
10/18/2007	10:00	Iron	mg/L				1.5	1.17	1.1	0.02
10/18/2007	10:00	Sulfite	mg/L				<20			
10/18/2007	14:30	Conductivity	µS/cm				17,720	17,910	21,700	519
10/18/2007	14:30	Temperature	C					12.9	16	16.1
10/18/2007	14:30	pH					7.8	7.8	7.8	6.3
10/18/2007	14:30	Turbidity	ntu				6.7	2.55	2.66	0.2
10/18/2007	14:30	Iron	mg/L				0.54	0.73	1.07	0
10/18/2007	14:30	Sulfite	mg/L				30			
10/19/2007		Conductivity	µS/cm				18,100	18,130	21,300	458
10/19/2007		Temperature	C				10.8	11	13.1	13
10/19/2007		pH	units				7.3	7.5	7.5	6.2
10/19/2007		Turbidity	ntu				19.6	15.8	7.47	0.46
10/19/2007		Iron	mg/L				1.31	1.24	1.13	0.01
10/19/2007		Sulfite	mg/L				<30			
10/22/2007		Conductivity	µS/cm				17,970	17,930	22,100	460
10/22/2007		Temperature	C				12.5	13.2	14.5	14.1
10/22/2007		pH	units				7.9	7.9	7.5	6.3
10/22/2007		Turbidity	ntu				20.3	12.8	7.28	
10/22/2007		Iron	mg/L				1.51	1.34	1.51	0.04
10/23/2007		Conductivity	µS/cm				17,930	17,810	21,500	424
10/23/2007		Temperature	C				12.5	13.3	15.5	15.1
10/23/2007		pH	units				7.5	7.5	7.5	6.3
10/23/2007		Turbidity	ntu				17.1	5.8	3.32	0.19
10/23/2007		Iron	mg/L				1.28	0.97	0.91	0.01
10/31/2007	10:00	Conductivity	µS/cm							
10/31/2007	10:00	Temperature	C							
10/31/2007	10:00	pH	units				7.5	7.5	7.5	6.2
10/31/2007	10:00	Turbidity	ntu				17.4	6.8	3	0.2

FIELD TEST RESULTS				UF			RO			
				Inlet	CONC	PERM	Makeup	FW	CONC	PERM
10/31/2007	10:00	Iron	mg/L				1.99	1.4	1.39	0
10/31/2007	14:30	Conductivity	µS/cm				17,670	17,540	21,700	
10/31/2007	14:30	Temperature	C				17.1	17.8	21.7	
10/31/2007	14:30	pH	units				7.4	7.3	7.5	
10/31/2007	14:30	Turbidity	ntu				15.2	7.6	3.25	
10/31/2007	14:30	Iron	mg/L				1.3	1.15	1.53	
11/1/2007	10:30	Conductivity	µS/cm				17,700	17,320	22,100	523
11/1/2007	10:30	Temperature	C				18.7	19.3	21	23.6
11/1/2007	10:30	pH	units				7.5	7.5	7.6	6.2
11/1/2007	10:30	Turbidity	ntu				13	7.53	2.82	0.3
11/1/2007	10:30	Iron	mg/L				1.74	1.36	1.25	0.01
11/1/2007	14:30	Conductivity	µS/cm				17,600	17,750	21,700	502
11/1/2007	14:30	Temperature	C				19.3	19.2	21.6	21.4
11/1/2007	14:30	pH	units				7.9	7.9	7.9	6
11/1/2007	14:30	Turbidity	ntu				20.3	6.34	2.26	0.31
11/1/2007	14:30	Iron	mg/L				2.67	1.7	1.51	0
11/6/2007		Conductivity	µS/cm				17,980	17,820	22,600	511
11/6/2007		Temperature	C				12.5	14.2	15.4	18.7
11/6/2007		pH	units				7.6	7.5	7.8	6.5
11/6/2007		Turbidity	ntu				13.9	1.89	0.84	0.33
11/6/2007		Iron	mg/L				1.56	1.33	1.28	0
11/7/2007		Conductivity	µS/cm				17,830	17,830	22,400	502
11/7/2007		Temperature	C				15.6	15.6	20.1	20
11/7/2007		pH	units				7.4	7.4	7.5	6.1
11/7/2007		Turbidity	ntu				17.5	12.5	0.64	0.19
11/7/2007		Iron	mg/L				1.83	1.83	1.29	0
11/9/2007		Conductivity	µS/cm				17,790	17,630	22,600	621
11/9/2007		Temperature	C				17.6	17.6	19.7	20
11/9/2007		pH	units				7.4	7.3	7.5	6.2
11/9/2007		Turbidity	ntu							
11/9/2007		Iron	mg/L							
11/13/2007	8:30	Conductivity	µS/cm				18,210	17,960	23,100	545
11/13/2007	8:30	Temperature	C				11.3	12.2	15.4	12.4
11/13/2007	8:30	pH	units				7.6	7.5		6.3
11/13/2007	10:45	Conductivity	µS/cm				17,920	17,700	22,600	529
11/13/2007	10:45	Temperature	C				16.7	17.5	19.3	20.2
11/13/2007	10:45	pH	units				7.4	7.3	7.4	6
11/13/2007	10:45	Turbidity	ntu				40.9	12	2.91	0.24
11/13/2007	10:45	Iron	mg/L				3.01	1.9	1.92	0.02
11/14/2007		Turbidity	ntu	20.3		1.53				
11/14/2007		Conductivity	µS/cm	17,840	17,930	17,940				
11/14/2007		Temperature	C	16.5	17.1	17.4				
11/14/2007		pH	units	7.4	7.4	7.4				
11/14/2007		Turbidity	ntu	12.1	10.5	0.2				
11/14/2007		Iron	mg/L	3.04	2.95	2.31				
11/16/2007		Conductivity	µS/cm	17,900	18,010	18,100	17,690		22,300	497
11/16/2007		Temperature	C	14.2	14.8	14.4	16.5		18.2	17.8
11/16/2007		pH	units				7.4		7.5	6.1
11/16/2007		Turbidity	ntu	17.9	16.3	1.08	1.48		0.26	0.13
11/16/2007		Iron	mg/L				1.48		1.39	0.05

FIELD TEST RESULTS				UF			RO			
				Inlet	**CONC**	**PERM**	**Makeup**	**FW**	**CONC**	**PERM**
11/26/2007		Conductivity	μS/cm	18,010	18,180	18,130	17,960		20,900	444
11/26/2007		Temperature	C	11.1	10.3	10.5	10.6		12.9	12.1
11/26/2007		pH	units				7.4		7.5	6.2
11/26/2007		Turbidity	ntu	8.57	11.5	2.94	1.91		1.22	0.2
11/26/2007		Iron	mg/L				1.42		1.22	0.03
11/28/2007		Turbidity	ntu	15.6	18.4	4.91				

Table B-2. Logsheet Data: Flow Rate and Conductivity Measurements

			Flow Rates - (gpm)				Conductivities - (μS/cm)			
Date	**Time**	**Field Tests**	**Makeup Pre-Filter**	**CONC**	**REC**	**PERM**	**Makeup Pre-Filter**	**Makeup Post-Filter**	**CONC**	**PERM**
10/8/07	9:30am		Data Acquisition System (DAS) not in service				18,650		21,800	400
10/8/07	1:14pm		DAS not in service				18,820		21,700	412
10/8/07	3:10pm		DAS not in service				18,780		21,700	406
10/9/07	morning		DAS not in service				14,910		17,210	374
10/9/07	11:00am		DAS not in service				14,300		16,630	355
10/10/07	morning	YES	DAS not in service				13,640		14,450	355
10/10/07	10:30am		DAS not in service				13,550		13,680	305
10/10/07	1:00pm		0.9	0.5	3	0.25	18,440		26,300	993
10/10/07	1:30		0.68	0.5	4	0.23	17,470		24,100	1013
10/10/07	2:00		1.23	1	3.5	0.27	17,590		22,100	766
10/10/07	3:30		1.74	1.5	3	0.3	17,540		20,900	583
10/10/07	4:00		2.22	2	2.5	0.31	17,620		20,100	510
10/10/07	4:30		1.53	1.25	3.25	0.3	17,620		21,700	541
10/10/07	5:25pm		1.53	1.25	3.25	0.29	17,600		21,000	572
10/11/07	9:45am		1.57	1.3	3.25	0.3	17,690		21,100	544
10/12/07	9:30am	YES	1.55	1.27	3.25	0.29	17,770		21,400	560
10/12/07	12:45pm	YES	1.55	1.27	3.25	0.29	17,540		21,300	582
10/17/07	10:30am		Changed Filter to 1.0 micron from 5 micron							
10/17/07	11:45am		1.45	1.08	3.25	0.31	17,910		21,700	519
10/17/07	1:45pm		1.53	1.25	3.25	0.27	17,820		21,200	524
10/17/07	2:00pm		Changed Filter to 0.38 micron							
10/17/07	2:30pm		1.53	1.19	3.25	0.29	17,865			
10/18/07	2:30pm	YES	1.6	1.31	3.25	0.28	17,640	17,830	20,900	494
10/19/07	9:25am	YES	1.5	1.2	3.25	0.26	18,100	18,130	21,300	458
10/19/07	9:45am		Changed Filter with 0.38 micron							
10/22/07	12:30pm	YES	1.43	1.07	3.25	0.29	17,970	17,930	22,100	460
10/22/07			Changed Filter with 0.38 micron							
10/23/07	11:00am	YES	1.64	1.26	3.25	0.33	17,930	17,810	21,500	424
10/24/07			NMSU Watering Field. Added ~ 214.5BBL of PW-Untreated on 4500 sqft							
10/31/07	8:40am		Changed Filter with 0.38 micron							
10/31/07	9:10am	YES	1.64	1.27	3.25	0.41	17,970	17,790	22,600	469
10/31/07	11:15am		1.6	1.26	3.25	0.35	17,730	17,570	21,900	466
10/31/07	11:40am		Changed Filter with 0.38 micron							
10/31/07	2:30pm	YES	1.57	1.27	3.25	0.34	17,670	17,540	21,700	495
11/1/07	10:30am	YES	1.6	1.25	3.25	0.37	17,700	17320	22,100	523
11/1/07	11:40am		Changed Filter with 0.38 micron							
11/1/07	2:30pm	YES	1.53	1.24	3.25	0.33	17,600	17,750	21,700	502
11/6/07	11:30am		Changed Filter with 0.38 micron							
11/6/07	12:00PM	YES	1.53	1.18	3.25	0.39	17,980	17820	22,600	511
11/7/07	9:00am		Changed Filter with 0.38 micron							
11/7/07	10:00am	YES	1.53	1.17	3.25	0.38	17,830	17,520	22400	502
11/7/07	12:30pm		1.5	1.14	3.25	0.32	17,810	17,670	22,100	462
11/7/07	12:40pm		Changed Filter with 0.38 micron							
11/9/07	11:40am	YES	1.5	1.1	3.25	0.38	17,790	17,630	22,600	627
11/13/07	8:30am	YES	1.5	1.1	3.25	0.38	18,210	17,960	23,100	545
11/13/07	10:45am	YES	1.47	1.06	3.25	0.36	17,920	17,700	22,600	529

			Flow Rates - (gpm)				Conductivities - (µS/cm)			
Date	**Time**	**Field Tests**	**Makeup Pre-Filter**	**CONC**	**REC**	**PERM**	**Makeup Pre-Filter**	**Makeup Post-Filter**	**CONC**	**PERM**
11/14/07		UF Unit was put in service, in process of optimizing system. UF DAS not in Service Pre-Filter Status - UF @ 5 micron RO @ 1 micron								
UF Unit		YES	3	0.75	2	2.25	17,840		17,930	17,940
11/16/07										
UF Unit	9:30	YES	3	0.75	2	2.25	17,980		18,010	18,100
RO Unit	to 10:30	YES	1.57	1.26	3.25	0.35	17,680		22,300	497
11/19/07			No Tests!							
11/26/07										
UF Unit	9:00	YES	3	0.75	2	2.25	18,010		18,180	18,130
RO Unit	to 10:00	YES	1.5	1.25	3.25	0.24	17,960		20,900	444
11/28/07		System Shutdown and Winterized! NMSU Watering Fields, PW-Untreated 120BBL on 4500 sqft and Treated-PW 45BBL on 4500 sqft								

Table B-3. Logsheet Data: Pressure and Temperature Measurements

			Pressures - (psi)				Temperatures (degrees C)			
Date	Time	Field Tests	Makeup Pre-Filter	Makeup Post-Filter	RO Feed	RO Conc	Makeup Pre-Filter	Makeup Post-Filter	CONC	PERM
10/8/07	9:30am						14.6		15.5	19
10/8/07	1:14pm		32	32	270	268	18		19.2	19.4
10/8/07	3:10pm		32	32	270	268				
10/9/07	morning		32	32	270	268				
10/9/07	11:00am		32	32	270	268	19.6		19.1	19.1
10/10/07	morning	YES	33	33	270	270	18.8		19.1	19
10/10/07	10:30am		31	31	270	268	19.1		19.7	19.6
10/10/07	1:00pm		36	36	274	274				26.3
10/10/07	1:30		36	36	274	274	22.5		29.4	29
10/10/07	2:00		36	36	274	274	22.3		27.6	27.8
10/10/07	3:30		36	36	274	274	22.4		25.3	25.4
10/10/07	4:00		36	36	274	274	22.2		25	24.7
10/10/07	4:30		36	36	274	274	22.5		26.2	25.6
10/10/07	5:25pm		36	36	274	274	22.2		25.5	25.5
10/11/07	9:45am		33.5	32.5	269	269	17.4		20.3	20.3
10/12/07	9:30am	YES	33	31	268	267	16.9		18.1	18.1
10/12/07	12:45pm	YES	33	31	268	267	21.1		24.2	24.1
10/17/07	10:30am									
10/17/07	11:45am		32	32	270	268				
10/17/07	1:45pm		33	24	260	258				
10/17/07	2:00pm									
10/17/07	2:30pm		33	33	270	270				
10/18/07	2:30pm	YES	33	33	269	269				
10/19/07	9:25am	YES	31	26	265	262				
10/19/07	9:45am									
10/22/07	12:30pm	YES	26	19	255	250	12.5	13.2	14.5	14.1
10/22/07										
10/23/07	11:00am	YES	31.5	28.5	264	262	12.5	13.3	15.5	15.1
10/24/07										
10/31/07	8:40am									
10/31/07	9:10am	YES	32	32	268	267	13.8	15.3	16.6	16.3
10/31/07	11:15am		33	27	263	260	18.2	18.9	20.6	21
10/31/07	11:40am									
10/31/07	2:30pm	YES	34	30	266	266	19.1	19.8	21.7	22.3
11/1/07	10:30am	YES	33	30	266	264	18.7	19.3	21	23.6
11/1/07	11:40am									
11/1/07	2:30pm	YES	33	28	265	262	19.3	19.2	21.6	21.4
11/6/07	11:30am									
11/6/07	12:00PM	YES	33	32	269	266	12.5	14.2	15.4	18.7
11/7/07	9:00am									
11/7/07	10:00am	YES	33	31	266	265	15.6	17.3	20.1	20
11/7/07	12:30pm		33	23	260	258	16.7	17	19.3	19.9
11/7/07	12:40pm									
11/9/07	11:40am	YES	33	28	265	263	17	17.6	19.7	20
11/13/07	8:30am	YES	31	31	266	266	11.3	12.2	15.4	12.4
11/13/07	10:45am	YES	33	27	264	261	16.7	17.5	19.3	20.2
UF Unit		YES	29	29	163	160	16.5		17.1	17.4

			Pressures - (psi)				Temperatures (degrees C)			
Date	**Time**	**Field Tests**	**Makeup Pre-Filter**	**Makeup Post-Filter**	**RO Feed**	**RO Conc**	**Makeup Pre-Filter**	**Makeup Post-Filter**	**CONC**	**PERM**
11/16/07										
UF Unit	9:30	YES	29	29	162	161	14.2		14.8	14.4
RO Unit	to 10:30	YES	32	31	267	265	16.5		17.8	18.2
11/19/07										
11/26/07										
UF Unit	9:00	YES	28	28	161	160	11.1		10.3	10.5
RO Unit	to 10:00	YES	32	28	265	264	10.6		12.9	12.1

Appendix C – Particulate Analysis

Samples were obtained for the raw inlet, pre/post cyclone, and RO feed pre/post filter for particulate analysis by Spectrex. Results indicate that the majority of particulate matter was less than 10 microns, and most was 1 micron or less in size. There is some doubt as to whether proper sampling procedures were followed, and this test will be repeated at the next phase of the pilot.

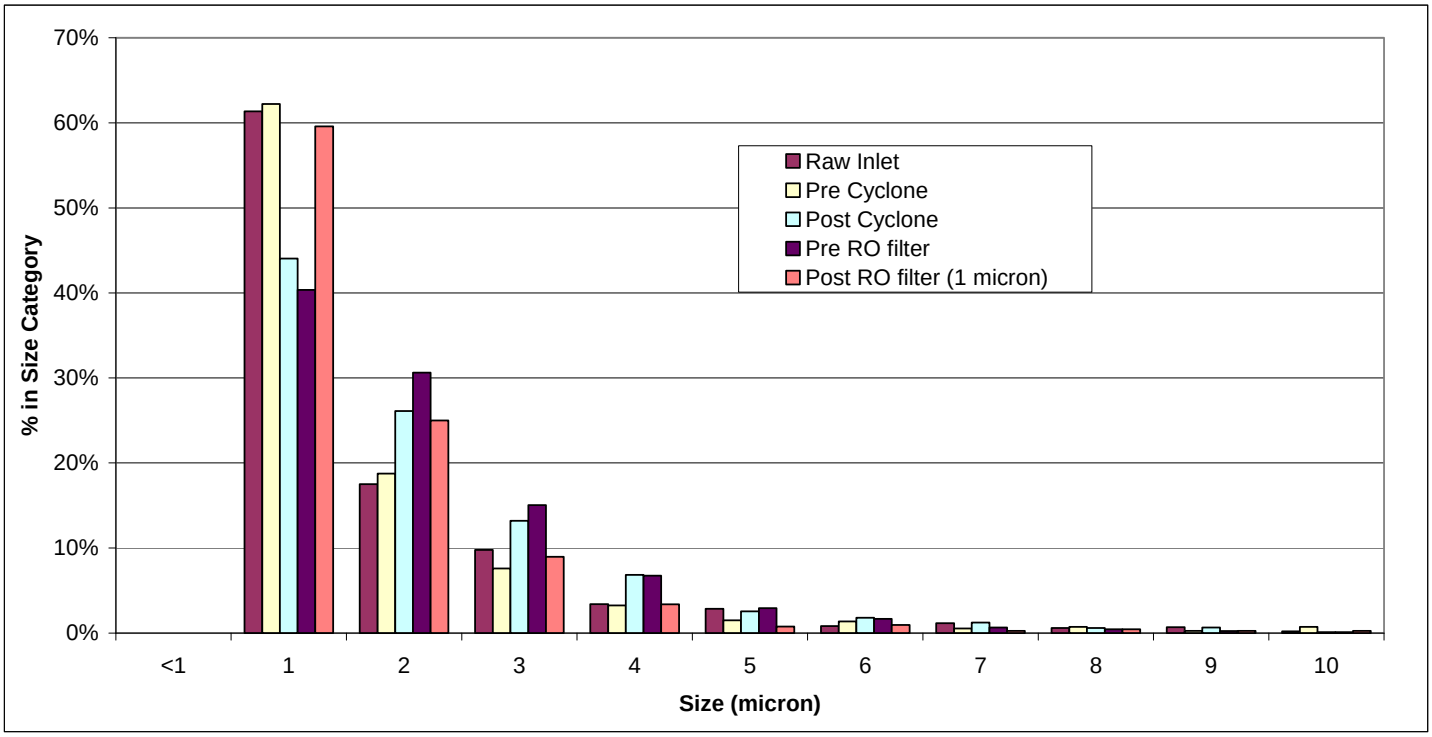

Figure C-1. Spectrex Particulate Analysis

Appendix D – Water Meter Data

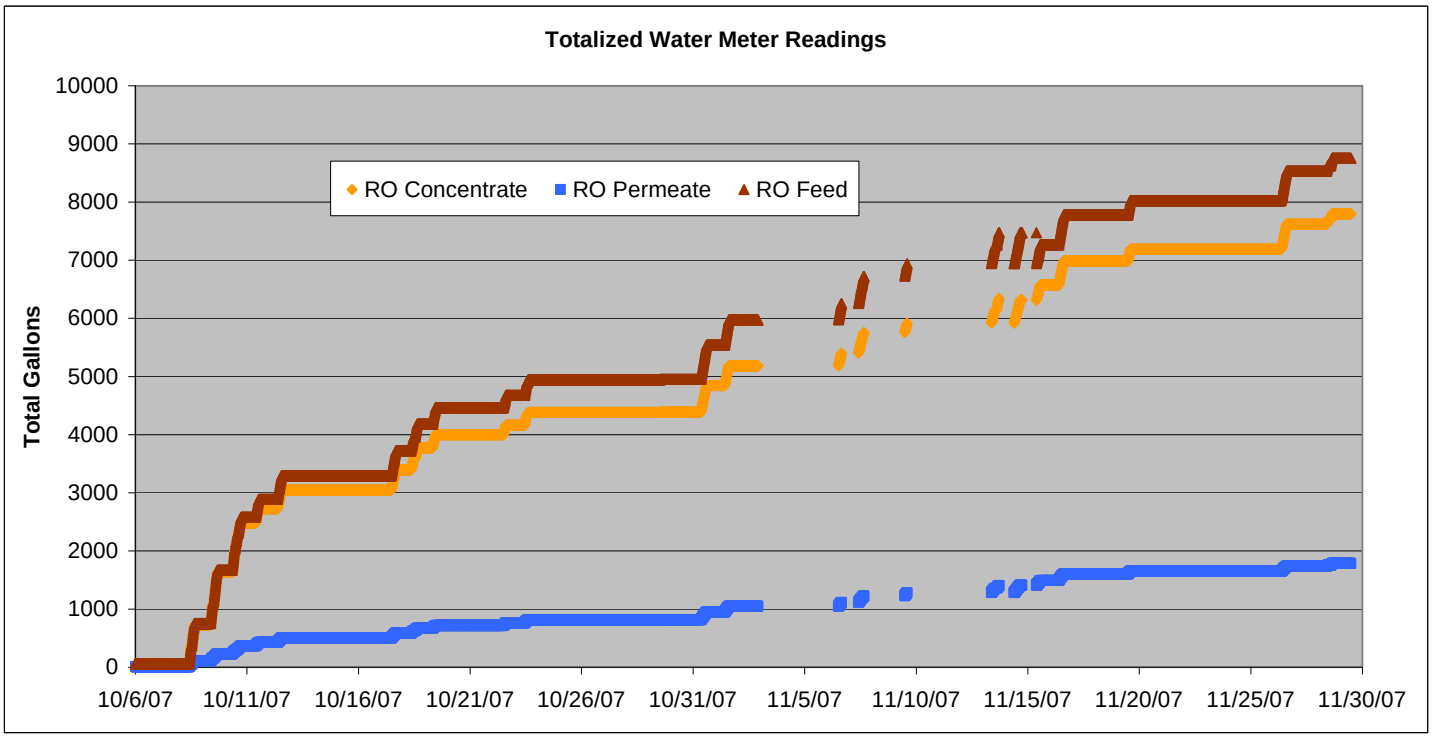

Figure D-1. Totalized Water Meter Data

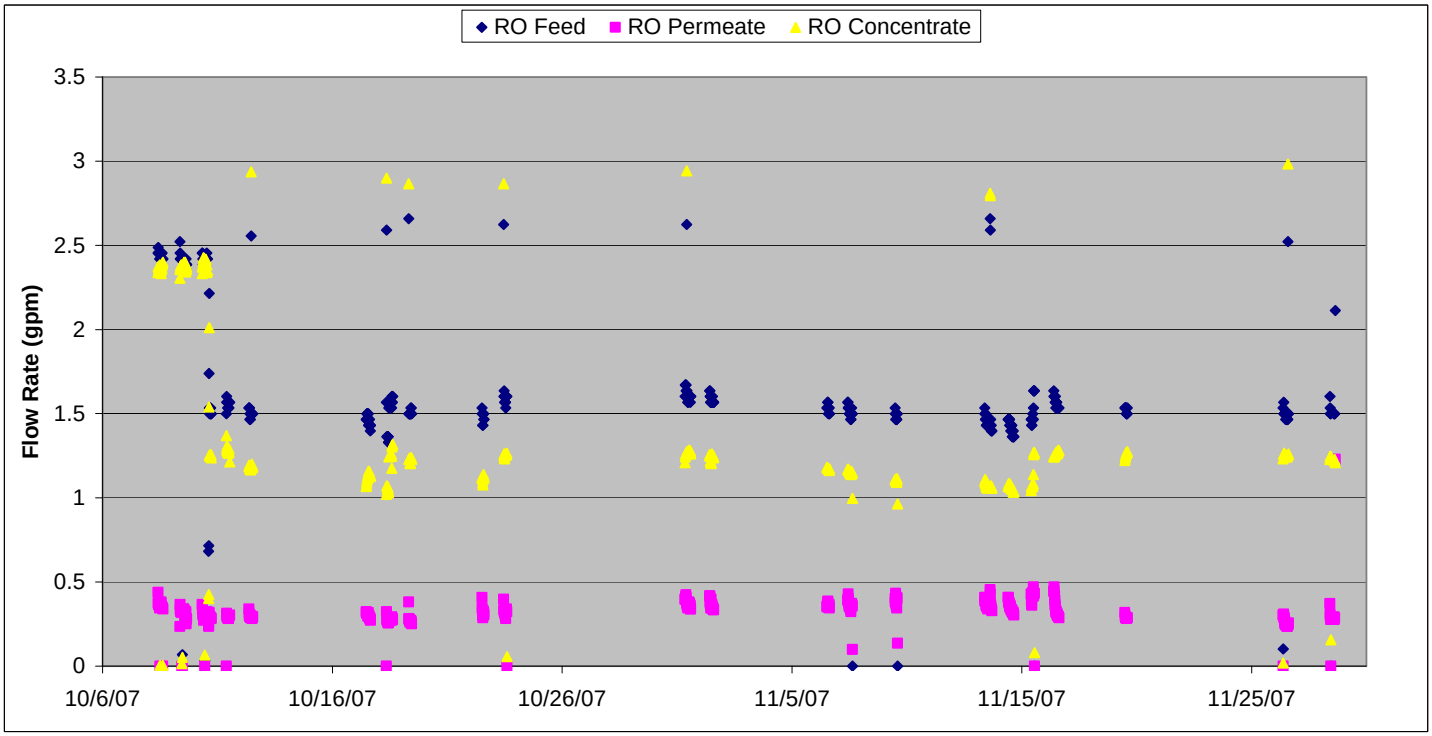

Figure D-2. Flow Meter Data

Distribution:

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1	MS 1104	Margie Tatro, 6200
1	MS 0706	D.J. Borns, 6312
1	MS 0706	A.R. Sattler, 6312
1	MS 1495	Jacqueline Kerby Moore 1495
1	MS 1033	Alma Giron, 1457
1	MS 0754	Patrick Brady, 6312
1	MS 0754	Thomas Mayer, 6316
1	MS 0892	Richard Kottenstette, 1716
1	MS 1108	M. Michael Hightower, 6332
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