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# Cost-Effective Recovery of Concentrated Cooling Tower Blowdown Using the CERRO Process

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COST-EFFECTIVE RECOVERY OF CONCENTRATED COOLING TOWER  
BLOWDOWN USING THE CERRO PROCESS

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COST-EFFECTIVE RECOVERY OF CONCENTRATED COOLING  
TOWER BLOWDOWN USING THE CERRO PROCESS

by

LINDSEY NICOLE LARSON, BSCE

THESIS

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## **Abstract**

The Concentrate Enhanced Recovery Reverse Osmosis (CERRO) process is a seawater-RO unit that can cost-effectively achieve extremely high recoveries from water high in silica, carbonate and sulfate concentrations. This relatively new technology takes advantage of the induction time of potential foulants to recover more water than what is normally achievable with a conventional desalination system. The scope of the project was to evaluate the efficiency of the CERRO process as a pilot study using cooling tower blowdown which varied in water quality parameters daily. It was found that the CERRO pilot could successfully achieve 85% recovery, and the main limitation on recovery was due to the presence of organics in the feed water and pilot system. A laboratory study was performed on the efficiency of granular activated carbon (GAC) as a possible pretreatment system, and an economic analysis was performed for a full-scale CERRO system.

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## **Chapter 1: Introduction**

This chapter discusses the limitations of traditional desalination technologies and introduces the CERRO process as an advanced reverse-osmosis process that can overcome these limitations. This chapter also focuses on the research objectives of this study, and applies the CERRO system as a cost-effective solution for water treatment in El Paso Electric's Power Plant processes.

### **1.1 Problem Statement**

Water is an extremely valuable resource that must be managed efficiently. In recent years, the need for fresh water sources has become increasingly necessary due to the growing stress on traditional water supplies. Desalination technologies offer one of the most efficient ways to regenerate fresh water from previously unusable supplies such as seawater, brackish groundwater and wastewater, and will continue to be a key component of sustainable development (Tonner, 2002). There are many types of membrane desalination processes, including nanofiltration (NF), vapor compression (VC), and reverse osmosis (RO), the latter being the most commonly used system within the United States. The cost of treating water with a regular RO system can be expensive, and there are limitations as to how much recovery can be achieved; therefore, new developments that will optimize the recovery of water in a cost-effective way are extremely valuable. Costs of operation include the capital cost at start-up, energy to provide the pressure to push concentrated water through the membranes, and the installation of methods to dispose of the high TDS concentrate waste that is produced during treatment. Although the cost of regenerating fresh water using RO desalination can be high, it is often the most economical solution for places that are far from available sources of freshwater when compared to transporting freshwater by pipes (Leven, 2013). Most RO systems are limited by the saturation of potential foulants, the most

common being calcium carbonate ( $\text{CaCO}_3$ ), calcium sulfate ( $\text{CaSO}_4$ ) and silica ( $\text{SiO}_2$ ). Due to this limitation, regular RO desalination systems have to run at a lower recovery in order to avoid supersaturation of these compounds which could result in precipitation and scaling of membranes. Scaling occurs when a precipitant deposits itself on the surface of the membrane and forms a seed for other solids of the same nature to attach to. As the membrane becomes covered in layers of the precipitant, pores of the membrane become clogged and the pressure must increase in order to drive the water through the membrane. As pressure is increased, the solids covering the membrane form a compressed layer that is difficult to remove, which leads to a decrease in permeate quality. More energy must be used to apply the pressure to force the water through the membranes, and eventually, fouled membranes must be replaced to resume normal RO operation. For this reason, RO systems are designed to keep flux as low as possible, and cross-flow velocity high to prevent membrane scaling. Desalination is the future of water treatment, and the limitations posed by high cost, the saturation of potential foulants, and concentrate disposal prove the need for new cost-effective technologies that have the potential to recover fresh water from concentrated water sources.

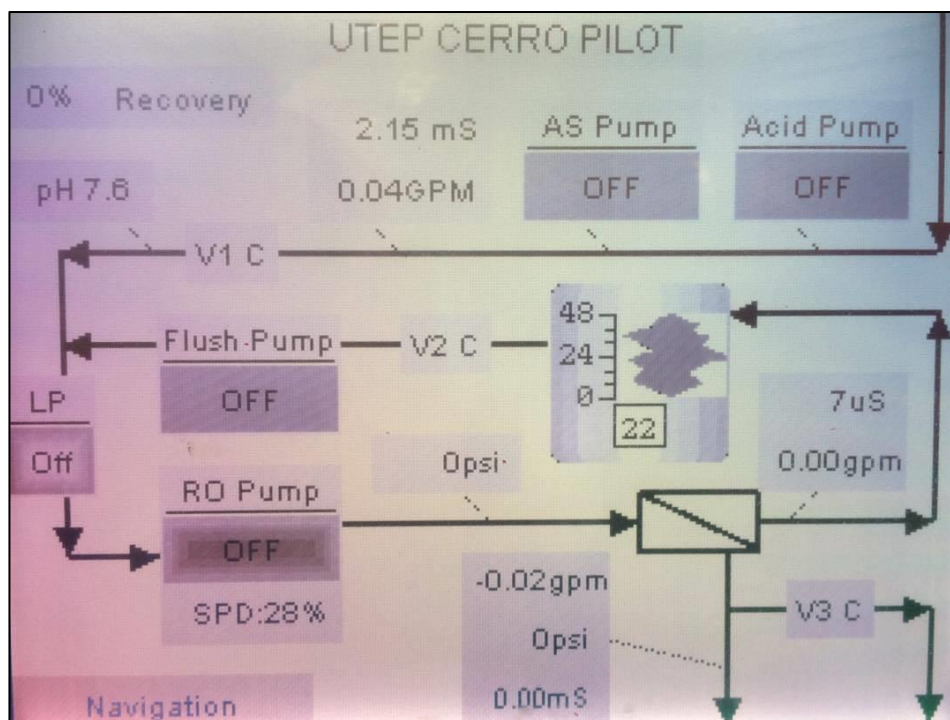
## **1.2 Concentrate Enhanced Recovery Reverse Osmosis (CERRO) Process**

In 2010, an advanced system called the “Concentrate Enhanced Recovery Reverse Osmosis” process was introduced as an extremely cost-effective alternative to regular RO desalination systems that can achieve extraordinarily high recoveries of concentrated water (Tarquin, 2012). The CERRO process is a simple seawater-RO system that has the ability to achieve a higher recovery than conventional RO systems because it takes advantage of the induction time of supersaturated compounds. While conventional RO systems will run at a recovery where the least soluble inorganic substance is not yet saturated, the CERRO process treats

the water until this compound is supersaturated and about to precipitate; therefore, it is treated slightly less than its induction time. At the moment immediately before precipitation begins, the concentrate is flushed from the membranes with permeate or feed water and the process restarts. The CERRO process was so effective that it was able to treat RO concentrate from the Kay Bailey Hutchison (KBH) Desalting Plant of El Paso, TX using a batch treatment pilot system to recoveries as high as 91% (Tarquin, 2012). The CERRO process can not only be used for the treatment of RO concentrate, but can also be used in many other applications, such as the treatment of wastewater from thermoelectric processes. For the purpose of this project, the CERRO process is being evaluated for treatment of water mainly comprised of cooling tower blowdown from the El Paso Electric Company's (EPEC) Newman Power Plant.

### **1.2.1 Parameters of Design of the CERRO Process**

The pilot plant used for the project at EPEC's Newman Power Plant was a single-pass system with a 3:2:1 vessel configuration. The system was automated with pressure gages, flow meters, sampling valves, and tanks for acid and antiscalant addition. The system would log various parameters such as flows, conductivity, temperature, pH, and recovery on a minute-by-minute basis. A remote-monitoring system was installed that allowed the user to access the log data via any internet connection, and allowed the user to change system settings and turn the system on and off. Figure 1.1 shows the screen that would appear on any device that was logged into the remote-monitoring system, identical to the screen on the actual CERRO pilot plant.

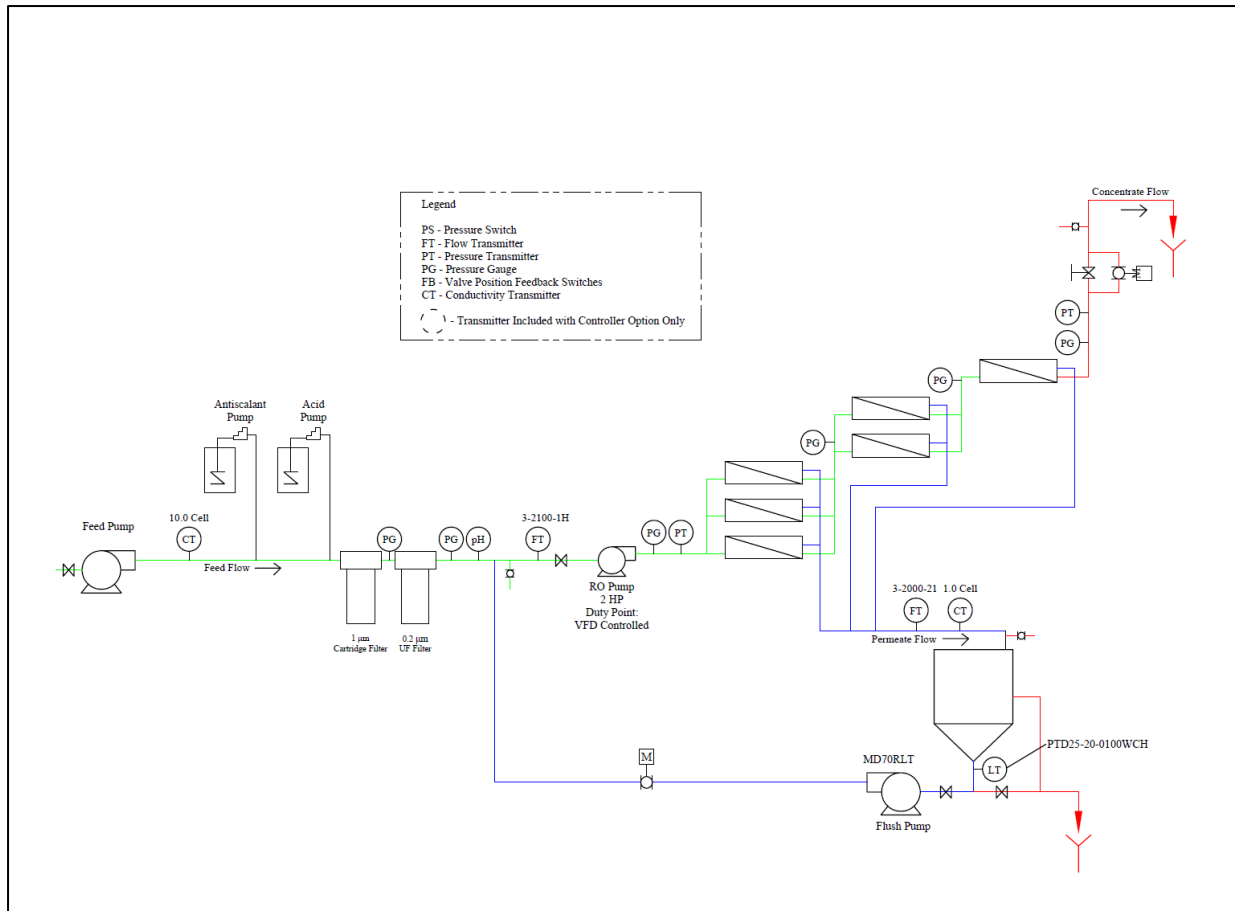


**Figure 1.1- CERRO Pilot Plant remote monitoring "system status" screen**

The system recovery was controlled with a manual concentrate valve, and the feed pressure was automatically adjusted to match a set permeate flow, which was set to 0.7 gpm for the purpose of this study. An image and schematic of the CERRO process are shown in Figure 1.2 and Figure 1.3, respectively.



**Figure 1.2- CERRO pilot unit located at Newman Power Plant**



**Figure 1.3- CERRO pilot unit schematic**

## 1.2.2 Pilot Plant Complications

This CERRO pilot plant was the first construction of the single-pass CERRO system, which was originally designed in the laboratory setting as a batch treatment system. One major challenge faced in the CERRO pilot testing was caused by inconsistent recovery settings due to oversensitivity of the needle in the concentrate valve. When the system was run for long periods of time (overnight or multiple days), it was noted that the recovery increased over time. For example, a sample taken in the morning of August 4 showed a recovery of 76.4% based on TDS laboratory data, and the sample taken the next morning showed a recovery of 88.7%, even though the recovery was not manually changed throughout the run. Since the system was designed to be controlled by a set recovery and permeate flow, the recovery should have been consistent over time

in an ideal situation. It was found that the needle valve was extremely sensitive to minor changes, such that tapping on the PVC pipe that transported water through the valve made the recovery change significantly. In a new full-scale system, changes in recovery would not be an issue, but for the pilot testing, this factor made data analysis more challenging. Another contributing problem was caused by incorrect recovery readings shown on the CERRO pilot unit screen. The recovery was calculated from values obtained from flow meters in the system which were not functioning properly. In many cases, the recovery would show as larger than 100% because concentrate flows were measured to be negative, both of which are impossible. Due to these factors, manual flow measurements were used to verify the recovery that was set. TDS data obtained from laboratory testing confirmed that manual flow measurements were an accurate way to measure recovery, so this method was continued throughout the entire project.

### **1.3 Newman Power Plant Background and Project Objective**

In 2010, an estimated 161 billion gallons per day were withdrawn for the generation of thermoelectric power, accounting for 45% of total water withdrawals in the U.S. (Maupin et al, 2010, NRDC, 2014). Most of that water is cycled in cooling towers that form a high TDS stream similar to RO concentrate, called blowdown. The length of time the concentrate can be cycled within the tower is limited because the high TDS concentration can cause precipitation and scaling, lead to microbiological growth and create potential for increased corrosion within the cooling towers. (Frassa, 2015). In semi-arid regions of the U.S., the blowdown water is typically disposed through discharge into an evaporation pond, which is an expensive process and wastes large amounts of water. El Paso Electric purchases 3 million gallons/ day (MGD) of treated wastewater from El Paso Water for its cooling towers. EPEC also has a well on-site that provides for process and domestic water uses.



The quality of water discharged from the cooling towers at EPEC is dependent upon the season. During the summer, the plant is running at maximum capacity, which leads to blowdown that has a TDS concentration that is often twice as high as it is in winter. Some of the blowdown and process water is recovered through a supplemental reverse-osmosis system before being discharged into a 45- acre evaporation pond located on-site (pictured in Figure 1.4).



**Figure 1.4- El Paso Electric's 45-acre evaporation pond at Newman Power Plant**

Currently, the amount of blowdown discharged is exceeding pond capacity, so additional private land is used for disposal of the excess water. The recovery needed for EPEC to contain all wastewater on-site was calculated using median evaporation and precipitation rates in El Paso, the quality and amount of wastewater estimated to be discharged on an annual basis, and the size of the existing evaporation lake located on-site (see Appendix A). A calculated net evaporation rate of 60 inches/year accounts for a total evaporation rate of 140 gallons/ minute (gpm) from the 45-acre evaporation pond on an annual basis. EPEC has determined that the annual discharge of waste from all plant processes is 750 gpm, which leaves an additional 610 gpm that is currently being disposed of onto Bowen Ranch. The purpose of this project is to investigate the feasibility of using the CERRO process to cost- effectively recover at least 81% of blowdown water that is currently

thrown away while at the same time, making EPEC self-sufficient in concentrate disposal by reducing the final disposal volume to less than 140 gpm.

## **Chapter 2: Methodology**

This chapter outlines the procedures and materials used for running the CERRO pilot plant, sample collection, membrane cleaning and laboratory tests used throughout the project. All laboratory tests were run according to the procedures in standard methods for the examination of water and wastewater.

### **2.1 CERRO System Procedure**

The acid and antiscalant tanks were filled with 5%  $\text{H}_2\text{SO}_4$  solution and 10% TriPol 6150 Antiscalant (for carbonates, sulfates and silica control). The pumps were primed before the system was turned on to ensure that air bubbles did not form in the lines. Immediately upon start-up of the pilot plant, the pressure drops across the cartridge and UF filters were checked. As the system would often run overnight and into the following days, the filters were changed if the pressure loss across a filter was close to reaching 10 psi. The recovery was set by adjusting the concentrate valve and manually measuring the permeate and concentrate flow rates using a graduated cylinder and a stopwatch. If the flows indicated the desired recovery, the batch was left until there were 2 minutes remaining, and then measured again. If the flow rates remained consistent, it would confirm that the system had reached equilibrium and the samples collected would be truly representative of the batch.

### **2.2 Sample Collection**

For the purpose of this study, it was important to ensure that the collection of samples remained consistent over the course of the testing period. Feed, permeate, and concentrate samples were collected regularly from the CERRO pilot plant with 2 minutes remaining in the batch, which would allow time for the system to stabilize and reach equilibrium after start-up and flushes

between batches. Concentrate samples were diluted on-site with permeate water to ensure the silica concentration would remain below 120 mg/L (the polymerization and precipitation threshold of silica). The samples were stored in 120 mL plastic sample containers. Most samples were analyzed in the lab the day of collection or the following day to minimize the time for precipitation to occur which could give inaccurate results for mass balance analyses. Samples that were analyzed later than one day after collection were noted in the 'Notes' section in Appendix A-2.

### **2.3 CERRO Membrane Cleaning Procedure**

In conducting a chemical cleaning of the membranes, the permeate water was released to waste and new permeate from the existing RO treatment system at EPEC was used to prepare the desired cleaner. The concentrate and permeate hoses were placed in the permeate tank so that the water would be recirculated, which would also heat up the water. For most cleaners, the temperature was ideally supposed to reach 45°C, but depending on the day the cleaning was performed, the highest the temperature would reach was approximately 35°C. It is expected that the membrane cleaning may have been more efficient if the correct temperature was used, as would be achieved in a full-scale system. The cleaners used for the CERRO membrane cleaning were from New Logic Research Inc. and TriSep Corporation. Listed below are the different types of cleaners and the nature of foulants each type was designed to target:

*NLR 404- Acidic Liquid Membrane Cleaner:* A 2% concentration was used to clean the membranes, which lowered the pH of the water to 2.5. This type of low-pH cleaner is used to target metallic-based foulants such as sulfates (specifically calcium sulfate for the CERRO system) and calcium carbonate. It is also used to remove inks and dyes.

*NLR 505- Alkaline Liquid Membrane Cleaner:* This cleaner targeted organics, biological components, dyes, oils and grease. A 2% concentration solution was used to clean the membranes at a pH of 11. Caustic soda was used to raise the pH when necessary.

*NLR 500- Oxidizing Powdered Membrane Cleaner:* This cleaner was designed to target biological foulants, organics, oil, grease, and dyes, very much like the NLR 505 cleaner. A 0.5% solution was made at a pH of 11.5. Caustic soda was used to raise the pH when necessary.

*TriClean 212 TF Membrane Cleaner:* This cleaner was designed to remove biological, colloidal, and organic fouling. It is also effective for emulsified oil and silica, and was used at a high pH.

## **2.4 Organics Testing**

The success of the high pH cleaners that were targeted towards organic foulants led to additional research on the presence of organics in the incoming feed water to the CERRO system. Three laboratory tests were performed to identify the type and amount of organics in the feed water. These tests included filtration using 0.1  $\mu\text{m}$  and 0.025  $\mu\text{m}$  filters, granular activated carbon (GAC) slurry tests, and GAC column testing. The instruments used for the analyses were Gas Chromatography Mass Spectrophotometry using an Agilent 5977 GC/MSD Analyzer, Total Organic Carbon (TOC) using a Shimadzu TOC-V<sub>CSH</sub> Analyzer and UV Spectrophotometry using an Agilent 8453 Spectrophotometer operated at 254 nm wavelength. The GC-MS scan was conducted by El Paso Water and it showed that low levels of organics were present in the feed water. Possible compounds were chloroethene (polyvinyl chloride, PVC) and 1-propene, but no further testing was conducted. The results are found in Appendix A-3. TOC analysis required daily calibration of the equipment with frequent testing, to verify that the prepared standard concentrations were correct. Although the analyzer was calibrated every time it was used, the

precision of the instrument was not reliable at TOC concentrations below 1 mg/L. Permeate samples would often read negative values (which is impossible because inorganic carbon cannot be greater than total carbon) due to the low precision of the instrument in low ranges. Therefore, the TOC data was compared with data using a UV spectrophotometer at a 254 nm wavelength. Since the nature of the organic compound was not known, a calibration curve could not be built, but absorbance values measured at the 254 nm wavelength were compared against each other to see if there was a trend. Figure 2.1 shows the types of compounds that may be present at specific wavelengths using the Agilent 8453 UV-Visible Spectrophotometer that was used for this project.

<b>Table 1</b> Lower Limit of UV Transmission for Some Common Solvents	
<b>Lower Limit</b>	<b>Solvent</b>
180–195 nm	Sulfuric acid (96%) Water Acetonitrile
200–210 nm	Cyclopentane n-Hexane Glycerol 2,2,4-Trimethylpentane Methanol
210–220 nm	n-Butyl alcohol Isopropyl alcohol Cyclohexane Ethyl ether
245–260 nm	Chloroform Ethyl acetate Methyl formate
265–275 nm	Carbon tetrachloride Dimethyl sulfoxide Dimethyl formamide Acetic acid
280–290 nm	Benzene Toluene m-Xylene
Above 300 nm	Pyridine Acetone Carbon disulfide

**Figure 2.1- Possible organics measured at wavelengths <300 nm**

It can be seen that there are many types of organic compounds in the 190-290 nm wavelength range, therefore, spectrum wavelength scans using the UV spectrophotometer were used to detect organics for comparison with TOC measurements.

### 2.4.1 Laboratory Filtration Testing

The first test performed in the lab was a filtration test to see if the organics could be removed by smaller filters than the sizes that were installed in the CERRO pilot plant. Since the pilot plant had a cartridge filter of 1  $\mu\text{m}$  and a UF filter of 0.2  $\mu\text{m}$ , the sizes used in the laboratory for the filter test were a 0.1  $\mu\text{m}$  and 0.025  $\mu\text{m}$  filters, obtained from Millipore Sigma. Below is a description of the filters used:

*Durapore Membrane Filter (0.1  $\mu\text{m}$ )-* 47 mm diameter Hydrophilic PVDF (Polyvinylidene difluoride) membrane designed to provide high flow rates and throughput.

*MF-Millipore Membrane Filter (0.025  $\mu\text{m}$ )-* 47 mm diameter membrane composed of cellulose acetate and cellulose nitrate.

These filters were chosen for analysis because of their small pore size to determine if the organics could be filtered out before entering the CERRO system. The test consisted of placing the sample in a filter connected to a vacuum flask previously cleaned with DI water, and then slowly filtering the sample into the clean flask. The sample was immediately collected in a glass vial and sealed with Parafilm to prevent any organics from entering the sample through the atmosphere. A DI sample was also filtered to see if any organic carbon was added to the sample by the filters.

### 2.4.2 GAC Slurry Test

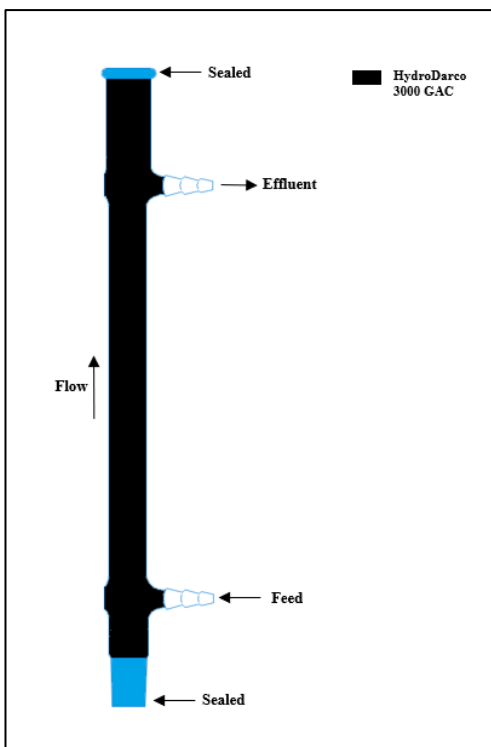
The GAC used for laboratory testing was HydroDarco 3000, which was specifically designed to have a “rapid adsorption of and high capacity for dissolved organics in drinking water” (Cabot Corporation, 2017). A GAC bed was tested first to determine whether the HD 3000 GAC would work for removing the organics. Essentially, a beaker was filled with GAC and feed water, allowed to sit for 15 minutes, filtered with a glass-fiber filter, and then tested with UV

spectrophotometry. It was determined that a significant amount of organics were removed with the HD 3000 GAC.

Testing was continued using GAC slurries to measure the adsorption efficiency of the GAC. The slurry test was conducted by adding amounts of GAC ranging from 0.5 g/L to 8 g/L to 1 liter of feed water and stirring for various amounts of time. Three separate GAC slurry tests were performed, with samples taken after 2, 4, 5.5 and 22 hours.

### 2.4.3 GAC Column Test

A reactor column was used to replicate a GAC column in the laboratory setting. The column was filled with GAC, and the top and bottom ends were sealed. Water was pumped into the bottom extension of the column at varying flow rates, and clean water was collected from the top as shown in Figure 2.2



**Figure 2.2- GAC column used for laboratory testing of organics removal**



The actual detention time in the column was determined by using a set flow rate from the feed pump and measuring the time it took for the water to enter the bottom of the GAC column and leave through the top outlet.

## **2.5 Laboratory Analysis**

Laboratory testing was essential in understanding the quality of the feed water and verifying the recovery achieved through mass balances. Lab testing included selected anion and cation determinations, total dissolved solids (TDS), total organic carbon (TOC), chlorides and total hardness titrations, alkalinity, and silica analyses.

## Chapter 3: Results

This chapter discusses the results of the CERRO pilot plant testing performed at the Newman Power Plant. Additionally, this chapter includes the results from the laboratory testing performed to evaluate the efficiency of GAC in removing organic constituents in the feed water.

### 3.1 CERRO System Feed Water Analysis

In this project, the feed conductivity ranged from 2.64- 4.64 mS/cm due to the season of year and the amount of cycles the water had in the cooling tower before being discharged. The maximum conductivity that could be reached within the cooling towers before being discharged was 4.5 mS/cm as a regulation set by EPEC. Since the plant was running at full capacity during the summer, many days had a high conductivity, but cooler days had a lower conductivity. Table 3.1 shows the chemical characteristics of the CERRO feed on two separate days.

**Table 3.1- CERRO feed water quality**

Date	Concentration								
	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	F mg/L	NO <sub>3</sub> mg/L	SO <sub>4</sub> mg/L	TDS mg/L
6/22 Feed	135.6	35.4	17.3	383.9	524.2	1.4	46.7	517.3	1800
7/13 Feed	216.6	82.0	12.3	700.5	822.4	2.5	158.6	1001.6	3030
% Difference	-60%	-132%	29%	-82%	-57%	-79%	-239%	-94%	-68%

It should be noted that there were large differences in feed water parameters. For example, sodium and nitrates increased by approximately 80% and 240% while magnesium decreased by 30% when comparing the feed sample taken on June 22 to the sample from July 13. Additionally, TDS was approximately 70% higher on July 13 than on June 22; therefore, recoveries had to be

adjusted to account for the major changes in feed water quality. For the same reason, the temperature of the incoming feed water changed by as much as 15°C because the CERRO pilot was being fed from a tank that was located outside.

### **3.2 CERRO System Feed Pressure Monitoring**

The daily change in feed water quality made the monitoring of feed pressures logged by the CERRO system a challenge. A table of cumulative information is shown in Appendix A-2, which shows a compilation of significant data obtained from lab testing and daily data logged by the CERRO server. This data was used to monitor the feed pressure changes of the system based on multiple parameters such as recovery, permeate flow, incoming feed conductivity, and temperature. In an ideal situation, if all these parameters remained constant, the feed pressure would be constant if no fouling occurs. If feed pressure increased while all other variables remained constant, this would indicate membrane fouling. A general rule of thumb in water treatment is that “for every 1° C increase in temperature, the permeate flow increases 3%” (Bonta, 2011). Since the CERRO pilot plant was controlled at a set permeate flow rate, it was assumed that the feed pressure would then decrease by approximately 3% for every 1°C increase in temperature. This is due to water having a lower viscosity and higher diffusion rate at higher temperatures. As previously mentioned, the CERRO system had a remote monitoring system that would log data to a server on a minute-by-minute basis. This data was used to monitor feed pressures and plot the trends in max pressures per batch, as well as feed pressure (logged as membrane pressure) and temperature vs. time. It was noted that many times, the feed pressure would fluctuate over time, which could be due to changing recovery, feed conductivity, feed temperature, or possible membrane fouling. Figures 3.1, 3.2 and 3.3 show data from a run completed on June 23. It can be seen that the max pressure per batch fluctuated by approximately 4%, and the temperature changed by approximately

2°C. It can be seen in Figure 3.1 that on June 23, the feed pressures remained consistent throughout the batches. Based on feed pressure trends over time and considering temperature changes, it was concluded that this pilot run was successful at the set recovery of 88% and incoming feed conductivity of 3.47 mS/cm.

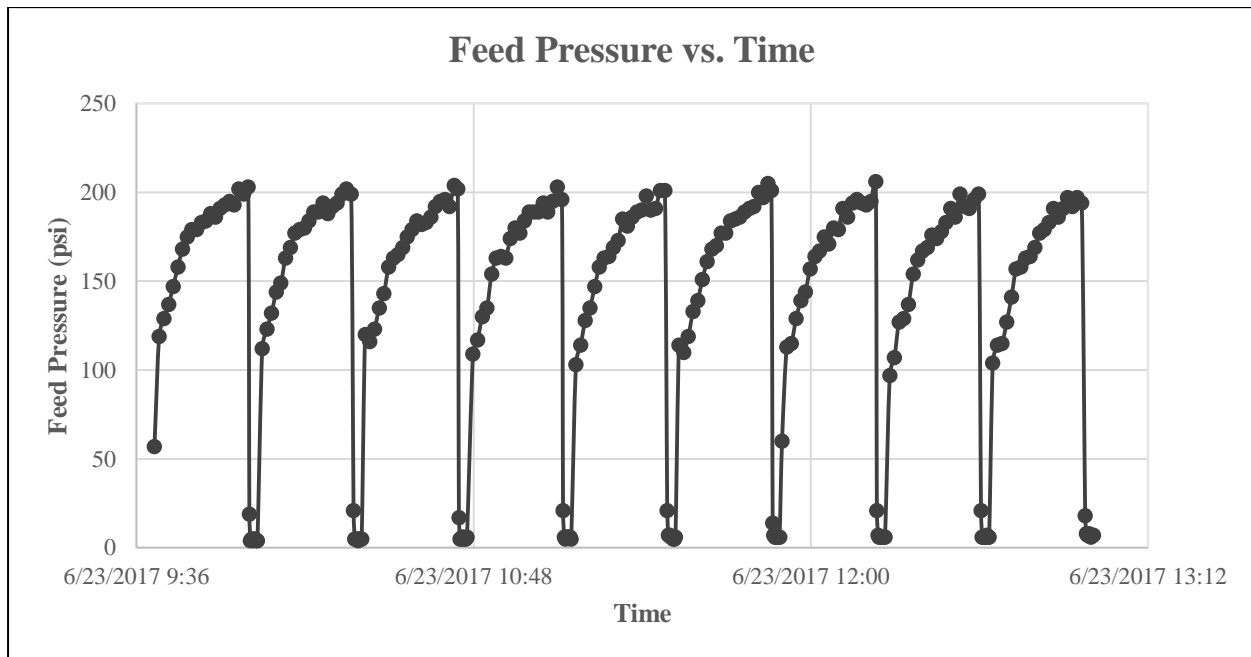


Figure 3.1- Feed pressure vs. time for CERRO pilot run on June 23

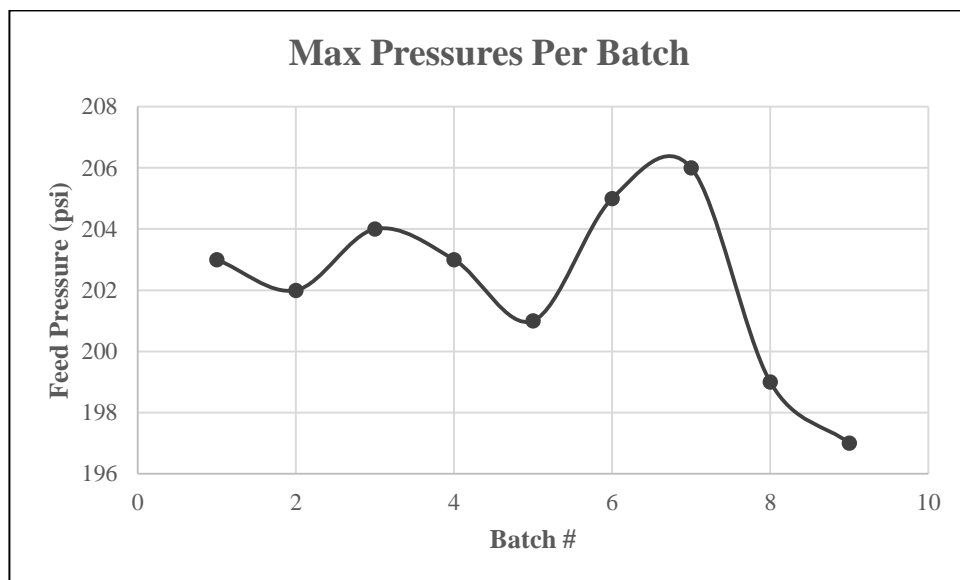
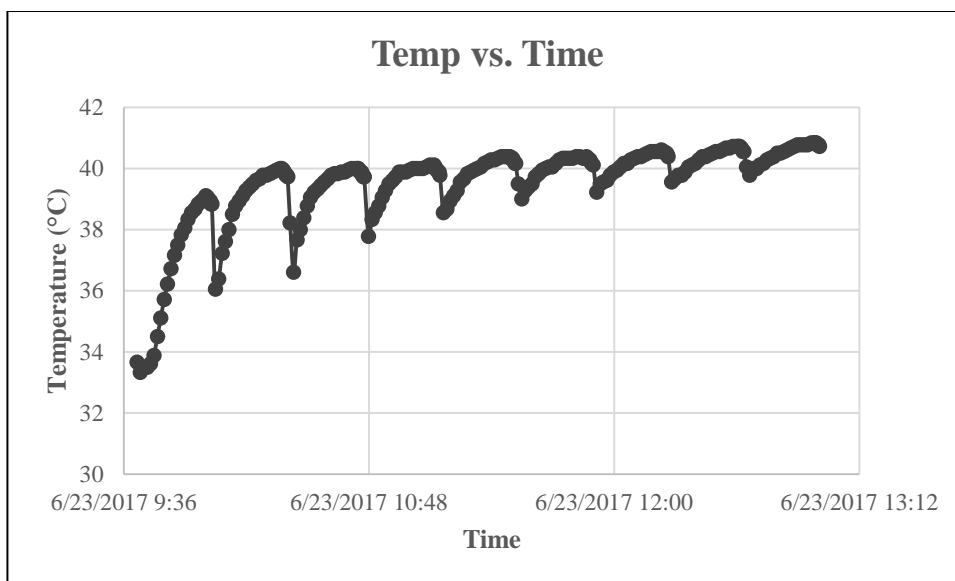
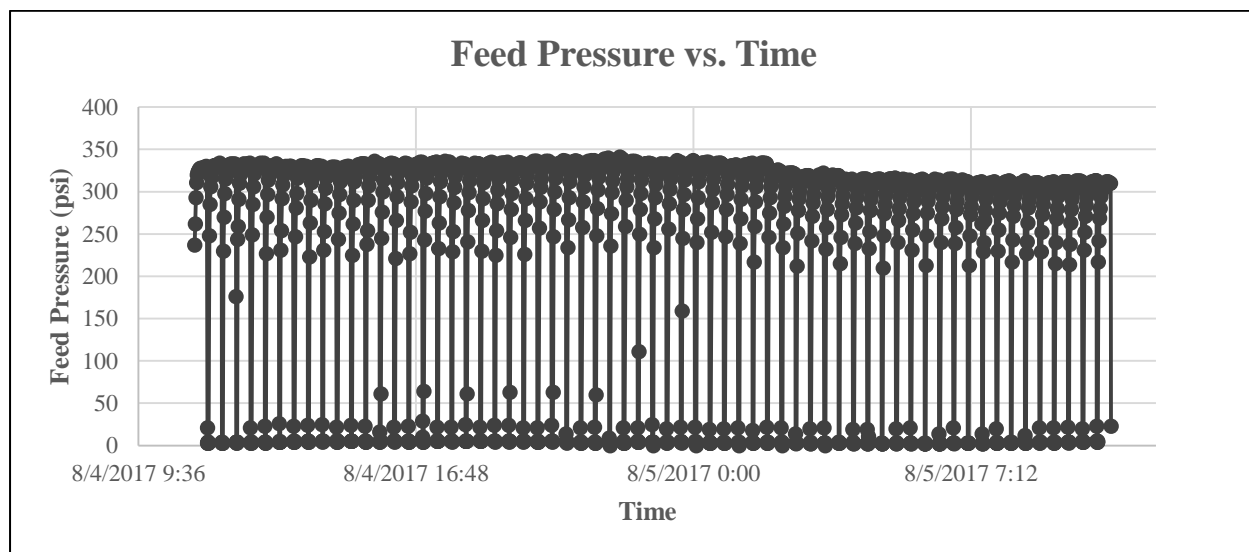


Figure 3.2- Max pressure per batch for CERRO pilot run on June 23

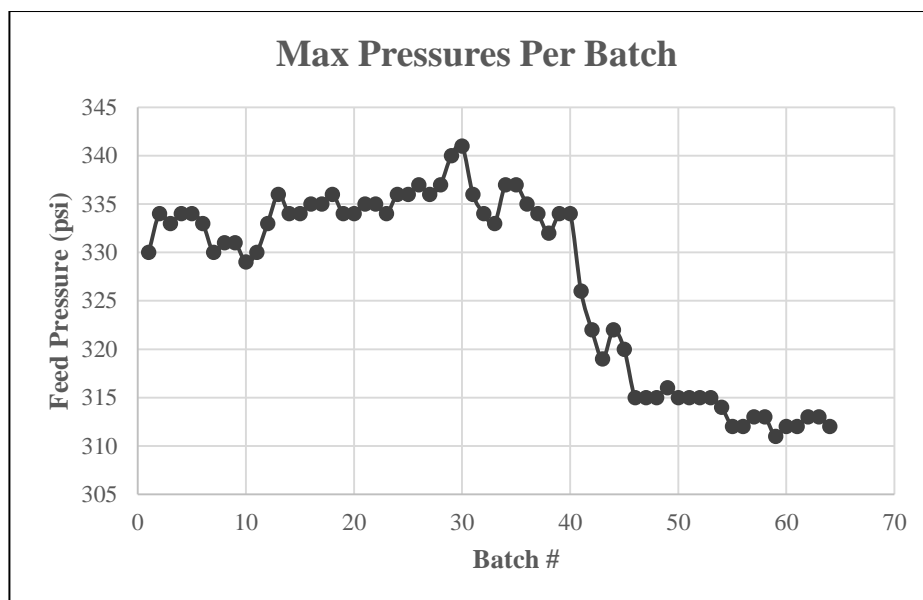


**Figure 3.3- Temp vs. time for CERRO pilot run on June 23**

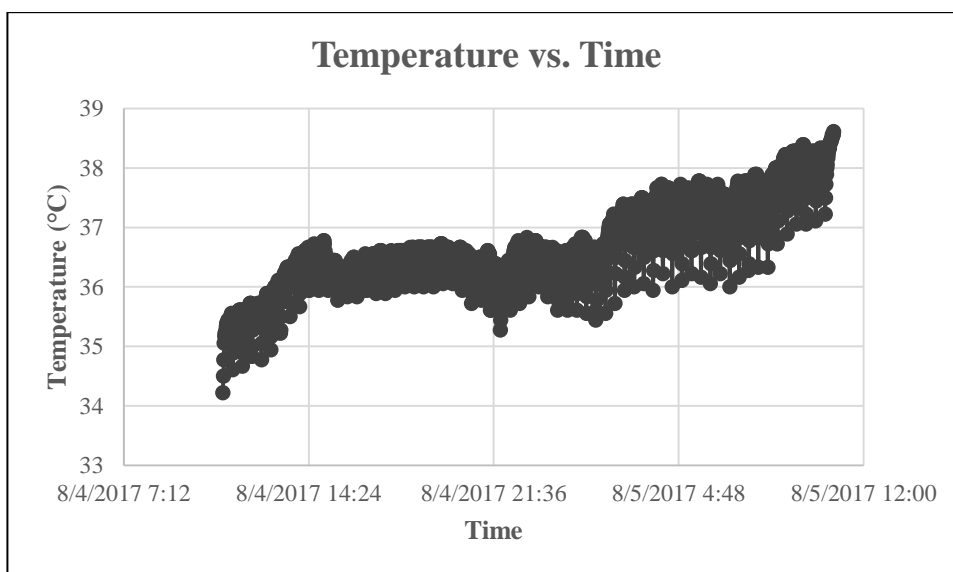
After one month of running the CERRO system, longer run times were being used to evaluate the trends of the pilot plant overnight and into the following day. Figures 3.4, 3.5 and 3.6 show the data from a run started on August 4, and ending in the morning on August 05.



**Figure 3.4- Feed pressure vs. time for CERRO pilot run from August 04-05**



**Figure 3.5- Max pressures per batch for CERRO pilot run on August 04-05**



**Figure 3.6- Temperature vs. time for CERRO pilot run on August 04-05**

The following trend is recognized: throughout the run, the temperature fluctuated (Figure 3.6), but overall the feed pressure decreased (Figures 3.4 and 3.5) as the temperature increased, and vice versa. The pressure decreased by approximately 9% from batch 30 to batch 60 and the temperature went up by 3°C, which corresponds with the 3% pressure increase per 1°C temperature change assumption. It should be noted that the incoming feed conductivity was relatively high at a value

of 4.15 mS/cm at a recovery of 76% on August 4 and a recovery of 89% on August 5. This shows that the CERRO system was performing at a high recovery while treating water that was near the maximum discharge allowance for conductivity (4.5 mS/cm). From this data it was concluded that the run on August 4-5 was successful.

### **3.3 Laboratory Data Results Verifying 85% Recovery Using the CERRO Process**

Although the changes in feed pressure seemed to match the temperature, feed conductivity, and recovery changes, laboratory testing such as Ion Chromatography and silica analyses were needed to confirm the results shown by monitoring feed pressures. Throughout the project, it was found that the ion mass balance data and silica tests confirmed the recoveries determined by TDS. As time progressed, it was becoming clear that a recovery of 80% or higher was achievable with the CERRO process, so multiple days were tested at a recovery of approximately 85%. After two months of testing, it was noted that concentrate samples that had been collected and left for multiple days were not showing signs of precipitation, so batch run times were increased from 20 minutes to 30 minutes. A summary of the results of one continuous run over the course of three days at 85% recovery is shown in Table 3.2.

**Table 3.2- Laboratory data for TDS, mass balance, and silica at 85% recovery**

Date	% Recovery (TDS)	% Recovery (Mass Balance)	% Recovery (Silica)
26-Sep	85.5%	85.9%	86.0%
27-Sep	86.2%	86.6%	86.0%
28-Sep	86.2%	86.9%	87.0%

The data from Table 3.2 show that a recovery of at least 85% is achievable with the CERRO process at 30-minute batch times with no fouling due to  $\text{CaSO}_4$ ,  $\text{SiO}_2$ , or  $\text{CaCO}_3$ . If fouling had occurred from one of these compounds, the mass balance would show precipitation and the sum

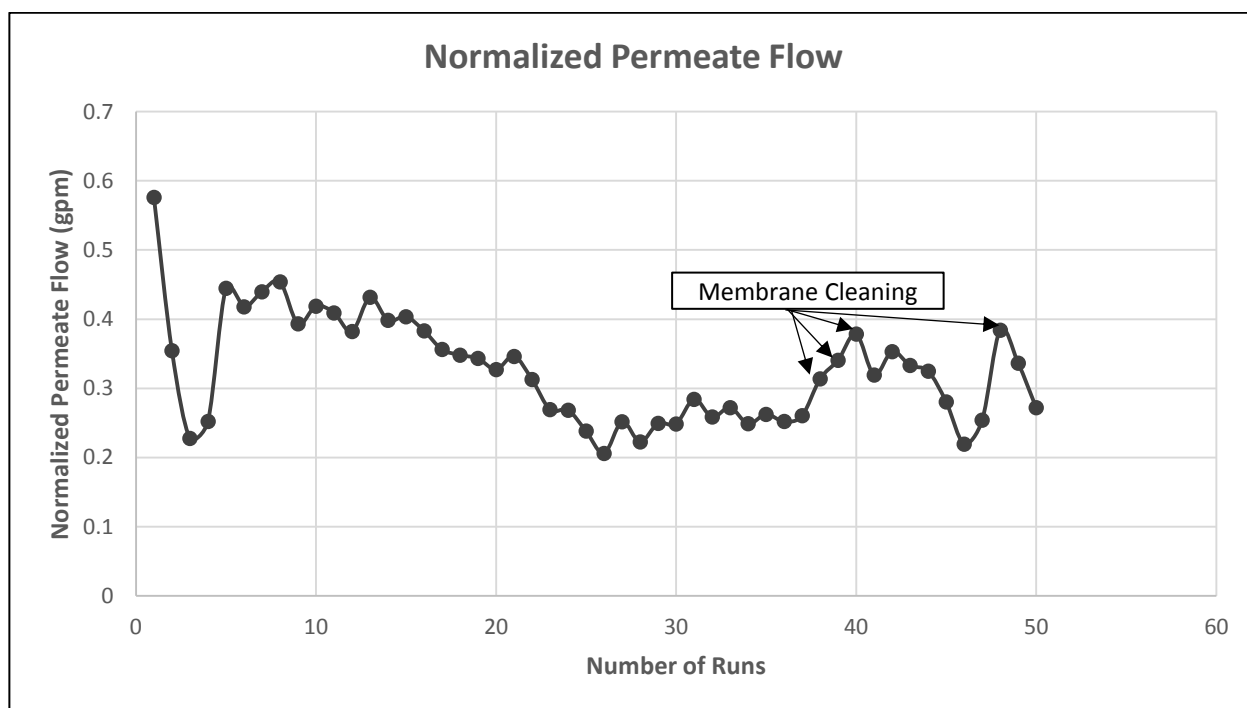
of ion concentrations in the permeate and concentrate water would not equal the feed concentrations. TDS laboratory results matched the recoveries determined by the mass balances, and it was verified from silica tests that there was no precipitation within the system (refer to daily mass balances in Appendix A-1). The CERRO feed water was comprised of blowdown water from only cooling towers 1, 2 and 3 because cooling tower 4 is discharged directly into the evaporation pond due to high silica concentrations. Currently, the flow from cooling tower 4 is approximately 150 gpm. The feed water coming into the CERRO system typically ranged from 60-83 mg/L of silica, whereas the sample taken from cooling tower 4 confirmed that the discharge had 95 mg/L of silica. Since the CERRO process was shown to successfully achieve at least 85% recovery on the feed water composed of blowdown from cooling towers 1, 2 and 3, the CERRO process should be successful at treating blowdown water that includes cooling tower 4, and thereby significantly reduce the discharge going into the evaporation pond.

### **3.4 Normalized Data Results**

For the first two months of testing, the CERRO system was able to continuously treat water at high recoveries and feed pressures that corresponded with fluctuations in recovery, feed conductivity, and temperature. As the project continued, it was noticed that feed pressures were increasing when compared to testing on a previous day with similar recovery and feed conductivity. Although the feed pressure data showed that it was unlikely that there was membrane fouling occurring, the data was normalized to separate the influence of constantly changing factors such as temperature, feed pressure, and conductivity in order to “measure the direct condition of the RO membrane” (Puretec Industrial Water, 2017). The DOW Chemical Company’s ‘FTNORM’ Software was used to calculate the normalized permeate flow on a daily basis to track the true performance of the membranes in the CERRO system. Since the increase in pressure wasn’t



noticed until partway through the project, a base normalized permeate flow was not calculated. Although the normalized permeate flow could not be compared to the flow of a brand new membrane, the data was tracked over the course of 50 runs, which provided a large amount of data points to compare the trend in normalized permeate flow rate over time. Figure 3.7 shows the daily normalized permeate flow trend as the project progressed.



**Figure 3.7- CERRO normalized permeate flow using DOW FTNORM Software**

Since the normalized permeate flow rate continued to decrease, there was indication that the membranes were fouling with a particular substance, even though previous laboratory data confirmed that the CERRO system was not fouling with constituents such as  $\text{CaSO}_4$ ,  $\text{SiO}_2$ , or  $\text{CaCO}_3$ . Due to the decreased normalized permeate flow rate, membrane cleanings were performed to determine if the membranes in the CERRO system were fouled. It is clear that there were significant spikes in normalized permeate flow rate after membrane cleanings, which proves that the membranes were being cleared of a particular foulant, resulting in an immediate increase in

normalized permeate flow rate. Although the membrane cleanings were proven to work, it was observed that the system would begin to foul immediately after the cleanings, and this occurred more often as runs continued. The types of membrane cleaners had a substantial impact on the effectiveness of the clean, and ultimately led to the discovery of organics in the feed water. Since the nature of the foulant was still unknown at the time, a low pH cleaner was used to target fouling that would be due to sulfates or carbonates. There was a slight color change during the low pH cleaning, but there was no change in feed pressure. Subsequently, the system was cleaned with a high pH cleaner for possible organics, which dropped the feed pressure significantly and turned the water brown. This is an indication that organic fouling may have been what was scaling the CERRO membranes. Table 3.3 describes a summary of the cleanings and the impact they had on the system.

**Table 3.3- Summary of membrane cleanings for the CERRO pilot unit**

Date	Membrane Cleaner	Cleaner Type	pH	Time Treated	Impact During/After Cleaning
18-Aug	NLR 404	Acidic Liquid Membrane Cleaner	Low	1 hour	Slight color change, low drop in pressure
	NLR 505	Alkaline Liquid Membrane Cleaner	High	45 mins	Large pressure drop, water turned brown
21-Aug	NLR 505	Alkaline Liquid Membrane Cleaner	High	1 hour	Not as large of a pressure drop as 18-Aug but pressure dropped a little more
22-Aug	NLR 550	Oxidizing Powdered Membrane Cleaner	High	3 hours	Best cleaning to date, water turned dark brown and CERRO had a large pressure drop
28-Aug	25% H <sub>2</sub> SO <sub>4</sub>	Acid	Low	1 hour	The system had run out of acid the previous night so this was a precaution in case of carbonate fouling
29-Aug	25% H <sub>2</sub> SO <sub>4</sub>	Acid	Low	1 hour	
5-Sep	NLR 550	Oxidizing Powdered Membrane Cleaner	High	45 mins	Water turned light brown
14-Sep	NLR 550	Oxidizing Powdered Membrane Cleaner	High	45 mins	Water turned light brown
22-Sep	Triclean 212 TF	High pH Membrane Cleaner	High	1 hour	Large pressure drop

### 3.5 Organic Testing Results

Originally, organics were not believed to be a concern for the CERRO system because the pilot plant was fit with a 1  $\mu\text{m}$  cartridge filter and a 0.2  $\mu\text{m}$  UF filter, which is usually sufficient for taking out organics that would possibly scale the membranes in the pilot system. The CERRO feed was composed of approximately 70% cooling tower blowdown and 30% water from EPEC's boilers and drains. Samples were not available for the water coming from the boilers and drains, but the cooling towers did have a large presence of organics as shown in Table 3.4. Table 3.5 shows the TOC and UV spectrophotometer results of eight feed samples collected on different days.

**Table 3.4- TOC concentrations in cooling towers**

Date	Sample Name	TOC Concentration (ppm)
19-Sep	Cooling Tower 2	12.72
	Cooling Tower 3	1.185
	Cooling Tower 4	4.127
25-Sep	Cooling Tower 1	15.25
	Cooling Tower 2	25.47
	Cooling Tower 3	7.446
	Cooling Tower 4	0.381

**Table 3.5- TOC and UV Spectrophotometer readings for CERRO feed water**

Date	Feed TOC Concentration (ppm)	Feed UV abs (254 nm)
19-Sep	4.485	-
25-Sep	4.272	0.101048
26-Sep	8.489	-
27-Sep	11.14	0.170794
10-Oct	10.98	0.15864
11-Oct	5.476	0.187883
17-Oct	7.4	-
19-Oct	4.077	0.098083

The table shows that within the course of a week, the concentrations of organic carbon within the cooling towers changed significantly, and the feed concentrations were continuously fluctuating. This is a possible explanation as to why the CERRO system had pressure increases only after two months, because it is possible that there were no organics present in the feed water at the start of the project. Alternatively, the organic fouling of the membrane could have been caused by biological growth within the pilot unit itself, even though attempts were made to prevent this by covering most of the pilot plant components with black plastic. It was noted that growth occurred within the permeate tank on August 2 (Figure 3.8), which may have been caused by the close proximity of the tank to a window which allowed plenty of light to enter the area, as shown in Figure 3.9.



**Figure 3.8- Growth in the CERRO pilot unit permeate tank**



**Figure 3.9- Location of CERRO pilot unit next to a well-lit area**

### **3.5.1 Laboratory Filtration Test Results**

Laboratory testing was performed to analyze the efficiency of small filter sizes and GAC for the removal of the organics. The samples collected from the laboratory tests using 0.1  $\mu\text{m}$  and 0.025  $\mu\text{m}$  filters were analyzed for TOC, and the results are shown in Table 3.6.

**Table 3.6- Laboratory filter test TOC results**

Date	Sample Name	TOC Concentration (ppm)
27-Sep	Feed unfiltered	11.14
	Feed filtered 0.1 micron	13.02
	Feed filtered 0.1 micron	15.62
10-Oct	DI blank	0.6958
	DI filtered 0.1 micron	1.768
	DI filtered 0.025 micron	3.991
	Feed unfiltered	10.98
	Feed filtered 0.1 micron	10.63
	Feed filtered 0.025 micron	11.79

The table shows that the filters added a small amount of TOC to the samples. The DI sample showed that the 0.025  $\mu\text{m}$  filter added the most TOC, which is most likely due to the organic material of the membrane itself. More sample analyses would be necessary to verify this data as the cost of filters precluded additional testing. The results clearly show that there was not a significant removal of TOC through filtration, so application of filters with 0.1  $\mu\text{m}$  and 0.025  $\mu\text{m}$  pore sizes in a full-scale system would not be beneficial. The lab-scale testing revealed that filtering out the TOC with a practically-sized membrane would not be possible and the nature of the organics was still unknown.

### 3.5.2 GAC Slurry Test Results and Freundlich Isotherm Generation

The next step in determining the efficiency of GAC removal was a slurry test to find the adsorption coefficient of the GAC. Once this number was known, a theoretical column could be designed and tested in the laboratory for application as a possible pretreatment system for the removal of organics. Figure 3.10 shows the results of the slurry tests on three separate days.

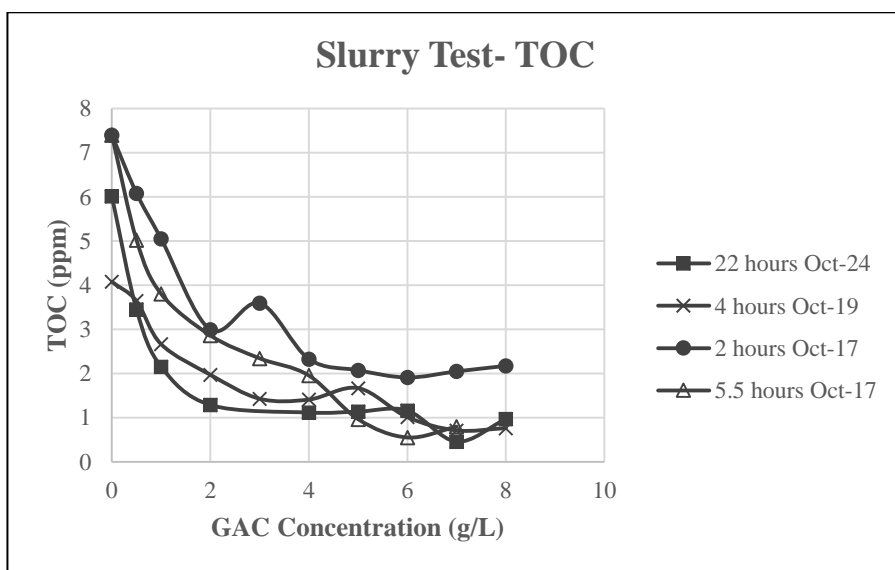
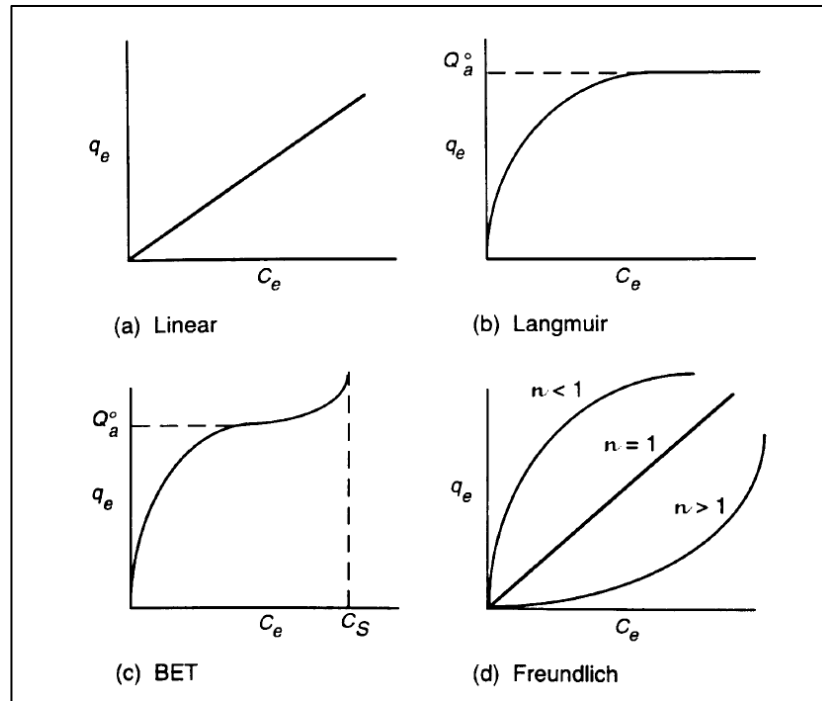


Figure 3.10-Slurry test TOC results

It is clear that the GAC was sufficient for removing organics present in the feed water, and this data was used to calculate the adsorption efficiency of the GAC. For the slurry test, it was necessary to determine the maximum adsorption capacity in order to find the removal of TOC per gram of GAC in the column. The isotherm was found by plotting and linearizing the data to find which isotherm best represented the data. Figure 3.11 below shows four of the most commonly-used adsorption isotherms that are applicable to organic removal using GAC.



**Figure 3.11- Commonly-used adsorption isotherms in water-treatment**

The adsorption capacity at equilibrium was calculated using equation 3.1.

$$q_e = \frac{(C_o - C_e)}{C_{solid}} \quad \text{Eq. (3.1)}$$

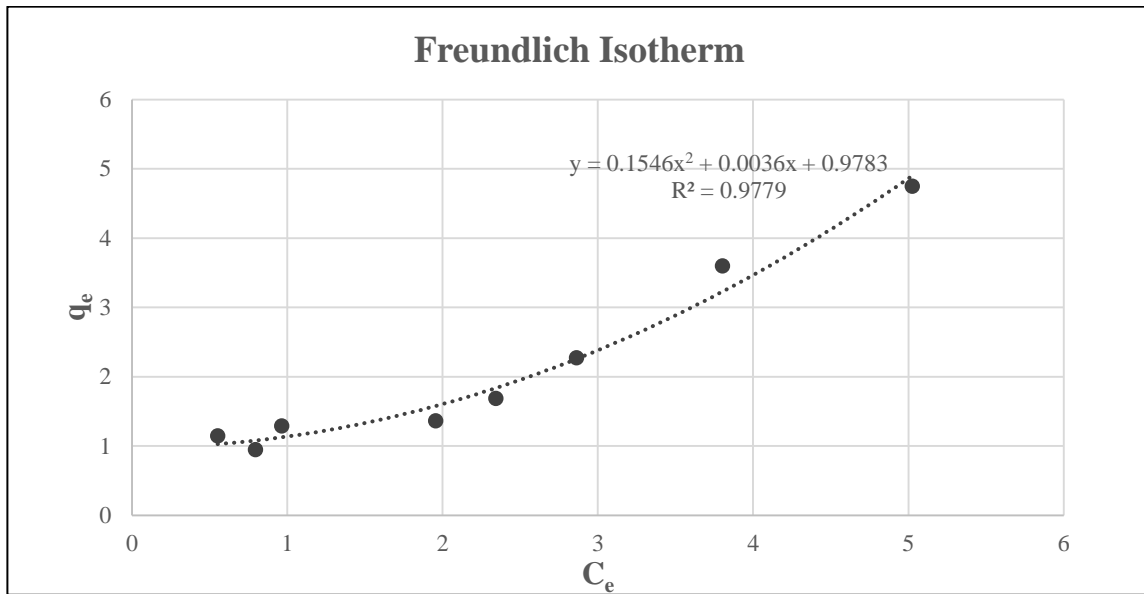
Where:

$C_o$  = initial concentration of TOC in the water

$C_e$  = concentration of TOC in the water at equilibrium

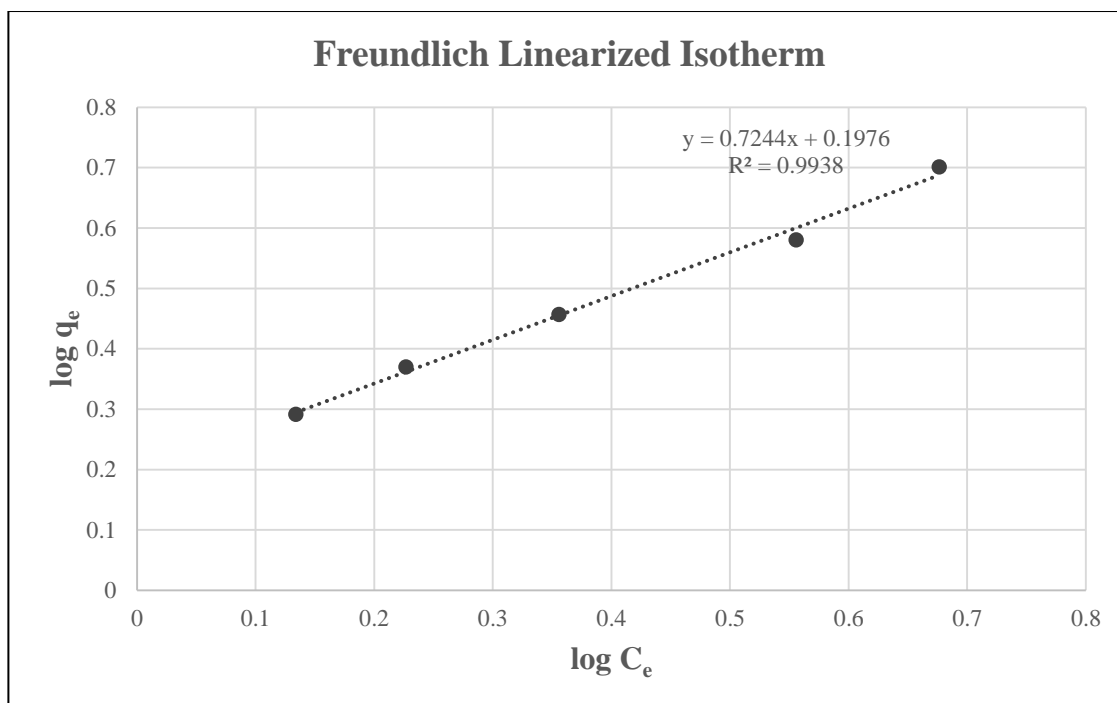
$C_{solid}$  = concentration of GAC used

A Freundlich isotherm was generated from the plot of  $q_e$  and  $C_e$  for the slurry test data from October 17 as shown in Figure 3.12. Figure 3.13 shows the linearized form of the isotherm from which the adsorption coefficient was determined.



**Figure 3.12- Freundlich isotherm using data from the 5.5-hour GAC slurry tests**



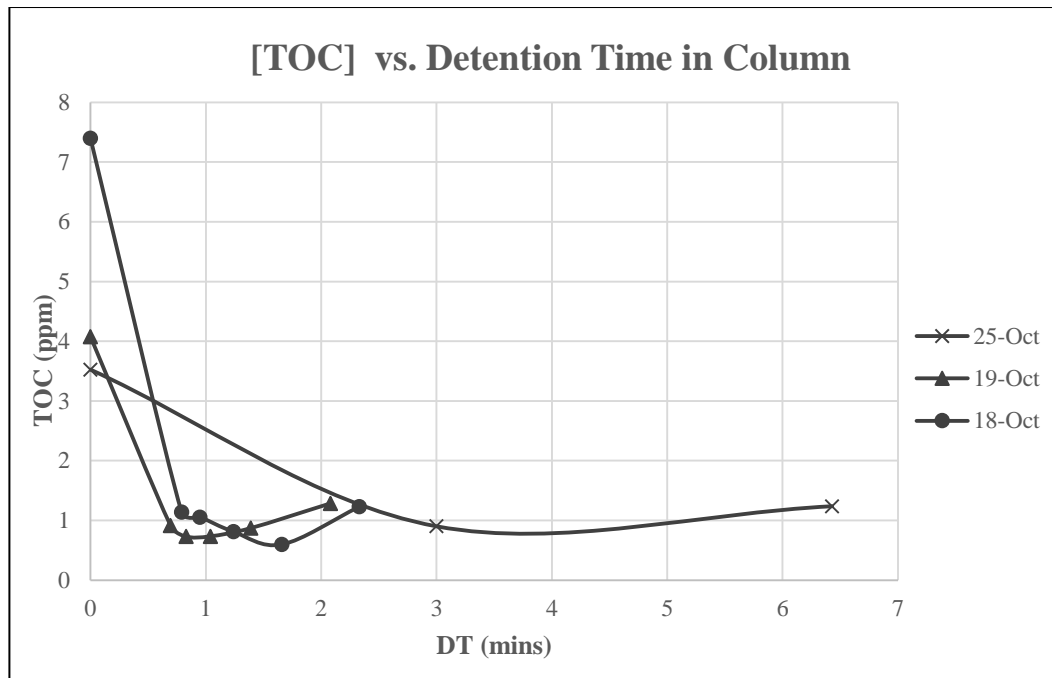


**Figure 3.13- Linearized Freundlich isotherm for calculation of max adsorption coefficient**

The correlation coefficient for the linearized form of the Freundlich isotherm was higher than any other type of isotherm. The intercept yielded a maximum adsorption coefficient of 1.5 mg of TOC removed per gram of GAC.

### 3.5.3 GAC Column Results

After the HD 3000 GAC was verified to remove organics from the CERRO feed water, a GAC column was tested in the laboratory to determine if it would be successful as a pretreatment system before a full-scale CERRO system. Figure 3.14 shows the concentration of TOC versus the detention time in the column from each of three different tests.



**Figure 3.14- TOC concentration vs. detention time in the laboratory GAC column**

It can be seen that the concentration of TOC never reached zero, even at the longest detention time of 6.4 minutes. A DI sample was analyzed along with the column samples from October 25, and the value measured for TOC was 0.55 ppm. This indicates that the precision of the TOC instrument is not high enough in very low ranges of TOC concentration. Since DI water should theoretically be free of TOC, it was concluded that the GAC column was successful in removing the organic contents to a concentration that was negligible, or similar to that in DI water.

### **3.5.4 Theoretical Column Design**

Using the maximum adsorption coefficient of 1.5 mg/g found from the GAC slurry tests, and assuming an average incoming feed TOC concentration of 7.5 mg/L, a theoretical column was designed to assess the feasibility of removing the organics before the water would reach the CERRO system. It was found that 20.86 tons of carbon would be needed per million gallons of feed water, which would result in a capital cost that would not be feasible as a pretreatment system for this particular project. It should be noted that the GAC column design was performed as only

an estimate based on limited data, and optimally, more research would need to be conducted in order to verify the GAC testing results for a more accurate GAC column design.

## Chapter 4: Economic Analysis

This chapter includes an order of magnitude estimate for the capital cost to build and install a full-scale CERRO system, and outlines an estimation of all operational costs involved. An estimate is provided for an ultrafiltration pretreatment system, which is specific to the location of this project at the Newman Power Plant, and would normally depend on the type of water being treated for future CERRO projects.

### 4.1 Capital Cost of the Full-Scale CERRO System

The CERRO system is a new technology with one full-scale system installed in the city of El Paso, TX and three more systems currently under construction. Due to the newness of the technology, an order of magnitude estimate calculation was made to determine the capital cost of a full scale CERRO unit specific to the Newman Power Plant project using equation 4.1.

$$C_2 = C_1 \left( \frac{Q_2}{Q_1} \right)^x \quad \text{Eq. (4.1)}$$

Where:

$C_1$  = cost at capacity  $Q_1$

$C_2$  = cost at capacity  $Q_2$

$x$  = correlating exponent

A capital cost ( $C_1$ ) of \$300,000 and feed flow rate ( $Q_1$ ) of 85 gpm were used from the cost and parameters of the first full-scale CERRO system that was built in El Paso, TX. A correlating exponent ( $x$ ) value of 0.6 was used, which resulted in a capital cost of \$1.1 million for a CERRO unit that would treat 750 gpm. This would account for all of the water discharged from the Newman Power Plant, and this value was originally specified as the target flow value in the project

objectives. It should be noted that an order of magnitude estimate is a preliminary estimate based on a previous design of the CERRO system; therefore, estimates can range within  $\pm 20\%$  of the actual cost (Blank & Tarquin, 2008).

## 4.2 Operating Costs of the Full-Scale CERRO System

Aside from the capital cost to build and install, continuous operating costs are involved in any desalination system. Multiple assumptions had to be made to provide an annual cost/thousand gallons. The costs for antiscalant and acid addition were calculated from previous projects in El Paso, TX wherein bulk materials were purchased under contract. The cost for the antiscalant was taken from an estimate obtained on September 10, 2015 from King Lee Technologies at a price of \$4,058/ 55 gallon drum of 100% antiscalant. The cost for the acid was calculated by taking a value of \$3.53/gallon of 78% pure  $H_2SO_4$ , which was a value obtained from a contract for a surface water treatment plant in El Paso, TX. Table 4.1 includes the rest of the assumptions made for the analysis.

**Table 4.1- Assumptions made for the CERRO cost analysis**

Item	Value	Item	Value
Recovery set point	85%	Feed conductivity, $\mu S/cm$	4,500
Feed flow rate, gpm	750	Permeate conductivity, $\mu S/cm$	175
Permeate flow rate, gpm	673.5	Concentrate conductivity, $\mu S/cm$	29,400
Antiscalant conc, mg/L	10	Product water conductivity, $\mu S/cm$	1000
Antiscalant cost, \$/gal	\$73.78	Pump & motor efficiency	60%
Acid cost, \$/gal	\$3.53	Flush time, min	3
Acid feed rate, gal/day	79.1	Flush flow rate, gpm	200
Power cost, \$/Kw-hr	\$0.1027	Membrane rejection, %	98%
Interest rate	4%	Contingencies, \$/yr	\$50,000
Amortization period, yrs	20	Cleaning volume, gal	1000
Process run time, min	30	NLR 550 Membrane Cleaner cost, \$/lb	\$1.88

### 4.3 Ultrafiltration Pretreatment System

For this project, it was deemed necessary to include the capital and operational costs of a UF system as pretreatment before the full-scale CERRO system. An estimate of these costs for a UF system operating at medium flux was retrieved from the American Water Works Association (AWWA). AWWA's journal article, "Microfiltration and Ultrafiltration Membranes for Drinking Water," lists the capital and operational costs from 2003 in units of \$/gpm (total capacity) of the UF system. The Civil Works Construction Cost Index System (CWCCIS) published by the US Army Corps of Engineers was then used to calculate the equivalent costs in 2017 dollars using Table A-2 from CSCCIS (found in Appendix A) and equation 4.2.

$$\frac{\text{Cost Index: Year A}}{\text{Cost Index: Year B}} * \text{Cost in Year B (Known)} = \text{Cost in Year A (Unknown)} \quad \text{Eq. (4.2)}$$

The capital costs included necessary equipment such as membranes, compressed air, chemical washing, and clean-in-place units, but did not include intake structures or residuals disposal. The operations and maintenance (O&M) costs estimated by AWWA include energy costs, chemicals, and membrane replacement (as cited in Robinson & He, Membrane Filtration Systems). Both capital and O&M costs were considered to be within  $\pm 25\%$  of the real cost. The tables used for the capital and operating costs in \$/gpm at low, medium, and high fluxes are shown in Appendix A.

### 4.4 Total Cost Analysis

The total cost included the amortized capital cost of the CERRO system and ultrafiltration pretreatment system over a 20-year period, and all assumptions stated in Table 4.1 were used. An

additional assumption made for the total cost analysis includes blending the permeate water with the feed water to create a product water of 1000 mS/cm (which matches the conductivity of the well water coming into the Newman Power Plant). The total cost also includes membrane cleanings at one time per month as a worst-case scenario. The full-scale CERRO plant would cost \$2.09/1000 gallons, and the complete table of costs and parameters can be found in Tables 4.2 and 4.3. It should be noted that the total disposal volume from the CERRO process was estimated to be 130 gpm, which is less than the stated objective of 140 gpm.

**Table 4.2- Costs of CERRO and UF pretreatment systems per calendar year**

UF Capital Amortization, \$/year	UF Operating costs, \$/year/1000 gal	CERRO Capital Amortization, \$/year	Power cost, \$/year	Membrane Cleaner, \$/year	Antiscalant cost, \$/year	Acid cost, \$/year	Total cost per calendar year, \$	Total cost per 1000 gal per calendar year, \$/1000 gal
\$195,962	\$0.11	\$81,522	\$144,228	\$902.40	\$290,848	\$101,890	\$834,451	\$2.09

**Table 4.3- Parameters of CERRO system**

Recovery	Pressure, psi	Final Permeate volume, gpd	Blend volume, gpd	Total product volume, gpd	Concentrate volume, gpd	Flush volume, gpd	Total disposal volume, gpd	Actual recovery	Total product volume, gal/yr
85%	294	918,000	216,386	1,134,386	162,000	26,182	188,182	83%	414,050,786

## **Chapter 5: Conclusions**

The results of this project reveal that a recovery of 85% was successfully achieved with the CERRO pilot system at 30-minute batch treatment times. No membrane fouling occurred due to dissolved compounds such as silica, calcium sulfate, or calcium carbonate in the feed water. It is believed that even higher recoveries can be achieved, as a few batches were run at 90% recovery and higher, but further pilot testing is recommended to be able to confirm this number with complete confidence.

There was fouling in the CERRO system possibly due to organics present in the feed water or biological growth within the pilot plant itself. Laboratory testing revealed that the concentration of organics in the feed water was extremely variable, and the data suggests that it is possible that there were no organics present in the feed water on multiple occasions, which would explain why the CERRO system had no indication of fouling in the first two months of the project. In the case of organic fouling, membrane cleanings proved to be successful and cost-effective for restoring the membranes back to near-optimal condition. If there were no pretreatment for removal of organics prior to the CERRO system, it is estimated that the CERRO system should be cleaned with a high-pH cleaner once a month to ensure that there is no build-up of organics on the membranes (this was included in the cost analysis of the CERRO plant). It should be noted that this is a worst-case-scenario estimate, and it is highly likely that the membranes would not need to be cleaned if the fouling was due to local biological growth from within the pilot plant. The total cost of a full-scale UF pretreatment and CERRO plant including capital and operating costs was estimated to be \$2.09 per 1000 gallons.



## **Chapter 6: Final Recommendations**

Although research is ongoing and major steps have been taken to progress the CERRO system, further optimizations still need to be made. It is recommended that research should be conducted in order to find the efficiency of the CERRO process at higher recoveries than 85% for this project. In previous projects, the CERRO system was successful in treating water without organics at recoveries higher than 90% (Tarquin, 2012), using feed water with conductivities higher than that at the Newman Power plant, so it is highly likely that this recovery could be achieved. Optimizations can be made on the acid and antiscalant additions, since this pilot plant testing was conducted at a pH of 4.5, and data suggests that the CERRO process could still be successful at a higher pH. For this project, it is recommended that the source and nature of the organics be determined. This would verify whether organics are an issue, or if there was local biological growth within the CERRO pilot plant itself. If organics are a potential foulant and a full-scale system is implemented, the decision can then be made about including a pretreatment system for their removal (if they cannot be removed prior to the CERRO system), or to clean the membranes monthly. If a pretreatment system is considered, it is recommended that an in-depth study should be conducted on the efficiency of GAC columns for removing the organics, as limited lab-scale testing suggests that this would be a viable option. With the CERRO process being a relatively new technology as an advanced desalination system, there are many optimizations to be made. It is necessary to continue the research to improve the CERRO process to render it a more cost-effective and efficient method for desalination.

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## Appendix A: Raw Data Used for Calculations

### Median Evaporation and Precipitation Rates in El Paso, TX

Month	Evaporation Rate (in/yr)	Precipitation Rate (in/yr)	Net Evaporation (in/yr)
Jan	2.63	0.7	1.93
Feb	3.49	0.65	2.84
March	5.73	0.46	5.27
April	7.45	0.45	7
May	8.17	0.65	7.52
June	9.6	0.88	8.72
July	8.96	1.67	7.29
Aug	7.59	1.61	5.98
Sept	6.33	1.49	4.84
Oct	5.02	0.97	4.05
Nov	3.53	0.67	2.86
Dec	2.56	0.78	1.78
<b>Total</b>	<b>71.06</b>	<b>10.98</b>	<b>60.08</b>

### UF Cost Estimates from the American Water Works Association (2005)

Total capacity, MGD at 20°C	Construction costs, \$/gpd		
	Low flux	Medium flux	High flux
0.1	9	4.9	3
1	2.6	1.75	1.25
10	1.2	0.79	0.59
100	0.8	0.53	0.39

Capacity, MGD at 20°C	O&M costs, \$/1,000 gallons filtrate		
	Low flux	Medium flux	High flux
0.1	0.09	0.112	0.142
1	0.06	0.072	0.09
10	0.046	0.057	0.071
100	0.04	0.046	0.057

# Cost Indices retrieved from the Civil Works Construction Cost Index System (CWCCIS),

## Army Corps of Engineers

Amendment #1, 30 Sep 17  
EM 1110-2-1304 (31 Mar 17)

TABLE A-2, YEARLY COST INDEXES BY CWBS FEATURE CODE  
Base Year 1967 = 100

		FY18*	FY19*	FY20*	FY21*	FY22*	FY23*	FY24*	FY25*	FY26*	FY27*
		Oct 17 - Sep 18	Oct 18 - Sep 19	Oct 19 - Sep 20	Oct 20 - Sep 21	Oct 21 - Sep 22	Oct 22 - Sep 23	Oct 23 - Sep 24	Oct 24 - Sep 25	Oct 24 - Sep 25	Oct 24 - Sep 25
CWBS - FEATURE CODES	Wt %										
02 RELOCATIONS	5%	876.24	893.77	911.64	929.88	948.47	967.44	986.79	1006.53	1026.66	1047.19
03 RESERVOIRS	5%	973.46	992.93	1012.78	1033.04	1053.70	1074.77	1096.27	1118.20	1140.56	1163.37
04 DAMS	15%	855.58	872.70	890.15	907.95	926.11	944.63	963.53	982.80	1002.45	1022.50
05 LOCKS	2%	852.55	869.60	886.99	904.73	922.83	941.28	960.11	979.31	998.90	1018.88
06 FISH & WILDLIFE FACILITIES	5%	842.36	859.21	876.39	893.92	911.80	930.03	948.63	967.61	986.96	1006.70
07 POWER PLANT	10%	776.81	792.35	808.19	824.36	840.85	857.66	874.82	892.31	910.16	928.36
08 ROADS, RAILROADS & BRIDGES	10%	876.24	893.77	911.64	929.88	948.47	967.44	986.79	1006.53	1026.66	1047.19
09 CHANNELS & CANALS	3%	901.74	919.77	938.17	956.93	976.07	995.59	1015.50	1035.81	1056.53	1077.66
10 BREAKWATER & SEAWALLS	5%	862.08	879.32	896.91	914.85	933.14	951.81	970.84	990.26	1010.06	1030.27
11 LEVEES & FLOODWALLS	5%	873.28	890.75	908.56	926.73	945.27	964.17	983.46	1003.12	1023.19	1043.65
12 NAVIGATION PORTS & HARBORS	10%	834.08	850.76	867.78	885.13	902.84	920.89	939.31	958.10	977.26	996.80
13 PUMPING PLANT	5%	827.52	844.07	860.96	878.18	895.74	913.65	931.93	950.57	969.58	988.97
14 RECREATION FACILITIES	5%	827.52	844.07	860.96	878.18	895.74	913.65	931.93	950.57	969.58	988.97
15 FLOODWAY CONTROL & DIVERSION STRUCTURE	2%	842.36	859.21	876.39	893.92	911.80	930.03	948.63	967.61	986.96	1006.70
16 BANK STABILIZATION	2%	904.79	922.89	941.35	960.17	979.38	998.96	1018.94	1039.32	1060.11	1081.31
17 BEACH REPLENISHMENT	2%	913.98	932.26	950.90	969.92	989.32	1009.10	1029.29	1049.87	1070.87	1092.29
18 CULTURAL RESOURCE PRESERVATION	2%	827.52	844.07	860.96	878.18	895.74	913.65	931.93	950.57	969.58	988.97
19 BUILDINGS, GROUNDS & UTILITIES	5%	827.52	844.07	860.96	878.18	895.74	913.65	931.93	950.57	969.58	988.97
20 PERMANENT OPERATING EQUIPMENT	2%	827.52	844.07	860.96	878.18	895.74	913.65	931.93	950.57	969.58	988.97
COMPOSITE INDEX (WEIGHTED AVERAGE)	100%	852.98	870.04	887.44	905.19	923.29	941.76	960.59	979.80	999.40	1019.39
YEARLY PERCENTAGE CHANGE		2.3%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%

Note: FY\* indicates data developed based on OMB projections.

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Amendment #1, 30 Sep 17  
EM 1110-2-1304 (31 Mar 17)

TABLE A-2, YEARLY COST INDEXES BY CWBS FEATURE CODE  
Base Year 1967 = 100

		FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07
		Oct 97 - Sep 98	Oct 98 - Sep 99	Oct 99 - Sep 00	Oct 00 - Sep 01	Oct 01 - Sep 02	Oct 02 - Sep 03	Oct 03 - Sep 04	Oct 04 - Sep 05	Oct 05 - Sep 06	Oct 06 - Sep 07
CWBS - FEATURE CODES	Wt %										
02 RELOCATIONS	5%	490.26	501.14	507.97	513.30	529.95	541.73	556.53	568.63	581.63	594.63
03 RESERVOIRS	5%	521.42	540.51	562.38	588.09	590.21	605.47	627.11	651.87	672.52	709.45
04 DAMS	15%	479.06	488.39	496.78	503.96	518.66	529.45	546.66	562.14	579.50	597.25
05 LOCKS	2%	472.47	480.10	488.88	495.43	510.94	522.49	534.93	548.85	563.39	578.57
06 FISH & WILDLIFE FACILITIES	5%	472.75	481.62	488.90	494.06	508.96	519.27	532.94	548.07	563.08	578.57
07 POWER PLANT	10%	458.96	465.38	472.73	479.63	490.08	498.28	507.07	517.14	528.85	541.06
08 ROADS, RAILROADS & BRIDGES	10%	490.26	501.14	507.97	513.30	529.95	541.73	556.53	568.63	581.63	594.63
09 CHANNELS & CANALS	3%	503.55	516.11	526.72	536.03	552.56	565.40	584.38	602.13	621.81	641.91
10 BREAKWATER & SEAWALLS	5%	510.50	520.83	527.86	534.68	550.06	563.81	583.43	603.04	623.15	643.61
11 LEVEES & FLOODWALLS	5%	495.99	503.35	512.62	518.66	535.78	549.87	567.00	582.88	599.37	616.57
12 NAVIGATION PORTS & HARBORS	10%	457.55	465.45	470.23	504.84	506.25	526.58	569.50	632.53	674.39	702.23
13 PUMPING PLANT	5%	459.40	460.16	468.05	472.18	486.16	497.40	503.78	505.47	505.52	505.88
14 RECREATION FACILITIES	5%	459.40	460.16	468.05	472.18	486.16	497.40	503.78	505.47	505.52	505.88
15 FLOODWAY CONTROL & DIVERSION STRUCTURE	2%	472.75	481.62	488.90	494.06	508.96	519.27	532.94	548.07	563.08	578.57
16 BANK STABILIZATION	2%	476.48	489.61	501.50	513.00	529.80	543.40	564.43	594.88	630.42	668.28
17 BEACH REPLENISHMENT	2%	507.09	521.89	532.71	543.21	567.10	584.67	601.88	630.27	659.93	689.40
18 CULTURAL RESOURCE PRESERVATION	2%	459.40	460.16	468.05	472.18	486.16	497.40	503.78	505.47	505.52	505.88
19 BUILDINGS, GROUNDS & UTILITIES	5%	459.40	460.16	468.05	472.18	486.16	497.40	503.78	505.47	505.52	505.88
20 PERMANENT OPERATING EQUIPMENT	2%	462.01	460.16	468.05	472.18	486.16	497.40	503.78	505.47	505.52	505.88
COMPOSITE INDEX (WEIGHTED AVERAGE)	100%	478.10	486.21	497.07	503.52	517.46	529.95	571.29	608.36	641.91	673.52
YEARLY PERCENTAGE CHANGE		1.3%	1.7%	2.2%	1.3%	2.8%	2.4%	7.8%	6.5%	5.5%	4.9%

Note: FY\* indicates data developed based on OMB projections.

A-42

## Appendix A-1: Mass Balances

**This program calculates the mass balance from the lab data**

Date = 6/22/2017 Sample EPEC  
I.D.= 06/22  
 Feed Flow= 0.5625  
 Conc Flow= 0.0625  
 Recvry = 88.9%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		135.6	524.2	517.3	1,800.0	35.4	17.3	383.9		1.4	46.7
Perm flo=	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5
Perm conc=		3.3	48.0	10.5	95.0	3.5	0.4	22.3		0.6	7.9
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=	0.2	1,185.3	4,413.9	4,550.7	15,605.0	285.8	149.9	3,268.0		7.7	355.7
Flow in	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	289	6	280	287	2	-1%
Cl	1,116	91	1,044	1,135	-19	2%
SO4	1,101	20	1,077	1,096	5	0%
TDS	3,832	180	3,692	3,871	-39	1%
K	75	7	68	74	1	-1%
Mg	37	1	35	36	1	-2%
Na	817	42	773	815	2	0%
Alk					0	-
F	3		2	2	1	-40%
NO3	100	15	102	117	-18	18%
Recvry =	88.9%					

Calc'd TDS 3,279  
 Measured 3,692  
 Diff 412  
 % diff= 11.2%

**This program calculates the mass balance from the lab data**

Date = 6/23/2017

Sample I.D.= EPEC 06/23

Feed Flow= 0.5675

Conc Flow= 0.0675

Recvry = 88.1%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		183.8	663.4	702.9	2,310.0	71.9	16.4	520.2		1.4	77.8
Perm flo=	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5
Perm conc=		2.3	45.6	7.5	80.0	6.3	0.2	30.0		0.6	14.4
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=		1,544.4	5,290.0	5,949.0	19,470.0	453.3	141.6	4,130.0		7.7	556.0
Flow in	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	395	4	395	399	-4	1%
Cl	1,425	86	1,352	1,438	-13	1%
SO4	1,510	14	1,520	1,534	-24	2%
TDS	4,962	151	4,974	5,126	-164	3%
K	154	12	116	128	27	-17%
Mg	35		36	37	-1	4%
Na	1,117	57	1,055	1,112	5	0%
Alk					0	-
F	3		2	2	1	-36%
NO3	167	27	160	187	-20	12%
Recvry =	88.1%					

Calc'd TDS 4,475  
 Measured 4,974  
 Diff 499  
 % diff= 10.0%

**This program calculates the mass balance from the lab data**

Date = 6/26/2017      Sample I.D.= EPEC 06/26  
 Feed Flow= 0.5405  
 Conc Flow= 0.0405  
 Recvry = 92.5%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		211.3	720.7	864.8	2,700.0	72.1	17.2	583.7		2.1	94.2
Perm flo=	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Perm conc=		1.7	28.6	5.5	80.0	3.1	0.2	13.7		0.7	8.8
Conc flo=	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Conc conc=		2,817.9	9,355.0	11,427.5	24,805.0	928.1	229.8	7,650.5		21.0	1,145.9
Flow in	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	432	3	432	435	-3	1%
Cl	1,474	54	1,434	1,488	-14	1%
SO4	1,769	11	1,752	1,762	7	0%
TDS	5,524	151	3,802	3,954	1,570	-28%
K	148	6	142	148	0	0%
Mg	35		35	36	0	1%
Na	1,194	26	1,173	1,199	-5	0%
Alk					0	-
F	4	1	3	4	0	2%
NO3	193	17	330	346	-154	80%
Recvry =	92.5%					

Calc'd TDS 4,971  
 Measured 3,802  
 Diff -  
 1,169  
 % diff= -30.7%



**This program calculates the mass balance from the lab data**

Date = 7/24/2017

Sample EPEC  
I.D.= 07/24

Feed  
Flow= 0.91

Conc  
Flow= 0.21

Recvry = 76.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		202.4	782.9	1,025.2	2,693.0	78.8	n.a.	672.7		2.3	141.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	22.0	2.3	50.0	0.6	n.a.	3.2		1.0	11.2
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		815.9	3,386.7	4,496.8	12,310.0	318.4	n.a.	2,867.2		9.1	595.8
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	697		648	648	49	-7%
Cl	2,696	58	2,692	2,750	-54	2%
SO4	3,531	6	3,574	3,580	-49	1%
TDS	9,276	132	9,785	9,917	-641	7%
K	271	2	253	255	17	-6%
Mg						-
Na	2,317	9	2,279	2,288	29	-1%
Alk					0	-
F	8	3	7	10	-2	24%
NO3	487	30	171	201	285	-59%
Recvry =	76.9%					

Calc'd  
TDS 9,454  
Measured 9,785  
Diff 331  
% diff= 3.4%

**This program calculates the mass balance from the lab data**

Date = 7/24/2017

Sample EPEC  
I.D.= 07/24

Feed  
Flow= 0.91

Conc  
Flow= 0.21

Recvry = 76.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		202.4	782.9	1,025.2	2,693.0	78.8	n.a.	672.7		2.3	141.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	22.0	2.3	50.0	0.6	n.a.	3.2		1.0	11.2
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		815.9	3,386.7	4,496.8	12,310.0	318.4	n.a.	2,867.2		9.1	595.8
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	697		648	648	49	-7%
Cl	2,696	58	2,692	2,750	-54	2%
SO4	3,531	6	3,574	3,580	-49	1%
TDS	9,276	132	9,785	9,917	-641	7%
K	271	2	253	255	17	-6%
Mg						-
Na	2,317	9	2,279	2,288	29	-1%
Alk					0	-
F	8	3	7	10	-2	24%
NO3	487	30	171	201	285	-59%
Recvry =	76.9%					

Calc'd  
TDS 9,454  
Measured 9,785  
Diff 331  
% diff= 3.4%

**This program calculates the mass balance from the lab data**

Date = 6/29/2017

Sample EPEC  
I.D.= 06/29

Feed  
Flow= 1.32

Conc  
Flow= 0.62

Recvry = 53.0%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		211.3	720.7	864.8		72.1	17.2	583.7		2.1	94.2
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.7	28.6	5.5		3.1	0.2	13.7		0.7	8.8
Conc flo=	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.1
Conc conc=		454.8	1,541.0	1,759.3		143.4	38.4	1,228.6		4.5	213.1
Flow in	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	1,056	5	1,067	1,072	-16	2%
Cl	3,601	76	3,616	3,692	-91	3%
SO4	4,321	15	4,129	4,143	177	-4%
TDS					0	-
K	360	8	337	345	16	-4%
Mg	86		90	91	-5	5%
Na	2,916	36	2,883	2,920	-3	0%
Alk					0	-
F	11	2	11	12	-2	15%
NO3	471	23	61	85	386	-82%
Recvry =	53.0%					

TDS  
WRONG

Calc'd TDS 12,133  
Measured  
Diff -  
12,133  
% diff= -

**This program calculates the mass balance from the lab data**

Date = 6/30/2017 Sample I.D.= EPEC  
06/30

Feed  
Flow= 1.095

Conc  
Flow= 0.395

Recvry = 63.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		225.7	750.2	899.6	2,860.0	73.2	17.8	600.0		2.6	104.7
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.4	17.2	1.8	30.0	1.5	0.1	5.8		0.6	5.8
Conc flo=	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Conc conc=		629.7	2,046.7	2,486.8	7,860.0	200.3	49.3	1,653.9		5.3	278.9
Flow in	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	935	4	941	945	-10	1%
Cl	3,109	45	3,060	3,105	4	0%
SO4	3,728	5	3,718	3,723	6	0%
TDS	11,853	79	11,751	11,831	23	0%
K	303	4	300	303	0	0%
Mg	74		74	74	0	1%
Na	2,487	15	2,473	2,488	-1	0%
Alk					0	-
F	11	1	8	9	1	-12%
NO3	434	15	80	95	339	-78%
Recvry =	63.9%					

Calc'd  
TDS 10,573  
Measured 11,751  
Diff 1,178  
% diff= 10.0%

**This program calculates the mass balance from the lab data**

Date = 7/3/2017

Sample EPEC  
I.D.= 07/03

Feed  
Flow= 1.095

Conc  
Flow= 0.395

Recvry = 63.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		238.9	808.7	931.1	2,990.0	82.7	16.1	660.5		2.7	112.8
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.1	8.3	1.8	40.0	1.6	0.0	8.5		0.4	4.2
Conc flo=	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Conc conc=		664.7	2,233.3	2,583.5	8,360.0	226.5	44.8	1,824.6		5.8	307.1
Flow in	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	990	3	994	997	-7	1%
Cl	3,352	22	3,339	3,361	-9	0%
SO4	3,859	5	3,863	3,867	-8	0%
TDS	12,392	106	12,499	12,605	-213	2%
K	343	4	339	343	0	0%
Mg	67		67	67	0	1%
Na	2,738	23	2,728	2,751	-13	0%
Alk					0	-
F	11	1	9	10	2	-14%
NO3	468	11	88	100	368	-79%
Recvry =	63.9%					

Calc'd TDS 11,337  
Measured 12,499  
Diff 1,161  
% diff= 9.3%

**This program calculates the mass balance from the lab data**

Date = 7/10/2017

Sample I.D.= EPEC 07/10

Feed Flow= 1.1165

Conc Flow= 0.4165

Recvry = 62.7%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		236.2	816.8	964.3	3,160.0	89.9	13.9	701.5		2.3	145.8
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.2	25.1	1.6	15.0	1.4	0.0	5.7		0.7	9.6
Conc flo=	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Conc conc=		615.5	2,145.0	2,542.2	8,090.0	235.5	32.2	1,879.3		5.2	398.2
Flow in	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	998	3	970	974	25	-2%
Cl	3,452	66	3,381	3,448	4	0%
SO4	4,075	4	4,008	4,012	63	-2%
TDS	13,354	40	12,754	12,793	561	-4%
K	380	4	371	375	5	-1%
Mg	59		51	51	8	-14%
Na	2,965	15	2,963	2,978	-13	0%
Alk					0	-
F	10	2	8	10	0	4%
NO3	616	25	115	140	476	-77%
Recvry =	62.7%					

Calc'd TDS 11,752  
 Measured 12,754  
 Diff 1,001  
 % diff= 7.8%

**This program calculates the mass balance from the lab data**

Date = 7/11/2017

Sample I.D.= EPEC 07/11

Feed Flow= 0.869

Conc Flow= 0.169

Recvry = 80.6%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		178.1	619.2	725.9	2,330.0	67.2	10.9	518.5		2.1	114.1
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		2.1	19.3	4.0	60.0	2.3	0.0	9.2		0.6	9.0
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		879.5	3,106.1	3,722.2	11,925.0	329.8	47.4	2,628.9		8.4	553.4
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	586	5	563	568	18	-3%
Cl	2,037	51	1,987	2,038	-1	0%
SO4	2,388	10	2,381	2,391	-4	0%
TDS	7,664	159	7,628	7,787	-123	2%
K	221	6	211	217	4	-2%
Mg	36		30	30	5	-15%
Na	1,705	24	1,682	1,706	-1	0%
Alk					0	-
F	7	1	5	7	0	0%
NO3	375	24	159	183	192	-51%
Recvry =	80.6%					

Calc'd TDS 6,859  
 Measured 7,628  
 Diff 769  
 % diff= 10.1%

**This program calculates the mass balance from the lab data**

Date = 7/12/2017

Sample I.D.= EPEC 07/12

Feed Flow= 0.925

Conc Flow= 0.225

Recvry = 75.7%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=	4,000.0	237.2	838.6	1,003.8	3,165.0	90.5	12.3	712.3		2.6	156.5
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=	120.0	1.4	18.9	4.1	40.0	3.1	0.0	13.3	10.0	0.6	9.7
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=	68,900.0	949.6	3,371.9	4,029.8	13,020.0	362.2	46.8	2,870.6	4,250.0	9.5	629.7
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.	14,005	318	58,677	58,995	- 44,990	321%
Ca	831	4	809	812	18	-2%
Cl	2,936	50	2,872	2,922	15	0%
SO4	3,514	11	3,432	3,443	72	-2%
TDS	11,081	106	11,088	11,194	-113	1%
K	317	8	308	317	0	0%
Mg	43		40	40	3	-8%
Na	2,494	35	2,445	2,480	14	-1%
Alk		26	3,619	3,646	-3,646	-
F	9	1	8	10	0	5%
NO3	548	26	181	207	341	-62%
Recvry =	75.7%					

Calc'd  
TDS 13,533  
Measured 11,088  
Diff -  
2,445  
% diff= -22.0%



**This program calculates the mass balance from the lab data**

Date = 7/13/2017

Sample EPEC  
I.D.= 07/13

Feed  
Flow= 0.9425

Conc  
Flow= 0.2425

Recvry = 74.3%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		216.6	822.4	1,001.6	3,030.0	82.0	12.3	700.5		2.5	158.6
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	13.3	2.4	40.0	2.0	0.0	8.1		0.6	9.3
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		797.1	3,201.1	3,877.5	11,960.0	302.0	75.5	2,680.2		7.7	609.4
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	773		732	732	41	-5%
Cl	2,934	35	2,938	2,974	-40	1%
SO4	3,573	6	3,559	3,565	8	0%
TDS	10,809	106	10,978	11,084	-275	3%
K	293	5	277	283	10	-3%
Mg	44		69	69	-26	58%
Na	2,499	21	2,460	2,481	18	-1%
Alk					0	-
F	9	1	7	9	1	-6%
NO3	566	25	175	200	366	-65%
Recvry =	74.3%					

Calc'd TDS 10,042  
Measured 10,978  
Diff 935  
% diff= 8.5%

**This program calculates the mass balance from the lab data**

Date = 7/14/2017

Sample EPEC  
I.D.= 07/14

Feed  
Flow= 0.877

Conc  
Flow= 0.177

Recvry = 79.8%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		209.9	793.2	990.5	3,220.0	78.9	12.7	675.5		2.4	153.7
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	18.9	2.7	35.0	1.5	0.0	5.8		0.7	10.0
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		998.0	3,849.6	4,850.6	15,500.0	384.1	64.2	3,313.0		8.7	737.8
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	697		669	669	28	-4%
Cl	2,633	50	2,579	2,629	4	0%
SO4	3,288	7	3,250	3,257	31	-1%
TDS	10,689	93	10,384	10,477	212	-2%
K	262	4	257	261	1	0%
Mg	42		43	43	-1	2%
Na	2,242	15	2,220	2,235	7	0%
Alk					0	-
F	8	2	6	8	0	-1%
NO3	510	27	212	239	271	-53%
Recvry =	79.8%					

Calc'd  
TDS 9,023  
Measured 10,384  
Diff 1,361  
% diff= 13.1%

**This program calculates the mass balance from the lab data**

Date = 7/17/2017

Sample EPEC  
I.D.= 07/17

Feed  
Flow= 1.1

Conc  
Flow= 0.4

Recvry = 63.6%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		215.9	792.7	940.7	3,140.0	79.8	n.a.	677.4		2.7	150.6
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	5.7	1.8	3.3	0.0	n.a.	2.1		0.1	4.0
Conc flo=	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Conc conc=		491.6	2,234.8	2,660.3	8,860.0	192.1	n.a.	1,805.5		6.7	443.8
Flow in	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	899		744	744	155	-17%
Cl	3,300	15	3,383	3,399	-98	3%
SO4	3,916	5	4,028	4,032	-116	3%
TDS	13,073	9	13,414	13,423	-349	3%
K	332		291	291	41	-12%
Mg						-
Na	2,820	6	2,734	2,739	81	-3%
Alk					0	-
F	11		10	10	1	-8%
NO3	627	11	128	138	489	-78%
Recvry =	63.6%					

Calc'd TDS 11,190  
Measured 13,414  
Diff 2,224  
% diff= 16.6%

Hardness as CaCO3 lab calc:

Feed (mg/L) 676 63% recovery  
Conc (mg/L) 1812

\*\*A total hardness titration was used to confirm the recovery achieved because Mg results from the IC test were not reliable.

**This program calculates the mass balance from the lab data**

Date = 7/18/2017

Sample EPEC

I.D.= 07/18

Feed 1.035

Flow=

Conc 0.335

Flow=

Recvry = 67.6%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		215.9	793.0	1,023.9	3,223.3	79.4	14.0	674.9		2.7	148.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.6	15.2	1.8	53.3	0.6	0.0	2.3		0.7	8.0
Conc flo=	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1
Conc conc=		625.2	2,433.2	3,148.6	9,826.7	233.3	68.2	2,072.0		6.7	467.0
Flow in	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	846	4	793	797	49	-6%
Cl	3,107	40	3,085	3,125	-19	1%
SO4	4,011	5	3,992	3,997	14	0%
TDS	12,627	141	12,460	12,601	26	0%
K	311	1	296	297	14	-4%
Mg						-
Na	2,644	6	2,627	2,633	11	0%
Alk					0	-
F	11	2	9	10	0	-2%
NO3	581	21	134	155	425	-73%
Recvry =	67.6%					

Calc'd TDS 10,802  
Measured 12,460  
Diff 1,658  
% diff= 13.3%

**Hardness as CaCO3 lab calc:**

Feed (mg/L) 672 0.68 recovery  
Conc (mg/L) 2100

\*\*A total hardness titration was used to confirm the recovery achieved because Mg results from the IC test were not reliable.

**This program calculates the mass balance from the lab data**

Date = 7/20/2017

Sample EPEC beginning  
I.D.= 07/20 of batch

Feed  
Flow= 1.06

Conc  
Flow= 0.36

Recvry = 66.0%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		207.6	792.0	1,028.6	3,280.0	80.4	0.0	684.0		3.1	144.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	16.0	1.7	40.0	0.5	0.0	1.8		0.8	8.1
Conc flo=	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Conc conc=		554.4	2,326.0	2,999.1	9,726.7	222.0	0.0	1,988.8		6.7	430.6
Flow in	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	833		755	755	78	-9%
Cl	3,178	42	3,169	3,212	-34	1%
SO4	4,127	5	4,087	4,091	36	-1%
TDS	13,160	106	13,254	13,360	-200	2%
K	323	1	303	304	19	-6%
Mg						-
Na	2,744	5	2,710	2,715	30	-1%
Alk						-
F	12	2	9	11	1	-9%
NO3	579	22	124	145	433	-75%
Recvry =	66.0%					

Calc'd  
TDS 11,033  
Measured 13,254  
Diff 2,220  
% diff= 16.8%

**This program calculates the mass balance from the lab data**

Date = 7/20/2017

Sample EPEC end of  
I.D.= 07/20 batch

Feed  
Flow= 1.087

Conc  
Flow= 0.387

Recvry = 64.4%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		205.6	787.6	1,021.4	3,205.0	78.3	0.0	671.7		2.3	142.0
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	14.1	1.4	20.0	0.3	0.0	1.3		0.7	7.6
Conc flo=	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Conc conc=		540.6	2,188.7	2,834.5	9,090.0	207.9	0.0	1,859.1		5.6	407.7
Flow in	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	846		792	792	54	-6%
Cl	3,240	37	3,206	3,243	-3	0%
SO4	4,202	4	4,152	4,156	47	-1%
TDS	13,186	53	13,315	13,368	-182	1%
K	322	1	305	305	17	-5%
Mg						-
Na	2,764	4	2,723	2,727	37	-1%
Alk						-
F	10	2	8	10	0	4%
NO3	584	20	117	138	447	-76%
Recvry =	64.4%					

Calc'd TDS 11,186  
Measured 13,315  
Diff 2,129  
% diff= 16.0%

**This program calculates the mass balance from the lab data**

Date = 7/21/2017

Sample EPEC  
I.D.= 07/21

Feed  
Flow= 0.91

Conc  
Flow= 0.21

Recvry = 76.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		202.4	782.9	1,025.2	3,235.0	78.8	n.a.	672.7		2.3	141.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	22.0	2.3	40.0	0.6	n.a.	3.2		1.0	11.2
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		815.9	3,386.7	4,496.8	14,010.0	318.4	n.a.	2,867.2		9.1	595.8
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	697		648	648	49	-7%
Cl	2,696	58	2,692	2,750	-54	2%
SO4	3,531	6	3,574	3,580	-49	1%
TDS	11,142	106	11,136	11,242	-99	1%
K	271	2	253	255	17	-6%
Mg						-
Na	2,317	9	2,279	2,288	29	-1%
Alk					0	-
F	8	3	7	10	-2	24%
NO3	487	30	171	201	285	-59%
Recvry =	76.9%					

Calc'd TDS 9,454  
Measured 11,136  
Diff 1,682  
% diff= 15.1%

**This program calculates the mass balance from the lab data**

Date = 7/24/2017

Sample EPEC  
I.D.= 07/24

Feed  
Flow= 0.91

Conc  
Flow= 0.21

Recvry = 76.9%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		202.4	782.9	1,025.2	2,693.0	78.8	n.a.	672.7		2.3	141.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		0.0	22.0	2.3	50.0	0.6	n.a.	3.2		1.0	11.2
Conc flo=	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Conc conc=		815.9	3,386.7	4,496.8	12,310.0	318.4	n.a.	2,867.2		9.1	595.8
Flow in	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	697		648	648	49	-7%
Cl	2,696	58	2,692	2,750	-54	2%
SO4	3,531	6	3,574	3,580	-49	1%
TDS	9,276	132	9,785	9,917	-641	7%
K	271	2	253	255	17	-6%
Mg						-
Na	2,317	9	2,279	2,288	29	-1%
Alk					0	-
F	8	3	7	10	-2	24%
NO3	487	30	171	201	285	-59%
Recvry =	76.9%					

Calc'd TDS 9,454  
Measured 9,785  
Diff 331  
% diff= 3.4%



**This program calculates the mass balance from the lab data**

Date = 8/24/2017

Sample I.D.= EPEC 08/24

Feed Flow= 0.84

Conc Flow= 0.1075

Recvry = 87.2%

Lab Data											
	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		132.6	484.0	496.1	1,636.7	31.3	14.9	345.0		1.3	38.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		2.5	15.6	3.4	40.0	1.0	0.0	6.1		0.8	3.4
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=		1,028.5	3,692.2	3,775.8	11,300.0	236.6	127.1	2,677.8		6.2	290.9
Flow in	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0

Calculations						
Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	422	7	418	425	-3	1%
Cl	1,539	41	1,502	1,544	-5	0%
SO4	1,577	9	1,536	1,545	32	-2%
TDS	5,204	106	4,598	4,704	500	-10%
K	100	3	96	99	1	-1%
Mg						-
Na	1,097	16	1,090	1,106	-9	1%
Alk					0	-
F	4	2	3	5	-1	15%
NO3	122	9	84	93	29	-24%
Recvry =	87.2%					

Calc'd TDS 4,645  
 Measured 4,598  
 Diff - 48  
 % diff= -1.0%

\*\*This mass balance was performed on 09/29. Mg results were not reliable.

**This program calculates the mass balance from the lab data**

Date = 8/25/2017

Sample I.D.= EPEC 08/25

Feed Flow= 0.68

Conc Flow= 0.1075

Recvry = 84.2%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		136.9	488.9	494.9	1,460.0	30.3		342.8		1.3	38.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.9	13.1	1.8	13.3	1.2		7.6	10.0	0.8	3.2
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=		851.2	2,981.4	2,883.0	10,416.7	185.6		2,081.9	4,250.0	6.1	227.0
Flow in	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	352	5	346	351	1	0%
Cl	1,258	35	1,213	1,248	11	-1%
SO4	1,274	5	1,173	1,178	96	-8%
TDS	3,758	35	4,238	4,274	-516	14%
K	78	3	76	79	-1	1%
Mg						-
Na	882	20	847	867	15	-2%
Alk		26	1,729	1,756	-1,756	-
F	3	2	2	4	-1	36%
NO3	99	8	65	74	25	-25%
Recvry =	84.2%					

Calc'd TDS 5,387  
 Measured 4,238  
 Diff - 1,148  
 % diff= -27.1%

\*\*This mass balance was performed on 09/29. Mg results were not reliable.

**This program calculates the mass balance from the lab data**

Date = 9/26/2017

Sample EPEC  
I.D.= 09/26

Feed  
Flow= 0.76

Conc  
Flow= 0.1075

Recvry = 85.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		146.9	549.2	492.3	2,003.3	37.6		399.3		1.5	44.6
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		2.4	28.8	3.0	76.7	1.0		6.8		1.5	7.6
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=		1,012.3	3,723.2	4,027.2	13,850.0	256.6		2,787.4		4.1	282.9
Flow in	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	423	6	412	418	4	-1%
Cl	1,580	76	1,515	1,591	-11	1%
SO4	1,416	8	1,639	1,646	-230	16%
TDS	5,763	203	5,635	5,839	-76	1%
K	108	3	104	107	1	-1%
Mg					0	-
Na	1,149	18	1,134	1,152	-4	0%
Alk					0	-
F	4	4	2	6	-2	37%
NO3	128	20	81	102	27	-21%
Recvry =	85.9%					

Calc'd TDS 4,806  
Measured 5,635  
Diff 830  
% diff= 14.7%

\*\*This mass balance was performed on 09/29. Mg results were not reliable.

**This program calculates the mass balance from the lab data**

Date = 9/27/2017

Sample EPEC  
I.D.= 09/27

Feed 0.8

Flow=

Conc 0.1075

Flow=

Recvry = 86.6%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		158.0	580.2	640.6	2,170.0	45.8		438.2		1.5	58.1
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		2.2	21.5	3.4	43.3	1.4		7.7		1.4	7.1
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=		1,194.7	4,267.8	4,812.4	15,733.3	338.8		3,264.6		7.3	409.3
Flow in	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	478	6	486	492	-14	3%
Cl	1,757	57	1,737	1,794	-37	2%
SO4	1,940	9	1,958	1,967	-27	1%
TDS	6,571	115	6,402	6,517	54	-1%
K	139	4	138	141	-3	2%
Mg					0	-
Na	1,327	20	1,328	1,349	-22	2%
Alk					0	-
F	4	4	3	7	-2	52%
NO3	176	19	118	136	39	-22%
Recvry =	86.6%					

Calc'd TDS 5,650  
Measured 6,402  
Diff 752  
% diff= 11.7%

\*\*This mass balance was performed on 09/29. Mg results were not reliable.

**This program calculates the mass balance from the lab data**

Date = 9/28/2017

Sample EPEC  
I.D.= 09/28

Feed  
Flow= 0.82

Conc  
Flow= 0.1075

Recvry = 86.9%

**Lab Data**

	Cond.	Ca	Cl	SO4	TDS	K	Mg	Na	Alk	F	NO3
Feed conc=		155.4	568.4	632.3	2,113.3	44.7		429.6		1.3	56.3
Perm flo=	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Perm conc=		1.9	18.6	2.4	46.7	1.1		6.2		1.4	6.2
Conc flo=	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conc conc=		1,183.9	4,210.0	4,795.5	15,276.7	332.9		3,208.4		6.6	401.7
Flow in	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0

**Calculations**

Parameter	Mass in	Perm Mass	Conc Mass	Perm+Conc	Diff	% Diff
Cond.						-
Ca	482	5	482	487	-5	1%
Cl	1,764	49	1,713	1,762	2	0%
SO4	1,962	6	1,951	1,958	5	0%
TDS	6,559	124	6,216	6,340	220	-3%
K	139	3	135	138	1	0%
Mg					0	-
Na	1,333	16	1,305	1,322	12	-1%
Alk					0	-
F	4	4	3	6	-2	55%
NO3	175	16	116	132	43	-25%
Recvry =	86.9%					

Calc'd TDS 5,590  
Measured 6,216  
Diff 626  
% diff= 10.1%

\*\*This mass balance was performed on 09/29. Mg results were not reliable. Measured NO<sub>3</sub> with spectrophotometer and confirmed that values from IC were not reliable. Feed water had an NO<sub>3</sub> concentration of 11 mg/L and concentrate had an NO<sub>3</sub> concentration of 34 mg/L.

## Appendix A-2: Table of Cumulative Information

Note: Many batches were run overnight and then the recovery was changed the next day. These are labeled as date (ON)- for overnight. The initial sample was collected after the recovery was changed, and the final sample was collected the next morning. In Aug and Sept many batches were run for multiple days. In the notes section it will describe when the batch was set and when the sample was taken. Under "Sample" ID it will describe what date the batch was set for the sample taken.

Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO <sub>2</sub>	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes
						Min	Max		Min	Max	Med		
22-Jun	6-22 Feed	1800	88.5%	88.9%	88.0%	36.5	40.5	2.64	138	164	164	12	
	6-22 perm	95											
	6-22 conc	15605											
23-Jun	6-23 Feed	2310	88.1%	88.1%	88.0%	39	40.8	3.47	197	206	203	9	
	6-23 perm	80											
	6-23 conc	19470											
26-Jun	6-26 Feed	2700	89.1%	92.5%	59.0%	35	40.2	3.86	243	376	251	22	**SiO <sub>2</sub> Sample precipitated, didn't test until 07/20
	6-26 perm	80											
	6-26 conc	24805											
28-Jun	6-28 Feed	2510	82.9%	83.1%	83.0%	38.7	40.9	3.66	206	299	229	20	
	6-28 perm	75											
	6-28 conc	14650											
29-Jun	6-29 Feed	70	98.8%	53.0%	55.0%	38.4	39	3.96	191	193	191	22	**feed sample taken during flush, TDS wrong. No silica feed sample so used average number from prev days
	6-29 perm	50											
	6-29 conc 1:2	5900											
30-Jun	6-30 Feed	2860	63.6%	63.9%	69.0%	37.5	38.4	4.15	207	211	209	28	
	6-30 perm	30											
	6-30 conc	7860											
3-Jul	7-03 Feed	2990	64.2%	63.9%	64.0%	36	37.3	4.44	212	218	217	14	
	7-03 perm	40											
	7-03 conc	8360											
10-Jul	7-10 Feed	3160	60.9%	62.7%	58.0%	35	36.3	4.44	212	216	214	22	
	7-10 perm	15											
	7-10 conc 1:2	8090											
11-Jul	7-11 Feed	2330	80.5%	80.6%	71.9%	36	37.3	4.59	219	227	221	16	
	7-11 perm	60											
	7-11 conc	11925											
12-Jul	7-12 Feed	3165	75.7%	75.7%	63.0%	36	37.8	4.64	225	234	228	29	
	7-12 perm	40											
	7-12 conc 1:2	13020											
13-Jul	7-13 Feed	3030	74.7%	74.3%	70.0%	36.2	37.9	4.64	230	240	233	31	
	7-13 perm	40											
	7-13 conc 1:2	11960											
14-Jul	7-14 Feed	3220	79.2%	79.8%	69.0%	35	36.4	4.59	249	262	251	34	
	7-14 perm	35											
	7-14 conc 1:2	15500											
17-Jul	7-17 Feed	3140	64.6%	63.6%	66.0%	34.5	34.9	4.54	218	221	220	8	
	7-17 perm	33											
	7-17 conc 1:3	8860											
18-Jul	7-18 Feed	3223	67.2%	67.6%	62.0%	34.1	35.7	4.59	229	239	235	33	
	7-18 perm	53											
	7-18 conc 1:2	9826											

Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO <sub>2</sub>	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes
						Min	Max		Min	Max	Media n		
20-Jul (ON)	7-20 Feed (initial)	3280	66.3%	66.0%	71.0%	34.2	35.6	4.54	230	240	237	65	Ran batches overnight into July 21 morning. <b>Checked recovery to see if it stayed the same, went down a little bit.</b> Initial sample was collected July 20 when recovery was set, final was collected July 21 when batch stopped
	7-20 perm (initial)	40											
	7-20 conc (initial) 1:2	9726											
	7-20 Feed (final)	3205	64.7%	64.4%	66.0%								
	7-20 perm (final)	20											
	7-20 conc (final) 1:2	9090											
21-Jul	7-21 Feed	3235	76.9%	76.9%	79.0%	35	36.2	4.59	260	303	287	42	
	7-21 perm	40											
	7-21 conc 1:3	14010											
24-Jul	7-24 Feed	2693	78.1%	76.9%	83.0%	33.6	39.11	3.5	239	254	242	24	Max pressure per batch decreased which makes sense because temperature increased
	7-24 perm	50											
	7-24 conc 1:3	12310											
25-Jul	7-25 Feed	2283	82.7%		83.0%	37.7	39.94	3.22	231	240	234	31	
	7-25 perm	50											
	7-25 conc 1:3	13190											
26-Jul	7-26 Feed	2173	83.6%		83.0%	38.7	40.33	3.22	231	240	234	31	
	7-26 perm	36											
	7-26 conc 1:3	13270											
27-Jul	7-27 Feed	2250	80.5%		81.0%	36.44	39.61	3.32	231	261	246	34	Jumps in pressure seemed to match the drops in temp
	7-27 perm	23											
	7-27 conc 1:3	11520											
28-Jul	7-28 Feed	2596	82.0%		83.0%	35.61	37.89	3.71	266	281	270	44	
	7-28 perm	56											
	7-28 conc 1:3	14410											
31-Jul	7-27 Feed	3023	86.6%		86.0%	35.22	36.83	4.3	322	348	329	37	
	7-27 perm	63											
	7-27 conc 1:3	22550											
1-Aug	8-01 Feed	3060	87.0%		87.0%	34.94	36.22	4.35	331	360	341	56	Ran until 6:00 am 08/02, pressure at about the same point as 07/31 at 37 batches.
	8-01 perm	30											
	8-01 conc 1:3	23550											

Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO2	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes
						Min	Max		Min	Max	Median		
2-Aug (ON)	8-02 Feed (initial)	3150	86.9%		87.0%	35.67	36.61	4.35	354	414	388	47	Initial sample collected 08/02 when batch set, final sample taken 08/03 morning to check recovery increase
	8-02 Perm (initial)	60											
	8-02 conc (initial)	24086											
	8-02 Feed (final)	3123	91.8%		92.0%								
	8-02 Perm (final)	43											
	8-02 conc (final)	38203											
3-Aug (ON)	8-03 feed (initial)	3123	82.4%		83.0%	35.5	36.67	4.35	335	386	354	60	Initial sample collected 08/03 when batch set, final sample taken 08/04 morning to check recovery increase
	8-03 perm (initial)	40											
	8-03 conc (initial)	17730											
	8-03 feed (final)	3103.3	90.2%		91.0%								
	8-03 perm (final)	43											
	8-03 conc (final)	31816											
4-Aug (ON)	8-04 feed (initial)	3103	76.4%		76.0%	35.33	38.61	4.15	311	341	333	64	Initial sample collected 08/04 when batch set, final sample taken 08/07 morning to check recovery. Batch shut off at 10:30 am 05/05
	8-04 perm (initial)	46											
	8-04 conc (initial)	13146											
	8-04 feed (final)	2390	88.7%		88.0%								
	8-04 perm (final)	73											
	8-04 conc (final)	21233											
7-Aug (ON)	8-07 feed (initial)	2390	77.7%		79.0%	37.7	40.5	3.56	261	295	276	66	Initial sample collected 08/07 when batch set, final sample taken 08/08 morning to check recovery increase
	8-07 perm(initial)	50											
	8-07 conc (initial)	10700											
	8-07 feed (final)	2460	78.0%		78.0%								
	8-07 perm (final)	55											
	8-07 conc (final)	11200											
8-Aug (ON)	8-08 feed (initial)	2526	78.1%		76.0%	37.2	39.2	3.71	283	316	301	65	Initial sample collected 08/08 when batch set, final sample taken 08/09 morning to check recovery increase
	8-08 perm (initial)	30											
	8-08 conc (initial)	11533											
	8-08 feed (final)	2680	82.5%		82.0%								
	8-08 perm (final)	33											
	8-08 conc (final)	15300											



Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO <sub>2</sub>	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes								
						Min	Max		Min	Max	Median										
9-Aug (ON)	08-09 feed (initial)	2680	75.5%		77.0%	38.11	39.61	3.71	289	308	297	60	Initial sample collected 08/09 when batch set, final sample taken 08/10 morning to check recovery increase								
	8-09 perm (initial)	33																			
	8-09 conc (initial)	10940																			
	8-09 feed (final)	2530	81.5%		80.0%																
	8-09 perm (final)	36																			
	8-09 conc (final)	13650																			
10-Aug (ON)	8-10 feed (initial)	2530	73.9%		77.0%	37.6	39.33	3.47	282	296	287	63	Initial sample collected 08/10 when batch set, final sample taken 08/11 morning to check recovery increase								
	8-10 perm (initial)	23																			
	8-10 conc (initial)	9706																			
	8-10 feed (final)	2296	78.0%		79.0%																
	8-10 perm (final)	26																			
	8-10 conc (final)	10423																			
11-Aug	08-11 feed (initial)	2680	75.5%		77.0%	38.11	39.61	3.71	289	308	297	60	Initial sample collected 08/11 when batch set, final sample taken 08/12 morning to check recovery increase								
	8-11 perm (initial)	33																			
	8-11 conc (initial)	10940																			
	8-11 feed (final)	2530	81.5%		80.0%																
	8-11 perm (final)	36																			
	8-11 conc (final)	13650																			
18-Aug	8-18 Feed	1553	75.7%		no pillows								Membrane Cleaning. Low pH to High pH Cleaning. Color change in water occurred during low pH cleaning. Possible organics. System ran long enough to collect samples for normalization. Shut off for the wknd								
	8-18 perm	50																			
	8-18 conc	6396																			
21-Aug	8-21 Feed	1506	75.8%		no pillows								Second Membrane Cleaning. High pH. Observed color change but less than previous day. Initial sample taken after membrane cleaning for normalization. System wasn't let run.								
	8-21 perm	40																			
	8-21 conc	6226																			

Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO <sub>2</sub>	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes
						Min	Max		Min	Max	Median		
22-Aug (ON)	8-22 feed (initial)	1403	70.4%		no pillows							Membrane powder Cleaning. Color change observed but less than previous two cleanings. Normalizatio n Base Flow set (0.38). Recovery reset to 70, initial sample taken. Final sample taken 08/23	
	8-22 perm (initial)	30											
	8-22 conc (initial)	4740											
	8-22 feed (final)	1476	87.1%	no pillows									
	8-22 perm (final)	73											
	8-22 conc (final)	11416											
23-Aug	08-23 feed (initial)	1476	79.2%		no pillows						System was run for one day and shut off.		
	8-23 perm (initial)	50											
	8-23 conc (initial)	7113											
24-Aug	8-24 Feed	1636	85.5%	87.2%	no pillows						Recovery set at 85, sample taken after recovery set. Valve taped. Ran until 08/28 (Monday). Log file showed that pH increased over weekend. Mass bal. IC on 09/29		
	8-24 perm	40											
	8-24 conc	11300											
25-Aug	8-24 Feed	1460	86.0%	84.2%	no pillows						Single sample, recovery not changed. Performed low pH cleanings on 08/28 and 08/29. Didn't have pH meter so we did 2 cleanings just to make sure. Mass bal IC on 09/29		
	8-24 perm	13											
	8-24 conc	10416											
30-Aug	08-29 Feed	1613	89.0%		88.9%						System was started remotely 08/29 afternoon. No initial sample taken. This sample taken 08/30 morning.		
	8-29 perm	66											
	8-29 conc	14616											
31-Aug	8-29 Feed final	1643	83.8%		83.9%						This sample taken 08/31 morning. This is the end of the batch that was started 08/29.		
	8-29 perm final	36											
	8-29 conc final	10166											

Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO <sub>2</sub>	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes
						Min	Max		Min	Max	Median		
31-Aug	08-31 Feed initial	1643	73.6%									This sample taken 08/31 morning after recovery was reset. Silica sample was not diluted so no information available.	
	08-31 perm initial	46											
	08-31 conc initial	6233											
22-Sep	9-22 Feed	1696	69.5%									09/21 Flush pump cap replaced. Needle Valve tightened. High pH cleaning ~30- 45min before testing system. Foul odor. 09/22 Permeate tank cleaned. System shut down over weekend. No silica sample.	
	9-22 perm	36											
	9-22 conc	5566											
25-Sep (ON)	9-25 Feed initial	1823	77.7%		78.0%							Initial sample taken 09/25 morning when recovery set. Final sample taken 09/26 morning.	
	9-25 perm initial	50											
	9-25 conc initial	8183											
	9-25 Feed final	2003	81.7%		82.0%								
	9-25 perm final	60											
	9-25 conc final	10933											
26-Sep	9-26 Feed initial	2003	85.5%	85.9%	86.0%							Initial sample taken 09/26 morning. Batch shut off in afternoon due to high pH and high pressure. Batch turned on again in the afternoon. Mass bal IC on 09/29	
	9-26 perm initial	76											
	9-26 conc initial	13850											
27-Sep	9-26 Feed	2170	86.2%	86.6%	86.0%							This sample taken in the morning, recovery was not changed. This batch is a continuation of batch started on 09/26. Mass bal IC on 09/29	
	9-26 perm	43											
	9-26 conc	15733											

Date	Sample	TDS (mg/L)	% Rec. TDS	% Rec. Mass Bal	% Rec. SiO <sub>2</sub>	Temp Range		Median Feed Cond.	Range of Max Feed Press/batch			Batches	Notes
						Min	Max		Min	Max	Median		
28-Sep	9-26 Feed final	2113	86.2%	86.9%	87.0%								Sample taken in the morning is end of batch started on 09/26. System shut off due to high pressures (440 psi). Mass bal IC on 09/29
	9-26 perm final	46											
	9-26 conc final	15276											

## Appendix A-3: GC-MS Volatile Organic Scan Results

### Library Search Report

Data Path : D:\MassHunter\GCMS\1\data\VOC\2017\10192017\  
 Data File : 17-52260.D  
 Acq On : 19 Oct 2017 12:25 pm  
 Operator : AJM/JLM  
 Sample : 17-52260  
 Misc :  
 ALS Vial : 1 Sample Multiplier: 1

Search Libraries: D:\MassHunter\Library\NIST14.L Minimum Quality: 0

Unknown Spectrum: Apex

Integration Events: RTE Integrator - voc.p

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
			<i>Possible</i>			
1	1.349	1.96	D:\MassHunter\Library\NIST14.L			
			Ethene, 1,1-difluoro-	350	000075-38-7	3
			Ethene, 1,1-difluoro-	351	000075-38-7	3
			Ethene, 1,2-difluoro-	349	001691-13-0	3
2	1.749	7.93	D:\MassHunter\Library\NIST14.L			
			Ethene, 1,1-difluoro-	351	000075-38-7	3
			Ethene, 1,2-difluoro-	349	001691-13-0	3
			Ethene, 1,1-difluoro-	348	000075-38-7	3
3	2.623	3.19	D:\MassHunter\Library\NIST14.L			
			Ethene, chloro-	324	000075-01-4	5
			Boric acid	322	010043-35-3	5
			Dimethyl sulfide	338	000075-18-3	5
4	2.712	2.65	D:\MassHunter\Library\NIST14.L			
			Ethene, 1,1-difluoro-	351	000075-38-7	3
			Ethyl Chloride	354	000075-00-3	3
			Ethyl Chloride	352	000075-00-3	3
5	3.038	2.01	D:\MassHunter\Library\NIST14.L			
			Ethyl Chloride	352	000075-00-3	3
			Ethene, 1,1-difluoro-	348	000075-38-7	3
			Ethene, 1,1-difluoro-	350	000075-38-7	3
6	3.340	0.62	D:\MassHunter\Library\NIST14.L			
			1-Buten-3-yne	126	000689-97-4	5
			1-Buten-3-yne	124	000689-97-4	5
			1-Buten-3-yne	127	000689-97-4	5
7	3.417	1.13	D:\MassHunter\Library\NIST14.L			
			Guanidine, methyl-	730	000471-29-4	3
			Guanidine, methyl-	729	000471-29-4	3
			Propanamide	736	000079-05-0	3
8	5.324	27.41	D:\MassHunter\Library\NIST14.L			
			1-Propene, 1-methoxy-	704	007319-16-6	9
			Tetrahydrofuran	677	000109-99-9	7
			Oxirane, ethyl-	681	000106-88-7	5

9	5.758	16.18	D:\MassHunter\Library\NIST14.L	(Surrogate)			
			Benzene, pentafluoro-		38594	000363-72-4	97
			Benzene, pentafluoro-		38595	000363-72-4	94
			Benzene, pentafluoro-		38592	000363-72-4	94
10	6.647	23.23	D:\MassHunter\Library\NIST14.L	(Surrogate) IS			
			Benzene, fluoro-		2821	000462-06-6	95
			Benzene, fluoro-		2819	000462-06-6	91
			Benzene, fluoro-		2820	000462-06-6	91
11	8.044	0.57	D:\MassHunter\Library\NIST14.L				
			Phosphoramidous difluoride		1614	025757-74-8	2
			Isothiazole		1554	000288-16-4	2
			1H-Tetrazol-5-amine		1611	004418-61-5	2
12	9.293	0.01	D:\MassHunter\Library\NIST14.L				
			Acetic acid, (aminooxy)-		2403	000645-88-5	1
			Acetic acid, (aminooxy)-		2406	000645-88-5	1
			Ethanamine, 2-(methylthio)-		2417	018542-42-2	1
13	10.607	0.76	D:\MassHunter\Library\NIST14.L				
			Methane, tribromo-		111959	000075-25-2	9
			Bromochloronitromethane		42702	135531-25-8	9
			2-Chloro-4-aminopyrimidine		13062	007461-50-9	5
14	13.004	0.07	D:\MassHunter\Library\NIST14.L				
			2,6-Dimethyl-3,5-dithioxo-2,3,4,5-tetrahydro-1,2,4-triazine		42506	006947-25-7	2
			3-Methylthio-6-methyl-5-thioxo-2,5-dihydro-1,2,4-triazine		42504	007448-19-3	2
			3H-Indole, 3-ethyl-2,3-dimethyl-		42440	001798-39-6	2
15	13.613	12.28	D:\MassHunter\Library\NIST14.L	(Surrogate)			
			Benzene, 1-bromo-3-fluoro-		43162	001073-06-9	98
			Benzene, 1-bromo-3-fluoro-		43163	001073-06-9	96
			p-Bromofluorobenzene		43159	000460-00-4	95

VOCclass.M Thu Oct 19 12:56:54 2017



Data Path : D:\MassHunter\GCMS\1\data\VOC\2017\10192017\  
 Data File : 17-52260.D  
 Acq On : 19 Oct 2017 12:25 pm  
 Operator : AJM/JLM  
 Sample : 17-52260  
 ALS Vial : 1 Sample Multiplier: 1

Quant Time: Oct 19 12:55:50 2017  
 Quant Method : D:\MassHunter\GCMS\1\methods\VOCclass.M  
 Quant Title : VOC  
 QLast Update : Thu May 04 13:37:40 2017  
 Response via : Initial Calibration

Compound	R.T.	QIon	Response	Conc	Units	Dev(Min)
-----						
Internal Standards						
1) Fluorobenzene	6.647	96	42177	4.00	ug/L	0.00
System Monitoring Compounds						
18) Pentafluorobenzene (S)	5.758	168	22119	3.43	ug/L	0.00
Spiked Amount	4.000	Range 70 - 130	Recovery	=	85.75%	
43) BFB (S)	13.613	95	9961	2.50	ug/L	0.00
Spiked Amount	4.000	Range 70 - 130	Recovery	=	62.50%#	
Target Compounds						
						Qvalue
2) Dichlorodifluoromethane	0.000		0	N.D.		
3) Chloromethane	0.000		0	N.D.		
4) Vinyl Chloride	0.000		0	N.D.		
5) Bromomethane	0.000		0	N.D.		
6) Chloroethane	0.000		0	N.D.		
7) Trichlorofluoromethane	0.000		0	N.D.		
8) 1,1-Dichloroethene	2.623	61	2022	0.55	ug/L #	39
9) Methylene Chloride	3.038	49	485	0.01	ug/L #	70
10) trans-1,2-Dichloroethene	0.000		0	N.D.		
11) MTBE	3.414	73	3212	Below Cal		92
12) 1,1-Dichloroethane	0.000		0	N.D.		
13) 2,2-Dichloropropane	0.000		0	N.D.		
14) cis-1,2-Dichloroethene	0.000		0	N.D.		
15) Bromochloromethane	0.000		0	N.D.		
16) Chloroform	5.367	83	4127	0.74	ug/L ✓	95
17) 1,1,1-Trichloroethane	0.000		0	N.D.		
19) Carbon Tetrachloride	5.758	117	1912	0.95	ug/L #	2
20) 1,1-Dichloropropene	5.761	75	1607	0.66	ug/L #	42
21) Benzene	0.000		0	N.D.		
22) 1,2-Dichloroethane	0.000		0	N.D.		
23) Trichloroethene	0.000		0	N.D.		
24) 1,2-Dichloropropane	0.000		0	N.D.		
25) Dibromomethane	0.000		0	N.D.		
26) Bromodichloromethane	8.044	83	1306	0.61	ug/L ✓	84
27) cis-1,3-Dichloropropene	0.000		0	N.D.		
28) Toluene	9.293	91	28	0.00	ug/L #	21
29) trans-1,3-Dichloropropene	0.000		0	N.D.		
30) 1,1,2-Trichloroethane	0.000		0	N.D.		
31) Tetrachloroethylene	0.000		0	N.D.		
32) 1,3-Dichloropropane	0.000		0	N.D.		
33) Dibromochloromethane	10.607	127	1122	0.62	ug/L ✓	94
34) 1,2-Dibromoethane	0.000		0	N.D.		
35) Chlorobenzene	0.000		0	N.D.		
36) 1,1,1,2-Tetrachloroethane	0.000		0	N.D.		
37) Ethylbenzene	0.000		0	N.D.		

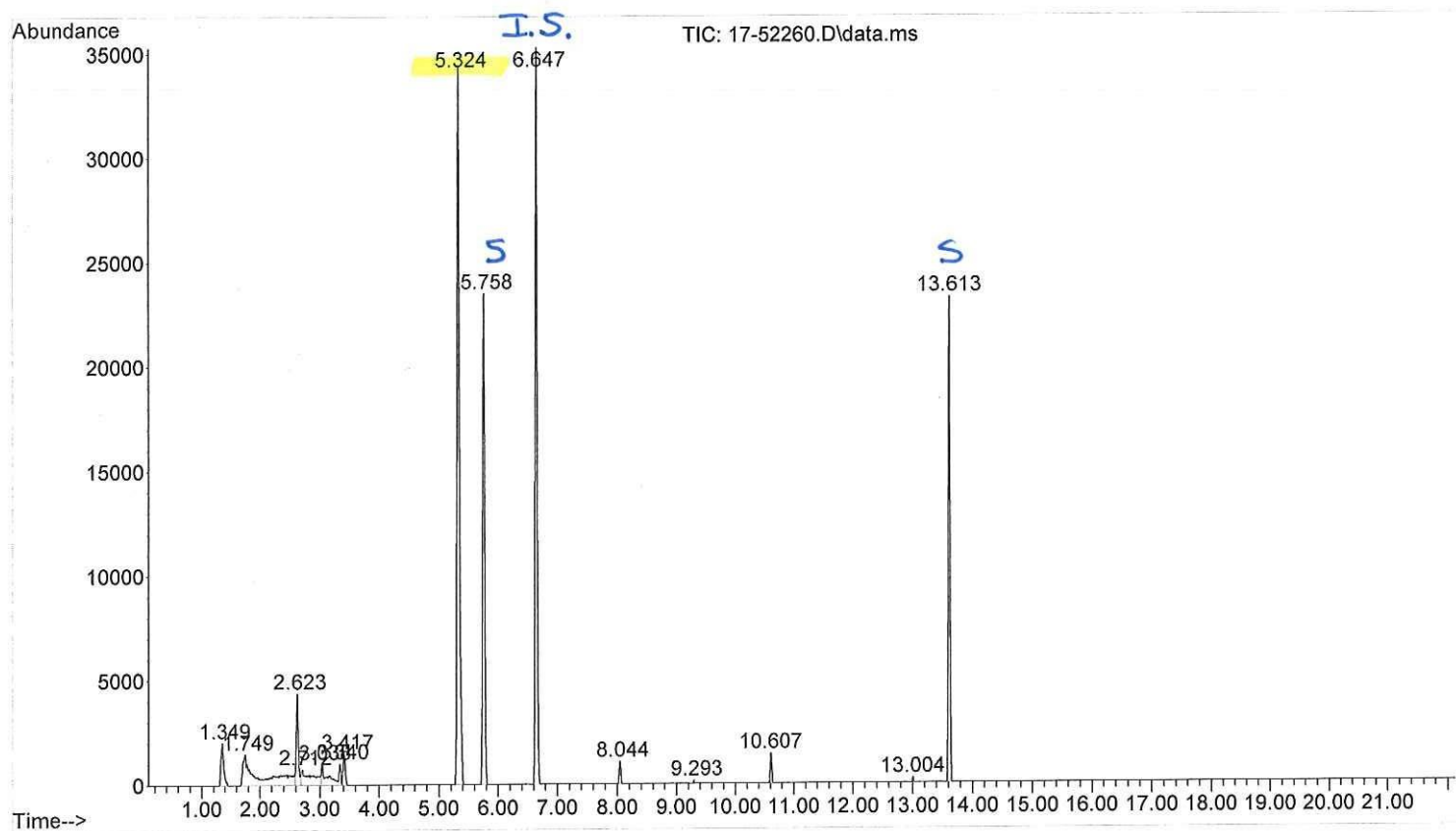
38)	m&p-Xylene	0.000		0	N.D.	
39)	o-Xylene	0.000		0	N.D.	
40)	Styrene	0.000		0	N.D.	
41)	Bromoform	13.004	173	255	0.08 ug/L #	29
42)	Isopropylbenzene	0.000		0	N.D.	
44)	Bromobenzene	0.000		0	N.D.	
45)	1,1,2,2-Tetrachloroethane	0.000		0	N.D.	
46)	1,2,3-Trichloropropane	0.000		0	N.D.	
47)	n-Propylbenzene	0.000		0	N.D.	
48)	2-Chlorotoluene	0.000		0	N.D.	
49)	4-Chlorotoluene	0.000		0	N.D.	
50)	1,3,5-Trimethylbenzene	0.000		0	N.D.	
51)	tert-Butylbenzene	0.000		0	N.D.	
52)	1,2,4-Trimethylbenzene	0.000		0	N.D.	
53)	sec-Butylbenzene	0.000		0	N.D.	
54)	1,3-Dichlorobenzene	0.000		0	N.D.	
55)	Isopropyltoluene	0.000		0	N.D.	
56)	1,4-Dichlorobenzene	0.000		0	N.D.	
57)	1,2-Dichlorobenzene	0.000		0	N.D.	
58)	n-Butylbenzene	0.000		0	N.D.	
59)	1,2-Dibromo-3-chloropr...	0.000		0	N.D.	
60)	1,2,4-Trichlorobenzene	0.000		0	N.D.	
61)	Hexachlorobutadiene	0.000		0	N.D.	
62)	Naphthalene	0.000		0	N.D.	
63)	1,2,3-Trichlorobenzene	0.000		0	N.D.	

(#) = qualifier out of range (m) = manual integration (+) = signals summed

VOCclass.M Thu Oct 19 12:58:16 2017



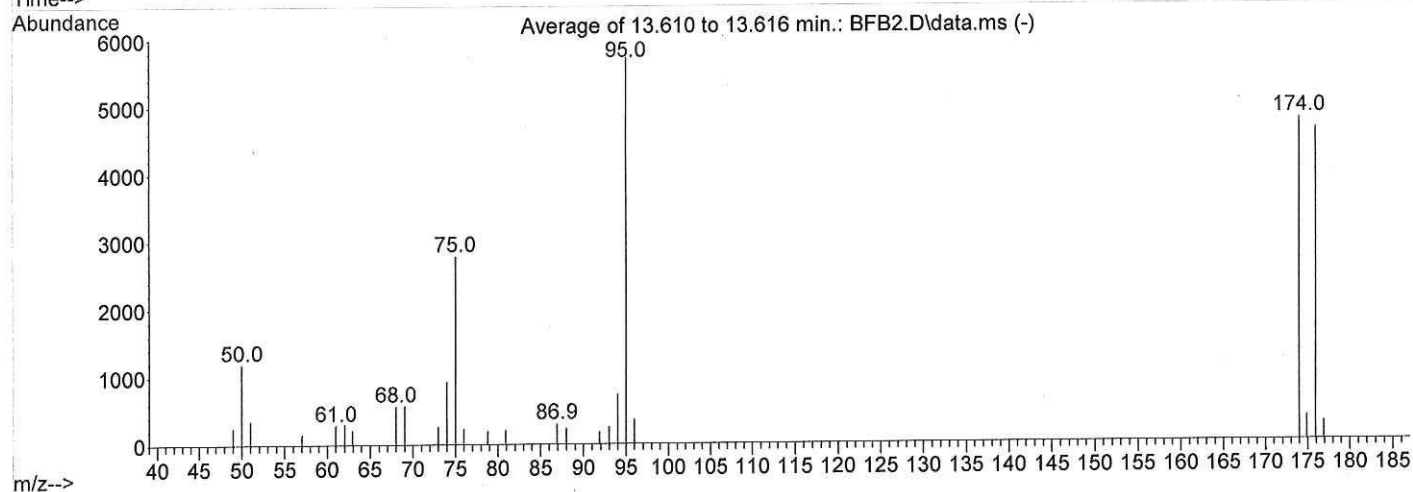
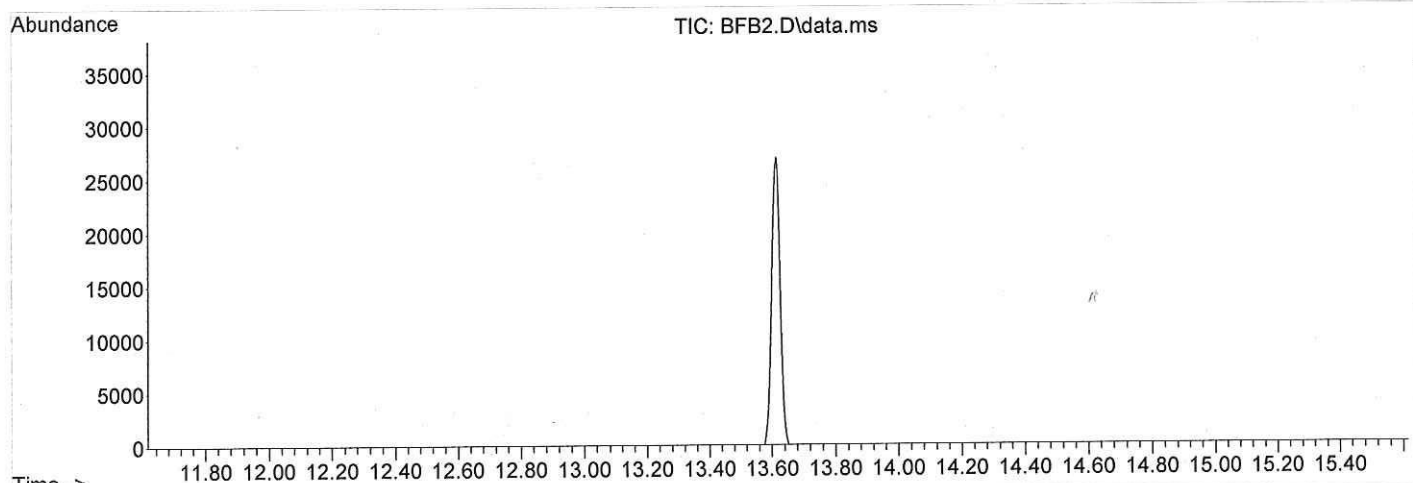
File :D:\MassHunter\GCMS\1\data\VOC\2017\10192017\17-52260.D  
Operator : AJM/JLM  
Acquired : 19 Oct 2017 12:25 pm using AcqMethod VOCclass.M  
Instrument : Agilent5977MSD  
Sample Name: 17-52260  
Misc Info :  
Vial Number: 1



Data Path : D:\MassHunter\GCMS\1\data\VOC\2017\10192017\  
 Data File : BFB2.D  
 Acq On : 19 Oct 2017 10:07  
 Operator : JLM  
 Sample : VOC BFB2  
 ALS Vial : 2 Sample Multiplier: 1

Integration File: voc.p

Method : D:\MassHunter\GCMS\1\methods\VOCclass.M  
 Title : VOC  
 Last Update : Thu May 04 13:37:40 2017



AutoFind: Scans 4394, 4395, 4396; Background Corrected with Scan 4381

Target Mass	Rel. to Mass	Lower Limit%	Upper Limit%	Rel. Abn%	Raw Abn	Result Pass/Fail
50	95	15	40	20.7	1189	PASS
75	95	30	80	48.6	2786	PASS
95	95	100	100	100.0	5736	PASS
96	95	5	9	6.4	367	PASS
173	174	0.00	2	0.0	0	PASS
174	95	50	100	83.4	4784	PASS
175	174	5	9	7.6	362	PASS
176	174	95	101	96.9	4638	PASS
177	176	5	9	6.0	276	PASS

## Quantitation Report (Not Reviewed)

Data Path : D:\MassHunter\GCMS\1\  
 Data File : SnapCopy.D  
 Acq On : 19 Oct 2017 10:52 am  
 Operator : AJM/JLM  
 Sample : CHK 5.0 9-113-8-17  
 ALS Vial : 1 Sample Multiplier: 1

Quant Time: Oct 19 11:14:05 2017  
 Quant Method : D:\MassHunter\GCMS\1\methods\VOCclass.M  
 Quant Title : VOC  
 QLast Update : Thu May 04 13:37:40 2017  
 Response via : Initial Calibration

Compound	R.T.	QIon	Response	Conc	Units	Dev(Min)
-----						
Internal Standards						
1) Fluorobenzene	6.647	96	43138	4.00	ug/L	0.00
System Monitoring Compounds						
18) Pentafluorobenzene (S)	5.758	168	22270	3.38	ug/L	0.00
Spiked Amount	4.000	Range 70 - 130	Recovery	=	84.50%	
43) BFB (S)	13.616	95	15393	3.77	ug/L	0.00
Spiked Amount	4.000	Range 70 - 130	Recovery	=	94.25%	
Target Compounds						
						Qvalue
2) Dichlorodifluoromethane	1.266	85	19852	5.75	ug/L	98
3) Chloromethane	1.401	52	6616	5.93	ug/L	100
4) Vinyl Chloride	1.484	62	21080	5.42	ug/L	100
5) Bromomethane	1.730	94	8131	4.46	ug/L	99
6) Chloroethane	0.000		0	N.D.		
7) Trichlorofluoromethane	2.035	101	26676	4.23	ug/L	100
8) 1,1-Dichloroethene	2.503	61	27005	4.70	ug/L	99
9) Methylene Chloride	3.032	49	24721	4.59	ug/L	98
10) trans-1,2-Dichloroethene	3.358	61	24681	4.77	ug/L	100
11) MTBE	3.410	73	50654	3.52	ug/L	100
12) 1,1-Dichloroethane	3.936	63	32959	4.50	ug/L	100
13) 2,2-Dichloropropane	4.816	77	26067	5.25	ug/L	97
14) cis-1,2-Dichloroethene	4.844	61	31044	5.80	ug/L	94
15) Bromochloromethane	5.198	130	12314	5.36	ug/L	99
16) Chloroform	5.367	83	33592	5.74	ug/L	99
17) 1,1,1-Trichloroethane	5.595	97	26461	5.37	ug/L	98
19) Carbon Tetrachloride	5.853	117	21524	5.17	ug/L	100
20) 1,1-Dichloropropene	5.865	75	23151	5.70	ug/L	99
21) Benzene	6.173	78	71249	6.00	ug/L	100
22) 1,2-Dichloroethane	6.222	62	27676	5.80	ug/L	99
23) Trichloroethene	7.228	130	18328	5.47	ug/L	99
24) 1,2-Dichloropropane	7.558	63	18609	6.13	ug/L	98
25) Dibromomethane	7.742	174	12039	4.79	ug/L	98
26) Bromodichloromethane	8.044	83	24974	5.51	ug/L	99
27) cis-1,3-Dichloropropene	8.785	75	22620	4.97	ug/L	100
28) Toluene	9.296	91	62250	4.48	ug/L	98
29) trans-1,3-Dichloropropene	9.721	75	22284	5.05	ug/L	99
30) 1,1,2-Trichloroethane	9.994	97	16799	5.40	ug/L	98
31) Tetrachloroethylene	10.185	166	17686	4.54	ug/L	98
32) 1,3-Dichloropropane	10.250	76	29281	5.50	ug/L	100
33) Dibromochloromethane	10.610	127	14360	4.73	ug/L	99
34) 1,2-Dibromoethane	10.739	107	16252	4.82	ug/L	98
35) Chlorobenzene	11.613	112	41182	4.26	ug/L	100
36) 1,1,1,2-Tetrachloroethane	11.785	131	16776	4.92	ug/L	99

37) Ethylbenzene	11.850	91	66359	4.05 ug/L	99
38) m&p-Xylene	12.062	91	119443	10.03 ug/L	99
39) o-Xylene	12.720	91	56394	4.10 ug/L	100
40) Styrene	12.754	104	50411	5.14 ug/L	99
41) Bromoform	13.006	173	12976	3.77 ug/L	97
42) Isopropylbenzene	13.391	105	64749	4.41 ug/L	99
44) Bromobenzene	13.816	77	31544	5.18 ug/L	99

VOCclass.M Thu Oct 19 11:15:52 2017

Pa 1

# Quantitation Report (Not Reviewed)

Data Path : D:\MassHunter\GCMS\1\  
Data File : SnapCopy.D  
Acq On : 19 Oct 2017 10:52 am  
Operator : AJM/JLM  
Sample : CHK 5.0 9-113-8-17  
ALS Vial : 1 Sample Multiplier: 1

Quant Time: Oct 19 11:14:05 2017  
Quant Method : D:\MassHunter\GCMS\1\methods\VOCclass.M  
Quant Title : VOC  
QLast Update : Thu May 04 13:37:40 2017  
Response via : Initial Calibration

Compound	R.T.	QIon	Response	Conc	Units	Dev(Min)
45) 1,1,2,2-Tetrachloroethane	13.939	83	21609	4.38	ug/L	100
46) 1,2,3-Trichloropropane	13.957	75	19574	5.31	ug/L	99
47) n-Propylbenzene	14.108	91	84706	4.17	ug/L	100
48) 2-Chlorotoluene	14.194	91	55813	4.76	ug/L	100
49) 4-Chlorotoluene	14.394	91	60794	4.55	ug/L	99
50) 1,3,5-Trimethylbenzene	14.446	105	63547	4.86	ug/L	99
51) tert-Butylbenzene	14.994	119	46450	3.77	ug/L	100
52) 1,2,4-Trimethylbenzene	15.083	105	63272	4.69	ug/L	100
53) sec-Butylbenzene	15.385	105	76203	4.13	ug/L	100
54) 1,3-Dichlorobenzene	15.496	146	37937	4.50	ug/L	98
55) Isopropyltoluene	15.674	119	64262	3.91	ug/L	100
56) 1,4-Dichlorobenzene	15.665	146	38314	4.18	ug/L	99
57) 1,2-Dichlorobenzene	16.299	146	34806	3.90	ug/L	98
58) n-Butylbenzene	16.394	91	57960	5.13	ug/L	99
59) 1,2-Dibromo-3-chloropr...	17.686	157	4231	4.27	ug/L #	84
60) 1,2,4-Trichlorobenzene	19.184	180	18701	3.72	ug/L	98
61) Hexachlorobutadiene	19.575	225	10518	4.34	ug/L	99
62) Naphthalene	19.591	128	45592	3.26	ug/L	100
63) 1,2,3-Trichlorobenzene	20.037	180	20060	3.11	ug/L	99

(#) = qualifier out of range (m) = manual integration (+) = signals summed

## **Vita**

Lindsey Nicole Larson joined the University of Texas at El Paso as an international student from Saskatchewan, Canada in July, 2012. She was the recipient of a full-ride athletic scholarship, and participated on the UTEP volleyball team through her undergraduate career. In April 2016, Lindsey began working as an undergraduate research assistant for the Center for Inland Desalination Systems (CIDS) laboratory under the supervision of Dr. Anthony Tarquin. There, she participated in multiple local projects involving drinking water, wastewater and brackish water treatment. She received a Bachelor of Science in Civil Engineering degree, and graduated Summa Cum Laude in May, 2017. She participated in a dual-credit program, and continued to serve as a graduate research assistant while pursuing a Master of Science in Environmental Engineering degree. She anticipates her graduation in December, 2017. Lindsey plans to pursue her athletic goals with the Canadian National Volleyball Team in 2018, and is looking forward to applying her experience and educational background in Environmental Engineering to further optimize desalination systems.

Email address: [lnlarson16@gmail.com](mailto:lnlarson16@gmail.com)

This thesis was typed by Lindsey Larson.