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Garver Industrial Design Project: Designing a Full-Scale Reverse Osmosis Water Treatment Facility for the City of Lawton, Oklahoma

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UNIVERSITY OF
ARKANSAS
COLLEGE OF ENGINEERING

LAWTON, OKLAHOMA
GROUNDWATER TREATMENT PLANT
DESIGN REPORT

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Executive Summary

A groundwater treatment facility was designed for Lawton, Oklahoma to address potential water scarcity due to drought conditions in southwest Oklahoma. The facility will produce five million gallons per day (MGD) of treated water. The plant will have the capacity of treating 4,085 gallons per minute of influent water at an 86% recovery. The water to be treated will come from the Arbuckle-Timbered Hills Aquifer. Studies have been conducted around the aquifer to identify the best well site locations.

A centralized treatment facility using reverse osmosis filtration as the main treatment technology has been designed. To prevent reverse osmosis membrane fouling, several pre-treatment steps including pH adjustment, ozonation, sand filtration, and pre-screening have been added to the process to extend the life of the membrane. The main contaminants to be removed in the treatment are chloride, fluoride, total dissolved solids, and arsenic which are all above the acceptable levels set by the Environmental Protection Agency.

The water produced by the new treatment plant will be pH neutral and will have lower contaminant levels than the water currently produced by the Southeast Water Treatment Plant. This ensures that both the new treated groundwater and current surface water streams can be mixed into the Southeast Water Treatment Plant's distribution system without damage to the existing infrastructure. The waste from the new plant will be sent to the Lawton wastewater treatment facility for treatment.

The total fixed capital cost for the plant is estimated to be $18.1 MM and the yearly operating cost is $1.6 MM. This estimate includes 20 plant operators spread between 4 shifts at $45 M per operator. Assuming the 5 MGD of water produced is sold, the current pricing structure for the City of Lawton should be sufficient to operate the treatment plant with a 5.4-year payback period with a 20-year net present worth of $20 MM at a 5 percent discount rate.

Introduction

Lawton, a city located in southwest Oklahoma, experienced drought conditions between 2011 and 2013 resulting in strict water conservation ordinances. To relieve the strain on surface water sources, the City of Lawton hired Garver in 2014 to analyze multiple well locations within the Arbuckle-Timbered Hills Aquifer (ATH) as potential sources for treatable water and to design a groundwater treatment system that produces 5 million gallons per day (MGD) of drinking water[1]. Garver has partnered with the University of Arkansas to design a groundwater treatment plant.

The population of Lawton is approximately 93,000 and covers 82 square miles. Lawton is predominantly a military community and is home to Fort Sill, an active-duty U.S. military base. The current sources of water for Lawton are Lake Lawtonka, Lake Ellsworth, and Lake Waurika. In 2011, low rainfall led both Lake Ellsworth and Lake Waurika to fall below 50% usable water levels[1]. With Oklahoma weather consistently attributing to drought conditions, state officials began to push for alternatives to local water sources. Drought conditions continued from 2011 into 2014, causing four consecutive years of water shortages within the city[2].

Unlike surface water sources, groundwater is not prone to evaporation in the summer, making groundwater desirable for an area with consistent drought conditions and high temperatures. Five potential wells in the ATH system capable of producing 5 MGD of water were identified. In 2016, the City of Lawton officially voted to allocate tax funds to finance the construction of the wells and a potable water treatment facility. As the population and business presence increases in Lawton, so does the water demand. By securing a drought-resistant water source, extreme conservation efforts can be reduced, benefiting the current and future needs of Lawton residents[3].

In 2016, the Layne Christensen Company (LCC) conducted an alternative water supply feasibility study to examine the usefulness of possible well locations. Ten well locations were drilled, chosen based on the results of a geophysical survey conducted by the LCC. Each well is identified using an alphabetical index corresponding to a location and water chemistry analysis report. Each well location is shown in Figure 1. After analysis of the data provided by the LCC, test well site K was selected as the primary water source due to its large capacity. Well site K is emphasized in Figure 1 with a red circle. The property where site K is located is owned by the City of Lawton, decreasing the project cost since the land does not require purchase.

Additionally, site K is located in east Lawton, near the current Southeast Water Treatment Plant (SEWTP) which is shown in aqua blue in Figure 1, where the proposed groundwater will be treated separately.

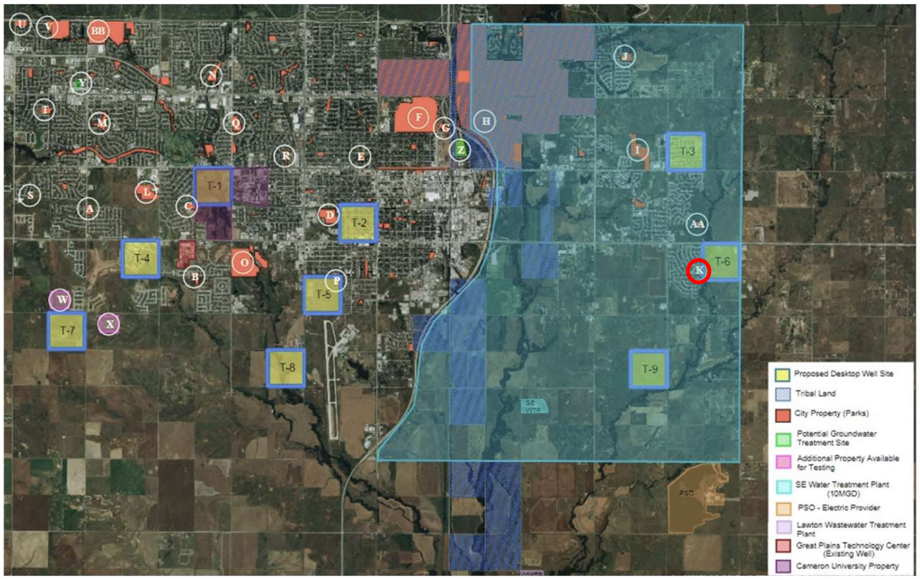


Figure 1. ATH Well Locations

After selecting site K, the next step was to develop a water treatment plan specific to the contaminant species and levels present. The treatment methods for groundwater and surface water have slightly different processes so the groundwater must be treated separately before it can be distributed. Analytical tests to determine the contaminant composition of the groundwater have been carried out but further testing may be beneficial to confirm levels. A full-scale facility has been designed meeting all EPA drinking water standards.

An example of a successful industrial-scale RO application is the Kay Bailey Hutchinson (KBH) water treatment plant in El Paso, Texas. KBH is the world's largest inland desalination plant, the KBH plant provides a steady supply of up to 27.5 MGD of water from sixteen production wells and sixteen blend wells located in the Hueco Bolson aquifer[4]. The KBH plant pre-treats with sand strainers, cartridge filters, and antiscalants before the water is pumped through five RO trains.

The City of Lawton has two drinking water treatment facilities and one wastewater treatment facility. The Medicine Park Water Treatment Plant (MPWTP) can produce 40 MGD of drinking water[6]. The second water treatment plant is the SEWTP which has a capacity of 10 MGD and an expansion capacity of 40 million gallons per day. Both plants treat surface water using coagulation, ozonation, granular activated carbon filtration, and chlorination to remove contaminants. The SEWTP treats an average of 5.5 MGD in the summer with a total capacity of 10 MGD. To prevent issues similar to Flint, Michigan, where pH differences caused by a change in water source corroded distribution piping leading to lead seepage[5], the current water distribution system of Lawton was examined as well as any residual contaminant levels present in the treated water. The contaminant profile of the water currently distributed in Lawton was used to assess if it would be safe to mix the existing water treatment stream with the new, treated groundwater stream.

Arbuckle-Timbered Hills Aquifer

The ATH Aquifer is in southwest Oklahoma and covers an area of 973 square kilometers[8]. The aquifer is used for limited public supply and domestic and industrial applications.

Test Hole Sites

Ten test sites were created to determine which areas within the aquifer were best suited for treatment. The location of each well was shown previously in Figure 1. Of the ten test holes completed, four were considered suitable for test pumping: sites F, K, O, and V. The yield from each well and the reasoning for the elimination of well sites AA, D, BB, P, Q, and T are displayed in Table 1. Site K was selected for future well drilling due to its high yield, lack of oil contamination, and low contaminant levels.

Table 1. Studied Wells

Well	Yield (gpm)	Notes
AA	835	Eliminated: Crude Oil Presence
D	-	Eliminated: Crude Oil Presence
BB	-	Eliminated: Dry
F	581	
K	2180	
O	1000	
P	-	Eliminated: Dry
Q	17	Eliminated: Below Capacity
T	450	Eliminated: Crude Oil Presence
V	800	

Project Objectives

- Design a centralized groundwater treatment process capable of producing 5 MGD of drinking water.
- Treat the influent water with reverse osmosis to meet safe drinking water standards by reducing high levels of chloride, fluoride, total dissolved solids, and arsenic.
- Distribute the produced water with the current water distribution system.

Project Scope

A total of 4,085 gallons per minute (gpm) of groundwater will be delivered to the new treatment facility at 115 psig and 77°F. Several wells will be drilled near the highest producing and least contaminated site, site K, which will be used as the contaminant level basis for the design of pre-treatment methods and the RO membrane system. Site K contains high levels of chloride, fluoride, total dissolved solids (TDS), and arsenic, which will have to be lowered to meet the EPA maximum contaminant levels (MCL) of 250 mg/L, 4 mg/L, 500 mg/L, and 0.01 mg/L, respectively[7]. Iron levels at site K were measured below quantifiable limits and may not be reliable. Therefore, the highest iron concentration from the ten wells studied, 0.892 mg/L, was used as a worst-case approximation. All the selected contaminant levels were chosen as a conservative design approach.

Technology Assessment

Treatability Studies

To determine the effectiveness of multiple treatment options, Garver sent well water samples to the Department of Civil and Environmental Engineering at the University of California, Los Angeles chemistry lab. Over nine months, two distinct treatment phases were performed. Synthetic water was tested in phase I and real groundwater was tested in Phase II.

During Phase I, combinations of treatments included coagulation, sand filtration, greensand filtration, nanofiltration, activated alumina, and reverse osmosis were tested. The most successful treatments, coagulation, greensand, nanofiltration, and reverse osmosis, were tested during Phase II. Ozonation was not included in the laboratory testing regimen and was added as a safety measure for decontamination and to oxidize soluble iron and arsenic. To better understand the various water treatment technologies, they were each researched independently and evaluated in conjunction with the treatability studies.

Ozonation

Ozone is used in water treatment to oxidize metal ions, particularly iron. Ozonation is more efficient for oxidation than aeration and provides decontamination, removing bacteria and viruses[9]. The concentration of organic matter in natural waters may vary from 0.2 – 10 mg/L. Although known as a toxic pollutant, ozone degrades to oxygen and partly into reactive hydroxide radicals[10]. When designing a process involving ozone, reactions between ozone and OH^- radicals must be analyzed. Ozone has high degradation rates in water; this rate increases in neutral to alkaline pH due to the increased formation of OH^- radicals. In acidic conditions, the rate of oxidation is slow because of the lack of OH^- radicals.

The optimal pH to facilitate oxidation and limit degradation is between pH 3 to 5.5. The solubility of ozone decreases at higher temperatures but reaction speed increases by a factor of 2–3 with every 10°C increase. However, this trend is not followed above 40°C, where the half-life of ozone is very short[9]. Therefore, the process should be kept near 20-25°C for increased solubility, moderate reaction speed, shortened retention times, and minimal ozone degradation. Some chemical species, such as carbonate and bicarbonate, have a strong affinity for OH^- radicals and are called scavengers due to their ability to lower oxidation capacity. A temperature of 25ºC and pH of 5.5 is recommended for increased oxidation rates and decreased decay rates.

Baffles in the contact tank are recommended for good mixing. A 5-minute retention time was suggested by Suez Technologies for iron (Fe) oxidation. The retention time allows the Fe (II) to oxidize and form insoluble Fe (III). Fe (III) reacts with water to form iron hydroxide, $Fe(OH)_3$, commonly known as red rust, a major factor in staining and blockages in piping systems. At levels above 0.05 mg/L, iron can cause issues in RO systems. At low pH, from 3 to 6, arsenic (As), specifically As (V), has a high affinity for absorptivity to $Fe(OH)_3$[11]. When iron is oxidized by ozonation, the $Fe(OH)_3$ and As (V) are both removed by sand filtration which will prevent RO degradation.

Sand Filtration

Sand filters remove fine inorganic and particulate matter from process water which cannot be economically removed by sedimentation. Sand filtration is a form of granular medium filtration in which the filtering medium consists of materials such as sand, anthracite, activated carbon, or other grains. Sand filtration is used for the removal of suspended matter, floating insoluble particles, turbidity, odors, and color. The water flows through a bed of sand, or a mixture of sand and gravel, where particles are removed by way of absorption or physical encapsulation. Sand filtration can also be used to remove oxidized iron from water[12].

There are two main types of sand filtration: gravity sand filtration and pressure sand filtration. Gravity filters are commonly constructed from concrete or steel. Rectangular, open-top, reinforced concrete units containing silica sand are the most commonly used design. Gravity sand filters use a support bed, usually 1–2 ft deep, preventing loss of fine sand and distributing backwash water throughout the sand bed[13]. The typical filtration rate of a gravity sand filter is 3 gpm/ft^2. A pressure filter is similar to a gravity sand filter but is operated under pressure in a completely enclosed vessel such as a steel tank. Pressurized filters can run at higher flowrates and occupy less space compared to gravity filters, making pressure filters ideal for implementation in higher flow processes. Pressure filters have been commonly used in public water supplies for the removal of iron from groundwater[13].

A pressure filter may be oriented vertically or horizontally depending on the space available. The media commonly used in a pressure sand filter is silica sand, however, a combination of media can be utilized to achieve different filtration rates. The typical filtration rate for a pressure vessel is 8 gpm/ft^2. Pressure filters offer lower installation and operation costs in small filtration plants.

Sand filtration was chosen for the design over greensand filtration because the same level of particulate removal can be achieved in combination with ozonation. Sand filtration does not require any potentially damaging chemical regeneration and any particles that escape the bed can be removed with a micron screen.

Reverse Osmosis

Reverse osmosis is a pressure-driven membrane process that overcomes osmotic pressure by applying high pressure to the feed water containing a high concentration of TDS. This creates a pressure gradient and forces water molecules to travel from the concentrated solute, through the semi-permeable membrane, to the less concentrated solvent on the other side. RO technology is typically used in desalination of seawater and brackish water, wastewater treatment, drinking water purification, food and beverage industries, and biomedical separation processes. RO membranes are typically spiral-wound and made from polyamide, cellulose, or other polymers. The molecular weight cutoff for RO membranes is approximately 100 g/mol with pore sizes ranging between 0.0001 to 0.0025 microns. Compared to traditional water treatment methods, RO is more efficient at removing particulate matter, dissolved contaminants, pathogenic micro-organisms, and hardness[14].

Dissolved solids are separated from the feed stream and result in a concentrated reject stream. RO is extremely efficient in arsenic removal. Arsenic is highly toxic and commonly found in groundwater sources. The two most prevalent forms of arsenic in the ATH water are the organic forms As (V) and As (III). In most water filtration systems, including RO, As (V) removal is more efficient than As (III) removal. To increase the arsenic removal in drinking water treatment, As (III) must be oxidized. In previous research of arsenic removal by RO treatment, about 50% to 80% of As (III) removal was achieved compared to 98% of As (V)[15]. Any As (V) remaining after ozonation and sand filtration will be removed by the RO system as an additional measure of safety.

Although a very effective and efficient water treatment method, RO membranes are susceptible to fouling, or pore plugging and blockage, due to particulate accumulation or biological growth on the membrane surface[16]. RO systems require frequent maintenance to avoid flux decrease and eventual system failure. To reduce the rate of fouling, the RO feed water requires pre-treatment to remove suspended solids and inorganics. Methods assessed for pre-treatment are discussed in the following section.

Recommendations

After evaluation of existing treatment technologies and water treatment plants, a final design was developed. It was determined during Phase II of the treatability study that complete removal of all contaminants can be achieved using coagulation, greensand, and RO, however, more processing was being done than necessary. The final design is shown in Figure 2 as a block flow diagram and includes a pH adjustment, ozonation, sand filtration, and RO. A small portion of the pretreated water bypasses the RO system and is blended with the RO product water. Due to low concentrations of contaminants in the RO product water, the two streams can be mixed and still meet all EPA drinking water standards. This bypass reduces the amount of processing done by the RO system and improves total system recovery. An additional pH adjustment is performed after the RO to prepare the treated water for mixing with the water treated at the SEWTP.

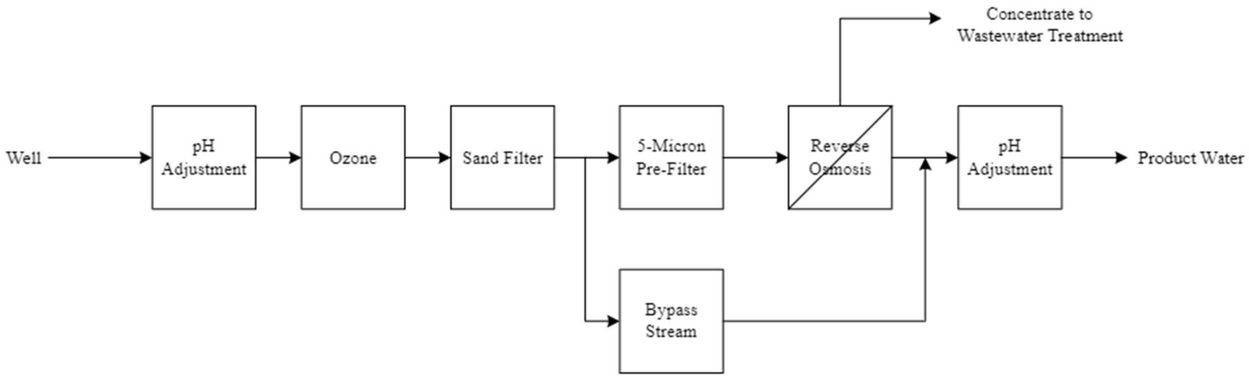


Figure 2. Block Flow Diagram

Process Design

Design Basis

The objective of this project is to produce 5 MGD of treated water. The process design must treat groundwater sourced from the ATH aquifer and remove the contaminants in the aquifer using various treatment methods to achieve a satisfactory quality of drinking water as regulated by the EPA. Contaminant details for the inlet and outlet process streams are shown in Table 2.

Table 2. Inlet and Outlet Process Streams

Contaminant	Feed (ppm)	Product (ppm)	Concentrate (ppm)
Bicarbonate	239.80	1.92	144.62
Bromide	1.01	0.11	6.66
Carbonate	14.40	0.00	0.05
Chloride	293.00	57.21	3183.01
Fluoride	8.81	1.15	56.91
Sulfate	101.00	10.90	666.60
Arsenic	0.02	0.00	0.00
Barium	0.01	0.00	0.11
Calcium	7.50	0.79	49.64
Iron	0.89	0.00	0.00
Magnesium	3.55	0.37	23.50
Potassium	6.14	0.80	39.66
Silica	12.10	1.25	80.22
Sodium	372.55	43.08	2382.21
Carbon Dioxide	0.92	85.39	87.33
Water Flow Rate (gpm)	4085	3525	561

Design Feed

The brackish feed has a 4,085 gpm flowrate and will be delivered to the facility at 115 psig and 77ºF. The feed water has a pH of 8.5 and high levels of fluoride, sodium, chloride, and arsenic (8.81 ppm, 364 ppm, 293 ppm, and 0.022 ppm respectively). A more detailed description of the feed properties and contaminants is presented in Table 2.

Product Water

The product water from the RO system has a pH of 4.8 and needs to be adjusted to a pH of 7 to safely mix with the existing municipal water system. The final product water meets all EPA drinking water standards. The product water is collected in an 18,000-gallon carbon steel tank and delivered to the SEWTP at ambient temperature and 20 psig. The final product water characteristics can be found in the Product column in Table 2.

Waste

The two sources of waste in the system are the excess ozone produced by the ozone generator and the brine from the RO system. Excess ozone is sent to the ozone destructor and vented. The brine from the RO system will be sent to the SEWTP and is the major source of waste. The RO Brine characteristics can be found in the Concentrate column in Table 2.

Process Description

The process flow diagram is shown in Figure 3. The material balance for this process is shown in Table 3. A stream of untreated groundwater, (1), enters the battery limits at 4,085 gpm. Hydrochloric acid is directly injected from (2) into (1) at 1.3 gpm to reduce the pH of the influent water. The water then flows into a feed surge tank (V-102) where the pressure is controlled at 65 psig.

Water from V-102 is mixed with ozone that is supplied by the ozone generator, R-101. Liquid oxygen is supplied to the ozone generator at a rate of 0.214 gpm and then converted to gas through an evaporator. The ozone exits the generator, is compressed, and is then injected into (3) prior to the ozone contactor, R-102. The combined flow enters the ozone contact tank where iron and arsenic are oxidized and precipitated out of solution. Residual ozone, oxygen, and nitrogen are de-gassed using automated valves above the ozone contactor and pass through an ozone destructor, R-103, which uses a metal catalyst to convert ozone into oxygen and then vents it to the atmosphere.

Post-ozonation, (9) flows into the pressurized sand filters, F-101 and F-102. Suspended particles, such as precipitated iron and arsenic, are removed by the sand filters. After filtering, the water enters the RO water storage tank, V-103. 350 gpm of pretreated water bypasses the RO system by way of (15) and is blended with the RO product water. Due to low concentrations of contaminants in the RO product water, the two streams can be mixed and still meet all EPA drinking water standards. This bypass reduces the amount of processing done by the RO system and improves total system recovery. An antiscalant is injected at 10 gpm into (16) before the RO system to reduce scaling in the RO membranes. The water is pressurized to 152 psi before entering a 5-micron filter, F-103. The permeate stream combines with the bypassed water and the concentrate stream is sent to the wastewater treatment plant.

Sodium hydroxide at 0.003 gpm is injected into (22) to neutralize the acidic product water. After mixing, the neutralized product water is pumped to the SEWTP's existing product water storage to be mixed with treated surface water and distributed via the existing municipal water system. Overall, the RO system achieves an 85% recovery with a total system recovery of 86%.

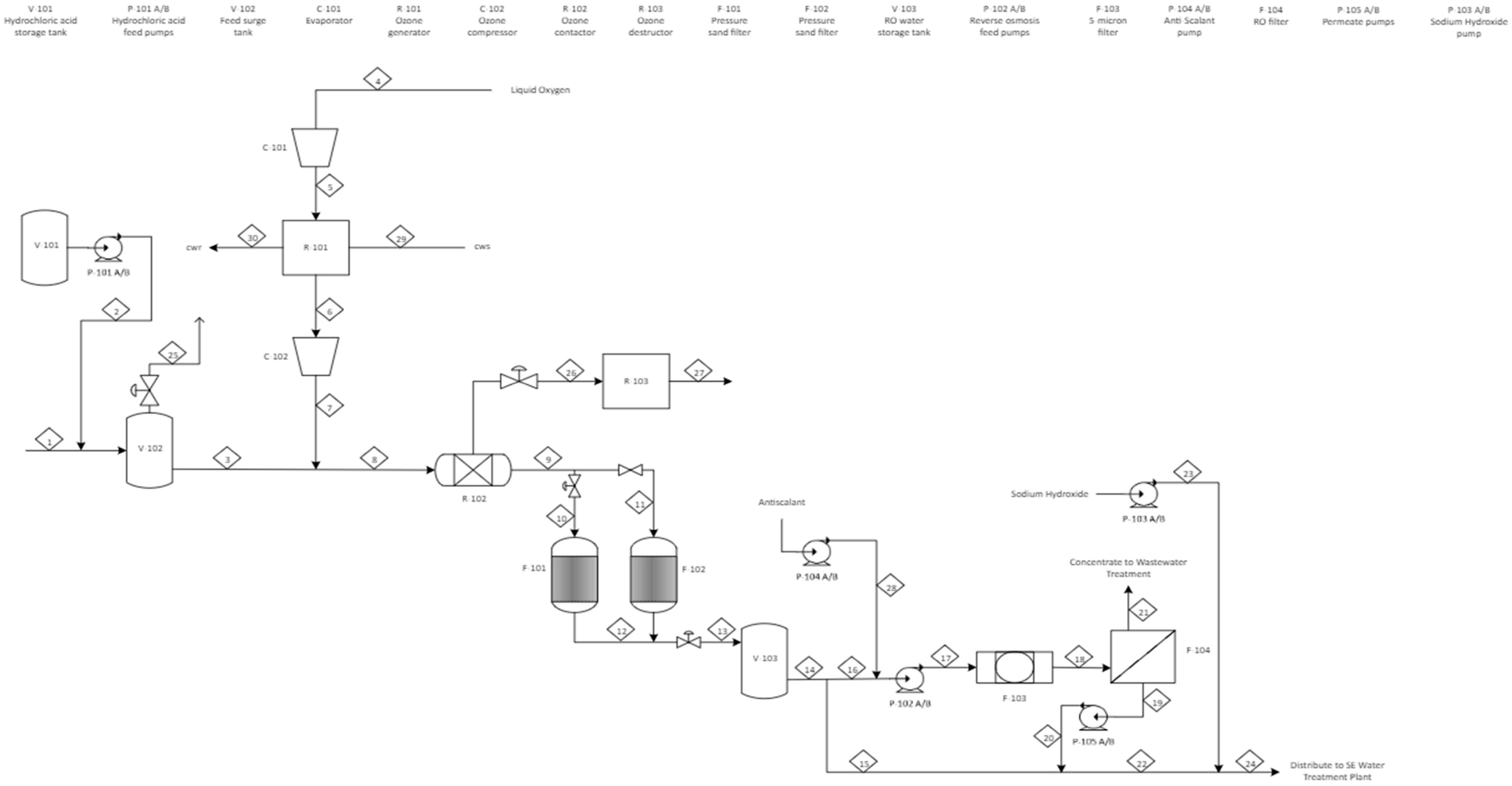


Figure 3. Process Flow Diagram

Table 3. Process Mass Balance

Stream		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Feed Flow (gph)		245100	76.6	245177	1.37	0	0	0	245177	245177	122588	122588	122588	245177	245177	21000	224177	224187	224187	190516	190516	33671	211516	0.177	211516	0	0	0	10	580.8	580.8
Gas Flow (CFM)		0	0	0	0.00	405.80	2.9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.5	0.5	0	0	0
Temp (F)		77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77
Pressure (psig)		111	112	65	14.69	36.25	14.5	75	60	51	51	51	45	45	41	33	33	151.31	147.31	0	33	93.33	33	33	33	111	20	20	30	30	30
Mass Flow (lbs/hr)		2049703	767	2050304	13	13	13	13	2050316	2050305	1025153	1025153	1025151	2050302	2050302	175630	1874672	1874756	1874756	1542163	1542163	332598	1717771	2	1717773	166	12	12	88	4850	4850
	Molecular	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)	Flow (lbs/hr)
Bicarbonate	HCO3(1-)	490.50	0.00	45.90	0.00	0.00	0.00	0.00	45.90	45.90	22.95	22.95	22.95	45.90	45.90	3.94	41.96	41.96	41.96	3.39	3.39	40.64	3.39	0.00	3.39	0.00	0.00	0.00	0.00	0.00	0.00
Bromide	Br(1-)	2.07	0.00	2.07	0.00	0.00	0.00	0.00	2.07	2.07	1.03	1.03	1.03	2.07	2.07	0.18	1.89	1.89	1.89	0.02	0.02	1.87	0.20	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Carbonate	CO3(2-)	29.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride	Cl(1-)	599.32	0.00	995.44	0.00	0.00	0.00	0.00	995.44	995.44	497.72	497.72	497.72	995.44	995.44	85.34	910.10	910.10	910.10	15.72	15.72	894.41	100.99	0.00	100.99	0.00	0.00	0.00	0.00	0.00	0.00
Fluoride	F(1-)	18.02	0.00	18.02	0.00	0.00	0.00	0.00	18.02	18.02	9.01	9.01	9.01	18.02	18.02	1.54	16.48	16.48	16.48	0.49	0.49	15.99	2.03	0.00	2.03	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	NO3(1-)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrite	NO2(1-)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	SO4(2-)	206.59	0.00	206.59	0.00	0.00	0.00	0.00	206.59	206.59	103.30	103.30	103.30	206.59	206.59	17.72	188.87	188.87	188.87	1.56	1.56	187.31	19.24	0.00	19.24	0.00	0.00	0.00	0.00	0.00	0.00
Mercury	Hg(2+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	Sb(5+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	As(3+)	0.05	0.00	0.05	0.00	0.00	0.00	0.00	0.05	0.05	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barium	Ba(2+)	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.03	0.03	0.01	0.01	0.01	0.03	0.03	0.00	0.03	0.03	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium	Ca(2+)	15.34	0.00	15.34	0.00	0.00	0.00	0.00	15.34	15.34	7.67	7.67	7.67	15.34	15.34	1.31	14.03	14.03	14.03	0.08	0.08	13.95	1.39	0.00	1.39	0.00	0.00	0.00	0.00	0.00	0.00
Chromium	Cr(3+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	Cu(3+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	Fe(2+)	1.82	0.00	1.82	0.00	0.00	0.00	0.00	1.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	Pb(2+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium	Mg(2+)	7.26	0.00	7.26	0.00	0.00	0.00	0.00	7.26	7.26	3.63	3.63	3.63	7.26	7.26	0.62	6.64	6.64	6.64	0.03	0.03	6.60	0.65	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	Mn(2+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium	K(1+)	12.56	0.00	12.56	0.00	0.00	0.00	0.00	12.56	12.56	6.28	6.28	6.28	12.56	12.56	1.07	11.49	11.49	11.49	0.35	0.35	11.14	1.41	0.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00
Selenium	Se(4+) or (6+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silica	SiO2	24.75	0.00	24.75	0.00	0.00	0.00	0.00	24.75	24.75	12.38	12.38	12.38	24.75	24.75	2.11	22.64	22.64	22.64	0.10	0.10	22.54	2.21	0.00	2.21	0.00	0.00	0.00	0.00	0.00	0.00
Sodium	Na(2+)	762.04	0.00	762.44	0.00	0.00	0.00	0.00	762.44	762.44	381.22	381.22	381.22	762.44	762.44	81.44	681.00	681.00	681.00	11.61	11.61	669.39	75.41	0.00	75.41	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium Oxide	MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron Hydroxide	Fe(OH)3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.48	1.74	1.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrochloric Acid	HCl	0.00	283.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	CO2	1.88	0.00	175.83	0.00	0.00	0.00	0.00	175.83	175.83	87.91	87.91	87.91	175.83	175.83	15.06	160.77	160.77	160.77	135.10	135.10	24.54	150.73	0.00	150.73	166.46	0.00	0.00	0.00	0.00	0.00
Ozone	O3	0.00	0.00	0.00	0.00	0.00	1.01	1.01	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
Oxygen	N2	0.00	0.00	0.00	12.84	12.84	11.56	11.56	11.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.56	11.86	0.00	0.00	0.00
Nitrogen	O2	0.00	0.00	0.00	0.26	0.26	0.26	0.26	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.26	0.00	0.00	0.00
Water	H2O	2047531.18	483.41	2048035.69	0.00	0.00	0.00	0.00	2048035.69	2048035.69	1024017.84	1024017.84	1024017.84	2048035.69	2048035.69	175419.45	1872616.24	1872699.74	1872699.74	1541994.07	1541994.07	330705.66	1717413.52	1.12	1717414.64	0.00	0.00	0.00	83.50	4849.68	4849.68
Sodium Hydroxide	NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	1.12	0.00	0.00	0.00	0.00	0.00	0.00
Anti-Scalant		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.09	0.00	0.00	0.00	0.00	0.00	0.00	4.09	0.00	0.00

Process Equipment

Feed Surge Tank and pH Adjustment

The feed surge tank is 34 ft tall with a diameter of 10 ft and has a 20,000-gallon capacity. The feed surge tank was designed for a five-minute retention time which is enough for an operator to respond to a process upset. A major role of the feed surge tank is to control the pressure through an automated pressure relief valve. The feed surge tank will reduce the well water pressure from 111 psig to 65 psig.

The hydrochloric acid is contained in a 20,000-gallon polyethylene tank. 20,000 gallons of 37 wt/wt% hydrochloric acid will be enough material for ten days at a feed rate of 1.28 gpm to reduce the water pH from 8.5 to 5.5. Acidic pH keeps divalent ions, such as magnesium and calcium, soluble which helps prevent RO membrane fouling. These ions also react with carbonate and bicarbonate ions to convert them into carbon dioxide, which is off-gassed. The hydrochloric acid will be dosed before the well water reaches the feed surge tank, providing mixing due to the turbulence in the piping system.

Ozone Generator, Injection, and Contactor

The amount of ozone required to precipitate the iron is 0.44 mg ozone/mg Fe. The maximum iron contaminant level received from initial well testing is 0.892 mg/L, therefore approximately 1.1 lb/hr of ozone is needed. The CFS-28 compact ozone generator system manufactured by Suez Technologies was selected to supply the ozone. The CFS-28 system includes the ozone generator, liquid oxygen system, medium-voltage power supply, cooling water skid, vent ozone destruct units, PLC-based control system, and control monitors for dissolved ozone, off-gas, and leak detection. The dielectric layer gaps on the electrodes located inside the generator cause the oxygen molecules to split, combine, and create the triatomic oxygen form. The liquid oxygen feed source supplies pure oxygen with 10 wt% ozone production capacity and requires 2.3 wt% nitrogen to work efficiently at pressures between 36–116 psig. To produce the necessary amount of ozone, 4.6 lb/hr of oxygen is required with 0.26 lb/hr nitrogen. Approximately 14.5 gpm of cooling water is supplied through an open loop at process temperature to cool the ozone generator. The ozone contactor will be a baffled, stainless steel tank capable of withstanding system pressures of 65 psig. The ozone is supplied into the process stream at high pressures via a nozzle injector with an in-pipe radial diffuser. The injector will be supplied by Suez. The ozone contactor will be sized at 3,330 ft^3 to allow for a 5-minute retention time to oxidize iron and arsenic and to provide a preliminary decontamination step.

Sand Filtration

Sand filtration prevents potentially harmful components from reaching and damaging the RO membrane. Sand filtration removes the oxidized iron, now in the insoluble form of $Fe(OH)_3$, from the process water. Pressure sand filtration was selected because higher filtration rates can be maintained while using less area than gravity filtration. The filtration media employed in the design of this unit is #20 silica sand with an effective size of 0.55 mm. This media is ideal for this treatment process due to the low turbidity associated with the process water and the ability to filter up to 20 microns, capable of withdrawing the coagulated $Fe(OH)_3$, from the process water.

Using a bed height of 3 ft and the properties of the #20 silica sand, the pressure drop across the pressurized sand filter was determined to be 1.12 psig. With a standing waterbed above the filtration media of 2 ft and a conservative filtration rate of over 5.83 gpm/ft^2, 3.30 minutes is the estimated time for the water to enter, filter, and exit the pressurized sand filter. To account for the 4,085 gpm capacity that is needed for this pressurized sand filter and the filtration rate of 5.83 gpm/ft^2 used previously, the filtration area of the pressurized sand filter is required to be 700 ft^2. For this design, two 10 ft diameter by 35 ft height, horizontally oriented, pressurized filtration vessels with an operational working pressure of 50–75 psig will be utilized, rated for a combined capacity of 5.8 MGD.

Sand filters require intermittent backwashing. Throughout operation the filter media will become coated with floc, plugging the voids between the filter grains, making the filter difficult to clean and susceptible to poor filtration efficiency[13]. The filtration media must be expanded to clean the filter during the backwash cycle. This expansion causes the filter grains to rub aggressively against each other, dislodging the floc from the media. The filter backwash flowrate must be great enough to suspend and agitate the filter media, suspending the flocs in the water for removal. If the backwash rate is too high, the media will be released from the filter[13]. The water that will be used during the backwash cycle can be raw well water since it has low turbidity. Recommended backwash flowrates range from 13–15 gpm/ft^2. The backwash flowrate will be 14 gpm/ft^2. A flowrate of 2,000 gpm is needed for the backwashing cycle per unit[13].

Reverse Osmosis Membrane System

The RO system consists of 5 Pure Aqua Inc. TW-20880 RO skids. The skids hold 20 pressure vessels with 8 elements each with a water treatment capacity of 635.1 gpm per skid. Each vessel is a self-contained RO system holding 13 pressure vessels for the first stage and 7 pressure vessels for the second stage of filtration. The membrane selected for the elements was the BW30HR-440i, a polyamide thin-film composite membrane with a maximum pressure of 600 psig. Each element has a maximum feed flow of 85 gpm and the operating pH ranges from 2 to 11.

Each skid comes with a feed pump that will provide 150 psi of pressure that will supply the whole unit with no booster pump needed for the second stage. The skids also contain a 5-micron filter capable of removing any large particulates that have passed the sand filters or sand particles themselves. With this system, it is possible to remove all contaminants to meet EPA drinking water standards. The RO system was designed using the ROSA membrane projection software and the simulation for the RO system can be found in Appendix A. This simulation details the contaminant levels and stream quality for each stage of the RO system as water passes through.

Product Water Storage and pH Adjustment

The product water from the RO system has a pH of 4.8 and needs to be adjusted to a pH of 7 to safely mix with the municipal water system. To adjust the pH, 0.003 gpm of 50% sodium hydroxide will be used. The product water will be sent to the SEWTP at 33 psig.

Wastewater

The plant will produce 561 gpm of RO concentrate. Waste stream contaminants are shown in Table 2. Mr. David Hastings, the superintendent of the wastewater treatment plant, confirmed that the plant can handle the additional flow and contaminants.

Metallurgy

Carbon steel is widely used as a material of construction in piping and vessels because it is one of the cheapest forms of steel. Unfortunately, the corrosion rate of carbon steel increases in acidic and salty environments. After the hydrochloric acid is mixed, the water pH will be 5.5

which causes greater corrosion rates[17]. In addition to acidic pH, ozonation can increase pitting in carbon steel.

Stainless steel provides better corrosion resistance than carbon steel due to increased chromium content that readily reacts with oxygen to produce a chromium oxide, corrosion-resistant layer. 304 stainless steel (SS 304) is the cheapest and most available type of stainless steel but is subject to intense corrosion in welding sites. To extend the life of the plant, the selected material of construction for most of the piping and vessels is low carbon 304 stainless steel (SS 304L). This selection will slow welding site corrosion over time. The only portions of the plant that will require a different material of construction are the hydrochloric acid vessel, hydrochloric acid piping, and the product tank. The hydrochloric acid will be stored in a 20,000-gallon polyethylene vessel and the piping connecting the hydrochloric vessel to the feed surge tank will be polyvinyl chloride.

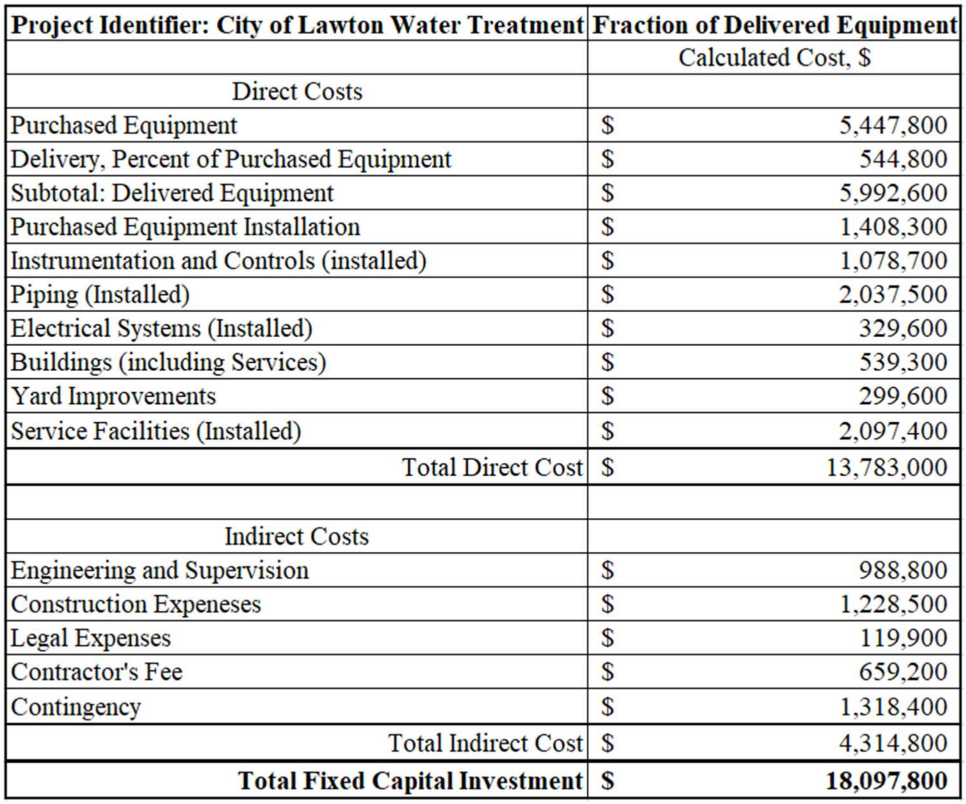
Capital Cost Estimate

The capital cost estimate is a factored estimate based on purchased equipment cost to determine other project expenses such as equipment installation, instrumentation, piping, service facilities, and other indirect costs. The total purchased equipment cost was estimated to be $5.5 MM. The equipment cost breakdown is shown in Table 4. The total fixed capital investment is estimated to be $18.1 MM. The fixed capital cost breakdown is shown in Table 5. This project has a 5.4-year payback period with a 20-year net present worth of $20 MM at a 5 percent discount rate.

Table 4. Purchased Equipment List

Vessels	Orientation	Length/Height (ft)	Diameter (ft)	MOC	Design Pressure (psig)	Working Pressure (psig)	Purchased Equipment Cost
Storage Tanks:							
V-101	Vertical	20	13.75	HDLPE	0	0	$ 45,100
V-102	Vertical	34	10	304L SS	230	111	$ 80,000
V-103	Vertical	34	10	304L SS	100	50	$ 70,000
Ozone Contactor:							
R-102	Horizontal	35	11	304L SS	122	61	$ 500,000
Sand Filters:							
F-102	Horizontal	35	10	304L SS	70	56	$ 640,000
F-103	Horizontal	35	10	304L SS	70	56	$ 640,000
Total							**$ 1,975,100**
Ozone System (R-101)	1						**Purchased Equipment Cost**
Total	**1**						**$ 1,560,000**
RO System (F-104)	1						**Purchased Equipment Cost**
Total							**$ 1,860,800**
Pumps and Compressors	**# of Units**	**Max GPD**	**Max Pressure (psig)**	**MOC**	**Power (HP)**	**Max Temperature (F)**	**Purchased Equipment Cost**
P -101 A/B	1	130	150	PVC	0.75	125	$ 10,000
P- 103 A/B	1	50	150	PVC	0.5	125	$ 10,000
P -104 A/B	1	300	150	PVC	0.5	125	$ 10,000
P - 105 A/B	1	3200	150	Sc 40	20	400	$ 21,900
Total							**$ 51,900**
Total							**$ 5,447,800**

Table 5. Fixed Capital Cost



Project Identifier: City of Lawton Water Treatment	**Fraction of Delivered Equipment**
	Calculated Cost, $
Direct Costs	
Purchased Equipment	$ 5,447,800
Delivery, Percent of Purchased Equipment	$ 544,800
Subtotal: Delivered Equipment	$ 5,992,600
Purchased Equipment Installation	$ 1,408,300
Instrumentation and Controls (installed)	$ 1,078,700
Piping (Installed)	$ 2,037,500
Electrical Systems (Installed)	$ 329,600
Buildings (including Services)	$ 539,300
Yard Improvements	$ 299,600
Service Facilities (Installed)	$ 2,097,400
Total Direct Cost	$ 13,783,000
Indirect Costs	
Engineering and Supervision	$ 988,800
Construction Expeneses	$ 1,228,500
Legal Expenses	$ 119,900
Contractor's Fee	$ 659,200
Contingency	$ 1,318,400
Total Indirect Cost	$ 4,314,800
Total Fixed Capital Investment	**$ 18,097,800**

Operating Costs

Operating costs are shown in Table 6. The total annual operating cost is $1.6 MM. The operating costs include chemical costs, operator wages, and the utility summary. The City of Lawton sells water at a rate of $3.96 per 1,000 gallons. If all the water produced at the new plant is sold at this rate, the plant will generate $7.3 MM a year in water sale revenue. When operating costs are accounted for, the total profit from the water treatment plant will be $5.7 MM a year. The RO membranes are rated for a service life of 3 years until they will need to be replaced for approximately $500 per element, costing $500 M for total membrane replacement.

Table 6. Operating Cost

Chemical	**Tons/Year**	**Cost/Ton**	**Annual Cost**
Hydrochloric Acid	3,360	$ 43.55	$ 146,300
Sodium Hydroxide	10	$ 125.00	$ 1,200
Liquid Oxygen	57	$ 1,145.00	$ 65,400
Anti-Scalant	17.9	$ 10,000.00	$ 179,200
Total			**$ 392,100**
Operators	**# of Operators**	**$/year**	**Annual Cost**
	20	$ 45,000.00	**$ 900,000**
Power	**KW per Year**		**Annual Cost**
P -101 A/B	6,100		$ 500
P- 103 A/B	6,100		$ 500
P- 104 A/B	6,100		$ 500
P -105 A/B	408,200		$ 31,100
RO System	2,795,300		$ 223,900
Ozone System	150,672		$ 12,100
Total			**$ 268,600**
Total Operating Cost			**$ 1,560,700**

Conclusion

After careful analysis of different water treatment methods, RO was the most feasible water treatment technology to reduce all contaminants to EPA drinking water standards. To protect the RO system, pH adjustment, ozonation, and sand filtration are utilized as pre-treatment. If iron concentrations are confirmed to be below quantifiable limits, the ozonation pre-treatment can be removed to significantly decrease project costs. The ozone generator is rated for up to 75 lb/day, allowing room for production capacity to increase to 14 MGD or to account for higher levels of iron.

The total fixed capital cost for the plant is estimated to be $18.1 MM and the yearly operating cost is $1.6 MM. The treatment plant has a 5.4-year payback period with a 20-year net present worth of $20 MM at a 5 percent discount rate.

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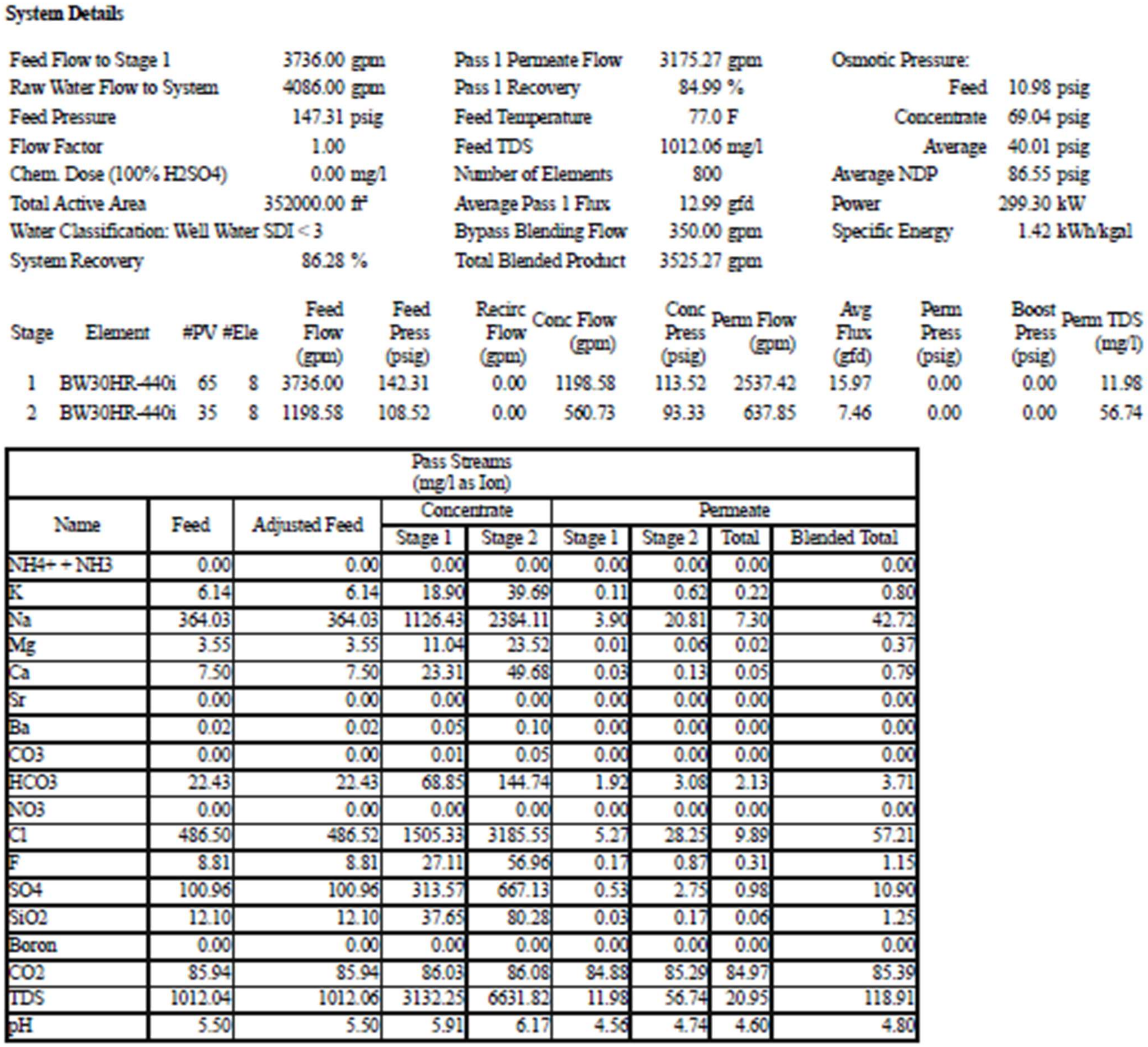
APPENDIX A. RO Simulation

Figure 1. Detailed ROSA Report



System Details

Feed Flow to Stage 1	3736.00 gpm	Pass 1 Permeate Flow	3175.27 gpm	Osmotic Pressure:	
Raw Water Flow to System	4086.00 gpm	Pass 1 Recovery	84.99 %	Feed	10.98 psig
Feed Pressure	147.31 psig	Feed Temperature	77.0 F	Concentrate	69.04 psig
Flow Factor	1.00	Feed TDS	1012.06 mg/l	Average	40.01 psig
Chem. Dose (100% H2SO4)	0.00 mg/l	Number of Elements	800	Average NDP	86.55 psig
Total Active Area	352000.00 ft²	Average Pass 1 Flux	12.99 gfd	Power	299.30 kW
Water Classification: Well Water SDI < 3		Bypass Blending Flow	350.00 gpm	Specific Energy	1.42 kWh/kgal
System Recovery	86.28 %	Total Blended Product	3525.27 gpm		

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30HR-440i	65	8	3736.00	142.31	0.00	1198.58	113.52	2537.42	15.97	0.00	0.00	11.98
2	BW30HR-440i	35	8	1198.58	108.52	0.00	560.73	93.33	637.85	7.46	0.00	0.00	56.74

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate		Permeate			
			Stage 1	Stage 2	Stage 1	Stage 2	Total	Blended Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	6.14	6.14	18.90	39.69	0.11	0.62	0.22	0.80
Na	364.03	364.03	1126.43	2384.11	3.90	20.81	7.30	42.72
Mg	3.55	3.55	11.04	23.52	0.01	0.06	0.02	0.37
Ca	7.50	7.50	23.31	49.68	0.03	0.13	0.05	0.79
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.02	0.02	0.05	0.10	0.00	0.00	0.00	0.00
CO3	0.00	0.00	0.01	0.05	0.00	0.00	0.00	0.00
HCO3	22.43	22.43	68.85	144.74	1.92	3.08	2.13	3.71
NO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	486.50	486.52	1505.33	3185.55	5.27	28.25	9.89	57.21
F	8.81	8.81	27.11	56.96	0.17	0.87	0.31	1.15
SO4	100.96	100.96	313.57	667.13	0.53	2.75	0.98	10.90
SiO2	12.10	12.10	37.65	80.28	0.03	0.17	0.06	1.25
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	85.94	85.94	86.03	86.08	84.88	85.29	84.97	85.39
TDS	1012.04	1012.06	3132.25	6631.82	11.98	56.74	20.95	118.91
pH	5.50	5.50	5.91	6.17	4.56	4.74	4.60	4.80

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	5.50	5.50	6.17
Langelier Saturation Index	-3.88	-3.88	-1.64
Stiff & Davis Stability Index	-3.48	-3.48	-1.93
Ionic Strength (Molal)	0.02	0.02	0.12
TDS (mg/l)	1012.04	1012.06	6631.82
HCO3	22.43	22.43	144.74
CO2	85.94	85.94	86.06
CO3	0.00	0.00	0.05
CaSO4 (% Saturation)	0.16	0.16	2.56
BaSO4 (% Saturation)	49.94	49.94	444.18
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	77.35	77.35	21426.53
SiO2 (% Saturation)	8.16	8.16	58.21
Mg(OH)2 (% Saturation)	0.00	0.00	0.00

To balance: 0.02 mg/l Cl added to feed.

Design Warnings

-None-

Solubility Warnings

BaSO4 (% Saturation) > 100%

CaF2 (% Saturation) > 100%

Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	5.89	7.07	57.48	1012.06	142.31
2	0.11	5.57	7.97	51.58	1127.05	136.13
3	0.11	5.27	9.06	46.02	1262.58	130.84
4	0.12	4.99	10.41	40.75	1424.80	126.37
5	0.13	4.73	12.13	35.75	1622.59	122.63
6	0.14	4.48	14.40	31.02	1868.55	119.54
7	0.16	4.21	17.53	26.54	2181.50	117.04
8	0.17	3.90	22.12	22.34	2589.25	115.05
Stage 2 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	3.45	27.01	34.25	3132.25	108.52
2	0.10	3.11	32.78	30.80	3480.10	105.54
3	0.10	2.77	40.37	27.69	3867.07	102.98
4	0.10	2.42	50.50	24.92	4291.72	100.77
5	0.09	2.09	64.16	22.50	4748.57	98.87
6	0.09	1.76	82.78	20.42	5227.32	97.21
7	0.08	1.46	108.30	18.65	5712.93	95.77
8	0.07	1.18	143.24	17.20	6187.12	94.48

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To replace my Honors Thesis requirement, I worked on an engineering group project for Garver, an engineering consulting firm. Garver requested that we design a water treatment facility for the city of Lawton, Oklahoma. Lawton is a city located in southwest Oklahoma that has previously struggled with drought conditions that have nearly depleted surface water resources. In response, Lawton intends to pump groundwater from the Arbuckle-Timbered Hills Aquifer to supplement the city's growing water needs. To accomplish this, our group designed a groundwater treatment facility capable of processing five million gallons per day of treated water with reverse osmosis as the main treatment technology.

My group elected me to hold the position of Team Coordinator. As Team Coordinator I took notes during all meetings, communicated information to our professor, and organized all of our research documents. Additionally, I recorded and organized notes from communications with vendors, Garver employees, and our professor. Since we were completely online this year due to COVID, I created a Microsoft Team that allowed us to easily access our documents and meet with our group, professor, and Garver employees safely.

Outside of my role as Team Coordinator, I completed research with my group over numerous treatment technologies and performed calculations for the individual steps within our process. Our final process utilized reverse osmosis technology. To prevent reverse osmosis membrane fouling, several pre-treatment steps including pH adjustment, ozonation, sand filtration, and pre-screening have been added to the process to extend the life of the membrane. The water produced by the new treatment plant will be pH neutral and will have lower contaminant levels than the water currently produced by the Southeast Water Treatment Plant located within Lawton, Oklahoma. This ensures that both the new treated groundwater and current surface water streams can be mixed into the Southeast Water Treatment Plant's distribution system without damaging the existing infrastructure. The waste from the new plant will be sent to the Lawton wastewater treatment facility for treatment. The total fixed capital cost for the plant was estimated to be $18.1 MM and the yearly operating cost is $1.6 MM.