5-2018

Direct Potable Reuse of Wastewater

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Direct Potable Reuse of Wastewater

WERC 2018

Task #6

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Aaron Henry : Personal Contributions and Reflection:

Over the course of the Spring 2018 semester I was a member of a 6-member team of senior honors Chemical Engineering students that competed in the WERC Environmental Design Competition in Las Cruces, New Mexico through New Mexico State University. Our team's task was to design a system for the "Direct Potable Reuse of Municipal Wastewater." In this task, we designed a municipal direct potable reuse drinking water plant for a town of 5000.

As a member of this team I was given many responsibilities to complete to ensure the timely and optimal completion of our project. Initially, I researched different methods to treat drinking water, and learned about all of the state and federal guidelines that drinking water plants must follow. After this initial research was conducted, I conferred with my colleagues to decide on a system we would use to treat wastewater.

After a design was decided on, I helped construct and piece together the bench scale system. I constructed the ultrafiltration unit and ran tests on the unit to ensure an optimal pressure drop across the membrane. I also calculated and mixed together a solution of salts and sugar aimed to mock the salt and organic carbon levels of the well water that would be tested at the competition.

After our bench scale design was constructed and the mock solution was treated using our system, I conducted tests on our water samples at the Arkansas Water Quality Lab. At the lab, I measured the pH, conductivity, and turbidity of water pulled after each stage of our system in order to test the efficacy of each stage, and to test if the treated water was within EPA guidelines for potable water. I wrote the Experimental Testing and Results section in our paper, outlining the methods used to measure the different parameters measured and analyzed our results.

Because our task was aimed at water scarce towns in the southwest, we contacted Silver City, New Mexico and designed our full-scale system based off of this town. In order to fully understand the thinking and challenges that a town in the southwest faces, I travled along with Boyce Bethel to Silver City to meet with town officials and the wastewater treatment plant officials to discuss our design and the feasibility of implementing it in the town. After meeting with town officials, Boyce and I also collected wastewater effluent from Silver Cities' wastewater treatment plant and transported it back to Fayetteville in order to prove our system could treat effluent from Silver City.

After our project was complete, I traveled along with my team to Las Cruces, New Mexico to present our project to a panel of judges in both a formal presentation and an informal poster presentation along with bench scale demonstration. As a result of our project and presentation scores, we were able to secure first place in our task.

Working with my team over the course of the past semester was immensely rewarding. I am proud to have been apart of such a hard working and successful team, and am thankful for the opportunity to represent the University of Arkansas at the WERC competition.

Appendix:

DIRECT POTABLE REUSE OF WASTEWATER

WERC 2018

Task #6

Poo Pig Sooie!

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Direct Potable Reuse of Wastewater

WERC 2018

Task #6

March 15, 2018

Poo Pig Sooie!

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1. EXECUTIVE SUMMARY

Water is essential to our societies and mankind. Currently, 844 million people across the globe lack access to potable water. By 2025, it is projected that half of the world population will be in a region of water stress.[5] The water crisis is often thought of as a problem limited to places that have always struggled to have clean water, but it is now affecting new areas such as the southwest United States. With increasing population demands and drought, the feasibility of direct potable reuse (DPR) of wastewater is being considered. According to an EPA report in 2017, there are only four operational or planned DPR facilities in the United States. Of these, the El Paso Advanced Water Purification Facility will be the only one to send treated water directly into the distribution system without blending or continuation onto conventional treatment.[1] As demand and water costs increase, we believe that the implementation of our DPR process for wastewater effluent is a viable option for many communities.

The primary contaminants in wastewater treatment plant (WWTP) effluent that must be targeted for potable reuse are organics, bacteria, pathogens, viruses, and suspended and dissolved solids. Our process consists of ozone treatment, granular activated carbon (GAC) treatment, a cartridge particulate filter, ultrafiltration, reverse osmosis, and ultraviolet disinfection. Ozone is used to kill microorganisms in the secondary WWTP effluent before it enters the rest of the system to prevent bio-fouling on the equipment. GAC is used to remove the majority of organic contaminants. A cartridge filter is between the GAC and ultrafiltration (UF) to prevent plugging of the UF membrane. Ultrafiltration is used as pretreatment for the reverse osmosis unit. UF was chosen for its ability to remove pathogens and viruses. Reverse osmosis will remove dissolved solids, a necessary step for the contaminated water to become potable. The final step is disinfection by ultraviolet treatment to ensure no live pathogens reach distribution.

Experiments were performed to determine if this combination of steps could effectively treat contaminated water. The necessary treatment must be able to reduce the total dissolved solids (TDS) level from 1,200 parts per million to less than 500 parts per million and reduce TOC from 10 parts per million to less than 0.1 parts per million. Fecal bacteria such as coliform must not be present for the water to be considered potable.[15]

A full size plant was designed based on the needs of a community of 5,000, using an average water demand of 100 gallons per person per day.[18] The Poo Pig Sooie team has found Silver City, New Mexico (population $\approx$ 10,000) to be an ideal city for implementation of the DPR process. This plant would be able to supplement 50% of the potable water (equivalent to a city with a population of 5,000) demands of the city for as little as $1.27 per 1,000 gallons.

2. OVERVIEW OF TASK

2.1 Purpose

The purpose of this task is to design a process that will effectively treat municipal wastewater treatment plant effluent streams for the purpose of direct potable reuse. The primary challenge faced by this idea is not a lack of technology, but rather the affordability of a solution and the social stigma surrounding "Toilet to Tap."

The following criteria were considered in completing this task:

- Following standards under the Clean Water Act and Safe Drinking Water Act to define potabilty
- Creating a reliable, affordable process that could be implemented as an advanced treatment for any municipal wastewater effluent
- Minimizing waste streams and ensuring safe disposal of these streams
- Maintaining safety of the process with respect to operation and public health
- Maintaining feasibility of process implementation and addressing the need for public acceptance
- Creating a business plan and cost analysis of the full-scale design
- Creating a bench-scale apparatus that can process five gallons of contaminated water to demonstrate the capability of the selected technology

2.2 Site Description

Silver City, New Mexico is an ideal location for implementation of the full scale process. Silver City has a population of approximately 10,000 people, and the Silver City Wastewater Treatment Plant treats an average of 1.3 million gallons per day. Currently, a portion of the treated effluent is sent to a golf course for irrigation purposes. The remainder is discharged to San Vincente dry creek, where it percolates into the soil and enters the groundwater. After construction of the DPR plant, a third of the wastewater treatment effluent would be sent to our designed tertiary treatment. Our process would be able to provide 500,000 gallons of potable water each day, supplementing approximately 50% of the city's water demand.

Two members of the team traveled to Silver City, New Mexico to discuss the project and design with the town manager, Alex Brown, and the utilities director Robert Esqueda. Beginning in the early 2000s, Silver City started a water conservation plan in which they increased water rates to discourage overuse of water. Increasing rates was extremely beneficial to decreasing usage. Silver City also conducted a study of their regional water to determine where the effluent from the wastewater treatment plant was going after it was discharged. The town proved that the effluent ends up in the aquifer that the town pulls its water from through the well fields. As a result, Silver City was granted recharge water rights. Investigating the endpoint of the WWTP effluent, Silver City saved and essentially gained $4.4 million of water rights. After Silver City's water conservation plan was implemented and consumer prices increased, the town is only using about 50% of their water rights. Therefore, investing in DPR is not currently necessary for Silver City. In the future, if Silver City's needs outgrow their water rights or if the quality of water from the wells decreases, it will be necessary to consider DPR as a solution.

While in Silver City, the team members also visited the wastewater treatment plant to talk to the employees and collect samples. Treating the Silver City wastewater effluent with the bench scale apparatus will prove that our designed system could be used to make the wastewater effluent potable.

3. TERTIARY WASTEWATER TREATMENT METHODS

In order to remove contaminants found in wastewater to create drinking water, the secondary treatment effluent must go through tertiary treatment. Tertiary treatment is the most advanced water treatment and will remove *Cryptosporidium*, *Giardia lamblia*, coliforms, dissolved solids, and other contaminants under the EPA National Drinking Water Regulations.[15] Tertiary treatment is any treatment beyond secondary treatment and can include a number of different phases including adsorption, filtration, reverse osmosis, and disinfection/advanced oxidation.

3.1 Adsorption

Adsorbents used in wastewater treatment are capable of removing dissolved organic material, heavy metals, biologics, and reducing turbidity. Typical adsorbents include clay, fly ash, sawdust, and activated carbon.[17] Granular activated carbon (GAC) is made from carbon rich raw organic materials like coconut shells and coal. GAC is also capable of adsorbing and removing chlorine specifically, which is beneficial when treating previously chlorine disinfected water. For this reason, a GAC system was implemented into our final design to both serve as a pretreatment for further filtration and to remove any chlorine added during secondary treatment that would foul an RO system.

3.2 Filtration

Filtration utilizes the spacing between particulate solids or the size of holes in membranes to reject material that is too large to pass. This process allows for the rejection of material regardless of type, and typically serves as a pretreatment for RO. Examples of different types of filtration include mixed media filtration, microfiltration, ultrafiltration, and biofiltration.

- Mixed Media Filtration: A three-layer filter made up of anthracite, sand, and garnet. The density of the particles increases down the filter, while the particle size decreases. This type of filtration is used in conventional filtration, however it is not capable of handling the high requirements of TOC reduction necessary in this case.[14]
- Microfiltration/Ultrafiltration: Membranes with pore sizes of 1 micrometer for microfiltration and 0.01 micrometer for ultrafiltration reject contaminants larger than the respective pore size. Therefore, microfiltration is able to remove all particles except for viruses and dissolved salts, while the only particle able to pass through ultrafiltration is dissolved salts. The high rejection of ultrafiltration makes the process ideal, and allows for a needed redundancy when treating wastewater for drinking water use when placed before an RO system.[23]
- Biofiltration: Biofiltration includes introducing a biofilm onto the surface of a filter in order to decrease water-borne diseases, turbidity, and TOC. However, these filters are subject to clogging and flow channeling due to the purposeful buildup on the membrane, making replacement costs add up and requiring a high amount of backwashing. For this reason, biofiltration was not included in the designed process.[3]

3.3 Reverse Osmosis

RO uses an applied pressure to force a concentrated solution through a semipermeable membrane that is selective against contaminants. Typical industrial RO systems are spiral wound and made with a polyamide thin film composite (TFC) sheet membrane. Feed water is separated as the permeate flows through the membrane, and the concentrated reject stream bypasses the membrane. RO systems require several pretreatment steps in order to decrease fouling but are exceptional at rejecting dissolved salts in the feed water. Typical salt rejection ranges from 95-99% of salts in the influent.[19] RO also serves as a needed redundancy for the rejected viruses, bacteria, and organics in the pretreatment steps and is the final step before disinfection.

3.4 Disinfection/Advanced Oxidation

The EPA requires a final disinfection step before effluent can be supplied as drinking water.[13] Disinfection protects public safety and ensures no potentially harmful microorganisms pass through the process. Similarly, advanced oxidation processes serve to both disinfect and oxidize the effluent water to decrease COD and BOD contributing compounds. Considered options included Chlorine, UV, hydrogen peroxide, and ozone treatment. Chlorine is destructive to membranes, and also produces carcinogenic disinfection byproducts that then have to be removed prior to distribution if the levels exceed regulations.[5] While ozone is capable of producing byproducts in the presence of Bromine, the GAC that follows would then remove these byproducts. UV is capable of disrupting the DNA of microorganisms based on the wavelength of light emitted in non-turbid water.[11] Hydrogen peroxide and ozone are both typical oxidizers, however ozone has a higher oxidizing potential.[9] Ozone can also be generated on site with an ozone generator, while hydrogen peroxide has to be shipped in. The addition of ozone also is effective regardless of turbidity, which can serve as pretreatment to filtration to reduce biofouling. Ozone was chosen as an optimal oxidation step, and UV was chosen for final disinfection.

4. DESIGN BASIS

4.1 Ozone Treatment

Ozone treatment was chosen as an initial disinfection step due to its effectiveness against pathogens and pharmaceutical residues. This primary disinfection step reduces the chances of biofouling on the following treatment train. Ozone was chosen over the common alternative of Chlorine disinfection because any byproducts are more easily removed in the following pretreatment steps. It has also been shown to be more effective than chlorine at killing bacteria and viruses.[4]

4.2 Carbon Treatment

Due to the high reduction of organic matter that is necessary, GAC adsorption was chosen for our process. Granular activated carbon adsorption is successfully used in many wastewater treatment processes and has been shown to greatly reduce organic compounds and heavy metals in water. Ozonated water increases the biological activity on a GAC and any ozone residuals left in the water will also be adsorbed. Enhanced biological activity removes more organic carbon than adsorption alone. The expected life of a GAC filter is increased when ozone is used as a pretreatment.[2] Water is sent through a cartridge filter before going to the ultrafiltration membrane to prevent clogging due to any particulates from the GAC.

4.3 Ultrafiltration

Ultrafiltration was chosen as the final pretreatment step for reverse osmosis. UF has been shown to be the most cost effective and efficient pretreatment.[11] The semipermeable membrane is able to reject colloids and macromolecules larger than 0.01 micron. This includes bacteria, pathogens, and viruses, so only dissolved solids will be able to pass through the UF membrane. This provides protection to the final water product and the reverse osmosis membrane.

4.4 Reverse Osmosis

Reverse osmosis is necessary to reduce the total dissolved solids concentration to potable levels and remove remaining organics. RO also serves as an added layer of protection against any viruses being sent to distribution. The nonporous membrane has the ability to remove particles larger than 0.1 nanometers at a 99% rejection rate. The life of the RO membrane increases when pretreatment steps are in place to remove any chlorine and other foulants.

4.5 Ultraviolet Disinfection

Ultraviolet treatment satisfies the EPA requirement for final disinfection before distribution.[13] UV will disrupt any microbiological activity in non-turbid water. The final product will then meet all EPA regulations to be sent directly into the water distribution system.

5. INDUSTRIAL PROCESS SCALE UP

The system is designed to produce 500,000 gallons of potable water per day. This meets the requirements of the WERC wastewater reuse prompt of supporting a town of 5,000 people with the full scale design. This is based on the average citizen in the southwest United States using 80-100 gallons of water per day. In order to achieve this flow rate, 590,000 gallons per day will be processed to yield a permeate stream at the desired flow rate of 500,000 gallons per day. The fraction of the feed that is processed into potable water is 86%.

5.1 Process Flow Diagram

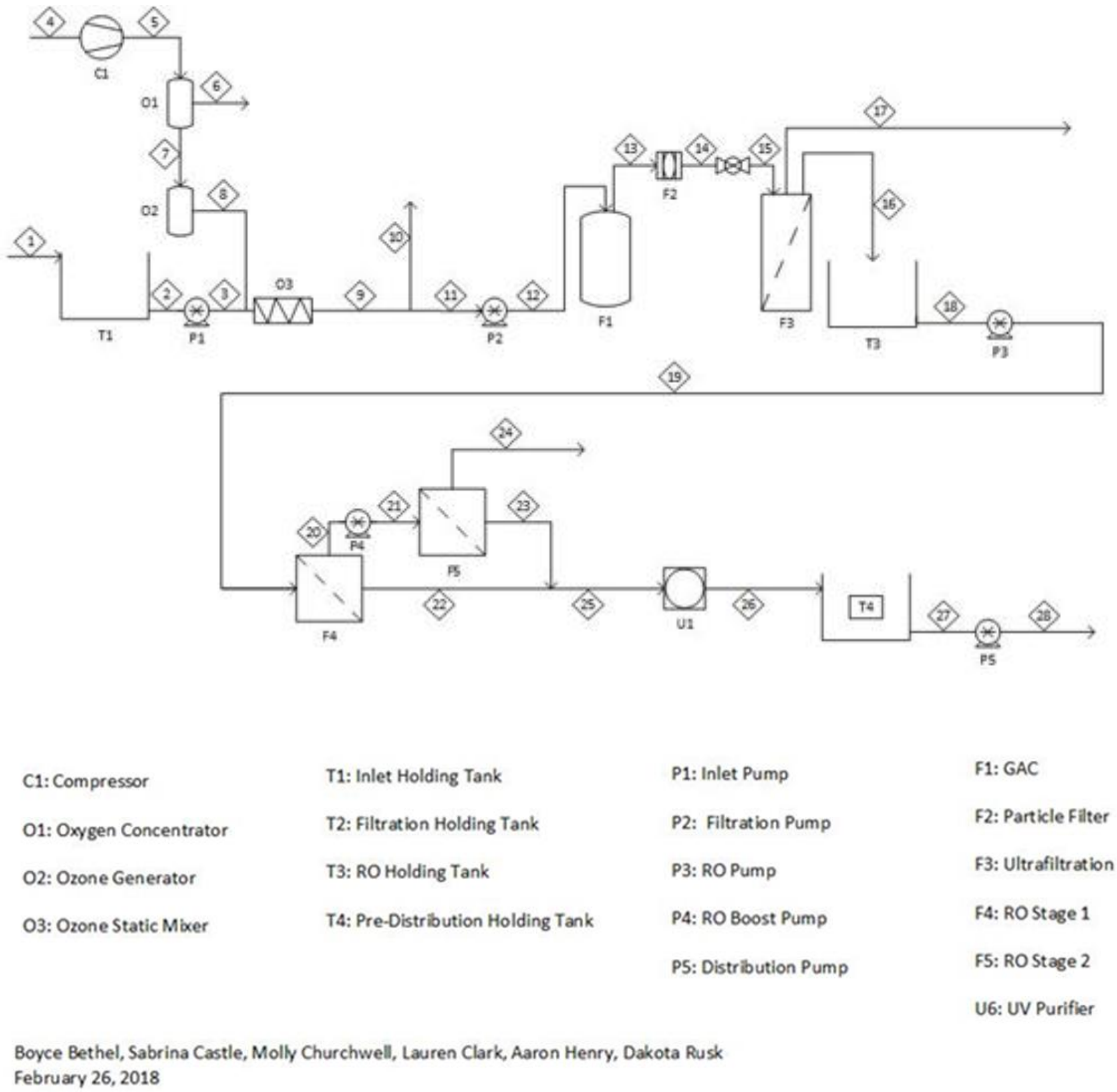

Figure 1: Full Scale Process Flow Diagram

5.2 Oxidation Scale-Up

The industrial ozonation unit is based on a system at Noland WWTP in Fayetteville, AR. The system draws in ambient air (stream 4) and concentrates the stream up to 93% oxygen that is then sent through an ozone generator. The generator produces 790 g/hr of ozone (stream 8) at a dosage of 10 ppm for an hourly flow rate of 20,834 gallons (stream 3). The process also adds oxygen to the water which, along with the ozone decomposition gases, would then be vented (stream 10) after proper residence time.

5.3 Activated Carbon Filtration Scale-Up

The granular activated carbon unit was scaled-up to compare to the recently installed GAC unit at the advanced water treatment facility in Rio Rancho, NM. This dual vessel unit contains 20,000 pounds of virgin GAC per unit with an effective size of 0.8-1.0 mm. For the set flow rate of 410 gallons per minute (stream 12), the empty bed contact time is approximately 20 minutes. Once the activated carbon has been exhausted, it can be returned to the manufacturer for reactivation at a fraction of the cost of new carbon. This allows municipal drinking water facilities to greatly reduce operating costs of the GAC.

5.4 Ultrafiltration Scale-Up

The industrial scale ultrafiltration unit was modeled using WAVE simulation software for membrane systems. The ultrafiltration system contains 12 Dow IntegraFlux SFD-2880XP ultrafiltration modules. The input into the system is to be 590,000 gallons per day (stream 15) with an output of approximately 575,000 gallons per day (stream 16). This system has an efficiency of 98%.

5.5 Reverse Osmosis Scale-Up

A single pass system with two stages was designed using WAVE simulation software. The first stage contains eight pressure vessels with six elements per vessel. The inlet pressure of the first stage is 90 psi and the concentrate stream going to the second stage has a pressure of 73 psi. The second stage contains four pressure vessels with six elements per vessel. A booster pump is utilized between the first and second stage to boost the inlet pressure to the second stage to 93 psi. The elements used for the simulation are XLE-440 elements from DOW, which are 40 inch by 8 inch cylindrical elements. The elements have an active surface area of 440 square feet. Using WAVE, this configuration has an expected recovery of 86%, giving a permeate flow rate of 350 gallons per minute (stream 25).

5.6 Ultraviolet Scale-Up

The last step of the treatment process is a class B ultraviolet purifier. A class B purifier has an intensity and saturation level of at least 16,000 uW-sec/cm^2. Although all pathogens have been removed, this ultraviolet step is in place to assure that no microorganisms pass to distribution. It also serves as necessary redundancy in a drinking water treatment process. This ultraviolet unit also fulfills the EPA regulation of having a final disinfectant stage.

5.7 Intended Water Reuse

The waste stream produced by ultrafiltration and reverse osmosis will be returned to the WWTP discharge station. After blending with the remaining effluent of the plant, the water will meet regulations of the treatment plant's EPA discharge permit.

5.8 Process Controls and Monitoring

In order to maintain quality control and effectiveness of the water purification system, samples will be taken regularly to insure that each part of the process is performing efficiently. Some parameters will be monitored every four hours, while other parameters, such as temperature and pressure, will be monitored continuously. Daily samples will be taken from the feed and product streams for analysis. Weekly samples will be taken from six sample points, including feed, after ozonation, after the particle filter, after ultrafiltration, after RO, and after UV. Taking routine samples at each of these locations will prevent large problems. If a sample is irregular, the filtration technique preceding the irregular sample will be examined to insure that it is functioning properly. Samples will be tested for all parameters for safe drinking water including total dissolved solids analysis, biological oxygen demand, coliform count, pH, conductivity, and turbidity.

6. ECONOMIC ANALYSIS

A capacity ratio was used to determine the capital cost of the ozonation unit by comparing to the capital cost of the equipment at the Noland WWTP in Fayetteville, AR. This method was also used to calculate the capital cost of the ultrafiltration, reverse osmosis, and UV systems. This calculation is based on the cost of the Torreele water plant in Koksijde, Belgium, which has an average RO recovery of 75%.[23] The Torreele plant produces 2,500,000 cubic meters of water per year—3.6 times greater than this design which produces 691,000 cubic meters per year. Using a capacity ratio and the six-tenths-factor rule, the equipment cost for these three stages was determined. The GAC unit recently installed in Rio Rancho, NM gave an appropriate purchase cost estimate due to similar product flow rates.

The fixed capital investment (FCI) was calculated using the cost of purchased equipment as a basis for other direct costs and indirect costs. Each capital cost category shown in Table 1 was provided by Plant Design and Economics for Chemical Engineers: 5th Edition for a fluid processing plant[20]. There is assumed to be space available for plant construction, so no new land purchase is necessary for the project.

Table 1: Fixed Capital Investment Costs

Fixed Capital Investment	
Direct Costs	
Purchased Eqpt	$ 3,087,826.00
Installation	$ 1,451,280.00
Instrumentation and Controls	$ 1,142,495.62
Piping	$ 2,099,721.68
Electrical	$ 339,660.86
Buildings	$ 555,808.68
Yard Improvements	$ 308,782.60
Service Facilities	$ 2,161,478.20
Indirect Costs	
Engineering and Supervision	$ 1,018,982.58
Construction	$ 1,266,008.66
Legal Expenses	$ 123,513.04
Contractor's Fee	$ 679,321.72
Contingency	$ 1,358,643.44
Total FCI	**$ 15,593,523.08**

The yearly operating cost includes power consumption and maintenance. Maintenance includes additional labor, anti-scaling chemicals, and lab testing.[23] All of these maintenance components are necessary in monitoring contaminant levels and preventing membrane scaling. These costs are found in Table 2 below and were obtained from the Torreele water treatment plant.

Table 2: Annual Operating Costs

Annual Operating Costs		
Power		
Pump	kWh/m^3	Cost/year
P1	0.07	$ 5,722.46
P2	0.12	$ 6,021.97
P3	0.57	$ 23,317.50
P4	0.07	$ 5,722.46
Other		
Maintenance		$ 191,362.00
Total		**$ 232,146.00**

The annual cost of the system was calculated using three methods over a thirty year payment period. The first cost comparison is calculated under the assumption that a Federal Grant will cover 100% of the fixed capital investment. The second comparison is calculated under the assumption that 50% of the FCI will be covered by a Federal Grant and 50% will be covered by a 0% interest federal subsidized loan. The third comparison assumes that 100% of the FCI is covered by a commercial loan with 6% interest. These three payment possibilities are compared in Table 3 below.

Table 3: Yearly Operating Cost Comparison

Annual Cost Comparison	
Yearly Operating Costs	
100% Grant	$232,146.00
50% Grant, 0% Federal Subsidized Loan (30 years)	$492,038.00
0% Grant, 6% Commercial Loan (30 years)	$1,364,998.48
Cost Per 1000 Gallons	
100% Grant	$1.27
50% Grant, 0% Federal Subsidized Loan (30 years)	$2.70
0% Grant, 6% Commercial Loan (30 years)	$7.48

Options for funding water treatment projects in New Mexico include the Clean Water State Revolving Fund (CWSRF) in partnership with the New Mexico Environment Department and the Water Project Fund.[8,24] Both funds include water recycle and reuse projects as an area of focus. The first purpose listed under the CWSRF Act is "to provide loans for the construction or rehabilitation of drinking water facilities." If the community meets the Federal Clean Water Act guidelines, it may qualify for 0% interest.[8] Silver City, NM will need to increase drinking water capacity production by 2021 if a high growth projection of 2.9% is assumed for the city.

7. BENCH SCALE DESIGN

The bench scale apparatus consists of three individual batch processes using six water treatment technologies. The technologies are as follows: ozone, granular activated carbon (GAC), cartridge filter, ultrafiltration (UF), reverse osmosis (RO), and ultraviolet light (UV). The first batch process is the ozone treatment. The second batch process includes GAC, the cartridge filter, and UF. The third batch process includes the RO and UV disinfection.

7.1 System Feed

Two feed sources were tested in the bench scale unit, the feed water specified by the competition as well as the effluent discharged from the Silver City, NM waste treatment plant. The water specified by the competition is water from Well 1 at the Bureau of Reclamation Brackish Groundwater Desalination Research Facility in Alamogordo, NM, that is treated with an unidentified organic matter. Therefore, different samples were prepared and obtained in order to test the bench scale process. A mock solution that mimics the well water was created and tested first to determine the process' ability to remove TOC, TDS, and coliform. The total dissolved solids concentration is approximately 1,200 ppm, made up primarily of sulfates as defined by the competition guidelines. To replicate the organic matter in the water, sucrose was added to the water to reach a total organic carbon concentration of 10 ppm. After the process was proven to reduce these components within the competition guidelines, samples of effluent water from Silver City, NM were transported to Fayetteville, AR and tested.

7.2 Process Flow Diagram

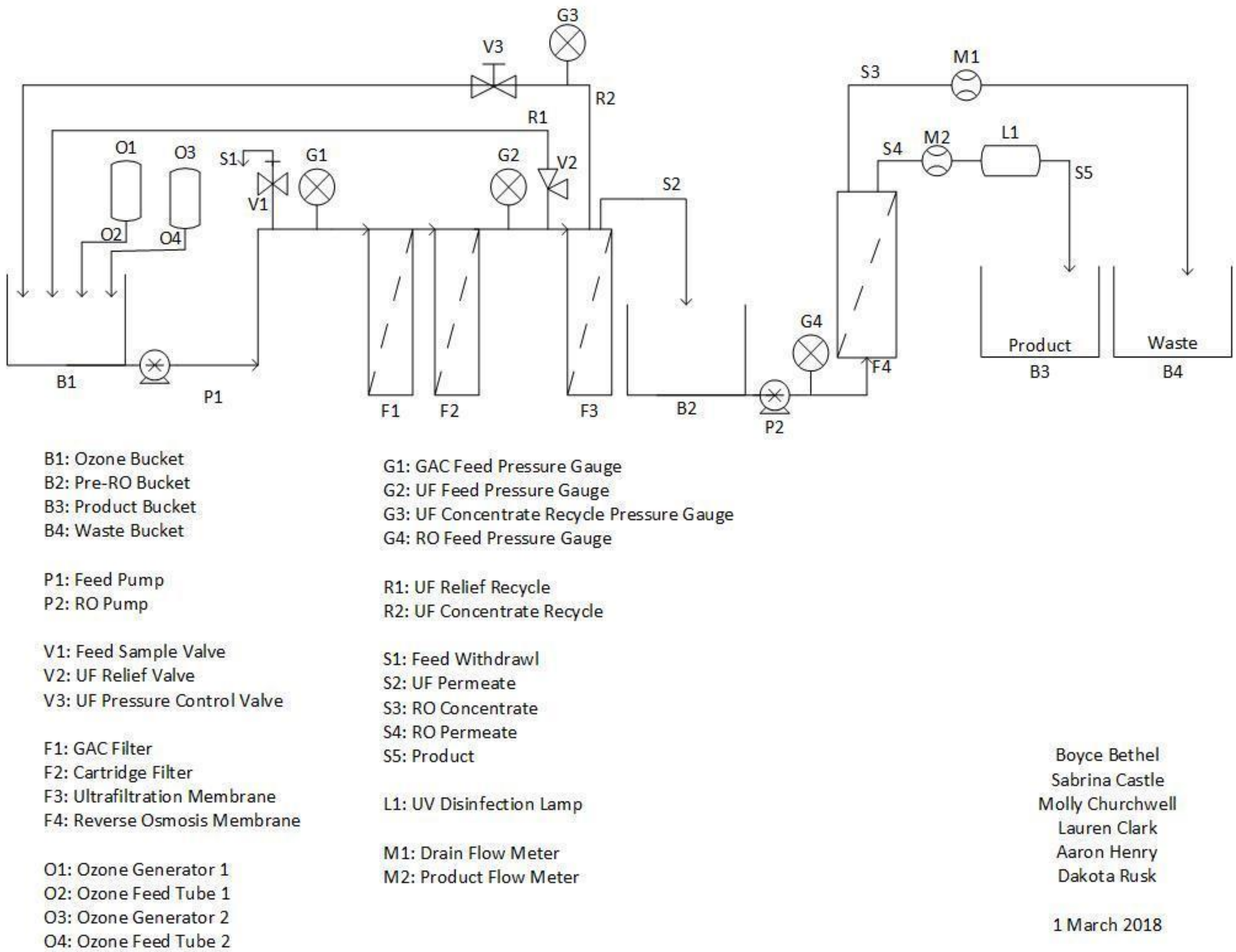

Figure 2: Bench Scale Process Flow Diagram

As seen in Figure 2, the five gallons of feed is initially treated with 10 ppm of ozone in the ozone bucket (B1). Once the ozonation is complete, the water is pumped from the ozonation bucket to the GAC (F1), and the solution goes directly from the GAC to the cartridge filter (F2) and UF (F3). The pressure control valve (V3) on the waste stream is adjusted to maintain the inlet and outlet pressures for the UF. The permeate from the UF (S2) flows into the pre-RO bucket (B2). The waste from the UF (R2) flows to the ozone bucket to reenter the process and mimic a batch ultrafiltration process. When insufficient feed water in the ozone bucket remains, the feed pump (P1) is shut down. The RO pump (P2) is turned on to pump the water from the pre-RO bucket into the RO (F4). The RO concentrate (S3) flows into the waste bucket (B4). The RO permeate flows (S4) through the UV lamp (L1) and into the product bucket (B3).

7.3 Experimental Apparatus

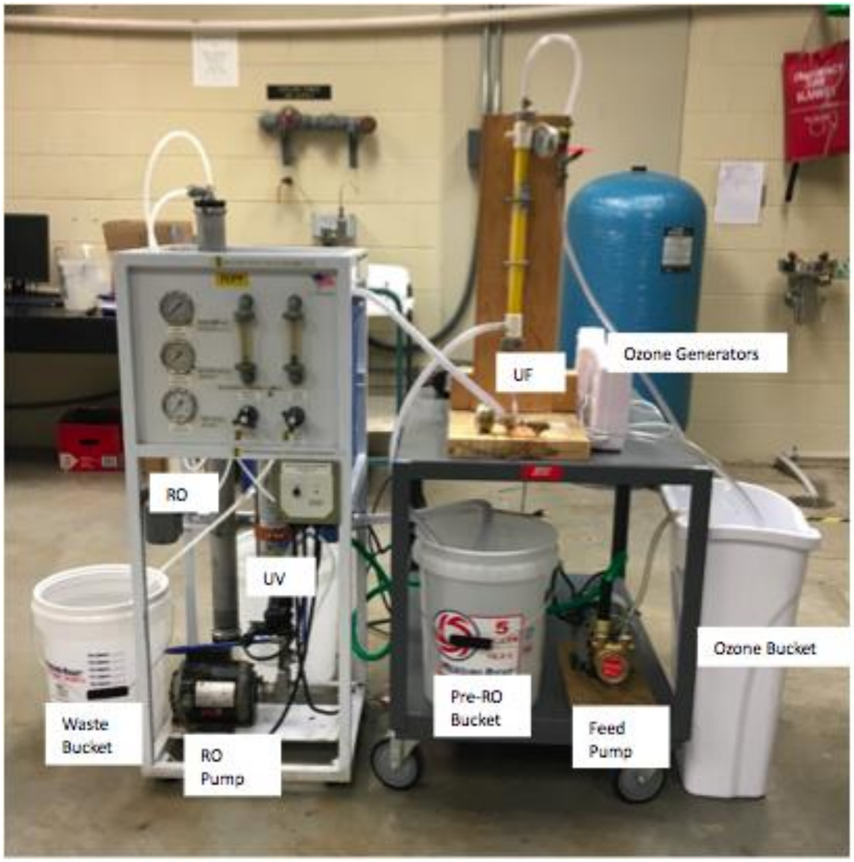

Figure 3: Front of Bench Scale Apparatus

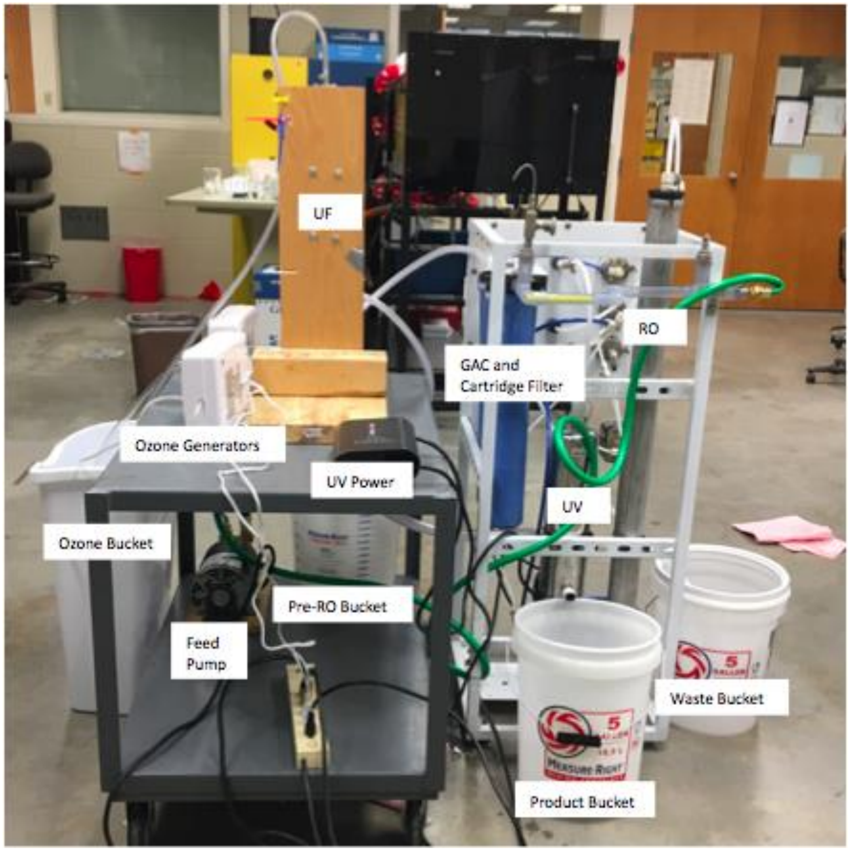

Figure 4: Back of Bench Scale Apparatus

7.4 Bench Scale Procedure

1. Fill the Ozone Bucket.
2. Turn on the Ozone Generator 1 and run for cycle 3 (10 minutes).
3. When the Ozone Generator 1 cycle is complete, turn on the Ozone Generator 2 and run for cycle 3 (10 minutes).
4. When the Ozone Generator 2 cycle is complete, turn on the Feed Pump to pump the water from the Ozone Bucket into the GAC, cartridge filter, and UF.
5. Monitor the inlet pressure for the UF to make sure it stays at 25 psig. Use the pressure control valve on the recycle stream to maintain inlet pressure.
6. Collect the UF permeate in the RO Feed Bucket.
7. Send the UF concentrate back into the ozone bucket to be pumped through the system again.

8. When the Ozone Bucket water level reaches the marked End Line, turn off the Feed Pump.
9. Turn on the RO Pump to pump the water through the RO membrane.
10. Collect the RO permeate after it flows through the UV Disinfection Lamp in the Product Bucket.
11. Collect the RO Concentrate in the Waste Bucket.

8. EXPERIMENTAL TESTING AND RESULTS

The treated water was tested for conductivity, turbidity, and total organic carbon (TOC) content levels. In addition to these criteria, total coliform and E. coli parameters were evaluated to assure our water meets the microbiological standards for drinking water. For experimental purposes, a mock solution was created based on the Well 1 composition data provided by BGNDRF. Effluent from the wastewater treatment plant in Silver City, NM was also treated using the bench scale process.

8.1 Sample Preparation and Analytical Methods

Each sample was collected at a volume of 500 milliliters. Samples were transported to the Arkansas Water Quality Lab where TOC, TDS, conductivity, pH, and total coliform tests were conducted. Table 3 summarizes the target parameters established by EPA regulation and the guidelines of Task 6. The only parameter level not mentioned in either the EPA standards or task description is the required conductivity levels. Since the conductivity and TDS concentration are closely related, the target conductivity reading was determined to be <1000 μS/cm.

Total Organic Carbon (TOC) was measured using the Water Quality Lab's SAN++ Automated Wet Chemist Analyzer from Skalar. This measures TOC by first acidifying the sample with sulfuric acid and sparging the sample with nitrogen. This liberates the sample of any inorganic or volatile organic carbon. The sample is then mixed with tetraborate reagent and passed through a UV coil. This oxidizes the organic carbon, generating carbon dioxide, which is then removed from the solution by acidification and sparging. The carbon dioxide emitted is measured by an infrared system.

TDS was measured by weighing an amount of the sample, passing the sample through a filter to remove any suspended solids, measuring the weight of the removed solids, then evaporating the remaining water and measuring the salts left behind in the solution on a scale.

Conductivity was measured using a conductivity probe. The probe was calibrated with 3 separate conductivity standards of 100, 1000, and 10,000 µS/cm. After the probe was calibrated, measurements of the samples conductivity were recorded and then measurements of the conductivity standards were taken again to ensure accurate readings. The pH of each sample was taken using a pH probe and standards following the same procedure as conductivity.

Total coliform and E. coli levels were tests using the Most Probable Number (MPN) test. In this method, 1 mL of the samples were added to a pre-prepared tray with wells that allowed for bacterial growth. Then diluted samples were added to another tray to allow for the use of MPN tables. Once the trays were filled with the samples, they were incubated for 24 hours, and the number of wells that were orange in color and the number of fluorescent cells present under blacklight were counted and referenced to the MPN tables to give an approximation of the coliform colonies and E. coli colonies in the sample.

8.2 Results

The final product requirements are: TDS below 500 ppm, TOC below 0.1 ppm, and pH between 6.5 and 8.5. The results of the bench scale experiments are shown in Table 4 and Table 5.

Table 4: Results from Mock Well Water

Sample	Conductivity (µS/cm)	TDS (mg/L)	pH	TOC (mg/L)
Feed 1 (B1)	2002	1197	7.26	10.96
Feed 2 (B1)	1994	1204.3	7.26	10.64
GAC/UF 1 (S2)	1392	805.8	8.18	0.75
GAC/UF 2 (S2)	1388	829	8.18	0.96
RO 1 (S5)	30.5	28.75	6.95	0.23
RO 2 (S5)	30.9	21	6.93	0.23

As seen in Table 4, the designed process is able to meet the target criteria of TDS and pH. The GAC and ultrafiltration units were able to reduce TOC concentration by 75-80% and conductivity by 15%. After reverse osmosis, TOC concentration was reduced to 0.23 ppm. Further experimentation will be conducted to reduce TOC levels even further. Conductivity and TDS were reduced by 95%, well under the EPA standard. The pH of the final effluent was approximately 7.

Table 5: Results from Silver City WWTP Effluent

Sample	Total Coliforms (MPN/100 mL)	E. coli (MPN/100 mL)	Conductivity (µS/cm)	pH	Turbidity (NTU's)	TDS (mg/L)	TOC (mg/L)
Feed (B1)	2419.6	461.1	773	7.96	5.96	452.3	3.83
After Ozone (B1)	1119.9	238.2	777	8.19	7.80	455.25	3.02
After UF (S2)	<1.0	<1.0	633	8.35	0.29	375.75	0.88
Product (S5)	<1.0	<1.0	23	7.88	0.16	30.50	0.25

As seen by Table 5, the bench scale system effectively removed coliform and E. coli. The conductivity, pH, and turbidity are within potable levels in the product.

9. FUTURE EXPERIMENTATION

In the weeks between the report being sent to auditors and the WERC competition, the Poo Pig Sooie team plans to continue running variations of solutions to ensure the validity of the chosen processes. Effluent from the wastewater treatment plant in Silver City, NM will be treated with the ozone process to determine the appropriate dosage and treatment times to reduce coliform colony count to zero.

10. REGULATIONS AND SAFETY CONSIDERATIONS

When determining what process would best accomplish the task of creating drinking water, a clear definition of what constitutes drinking water was necessary. The EPA sets a national limit on 90 different contaminants that could be in drinking water, and the Safe Drinking Water Act gives states the ability to create regulations no less stringent that the EPA's.[7] Therefore, the guidelines for drinking water as outlined by the national regulations were used as a basis to determine whether the effluent water could be qualified as drinking water. The EPA includes both primary and secondary regulations, referring to regulations that are enforceable and unenforceable respectively. Both were taken into consideration while analyzing water samples.

The contaminants that were focused on included TOC, TDS, and total coliform. Based on the EPA national regulations, the maximum limit for total coliform is 5.0% of samples coliform positive per month.[16] Total coliform positive indicates that there is total coliform in the sample, without discrimination between types (such as *E. coli*). To enforce the 5.0% rule on total coliform, sampling regulations are in place based on the number of people serviced. Therefore, on the bench scale process, the EPA public health goal of zero total coliform was used as a benchmark to prove that the water is drinking water. For TDS, there is a secondary regulation at a limit of 500 mg/L. However, the taste and palatability of water is rated as excellent at a level below 300 mg/L, so the goal was to remain at or below this level.[21]

TOC itself is not regulated by the EPA but can result in disinfection byproducts in the effluent if not removed.[6] Therefore, a recommended goal of 2 mg/L was used to ensure the effluent water was drinking quality, and then the given requirement of 0.1 ppm was also followed.

10.1 Ozone Safety

Due to the production of ozone on site and its usage in disinfection, ozone safety must be considered. Ozone as a gas ranges from colorless to blue and is characterized by having a strong pungent odor. The odor threshold is 0.02 to 0.05 ppm, however, longer exposure decreases sensitivity. Inhalation of ozone can lead to a headache, coughing, dry throat, heavy chest, and/or shortness of breath which can be combated by exposure to fresh air and oxygen therapy. The NIOSH ceiling exposure limit is 0.1 ppm for light exposure, and the Immediately Dangerous to Life and Health value is 5 ppm. In regards to long-term exposure, ozone is a radiomimetic agent. Similar to exposure to excess sunlight, this can cause aging and drying of the skin. Ozone does not show carcinogenic, teratogenic, or mutagenic characteristics. Ozone is highly reactive, and should not have contact with oxidizable substances including alkenes, benzene and other aromatic compounds, rubber, dicyanogen, bromine diethyl ether, dinitrogen tetroxide, nitrogen trichloride, hydrogen bromide, and tetrafluorohydrazine.[20] Ozone detection units should be in place at an industrial site to ensure worker safety.

11. PUBLIC INVOLVEMENT

Education and involvement of the public is a vital step towards the implementation of this process. There is currently a stigma associated with converting wastewater to drinking water. It is often viewed as "unsanitary" and "unhealthy," but the multi-barrier filtration and disinfection process removes contaminants to potable levels. The people affected by this water treatment need to be informed of the advantages of direct potable reuse. The main points of discussion would be how DPR is essential in preventing water scarcity in many areas where other options are not available. Many communities, including Silver City, NM, already practice de facto reuse when wastewater treatment plant effluent is returned to a surface or groundwater source and then sent to a drinking water plant. It will be important to illustrate that implementing this process will reduce the cost of their water bill, while delivering higher quality water to their homes. The public will also need to be involved during the implementation process to get input on how to best serve the community. One specific way to do this would be to allow members of the public to tour a pilot facility to build their confidence. This is a solution geared toward areas that are struggling to provide water, so the need may outweigh the stigma and the public would be more accepting. However, the same process can be used indirectly, as is done in many areas where the public was unwilling to drink DPR water, by injecting the effluent into a reservoir or the groundwater prior to distribution.

12. CONCLUSIONS

Implementation of this process will effectively treat wastewater treatment plant effluent to drinking water standards. For communities who struggle during seasons of drought, potable reuse is the most viable option. Our process is cost effective and less expensive than what water currently costs in some places throughout the southwest. The public must be educated and involved throughout the process in order to successfully start up a plant. Should the public not support direct potable reuse, it is important to note that indirect potable reuse is also an option. Although additional treatment would not be necessary, a project without public support will not be successful and the community will be no better off in times of a water crisis.

13. ACKNOWLEDGEMENTS

Thank you Dr. Robert Cross and Dr. Robert E. Babcock; Brina Smith and the Water Quality Lab; Thom Vinson and the Noland Wastewater Treatment Plant team; Larry Lloyd and the Beaver Water District; Emmanuel Van Houtte and the Torreele water treatment facility; Alex Brown and Robert Esqueda from Silver City; Chris Marrufo and the Silver City Wastewater Treatment Plant.

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Beaver **Water** District

March 9, 2018

WERC 2018
Task #6 Team
Ralph E. Martin Department of Chemical Engineering
University of Arkansas
Fayetteville, AR 72701

Re: Review and audit of Task #6 Team proposal

To whom it may concern:

Within the past few months, I was able to provide a tour of Beaver Water District's (BWD) conventional water treatment plant for two teams from the UA Chemical Engineering Department. One of those two groups was Task #6 Team whose project was the evaluation of direct potable reuse (DPR) of wastewater. The team leader recently contacted me to ask for a review of their final proposal. The concept of DPR has been around for some time but has recently moved to the forefront of discussion of water supply options, especially in arid climates where traditional sources are becoming scarcer. A few DPR examples exist in the western US, while several more indirect potable reuse projects have been developed. The Team's overall approach and process scheme are well thought out and reasonable. In reviewing the proposal, I have developed the following comments:

- The use of ozone as a disinfectant is an excellent choice given its strong oxidation potential. Ozone is not without special design considerations. Ozone off-gassing will likely occur given that it is not practical to feed the exact amount of ozone to meet the demand. Since ozone has health risks associated with exposure to humans, many ozone systems will be equipped with an ozone destruct unit to remove any excess ozone. Ozone does have a disinfectant by-product that must be considered when using ozone. Specifically, if bromine is present in the water supply source, then brominated compounds can be created which are regulated by the Safe Drinking Water Act (SDWA).

- After final treatment, the potable water must be chlorinated before being pumped into the water supply distribution system. While all of the bacteria, viruses and pathogens may have been removed in the treatment process, the distribution system piping may contain a biofilm within the pipes that can impart contaminants into the water. Additionally, piping leaks (including breaks) have the potential to introduce contaminants into the water. Therefore, current regulations require the presence of a disinfectant with a long-lasting residual, normally chlorine. While there are disinfectant by-products concerns with chlorine, they can be addressed and managed, particularly in this situation where so much of the organics have been removed.

- Sampling requirement for potable water are set out in the SDWA regulations and must be followed. These typically include 4-hour samples throughout the day for multiple parameters, as well as continuous monitoring for other parameters.

- The lead and copper regulations will require that potable water delivered through a distribution system be treated so as not to be corrosive. This may be accomplished by careful pH adjustment and monitoring to make sure that the water is non-corrosive, or by the addition of corrosion control chemical agents. The recent crisis in Flint, MI, has brought this issue to the public's attention in a very significant way.

- The SDWA regulations also have requirements for total organic carbon reduction with respect to the DBP rule. The TOC reduction requirements are based on a matrix that considers the raw water TOC and alkalinity to determine the percentage reduction requirements for TOC.

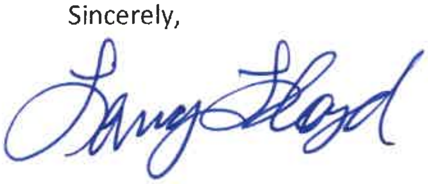
- The proposal indicated that waste streams from the process, particularly from the membrane reject, could be piped to the wastewater treatment plant and "blended with the remaining effluent" for discharge to the receiving stream. The Clean Water Act and associated regulations require that all waste streams meet minimum levels of treatment. Blending without treatment is generally not permitted. These waste streams, since they will include membrane reject, will be high strength waste, and will have to be treated. The cost to do so could be significant.

- The GAC replacement schedule will be highly dependent on the source water supply characteristics. Length of service for GAC can range from a few months to several years. The feeding of ozone may help extend the GAC life. When the carbon is spent, the carbon vendor will remove the spent carbon and replace it with regenerated carbon ("used" as opposed to "virgin" carbon). He will then take the spent carbon back to his facility for regeneration for the next customer.

- The cost of $1.24 per thousand gallons is not a realistic number. Our conventional water treatment facility at BWD wholesales water at $1.34 per thousand gallons with a much simpler treatment scheme. There are very few federal grants for water systems in our current political climate. Low interest loans are available (at or below Treasury rates). Assuming that all of the capital cost and O&M cost estimates are reasonably accurate, funding of the $15M project will result in a cost per thousand gallons much higher than the $1.24 best case scenario.

Once again, I thought that the team developed a well thought out process scheme for DPR. No doubt soon we will see more and more such systems installed to meet our water demands, not only in the US, but throughout the world. It has been a pleasure interacting with this team.

Sincerely,



Larry Lloyd, PE, BCEE
Chief Operating Officer

March 12, 2018

Poo Pig Sooie Gang,

First off I would like to congratulate you on an epic presentation! You should be proud of this accomplishment. The thoughtfulness of the design was quite impressive. I was also impressed with the various disinfection methods being utilized in tandem with one another. The analysis was very impressive, lucid and concise. The statistical analogy was spot on and left no doubt to it's integrity!

Your six-step disinfection system was very well thought out and should be emphasized in any public forum in regards to any implementation of this system. Be prepared to elaborate on all data! With the depletion of ground water in the Southwestern U.S., this seems to be the way of the future.

<u>Questions</u>

1. What are the long-term effects of daily exposure to ozone?
2. How often will the membrane filtration media need to be replaced?
3. Does the new facility need to be a part of the WWTP?
4. What qualifications would one need to operate this facility (type of training)?

<u>Cost Reality</u>

New Mexico is one of the poorest states in the union. Could Silver City afford such a facility? Can the fixed capital investment costs truly be applied to our community? What about cost over runs? Without federal and state supplements and grants there is simply no was a community of our size could handle the cost! Fifteen point five million is a hefty price, which is nearly twice as much as our operating budget! Will the additional potable water source be able to pay for the projected operation costs? How many new employees will the city have to hire to operate the new facility? Will this effect the city's ability to provide services? Will other departments suffer from the addition of the facility?

These are simply questions the public might want to know! The biggest hurdle will be from *toilet to tap*! That's a very hard concept to accept. Therefore, a significant public information campaign would need to be undertaken to persuade a reluctant public.

Once again thank you and good luck, it makes me feel confident that our country is in such great hands, fantastic job!

Chris Marrufo
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To Team 'Poo Pig Sooie !'

Alliance of Boyce Bethel, Sabrina Castle, Molly Churchwell, Lauren Clark, Aaron Henry and Dakota Rusk

Ralph E. Martin Department of Chemical Engineering

University of Arkansas

Fayetteville, AR

I have received your report 'Direct potable reuse of wastewater' and was requested to review it. I have a fairly long history with water reuse. I performed tests on effluent starting 1997 and those resulted in the Torreele facility at Koksijde (Flanders, Belgium) that is one of the first Indirect Potable Reuse (IPR) projects worldwide. In all those years I have been involved many times in discussions or panels about potable water reuse. I am very pleased that the authors of this report consider water reuse as a viable option for potable water production. Climate change and the drought involved will prove this more and more in the forthcoming years.

The authors have chosen a multiple barrier approach for their project. This is the only right choice when water reuse is involved. Off course one could argue what would be the best order of treatment. The option chosen here is different from what we consider for future direct reuse (GAC would be added after RO at the Torreele facility) or what is done in Orange County (Groundwater Replenishment Project). But it does not mean that it is not a good choice. In Windhoek, where they perform reuse since 50 years, RO is not even part of the process.

As mentioned ozone will disinfect the water. However byproducts could be produced (p 9). In the presence of bromine, bromate could be formed as well as nitrosamines (e.g. NDMA) under certain conditions. But with carbon filtration (GAC) following ozone these byproducts should be absorbed so this is a good option and combination.

After ozone /GAC a cartridge filter was proposed prior to UF. Personally I would place the cartridge filter after the UF treatment. The choice was made to avoid plugging of the UF filter but as GAC filter media have a certain size I assume this risk is minor. To my opinion carbon grains would not plug the pores as these are much smaller compared to the size of the carbon. On the contrary RO membranes are very vulnerable to all kinds of contamination and as UF filtrate does not go directly to RO – reservoir, dosing pumps, HP pumps, … are in between – any failure (e.g. corrosion on pumps, …) could cause damage to the RO membranes and they are the most important part of the process.

Attention was also paid for public involvement. This is very important. The best is to involve the public from the start. They could be invited to the test facilities as we have done in the late 1990's. To my opinion, if you want to go forward with this project, tests should be performed on a larger scale. Your experiments have shown good results but they do not guarantee a 'full-scale' success. My concern is biofouling. You mentioned that the ozone should prevent biofouling on the RO membranes but as GAC is added after ozone as one of the first steps in the treatment, when nutrients are still abundant, regrowth could be a fact causing biofouling. RO membranes treating the cleanest waters tend to suffer from biofouling after a while.

In this report control systems are not mentioned too much. Off course if direct reuse is considered it is very important to detect any failure within the shortest delay. So attention should be given to it.

Concentrate will also be an issue. I have performed tests with willows to treat RO concentrate and they resulted in good developed plants and substantial nutrient removal. As the site would be considered in an arid region a similar practice could create a 'green buffer' around the site.

To conclude, this report gives an interesting treatment scheme for direct reuse, different from what is commonly done. It is well written and documented and the financial outcome should be beneficial as the alternatives lack or would be costly. Experiments were performed to show the outcome. I would advise however tests on a bigger scale to benchmark the scheme and the biofouling issue. It could eventually result in changing the order of treatment if this would prove to be better. Attention should be paid in monitoring the performance to avoid incidents. I wish all of you success in the future.

Kind regards

Emmanuel Van Houtte

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Working at IWVA, Doornpannestraat 1, 8670 KOKSIJDE (BELGIUM)

March 13, 2018

UTILITIES DEPARTMENT
TOWN OF SILVER CITY
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To Whom It May Concern:

The Town of Silver City was chosen as a sample site for a potential Direct Potable Reuse system to supplement its water supply by the Poo Pig Sooie! Team from the University of Arkansas and was asked to provide a review of their paper titled *Direct Potable Reuse of Wastewater.*

After having reviewed the paper, it is without question that the engineering and technology exist to accomplish the task of converting effluent waters from a wastewater treatment plant into potable water, however, two key obstacles must be overcome to implement such a project. One obstacle in implementing idea lies in the funding to do so. Based on the estimated costs identified in the report, it would be difficult for a smaller community to fund such a project. For most entities looking to construct such a facility they would most likely have to seek multiple funding sources to cover engineering and construction costs. Although it was mentioned that grants could possibly be obtained for the construction, it has become more difficult for communities and cities to obtain 100 % grants as competition for the available grants has increased and the availability of 100% grants have decreased with many funding agencies now moving to grant/loan combinations or 100% loan funding. In addition, many funding agencies have funding limits and may not have the capacity to provide the full amount needed for the implementation of such a project. Multiple funding sources may have to be pooled together to have sufficient funding to do so.

Another obstacle, and probably the most important, is the willingness of the people of the community or city to accept the use of wastewater effluent as a source of potable water. Although it can be accomplished though engineering and technology, considerable effort must be made to educate the public, demonstrate the need, and gain support for such a project before it is implemented. It is possible that if negative public perception of the project prevails, consumers will refuse to consume the water. This will then affect revenues and the ability to repay debt incurred for the construction of the project. A city or community may have to exhaust all other options to increase their water supply before a Direct Potable Reuse system will be accepted by the public.

If the two obstacles discussed above can be overcome, Direct Potable Reuse is a viable option to communities or cities who must find alternative sources of water to meet existing and future demands. As sources of water diminish it is believed that more communities will embrace the option of Direct Potable Reuse.

Robert M. Esqueda
Utilities Director
Town of Silver City