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WWE: Final Report

Wyoming Wastewater Engineers

University of Wyoming

1000 E University Ave, Laramie, WY 82070

WEFTEC Student Design Committee

C/O: Jojo La

Leonard Rice Engineers

1221 Auraria Parkway

Denver, CO 80204

December 14, 2015

Dear Ms. La,

Following this letter is the requested Final Report for the WEFTEC Student Design Competition. The main components of this report include a description of the problem as understood by the Wyoming Wastewater Engineers (WWE) and an explanation of our solution. This report includes a six-step decision methodology and the decision criteria. A project scope and alternatives for both advanced water treatment and disinfection are included in this document as well.

We thank you for your assistance throughout this project and for the opportunity to participate in this competition.

Regards,

Wyoming Wastewater Engineers

WYOMING WASTEWATER ENGINEERS: FINAL SUBMISSION

WEFTEC Student Design Competition, Rocky Mountain Region

Erica Gilrein, Joseph Meier, Antolin Barraza, Sierra Johnson, Shelby Kindsvater, Megan Varner

Executive Summary

Wastewater treatment facilities are essential in current society. Different system designs have been employed to increase efficiency while maintaining low capital and operating costs. In the past decades, plate settlers and media filters following coagulation and flocculation were the main systems implemented for advanced wastewater treatment following secondary biological treatment. This type of treatment has been added primarily for additional phosphorus and particle removal. However, the advancement of dissolved-air flotation, integrated-system filtration, and membrane technology has influenced advanced wastewater treatment designs and is becoming more appealing as energy and chemical use and costs become critical design criteria. Thus, innovative and cost-effective wastewater treatment facility designs must be examined on a case-by-case basis.

Parker Water and Sanitation District (PWSD) provides drinking water and wastewater treatment to over 50,000 people in and surrounding Parker, CO. On average, they treat 2.6 million gallons of wastewater per day (mgd). PWSD has a current treatment capacity of 4.0 mgd split equally between two treatment plants. The influent is expected to exceed the current total capacity by 2021; therefore, expansion is needed to reach a projected 6.0 mgd total capacity.

PWSD has discharge permit requirements which include a maximum phosphorous concentration of 0.05 mg/L, a maximum 30-day average total suspended solids (TSS) concentration of 30 mg/L, and a maximum ammonia concentration of 2.7 to 5.1 mg/L depending on the month of year. The wastewater currently requires tertiary treatment to meet the phosphorus standard. In addition, the disinfection system will require expansion, providing an opportunity to change the method of disinfection to a better alternative if desired.

Wyoming Wastewater Engineers has been awarded the task to assess AWT and disinfection options, make a recommendation for expansion of these facilities, and develop a conceptual design. Six different AWT alternatives and five different disinfection alternatives were researched and developed in order to choose the best alternative for each. The AWT alternatives include a Coagulation/Flocculation/Upflow/Media filter system, a Coagulation/Flocculation/DAF/Media filter system, an Actiflo/Media filter system, Blue PRO, an Actiflo/Membrane filter system, and a Coagulation/Membrane filter system, while the disinfection alternatives include chlorine dioxide, sodium hypochlorite delivery or onsite generation, ultraviolet (UV), and ozone. A six-step decision-making process was employed to determine the most sustainable and cost-effective design based on several environmental, societal, and economic criteria. Once the designs were analyzed for the chosen criteria, a net present value for each system was calculated based on a 25-year design life.

Based on a study of costs and benefits, it was decided to recommend a Blue PRO advanced water treatment system with UV disinfection. The Blue PRO design by Blue Water Technology utilizes 18 Blue PRO modules to filter and adsorb phosphorus and particles. The UV system utilizes 160 UV lamps by Trojan UV. The UV lamps will be designed as two 3 mgd channels each containing 10 units, with each unit consisting of 8 lamps for a total of 160 lamps; 80 in each channel. These systems will treat 6 mgd of wastewater from Parker, Colorado.

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Background

Parker Water and Sanitation District (PWSD) provides drinking water and wastewater treatment to over 50,000 people in and surrounding Parker, CO. On average, they treat 2.6 million gallons of wastewater per day (mgd).[1] PWSD currently has two facilities in use, the North Water Reclamation Facility (NWRF) and the South Water Reclamation Facility (SWRF). Each facility is able to process 2.0 mgd.[2] The total PWSD wastewater flow is expected to exceed the current total capacity of 4.0 mgd by 2021; therefore, expansion is needed to reach a projected 6.0 mgd capacity. AWT and disinfection expansion will take place at the NWRF since the SWRF is older and less reliable.

PWSD has discharge permit requirements which include a maximum phosphorous concentration of 0.05 mg/L, a maximum 30-day average total suspended solids (TSS) concentration of 30 mg/L, and a maximum ammonia concentration of 2.7 to 5.1 mg/L depending on the month of year.[3] The permit also requires an *E. coli* concentration of less than 128 colonies per 100 mL.[4]

A Biological Nutrient Removal (BNR) process currently removes organics, nitrogen, and phosphorus through an anaerobic/anoxic/aerobic configuration. While this treatment meets and exceeds the TSS removal requirements by about 28.5 mg/L and the monthly ammonia nitrogen levels by 3.9 mg/L, the phosphorus content is about 1.0 mg/L.[5] This phosphorus concentration from the biological processes is not sufficient to meet permit requirements of 0.05 milligrams per liter. An advanced water treatment (AWT) system removes additional phosphorus to about 0.03 mg/L.

The AWT system begins by dosing the secondary effluent with sulfuric acid to drop the pH to 6.0-6.5, the optimal range for alum coagulation. Then 60 mg/L of alum and 0.4 mg/L of a 0.8% solution polymer coagulant are added with an in-line static mixer. The alum reacts with the insoluble phosphorous in the water to make aluminum phosphate; the polymer allows for interparticle bridging between the small aluminum phosphate particles. The water enters a mechanical flocculation basin with a retention time of five minutes. The floc is removed in an upflow clarifier with MRI plate settlers. The remaining solids are removed by a Tonka multimedia filter with anthracite coal, sand, and gravel. The filter run time between backwashes is about 25 hours in the summer and 10-12 hours in the winter.

The system operates in three parallel treatment trains. It was designed with redundancy, so that one of the three systems can be off at all times. Although the system is rated for 700 gallons per minute (gpm), it runs below this capacity because of a lack of freeboard in the system. If the system were to run at full capacity, water would splash out of the flocculation basins. There are also significant problems with the bearings in the flocculation paddles; they often need to be repaired. Plant engineers and operators

[1] Parker Water and Sanitation District. *Request for Proposal: North Water Reclamation Facility Infrastructure Improvement Plan*. (N.p.: Parker Water and Sanitation District, 2015).
[2] Ibid.
[3] Parker Water and Sanitation District. *Water and Wastewater Master Plan*. (N.p.: Parker Water and Sanitation District, 2014).
[4] Ibid.
[5] Ibid.

expressed concern that the baffle walls between system components are shearing the floc, and floc formation is generally a problem in the winter.[6]

The filtered water is disinfected with 5 mg/L of sodium hypochlorite (bleach). Sodium hydroxide is dosed with the bleach to increase the pH to 7.0-7.5 to meet permit requirements. After contact time with the chlorine, sodium bisulfate is added for dechlorination to meet the effluent requirement of 0.5 mg/L chlorine. The effluent is discharged into the Cherry Creek Basin.[7]

The NWRF was built in 2004 and has a large portion of its infrastructure designated for the AWT process. It was designed to allow future expansions. The SWRF was originally built in 1988 and has had extensive construction needs over the past 27 years. By Colorado law, when the influent to the facility reaches 80% of treatment capacity, the wastewater treatment entity must initiate planning and engineering for facility expansion.[8] Currently the SWRF is at 74% of its hydraulic capacity and the NWRF is at 64%.[9]

PWSD is now considering two expansion alternatives: move all treatment operations to the NWRF and decommission the SWRF entirely, or keep the SWRF on line to provide a maximum of 2.0 mgd of secondary treatment and expand the NWRF to 4.0 mgd.[10] Regardless of the expansion alternative, all AWT will take place at the NWRF, so it must be expanded to handle 6.0 mgd. PWSD wants to consider new AWT processes and means of disinfection. Other consultants will be developing primary and secondary treatment expansions.

Problem Statement

Parker Water and Sanitation District will expand its AWT and disinfection capacity from 2 mgd to 6 mgd at the North Water Reclamation Facility. The Wyoming Wastewater Engineers team was hired to complete an alternatives analysis to determine the best AWT and disinfection options for the NWRF and to complete a conceptual design for the selected alternatives.

Decision Methodology

A six-step decision making process was used to select the best AWT and disinfection alternatives. Figure 1 shows a visualization of the process. The six-step process was selected because it is a rational method of decision making, and the steps coincide with the project expectations. The first step is problem definition, which was summarized in the Background and Problem Statement sections. The second step is to develop goals and criteria. Initial criteria were selected based on client expectations, and were refined throughout the project. These criteria relate to the triple bottom line theory correlating societal and environmental impacts with the economic bottom line of PWSD. The third step is to develop alternatives. Alternatives were selected based on combinations of available processes. The fourth step is

[6] Information gained from facility tour
[7] Ibid.
[8] Parker Water and Sanitation District. *Water and Wastewater Master Plan*. (N.p.: Parker Water and Sanitation District, 2014).
[9] Parker Water and Sanitation District. *Request for Proposal: North Water Reclamation Facility Infrastructure Improvement Plan*. (N.p.: Parker Water and Sanitation District, 2015).
[10] Parker Water and Sanitation District. *Water and Wastewater Master Plan*. (N.p.: Parker Water and Sanitation District, 2014).

to collect information, which was completed by team member research. The fifth step is to analyze alternatives with a decision model. Utility functions were established to create normalized benefit scores. Benefit scores were used to compare each alternative and select the best option. Cost-benefit analysis was selected because it allows the team to make a decision that is not based entirely on cost or benefit, and allows for a clear visual comparison of alternatives. Each criterion was weighted equally for initial analysis. A sensitivity analysis was completed by significantly altering the weights of each criterion. The sixth step in the process is to develop the selected alternative. This step was completed during the conceptual design stage of the project.

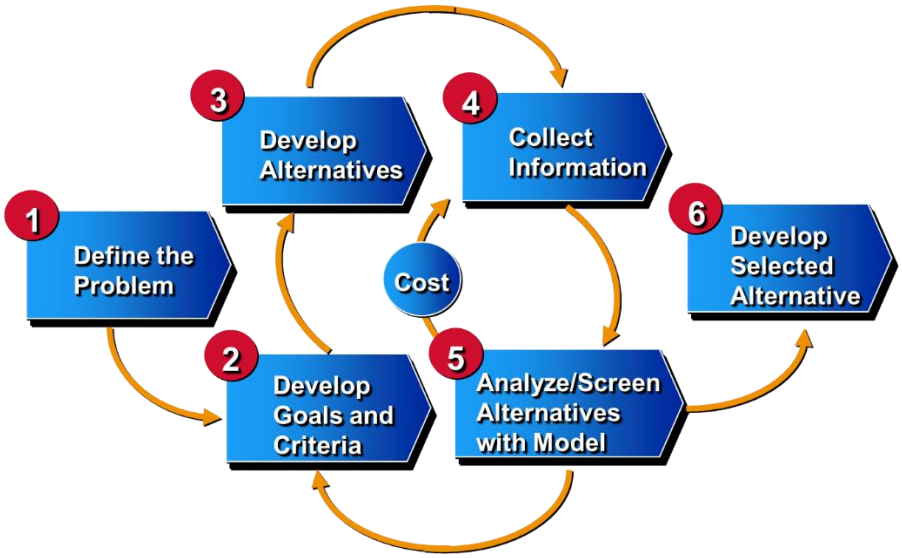

Figure 1: Six Step Decision Making Process

Scope of Work

Wyoming Wastewater Engineers developed the following scope of work to organize the evaluation and conceptual design tasks. These tasks follow the decision process described above and state the main objectives from each task.

Task 1: Assign Team Roles

- General Manager, Lead Engineer, Site Investigator, Sustainability Engineer, Process Engineers
- Establish responsibilities of each individual member

Task 2: Gather information from provided sources

- Construct Background
- Prepare Problem Statement
- Analyze existing infrastructure and technology being used
- Identify permit requirements
- Site Visit

Task 3: Decision Methodology

- Obtain decision methodology that will evaluate alternatives, taking into account different criteria
    - 6 step decision making process

Task 4: Create a list of Evaluation Criteria

- Produce a list of acceptable criteria to compare the alternatives
- Eliminate negligible criteria (criteria that have the same score or negligible differences in scores for all alternatives)
- Identify criteria that will facilitate fatal flaw analysis

Task 5: Identify Alternatives:

- Prepare list of possible alternatives
- Eliminate alternatives that do not meet minimum criteria
- Research potential alternatives to find evaluation criteria inputs
    - Advanced Water Treatment
    - Disinfection

Task 6: Build Decision Matrix

- Prepare evaluation criteria measures
- Create utility functions by defining maximum and minimum scores for each criteria
- Obtain scores for different alternatives based on criteria utility functions
- Provide criteria weights as a measure of relative importance

Task 7: Evaluate Alternatives:

- Apply decision matrix on possible alternatives
- Conduct sensitivity analysis through criteria weights
- Select preferred alternative

Task 8: Create Conceptual Design

- Site Plan
- Design Plan (Product Unit)
- Advanced Water Treatment Design Plan
    - Written Description
    - Design Criteria
    - Figure
- Disinfection Design Plan
    - Written description
    - Design Criteria
    - Figure
- Process flow diagram

Task 9: Develop Conclusions

- Additional studies
- Alternatives not considered

Criteria Development

A major part of the decision analysis is the criteria by which all alternatives are evaluated. Criteria and their measures provide a means to rationally compare alternatives, and to evaluate alternatives through different priorities of PWSD.

The evaluation criteria were divided into three categories, following the triple bottom line theory of sustainability: economic, social, and environmental. The final criteria used in the decision matrix are listed following this paragraph. Subcriteria are listed as subbullets, while criteria measures are shown in parentheses. A qualitative criteria measure indicates that a relative value was chosen on a 0 to 1 scale, where 1 is the maximum score. Qualitative criteria measures are further explained in the Decision Matrix section of this document.

Economic:

- Twenty-five year net present-value cost, capital and operating (2015 dollars)

Social:

- Operational intensity (Qualitative)
- Public safety (Truck visits per year) *
- Operator safety (Qualitative)*

Environmental:

- Energy Use (Kilowatt-hours per year)
- Chemical Use* (Yes/No)
- Effluent water quality
    - Ammonia/nitrogen removal (%)
    - Total suspended solids (mg/L)
    - Protozoa (Log removal)
- Footprint (square feet)

*Criteria used for disinfection systems only

Fatal Flaw

Since the proposed alternative systems were designed for a specific capacity, disinfection capability, and phosphorus removal, these criteria were the same for each alternative. The fatal-flaw criteria were used only to eliminate impractical alternatives. Final alternatives were not evaluated under fatal-flaw criteria since the measures were the same for each. The fatal-flaw criteria are listed as follows:

- Capacity- Must be able to treat 6 mgd
- Time to build- Must be completed by 2021
- *E. coli*- Must have an effluent concentration of less than 128 colonies per 100 mL
- Phosphorus- Must have an effluent concentration no greater than 0.05 mg/L

Criteria that were considered but eliminated from the decision matrix are listed in

Appendix 1: Eliminated Criteria.

Advanced Water Treatment Alternatives

A brief description of all AWT alternatives is included in this section. Detailed information including scores for evaluation criteria and figures of these alternatives are included in Appendix 4: Detailed Alternatives Description. Appendix 2: Eliminated Alternatives describes the alternatives that were excluded from the final evaluation. The following are the alternatives that were evaluated.

Alternative 1: Floc/Plate Settlers/Media Filter

This system mimics the existing system in the plant and will add 4.0 mgd to the existing capacity. Alum and a polymer are added using an in-line static mixer. Alum dose is adjusted so the phosphorous bonds to create aluminum phosphate. During flocculation, the aluminum phosphate attaches to the polymer due to interparticle bridging. Mechanical mixing (flocculation) for a 20-minute retention time[11] allows the particle to form a large floc. The current system has a retention time of only five minutes, but the new systems will have longer times and lower G-values to form a better floc. Clarification using Meurer Research Institute plate settlers follows flocculation. Water flows slowly upward from the bottom of the basin though a set of plates inclined at 55-60 degrees.[12] Sludge settles onto the plates and clarified water exits through perforated tubes on the surface of the basin. The projected loading rate is 0.34 gpm/ft^2, while the actual loading rate is 9.1 gpm/ft^2.[13] Sludge is collected from the bottom of the basin by a Cable-Vac sludge collector. The clean water travels to a multi-media filter composed of gravel, sand, and anthracite coal. The filtration rate is typically about 5 gpm/ft^2.[14] Backwash currently takes place every 10-25 hours, but this time could be increased with the formation of a better floc and improved clarification.

Alternative 2: ACTIFLO/Media Filter

This system will add 4.0 mgd capacity to the existing system. Coagulation, flocculation, and clarification all take place within one system, the ACTIFLO system made by Veolia Water Technologies. Coagulation takes place through rapid mixing of alum, creating aluminum phosphate. Flocculation takes place in a mechanical mixer, with fine sand and polymer added as flocculation aids. Clarification takes place in an upflow tube clarifier. Sludge collected from the bottom of the clarification section is pumped to the hydrocyclone, which shears particles off the sand, and recycles the sand for use in flocculation.[15] The clean water travels to a multi-media filter composed of gravel, sand, and anthracite coal. The filtration rate is typically about 5 gpm/ft^2.[16] Backwash currently takes place every 10-25 hours, but this time could be increased with the formation of a better floc and improved clarification.

Alternative 3: Floc/DAF/Media Filter

This system will add 4.0 mgd capacity to the existing system. Coagulation, flocculation, and clarification all take place within one system, the Greendaf made by Degremont. Coagulation takes place through jet

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[11] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011).
[12] "MRI Plate Settlers." *Muerer Research Institute.* http://www.meurerresearch.com/wp-content/uploads/2011/03/platesettler_singles1.pdf?cf77d6
[13] Information determined using a consulting company software
[14] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011), 19-7
[15] "ACTIFLO". *Veolia Water Technologies*. http://technomaps.veoliawatertechnologies.com/actiflo/en/
[16] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011), 19-7

injection of ferric chloride or alum and a polymer. Ferric or alum dose is determined through jar tests for removal of all particulate phosphorus. Aluminum phosphate attaches to the polymer by interparticle bridging. Flocculation takes place in a vertical baffled chamber with a retention time of 5-7 minutes.[17] As water travels through the chamber, floc grows and low G values ensure that the particles do not shear. A purified water and air combination is injected at the end of the floc basin. Flocculated particles attach to the air bubbles and float to the surface. A skimmer removes the sludge and the clean water exits the bottom of the basin through a permeable floor. A small portion, about 8-10% of the treated water is recycled into the dissolved air system. The air is typically pressurized to 200-800 kPa. The hydraulic loading rate for this DAF system is 6 gpm/ft^2.[18] The clean water travels to a multi-media filter composed of gravel, sand, and anthracite coal. The filtration rate is typically about 5 gpm/ft^2.[19] Backwash currently takes place every 10-25 hours, but this time could be increased with the formation of a better floc and improved clarification.

Alternative 4: Blue PRO

This system will have a 6.0 mgd treatment capacity. Blue PRO filters are continuous-backwashing filters that eliminate the need for coagulation/flocculation basins. The ferric-coated filter media is used to remove metals, contaminants, solids, and nutrients from the water primarily through adsorption. Influent comes directly from secondary treatment, is dosed with ferric chloride to coat the media, flows upwards through the filters, and exits as effluent from weirs at the top of the filters (see the Advanced Water Treatment Conceptual Design section for figure). The filter is continuously backwashed with the aid of an airlift and a washbox. The bottom portion of the filter is sloped down to a single point where the bottom of an airlift is stationed. The airlift moves the media to the washbox located at the top of the filter where it is scoured and cleansed of all ferric coating and contaminants adsorbed. The reject stream is recycled back to the beginning of secondary treatment. The clean media is then released from the washbox and returned to the top of the filter media bed where it will slowly gravitate downwards against the flow of the water being treated. Typical filter bed turnover occurs every 4-8 hours. Typical media loss is about 1% every five years. No treatment interruption time is required for backwashing.[20]

Alternative 5: ACTIFLO/Membrane

This system will have a 6.0 mgd treatment capacity. It combines the ACTIFLO system described in Alternative 2 with ultrafiltration hollow-fiber membranes. Ceramic membranes were also considered since the Parker Water Treatment Plant has the first facility in North America to employ ceramic membranes at that magnitude, but were ruled out due to their equivalent benefit but high cost. Ceramic membrane Bio-Reactors as well as Ceramic Plates were also considered, but fatal-flawed out due to capacity constraints.

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[17] Degremont. “Greendaf”. *Docslide.* http://docslide.us/technology/greendaf-tertiary-phosphate-removal-by-rapid-flotation.html

[18] Information determined using a consulting company software

[19] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011), 19-7

[20] “CENTRA-FLO: Blue PRO”. *Blue Water Technologies.* https://www.bluewater-technologies.com/products/bluepro.html

This advanced filtration process is designed to deliver high quality potable water with effluent water having low TSS, turbidity, and pathogen concentration. The membrane systems incorporate a unique backwashing process to keep the membranes clean and minimize waste by reversing the flow direction temporarily when solids accumulate on fiber surface. The membranes are engineered for integration into existing systems, high durability, and compactness. The membrane modules are composed of high strength Polyvinylidene Fluoride (PVDF) material with a unique spinning method to produce high integrity and fiber breakage resistance. The design life is seven to ten years for the membranes and 20-30 years for the skids and immediate equipment.[21]

Alternative 6: Coagulation/Membrane

This system uses the ultrafiltration hollow-fiber membranes described in Alternative 5 in combination with coagulation. The water is dosed with alum to create aluminum phosphate. Aluminum phosphate particles are removed in the membrane filter through size exclusion. In order to deal with a high solids loading rate, this alternative utilizes a 30% lower loading rate than the Actiflo/ membrane system and requires 30% more modules.

Disinfection Alternatives

This section includes descriptions of the disinfection alternatives. More detail including criteria scores and figures are located in Appendix 4: Detailed Alternatives Description.

Alternative 1: Sodium Hypochlorite Delivery

This system requires 4 mgd of expansion of the current disinfection system in the plant, including new contactor basins, chemical pumps, and storage units. Sodium hypochlorite is a disinfection alternative that effectively uses the disinfectant properties of chlorine. When sodium hypochlorite is added to water, the ions separate into hypochlorous acid, sodium, and hydroxide. The hypochlorous acid oxidizes molecules inside organisms, which damages cells and leaves the organism dead or unable to reproduce.

Alternative 2: Sodium Hypochlorite, Onsite Generation

Sodium hypochlorite can be easily produced on-site. The process of creating sodium hypochlorite is very simple, requiring only salt, water, and electricity. When a brine solution is exposed to positive and negative anodes, several chemical reactions take place which yield a sodium hypochlorite solution. The final solution will typically have a sodium hypochlorite concentration of 0.8%.[22] The onsite system will include the same contactor expansion as above.

Alternative 3: Chlorine Dioxide

A purate-chlorine dioxide system was evaluated for a 6 mgd design flow. The purate system uses two chemicals, purate and sulfuric acid, to create chlorine dioxide which is used to inactive pathogens

[21] From information sent by manufacturer

[22] "ClorTec: On-Site Sodium Hypochlorite Generation". *Severn Trent De Nora,* 2013. http://www.severntrentdenora.com/products-and-services/seawater-electrochlorination-systems/clortec/750-0210.pdf

through oxidation.[23] The system feeds the chemicals into a reactor for mixing. After mixing, they are fed into the wastewater stream for disinfection. Purate is a solution of sodium chlorate and hydrogen peroxide, which reacts with sulfuric acid to produce the chlorine dioxide without creating chlorine gas.

Alternative 4: Ultraviolet (UV)

UV disinfection works by exposing pathogens to photons (radiation) created by UV lightbulbs. These photons are able to penetrate cell walls and disrupt genetic material, hindering the cell from reproducing.[24] The organisms may not die instantly, but if dosed correctly they will not be able to reproduce and are prevented from infecting a host.

UV light can be easily produced by striking an electric arc through pressurized mercury vapor. UV bulbs come in a variety of pressures and intensities; intensity is either high or low and the different pressures are low, medium, and high.[25] Different configurations yield different results, but it has been shown that the optimum UV wavelength to inactivate microorganisms is in the range of 250 to 270 nm.[26]

Alternative 5: Ozone

Ozone (O_3) disinfects wastewater by oxidizing the cell walls of or damaging the nucleic acids inside bacteria and other microorganisms.[27] The first step in ozone disinfection is the production of ozone using an ozone generator located at the wastewater treatment plant. Ozone must be generated on site because it decomposes rapidly. Ozone is produced using liquid oxygen which is trucked in. Once the ozone is created, it enters the wastewater through a series of diffusers in a contact tank. A typical ozone concentration requirement is about 5 to 10 mg/L. After a contact time of 10-30 minutes, the wastewater exits the plant. When the ozone passes through the wastewater in the contact tank, it is collected at the top and goes through a thermal destruct process. This removes the ozone so the air can be put safely back into the environment.[28]

Alternative Selection

The alternatives listed in the previous section were evaluated in a decision matrix (Table 1). Quantitative and qualitative scores for each alternative were entered into the matrix in the left column for each alternative, while the right column shows the weighted, normalized score. The normalized scores were calculated using utility functions, such as the one shown in Figure 2; for example, in this utility function

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[23] NALCO. "Purate: On-site Chlorine Dioxide Generation". *Ecolab,* 2014. http://www.ecolab.com/~/media/Ecolab/Ecolab%20Site/Page%20Content/Documents/Purate/B1349.ashx

[24] National Service Center for Environmental Publications. "Wastewater Technology Fact Sheet: Disinfection for Small Systems". *Environmental Protection Agency*. http://tinyurl.com/olfykwk

[25] "Ultraviolet Disinfection". *Environmental Technology Initiative.* http://www.nesc.wvu.edu/pdf/WW/publications/eti/UV_Dis_tech.pdf

[25] National Service Center for Environmental Publications. "Wastewater Technology Fact Sheet: Disinfection for Small Systems". Environmental Protection Agency. http://tinyurl.com/olfykwk

[27] "Wastewater Disinfection Factsheet: Ozone Disinfection". Environmental Protection Agency. http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_ozon.pdf

[28] "Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule". Environmental Protection Agency. http://water.epa.gov/lawsregs/rulesregs/sdwa/stage2/upload/technologiesandcostforfinallt2swtrfinalstage2ddbruledec2005.pdf

an input value of 2-log removal would give a normalized score of about 0.43, while an input value of 4-log removal would give a normalized score of 1. Different utility functions were developed for all criteria. The scores were then weighted based on the relative importance of the criteria.

The weighted, normalized scores for each criterion were summed and plotted with the net present cost over a 25-year lifespan, shown in Figure 3 and Figure 4. Scores are shown as evenly weighted in these figures. A more complete version of the decision matrix is shown in Appendix 3: Decision Matrix.

Table 1: AWT and Disinfection Decision Criteria and Cost Data with Weighted, Normalized Benefit Scores

Advanced Water Treatment												
Criteria	Floc/Plate Settlers/Media Filter		ACTIFLO/Media Filter		Floc/DAF/Media Filter		BluePRO		ACTIFLO/Membrane		Coag/Membrane	
	Input	WNScore	Input	WNScore	Input	WNScore	Input	WNScore	Input	WNScore	Input	WNScore
Ammonia-Nitrogen Removal (%)	0	0.000	0	0.000	0	0.000	85	0.142	0	0.000	0	0.000
TSS Removal (%)	80	0.000	80	0.000	80	0.000	80	0.000	98	0.150	98	0.150
Energy Use (kWh/yr)	1,428,860	0.017	1,572,860	0.000	816,430	0.087	125,740	0.167	720,000	0.098	585,000	0.114
Footprint (ft^2)	5040	0.000	2100	0.122	2120	0.121	1024	0.167	2400	0.110	1700	0.139
Operational Intensity*	0.6	0.100	0.4	0.067	0.7	0.117	0.8	0.133	0.1	0.017	0.3	0.050
Number of years in use	23	0.167	20	0.137	6	0.000	15	0.088	10	0.039	10	0.039
Total	-	0.283	-	0.326	-	0.325	-	0.697	-	0.414	-	0.492
25-Year PV ($)		10,010,000		10,990,000		8,940,000		3,402,047		15,200,000		10,100,000

Disinfection										
Criteria	NaOCl		On-site NaOCl		Chlorine Dioxide		UV		Ozone	
	Input	WNScore	Input	WNScore	Input	WNScore	Input	WNScore	Input	WNScore
Protozoa (Log Removal)	0.5	0.000	0.5	0.000	2	0.061	4	0.143	1	0.020
Energy Use (kWh/yr)	6,570	0.143	109,500	0.132	13,140	0.142	340,000	0.106	1,314,000	0.000
Chemical Use (Y/N)	Yes	0.000	Yes	0.000	Yes	0.000	No	0.143	No	0.143
Footprint (ft^2)	3390	0.000	875	0.113	476	0.130	198	0.143	1800	0.071
Operational Intensity*	1.0	0.143	0.8	0.114	0.8	0.114	0.7	0.100	0.4	0.057
Operator Safety*	0.8	0.114	0.9	0.129	0.7	0.100	0.9	0.129	0.5	0.071
Public Safety (Yearly Truck Traffic)	17	0.065	0	0.143	12	0.088	0	0.143	31	0.000
Total	-	0.465	-	0.630	-	0.636	-	0.906	-	0.363
25-Year PV ($)		965,000		2,754,124		1,261,000		1,464,899		5,374,952

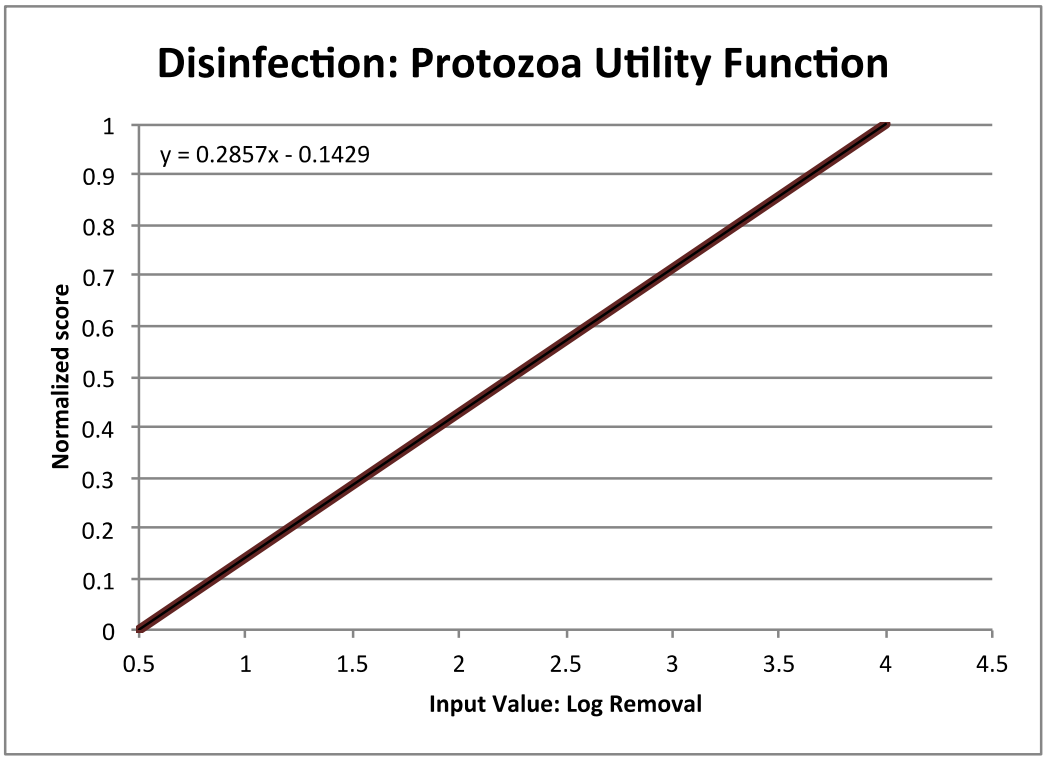

Figure 2: Example Utility Function

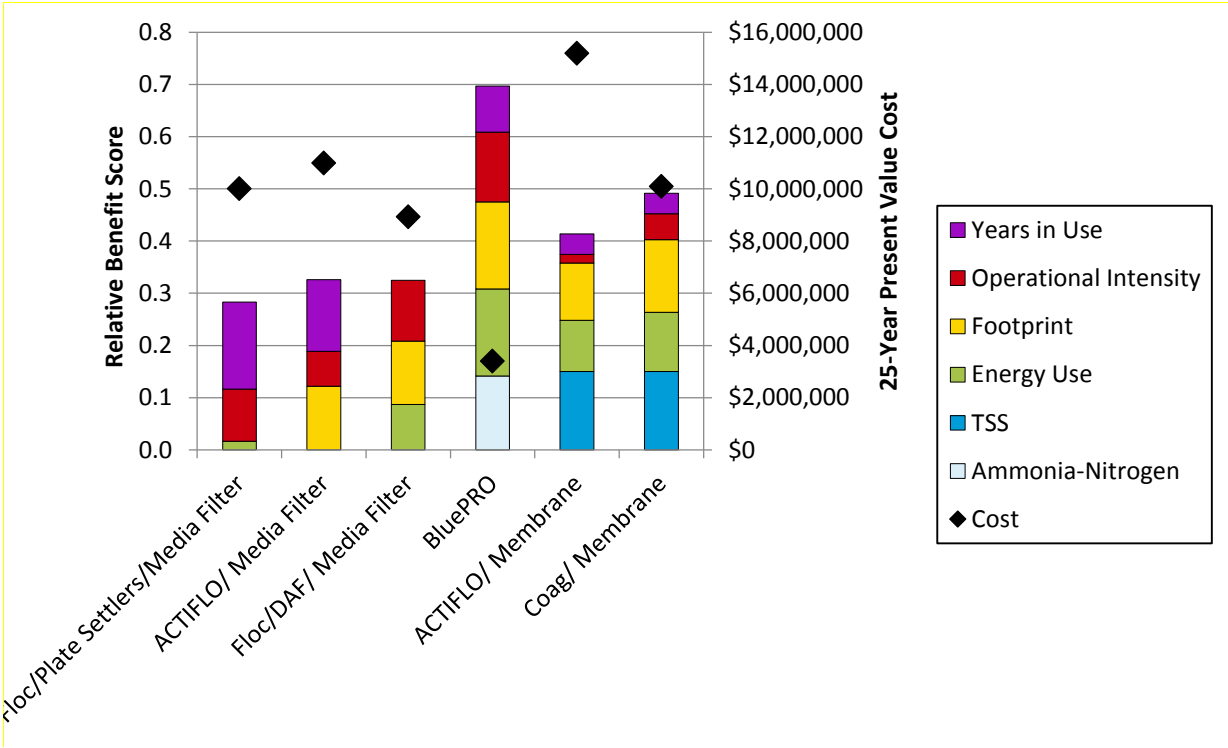

Figure 3: Advanced Water Treatment Cost-Benefit Chart (Equally Weighted Criteria)

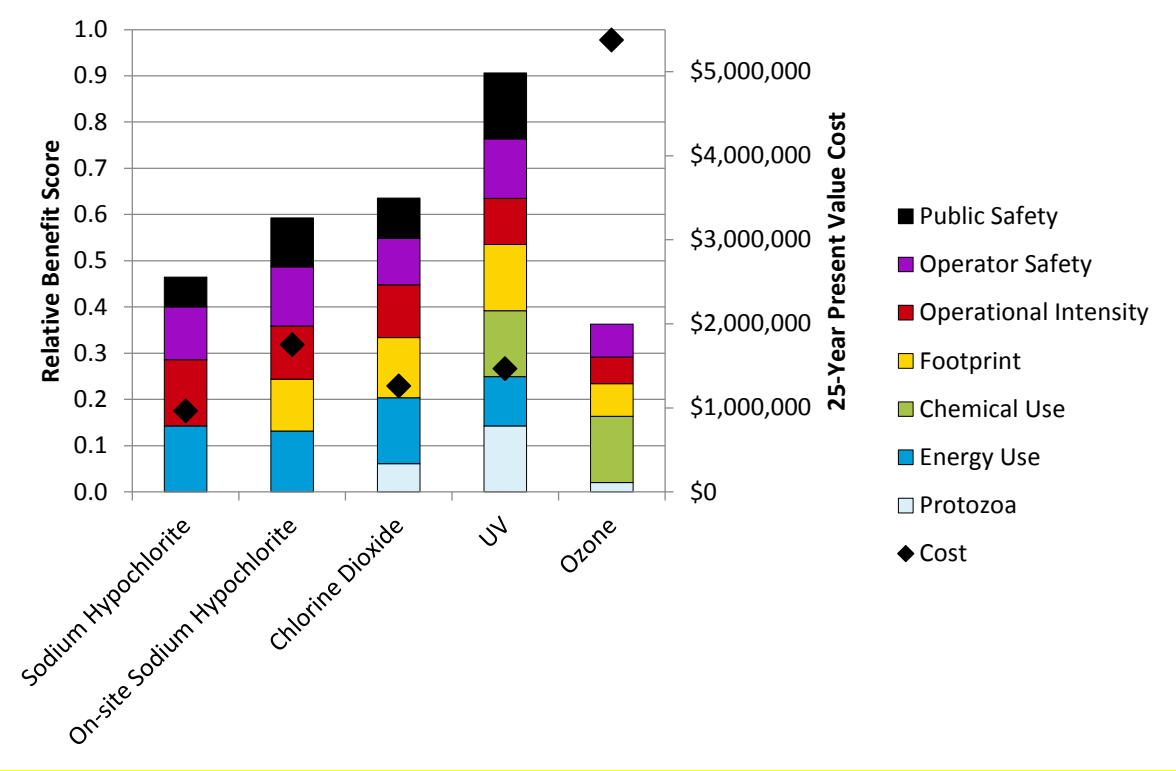

Figure 4: Disinfection Cost-Benefit Chart (Equally Weighted Criteria)

The decision matrix weighed the importance of all criteria for both AWT and disinfection to calculate a weighted score. Initially, all criteria were weighted the same. A sensitivity analysis was completed in which the weights for the criteria were changed, with one having a significantly higher weight while the rest had varied smaller weights. Changing the criteria weights did not have a significant effect on the relative benefit scores or the end decision for both the AWT and disinfection alternatives.

After comparing the benefits and costs for the six final AWT alternatives, a Blue PRO system was chosen based on its highest benefit score and lowest cost. After studying five disinfection alternatives, a UV system was chosen based on its highest benefit score, with benefits in every area, and its reasonable cost.

Advanced Water Treatment Conceptual Design

As described previously, the Blue PRO system was selected as the preferred AWT system.

Operating Principle

The Blue PRO system is a continuous backwash gravity sand filter that has been proven to remove phosphorus through adsorption (see Figure 5 and Figure 6). Employment of Blue PRO filters eliminates the need for flocculation and clarification basins. The influent wastewater only requires addition of Ferric Chloride before passing through the Blue PRO filters. The Ferric Chloride added to the influent results in a coat of hydro ferric oxide (HFO) on the media, which is the primary mechanism through which adsorption of both particulate and soluble phosphorus occurs. Continuous backwash is achieved through an airlift that pushes older sand on the bottom of the filter to the top where it enters a

washbox. The sand is scoured within the washbox where waste HFO, phosphorus sludge, and solids are removed and sent into the reject stream, which is recycled to the headworks section of the treatment plant. The sand is recoated with HFO and returned to the top of the filter, where it will repeat its cycle.[29]

Picture

[29] "CENTRA-FLO: Blue PRO". *Blue Water Technologies.* https://www.bluewater-technologies.com/products/bluepro.html

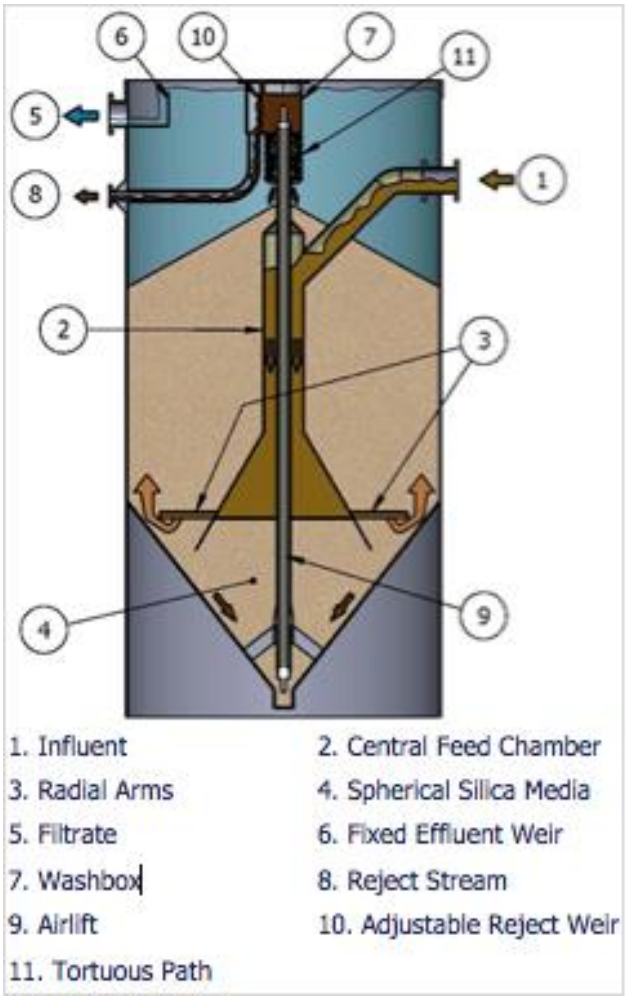

Figure 5: Blue PRO Schematic[30]

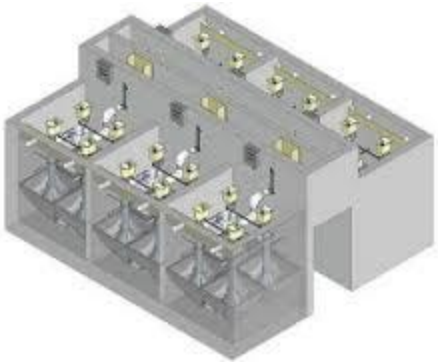

Figure 6: Blue PRO Visualization[31]

[30] Ibid.

[31] "Low Phosphorus Installation Complete in Marlborough, Massachusetts". *Blue Water Technologies.* https://www.bluewater-technologies.com/headlines/marlborough.html

Evaluation Criteria

- Energy Use: 125,740 kWh/yr
- Footprint: 2000 ft^2 total
- Operational Intensity: Low; only an air compressor and washbox for each filter
- Total years of successful use in similar plants: 15

Advantages and Disadvantages

- Continuous backwash- no need to take filter offline to backwash
- Only 1% loss of media over five years- no need to replace media periodically
- Adsorptive properties of Ferric utilized- removes both soluble and particulate contaminates
- Temperature and pH flexibility – filters still effective over wide range of water conditions
- Does not affect or lowers transmissivity for UV disinfection
- Ferric Chloride required- adds truck traffic and requires storage of chemicals onsite[32]

Cost

Cost for equipment/installation was estimated by the manufacturer and includes:

- 18 complete filter assemblies (product code CF64-80AG)
- 18 airlift assemblies
- 18 washbox and torturous path assemblies
- 18 automatic cell isolation butterfly valves
- 333 tons of filter media
- 1 Ferric pump with one spare
- 1 control panel
- 1 pH sensor
- 1 Phosphorus analyzer
- 1 RCS monitoring and control system
- 1 set of aluminum stairs
- 1 lot of walkway/railing, 1 lot of covers
- 1 rotary screw compressor on VFD
- 1 particulate filter
- 1 Dessicant air dryer
- 1 receiver
- and 5 air control panels.

The capital cost is the sum of the manufacturer cost estimates for the equipment listed previously and necessary concrete costs. Material, pumping, and installation costs for 6,000 cubic feet of concrete was calculated using an assumed value of $1200 per cubic yard of concrete[33]. Annual O&M cost is a sum of the manufacturer estimate of energy costs ($12,574), chemical costs ($119,929), operator costs ($3,650), and parts replacement ($1,774). The 25-year present value was calculated assuming an interest rate of 4%.

Total capital cost: $1,247,000
Annual O&M costs: $138,000
Total 25-year Present Value: $3,402,000[34]

[32] Ibid.
[33] http://concrete.promatcher.com/cost/
[34] Ibid.

Design Criteria

The design for implementation of the Blue PRO system was largely obtained through recommendations from the manufacturer, Blue Water Technologies. The assumed parameters of influent from secondary treatment and predicted effluent parameters can be seen in Table 2. According to the manufacturer, approximately 90-95% of phosphorus, TSS, metals, and nutrients are removed from the water with each filter pass.

Table 2: Blue PRO Filter Water Design Parameters

Parameter	Influent[1]	Effluent[1]	Units
Average Daily Flow (ADF)	4.3	4.0	MGD
Peak Hour Flow (PHF)/Design Flow	6.3	6.0	MGD
Peak Monthly Flow (PMF)	0.1	0.0	MGD
Minimum Flow Per Cell	22		gpm
Minimum Ambient Temperature	45		°F
Water Temperature	55 to 77		°F
pH	6.0 to 7.0		
Alkalinity	9 to 110		mg/L
Total Suspended Solids (TSS)[2]	< 15	< 3	mg/L
TP-P (mg/L)	<0.30	< 0.03	mg/L
Biochemical Oxygen Demand (BOD)	< 15	< 3	mg/L

To meet these parameters for water treatment, it is necessary to install 18 total Blue PRO filters with dimensions of 7.5'x7.5'x 7' high. This results in a total required filter area of 1024 square feet. To allow for adequate storage of ferric chloride, piping, compressors, and accessibility, 2000 square feet will be necessary for the system. The manufacturer recommended an underground concrete tank design for this project. No building to cover the filters will be necessary. The site plan can be seen in Figure 7. Four feet of hydraulic head will be required going into each filter. Five feet of head space above the units will be required for removal and maintenance of the airlifts. At peak flow (full capacity), only 16 total filters are required and at anticipated average flow only 14 total filters will need to be online. This allows for maintenance of at least two filters during peak flow if necessary without reducing the influent flow rate. The optimum filter-loading rate will be 3.3 gpm/ft^2 at average daily flow and 4.2 gpm/ft^2 at peak daily flow, with a reject stream of 11 gpm per operating filter (not described in Table 2, but given by manufacturer). Ferric chloride will be dosed to the influent going into each individual filter at approximately 5-10 ppm, where the optimum dosing rate will be determined after installation and during commissioning and startup.[35]

[35] Ibid.

Site Plan

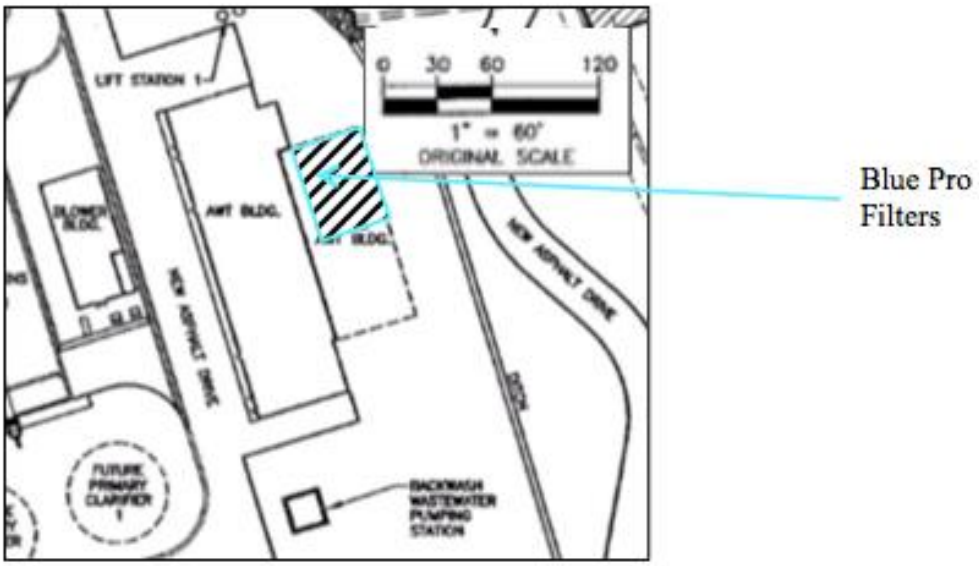

Figure 7: AWT Site Plan

Disinfection Conceptual Design

Operating Principle

As described above, UV was selected as the preferred disinfection alternative. UV disinfection works by exposing different pathogens to photons (radiation) created by UV lightbulbs. These photons are able to penetrate cell walls and disrupt genetic material, hindering the cell from reproducing.[36] The organisms might not die instantly but, if dosed correctly, will not be able to reproduce and are prevented from infecting a host.

UV light can be easily produced by striking an electric arc through pressurized mercury vapor. UV light bulbs come in a variety of pressures and intensities; intensity is either high or low and the different pressures are low, medium, and high.[37] Different configurations yield different results, but it has been shown that the optimum wavelength to inactivate microorganisms is in the range of 250 to 270 nm.[38]

[36] National Service Center for Environmental Publications. "Wastewater Technology Fact Sheet: Disinfection for Small Systems". *Environmental Protection Agency*. http://tinyurl.com/olfykwk
[37] "Ultraviolet Disinfection". *Environmental Technology Initiative.* http://www.nesc.wvu.edu/pdf/WW/publications/eti/UV_Dis_tech.pdf
[38] National Service Center for Environmental Publications. "Wastewater Technology Fact Sheet: Disinfection for Small Systems". *Environmental Protection Agency*. http://tinyurl.com/olfykwk

Picture

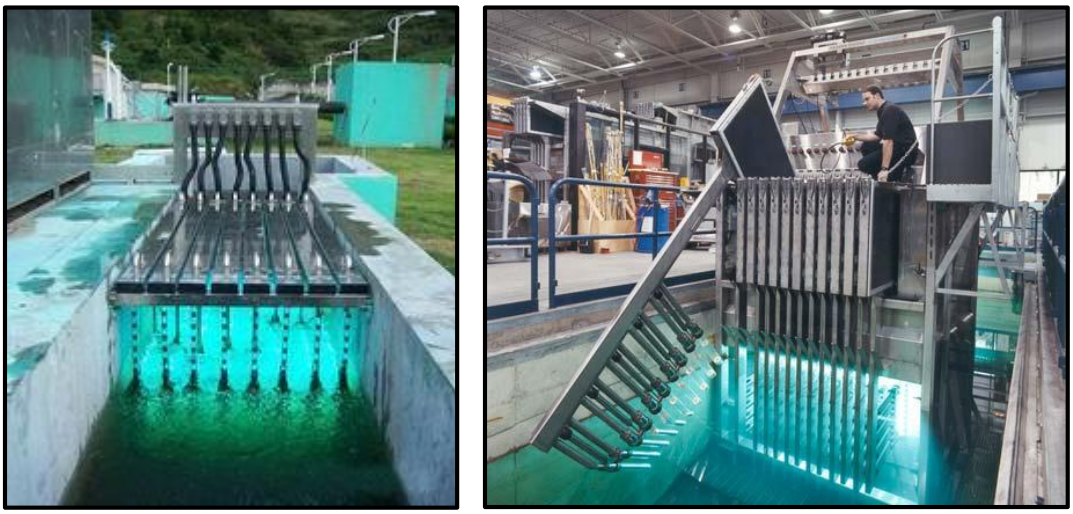

Figure 8: UV System[39]

Evaluation Criteria

- Safety: No truck traffic
- Aesthetics: No smell
- Operational intensity: Low
- Size of plant expansion required: 198 ft²
- Chemical use: None
- Energy use: 340,000 kWh/yr.
- Protozoa removal: 4-log inactivation
- Time for build: 9 months[40]

Advantages and Disadvantages

- It is a physical process, removes all chemical exposure and any residual effects.
- Eliminates truck traffic
- Very effective in inactivating most viruses, bacteria, spores, and cysts. Does a better job at inactivating protozoa than chlorine methods.
- Shorter contact time compared to other disinfectants
- Equipment uses less space compared to other methods and is user-friendly.

Cost

Cost was estimated using EPA data[41], supplemented by CH2M Hill energy estimates. The total capital cost provided by the EPA included indirect cost as well as direct process cost. The indirect cost includes

[39] http://upload.ecvv.com/upload/Product/20119/China_welnic_Wastewater_automatic_cleaning_UV_sterilizer20119271538024.jpg

[40] Estimates provided by CPES program supplied by Ed Meyer CH2M Hill, Personal Communication, November 2015

[41] "Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule". *Environmental Protection Agency.*

as training, treatability testing, and spare parts while the direct process cost includes construction and installation, pipes and valves, adjusted pumping, adjusted housing, UV reactors, electrical work, and a UPS system. The EPA also provided annual operation and maintenance cost that included replacement parts, power cost, and labor. The total present value was estimated using a design life of 25yrs and assuming a 4% interest rate.

Total Capital Cost: $759,000
Annual O&M Costs: $45,200
Total 25-yr Present Value: $1,465,000

Design Criteria

The design of the UV disinfection system began by obtaining the typical dimensions for a UV system treating 3 mgd, these dimensions came out to be 33'x3'. A flow of 3 mgd was picked to divide the total flow, 6 mgd, into two channels for maintenance and repairs. The energy consumption of the system was estimated at 340,000kWh, obtained from CH2M Hill software.[42] Using the energy consumption for one year it was found that the necessary power output of the system was 38.8kW. The UV lamps to be used in this system are TrojanUV3000PLUS lamps with a power output of 250W each. Knowing these parameters, the total number of lamps needed was found to be 160, with 80 in each channel. The TrojanUV3000PLUS units have a maximum of 8 lamps, so each channel will have 10 units. The units have a depth of 5'4", and the channels will be built to a depth of 6' providing 8" of freeboard. The estimated detention time will be two minutes in normal conditions and one minute if one channel requires maintenance or repairs. The TrojanUV3000PLUS units will be placed so that there are 18' of channel upstream and 5' of channel downstream of the units, so a uniform flow occurs during treatment within the UV system.

Site Plan: The UV system is indicated in blue.

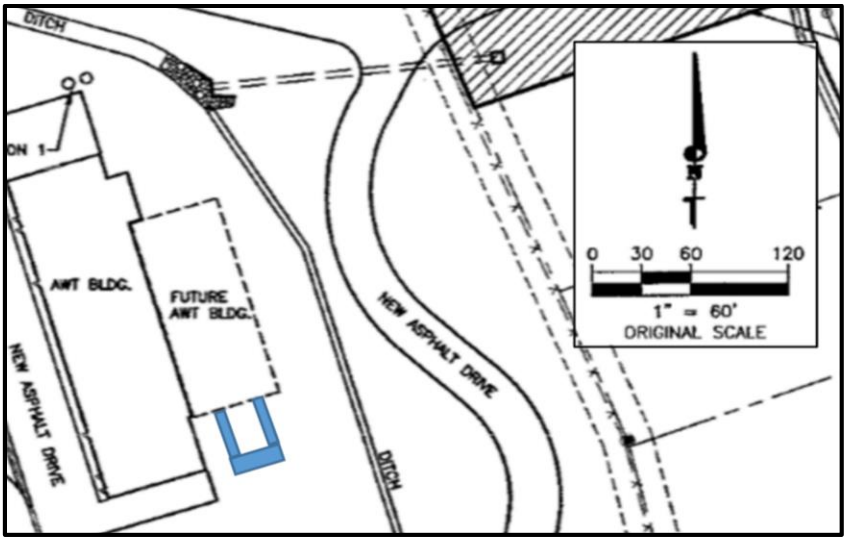

Figure 9: Disinfection Site Plan

[42] http://water.epa.gov/lawsregs/rulesregs/sdwa/stage2/upload/technologiesandcostforfinallt2swtrfinalstage2ddbruledec2005.pdf

Conclusion

WWE were tasked with evaluating AWT and disinfection alternatives and developing a conceptual design for the preferred alternatives. Six AWT alternatives and five disinfection alternatives were considered. A thorough sustainability evaluation was performed to evaluate and select the optimal alternatives for recommendation. WWE recommends that Parker Water and Sanitation District install a Blue PRO AWT system combined with a UV disinfection system design at the Parker Wastewater Treatment North Water Reclamation Facility.

The design flow to these systems will be six million gallons of wastewater per day. The Blue PRO will be constructed with 18 filter modules and the UV system will be constructed with 160 UV lamps by Trojan UV. The UV lamps will be designed as two, 3 mgd channels each containing 10 units; each unit consists of 8 lamps for a total 80 lamps per channel.

The capital cost for the Blue PRO system is approximately $1 million with a total annual cost of $140,000 for operation and maintenance. This results in a net present value of $3.4 million over the 25 year design life, assuming a single capital cost for the equipment over the design life.

The capital cost for the UV system is $759,000 with a total annual cost of $45,200 for operation and maintenance. This results in a net present value of $1.5 million over the 25 year design life, assuming a single capital cost for the equipment as well. This design will meet permit requirements of 80% TSS removal removal of *E. coli* to greater than 128 colonies per 100mL. Additional UV benefits include no chemical use or truck traffic, while achieving a 4-log removal of protozoa. Only 466,000 total kWh/yr and 1,222 ft^2 of the available plant area are consumed.

This recommendation is based on the following: The Blue PRO had the lowest cost and highest benefit score among the six AWT alternatives. Similarly, UV had the highest benefit score with benefits in each area between the five disinfection alternatives, and can be constructed and operated at a reasonable cost. Therefore, these systems should be implemented for Parker Water and Sanitation District in the North Reclamation Facility expansion for the advanced water treatment and disinfection processes. These conclusions are based on the cost-benefit graph illustrated in Figure 3 and Figure 4.

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Appendix 1: Eliminated Criteria

Several criteria were considered but eliminated from the decision matrix. These criteria are listed following, with an explanation for the elimination of each one.

Eliminated Criteria:

- Compatibility with current systems: Negligible in the decision matrix
- Greenhouse gases: Accounted for by Energy Use
- Feasibility: Negligible since all alternative processes have been proven at full scale
- Operation and maintenance constraints: Accounted for in costs
- Operator training: Negligible
- Aesthetics – Odor: Equivalent for all systems and negligible
- BOD_5 : Negligible
- Jobs created: Approximately equivalent for all systems
- Safety: Operator and Public*: Equivalent for all systems
- Lifespan: Accounted for in twenty-five year present-value cost

*Criteria eliminated for AWT only

Appendix 2: Eliminated Alternatives

AWT Systems

Biological – PWSD already utilizes a biological treatment system, which is inadequate for current permit regulations.

Reverse Osmosis, Distillation, and Electrodialysis – These systems are generally used for desalination technologies, and would provide a much higher water quality than necessary at an unreasonable cost. They also produce significant concentrate streams that would have to be treated in the plant.

Disinfection Systems

Chlorine gas, Solid Calcium Hypochlorite, and Chloramine – Sodium hypochlorite is a proven technology that provides residual protection but is safer than chlorine gas and less expensive than all other alternative disinfection systems.[43]

Pasteurization and E-Beam – These systems are currently untested in the state of Colorado and would require a pilot plant, which would bring the completion date of the expansion project past the date that PWSD requires the systems to begin operations.

[43] http://pce.comcastbiz.net/media/Chlorine$20Gas$20vs.$20Sodium$20Hypochlorite.pdf

Appendix 3: Decision Matrix

Table 3:Decision Matrix for Advanced Water Treatment

AWT	Criteria	Sub-Criteria	Units	Min Limit	Max Limit	High or Low?	Scale	Weight (%)
Environmental	Water Quality Obtained	Ammonia-Nitrogen Removal	%	0	100	High	0.010000	0.1667
		TSS Removal	%	80	100	High	0.050000	0.1667
	Energy Use	.....	kWh/yr	125740	1572860	Low	0.000001	0.1667
	Footprint	.....	square feet	1024	5040	Low	0.000249	0.1667
Societal	Operational Intensity*	.....	Number	0	1	High	1.000000	0.1667
	Number of years in use	.....	Number	6	23	High	0.058824	0.1667
	*Qualitative criteria (See "Qualitative Scales" page)						Total-->	1
Economic	Cost	Capital	$	[redacted]		Low	[redacted]	
		Operation and Maintenance	$			Low		
		Present Value over 25-yrs with 4% interest	$			Low		
		Lifespan	Number			High		

Table 4: Decision Matrix for Disinfection

Disinfection	Criteria	Sub-criteria	Units	Min Limit	Max Limit	High or Low?	Scale	Weight (%)
Environmental	Water Quality Obtained	Protozoa	Log removal	0.5	4	High	0.2857143	0.1429
	Energy Use	.....	kWh/yr	6,570	1,314,000	Low	0.0000008	0.1429
	Chemical Use	.....	Yes/No	0	1	Low	1.0000000	0.1429
	Footprint	.....	square feet	198	3,390	Low	0.0003133	0.1429
Societal	Operational Intensity*	.....	Number	0	1	High	1.0000000	0.1429
	Safety	Operator*	Number	0	1	High	1.0000000	0.1429
		Public	Trucks/yr	0	31	Low	0.0322581	0.1429
	*Qualitative criteria (See "Qualitative Scales" page)						Total-->	1
Economic	Cost	Capital	$	[redacted]		Low	[redacted]	
		Operation and Mainenance	$			Low		
		Present Value over 25-yrs with 4% interest	$			Low		
		Lifespan	Number			High		

Table 5: Qualitative Criteria Scales

	Worst Case Scenario						Best Case Scenario			
Criteria	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Safety	Certain death caused by implementation			Accidents can be avoided with knowledge of alternative				Zero chance of an accident, harmless when operated incorrectly			
Operational Intensity	Several points of failure, little to no points of redundancy			Average points of failure, average points of redundancy				Little to no failure points, several points of redundancy			

Appendix 4: Detailed Alternatives Description

Advanced Water Treatment Alternatives

Alternative 1: MRI Plate Settlers, Media Filter

Basic Operating Principle

This system mimics the existing system in the plant. Alum and a polymer are added using an in-line static mixer. Alum dose is adjusted to make insoluble phosphorous bond and create aluminum phosphate. During flocculation, the aluminum phosphate attaches to the polymer due to interparticle bridging. Mechanical mixing for a 20-30 minute retention time[44] allows the particle to form a large floc. The current system has a retention time of only five minutes, but the new systems will have longer times and lower G values to form a better floc. Clarification using Meurer Research Institute plate settlers follows flocculation. Water flows slowly upward from the bottom of the basin though a set of plates inclined at 55-60 degrees.[45] Sludge settles onto the plates and clarified water exits through perforated tubes on the surface of the basin. The typical overflow rate is 60-180 $m^3/d/m^2$.[46] Sludge is collected from the bottom of the basin by a Cable-Vac sludge collector. The clean water travels to a multi-media filter composed of gravel, sand, and anthracite coal. The filtration rate is typically 5 gpm/ft^2.[47] Backwash currently takes place every 10-25 hours, but this time could be increased with better floc formation.

Picture

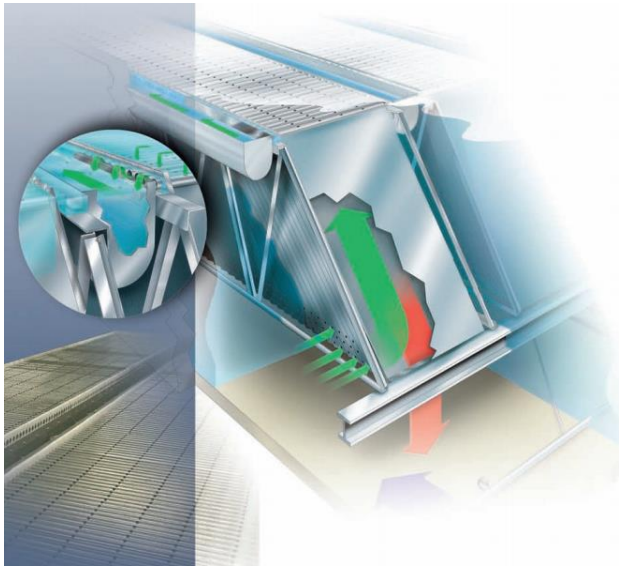


Figure 10: MRI Plate Settler

[44] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011).
[45] "MRI Plate Settlers." *Muerer Research Institute.* http://www.meurerresearch.com/wp-content/uploads/2011/03/platesettler_singles1.pdf?cf77d6
[46] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011).
[47] Ibid, 19-7

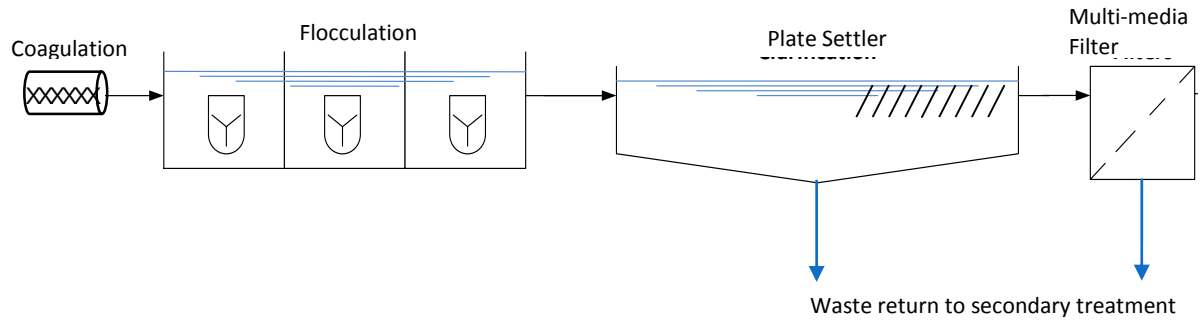


Figure 11: Plate Settler Process Flow Diagram

Design Criteria

Table 6: AWT Alternative 1 Design Criteria

Alternative 1 Design Criteria			
	Value	**Range**	**Units**
Flow Rate	4		Mgd
Floc			
Retention time	30	20-30	min
Volume	83333		gal
Clarifier			
Loading Rate	60	60-180	$m^3/day/m^2$
Area	5040		ft^2
Filter			
Filt. Rate	12	5-24	m/hr
Area	52.57		m^2
	565.6		ft^2

Evaluation Criteria:

- Phosphorous removal: all particulate P, assumed to be down to 0.03 mg/L based on the current system
- TSS removal: 0-5 mg/L final TSS[48]
- Ammonia Nitrogen Removal: none
- Clarifier years of operation: 23
- Operational complexity: floc paddles and sludge collection contribute to complexity

[48] Ibid, 19-5

Site Plan

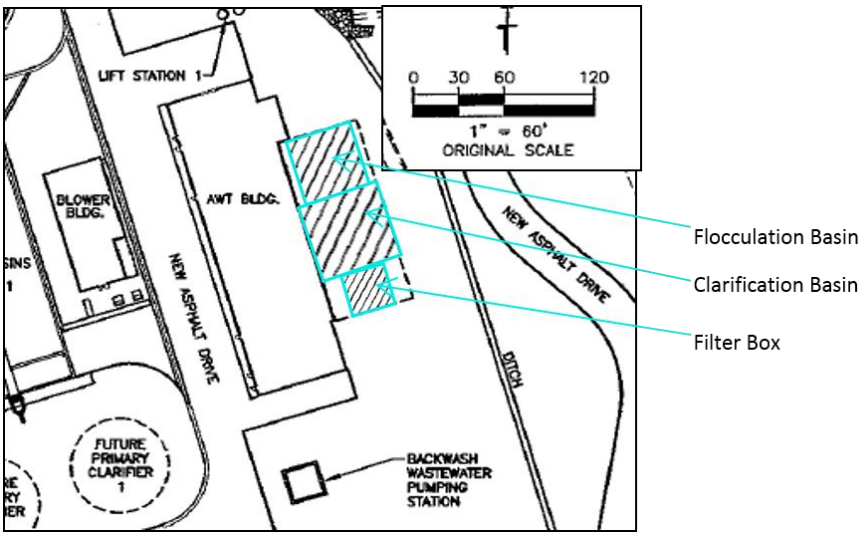


Figure 12: Plate Settler Site Plan

Benefits and Drawbacks

This is similar to the existing system, so operators will already know how to run the system. Based on current problems, there could be clogging of clarifier and problems with mechanical parts in the floc basin. Currently, the plant is not forming a good floc and the filters are being loaded with excess solids. Unless this problem is solved, the filters will continue to have short runs. Other than that, the filters require little maintenance.

Costs[49]

Table 7: AWT Alternative 1 Costs

Capital Cost	**million $**
Flocculation	1
Sedimentation	1.08
Filtration	1.8
O & M Cost	**thousand $/yr**
Coagulation	154
Flocculation	38.7
Sedimentation	50
Filtration	150
25-yr NPV	**$6.13 million**

[49] All costs determined using a consulting company software

Alternative 2: ACTIFLO, Media Filter

Basic Operating Principle

This system will have an additional 4.0 mgd capacity that is added to the existing system. Coagulation, flocculation, and clarification all take place within one system, the ACTIFLO system made by Veolia Water Technologies. Coagulation takes place through rapid mixing of ferric chloride or alum. This creates aluminum phosphate. Flocculation takes place in a mechanical mixer, with fine sand and polymer added as flocculation aids. Clarification takes place in an upflow tube clarifier. Sludge goes to the hydrocyclone, which shears particles off the sand, and recycles the sand for use in flocculation. The clean water travels to a multi-media filter composed of gravel, sand, and anthracite coal. The filtration rate is typically 5 gpm/ft^2.[50] Backwash currently takes place every 10-25 hours, but this time could be increased with the formation of a better floc.

Picture

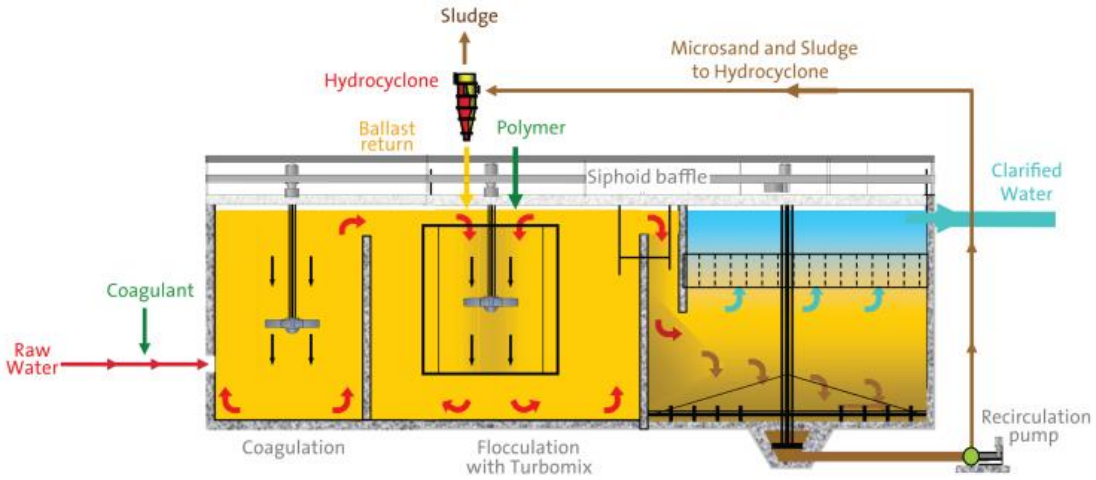


Figure 13: ACTIFLO System

Design Criteria

Table 8: AWT Alternative 2 Design Criteria

ACTIFLO Design Criteria			
	Value	**Range**	**Units**
Flow Rate	4		mgd
Clarifier			
Loading Rate	30	60-180	gpm/ft^2
Area	2100		ft^2
Filter			
Filt. Rate	12	5-24	m/hr
Area	52.57		m^2
	565.6		ft^2

[50] Water and Wastewater engineering, 19-7

Evaluation Criteria:

- Phosphorous removal: all particulate P, assumed to be down to 0.03 mg/L based on the current system
- TSS removal: 0-5 mg/L final TSS[51]
- Ammonia Nitrogen Removal: none
- Clarifier years of operation: 20
- Operational complexity: moving parts in coagulation, flocculation, and hydrocyclone contribute significant complexity

Site Plan

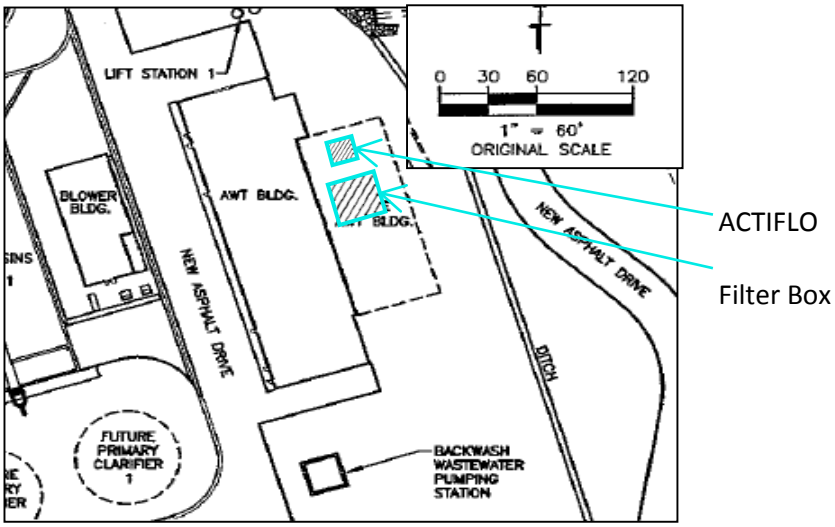


Figure 14: ACTIFLO Site Plan

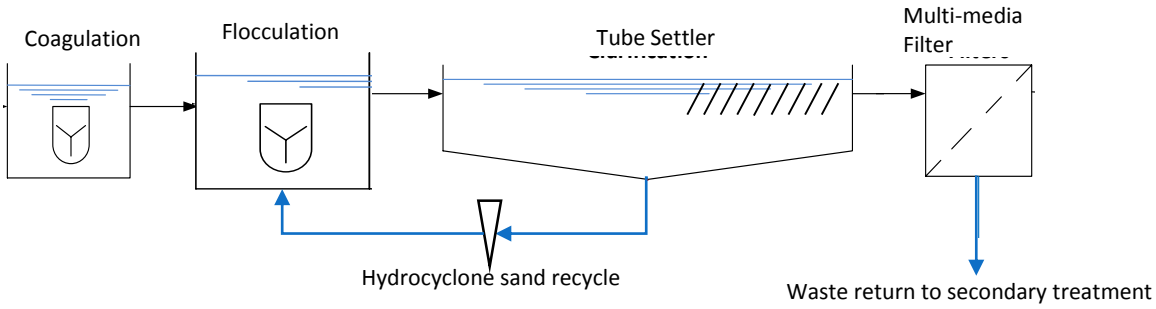


Figure 15: ACTIFLO Process Flow Diagram

Benefits and Drawbacks

The system has a small footprint and will ensure better floc formation. There could be issues with clogging in the tube settlers. It is used in their water treatment plant, so they are familiar with it.

[51] Ibid, 19-5

Costs[52]

Table 9: AWT Alternative 2 Costs

Capital Cost	**million $**
ACTIFLO	2.1
Filtration	1.8
O & M Cost	**thousand $/yr**
Coagulation	154
ACTIFLO	150
Filtration	150
25-yr NPV	**$7.1 million**

Alternative 3: GreenDAF, Media Filter

Basic Operating Principle

This system will have an additional 4.0 mgd capacity that is added to the existing system. Coagulation, flocculation, and clarification all take place within one system, the Greendaf made by Degremont. Coagulation takes place through jet injection of ferric chloride or alum and a polymer. Ferric or Alum does is determined through jar tests for removal of all particulate phosphorus. Aluminum phosphate attaches to the polymer due to interparticle bridging. Flocculation takes place in a vertical baffled chamber with a retention time of 5-7 minutes.[53] As water travels through the chamber, floc grows and low G values ensure that the particles do not shear. A purified water and air combination is injected at the end of the floc basin. Particles attach to the air bubbles and float to the surface. A skimmer removes the sludge and the clean water exits the bottom of the basin through a permeable floor. A small portion, about 8-10% ,of the treated water is recycled into the dissolved air system. The hydraulic loading rate of the Greendaf is about 6 gpm/ft^2.[54] The air is typically pressurized to 200-800 kPa. The clean water travels to a multi-media filter composed of gravel, sand, and anthracite coal. The filtration rate is typically 5 gpm/ft^2.[55] Backwash currently takes place every 10-25 hours, but this time could be increased with the formation of a better floc.

[52] Cost information determined using consulting company software
[53] Degremont. "Greendaf". *Docslide.* http://docslide.us/technology/greendaf-tertiary-phosphate-removal-by-rapid-flotation.html
[54] Information from consulting company software
[55] Davis, Mackenzie. *Water and Wastewater Engineering.* (New York: McGraw Hill, 2011), 19-7

Picture

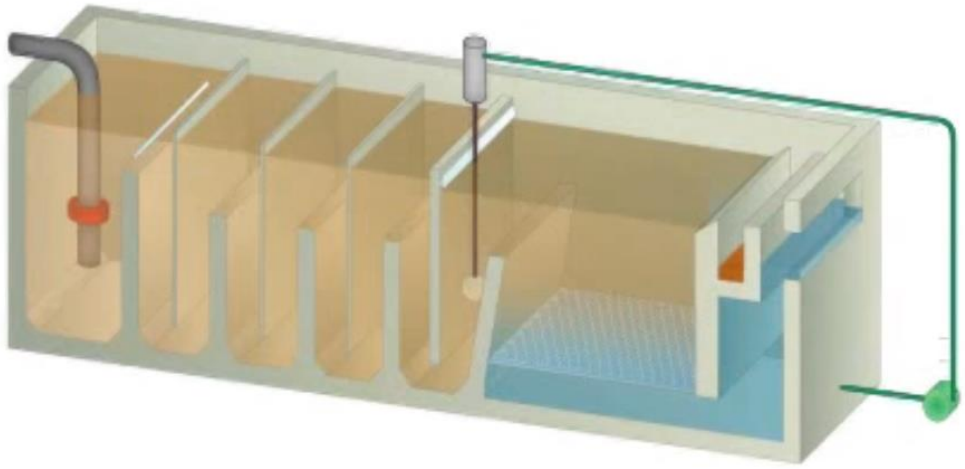


Figure 16: GreenDAF System

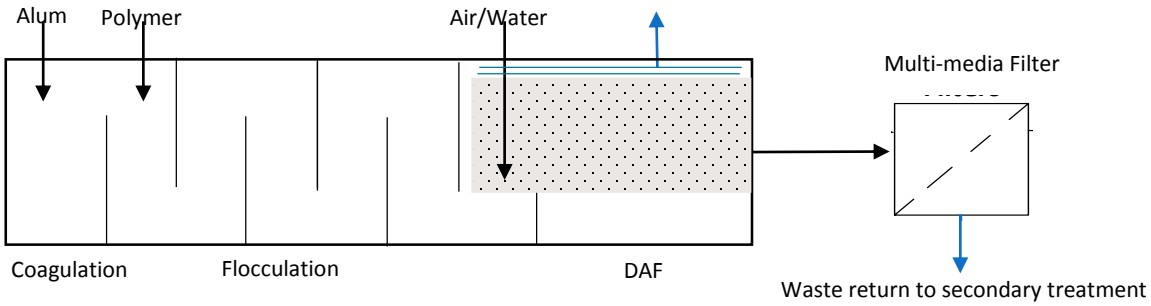


Figure 17: GreenDAF Process Flow Diagram

Design Criteria

Table 10: AWT Alternative 3 Design Criteria

GreenDAF Design Criteria			
	Value	**Range**	**Units**
Flow Rate	4		mgd
Floc			
Retention time		5-7	min
Clarifier			
Loading Rate	6		gpm/ft^2
Area	720		ft2
Filter			
Filt. Rate	12	5-24	m/hr
Area	52.57		m^2
	565.6		ft^2

Evaluation Criteria:

- Phosphorous removal: all particulate P, assumed to be down to 0.03 mg/L based on the current system
- TSS removal: 0-5 mg/L final TSS[56]
- Ammonia Nitrogen Removal: none
- Years of operation: at least 6
- Operational complexity: no moving parts, only pressurized air system

Site Plan

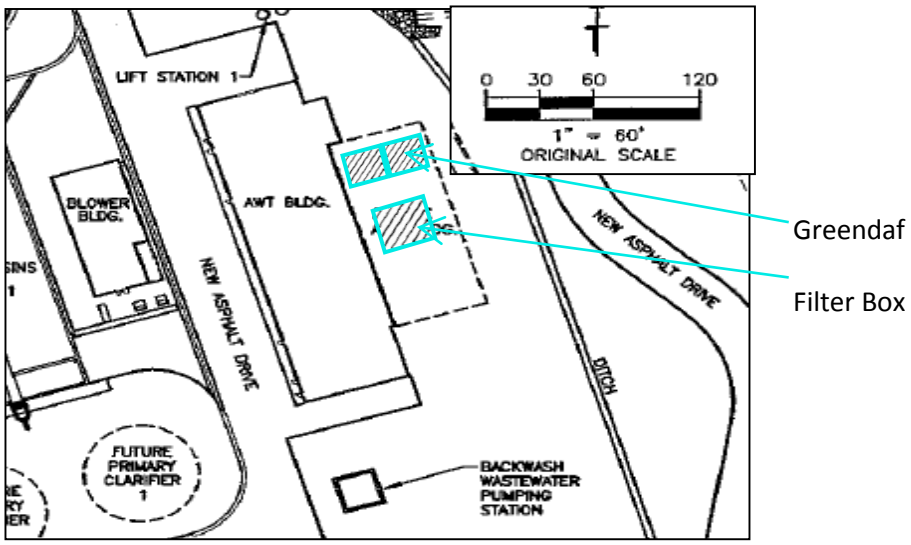


Figure 18: GreenDAF Site Plan

Benefits and Drawbacks

The system can start up and shut down instantly. DAF is used for sludge thickening in the plant, so it is somewhat familiar.

Costs[57]

Table 11: AWT Alternative 3 Costs

Capital Cost	**million $**
DAF	1.44
Filtration	1.8
O & M Cost	**thousand $/yr**
Coagulation	77
Sedimentation	61
Filtration	150
25-yr NPV	**$5.7 million**

[56] Ibid, 19-5
[57] Costs determined using a consulting company software

Alternative 4: Blue PRO

More detail for the Blue PRO system is located in the Advanced Water Treatment Conceptual Design section.

Alternative 5: Ultrafiltration Hollow-Fiber Membranes

Basic Operating Principle

Act as an absolute barrier filtering out anything larger than the given pore size of 0.01 micron.

Picture

Figure 18: Ultrafiltration Hollow-Fiber Membrane System

Design Criteria

This advanced filtration process is designed to deliver high quality potable water with effluent water having a turbidity and total suspended solids concentration of less than 0.1 NTU and 1 mg/L respectively. Also, these membranes are designed to have 5.5 log removal of bacteria, 5.5 log removal of Giardia, 5.5 log removal of Cryptosporidium, and 1.5 log removal of viruses, with a flux of 20-65 gallons/ft^2/day. They incorporate a unique backwashing process to keep the membranes clean and minimize waste by reversing the flow direction temporarily when solids accumulate on fiber surface. The membranes are engineered and designed not only for integration into existing systems, but also for high durability and compactness. They remove 60-90% of the total influent phosphorus depending on fraction of particulate phosphorus. Additionally, 60-90% of BOD_5 is removed depending on the portion of dissolved BOD_5 versus particulate in process stream. The membrane modules are composed of high strength PVDF material and utilize a unique spinning method. They are high integrity and breakage-resistant fibers with a design life of seven to ten years, and 20-30 years for the skids and immediate equipment.[58]

[58] http://www.westech-inc.com/en-usa/products/ultrafiltration-membrane-system

Site Plan

Figure 19: Ultrafiltration Hollow-Fiber Membrane Site Plan

Benefits and Drawbacks

- Can handle high flow rates with low fouling
- Automated clean-in-place system
- Built on skids for easy installation
- Small foot print
- Easily expandable
- Easy operation and maintenance
- Expensive
- Fiber breakage

Cost

25- Year Net Present Value: $2,600,000

Disinfection Alternatives

Alternative 1: Sodium Hypochlorite

Basic Operating Principle

The Parker Water and Sanitation District (PWSD) currently uses sodium hypochlorite. They use offsite generation where the solution is brought in at a 12% concentration and stored at 8%.[59] Through a pump system, they add sodium hypochlorite to disinfect the wastewater. This system requires 4 mgd of expansion in the current disinfection system in the plant. Sodium hypochlorite is a disinfecting

[59] PWSD tour

alternative that effectively uses the disinfectant properties of chlorine. When sodium hypochlorite is added to water, hypochlorous acid, sodium and hydroxide are separated. The hypochlorous acid oxidizes molecules inside organisms. The reactions damage cells, leaving the organism dead or unable to reproduce.

Picture

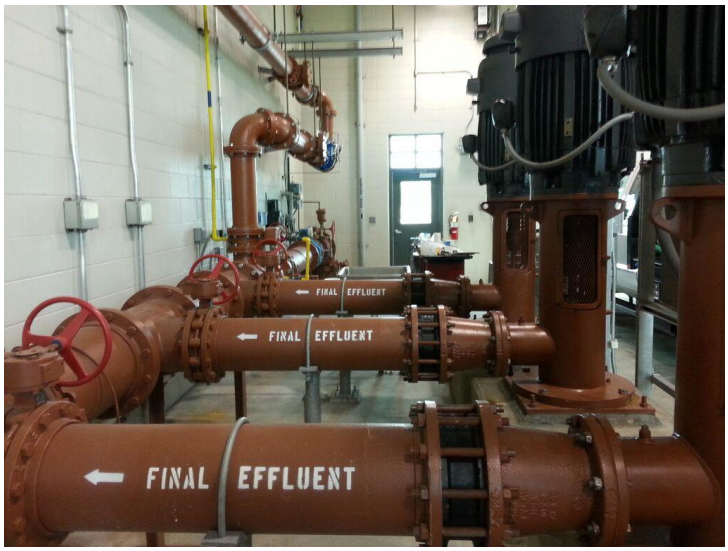


Figure 20: Current Sodium Hypochlorite Systems

Design Criteria

- 150 lb/day
- Storage capacity of 5,000 gallons
    - 22 days with current system. No additional storage capacity needed
- Need additional pump system and additional contactor
- Energy use of 6,570 kWh/year[60]
- Log removal of protozoa: 0.5
- Footprint: 3,390 ft^2
- Trucks/year: 17[61]

[60] CH2M Hill Employee conversation
[61] http://www.cityofames.org/Modules/ShowDocument.aspx?documentID=5867

Site Plan

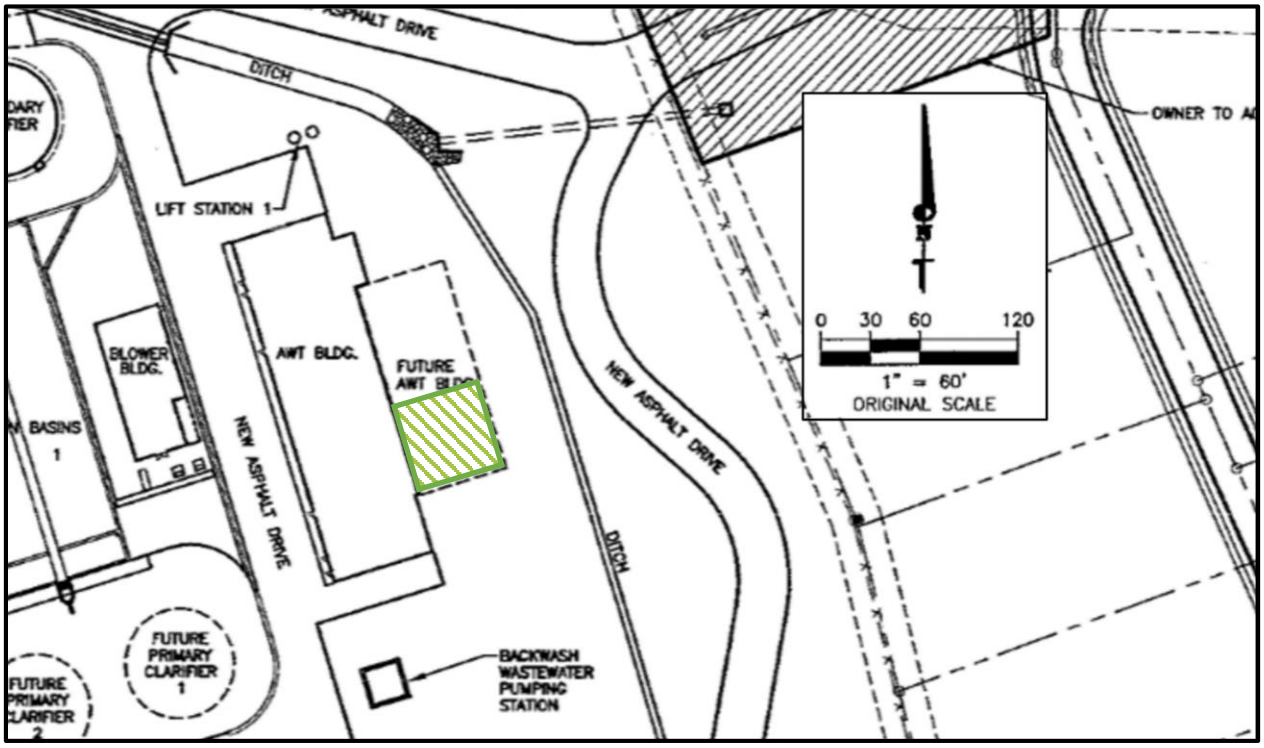


Figure 21: Disinfection Alternative 1 Site Plan

Benefits and Drawbacks

- Currently used at the plant
- Easier to handle than gaseous chlorine
- Corrosive; cannot be stored for more than a month

Costs

- Total Capital Cost: $896,000[62]
- Total O&M: $69,000
- **Total Present Value: $965,000**

Alternative 2: Chlorine Dioxide – Purate System

Basic Operating Principle

The chlorine dioxide purate system uses a two-chemical feed to inactive bacteria through oxidation. These chemicals are purate and sulfuric acid. The system feeds the purate and sulfuric acid into a reactor for mixing. After mixing, it is fed into the wastewater stream for disinfection. Purate is a solution of sodium chlorate and hydrogen peroxide. It reacts with sulfuric acid to produce the chlorine dioxide without creating chlorine dioxide gas.

[62] Ibid.

Picture

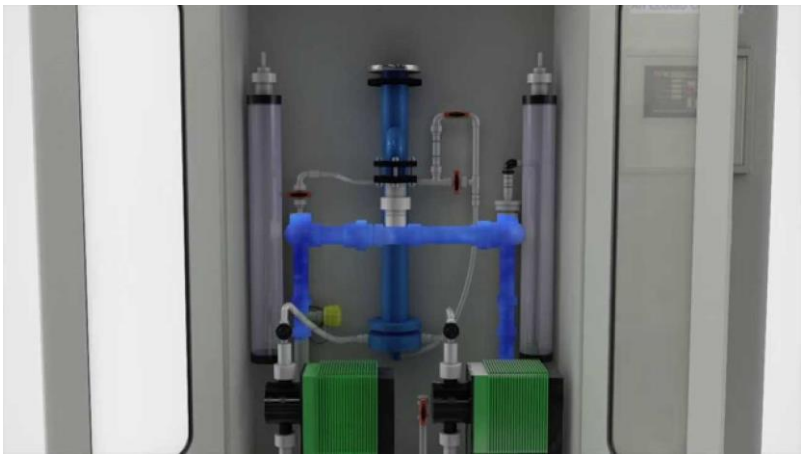


Figure 22: Disinfection Alternative 1 System[63]

Design Criteria

- Dose: 1.5 mg/L as ClO_2
- 15-minute contactor
- Maintain chlorine and sodium bisulfate systems for back up
- 75 lb/day generator
- May need an additional building for purate system
- Energy use 13,140 kWh/year[64]
- Log removal of protozoa: 2.0
- Footprint: 476 square feet
- Trucks/year: 12

Site Plan

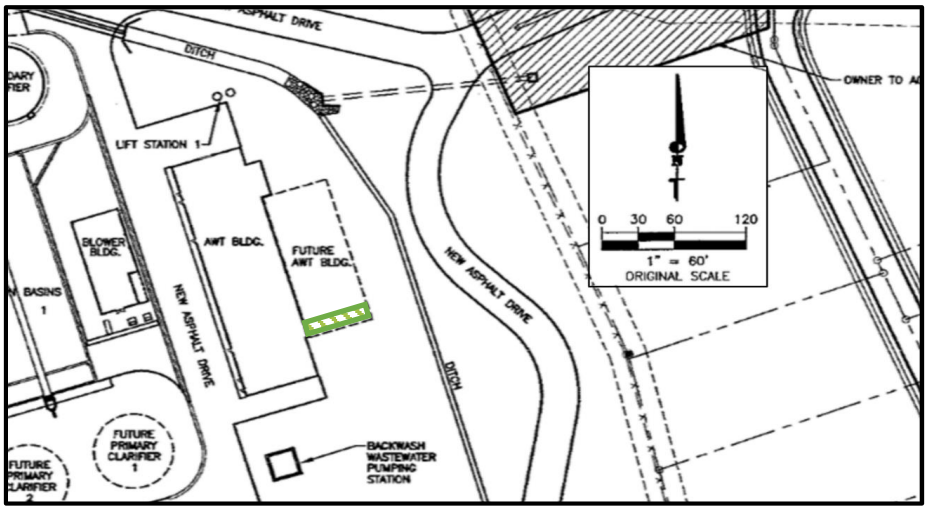


Figure 23: Disinfection Alternative 2 Site Plan

[63] http://www.ecolab.com/~/media/Ecolab/Ecolab%20Site/Page%20Content/Documents/Purate/B1349.ashx
[64] CH2M Hill Employee

Benefits and Drawbacks

- No chlorine gas used or produced[65]
- Simple two-chemical feed
    - Purate and sulfuric acid
    - Effectively deactivates two chlorine resistant pathogens, Giardia and Cryptosporidium
- Two new hazardous chemicals

Costs

- Total Capital Cost: $1,133,00
- Total O&M: $128,000
- **Total Present Value: $1,261,000**[66]

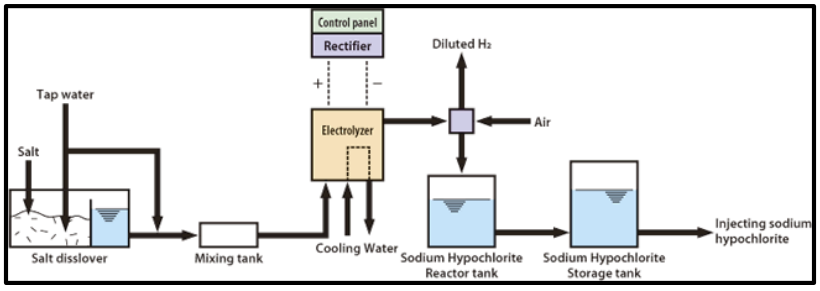
Alternative 3: On-site Sodium Hypochlorite Generation

Operating Principle

Sodium hypochlorite is a disinfecting alternative that effectively uses the disinfectant properties of chlorine. When sodium hypochlorite is added to water, hypochlorous acid, sodium and hydroxide are separated. The hypochlorous helps to oxidize molecules inside different organisms[67]. The reactions damage cells, leaving the organism most likely dead or unable to reproduce.

Sodium hypochlorite can be easily produced on-site. The process of creating sodium hypochlorite is very simple, requiring only salt, water, and electricity. When a brine solution is exposed to positive and negative anodes, several chemical reactions take place which yield a sodium hypochlorite solution. The final solution will typically have a sodium hypochlorite concentration of 0.8%[68].

Picture



[65] http://www.ecolab.com/~/media/Ecolab/Ecolab%20Site/Page%20Content/Documents/Purate/B1349.ashx

[66] http://water.epa.gov/lawsregs/rulesregs/sdwa/stage2/upload/technologiesandcostforfinallt2swtrfinalstage2ddbruledec2005.pdf

[67] http://www.lenntech.com/processes/disinfection/chemical/disinfectants-sodium-hypochlorite.htm

[68] http://www.severntrentdenora.com/products-and-services/seawater-electrochlorination-systems/clortec/750-0210.pdf

Figure 24: Disinfection Alternative 3 Process Description[69] and ClorTec CT-200 System[70]

Evaluation Criteria

- Safety: 8 truck deliveries per year
- Aesthetics: No smell
- Operational intensity: Low Intensity
- Size of plant expansion required: 875 ft^2
- Uses chemicals
- Energy use: 109,500 kWh/yr.
- Protozoa removal: 2-log inactivation
- Time for build: 6 months

Site Plan

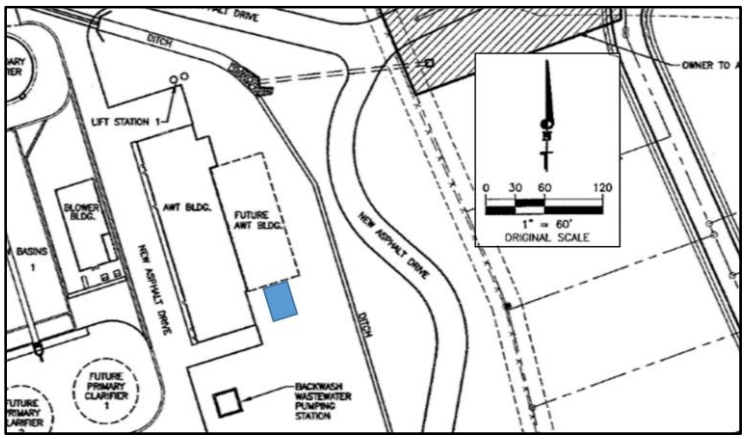


Figure 25: Disinfection Alternative 3 Site Plan

[69] http://2.imimg.com/data2/LP/ML/MY-1745588/production-of-sodium-hypochlorite.gif

[70] http://www.severntrentdenora.com/products-and-services/seawater-electrochlorination-systems/clortec/750-0210.pdf

Benefits and Drawbacks

- Well-established method for disinfection.
- There are no hazardous chemicals used in the creation of the solution
- The final solution is less concentrated than the solution that would be supplied to the plant
- No need to store large amounts of the concentrated solution
- What is stored does not decay as fast as concentrated solution

Costs

The cost estimates were obtained using CH2M Hill software.

Total Capital Cost: $1,004,030

Annual O&M: $48,000

Total Present Value: $1,754,000

Alternative 4: UV Disinfection

More detail for the UV Disinfection system is located in the Disinfection Conceptual Design section of this document.

Alternative 5: Ozone Disinfection

Basic Operating Principle

Ozone (O_3) disinfects wastewater by oxidizing the cell walls of or damaging the nucleic acids inside bacteria and other microorganisms[71].

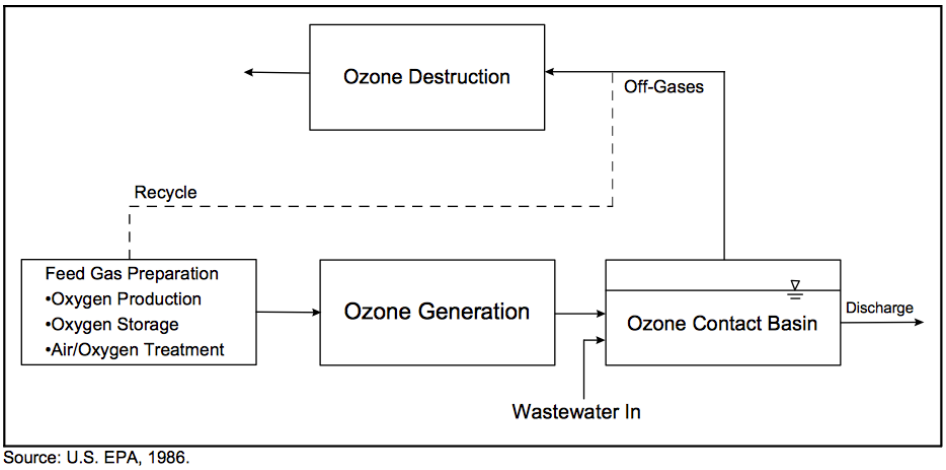
The first step in ozone disinfection is the production of ozone using an ozone generator located at the wastewater treatment plant. Ozone must be generated because it decomposes rapidly. These produce ozone using oxygen either from an air intake or from liquid oxygen which is trucked in. Once the ozone is created, it enters the wastewater through a series of diffusers in a contact tank. A typical ozone concentration requirement is about 5 to 10 mg/L[72]. After a contact time of 10-30 minutes, the wastewater is ready to exit the plant[73]. When the ozone passes through the wastewater in the contact tank, it is collected at the top and goes through a thermal destruct process[74]. This removes the ozone so the air can be put safely back into the environment. Figure 28 shows a basic layout of this process.

---

[71] United States Environmental Protection Agency. (1999) *Wastewater Disinfection Factsheet: Ozone Disinfection.* http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_ozon.pdf

[72] Ibid.
[73] Ibid.
[74] Ibid.

Picture



Source: U.S. EPA, 1986.

Figure 28: Unit Processes for Ozone Disinfection

Design Criteria

The main goal of disinfection is to remove most *E. coli*, leaving an effluent concentration of no greater than 128 colonies per 100mL as required by the PWSD permits. After the wastewater leaves the plant, however, an intake downstream takes up this water and pumps it to the Reuter-Hess reservoir, which is an intake for PWSD's drinking water plant. Since this wastewater is indirectly becoming a drinking water source, other considerations such as cryptosporidium and giardia removal are important as well. The ozone generator at this plant must be able to treat 6 mgd, which requires an ozone production of 5 to 10kg per hour[75].

Site Plan

A 6 mgd wastewater treatment plant must treat 557 cubic feet of wastewater per minute. Using the hydraulic retention time equation and a contact time of 10 to 30 min, we find that an ozone contact tank sized at 5,570 to 16,710 cubic feet is necessary. For conservativeness, this site plan was designed for the largest contact tank. A square shape with a 22' depth was assumed, leaving dimensions of 22'dx30'wx30'l. This leaves about 3.5' of freeboard at the top for ozone gas collection.

The ozone generator is about 2mx3m (6.6'x9.8')[76]. There is sufficient room at the plant for this system, without infringing upon planned future sites of other treatment components.

Figure 29 shows the location of the new systems. Other components besides the disinfection basin can be located in either the future AWT (advanced water treatment) building (1), depending on whether that will be required for those systems, in the AWT building replacing the NaOCl storage space (2), or in a new building (outbuilding).

[75] Ozonia. (2011) XF^{TM} Vessels. http://www.ozonia.com/media/pdf/ozone/OZAT-CFV-screen.pdf

[76] Ibid.

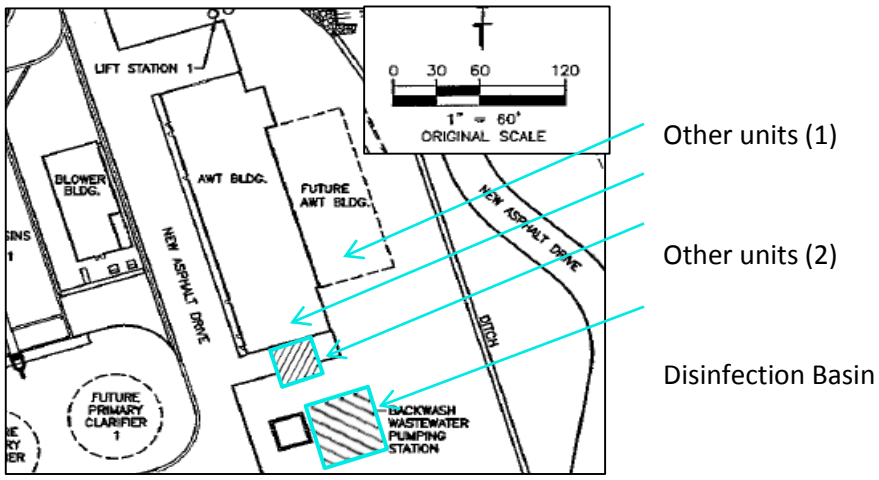


Figure 29: Possible Site Plan for Ozone Disinfection Systems

Benefits and Drawbacks

- Ozone treatment is not new and has been thoroughly tested.
- An ozone disinfection system would have a relatively small footprint.
- For an ozone generator with an air intake, the only costs associated are maintenance and electricity. Generators using liquid oxygen require less electricity than those using air, but require delivery of the liquid oxygen[77]. This increases truck traffic (a measure of public safety).
- Ozone is a toxic gas, but the smell of ozone is noticeable before it reaches a toxic concentration in the air. However, only a very small leak is required to produce a toxic concentration.
- Very few to no harmful residuals are created in the disinfection process. It also raises the dissolved oxygen content of the final effluent, benefiting the receiving water body.
- Ozone is more effective than chlorine in removing viruses, bacteria, and protozoa
- Finally, an ozone disinfection system requires complex technology and equipment. Additionally, ozone is highly corrosive.

Costs

	Air[78]	Liquid O_2[79]	
Initial capital cost	3,817,000	3,486,000	$
Yearly O+M	201,000	201,000	$
Total PV	5,706,000	5,375,000	$

[77] Ibid.

[78] United States Environmental Protection Agency. (2005) *Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule*. http://water.epa.gov/lawsregs/rulesregs/sdwa/stage2/upload/technologiesandcostforfinallt2swtrfinalstage2ddbruledec2005.pdf

[79] Ibid.