WEF and AZ Water Student Design
Competition 2021 Report:
New Gilbert North Water Treatment Plant

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Letter of Transmittal

2021 Water Environment Federation Student Design Competition Team

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Northern Arizona University

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2021 Regional Student Design Competition

Dear AZ Water Association Judging Panel,

The Northern Arizona University Student Design Team is glad to present the final design of New Gilbert North Gilbert Water Treatment Plant project for Water Environment Federation student design competition. Final design consists of design criteria based on historical flow rates analysis, population growth, drinking water regulations, selection of treatment process technologies including a lifecycle cost Analysis. Final design objectives are to design a new water treatment plant for the Town of Gilbert with finished water that has below 2.0mg/l of TOC. In addition, the client showed interest in decreased chemical usage in the plant and using new or innovative water treatment technologies.

The North Gilbert Water Treatment Plant (NWTP) was constructed in the late 90's for an initial capacity of 15 MGD and expanded in 2002 to a maximum month flow of 45 MGD. NWTP receives its source water from SRP via the Eastern Canal. SRP manages several dams and reservoirs on the Salt and Verde rivers and several dams east of Phoenix. The water is conveyed to Gilbert through a series of canals, including the Eastern Canal. The facility is operational year-round except when the SRP conducts periodic canal dries up to perform construction and maintenance in and around the canals. The NWTP site also includes one groundwater well, that is used to blend the NWTP surface water just prior to the finished water reservoirs to manage arsenic and nitrate concentrations. Groundwater can also be blended at the front of the plant.

The new design of the plant is broken into three phases to accommodate demand supply; phase 0, phase 1, and phase 2, with productions in MGD of; 45, 60, and 70 by the years; 2021, 2030, and 2050.

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List of Abbreviations

ADEQ – Arizona Department of Environmental Quality
BAC – Biologically Activated Carbon
DBP – Disinfection By-Products
DDF – Daily Demand Factor
EPA – Environmental Protection Agency
LOX – Liquid Oxygen
MCESD – Maricopa County Environmental Services Department
MGD – Million Gallons per Day
NGNWTP – New Gilbert North Water Treatment Plant
NWTP – North Gilbert Water Treatment Plant
O&M – Operation and Maintenance
ppm – parts per million
RO – Reverse Osmosis
SVWTP – San Tan Valley Water Treatment Plant
TOC – Total Organic Contents
UF – Ultrafiltration
UV – Ultraviolet
WTP – Water Treatment Plan

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Water/Wastewater Engineer at HDR Inc.

1.0. Project Introduction

The project goal is to design a new Water Treatment Plant (WTP) in Gilbert, Arizona. The new facility will need to initially treat 45 million gallons per day (MGD) of water in 2021 and be able to treat 70MGD by 2050.

1.1. Project Location

The water treatment plant will be located in Gilbert, Arizona at the southwest corner of Guadalupe Road and Higley Road. The current treatment plant sits just east of the Salt River Watersheds Eastern Canal and to the west of Nichols Park. The location of the treatment plant can be seen in Appendix - A.1.

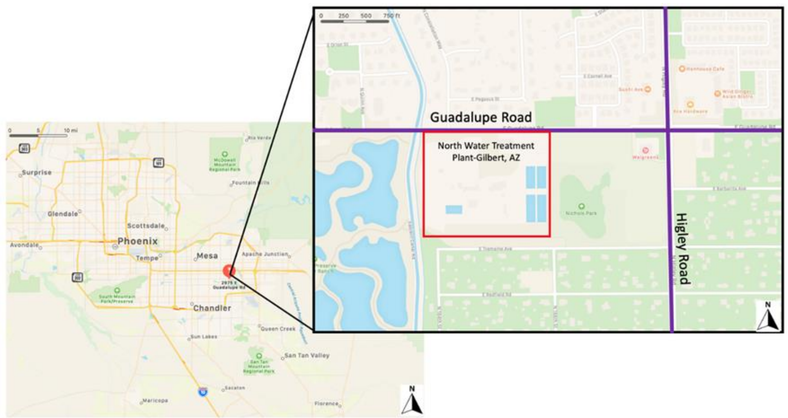


Figure 1-1: Project Location-Gilbert, Arizona [1,2]

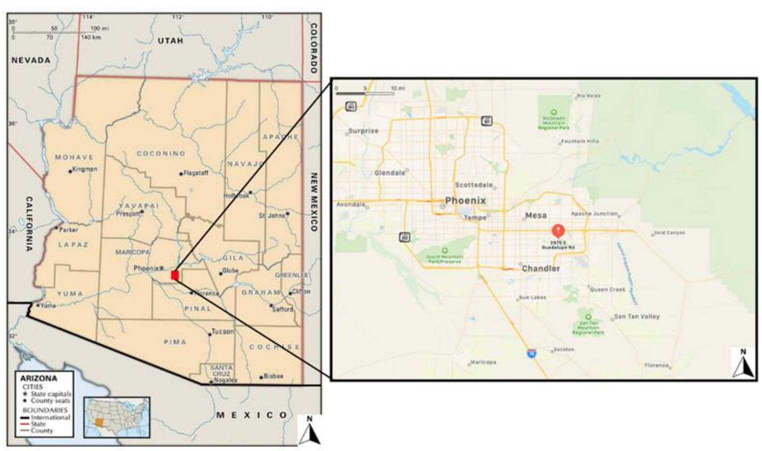


Figure 1-2: Project Location-Guadalupe Rd and Higley Rd

1.2. Background

While the current water treatment facility of Gilbert meets the volume demands of the current population, it has begun to have trouble keeping up with increases in turbidity and Total Organic Content (TOC) within the water caused by forest fires along the source canal. These existing facilities cannot be improved further to handle the increased TOC levels. As such, the city requests a replacement plant that will lower the TOC and turbidity levels in the finished water, while still meeting all other water regulations.

1.3. Constraints

Constraints include: meeting water regulations from the Environmental Protection Agency (EPA), Arizona Department of Environmental Quality (ADEQ), and the Maricopa County Environmental Services Department (MCESD); meeting the expected water demand in the projects finish year, and demand for each phase of construction; having the ability to meet demand while conducting maintenance; fitting on the available land; and will be built in phases up to the final demand volume.

1.4. Objectives

The objective is to design a new WTP for Gilbert, Arizona with finished water containing less than 2.0mg/l of TOC. In addition, the client showed interested in decreasing chemical usage throughout the plant and examining new or innovative water treatment technologies.

1.5. Exclusions

This project excludes design work related to the collection and transportation of the WTP's water from or to the WTP, operation procedures for the designed WTP, a formal environmental impacts statement, acquiring permits, conducting lab tests/studies, and a fully detailed construction plan.

2.0. Site investigation

Due to the ongoing pandemic, the field work consisted of a virtual walkthrough of the existing North Gilbert Water Treatment Plant (NWTP). All relevant data was provided by the client during this virtual walkthrough. The water used at the NWTP comes from the Salt River Watershed's Eastern canal. The canal is supplied with water from both the Verde River and Salt River. The existing plant also uses groundwater wells on a conditional basis. The source water is generally high in TOC at approximately 3.6mg/l. There is also concern for high levels of organics, turbidity, arsenic, and nitrates as well as Disinfection Bi-Products (DBP) formed from the use of chlorine. Right now, the plant can treat a maximum of 45MGD using conventional treatment methods. A photograph of the existing layout can be found in Appendix - A.2.

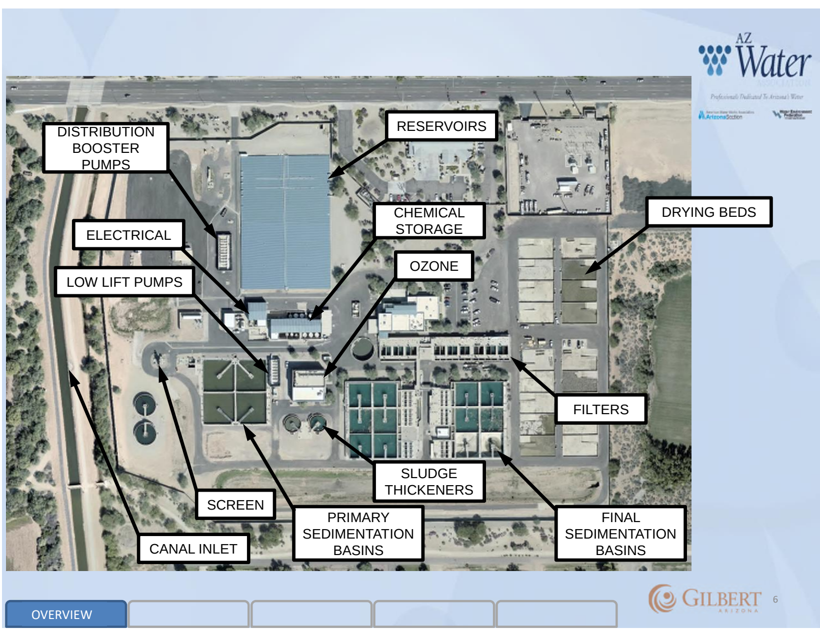


Figure 2-1: Existing Plant Layout Photograph [2]

Table 2-1: Table of Water Characteristics

Table 4 NWTP source water quality data summary (January 2015-April 2018)

Primary Source	Salt River				Verde River			
	Average[1]	Range[1]	Count[1]	Non-Detect Count	Average[1]	Range[1]	Count[1]	Non-Detect Count
Alkalinity as $CaCO_3$ (mg/L)	156	110-217	503	-	191	111-256	437	-
Arsenic (µg/L)	6.0	3.2-8.9	155	-	8.6	3.6-14.1	155	-
Bromide (mg/L)	0.147	0.054-0.231	142	10	0.106	0.052-0.225	111	35
Conductivity (µS/cm)	1761	630-2288	504	-	833	326-1768	438	-
Nitrate (mg/L as N)	1.14	0.03-5.36	438	66	0.81	0.003-5.07	418	18
pH (SU)	8.23	7.89-8.51	503	-	8.31	7.82-8.74	437	-
Temperature (°C)	25.2	12.7-29.1	503	-	19.5	10.8-29.2	434	-
Total Organic Carbon (mg/L)	3.51	1.08-6.46	282	-	3.67	0.46-6.86	293	4
Turbidity (NTU)	10.2	3.62-157	504	-	15.1	2.83-87.2	438	-

[1]*Non-detect data not included*

3.0. Demand Calculations

The current (2020) population is estimated at about 252 thousand [1]. Population estimates go out to the year 2050 with an estimate of about 318 thousand in the year 2050 [1]. The estimated build out population was 330 thousand [2]. The buildout population was used in calculations because it was relatively close to the longest-term population estimates.

The current population and current production potential for both the NWTP and the San Tan Valley Water Treatment Plant (SVWTP) were used to estimate the average per capita demand. This value was used to calculate the total potential production required by the New Gilbert North Water Treatment Plant (NGNWTP) of about 66 MGD. This was rounded up to an even 70 MGD. Daily demand factors were carried through from the original plants' potential production under the assumption that the existing plants have sufficient daily demand factors. Detailed calculations can be found in Appendix - B.

Demand was separated into three phases; phase zero, phase one, and phase two, for the years; 2021, 2030, and 2050 respectively, for the demands; 45, 60, and 70, respectively in MGD. These demands were found using the same method as the 2050 demand, using population estimates for their respective years [1]. This is summarized in Table 3-1, and detailed calculations can be found in Appendix - B.

Table 3-1 Production of NGWTP

Production of NGWTP by Year		
	Year	Design Production(MGD)
Phase 0	2021	45
Phase 1	2030	60
Phase 2	2050	70

4.0. Treatment Process Selection

Alternative processes were selected using decision matrices. Each decision matrix involved criteria, weighting those criteria, generating scores for each alternative, normalizing those scores, and then weighting those scores to determine the best possible alternative.

4.1. Preliminary Process

The preliminary screening was considered simple enough not to merit a formal decision-making process, and a bar screen was chosen due to its ubiquitous usage in existing WTPs. This means that the structure will be the most cost efficient, as commercial versions will be cheaply available and WTP workers will be familiar with its Operation and Maintenance (O&M), and there is little doubt about the effectiveness of its function. The bar screen will catch large objects, isolating them from the plant and preventing them from causing damage to more expensive treatment processes. The bar screen will reduce maintenance costs for processes further down the line, reducing overall maintenance costs for the facility. Image of chosen bar screen can be seen in Appendix - C

4.2. Clarifiers

The plant design used a primary and secondary clarifier. Each used a different decision-making process because each was implemented for a different reason. The primary clarifier was desired to reduce initial turbidity and TOC levels coming into the plant from the source water. The secondary clarifier was desired to remove Disinfection Byproducts (DBP)s.

4.2.1. Primary

There were two alternative designs considered for the primary clarifier design. A decision matrix was used to compare these two technologies to each other and can be found, in full, in Appendix - D.1.

There were six criteria used to determine the best technology for the primary clarifier and were weighted based on the clients' needs. These criteria were lifecycle cost, O&M, social and environmental factors, staffing levels, process efficiency improvements, and feasibility and constructability.

Lifecycle costs and O&M costs were estimated using a WTP cost estimation formula [3], social and environmental factors were judged based on engineering judgment, staffing levels were based on available literature [4], process efficiency improvements were based on typical TOC removal rates [5], and feasibility and constructability were based on engineering judgement.

Alternative 1-Rectangular Tank Clarifier: Rectangular clarifiers take less area than other clarifier designs. They provide an extensive pathway for the treated water and suspended solids and will not lead to short circuiting and increased sludge settling associated with circular clarifiers.

Alternative 2-Circular Tank Clarifier: Circular clarifiers function differently than the other clarifiers. Circular clarifiers function by having an inlet at the bottom of the tank. Circular tanks are easy to maintain. However, circular tanks require more land compared to the other designs.

Table 4-1 shows the final weighted scores for the alternatives from highest scoring to lowest scoring.

Table 4-1: Primary Clarifier Alternatives Weighted Decision Matrix

	Weighted Score						
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	2	2	1	1	3	3	
Rectangular	2.00	1.00	0.67	1.00	3.00	3.00	7.67
Circular	1.73	2.00	1.00	1.00	1.00	2.00	6.73

The rectangular clarifier was found to be the best alternative. The reason this alternative is preferred is because it had the greatest process efficiency improvements.

4.2.2. Secondary

There were four alternative designs considered for the secondary clarifier. A decision matrix was used to compare these four technologies to each other and can be found, in full, in Appendix - D.2.

There were six criteria used to determine the best technology for the primary clarifier and were weighted based on the client's needs. These criteria were lifecycle cost, O&M, social and environmental factors, staffing levels, process efficiency improvements, and feasibility and constructability.

The lifecycle cost was written in a dollar amount with a higher value being less desirable than a lower value and determined using a WTP cost estimation formula [3]. The same is true for the M&O cost. Social and environmental impacts were scored based on the expected TOC removal and shock load tolerance of the system found in available literature [4] with a lower value being less desirable than a higher value. Staffing levels were based on available literature and engineering judgement [3] with a higher value being less desirable than a lower value. Process efficiency improvements were estimated on average retention times found in available literature [4] with a higher value being less desirable than a lower value. Lastly, feasibility/constructability was scored based on evidence from available literature, and engineering judgement [5] with a higher value being less desirable than a lower value.

Alternative 1: Rectangular clarifiers work by allowing the particles to collect together and fall out of the water by the time they reach the end of the basin. These clarifiers balance between conserving space and price at the cost of being less efficient than some the other designs [5]. They were found to have an estimated capital cost of six-million dollars and an O&M cost of 220-thousand dollars per year.

Alternative 2: Circular clarifiers work by allowing the particles to float to the bottom where they are picked up by a scraper while the treated water floats along the top and leaves the basin. These basins are famously easy to design, and maintain, and infamously take up a larger footprint, require more parts, and additional considerations for flow splitting and short circuiting [5]. They were found to have an estimated capital cost of 2.5-million dollars, and an O&M cost of 28-thousand dollars per year.

Alternative 3: Lamella/Plate clarifiers fill a typical rectangular basin with several pipes to increase the effective surface area particles can settle onto. This makes this basin the best in terms of capacity per unit area and removal of particles, but require more design effort, are more expensive, and more maintenance intensive than other clarifiers [5]. They were found to have an estimated capital cost of 110-million dollars and an O&M of 1.5-million dollars per year.

Alternative 4: Floc Blanket clarifiers fill a hopper bottomed tank with a layer of floc that acts as a filter for the water pumped up through this floc layer. It is extremely cost effective, and low maintenance. However, it is susceptible to system shocks, and has a much longer retention time [4]. They were found to have an estimated capital cost of 340-thousand dollars and an O&M of 5 thousand dollars per year.

Table 4-2 shows the final weighted scoring for all the secondary clarifier alternatives in order of highest scoring to lowest scoring.

Table 4-2: Secondary Clarifier Alternatives Weighted Decision Matrix

Weighted Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	1.5	1.5	1	1	3	2	
Circular	0.209	0.274	0.500	1.000	3.000	1.800	6.783
Floc Blanket	1.500	1.500	0.214	0.200	1.800	1.000	6.214
Lamella/Plate	0.005	0.005	1.000	0.200	3.000	1.400	5.610
Rectangular	0.084	0.035	0.429	0.800	1.800	2.000	5.147

The circular clarifier was found to be the best alternative. The reason this alternative is preferred is because it is the most cost effective when land is not highly weighted, and land is not highly weighted.

4.3. Primary Treatment

The primary treatment includes the filtration and disinfection portions of the treatment process.

4.3.1. Filtration

There were five alternative designs considered for the filtration design. A decision matrix was used to compare these five alternatives can be found, in full, in Appendix - D.3.

There were six criteria used to determine the best technology for the primary clarifier and were weighted based on the clients' needs. These criteria were lifecycle cost, O&M, social and environmental factors, staffing levels, process efficiency improvements, and feasibility and constructability.

The lifecycle costs were written in a dollar amount with a higher value being less desirable than a lower value and determined using a WTP cost estimation formula [3]. For the environmental impacts, the waste and power needed for each alternative were considered. A value of 1 corresponded to little/no waste/power usage. A value of 2 correlated to moderate waste/power usage and a value of 3 equated to a high amount of waste/power usage. For staffing levels, how frequent and difficult maintenance is was used. For maintenance, a 1 was given for little maintenance, a 2 for moderate maintenance, and a 3 was given for high maintenance technology. For process efficiency improvements, the number of microbes, organics and inorganics was analyzed. The alternatives were scored on a 1-5 scale with a higher value equating to a higher number of pollutants removed. For feasibility/constructability, the size of the technology and difficulty of implementing the technology was analyzed. It was scored on a 1-5 scale with a higher value equating to a more feasible solution.

Alternative 1-Rapid Sand Filtration: In this type of filtration system, particles will get absorbed into the filtration material. Sand filtration is generally effective in reducing pollutants at a reasonable cost. It is also relatively easy to maintain through backwashing. Dual sand filtration systems have a high filtration rate and require a small area [6].

Alternative 2-Ultrafiltration (UF): Ultrafiltration is a low-pressure membrane filter. The UF membrane has a nominal pore size of 0.01 micrometers making it an effective technology for the removal of viruses, bacteria, protozoans, suspended solids, and turbidity. Chemicals will be needed to clean the membranes regularly. There are no DBP and a smaller construction footprint with this design. Unfortunately, UF membranes will not remove dissolved organic matter which may cause poor color, taste, and odor [7, 8]. The technology is also expensive.

Alternative 3-Reverse Osmosis (RO) with Pre-Treatment: Reverse osmosis is a high-pressure process where water gets pushed towards a semipermeable membrane to separate contaminants from a filtered stream of water, leaving a waste stream behind. If the water being treated has a high salt content, this can cause undesirable environmental effects. Nearly all RO systems will need pre-treatment before being used because RO membranes foul easily. A good choice of pre-treatment is microfiltration or ultrafiltration. While RO systems treat water without chemical dosing, bacteria will still get trapped in the membranes. This means the RO will need to be cleaned from with biocides; however, the system should work more efficiently with a pre-treatment. The cost for a RO system is high and generally not feasible for large treatment plants [9, 8].

Alternative 4-Slow Bio-Sand Filter: Slow bio-sand filters works best when the water coming in is ozonated which increases its biodegradable organic matter. One advantage is that bio-sand filters do not have chlorine coming in with the filter influent. Biofilters remove organic matter, various minerals, and improve taste and odor. The filter media in the biofilter will need to be changed out or regenerated periodically to keep the system working, so there is some maintenance involved. Slow filters take up a large amount of area to work properly [7, 10].

Alternative 5-Cloth Media Filtration: Cloth Media Filtration has water going through a series of discs with cloth over them. This is an inexpensive treatment technology as well as one that has few harmful impacts and does not take up much space. Cloth media filtration devices are low maintenance, but they are not as effective in removing TOC as other alternatives [11, 12].

Table 4-1 shows the final weighted scoring for all the filtration alternatives in order of highest scoring to lowest scoring.

Table 4-1: Filtration Alternatives Weighted Decision Matrix

			Weighted Score				
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	2	2	1	1	3	1	
Rapid Sand Filter (Anthracite/Sand)	2.00	0.72	1.00	0.50	2.40	1.00	7.62
Cloth Media Filter	1.77	2.00	1.00	1.00	0.60	1.00	7.37
Slow Bio-Sand Filter	1.23	0.56	1.00	0.33	2.70	0.67	6.48
Ultrafiltration	1.00	0.02	0.33	0.33	3.00	0.33	5.02
Reverse Osmosis w/ Pre-Treatment	0.18	0.05	0.50	0.50	2.70	0.67	4.60

The rapid sand filter was found to be the best alternative. The reason this alternative is preferred is because it has a reasonable capital/operating cost, it has little to no negative environmental impacts, it does not require a high amount of maintenance, and it does a good job in removing unwanted pollutants from the water. As rapid sand filters are fairly common and have a relatively small footprint, it scored well in the feasibility/constructability category.

4.3.2. Disinfection

There were five alternative designs considered for the disinfection treatment. A decision matrix was used to compare these four technologies to each other and can be found, in full, in Appendix - D.4.

There were six criteria used to determine the best technology for the primary clarifier and were weighted based on the clients' needs. These criteria were lifecycle cost, O&M, social and environmental factors, staffing levels, process efficiency improvements, and feasibility and constructability.

The life cycle costs are written in a dollar amount with a higher value being less desirable than a lower value. For the environmental impacts, the amount of DBPs created were analyzed. A value of 1 corresponded too little to no DBPs with a value of 2 being moderate DBPs and a value of 3 equating to a high amount of DBPs. For staffing levels, how frequent and difficult maintenance is was used. For maintenance, a 1 was given for little maintenance, a 2 for moderate maintenance, and a 3 was given for high maintenance. For process efficiency improvements, the number of microbes, organics and inorganics was analyzed. The alternatives were scored on a 1-5 scale with a higher value equating to a higher number of pollutants removed. For feasibility/constructability, the size of the technology and difficulty of implementing the technology was analyzed. It was scored on a 1-5 scale with a higher value equating to a more feasible solution.

Alternative 1-Ozonation with liquid oxygen (LOX) and Chlorination (Sodium Hypochlorite): The existing disinfection technologies at the NWTP include pre-ozonation before the final sedimentation basins followed by chlorine dosing after the filtration. The use of ozone as a disinfectant is relatively expensive, but it does an effective job in eliminating organics, taste and odor, bacteria, and viruses. A LOX storage tank, ozone generator, and contact chamber are all needed for this process. The use of LOX rather than natural air is used to reduce maintenance in large treatment plants. If the source water has Bromide, there will be a reaction with the ozone causing Bromate. Ozone does not cause the other DBPs that chlorine does [13, 14]. Sodium Hypochlorite can be very useful in reducing some pathogenic organisms in water; however, chlorine does react with some natural organics causing the formation of DBPs. Compared to chlorine gas, it is safer to store and handle. It can also cause taste and odor problems. Chlorine acts as an effective residual for the water leaving the plant, and it is relatively inexpensive and does not require a lot of maintenance [15, 16].

Alternative 2-Ozonation with LOX: The use of ozone as a disinfectant is relatively expensive, but it does an effective job in eliminating organics, taste and odor, bacteria, and viruses. A LOX storage tank, ozone generator, and contact chamber are all needed for this process. The use of LOX rather than natural air is used to reduce maintenance in large treatment plants. If the source water has Bromide, there will be a reaction with the ozone causing Bromate. Ozone does not cause the other DBPs that chlorine does [13, 14].

Alternative 3-Pre-Ozonation with LOX and Ultraviolet Radiation: The ozone system will be the same as above with the storage tank, ozone generators as well as the contact chamber [13, 14]. After the filtration, a series of UV lights would be added. UV has the advantages of having short treatment time, having no odor/taste problems, no chemical dosing needed as well as not forming any DBPs. Unfortunately, UV does not provide any residual downstream of treatment, and does require electricity [15, 16, 8].

Alternative 4-Ultraviolet Radiation: The UV system would be the same as mentioned above. If used alone, it is slightly less effective than with pre-ozonated water. It is relatively inexpensive considering how UV systems have been growing in popularity [15, 16, 8].

Alternative 5-Chlorination (Sodium Hypochlorite): Chlorination can be useful in reducing pathogenic organisms in water, but it can easily form DBPs by reacting with natural organics in the water. It may also cause taste and odor problems. Chlorine acts as an effective residual for the water leaving the plant, and it is not expensive [15, 16].

Table 4-3 shows the final weighted scoring for all the disinfection alternatives in order of highest scoring to lowest scoring.

Table 4-3: Disinfection Alternatives Weighted Decision Matrix

			Weighted Score				
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	2	1	1	1	4	1	10
Pre-Ozonation (LOX) and UV (Trojan UV Signa)	0.15	0.03	1.00	0.50	4.00	0.80	6.48
UV (Trojan UV Signa)	1.07	0.56	1.00	1.00	1.60	1.00	6.24
Chlorination (Sodium Hypochlorite)	2.00	1.00	0.33	0.50	1.60	0.40	5.83
Ozonation (LOX)	0.17	0.03	1.00	0.50	3.20	0.90	5.80
Pre-Ozonation (LOX) and Chlorination (Sodium Hypochlorite)	0.16	0.03	0.33	0.33	4.00	0.20	5.05

The preferred solution for a disinfection technology is Pre-Ozonation (LOX) and UV Radiation. While they have relatively high capital and operating costs, the negative environmental impacts are low as well as the maintenance needed. The combination of Pre-Ozonation and UV Radiation is effective in removing pollutants from the water as well as reducing poor taste and odor. The feasibility/constructability also scored reasonably.

4.4. Solid Management

There were four alternative designs considered for the solids management design. A decision matrix was used to compare these four alternatives to each other and can be found in Appendix - D.5.

There were four criteria used to determine the best technology for the solid management and were weighted based on the client's needs. These criteria were initial investment cost, total lifecycle cost, and social and environmental factors.

Alternative 1-Belt Filter Press: A belt filter press is a machine that separates solids and liquids. It is a type of filter that dewaters sludge as it moves through the system. This system mainly runs sludge made of biosolids into a collection tank, and as the system is run, the solids are slowly pressed until all liquid is drained [17].

Alternative 2-Centrifugal thickening: Centrifugal thickening is the process of increasing the sludge concentration by migrating particles to the walls of a rapidly rotating cylindrical bowl through the usage of a centrifugal forces [18]. This process includes the use of dewatering and produces non-liquid material that is also known as "cake" [4]. Dewatering centrifuges requires high energy consumption per unit of solids to achieve higher solid concentrations [19].

Alternative 3-Gravity Thickening: Gravity Thickening is a system that increases the solid concentration by letting the particles settle to the base of a cylinder and producing a thickened solids stream at the base and a diluted stream at the surface [20]. A gravity sludge thickener has the same design and mechanism as a primary clarifier. This technology is fitted with a stirrer to stir the basin and let the biosolids settle at the center of the tank and flow out to the periphery. As the water flows outward from the center of the tank, the suspended solids sink to the base of the cylindrical bowl and are scraped into a cone-shaped outlet with a rotating scraper and removed at the thickened sludge product stream. As the sludge is taken, the basin is left with a diluted stream [20].

Alternative 4-Heat Drying: Heat drying is the process of using heat to evaporate water from biosolids. The heat is utilized in direct and/or indirect dryers. A major advantage of using a heat drying process is that it produces Class A biosolids, which meet the highest standards in pathogen reduction requirement. This is an effective biosolid management for facilities that are focused on the reduction of biosolid volume while producing reusable end products [21].

Table 4-4 shows the final weighted scoring for all the biosolids management alternatives in order of highest scoring to lowest scoring.

Table 4-4: Biosolids Management Alternatives Weighted Decision Matrix

	Weighted Score			
Alternatives	Initial Investment	Total Lifecycle Cost	Social & Environmental Factors	Total Weighted Score
Weight	5	3	2	10
Belt Filter Press	5.00	3.00	2.00	10.00
Heat Drying	2.00	2.40	1.33	5.73
Centrifuge Thickening	0.92	2.70	1.78	5.40
Gravity Thickening	0.19	2.40	1.56	4.14

The belt filter press was found to be the best alternative because is scored the highest in every category.

5.0. Hydraulics

5.1. Plant Layout

A layout drawing of the NGNWTP was created in AUTOCAD showing all the treatment processes with their approximate locations with respect to each other. It shows the treatment process of the plant starting at the source water going through each treatment step for each phase until the storage tank at the end of the process. This layout can be found in Appendix - E. Figure 5-1 shows a simplified diagram that displays the order of processes for the NGNWTP.

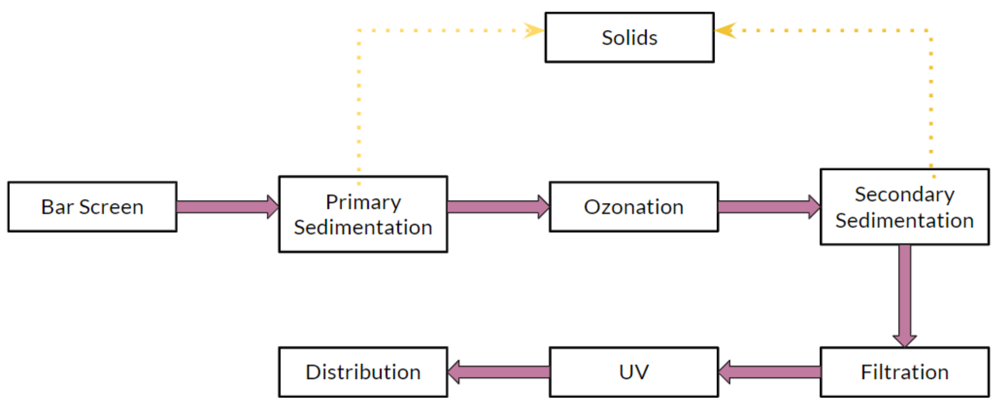


Figure 5-1: NGNWTP Process Outline

5.2. Hydraulic Analysis

The treatment plant will be designed for a maximum capacity of 70 MGD flow. The pipe material throughout the plant will be ductile iron with a diameter of 3 ft. The final layout of the treatment plant, with all the treatments and their elevation, can be found in Appendix - E.

The treatment will only require a pump system to transport water after the primary sedimentation tank to the ozonation treatment. For the remaining section of the plant, gravity pipes will be used to transport the water after the ozonation to the collection tank. To illustrate the resistance in which the pump system faces due to friction and elevation change over the range of flows, a system curve was generated, as shown in Appendix - F.1.

For the plant, there will be a total of 3 pumps (2 in use and 1 for redundancy) that are placed in parallel. The pump chosen to transport the required flowrate is a Multistage/Double Suction 3420 Centrifugal Pump by Goulds due to its capacity of handling 65,000 GPM, as shown in Appendix - F.2.

6.0. Design Recommendation

Below are all the of the designs for the selected treatment processes.

6.1. Preliminary Process

The preliminary screening was considered simple enough not to merit a formal decision-making process, and a bar screen was chosen due to its ubiquitous usage in existing WTPs. This means that the structure will be the most cost efficient, as commercial versions will be cheaply available and WTP workers will be familiar with its Operation and Maintenance (O&M), and there is little doubt about the effectiveness of its function. The bar screen will catch large objects, isolating them from the plant and preventing them from causing damage to more expensive treatment processes. The bar screen will reduce maintenance costs for processes further down the line, reducing overall maintenance costs for the facility. Image of chosen bar screen can be seen in Appendix - C.

6.2. Clarifiers

The design of the two clarifiers is given below.

6.2.1. Primary

The primary clarifier design is a rectangular clarifier. Equation 6-1 was used to determine the settling velocity of the slowest settling particle to estimate a surface overflow rate and this to calculate the total area needed for each phase. Phase zero will implement one clarifier with a width, depth, and length of $13.32m$, $4.32m$, and $37.32m$ respectively. This gives a total surface area of $496m^2$. Phase one will implement another clarifier of the same dimensions for a total of two clarifiers. This gives a total surface area of $992m^2$. Phase two will not add any more clarifiers as the phase one clarifier total is sufficient to satisfy phase two demand. Rectangular design information and final design can be found in Appendix - G

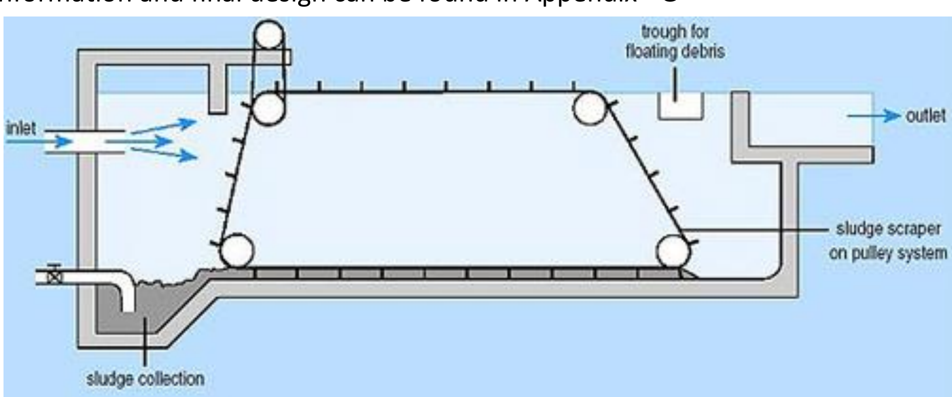


Figure 6-1: Rectangular Sedimentation Tank

6.2.2. Secondary

The complete calculations for design parameters, design diameter, and overdesign percentages can be found in Appendix - H.

The secondary clarifier design is a circular clarifier. Type one settling was assumed to control. Stokes's equation, found in Equation 6-1, was used to determine the settling velocity of the slowest settling particle. The particle diameter was chosen as $0.1\ mm$ per the smallest settable solid diameter without coagulants [5], a specific density of $2650 kg/m^3$ was chosen per recommended values [22], and all other values were chosen for water under standard conditions [23]. The Reynolds number was then checked to ensure the assumption of laminar flow was correct. It was. This settling velocity was used with the phase two discharge to estimate a surface overflow rate and this to calculate the total area needed for each phase. By trial and error, a count of six clarifiers, each with a diameter of $14m$, was found to meet each phase's flow requirements while minimizing overdesign and maintaining a singular clarifier design. Depth of the clarifier was $4m$ based on the suggested depth for a $14m$ diameter circular clarifier, and the recommended additional depth for freeboard [5]. With these values the volume was calculated and used to find the detention time.

Equation 6-1: Stokes Settling Velocity for Spherical Particles Under Laminar Conditions

$$v_s = \frac{g(\rho_s - \rho)d^2}{18\mu}$$

Phase zero will implement five $14m$ diameter clarifiers, four for demand and one for redundancy that will have a total surface area of $769m^2$. Phase one will implement two more $14m$ circular clarifiers to increase the surface area by $307m^2$. At this point there will be seven circular clarifiers, six for demand and one for redundancy, with a total combined area of $1076m^2$. Phase two will not see any more secondary clarifiers added, as the phase one surface area provides enough surface overflow rate to accommodate the phase two demand. Each clarifier will have a depth of $4m$, this includes freeboard, and a detention time of approximately 12 minutes.

Figure 6-2 below is an example of what the circular clarifier would look like, not to scale.

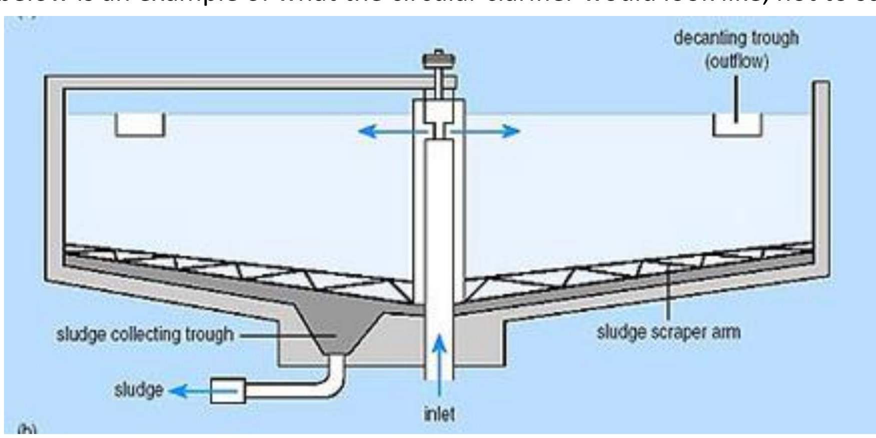


Figure 6-2: Circular Clarifier Cross Section

6.3. Primary Treatment

The design of the filtration and disinfection treatment are given below.

6.3.1. Filtration

A rapid sand filter will be the filtration technology. The Veolia Filtraflo TGV will be utilized as the rapid sand filter. Some of the key components for a rapid sand filter are a filter tank made of concrete, the filter media, an underdrain system, and wash water troughs. The filtration system will be multi-media including sand, manganese dioxide and anthracite based on the Veolia recommendation. Manganese Dioxide "creates a catalytic effect in the chemical oxidation-reduction reactions necessary to remove iron, manganese, H2S, arsenic and radium. Manganese dioxide's catalytic reaction allows iron and manganese that are not oxidized to catalytically precipitate and be adsorbed directly onto MnO2-based media" [24].

The required filter area for each phase was found using Equation I-1. The desired velocity used was m/hr 16due to the Veolia Filtraflow TGV capabilities. Equation I-2 was used to find the minimum number of filters needed assuming a standard filter area of $50m^2$. The area needed for each individual filter was found using Equation I-3. The dimensions for each individual filter and the total filtration were found. The actual velocity was found with Equation I-1.

For Phase zero, there will be ten $8m$ by $6m$ filters and the whole filtration unit will be $18m$ in width by $38m$ in length. For Phase one, there will be four more filters of the same size, and the whole filtration unit will be $18m$ in width by $59m$ in length. For Phase two, there will be two more filters added and the whole filtration unit will be $18m$ in width by $56m$ in length. The filter media will be $1.5m$ deep with $0.9m$ of anthracite, $0.3m$ of manganese dioxide and $0.3m$ of sand. The water level can be up to $1.4m$ above the media. The calculations for the recommended filters along with the Veolia Filtraflo TGV filtration specifications can be found in Appendix - I.

6.3.2. Disinfection

The necessary ozone generation rate to dose 45MGD of water with 4ppm of ozone is $1668\ lbs/day$. The necessary ozone generation rate to dose 70MGD of water with 4ppm of ozone is $2594\ lbs/day$. For Phase zero, two Ozonia CFV-30 ozone generators will be needed. One will be used for ozone treatment, and the other will be used for redundancy. For Phase one, another Ozonia CFV-30 ozone generator will be added. Ozonia Dome Bubble Diffusers will be used in an over-under ozone contact chamber. For Phase zero, one chamber will be used for ozone treatment, and the other is for redundancy. For Phase one, another chamber will be added, so two will be used for ozone treatment, and one for redundancy. The dimensions for each contact chamber are $6.6m$ deep by $3.4m$ wide by $16.5m$ long. This accounts for $0.6m$ of freeboard. There will be 11 contact cells with the first being the inlet chamber. The inlet will be at ground level, and the outlet will be at the bottom of the chamber. A depiction of an over-under ozone contact chamber can be seen in Appendix - J.3. The ozone information can be found in Appendix - J.2

For the UV lights for Phase zero, a total of 6 banks will be needed to disinfect 45MGD. 5 will be used for flow with 1 for redundancy. For Phase one, a total of 8 banks will be needed to disinfect 60MGD. Of those, 7 will be used for flow with 1 for redundancy. For Phase two, a total of 9 banks will be needed to disinfect 70MGD. Of those, 8 will be used for flow with 1 for redundancy. Approximately 60% of the individual lamps will need to be replaced annually. An open channel will be utilized for the UV disinfection. The dimensions for the UV channel are $2m$ wide by $1.8m$ deep by $18m$ long. The information for the TrojanUV Signa lamps can be found in Appendix - K.1, with the specifications found in Appendix - K.2,and Photos of a sample UV channel can be seen in Appendix - K.3.

Considering no residual is provided with the use of ozone or UV, a small amount of chlorine will also be added to provide a residual for distribution.

7.0. Cost of Implementation

Detailed results of the cost of each process per phase, Consumer Price Indexes used, preliminary cost estimator equations, and a detailed example hand calculation can all be found in Appendix - L.

Initial cost estimates were found using two methods. Method one was getting a quote from vendors. Method two used cost estimation formulas from an academic research paper that combined the Engineering News Record, Bureau of Labor Statistics cost indexes, and prices of energy and labor [3]. Method one was used for UV treatment. Method two was used for all other treatment processes.

All cost estimates using method one or method two were then converted to their 2021 equivalent money using Equation 7-1 [25] and interest rates from the Consumer Price Index for All Urban Consumers as the interest rate in the equation [26]. Then phase one and phase two principal costs, that is construction and other initial costs, were converted to a present value from their future value. This was done using a rate of inflation of 2% based on the assumption that the rate of inflation will follow a linear regression model based on the data from the Consumer Price Index for All Consumers over the last two decades.

Equation 7-1: Present Value for Single Amount

$$P = F(1+i)^{-n}$$

Then O&M costs for phases one and two were converted to a present value using Equation 7-2 and the same assumptions used to convert phase one and phase two principal costs. The O&M costs were taken out to the year 2060 to account for the phase two O&M costs.

Equation 7-2: Present Value for Uniform Series

$$P = A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)$$

The total cost of Implementation was found to be about $134 million. Table 7-1 below gives the cost estimated in 2021 dollars for each phase of construction for capital costs and O&M costs. Table 7-2 below gives the cost estimated in 2021 dollars for each fully completed treatment process in terms of the process's capital costs and O&M costs. Table 7-3 below gives the O&M cost estimated in 2021 dollars per year for each treatment process by phase.

Table 7-1: Cost of Implementation by Phase

Phase Completion Costs		
Phase #	Capital	O&M
Phase 0	$ 20,069,669	$ 63,406,973
Phase 1	$ 15,811,711	$ 28,167,445
Phase 2	$ 3,251,387	$ 4,382,488
Grand Total	$ 39,132,767	$ 95,956,906

Table 7-2: Cost of Implementation by Treatment

Process Completion Costs		
Process	Capital	O&M
Ozone	$ 21,364,482	$ 62,830,669
Rapid Sand Filter (Anthracite/Sand)	$ 8,747,502	$ 13,381,893
UV Lights	$ 6,588,000	$ 2,040,595
Primary Clarifier	$ 1,879,000	$ 17,259,193
Secondary Clarifier	$ 553,782	$ 444,556
Grand Total	$ 39,132,767	$ 95,956,906

Table 7-3: Annual Cost of Each Process by Phase in Dollars per Year

Process Annual O&M Cost			
	Phase 0	Phase 1	Phase 2
Ozone	$ 1,715,268	$ 836,591	$ -
Rapid Sand Filter (Anthracite/Sand)	$ 420,669	$ 89,591	$ 55,296
UV Lights	$ 36,000	$ 36,000	$ 36,000
Primary Clarifier	$ 257,095	$ 321,369	$ 401,711
Secondary Clarifier	$ 9,577	$ 8,973	$ -

8.0. Impacts

8.1. Social

Water treatment plants have a huge social impact in the sense that the public is provided with clean and safe water. The public will notice a change in taste and quality, and they will take interest in the sound/sight/smell of water treatment plants. This is most prominent with the clarifiers and the solids odor emissions. The public has no problem complaining when there is a taste or odor problem with the treated water. The negative social impacts include noise and odor pollution at the treatment facility. Ozone and UV are going to be a more primary method of disinfection which reduces the chlorine needed. This is a positive social aspect since there is generally a negative stigma around the use of chlorine in water. It will also be well received that the treatment plant is able to keep up with the growing population over time. Fortunately, people tend to be supportive knowing how clean their water is given that it is such a valuable resource.

8.2. Economic

With the chosen preliminary technology, the operating cost of the plant is reduced overall. For the primary sedimentation basins, there is a relatively low construction cost and lower maintenance needed compared to other alternatives. The ozone system and secondary sedimentation basins are expensive to build and maintain, but they are essential. The filtration system is not near as expensive as some other options considering some would require large amounts of energy and high life cycle costs. The recommended solids system is also low energy and has the ability to withstand a future increase in solid production resulting in an increase. The chosen belt presses will reduce the cost of transportation and storage of the solid waste. This remodel of the treatment plant will cost the city of Gilbert millions of dollars which means the residents may have higher taxes and water bills in order to complete this project. The public may not be fully on board due to how expensive this project is especially since it will not be fully expanded until 2050. The construction of this facility will provide numerous jobs in the city which is a positive aspect for this project. There will likely be an increase in population and businesses if there is guaranteed access to safe, clean, and good tasting water.

8.3. Environmental

The preliminary technology allows for a reduction in additional chemicals needed in the sedimentation phase of the treatment process. With two different sets of sedimentation basins separated by ozonation, there is not as much of reliance on chemicals for the second and larger set of sedimentation basins. Unfortunately, the chosen preliminary treatment methods can be difficult to function properly in cold weather; however, the climate in Gilbert is normally dry and hot. The sedimentation basins take up a lot of land but have high efficiency and a small occurrence of short circuiting. Ozone treatment can create DBPs if there are bromide ions in the source water which is undesirable. Ozone is also highly corrosive as well as toxic, so it should be handled with care. The byproducts associated with clarifiers are bad for the environment. Solid residual can be used in land application, disposed is surface discharge or put into a landfill [27].

9.0. Summary of Engineering Work

The scope and schedule of the project were updated after the actual competition problem statement was received and as the design work was completed.

9.1. Scope

The following describes how the scope of the project changed from the original design proposal and what the causes of those changes were.

9.1.1. Planned

The original scope can be found in Appendix - M.

The original scope involved administrative work to prepare for the competition, an ambiguous site investigation, treatment design for a wastewater treatment plant up to advanced (tertiary) treatment, a full hydraulics analysis, cost of the project, project impacts, and the projects deliverables.

9.1.2. Actual

The actual scope can be found in Appendix - M.2.

The actual scope ended up involving the administrative work to prepare for the competition, a virtual site visit, research, treatment design for a water treatment plant, partial hydraulic design, cost of the project, project impacts, and the projects deliverables.

The analysis of the data from the site investigation was less because all the information within the scope that potentially would need to be collected was provided by the client. The design capacity proceeded like expected with exception of the daily demand factors which were included in the calculation methods. The nomenclature for the treatment design changed, but the overall concepts remained mostly the same with the exception of the influent and effluent quality. The hydraulics analysis, cost of project, project impacts, and project deliverables all proceeded as expected.

9.1.3. Causes

The scope changes came primarily from the assumption that the design would be for a wastewater treatment plant, like it had been in the past three years, when it was for a WTP. This added additional research concerning WTPs and changed treatment processes being designed. The site investigation and design capacity portions were also altered based on what the client provided.

9.2. Schedule

The following describes how the schedule of the project changed from the original design proposals and what the causes of those changes were.

9.2.1. Planned

The Gantt chart of the planned schedule can be found in 0.

The original schedule planned for the completion of the design of the wastewater treatment plant treatment process in series, one after the other. Everything up to and including primary treatment was to be done by the 30%. Everything up to and including cost of the project was to be done by the 60%. The assumption was that everything would need to be done before the competition, which would be around the time of the 60% deadline, with the exception of the cost of project and deliverables specific to the 100% submittal.

9.2.2. Actual

The Gantt chart of the actual schedule can be found in 0.

The actual schedule planned for the completion of the design of the water treatment plant treatment processes in parallel, all at the same time. There was a concern that this would reduce the efficacy of each design, but that attempting to complete them in series would lengthen the project timeline past the deadline and make it more susceptible to setbacks further worsening the time crunch (as is the case of things in series vs in parallel).

9.2.3. Causes

The causes of the schedule changes are easily identifiable as there were at least two potential work weeks lost plus changes to the expected scope.

NAU made the decision to start the semester a week early in an attempt to combat the ongoing pandemic. However, the date the WEF competition provided the problem statement did not change, and so a week was lost without meaningful work being able to be accomplished. NAU also made the decision to cancel their spring break, again to combat the ongoing pandemic. This was a second work week lost. These caused a compression of the timeline and the decision to attempt design of the treatment processes in parallel. The change from a wastewater treatment plant to a WTP did not directly change the schedule but exacerbated the existing time crunch.

10.0. Summary of Engineering Costs

The original predictions and actual staffing and costs of the project are given below.

10.1. Staffing

The following describes how the staffing changed from the original design proposal and what the causes of those changes were.

10.1.1. Planned

The planned staffing table can be found in Appendix - M.1.

Table 10-1 shows a summary of the planned staffing hours for each major task. Most of the hours were expected to go towards treatment design and project deliverables, with few towards competition preparation.

Table 10-1: Planned Staffing Summary

Task Number	Task Name	Work (Hours)	SENG	ENG	LAB	INT	AA
1	Prepare for Competition	20	2	6	3	6	3
2	Site Investigation	55	14	5	17	0	19
3	Treatment Design	325	41	176	11	86	11
4	Hydraulics	40	4	23	1	11	1
5	Cost of Project	30	3	18	0	9	0
6	Project Impacts	60	6	33	3	15	3
7	Project Deliverables	105	20	51	8	22	4
Total		**635**	**90**	**312**	**43**	**149**	**41**

10.1.2. Actual

The actual staffing table can be found in Appendix - M.2.

Table 10-2 shows a summary of the actual staffing hours for each major task. Most the hours went towards treatment design and project deliverables. A sizeable number of the hours went towards preparing for the competition and hydraulic analysis.

Table 10-2: Actual Staffing Summary

Task Number	Task Name	Work (Hours)	SENG	ENG	LAB	INT	AA
1	Prepare for Competition	65	11	21	6	21	6
2	Site Investigation	9	3	4	0	2	0
3	Treatment Design	209	31	75	4	99	0
4	Hydraulics	54	7	23	0	24	0
5	Cost of Project	15	3	0	0	12	0
6	Project Impacts	21	3	9	0	9	0
7	Project Deliverables	302	51	73	28	30	120
8	Project Management	30	10	0	0	0	20
	Total	**705**	**119**	**205**	**38**	**197**	**146**

10.1.3. Causes

Changes in staffing came from misestimations of how long different processes would take to complete. They also came from the change in the expected project, resulting in more preparation for the competition.

10.2. Costs of Engineering Services

The following describes how the cost of engineering services for the project changed from the original design proposal and what the causes of those changes were.

10.2.1. Planned

Table 10-3 shows the planned cost of engineering services summarized. As can be seen, most of the cost was expected to come from staffing costs, with some additional costs coming from travel and supplies.

Table 10-3: Planned Cost of Engineering Services Summary

Staffing				
	Positions	**Hours**	**Billing Rate**	**Total Pay**
	Senior Engineer	90	$185.00	$16,650
	Engineer	312	$80.00	$24,960
	Lab Technician	43	$45.00	$1,935
	Intern	149	$17.00	$2,533
	Admin Assistant	41	$35.50	$1,455.5
			Subtotal	*$47,533.5*
Travel				
	Item	**Notes**	**Rate**	**Total Pay**
	Site Visit	1 trip at 288 miles	$0.58/ miles	$67.04
	Rental Vehicle	1 day	$62/day	$62
	Competition	1 trip at 310 miles	$0.58/miles	$179.8
	Rental Vehicle	3 days (extra 1 day to return the vehicle)	$62/day	$186
	Hotel	2 rooms 2 nights	$100/ night/room	$400.00
	Meals	2 nights (3 meals per day for 5 people)	$60/person/day	$600
			Subtotal	*$1494.84*
Supplies				
	Items	**Notes**	**Rate**	**Total**
	3D Printing	at 1kg	$0.05/g	$50
	Membership	5 people	$35/person	$175
			Subtotal	*$225*

10.2.2. Actual

Table 10-4 shows the actual cost of engineering services summarized. As can be seen, all the cost of came from staffing costs. Most of the cost comes from the senior engineer and engineer. These are because of both their high billing rate and high hours.

Table 10-4: Actual Cost of Engineering Services Summary

Positions	Hours	Billing rate	Total pay
Senior Engineer	89	$ 185	$ 16,465
Engineer	169	$ 80	$ 13,520
Lab Technician	27	$ 45	$ 1,215
Intern	177	$ 17	$ 3,009
Admin Assistant	83	$ 35	$ 2,905

10.2.3. Causes

The majority of the changes to the cost of the project came from the complete removal of the travel and supplies section of the planned cost of engineering services. These were removed as the ongoing pandemic prevented travel, and the supplies were not needed. The membership fees were still needed but were not included in the actual cost of engineering services.

Changes in the staff billing came from the previously described changes in actual hours worked.

11.0. Conclusion

The recommended design will allow for a decrease in TOC and other pollutants in the water coming from the Salt River Watershed's Eastern Canal. By the end of phase two, there will be a large increase in treated water of 70MGD by 2050 while the current plant only allows for the treatment of up to 45MGD. The facility makes use of a conventional water treatment with additional technologies in place to ensure the highest quality water possible. The utilization of UV allows for a decrease in chemicals that need to be added to the water which is a positive. There are a number of redundant technologies that allow for maintenance and expansion. While there are some drawbacks to the chosen technologies, including cost and maintenance, there is an overall improvement in the quality of the discharge which meets the client's objective.

12.0. Works Cited

[1] Maricopa Association of Governments, "Socioeconomic Projections Population and Employment by Municipal Planning Area, Jurisdiction, and Regional Analysis Zone," Maricopa Association of Governments, Phoenix, 2019.

[2] A. Water, Interviewee, *AZ Water Student Design Competition 2021.* [Interview]. January 2021.

[3] J. R. Sharma, "Development of a Preliminary Cost Estimation Method for Water Treatment Plants," The Universtiy of Texas at Arlington, Arlington, 2010.

[4] S. Parsons and B. Jefferson, Introduction to Potable Water Treatment Processes, Blackwell Publishing, 2006.

[5] Water Environment Federation, Clarifier Design, Alexandria: McGraw-Hill, 2005.

[6] T. Engelhardt, "Granular Media Filtration for Water Treatment Applications," [Online]. Available: https://www.hach.com/cms-portals/hach_com/cms/documents/pdf/applicationseminars/ Granular-Media-Filtration1.pdf.

[7] C. Halle, "Biofiltration in Drinking Water Treatment: Reduction of Membrane Fouling and Biodegradation of Organic Trace Contaminants," 2009. [Online]. Available: https://uwspace.uwaterloo.ca/bitstream/handle/10012/5022/ CHalle_Thesis_%20160210_1901_FINAL%20SUBMISSION.pdf?isAllowed=y&sequence=1.

[8] I. Najm and R. Trussell, 1999. [Online]. Available: https://www.nap.edu/read/9595/chapter/13#227.

[9] A. Basilla, "Aqua OX Water Filters," [Online]. Available: https://www.aquaoxwaterfilters.com/reverse-osmosis-water-filtration-pros-and-cons/.

[10] A. Cumming, "Stars Electronic Theses and Dissertations," 2015. [Online]. Available: https://stars.library.ucf.edu/cgi/viewcontent.cgi?article=1066&context=etd.

[11] "Aqua Ceell Water Recycling," [Online]. Available: https://aquacell.com.au/v2/wp-content/uploads/2018/10/Aqua-Cloth-Media-Filtration-Brochure.pdf.

[12] "Aqua Aerobic Systems," [Online]. Available: https://www.aqua-aerobic.com/.

[13] Pennsylvania Department of Environmental Protection, [Online]. Available: http://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/dw-27_ozone_wb.pdf.

[14] US EPA, 1999. [Online]. Available: https://www.epa.gov/sites/production/files/2015-06/documents/ozon.pdf.

[15] M. Ishaq, Z. Afsheen and A. Khan, 2018. [Online]. Available: https://www.intechopen.com/books/photocatalysts-applications-and-attributes/disinfection-methods.

[16] S. Sharma and A. Bhattacharya, 2016. [Online]. Available: https://link.springer.com/article/10.1007/s13201-016-0455-7.

[17] "EPA," [Online]. Available: https://www.epa.gov/biosolids/fact-sheet-belt-filter-press. [Accessed 7 February 2021].

[18] "Sludge Processing," [Online]. Available: https://www.sludgeprocessing.com/sludge-thickening/centrifugal-thickening/. [Accessed 7 February 2021].

[19] "EPA," [Online]. Available: https://www.epa.gov/biosolids/fact-sheet-centrifuge-thickening-and-dewatering. [Accessed 7 February 2021].

[20] "Sludg Processing," [Online]. Available: https://www.sludgeprocessing.com/sludge-thickening/gravity-thickening/. . [Accessed 7 February 2021].

[21] "EPA," [Online]. Available: https://www.epa.gov/biosolids/ fact-sheet-heat-drying#:~:text=Heat%20drying%20occurs%20when%20heat,for%20producing%20Class%20A%20biosolids. [Accessed 7 February 2021].

[22] M. L. Davis, Water and Wastewater Engineering Design Principles and Practice, McGraw-Hill.

[23] R. J. Houghtalen, O. A. Akan and N. H. C. Hwang, Fundamentals of Hydraulic Engineering Systems Fourth Edition, Upper Saddle River: Pearson, 2010.

[24] Water Conditioning and Purification, "The Magic of Manganese Dioxide: What It Is and Why You Should Care," [Online]. Available: http://wcponline.com/2013/03/03/magic-manganese-dioxide-care/.

[25] NAU Engineering Department, *Engineering Economics Basics - CENE 386,* Flagstaff: NAU.

[26] U.S. Bureau of Labor Statistics, "CPI Variance Estimate Tables," U.S. Bureau of Labor Statistics, Washington, DC, 2021.

[27] National Drinking Water Clearinghouse, [Online]. Available: https://water-research.net/Waterlibrary/septic/waterreatmentresiduals.pdf.

[28] Z. Tabatabaei and A. Mahvi, "Two-Stage Sand Filtration of Secondary Effluent for Agricultural Reuse".

[29] "Veolia Water Technologies," [Online]. Available: https://www.veoliawatertechnologies.com/asia/en/solutions/products/filtraflo-tgv.

[30] SUEZ Water Technologies and Solutions, [Online]. Available: https://www.suezwatertechnologies.com/products/disinfection-oxidation/ozonia-dome-diffuser.

[31] D. Ender and A. Mustafa, "Performace of Efficiency Indexes for Contact Tanks," Journal of Environmental Engineering, 2018.

[32] TrojanUV Disinfection Technologies, [Online]. Available: https://www.resources.trojanuv.com/wp-content/uploads/2020/12/TrojanUVSigna-Brochure.pdf.

Appendices

Appendix - A: General Project Information

Appendix - A.1: Project Location

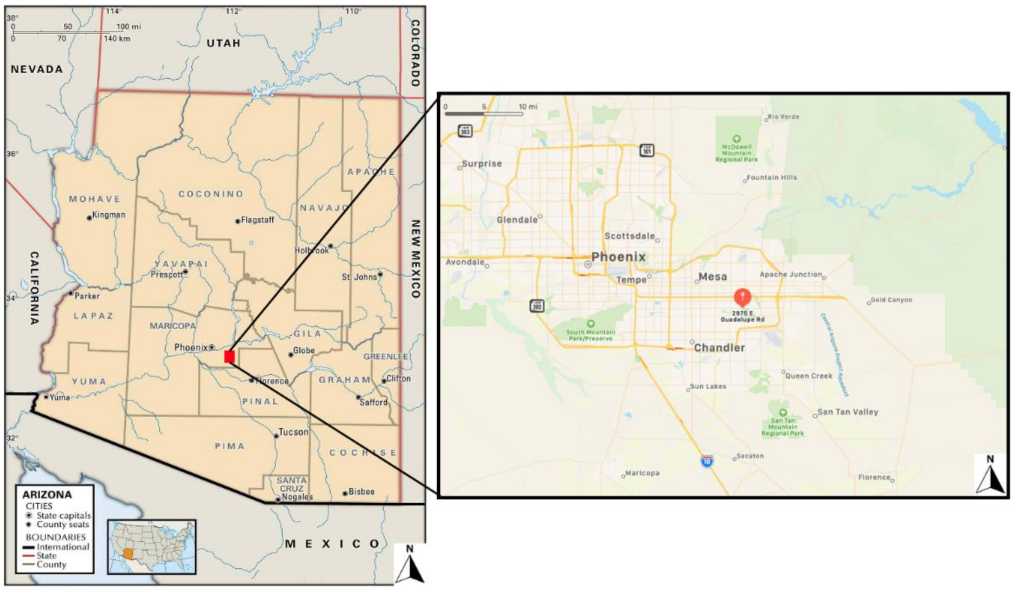


Figure A-1: Project Location-Gilbert, Arizona [1,2]

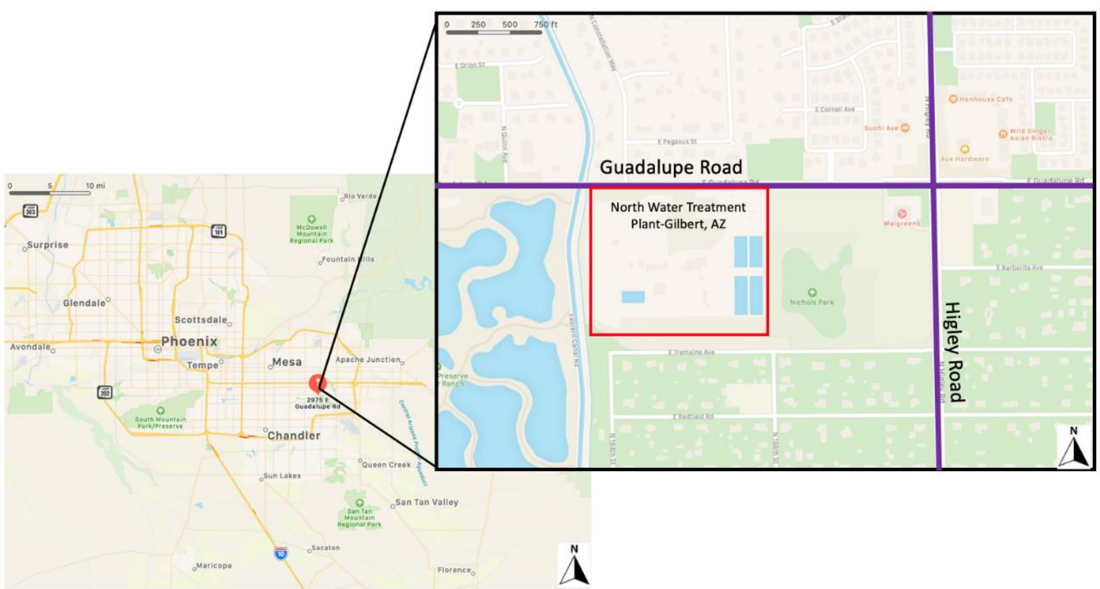


Figure A-2: Project Location-Guadalupe Rd and Higley Rd

Appendix - A.2: Existing Plant

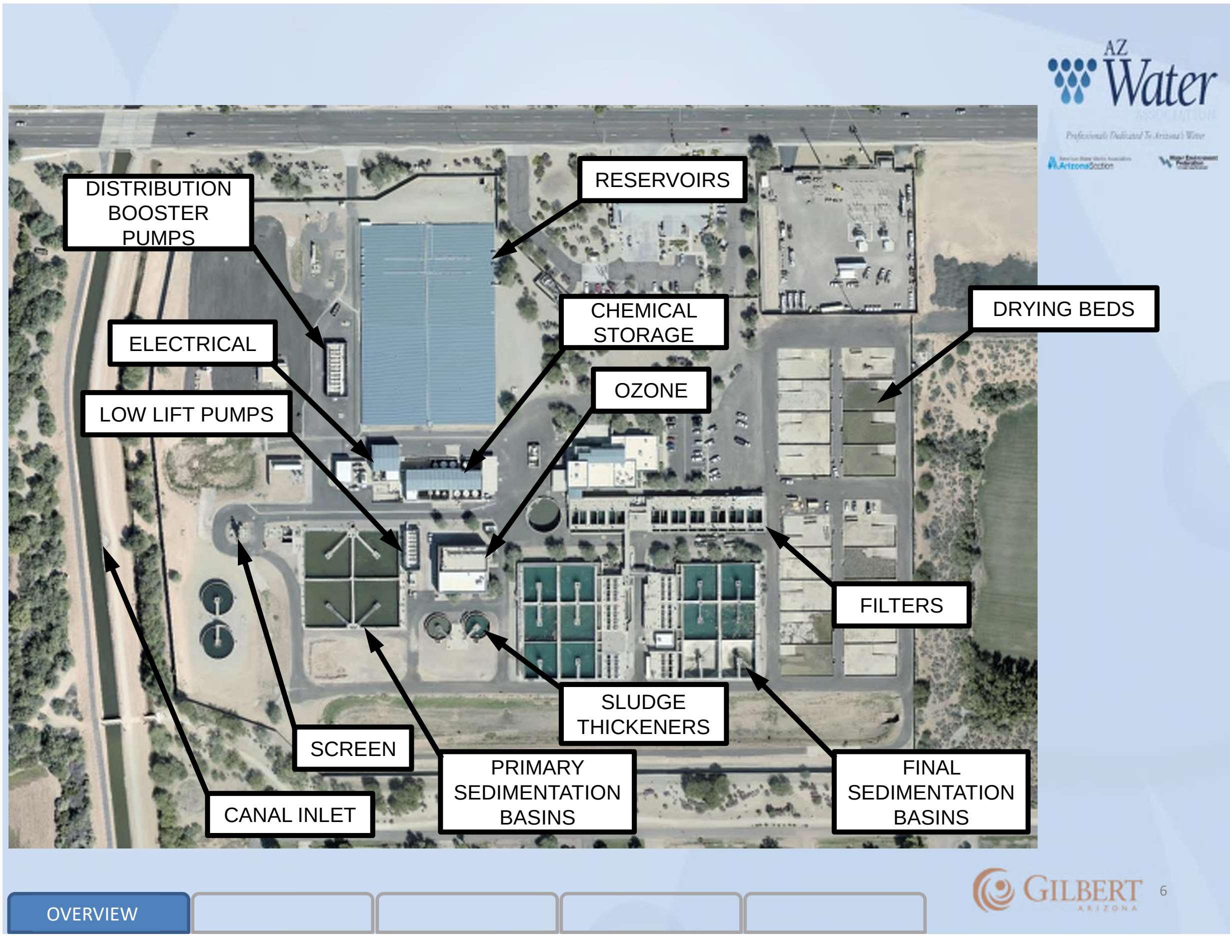


Figure A-3: Existing Plant Layout Photograph [2]

Appendix - B: Demand Calculations

Table B-1: Demand Calculations

Current Possible Water Production			
Water Source	Value	Unit	Source
NWTP	45	mgd	Gilbert 2019 H2O report
SVWTP	24	mgd	Gilbert 2019 H2O report
Total	69	mgd	NWTP + SVWTP

Population Estimates		
Year	Population	Source
2019	252260	MAG pop. Estimate
2050	318100	MAG pop. Estimate
Build Out	330000	Kickoff Report

Demand per capita (gallons per day per person)	
274	$\bar{q} = \frac{Q_{2019}}{pop_{2019}}$
Total production needed by Build Out Date(mgd)*	
90	$Q_{build\ out} = \bar{q} * pop_{build\ out}$
Total production needed by NGWTP(mgd)**	
66	$Q_{NGWTP} = Q_{build\ out} - Q_{SVWTP}$

Appendix - C- Bar screen

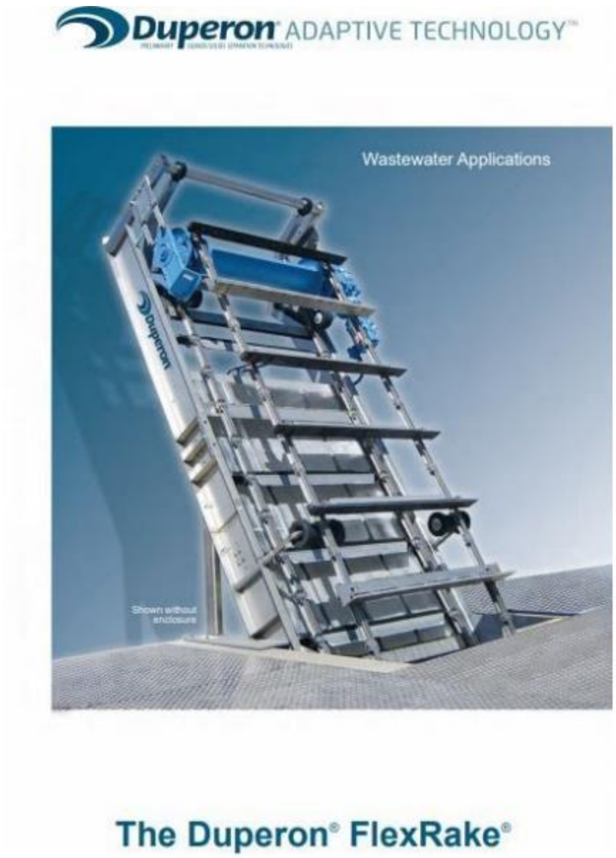


Figure C-1: Duperon Flex Rake

Appendix - D: Detailed Decision Matrices

Appendix - D.1: Primary Clarifier

Table D-1: Primary Clarifier Decision Matrix

Primary Clarifier							
Raw Value							
Alternatives	Lifecycle Costs ($)	M&O ($/yr)	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	
Best Value	750,000	103,500	2.00	2.00	3.00	3.00	
Rectangular	750,000	206,880	3.00	2.00	3.00	3.00	
Circular	864,600	103,500	2.00	2.00	1.00	2.00	
Normalized Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	
Rectangular	1.00	0.50	0.67	1.00	1.00	1.00	
Circular	0.87	1.00	1.00	1.00	0.33	0.67	
Weighted Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	2	2	1	1	3	3	
Rectangular	2.00	1.00	0.67	1.00	3.00	3.00	7.67
Circular	1.73	2.00	1.00	1.00	1.00	2.00	6.73

Appendix - D.2: Secondary Clarifier

Table D-2: Secondary Clarifier Decision Matrix

Secondary Clarifier							
Raw Value							
Alternatives	Lifecycle Costs ($)	M&O ($/yr)	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	
Best Value	336,854	5,053	3	10	6	10	
Circular	2,419,055	27,665	6.00	10.00	6.00	9.00	
Rectangular	6,030,664	219,597	7.00	8.00	10.00	10.00	
Floc Blanket	336,854	5,053	14.00	2.00	10.00	5.00	
Lamella/Plate	109,433,114	1,549,923	3.00	2.00	6.00	7.00	
Normalized Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	
Circular	0.139	0.183	0.500	1.000	1.000	0.900	
Rectangular	0.056	0.023	0.429	0.800	0.600	1.000	
Floc Blanket	1.000	1.000	0.214	0.200	0.600	0.500	
Lamella/Plate	0.003	0.003	1.000	0.200	1.000	0.700	
Weighted Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	1.5	1.5	1	1	3	2	
Circular	0.209	0.274	0.500	1.000	3.000	1.800	6.783
Rectangular	0.084	0.035	0.429	0.800	1.800	2.000	5.147
Floc Blanket	1.500	1.500	0.214	0.200	1.800	1.000	6.214
Lamella/Plate	0.005	0.005	1.000	0.200	3.000	1.400	5.610

Appendix - D.3: Filtration

Table D-3: Filtration Decision Matrix

Filtration

Raw Value

Alternatives	Lifecycle Costs ($)	M&O ($/yr)	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability
Best Value	8,854,154	200,000	1.00	1.00	5.00	3.00
Rapid Sand Filter (Anthracite/Sand)	8,854,154	554,889	1.00	2.00	4.00	3.00
Cloth Media Filter	10,000,000	200,000	1.00	1.00	1.00	3.00
Slow Bio-Sand Filter	14,412,231	720,611	1.00	3.00	4.50	2.00
Ultrafiltration	98,139,691	8,247,032	2.00	2.00	4.50	2.00
Reverse Osmosis w/ Pre-Treatment	196,279,382	17,729,152	3.00	3.00	5.00	1.00

Normalized Score

Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability
Rapid Sand Filter (Anthracite/Sand)	1.00	0.36	1.00	0.50	0.80	1.00
Cloth Media Filter	0.89	1.00	1.00	1.00	0.20	1.00
Slow Bio-Sand Filter	0.61	0.28	1.00	0.33	0.90	0.67
Ultrafiltration	0.50	0.01	0.33	0.33	1.00	0.33
Reverse Osmosis w/ Pre-Treatment	0.09	0.02	0.50	0.50	0.90	0.67

Weighted Score

Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	2	2	1	1	3	1	
Rapid Sand Filter (Anthracite/Sand)	2.00	0.72	1.00	0.50	2.40	1.00	7.62
Cloth Media Filter	1.77	2.00	1.00	1.00	0.60	1.00	7.37
Slow Bio-Sand Filter	1.23	0.56	1.00	0.33	2.70	0.67	6.48
Ultrafiltration	1.00	0.02	0.33	0.33	3.00	0.33	5.02
Reverse Osmosis w/ Pre-Treatment	0.18	0.05	0.50	0.50	2.70	0.67	4.60

Appendix - D.4: Disinfection

Table D-4: Disinfection Decision Matrix

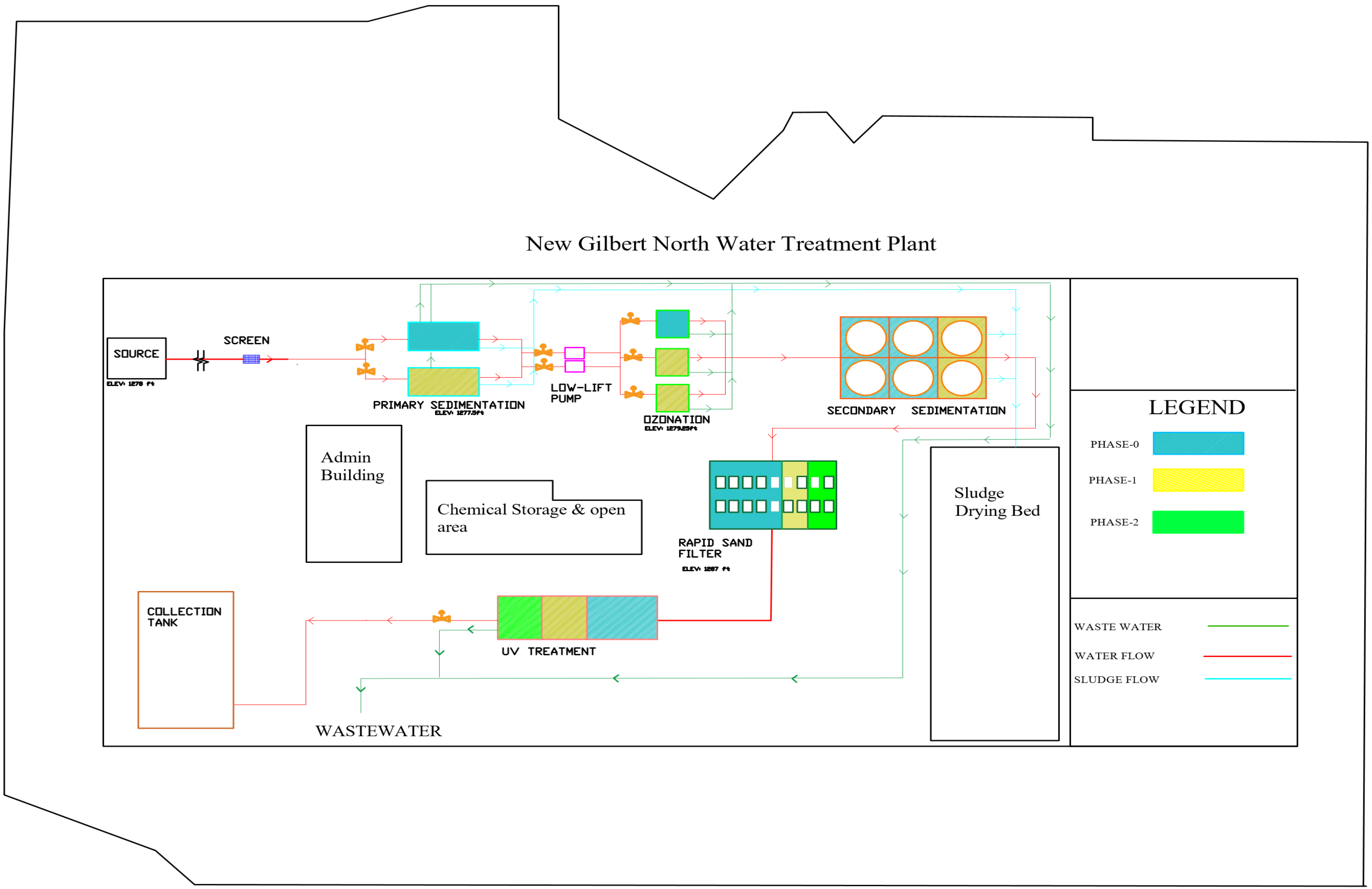
Disinfection							
Raw Value							
Alternatives	Lifecycle Costs ($)	M&O ($/yr)	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	
Best Value	1,769,525	77,407	1	1	5	5	
Pre-Ozonation (LOX) and UV (Trojan UV Signa)	24,255,528	2,641,729	1.00	2.00	5.00	4.00	
UV (Trojan UV Signa)	3,294,000	138,000	1.00	1.00	2.00	5.00	
Chlorination (Sodium Hypochlorite)	1,769,525	77,407	3.00	2.00	2.00	2.00	
Ozonation (LOX)	20,961,528	2,503,729	1.00	2.00	4.00	4.50	
Pre-Ozonation (LOX) and Chlorination (Sodium Hypochlorite)	22,731,053	2,581,135	3.00	3.00	5.00	1.00	
Normalized Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	
Pre-Ozonation (LOX) and UV (Trojan UV Signa)	0.07	0.03	1.00	0.50	1.00	0.80	
UV (Trojan UV Signa)	0.54	0.56	1.00	1.00	0.40	1.00	
Chlorination (Sodium Hypochlorite)	1.00	1.00	0.33	0.50	0.40	0.40	
Ozonation (LOX)	0.08	0.03	1.00	0.50	0.80	0.90	
Pre-Ozonation (LOX) and Chlorination (Sodium Hypochlorite)	0.08	0.03	0.33	0.33	1.00	0.20	
Weighted Score							
Alternatives	Lifecycle Costs	M&O	Social & Environmental Factors	Staffing Levels	Process Efficiency Improvements	Feasibility/ Constructability	Total Weighted Score
Weight	2	1	1	1	4	1	10
Pre-Ozonation (LOX) and UV (Trojan UV Signa)	0.15	0.03	1.00	0.50	4.00	0.80	6.48
UV (Trojan UV Signa)	1.07	0.56	1.00	1.00	1.60	1.00	6.24
Chlorination (Sodium Hypochlorite)	2.00	1.00	0.33	0.50	1.60	0.40	5.83
Ozonation (LOX)	0.17	0.03	1.00	0.50	3.20	0.90	5.80
Pre-Ozonation (LOX) and Chlorination (Sodium Hypochlorite)	0.16	0.03	0.33	0.33	4.00	0.20	5.05

Appendix - D.5: Biosolids Management

Table D-5: Biosolids Management Decision Matrix

Biosolids				
Raw Value				
Alternatives	Initial Investment($)	Total Lifecycle Cost	Social & Environmental Factors	
Best Value	120,000	10.00	9.00	
Belt Filter Press	120,000	10.00	9.00	
Heat Drying	300,000	8.00	6.00	
Centrifuge Thickening	650,000	9.00	8.00	
Gravity Thickening	3,200,000	8.00	7.00	
Normalized Score				
Alternatives	Initial Investment	Total Lifecycle Cost	Social & Environmental Factors	
Belt Filter Press	1.00	0.36	1.00	
Heat Drying	0.61	0.28	1.00	
Centrifuge Thickening	0.09	0.02	0.50	
Gravity Thickening	0.50	0.01	0.33	
Weighted Score				
Alternatives	Initial Investment	Total Lifecycle Cost	Social & Environmental Factors	Total Weighted Score
Weight	5	3	2	10
Belt Filter Press	5.00	3.00	2.00	10.00
Heat Drying	2.00	2.40	1.33	5.73
Centrifuge Thickening	0.92	2.70	1.78	5.40
Gravity Thickening	0.19	2.40	1.56	4.14

Appendix - E: Plant layout



BOUNDARY WALL

E-1

DRAWING: LAYOUT

OF: 1

PAGE: 1

BY: XX

SCALE: 1" : 40'

0 10 20 40

DATE: 4/6/2021

DUE: 4/7/2021

REVISION: 1

PROJECT: PROJECT LAYOUT

PROJECT WEF

Appendix - F: Hydraulic Analysis

Appendix - F.1: Pump Curves

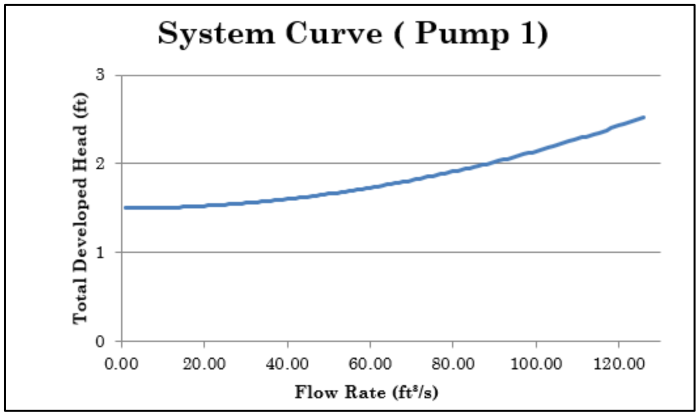


Figure F-1: System Curve- Pump 1

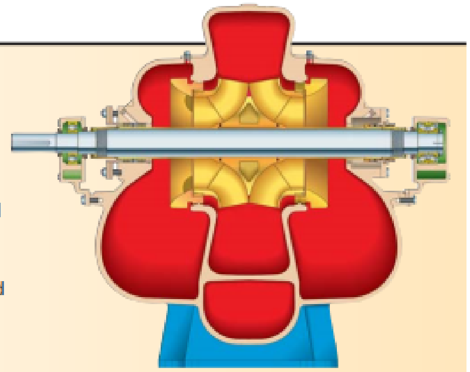
Appendix - F.2: Selected Pump

Goulds 3400

Large Capacity

Model 3420

- Sleeve bearings available
- Grease or ring oil lubricated bearings
- Packing or mechanical seals available (including cartridge and split type seals)
- Dual volute casings standard on all sizes
- Labyrinth bearing protection standard
- Alloy constructions not shown below are also available
- Shaft sleeve nuts threaded against rotation as standard
- Vertical mounting available on some sizes
- Impeller wear rings standard

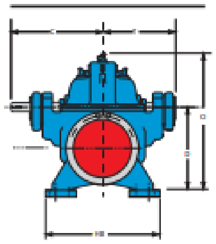


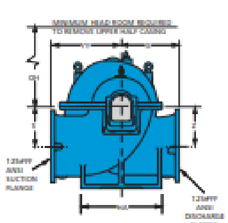
Materials of Construction

Part Description	Bronze Fitted	All Iron	316 SS Fitted	All 316 SS
Casing	Cast Iron			316 SS
Impeller	Bronze	Cast Iron	316 SS	
Lantern Ring	Teflon			
Packing	Graphite Impregnated Yarn			
Packing Gland	Bronze	Cast Iron	316 SS	
Mechanical Seal Gland	Cast Iron			316 SS
Shaft	Carbon Steel			
Shaft Sleeve Nut	Bronze	Cast Iron	316 SS	
Shaft Sleeve[1]	Bronze	Cast Iron	316 SS	
Casing Wear Ring[1]	Bronze	Cast Iron	316 SS	
Bearing Housings	Cast Iron			
Impeller Wear Ring[1]	Bronze	Cast Iron	316 SS	
Bearings	Steel (Anti-Friction)			

[1] Also available in hardened/hard metal coated materials.

Dimensions





Pump Size	C	T	D	O	OH	S & Z	X	YY	HA	HB	Weight Lbs. (kg)
12x14-15	33.0 (838)	26.8 (679)	26.4 (670)	42.3 (1073)	25.0 (635)	14.8 (375)	17.8 (451)	24.8 (629)	33.0 (838)	24.0 (610)	2600 (1179)
16x18-17/H	33.0 (838)	26.8 (679)	33.5 (851)	54.3 (1378)	31.0 (787)	18.8 (476)	20.9 (530)	31.5 (800)	33.0 (838)	24.0 (610)	3500 (1588)
16x18-30/G/H	44.4 (1127)	36.6 (930)	36.0 (914)	62.3 (1581)	41.3 (1048)	22.5 (572)	28.0 (711)	34.0 (864)	46.0 (1168)	47.0 (1194)	7060 (3202)
18x20-24/G	39.1 (992)	30.8 (783)	35.5 (902)	59.9 (1521)	38.0 (965)	19.5 (495)	20.6 (524)	38.9 (989)	49.0 (1245)	46.0 (1168)	5650 (2563)
18x20-30	44.4 (1127)	36.6 (930)	37.5 (953)	64.3 (1632)	41.8 (1060)	22.8 (578)	29.0 (737)	35.0 (889)	48.0 (1219)	47.0 (1194)	7500 (3402)
20x24-24	44.4 (1127)	36.6 (930)	38.0 (965)	63.8 (1619)	37.8 (959)	20.5 (521)	26.6 (675)	34.0 (864)	42.0 (1067)	47.0 (1194)	7200 (3266)
20x24-28/G/H	37.9 (962)	37.9 (962)	42.1 (1070)	70.3 (1784)	44.0 (1118)	23.1 (587)	24.5 (622)	46.2 (1173)	56.0 (1422)	54.0 (1372)	8650 (3924)
20x24-30	46.0 (1168)	36.6 (930)	40.5 (1029)	68.0 (1727)	42.5 (1080)	23.5 (597)	29.5 (749)	36.0 (914)	50.0 (1270)	47.0 (1194)	8000 (3629)
24x30-32/G/H/N	44.4 (1127)	39.8 (1010)	44.0 (1118)	74.1 (1883)	45.0 (1143)	22.5 (572)	36.0 (914)	50.0 (1270)	56.0 (1422)	51.0 (1295)	11,500 (5216)
30x30-31/G	50.0 (1270)	42.9 (1089)	53.3 (1353)	86.4 (2196)	50.7 (1287)	33.4 (848)	40.0 (1016)	52.0 (1321)	63.4 (1610)	53.4 (1356)	16,200 (7348)
30x30-38/G	53.0 (1346)	42.9 (1089)	53.3 (1353)	87.5 (2223)	53.3 (1353)	30.8 (781)	36.5 (927)	54.5 (1384)	63.4 (1610)	53.4 (1356)	15,400 (6985)
30x36-42/G/H	60.8 (1545)	47.6 (1210)	58.0 (1473)	97.5 (2477)	62.0 (1575)	34.0 (864)	36.0 (914)	54.5 (1384)	78.0 (1981)	76.0 (1930)	25,250 (11,453)

All dimensions in inches (mm) and are not to be used for construction or installation purposes. Standard rotation is right hand (CW). Optional rotation is left hand (CCW). Steel casings will have 150#RF flanges.

9

Figure F-2: Goulds Pump Information Sheet

Appendix - G: Primary Clarifier Design Information

Table G-1: Rectangular Clarifier Dimensions

Rectangular clarifier	
Dimensions of Clarifier	13.3m wide, 4.3m depth, 37.3m long
Phase 0 **(2025)** **45 MGD**	1 Rectangular Tank Surface area : 496m^2
Phase 1 **(2030)** **60 MGD**	Adding 1 Tank (Total 2 rectangular clarifiers) Total Surface area: 992m^2

Table G-2: Rectangular Design Information

Flowrate	2.4 m^3/s
Dynamic visocisty	0.00157 pa*s
Density of water	1000 kg
Partivle siz	0.1 mm
Desity of particle	2650 kg/m^3
gravity	9.81 m/s^2
Settling velocity	0.0057 m/s
surface area	421
surface overflow rate	0.0057
depth	4.3 m

Appendix - H: Secondary Clarifier Design Information

Appendix - H.1: Clarifier Design Parameters Calculations

Table H-1: Secondary Clarifier Design Parameters Calculations

Description	Name	Variable	Value	Unit	Value	Unit	Source	Page Number(s)	Equation/Table Number
Flowrate of "Fresh" water into the Clarifier	In Flowrate	Q_in	1.97	m^3/s		mgd			
Flowrate of the Recycled Water	Underflow Flow Rate	Q_Under	0.99	m^3/s		mgd			
Flow of Water Leaving the Clarifier	Overflow Flow Rate	Q_Over	1.97	m^3/s	45	mgd			
Flowrate of Underflow and Flowrate together Entering the Clairfier	Flowrate	Q	2.96	m^3/s		mgd			
The Flowrate per Unit of Surface Area of the Clarifier	Surface Overflow Rate	SOR	0.01	m^3/s/m^2					
Radius of the Clarifier	Radius	r	12.82	m					
Diamter of the Clarifier	Diamter	d	25.64	m					
Depth of the Clarifier	Depth	h	4	m					
Area of the water surface	Area	A	516	m^2					
The Volume of the Clarifier	Tank Volume	V	2065	m^3					
Time the Water spends in the Clarifier before leaving	Detention Time	t_o	698	s					
The acceleration caused by Earths Gravtiy	Gravitational Acceleration	g	9.81	m/s^2			Assumed Knowledge		
The Dynamic Viscosity of Water at Standard Conditions	Dynamic Viscosity of Water	mue_water	0.00157	Pa*s			Fundamentals of Hydraulic Engineering Systems	Front Cover	
Density of Water at Standard Conditions	Density of Water	roe_water	1000	kg/m^3			Fundamentals of Hydraulic Engineering Systems	Front Cover	
Kinemativ viscosity of water at standard conditions	Kinematic viscosity of water	nue_water	0.00000157	m^2/s			Fundamentals of Hydraulic Engineering Systems	Front Cover	
Density of the Particle being considered	Density of Settling Particles	roe_Particle	2650	kg/m^3			Assumed from Water and Wastewater Sedimentation Section		
Diamter of the particle being considered	Diameter of Particles	d_Particle	0.0001	m	0.1	mm	Assumed from Water and Wastewater Sedimentation Section		
Settling Velocity of the particle being considered	Settling Velocity	v_s	0.0057	m/s			Assumed from Water and Wastewater Sedimentation Section	10-4	10-12
reynolds number for the particle	Reynolds Number	Re	0.3648	Unitless			Assumed from Water and Wastewater Sedimentation Section	10-4	10-9

Appendix - H.2: Design Diameter Calculations

Table H-2: Secondary Clarifier Design Diameter Calculations

	Total Surface Area(m^2)	Diameter (m)	Total Surface Area (ft^2)	Diameter (ft)	Tank Count	Surface Area per Tank (m^2)	Tank Diamter (m)	Design Diamter (m)
Phase 0	520	25.73	5597.23	84.42	4	130.00	12.87	13
Phase 1	700	29.85	7534.74	97.95	6	116.67	12.19	13
Phase 2	810	32.11	8718.77	105.36	6	135.00	13.11	14

Appendix - H.3: Phase Overdesign Calculations

Table H-3: Secondary Clarifier Overdesign Calculations

	Final Design	Added Deisgı
Design Diamter(m)	14	
Phase 0 Surface area(m^2)	616	
Phase 1 Surface area(m^2)	924	308
Phase 2 Surface area(m^2)	924	
Phase 0 Overdesign Percentage	18%	
Phase 1 Overdesign Percentage	32%	
Phase 2 Overdesign Percentage	14%	

Appendix - I: Filtration Design Information

Appendix - I.1: Filtration Calculations

Equation I-1: Total Required Filter Area [14]

$$A_T = Q/V$$

Where:

- A_T = Total required filter area (m^2)
- Q = Inlet water flowrate ($\frac{m^3}{h}$)
- V = Desired filtration velocity ($\frac{m}{h}$)

Equation I-2: Minimum Number Filters Needed [14]

$$\#Filters = A_T/50m^2$$

Where:

- $\#Filters$ = minimum number filters needed
- A_T = total required filter area (m^2)
- $50m^2$ = standard size of a single filter

Equation I-3: Area of Each Individual Filter [14]

$$A_I = A_T/\#Filters$$

Where:

- A_I = Area of each individual filter
- A_T = Total required filter area (m^2)
- $\#Filters$ = Number of filters (including redundancy)

The phasing can be seen in Table I-8: Filtration Phasing.

Table I-8: Filtration Phasing

Rapid Sand Filtration-Veolia Filtraflo TGV			
	Phase 0 (2025)	Phase 1 (2030)	Phase 2 (2050)
Q (MGD)	45	60	70
Q (CMD)	7098	9464	11829
Desired Velocity (m/hr)	16	16	16
Total Required Filter Area, AT (m^2)	443.6	591.5	739.3
Minimum Filters Needed (with filter size of 50m^2)	9	12	15
Number of Filters Total	10 filters-9 for treatment, 1 for redundancy	14 filters-12 for treatment, 2 for redundancy	16 filters-15 for treatment, 1 for redundancy
Area Needed per Individual Filter, AI (m^2)	44.4	42.2	46.2
Dimensions of Each Individual Filter	8m X 6m	8m X 6m	8m X 6m
Area of Each Individual Filter (m^2)	48m	48m	48m
Area of All Filters (m^2)	480	672	768
Actual Velocity (m/hr)	14.8	14.1	15.4
Depth of Anthracite (m)	0.9	0.9	0.9
Depth of Manganese Dioxide (m)	0.3	0.3	0.3
Depth of Sand (m)	0.3	0.3	0.3
Total Depth of Media (m)	1.5	1.5	1.5
Water Level	up to 1.4m above media	up to 1.4m above media	up to 1.4m above media
Height of Filtration Unit (including 1m for underdrain system, media, water level, 0.6m freeboard)	4.5m	4.5m	4.5m
Width of Unit (m)	18	18	18
Length of Unit (m)	38	50	56

The percent removal of BOD, TSS and Nitrate can be seen in Table 17.2: Percent of Pollutants Removed-Filtration. The BOD, TSS and Nitrate removal from the filtration system is based on a study done on the efficiency of pollutant removal in sand filtration systems [28].

Table I.9: Percent of Pollutants Removed-Filtration [28]

Filtration	
	% Removal
BOD Removal	78
TSS Removal	89
Nitrate Removal	34

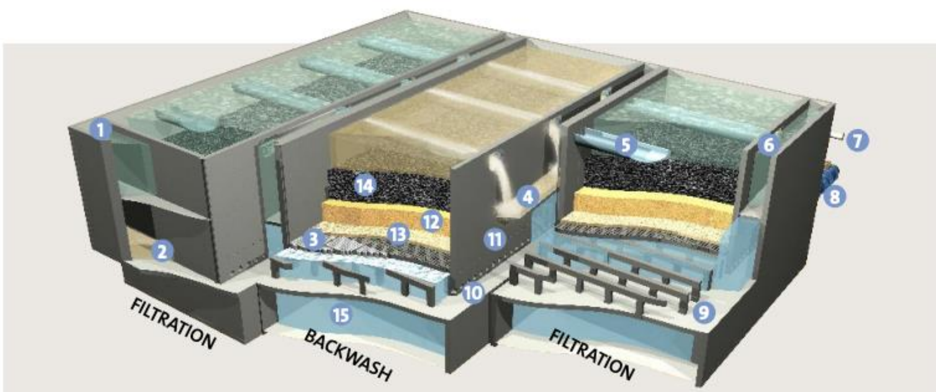
Appendix - I.1: Filtration Specifications

Filtraflo TGV

High speed filtration

After the clarification phase, filtration is the key treatment step in water treatment plants for the removal of suspended solids. Veolia Water Technologies has especially developed the high rate filtration system Filtraflo TGV for this treatment step.

Filtraflo TGV filters employ the familiar basic principle of rapid gravitational filtration of settled water through a granular media. The filtering bed is composed of single, dual or triple media layers. Filtraflo TGV is actually the most advanced and the most compact gravity filtration system within the VWT' filtration technology portfolio.



1. *Filters's Raw water inlet*
2. *Backwash water outlet*
3. *Slabs and nozzles*
4. *Dirty backwash water exit*
5. *Distribution (feed) & evacuation backwash) trough*
6. *Raw water inlet*
7. *Scour air feed*
8. *Backwash water feed*
9. *Nozzled slabs supports*
10. *Holes for backwash/filtered water pathway*
11. *Holes for scour air pathway*
12. *Sand layer*
13. *Gravel layer*
14. *Anthracite layer*
15. *Filtered water*

Operating process

The high rate Filtraflo TGV filters combine a deep sand bed (2.0 m) with a coarse filter sand (effective size 1.35 mm). The principle of Filtraflo TGV is to increase the depth and the grain size of the media, this allows the suspended solids to penetrate deeper into the filter bed, thus allowing a "volume filtration" rather than a "surface filtration".

As a consequence, high rate Filtraflo™ TGV filters can retain a larger amounts of suspended solids than conventional filters.

Optimized backwashing

Unlike conventional filters with mainly superficial clogging, the backwashing of high rate filters must be engineered to remove deeply imbedded particles distributed throughout the sand bed. To achieve such action, backwashing velocity needs to be much higher than the filtration rate.

The backwashing of the Filtraflo TGV filters includes isolation of filters, air scour, combined air and water backwash and final rinse. The first two stages are to expand and stir the filter bed to remove the bulk of the accumulated solids.

The final rinsing step by water alone allows to flush the remaining particles out of the filter.

Figure I-1: Veolia Filtraflow TGV Information [29]

Applications

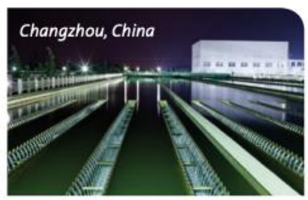
Filtraflo TGV is recommended for drinking water, process water production and for tertiary wastewater polishing.

- Removal of suspended solids, iron & manganese
- Adsorption of micro-pollutants (pesticides, detergents, organic-chloride compounds,...) when using Granular Activated Carbon media
- PH & alkalinity adjustment when used for remineralization

Perfect combination of Actiflo®/Multiflo™

The unique combination of VWT's Actiflo or Multiflo settlers and Filtraflo TGV filters results in the ideal compact solutions, by significantly reducing the footprint of water treatment plants with a limited available area, and efficiently producing high quality of treated water.


Abu Dhabi, UAE


Changzhou, China


Chengde Steel, China


Baoji, China


Jinhai, China


Oset-Oslo, Norway

Advantages

- **High media level, high water level above media: deep filter**
  - media height: 1.5m up to 2m
  - high water level (above the media): 1.2m up to 1.4m
- **Excellent filtered water quality**
  - using mono-media: 0.1 to 0.2NTU, 24h filtration cycles
  - with chemicals on dual-media: < 0.3NTU, 40h filtration cycles
- **Very high filtration rate: 15 - 20m/h**
- **Optimum performance guarantee with regular backwashing**

Selected references

Drinking water plants

> **Chengdu No.6-Plant B DWTP, China**
460,000 m^3/d (Multiflo + Filtraflo TGV)

> **Baoji DWTP, China**
90,000 m^3/d (Multiflo + Filtraflo TGV)

> **Huachipa - Lima DWTP, Peru**
432,000 m^3/d (Multiflo + Filtraflo TGV)

> **Shanghai Pudong Linjiang DWTP, China**
200,000 m^3/d (Actiflo + Filtraflo TGV)

> **Shanghai Pudong Jinhai DWTP, China**
400,000 m^3/d (Multiflo + Filtraflo TGV)

> **Changzhou DWTP, China**
400,000 m^3/d (Multiflo + Filtraflo TGV)

> **Oset-Oslo DWTP, Norway**
390,000 m^3/d (Actiflo + Filtraflo TGV)

> **Kanhan DWTP, India**
240,000 m^3/d (Multiflo + Filtraflo TGV)

> **Hau Giang DWTP, Vietnam**
100,000 m^3/d (Multiflo + Filtraflo TGV)

> **Yantai Fushan DWTP, China**
200,000 m^3/d (Multiflo + Filtraflo TGV)

Municipal wastewater polishing

> **Abu Dhabi Wathba WWTPs, UAE**
415,200 m^3/d, tertiary filtration

> **Allahamah Al Ain WWTPs, UAE**
233,300 m^3/d, tertiary filtration

Process water plants

> **Celulose Riograndense, Brazil**
140,000 m^3/d (Actiflo + Filtraflo TGV)

> **Fibria, Horizonte 2, Brazil**
185,000 m^3/d (Actiflo + Filtraflo TGV)

Industrial wastewater polishing

> **Chengde Steel, China**
100,000 m^3/d (MBBR + Multiflo + Filtraflo TGV)

> **Nyukoyu WWTP - Yanshan Integrated Refinery Complex, China**
24,000 m^3/d + 12,000 m^3/d (Actiflo Carb + Filtraflo TGV)

Figure I-2: Veolia Filtraflow TGV Advantages

Appendix - J: Ozone Design Information

Appendix - J.1: Ozone Calculations

With a desired ozone dosage of 4ppm, Equation J-1: Necessary Ozone Generation Rate was used to determine the necessary ozone generation rate for 45MGD and 70MGD. The information for the ozone generators can be seen in Table J.3: Ozone Calculations.

Equation J-1: Necessary Ozone Generation Rate [22]

$$O_3GenRate = Q * O_{3\ dos} * 8.34/eff.$$

Where:

- $O_3GenRate$ = Necessary ozone generation rate ($\frac{lbs}{day}$)
- Q = Flowrate (MGD)
- $O_{3\ dos}$ = Desired ozone dosage ($\frac{mg}{l}$)
- $Eff.$ = Ozone transfer efficiency (decimal)

In order to determine the dimensions of the ozone contact chamber, Figure J-3: Ozonia Bubble Diffusers Information below was used to find the required contact time (Ct) for Cryptosporidium oocysts. While the average number of microorganisms was not given for the source water, Cryptosporidium oocysts generally need the longest contact time compared to Giardia cysts and Viruses which is why it was used. Using log inactivation 2 and an average of 20°C, a Ct value of 7.8 was used. In order to find the effective contact time, Equation J-2: t_{10} Calculation was used.

Equation J-2: t_{10} Calculation [22]

$$t_{10} = \frac{C_t}{C}$$

Where:

- t_{10} = Effective contact time (time needed in minutes for 10% volume to pass through)
- C_t = Required Cryptosporidium oocysts contact time ($mg * \frac{min}{l}$)
- C = Transferred ozone dose ($\frac{4mg}{l}$)

After this, Equation J-3: t_0 Calculation was used to find the theoretical detention time. The value for t10/t0 was assumed to be 0.7 due to the “Superior” performance of an over-under contact chamber.

Equation J-3: t_0 Calculation [22]

$$t_0 = \frac{t_{10}}{[t_{10}/t_0]}$$

Where:

- t_0 = Theoretical detention time (minutes)
- t_{10} = Effective contact time (time in minutes needed for 10% volume to pass through)
- $\frac{t_{10}}{t_0}$ = EPA’s assumed ratio of effective contact time to the theoretical detention time (minutes)

In order to calculate the required volume for the contact chamber, Equation J-4: Volume of Ozone Contact Chamber was used.

Equation J-4: Volume of Ozone Contact Chamber [22]

$$V = t_0 * Q$$

Where:

- V = Required contact chamber volume (m^3)
- t_0 = Theoretical detention time (minutes)
- Q = Flowrate (CMD)

"Using the Henry and Freeman optimum ratios, a depth of 6.0m and an assumed $H = 4l$: $L = \frac{H}{4} = \frac{6}{4} = \frac{1.5m}{cell}$" [22]. In order to find the width of the cell, Equation J-5: Width of Cell Calculation was used assuming a depth of 6m, 1.5m/cell and 10 cells.

Equation J-5: Width of Cell Calculation [22]

$$W = \frac{V}{H * L * \#Cells}$$

Where:

- W = Width of cell (m)
- V = Required contact chamber volume (m^3)
- H = Height of contact chamber (m)
- L = length of cell (m)
- $\#Cells$ = Number of cells not including inlet chamber

Table J.3: Ozone Calculations

Ozone		
Desired Ozone Dosage		4ppm (4mg/l)
Ozone Concentration in Feed Gas (assumption)		Assume 12%
	Water Flowrate	45MGD
	$O_3 GenRate$	1668lb/d (32.5kg/hr)
	O3 Generator	Two Ozonia CFV-30 (one for primary use, one for redundancy) Max O3 production of 1899.5lb/d or 35.9kg/hr
	Ozone Diffuser	Ozonia Dome Bubble Diffusers
	Number of Cells	10 (9 contact cells and 1 inlet cell)
	Ct (@20°C)	7.8 mg*min/L
Phase 0 (2025) 45MGD	Ct/t	1.95min
	t0	2.8min
	Volume of Chamber	329.5m3
	Width of Cell	4.57m
	Required Contact Chamber Dimensions	6m deep X 3.4m wide X 16.5m long Two Chambers (one for primary use, one for redundancy)
	Contact Chamber Dimensions Accounting for Freeboard	6.6m deep X 3.4m wide X 16.5m long
	Water Flowrate	70MGD
	$O_3 GenRate$	2594.67lb/d (49.03kg/hr)
Phase 1 (2030) 70MGD	O3 Generator	Add one Ozonia (two for primary use, one for redundancy CFV-30 (O3 production of 1899.5lb/d or 35.9kg/hr)
	Required Contact Chamber Dimensions	6m deep X 3.4m wide X 20m long Three Chambers (two for primary use, one for redundancy)
	Contact Chamber Dimensions Accounting for Freeboard	6.6m deep X 3.4m wide X 20m long

The percent of pollutants was found using the stand log inactivation method. Appendix F-4: Calculation References shows the log-inactivation credit used in Equation J-6: Percent Removal [22]. shows the percent of pollutants removed.

Equation J-6: Percent Removal [22]

$$\%\ Removal = 100 - \left(\frac{100}{10^{LI}}\right)$$

Where:

- $\%\ Removal$ = Percent of pollutants removed
- LI = log inactivation, dimensionless

Table J.4: Percent of Pollutants Removed-Ozone

Percent of Pollutants Removed	
	% Removal
Giardia Cysts	99.7
Virus	99.0
Cryptosporidium	99.9

Appendix - J.2: Ozone Specifications

ozone technology: ozonia® CFV

ozonia® fused dielectrics provide the industry's highest reliability and availability.

The **ozonia® CFV** range is designed **for medium-sized ozone applications**. The design is based on feedback from hundreds of operators and includes the latest technology to ensure continuous operation at full-load in industrial environments. A feature of the **ozonia® CFV** units is the fused dielectric tubes which provides high availability. **ozonia® CFV** units are particularly suitable for remote service in drinking water plants.

An **ozonia® CFV** unit is an integrated package including the ozone generator, the power supply, PLC control, process related control equipment and skid interconnections. The PLC system and optional bus ensures flexibility of operation and enables easy integration into many types of plant concepts.

ozonia® CFV ozone generators can be used with oxygen or air feed gases.

how it works

Ozone, the triatomic form of oxygen, is generated by recombining oxygen atoms with oxygen molecules. This process takes place in the gap between the dielectric layer on the high voltage electrode, and an earth electrode in the ozone generator vessel. When high voltage is applied to this arrangement, a silent electrical discharge occurs in the gap which then excites the oxygen molecules in the feed gas flowing through the gap. This causes them to split and combine with other oxygen molecules to form ozone.

suez provides full ozone systems including:

- air preparation systems
- ozone generation
- ozone contacting
- ozone destruction
- control systems including monitoring

main features

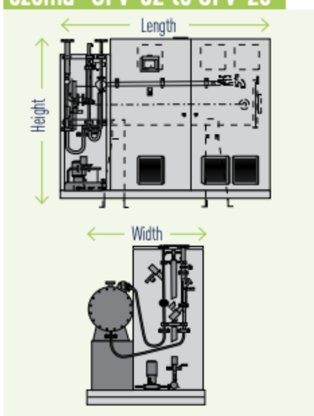
- the industry's most robust electrodes
- fused dielectrics allows the industry's highest availability
- manufacturing facilities: Europe, China and North America
- globally adaptable standards
- industry-leading engineering capabilities
- reliability & long service life

Figure J-1: Ozonia CFV-30 Information [30]

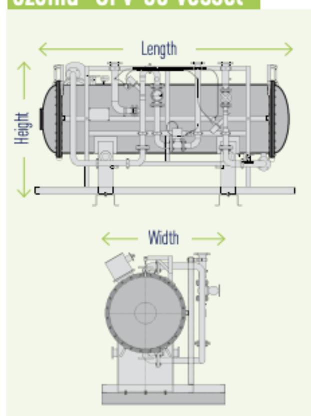
model	feedgas oxygen			feedgas air		
	max production O_3		concentration O_3	max production O_3		concentration O_3
	lb/d	kg/h	(%-wt)	lb/d	kg/h	(%-wt)
ozonia® CFV-02	100.5	1.9	6 to 14	48,1	0,9	1 to 5
ozonia® CFV-03	148.2	2.8	6 to 14	72,5	1,4	1 to 5
ozonia® CFV-04	195.8	3.7	6 to 14	94,2	1,8	1 to 5
ozonia® CFV-05	301.6	5.7	6 to 14	139,2	2,6	1 to 5
ozonia® CFV-10	597.9	11.3	6 to 14	278,8	5,3	1 to 5
ozonia® CFV-15	904.8	17.1	6 to 14	421,7	8,0	1 to 5
ozonia® CFV-20	1,153.5	21.8	6 to 14	537,6	10,2	1 to 5
ozonia® CFV-30	1,899.5	35.9	6 to 14	-	-	-

* at standard conditions

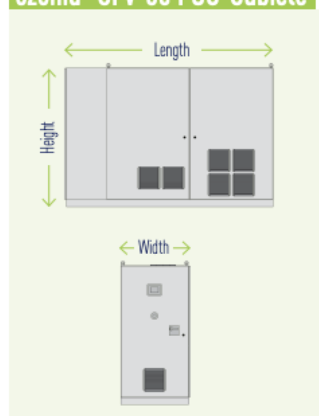
ozonia® CFV-02 to CFV-20



ozonia® CFV-30 Vessel



ozonia® CFV-30 PSU-Cubicle



technical features

- **ambient temperature:** +5 to 40°C
- **design altitude:** < 1,000m.a.s.l.
- **humidity:** RH < 65% (yearly average)
- **voltage:** 3 x 360 to 495 VAC
- **frequency:** 50 / 60 Hz

options

- **profinet (Siemens PLC)**
- **modbus TCP (Allen Bradley PLC**
- **modbus TCP (Schneider PLC)**
- **power-cut and lightning protection**
- **power analyser**

remote control and alarms

- **supply ON/OFF**
- **enable REMOTE**
- **alarm RESET**
- **emergency STOP**
- **gasflow ON**
- **collective ALARM**
- **setpoint current (4-20 mA)**

model	L x H x W		weight	
	inch	mm	lb	kg
ozonia® CFV-02	78.74 x 78.74 x 45.27	2,000 x 2,000 x 1,150	~ 1653	~750
ozonia® CFV-03	78.74 x 78.74 x 45.27	2,000 x 2,000 x 1,150	~1874	~ 850
ozonia® CFV-04	78.74 x 78.74 x 45.27	2,000 x 2,000 x 1,150	~ 2,094	~ 950
ozonia® CFV-05	98.42 x 78.74 x 45.27	2,500 x 2,000 x 1,500	~ 4,409	~ 2,000
ozonia® CFV-10	114.17 x 78.74 x 74.80	2,900 x 2,000 x 1,900	~ 4,519	~ 2,050
ozonia® CFV-15	114.17 x 78.74 x 74.80	2,900 x 2,000 x 1,900	~ 5,511	~ 2,500
ozonia® CFV-20	114.17 x 78.74 x 74.80	2,900 x 2,000 x 1,900	~ 6,614	~ 3,000
ozonia® CFV-30 Vessel	135.82 x 74.80 x 61.02	3,450 x 1,900 x 1,550	~ 8,377	~ 3,800
ozonia® CFV-30 PSU-Cubicle	118.11 x 78.74 x 39.37	3,000 x 2,000 x 1,000	~ 4,960	~ 2,250

Figure J-2: Ozonia CFV-30 Specifications [30]

Ozonia* Dome Diffusers

Efficiently introduce ozone to processes with mass-transfer diffusers.

It is important that ozone is introduced to the process in the most efficient way. One of the more popular methods is to install dome type diffusers at the bottom of a contact tank and to bubble the ozone-containing gas through the water volume in the tank.

High efficiency ozone gas mass transfer

The application, medium flow rate, and ozone dose rate are critical factors which will determine the size and number of dome diffusers required and will also influence the geometry of the contact tank. As an example, drinking water applications require a relatively low ozone dose, short contact time and one ozonation chamber with diffusers whereas waste treatment plants require a much higher ozone dose, longer contact times and a multiple of ozonation chambers.

The diffuser elements are designed that a cloud of homogeneous small-sized bubbles are produced, creating a large bubble/water contact area to ensure a maximum mass-transfer rate.

Features

- Mass-transfer rate >90%
- Homogeneous bubble formation
- Highly resistant ceramic material
- Extreme stability over long service periods
- Easy installation
- Maintenance-free
- Widely accepted technology

Figure J-3: Ozonia Bubble Diffusers Information [30]

Appendix - J.3: Ozone Contact Chamber

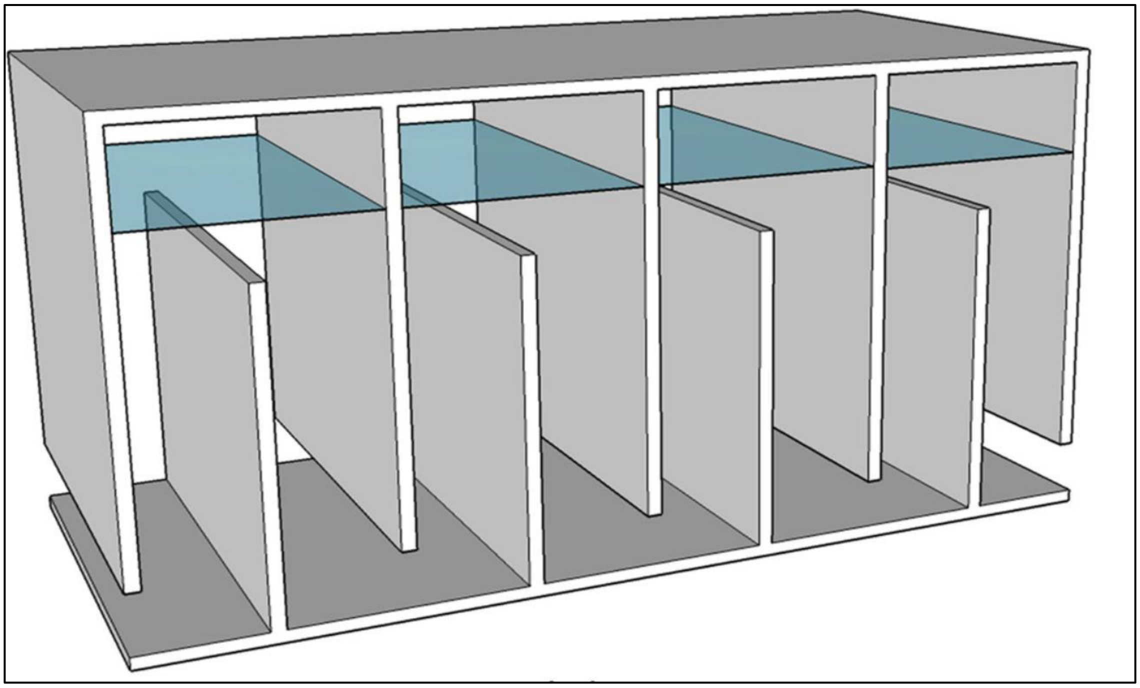


Figure J.9: Depiction of an Over-Under Ozone Contact Chamber [31]

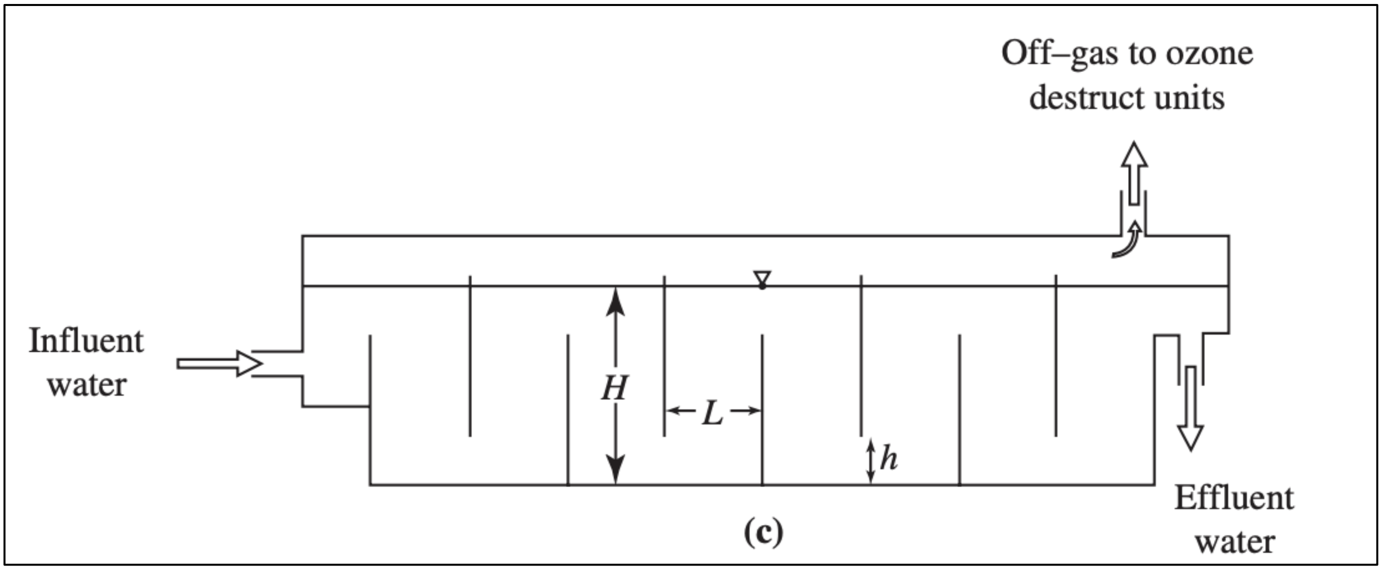


Figure J.10: Over-Under Ozone Contact Chamber Height vs Length [22]

Appendix - J.4: Ozone Calculation References

Ct values (mg · min/L) for *Cryptosporidium* inactivation by ozone

Log inactivation	Water temperature, °C										
	< = 0.5	1	2	3	5	7	10	15	20	25	30
0.25	6.0	5.8	5.2	4.8	4.0	3.3	2.5	1.6	1.0	0.6	0.39
0.5	12	12	10	9.5	7.9	6.5	4.9	3.1	2.0	1.2	0.78
1	24	23	21	19	16	13	9.9	6.2	3.9	2.5	1.6
1.5	36	35	31	29	24	20	15	9.3	5.9	3.7	2.4
2	48	46	42	38	32	26	20	12	7.8	4.9	3.1
2.5	60	58	52	48	40	33	25	16	9.8	6.2	3.9
3	72	69	63	57	47	39	30	19	12	7.4	4.7

Source: (2006) Code of Federal Regulations, 40 CFR 141.720.

Figure J.11: Cryptosporidium Oocosts Ct Times [22]

TABLE 13-10
Standard log-removal credits for treatment

Process	Log removal credit		
	Giardia cysts	Viruses	*Cryptosporidium* oocysts
Conventional filtration plants	2.5	2	3
Direct filtration plants	2	1	2.5

Figure J.12: Standard Log-Removal Credits Used to Find % Pollutants Removed [22]

Appendix - K: UV Design Information

Appendix - K.1: UV Information

The recommended phasing information for the TrojanUV Signa lamps can be seen in Table K-1: UV Information [32]. The number of lamps was recommended from TrojanUV directly [32].

Table K-1: UV Information

UV		
TrojanUV Signa lamps will be used	Each TrojanUV solo lamp is 1000 Watts	
Watts per TrojanUV solo lamp	1000	
Dimensions of UV Channel	2m wide X 1.2m deep X 18m long	
Phase 0 (2025) 45MGD	144 lamps	
	Approx. 87 lamps replaced per year	
	6 Banks-5 for flow, 1 for redundancy	
	144,000 W in Channel	
Phase 1 (2030) 60MGD	Add 48 lamps (192 total)	
	Approx. 116 lamps replaced per year	
	8 Banks-7 for flow, 1 for redundancy	
	144,000 W in Channel	
Phase 2 (2050) 70MGD	Add 24 lamps (216 total)	
	Approx.130 lamps replaced per year	
	9 Banks-8 for flow, 1 for redundancy	
	144,000 W in Channel	

The percent of pollutants was found using Equation J-6: Percent Removal [22]. shows the percent of pollutants removed.

Table K-2: Percent of Pollutants Removed-UV

Percent of Pollutants Removed	
	% Removal
Giardia Cysts	99.7
Virus	99.0
Cryptosporidium	99.9

Appendix - K.2: TrojanUV Signa Specifications

System Specifications	
System Characteristics	TrojanUVSigna
Lamp Type	TrojanUV Solo Lamp (amalgam)
Lamp Driver	Electronic, high-efficiency (99% power factor)
Input Power Per Lamp	1000 Watts
Lamp Control	30 - 100% variable lamp power (1% increments)
Lamp Configuration	Staggered, inclined array (two-row, four-row or six-row)
Module/Bank Frame	Type 6P (IP67)
Ballast Enclosure	Type 4X (IP66)
Cleaning System	Automatic ActiClean chemical/mechanical
UV Intensity Sensor	1 per bank – with automatic chemical cleaning
Bank Lifting Device	1 per bank - Automatic Raising Mechanism (ARM)
Level Control Device	Fixed weir or motorized weir gate
Water Level Sensor	High and low water level sensors available (one per channel)
Installation Location	Indoors or outdoors
System Control Center	Standard color HMI, 16 digital I/O, 4 analog I/O, SCADA compatible PLC options available

Figure K.13: UV Specifications [32]

Appendix - K.3: UV Open Channel Examples

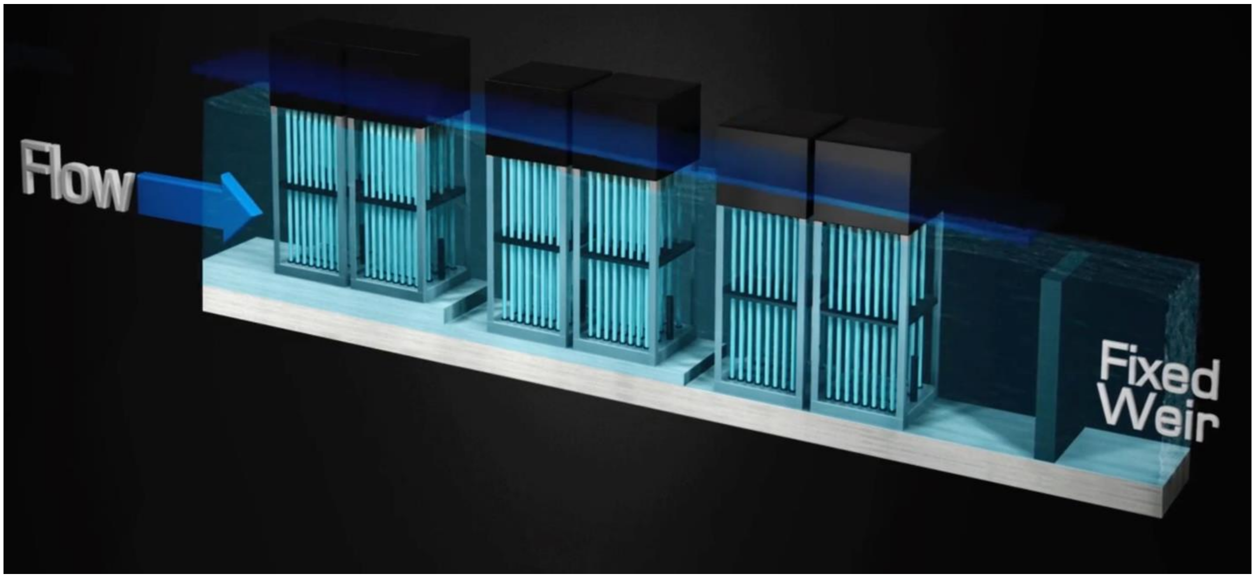
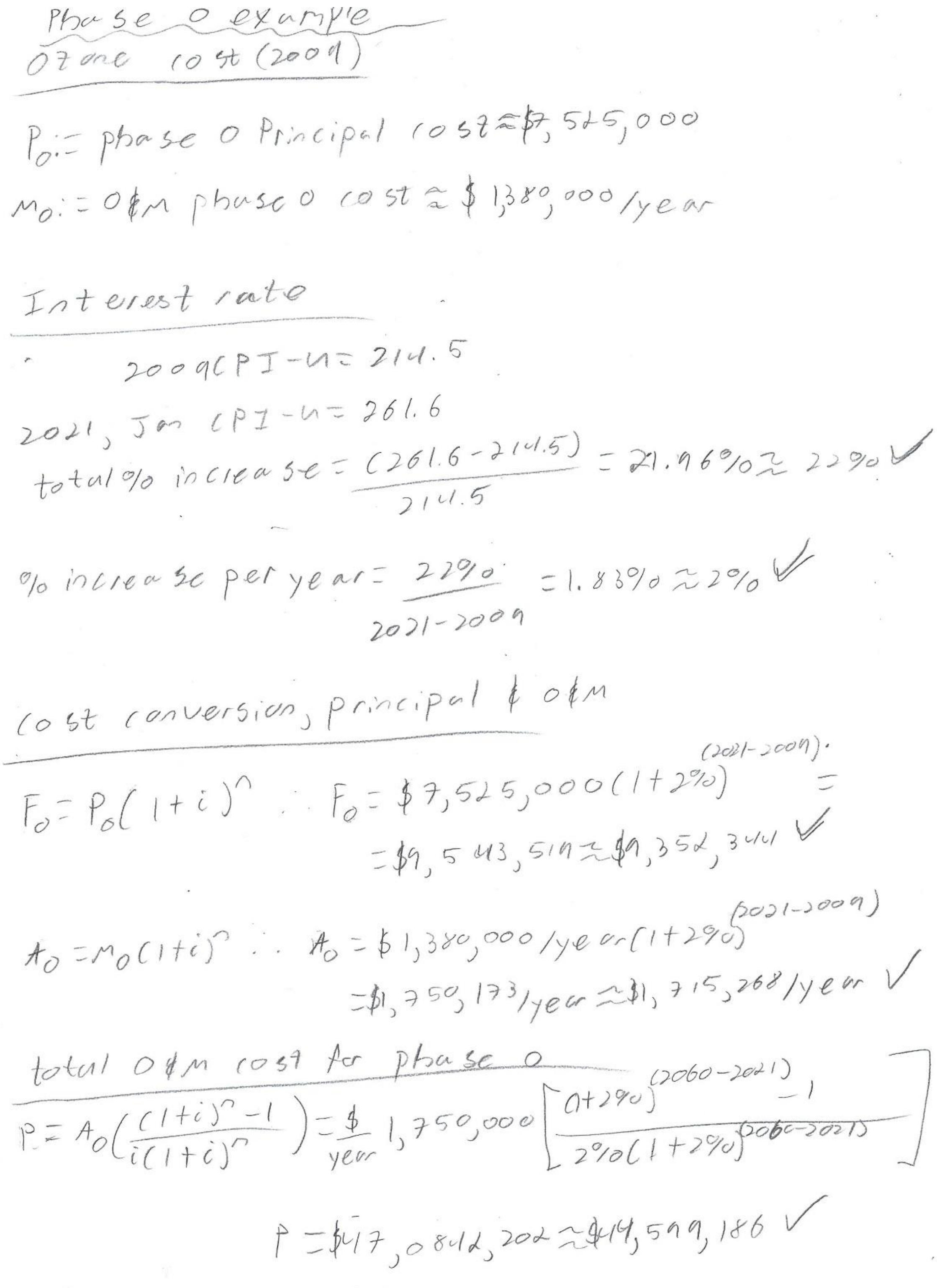


Figure K.14: Diagram of UV Channel [32]

Figure K.15: UV Channel Example [32]

Appendix - L: Cost of Implementation Calculations

Appendix - L.1: Example Hand Calculation



Phase 0 example

Ozone cost (2009)

P_0 := phase 0 Principal cost ≈ \$7,525,000

M_0 := O&M phase 0 cost ≈ \$1,380,000/year

Interest rate

2009 CPI-U = 214.5

2021, Jan CPI-U = 261.6

total % increase = $\frac{(261.6 - 214.5)}{214.5}$ = 21.96% ≈ 22% ✓

% increase per year = $\frac{22\%}{2021-2009}$ = 1.83% ≈ 2% ✓

cost conversion, principal & O&M

$F_0 = P_0(1+i)^n$ ∴ $F_0 = \$7,525,000(1+2\%)^{(2021-2009)}$ =

= \$9,543,519 ≈ \$9,352,344 ✓

$A_0 = M_0(1+i)^n$ ∴ $A_0 = \$1,380,000/\text{year}(1+2\%)^{(2021-2009)}$

= \$1,750,173/year ≈ \$1,715,268/year ✓

total O&M cost for phase 0

$P = A_0\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right) = \frac{\$}{\text{year}} 1,750,000\left[\frac{(1+2\%)^{(2060-2021)} - 1}{2\%(1+2\%)^{(2060-2021)}}\right]$

P = \$47,0842,202 ≈ \$44,599,186 ✓

Figure L-1: Ozone Phase Zero Cost Hand Calculation Example

Appendix - L.2: CPI-U Indexes Table

Table L-1: Consumer Price Indexes for All Urban Consumers

CPI for All Urban Consumers (CPI-U)					
Original Data Value					
Series Id:	CUUR0000SA0				
Not Seasonally Adjusted					
Series Title:	All items in U.S. city average, all urban consumers, not seasonally adjusted				
Area:	U.S. city average				
Item:	All items				
Base Period:	1982-84=100				
Years:	2000 to 2020				
Year	**Annual**				
2000	172.2				
2001	177.1				
2002	179.9				
2003	184.0				
2004	188.9				
2005	195.3				
2006	201.6				
2007	207.342				
2008	215.303				
2009	214.537				
2010	218.056				
2011	224.939				
2012	229.594				
2013	232.957				
2014	236.736				
2015	237.017				
2016	240.007				
2017	245.120				
2018	251.107				
2019	255.657				
2020	258.811				
2021	261.582				

Appendix - L.3: Cost Breakdown by Treatment Process

Appendix - L.3.1: Ozone

Table L-2: Ozone Cost Conversion Breakdown

Ozone				
Constants		Name	Value	Unit
		Initial year	2009	Year
		Common Year	2021	Year
		Year Difference	12	Year
		Annual of Initial year CPI	214.537	
		January of 2021 CPI	261.582	
		Percentage increase between Years	22%	%
		Per year Inflation	2%	%
		Projected Present Inflation Rate	2%	%
Phase 0	Initial year Money	Principal Cost	$ 7,525,674	$
		O&M Cost	$ 1,380,248	$/yr
	2021 Money	Principal Cost	$ 9,352,344	$
		O&M Cost	$ 1,715,268	$/yr
		O&M Cost	$ 44,599,186	$
Phase 1	Initial year Money	Principal Cost	$ 9,665,965	$
		O&M Cost	$ 673,190	$/yr
	2021 Money	Principal Cost	$ 12,012,138	$
		O&M Cost	$ 836,591	$/yr
		O&M Cost	$ 18,231,483	$
Phase 2	Initial year Money	Principal Cost		$
		O&M Cost		$/yr
	2021 Money	Principal Cost	$ -	$
		O&M Cost	$ -	$/yr
		O&M Cost	$ -	$
Completion	2021 Money	Total Cost	$ 84,195,151	$

Appendix - L.3.2: Rapid Sand Filter

Table L-3: Rapid Sand Filter Cost Conversion Breakdown

Rapid Sand Filter (Anthracite/Sand)					
Constants		Name	Value		Unit
		Initial year		2009	Year
		Common Year		2021	Year
		Year Difference		12	Year
		January of Initial year CPI		214.537	
		January of 2021 CPI		261.582	
		Percentage increase between Years		22%	%
		Per year Inflation		2%	%
		Projected Present Inflation Rate		2%	%
Phase 0	Initial year Money	Principal Cost	$	5,108,852	$
		O&M Cost	$	338,505	$/yr
	2021 Money	Principal Cost	$	6,348,899	$
		O&M Cost	$	420,669	$/yr
		O&M Cost	$	10,937,925	$
Phase 1	Initial year Money	Principal Cost	$	1,080,864	$
		O&M Cost	$	72,093	$/yr
	2021 Money	Principal Cost	$	1,343,216	$
		O&M Cost	$	89,591	$/yr
		O&M Cost	$	1,952,429	$
Phase 2	Initial year Money	Principal Cost	$	849,252	$
		O&M Cost	$	44,495	$/yr
	2021 Money	Principal Cost	$	1,055,387	$
		O&M Cost	$	55,296	$/yr
		O&M Cost	$	491,539	$
Completion	2021 Money	Total Cost	$	22,129,395	$

Appendix - L.3.3: UV Treatment

Table L-4: UV Treatment Cost Conversion Breakdown

UV Lights				
Constants		Name	Value	Unit
		Initial year	2009	Year
		Common Year	2021	Year
		Year Difference	12	Year
		January of Initial year CPI	214.537	
		January of 2021 CPI	261.582	
		Percentage increase between Years	22%	%
		Per year Inflation	2%	%
		Projected Present Inflation Rate	2%	%
Phase 0	Initial year Money	Principal Cost	$ 2,196,000	$
		O&M Cost	$ 36,000	$/yr
	2021 Money	Principal Cost	$ 2,729,024	$
		O&M Cost	$ 44,738	$/yr
		O&M Cost	$ 1,163,248	$
Phase 1	Initial year Money	Principal Cost	$ 732,000	$
		O&M Cost	$ 48,000	$/yr
	2021 Money	Principal Cost	$ 909,675	$
		O&M Cost	$ 59,651	$/yr
		O&M Cost	$ 1,299,946	$
Phase 2	Initial year Money	Principal Cost	$ 366,000	$
		O&M Cost	$ 54,000	$/yr
	2021 Money	Principal Cost	$ 454,837	$
		O&M Cost	$ 67,107	$/yr
		O&M Cost	$ 596,536	$
Completion	2021 Money	Total Cost	$ 7,153,267	$

Appendix - L.3.4: Primary Clarifier

Table L-5: Primary Clarifier Cost Conversion Breakdown

Primary Clarifier				
Constants		Name	Value	Unit
		Initial year	2009	Year
		Common Year	2021	Year
		Year Difference	12	Year
		January of Initial year CPI	214.537	
		January of 2021 CPI	261.582	
		Percentage increase between Years	22%	%
		Per year Inflation	2%	%
		Projected Present Inflation Rate	2%	%
Phase 0	Initial year Money	Principal Cost	$ 1,512,000	$
		O&M Cost	$ 206,880	$/yr
	2021 Money	Principal Cost	$ 1,879,000	$
		O&M Cost	$ 257,095	$/yr
		O&M Cost	$ 6,684,800	$
Phase 1	Initial year Money	Principal Cost		$
		O&M Cost	$ 258,600	$/yr
	2021 Money	Principal Cost	$ -	$
		O&M Cost	$ 321,369	$/yr
		O&M Cost	$ 7,003,460	$
Phase 2	Initial year Money	Principal Cost		$
		O&M Cost	$ 323,250	$/yr
	2021 Money	Principal Cost	$ -	$
		O&M Cost	$ 401,711	$/yr
		O&M Cost	$ 3,570,933	$
Completion	2021 Money	Total Cost	$ 19,138,194	$

Appendix - L.3.5: Secondary Clarifier

Table L-6: Secondary Clarifier Cost Conversion Breakdown

Secondary Clarifier				
Constants		Name	Value	Unit
		Initial year	2009	Year
		Common Year	2021	Year
		Year Difference	12	Year
		January of Initial year CPI	214.537	
		January of 2021 CPI	261.582	
		Percentage increase between Years	22%	%
		Per year Inflation	2%	%
		Projected Present Inflation Rate	2%	%
Phase 0	Initial year Money	Principal Cost	$ 236,114	$
		O&M Cost	$ 7,707	$/yr
	2021 Money	Principal Cost	$ 293,425	$
		O&M Cost	$ 9,577	$/yr
		O&M Cost	$ 249,017	$
Phase 1	Initial year Money	Principal Cost	$ 209,505	$
		O&M Cost	$ 7,220	$/yr
	2021 Money	Principal Cost	$ 260,357	$
		O&M Cost	$ 8,973	$/yr
		O&M Cost	$ 195,539	$
Phase 2	Initial year Money	Principal Cost	$ -	$
		O&M Cost	$ -	$/yr
	2021 Money	Principal Cost	$ -	$
		O&M Cost	$ -	$/yr
		O&M Cost	$ -	$
Completion	2021 Money	Total Cost	$ 998,338	$

Appendix - L.4: Preliminary Cost Estimation Tables by Jwala Raj Sharma

The formulas used can be identified by the red box outlining them.

Table 4.1: Generalized Construction Cost Equations Applicable for 1 to 200 mgd Water Treatment Plants

Treatment Units	Construction Costs											
	Cost Equations	Eq. No.	Component Cost-Percentages								Applicable Ranges of x	
			A	B	C	D	E	F	G	H	Minimum	Maximum
Raw Water Pumping												
Raw Water Pumping Facilities												
TDH = 30 ft.	$CC = 9355.4\,x + 60290$	4.1		40			19	36	5		1	200
TDH = 100 ft.	$CC = 12627\,x + 68364$	4.2		45			15	27	13		1	200
	x = plant capacity, mgd											
Pretreatment												
Chlorine Storage and Feed												
Cylinder Storage	$CC = 3E{-}6\,x^3 - 0.0423\,x^2 + 267.97\,x + 29368$	4.3		40			6	4	3	47	10	10,000
On-site storage tank with rail delivery	$CC = 1E{-}6\,x^3 - 0.0158\,x^2 + 98.896\,x + 10708$	4.4		80		2	10	4	3	1	2,000	10,000
Direct feed from rail car	$CC = 0.0019\,x^2 + 13.734\,x + 47956$	4.5		82			8	5	3	2	2,000	10,000
	x = chlorine feed capacity, lb/day											
Chlorine Dioxide Generating and Feed	$CC = -0.0783\,x^2 + 663.68\,x + 82909$	4.6		29			36	3	2	30	1	5,000
	x = chlorine dioxide feed capacity, lb/day											
Ozone Generations Systems	$CC = 0.0002\,x^3 - 1.3451\,x^2 + 4147.8\,x + 212878$	4.7		83			15			2	10	3,500
	x = ozone generation capacity, lb/day											
Ozone Contact Chambers	$CC = 6E{-}6\,x^2 + 5.181\,x + 41901$	4.8		6	21	24	49				460	92,000
	x = contact chamber volume, ft^3											
On-Site Hypochlorite Generation Systems	$CC = 8E{-}6\,x^3 - 0.1413\,x^2 + 884.72\,x + 87471$	4.9		66			25	3	6		10	10,000
	x = hypochlorite generation rate, lb/day											
Powdered Activated Carbon Feed Systems	$CC = -0.0577\,x^2 + 778.86\,x + 175653$	4.10	1	56	4	5	8	14	10	2	3.5	7,000
	x = feed capacity, lb/hr											
Powdered Carbon Regeneration – Fluidized Bed Process	$CC = 7E{-}7\,x^3 - 0.0361\,x^2 + 832.64\,x + 2000000$	4.11		49			42		8	1	209	33,360
	x = regeneration capacity, lb/day											

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Figure L-2: Cost Estimation Tables (1/5)

Table 4.3 - continued

Treatment Units	Operation and Maintenance Costs: Cost Equations	Eq. No.	Component Cost-Percentages: I	J	K	L	M	Applicable Ranges of x: Minimum	Maximum
Circular Clarifiers, Ferric and Alum Sludge	$O\&MC = 7E{-}10\ x^3 - 0.00005\ x^2 + 1.5792\ x + 6734$	4.152	3			73	24	30	200
	x = surface area, ft^2								
Rectangular Clarifiers	$O\&MC = -0.00003\ x^2 + 4.2485\ x + 7748$	4.153	3			88	9	240	4,800
	x = Surface Area, ft^2								
Filtration									
Gravity Filtration Structures	$O\&MC = 0.1929\ x^3 - 48.023\ x^2 + 8242.7\ x + 47252$	4.154	31			62	7	1	200
	x = plant flow rate, mgd								
Backwash Pumping Facilities	$O\&MC = 3E{-}9\ x^3 - 0.0001\ x^2 + 4.8751\ x + 10915$	4.155	51			32	17	140	28,000
	x = pumping capacity, gpm								
Hydraulic Surface Wash Systems	$O\&MC = 4E{-}9\ x^3 - 0.0002\ x^2 + 3.8176\ x + 4446$	4.156	44			53	3	140	28,000
	x = total filter area, ft^2								
Air-Water Backwash Facilities	$O\&MC = 3E{-}9\ x^3 - 0.0001\ x^2 + 4.905\ x + 10915$	4.157	51			17	32	140	28,000
	x = total filter area, ft^2								
Continuous Automatic Backwash Filter	$O\&MC = -0.3285\ x^3 + 95.238\ x^2 + 7077.8\ x + 39086$	4.158	63			33	4	1	200
	x = plant flow, mgd								
Pressure Diatomite Filters	$O\&MC = 1.1709\ x^3 - 370.39\ x^2 + 48425\ x + 119921$	4.159	52			44	4	1	200
	x = plant flow, mgd								
Vacuum Diatomite Filters	$O\&MC = 1.0651\ x^3 - 345.18\ x^2 + 45849\ x + 106841$	4.160	48			48	4	1	200
	x = plant flow, mgd								
Pressure Filtration Plants	$O\&MC = 0.2532\ x^3 - 81.527\ x^2 + 16236\ x + 66980$	4.161	41			49	10	1	200
	x = plant flow, mgd								
Taste and Odor Control									
Potassium Permanganate Feed Systems	$O\&MC = 2840.2\ \ln(x) + 8594$	4.162	4			95	1	1	500
	x = feed capacity, lb/day								
Disinfection									
Anhydrous Ammonia Feed Facilities	$O\&MC = 7E{-}7\ x^3 - 0.0057\ x^2 + 20.58\ x + 26763$	4.163	6			68	26	250	5,000
	x = feed capacity, lb/day								
Aqua Ammonia Feed Facilities	$O\&MC = 2E{-}8\ x^3 - 0.0002\ x^2 + 0.7276\ x + 7107$	4.164	1			89	10	250	5,000
	x = feed capacity, lb/day								
Reverse Osmosis	$O\&MC = 391189\ x + 207533$	4.165	57			1	42	1	200
	x = plant capacity, mgd								

Figure L-3: Cost Estimation Tables (2/5)

Table 4.3: Generalized O&M Cost Equations Applicable to 1 mgd to 200 mgd Water Treatment Plants

Treatment Units	Operation and Maintenance Costs								
	Cost Equations	Eq. No.	Component Cost-Percentages					Applicable Ranges of x	
			I	J	K	L	M	Minimum	Maximum
Raw Water Pumping									
Raw Water Pumping Facilities									
TDH = 30 ft.	$O\&MC = 5768.2\,x + 23723$	4.124	73			22	5	1	200
TDH = 100 ft.	$O\&MC = 8709.5\,x + 23723$	4.125	81			15	4	1	200
	x = plant capacity, mgd								
Pretreatment									
Chlorine Storage and Feed									
Cylinder Storage	$O\&MC = 5E{-}7\,x^3 - 0.0085\,x^2 + 65.019\,x + 20205$	4.126	18			74	8	10	10,000
On-site storage tank with rail delivery	$O\&MC = -0.003\,x^2 + 5.8195\,x + 43965$	4.127	2			75	23	2,000	10,000
Direct feed from rail car	$O\&MC = -0.00006\,x^2 + 2.1722\,x + 42499$	4.128	3			68	29	2,000	10,000
	x = chlorine feed capacity, lb/day								
Chlorine Dioxide Generating and Feed	$O\&MC = -0.0106\,x^2 + 105.82\,x + 32441$	4.129	6			85	9	1	5,000
	x = chlorine dioxide feed capacity, lb/day								
Ozone Generations Systems	$O\&MC = -0.0093\,x^2 + 354.32\,x + 33867$	4.130	76			16	8	10	3,500
	x = ozone generation capacity, lb/day								
On-Site Hypochlorite Generation Systems	$O\&MC = -0.0034\,x^2 + 147.44\,x + 25004$	4.131	70			20	10	10	10,000
	x = hypochlorite generation rate, lb/day								
Powdered Activated Carbon Feed Systems	$O\&MC = -0.0204\,x^2 + 262.07\,x + 54144$	4.132	27			56	17	3.5	7,000
	x = feed capacity, lb/hr								
Powdered Carbon Regeneration – Fluidized Bed Process	$O\&MC = 3E{-}8\,x^3 - 0.012\,x^2 + 300.16\,x + 68295$	4.133	41	44		13	2	220	32,570
	x = regeneration capacity, lb/day								
Powdered Carbon Regeneration – Atomized Suspension Process	$O\&MC = 56.048\,x + 53991$	4.134	7	75		16	2	1,000	10,000
	x = regeneration capacity, lb/day								
Aeration									
Diffused Aeration Basin	$O\&MC = 19557\,x + 76673$	4.135	74			25	1	1.9	380
	x = aeration basin volume, 1000 ft^3								
Aeration Towers	$O\&MC = 1525.2\,x + 4343$	4.136	63			22	15	0.68	256
	x = aeration tower volume, 1000 ft^3								

Figure L-4: Cost Estimation Tables (3/5)

Table 4.3 - continued

Treatment Units	Operation and Maintenance Costs								
	Cost Equations	Eq. No.	Component Cost-Percentages					Applicable Ranges of x	
			I	J	K	L	M	Minimum	Maximum
Circular Clarifiers, Ferric and Alum Sludge	$O\&MC = 7E{-}10\ x^3 - 0.00005\ x^2 + 1.5792\ x + 6734$	4.152	3			73	24	30	200
	x = surface area, ft^2								
Rectangular Clarifiers	$O\&MC = -0.00003\ x^2 + 4.2485\ x + 7748$	4.153	3			88	9	240	4,800
	x = Surface Area, ft^2								
Filtration									
Gravity Filtration Structures	$O\&MC = 0.1929\ x^3 - 48.023\ x^2 + 8242.7\ x + 47252$	4.154	31			62	7	1	200
	x = plant flow rate, mgd								
Backwash Pumping Facilities	$O\&MC = 3E{-}9\ x^3 - 0.0001\ x^2 + 4.8751\ x + 10915$	4.155	51			32	17	140	28,000
	x = pumping capacity, gpm								
Hydraulic Surface Wash Systems	$O\&MC = 4E{-}9\ x^3 - 0.0002\ x^2 + 3.8176\ x + 4446$	4.156	44			53	3	140	28,000
	x = total filter area, ft^2								
Air-Water Backwash Facilities	$O\&MC = 3E{-}9\ x^3 - 0.0001\ x^2 + 4.905\ x + 10915$	4.157	51			17	32	140	28,000
	x = total filter area, ft^2								
Continuous Automatic Backwash Filter	$O\&MC = -0.3285\ x^3 + 95.238\ x^2 + 7077.8\ x + 39086$	4.158	63			33	4	1	200
	x = plant flow, mgd								
Pressure Diatomite Filters	$O\&MC = 1.1709\ x^3 - 370.39\ x^2 + 48425\ x + 119921$	4.159	52			44	4	1	200
	x = plant flow, mgd								
Vacuum Diatomite Filters	$O\&MC = 1.0651\ x^3 - 345.18\ x^2 + 45849\ x + 106841$	4.160	48			48	4	1	200
	x = plant flow, mgd								
Pressure Filtration Plants	$O\&MC = 0.2532\ x^3 - 81.527\ x^2 + 16236\ x + 66980$	4.161	41			49	10	1	200
	x = plant flow, mgd								
Taste and Odor Control									
Potassium Permanganate Feed Systems	$O\&MC = 2840.2\ \ln(x) + 8594$	4.162	4			95	1	1	500
	x = feed capacity, lb/day								
Disinfection									
Anhydrous Ammonia Feed Facilities	$O\&MC = 7E{-}7\ x^3 - 0.0057\ x^2 + 20.58\ x + 26763$	4.163	6			68	26	250	5,000
	x = feed capacity, lb/day								
Aqua Ammonia Feed Facilities	$O\&MC = 2E{-}8\ x^3 - 0.0002\ x^2 + 0.7276\ x + 7107$	4.164	1			89	10	250	5,000
	x = feed capacity, lb/day								
Reverse Osmosis	$O\&MC = 391189\ x + 207533$	4.165	57			1	42	1	200
	x = plant capacity, mgd								

Figure L-5: Cost Estimation Tables (4/5)

Table 4.3 - continued

Treatment Units	Operation and Maintenance Costs								
	Cost Equations	Eq. No.	Component Cost-Percentages					Applicable Ranges of x	
			I	J	K	L	M	Minimum	Maximum
Circular Clarifiers, Ferric and Alum Sludge	$O\&MC = 7E{-}10\ x^3 - 0.00005\ x^2 + 1.5792\ x + 6734$	4.152	3			73	24	30	200
	x = surface area, ft^2								
Rectangular Clarifiers	$O\&MC = -\ 0.00003\ x^2 + 4.2485\ x + 7748$	4.153	3			88	9	240	4,800
	x = Surface Area, ft^2								
Filtration									
Gravity Filtration Structures	$O\&MC = 0.1929\ x^3 - 48.023\ x^2 + 8242.7\ x + 47252$	4.154	31			62	7	1	200
	x = plant flow rate, mgd								
Backwash Pumping Facilities	$O\&MC = 3E{-}9\ x^3 - 0.0001\ x^2 + 4.8751\ x + 10915$	4.155	51			32	17	140	28,000
	x = pumping capacity, gpm								
Hydraulic Surface Wash Systems	$O\&MC = 4E{-}9\ x^3 - 0.0002\ x^2 + 3.8176\ x + 4446$	4.156	44			53	3	140	28,000
	x = total filter area, ft^2								
Air-Water Backwash Facilities	$O\&MC = 3E{-}9\ x^3 - 0.0001\ x^2 + 4.905\ x + 10915$	4.157	51			17	32	140	28,000
	x = total filter area, ft^2								
Continuous Automatic Backwash Filter	$O\&MC = -\ 0.3285\ x^3 + 95.238\ x^2 + 7077.8\ x + 39086$	4.158	63			33	4	1	200
	x = plant flow, mgd								
Pressure Diatomite Filters	$O\&MC = 1.1709\ x^3 - 370.39\ x^2 + 48425\ x + 119921$	4.159	52			44	4	1	200
	x = plant flow, mgd								
Vacuum Diatomite Filters	$O\&MC = 1.0651\ x^3 - 345.18\ x^2 + 45849\ x + 106841$	4.160	48			48	4	1	200
	x = plant flow, mgd								
Pressure Filtration Plants	$O\&MC = 0.2532\ x^3 - 81.527\ x^2 + 16236\ x + 66980$	4.161	41			49	10	1	200
	x = plant flow, mgd								
Taste and Odor Control									
Potassium Permanganate Feed Systems	$O\&MC = 2840.2\ \ln(x) + 8594$	4.162	4			95	1	1	500
	x = feed capacity, lb/day								
Disinfection									
Anhydrous Ammonia Feed Facilities	$O\&MC = 7E{-}7\ x^3 - 0.0057\ x^2 + 20.58\ x + 26763$	4.163	6			68	26	250	5,000
	x = feed capacity, lb/day								
Aqua Ammonia Feed Facilities	$O\&MC = 2E{-}8\ x^3 - 0.0002\ x^2 + 0.7276\ x + 7107$	4.164	1			89	10	250	5,000
	x = feed capacity, lb/day								
Reverse Osmosis	$O\&MC = 391189\ x + 207533$	4.165	57			1	42	1	200
	x = plant capacity, mgd								

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Figure L-6: Cost Estimation Tables (5/5)

Appendix - M: Staffing/Scope

Appendix - M.1: Planned

Table M-1: Planned Staffing

Task Number	Task Name	Work (Hours)	SENG	ENG	LAB	INT	AA
1	**Prepare for Competition**	20					
1.1	Research for Treatment Process	15	1	5	2	5	2
1.2	Registration	5	1	1	1	1	1
2	**Site Investigation**	55					
2.1	Site Visit	25	7	0	9	0	9
2.2	**Analysis of Provided Data**	30					
2.2.1	Treatment Plant Constraints/Criterion	15	5	4	2	0	4
2.2.2	Source Water Characteristics	10	1	1	4	0	4
2.2.3	Develop Site Plan of Existing Plant	5	1	0	2	0	2
3	**Treatment Design**	325					
3.1	**Design Capacity**	30					
3.1.1	Estimate Daily Demand Factors	10	1	5	0	4	0
3.1.2	Calc. End of Lifecycle Capacity	10	1	5	0	4	0
3.1.3	Effluent Regulations	10	2	6	0	2	0
3.2	**Preliminary Treatment**	40					
3.2.1	Evaluate and Select Preliminary Treatment Options	20	4	8	2	4	2
3.2.2	Design Preliminary Treatment Options	20	6	10	0	4	0
3.3	**Primary Treatment**	60					
3.3.1	Evaluate and Choose Primary Treatment Options						
3.3.1.1	Sedimentation basin	30	3	17	1	8	1
3.3.1.2	Coagulation/Flocculation	15	1	8	1	4	1
3.3.1.3	Primary Sludge Handling	15	2	8	1	3	1
3.3.2	Design Primary Treatment						
3.4	**Secondary Treatment**	85					
3.4.1	**BOD/Organic Matter Removal**	40					
3.4.1.1	Evaluate and Choose BOD/Organic Matter Removal Options	20	2	11	1	5	1
3.4.1.2	Design BOD/Organic Matter Removal Options	20	2	12	0	6	0
3.4.2	**Disinfection**	45					
3.4.2.1	Evaluate and Choose Disinfection Options	20	2	11	1	5	1
3.4.2.2	Design Disinfection Options	25	3	15	0	7	0
3.5	**Tertiary Treatment**	55					
3.5.1	Evaluate and Choose Tertiary Options	25	3	12	2	6	2
3.5.2	Design Tertiary Options	30	3	18		9	0
3.6	**Biosolids Management**	55					
3.6.1	Evaluate and Choose Biosolids Options	25	3	12	2	6	2
3.6.2	Design Biosolids Options	30	3	18	0	9	0
4	**Hydraulics**	40					
4.1	System Analysis	20	2	11	1	5	1
4.2	Pump Selection	20	2	12	0	6	0
5	**Cost of Project**	30					
5.1	Construction Cost	10	1	6	0	3	0
5.2	Operation Cost	10	1	6	0	3	0
5.3	Expected Lifespan Cost	10	1	6	0	3	0
6	**Project Impacts**	60					
6.1	Environmental Impact	20	2	11	1	5	1
6.2	Economical Impact	20	2	11	1	5	1
6.3	Societal Impact	20	2	11	1	5	1
7	**Project Deliverables**	105					
7.1	**30% Completion**	20					
7.1.1	30% Report	15	3	6	2	3	1
7.1.2	30% Presentation	5	1	3	0	1	0
7.2	**60% Completion**	20					
7.2.1	60% Report	15	3	6	2	3	1
7.2.2	60% Presentation	5	1	3	0	1	0
7.3	**90% Completion**	40					
7.3.1	90% Report	15	3	6	2	3	1
7.3.2	Practice Presentation	5	1	3	0	1	0
7.3.3	90% Website	20	2	12	0	6	0
7.4	**100% Completion**	25					
7.4.1	Final Presentation	5	1	3	0	1	0
7.4.2	Final Report	10	3	3	2	1	1
7.4.3	Final Website	10	2	6	0	2	0
Total							**41**

Appendix - M.2: Actual

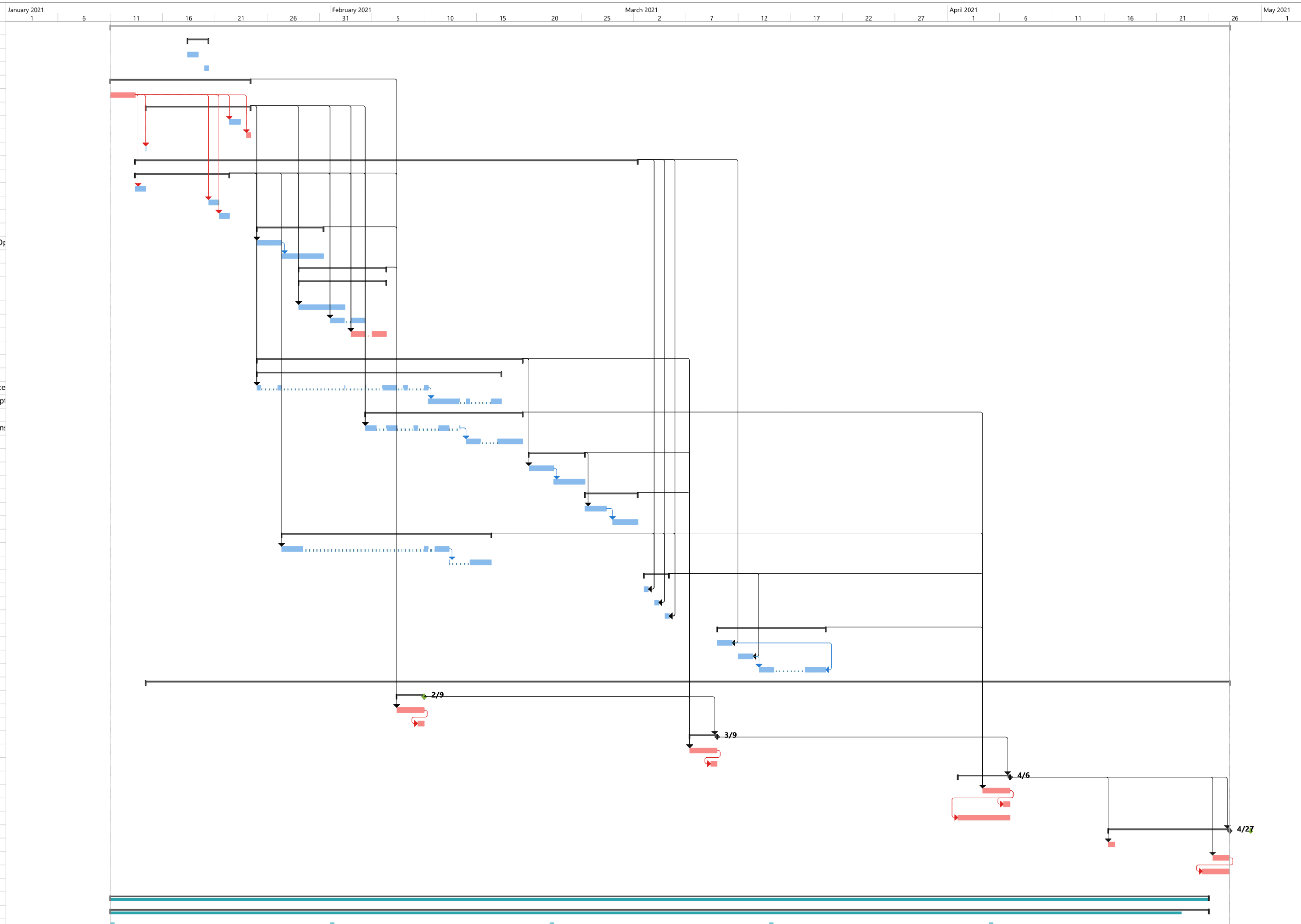
Table M-2: Actual Staffing

Task Number	Task Name	Work (Hours)	SENG	ENG	LAB	INT	AA
1	**Prepare for Competition**	**65**	**11**	**21**	**6**	**21**	**6**
1.1	Research for Treatment Process	60	10	20	5	20	5
1.2	Registration	5	1	1	1	1	1
2	**Site Investigation**	**9**	**3**	**4**	**0**	**2**	**0**
2.1	Analysis of Provided Data	4	1	2	0	1	0
2.2	Treatment Plant Constraints/Criteria	5	2	2	0	1	0
3	**Treatment Design**	**209**	**31**	**75**	**4**	**99**	**0**
3.1	Design Capacity	30	5	10	0	15	0
3.2	**Evaluate and Select Treatment Options**	**93**	**10**	**20**	**0**	**63**	**0**
3.2.1	Primary Clarifier	29	2	7	0	20	0
3.2.2	Secondary Clarifier	6	2	1	0	3	0
3.2.3	Disinfection	16	2	4	0	10	0
3.2.4	Filtration	16	2	4	0	10	0
3.2.5	Solids	26	2	4	0	20	0
3.3	**Design Treatment Options**	**86**	**16**	**45**	**4**	**21**	**0**
3.3.1	Primary Clarifier	40	5	25	0	10	0
3.3.2	Secondary Clarifier	20	5	10	0	5	0
3.3.3	Disinfection	13	3	5	2	3	0
3.3.4	Filtration	13	3	5	2	3	0
4	**Hydraulics**	**54**	**7**	**23**	**0**	**24**	**0**
4.1	Site Layout	14	1	6	0	7	0
4.2	System Analysis	30	5	15	0	10	0
4.3	Pump Selection	10	1	2	0	7	0
5	**Cost of Project**	**15**	**3**	**0**	**0**	**12**	**0**
5.1	Construction Costs	5	1	0	0	4	0
5.2	Maintance and Operation Costs	5	1	0	0	4	0
5.3	Adjust Costs to Common Year Money	5	1	0	0	4	0
6	**Project Impacts**	**21**	**3**	**9**	**0**	**9**	**0**
6.1	Environmnetal Impacts	7	1	3	0	3	0
6.2	Evonomical Impacts	7	1	3	0	3	0
6.3	Societal Impacts	7	1	3	0	3	0
7	**Project Deliverables**	**302**	**51**	**73**	**28**	**30**	**120**
7.1	**30% Completion**	**31**	**4**	**8**	**3**	**4**	**12**
7.1.1	30% Report	25	3	7	2	3	10
7.1.2	30% Presentation	6	1	1	1	1	2
7.2	**60% Completion**	**57**	**8**	**13**	**5**	**6**	**25**
7.2.1	60% Report	30	5	10	2	3	10
7.2.2	60% Presentation	27	3	3	3	3	15
7.3	**90% Completion**	**65**	**9**	**14**	**6**	**6**	**30**
7.3.1	90% Report	29	5	10	2	2	10
7.3.2	Practice Presentation	27	3	3	3	3	15
7.3.3	90% Website	9	1	1	1	1	5
7.4	**100% Completion**	**53**	**9**	**14**	**6**	**6**	**18**
7.4.1	Final Presentation	15	3	3	3	3	3
7.4.2	Final Report	29	5	10	2	2	10
7.4.3	Final Website	9	1	1	1	1	5
7.5	**Competition Deliverables**	**96**	**21**	**24**	**8**	**8**	**35**
7.5.1	Project Plan	29	9	8	1	1	10
7.5.2	Presentation	21	1	6	2	2	10
7.5.3	Final Report	46	11	10	5	5	15
8	**Project Management**	**30**	**10**	**0**	**0**	**0**	**20**

Appendix - N: Gant Charts

Appendix - N.1: Planned

ID	Task Name
0	**Project1**
1	**1 Prepare for Competition**
2	1.1 Research for Treatment Process
3	1.2 Registration
4	**2 Site Investigation**
5	2.1 Site Visit
6	**2.2 Analysis of Provided Data**
7	2.2.1 Treatment Plant Constraints/Criterion
8	2.2.2 Source Water Characteristics
9	2.2.3 Develop Site Plan of Existing Plant
10	**3 Treatment Design**
11	**3.1 Design Capacity**
12	3.1.1 Estimate Daily Demand Factors
13	3.1.2 Calc. End of Lifecycle Capacity
14	3.1.3 Effluent Regulations
15	**3.2 Preliminary Treatment**
16	3.2.1 Evaluate and Select Preliminary Treatment Op
17	3.2.2 Design Preliminary Treatment Options
18	**3.3 Primary Treatment**
19	**3.3.1 Evaluate and Choose Primary Treatment Options**
20	3.3.1.1 Sedimentation basin
21	3.3.1.2 Coagulation/Flocculation
22	3.3.1.3 Primary Sludge Handling
23	3.3.2 Design Primary Treatment
24	**3.4 Secondary Treatment**
25	**3.4.1 BOD/Organic Matter Removal**
26	3.4.1.1 Evaluate and Choose BOD/Organic Matte
27	3.4.1.2 Design BOD/Organic Matter Removal Opt
28	**3.4.2 Disinfection**
29	3.4.2.1 Evaluate and Choose Disinfection Option
30	3.4.2.2 Design Disinfection Options
31	**3.5 Tertiary Treatment**
32	3.5.1 Evaluate and Choose Tertiary Options
33	3.5.2 Design Tertiary Options
34	**3.6 Biosolids Management**
35	3.6.1 Evaluate and Choose Biosolids Options
36	3.6.2 Design Biosolids Options
37	**4 Hydraulics**
38	4.1 System Analysis
39	4.2 Pump Selection
40	**5 Cost of Project**
41	5.1 Construction Cost
42	5.2 Operation Cost
43	5.3 Expected Lifespan Cost
44	**6 Project Impacts**
45	6.1 Environmental Impact
46	6.2 Economical Impact
47	6.3 Societal Impact
48	**7 Project Deliverables**
49	**7.1 30% Completion**
50	7.1.1 30% Report
51	7.1.2 30% Presentation
52	**7.2 60% Completion**
53	7.2.1 60% Report
54	7.2.2 60% Presentation
55	**7.3 90% Completion**
56	7.3.1 90% Report
57	7.3.2 Practice Presentation
58	7.3.3 90% Website
59	**7.4 100% Completion**
60	7.4.1 Final Presentation
61	7.4.2 Final Report
62	7.4.3 Final Website
63	7.5 Competition Deliverables
64	**8 Project Management**
65	**8.1 Meetings**
93	**8.2 Schedule/Resource Management Meetings**

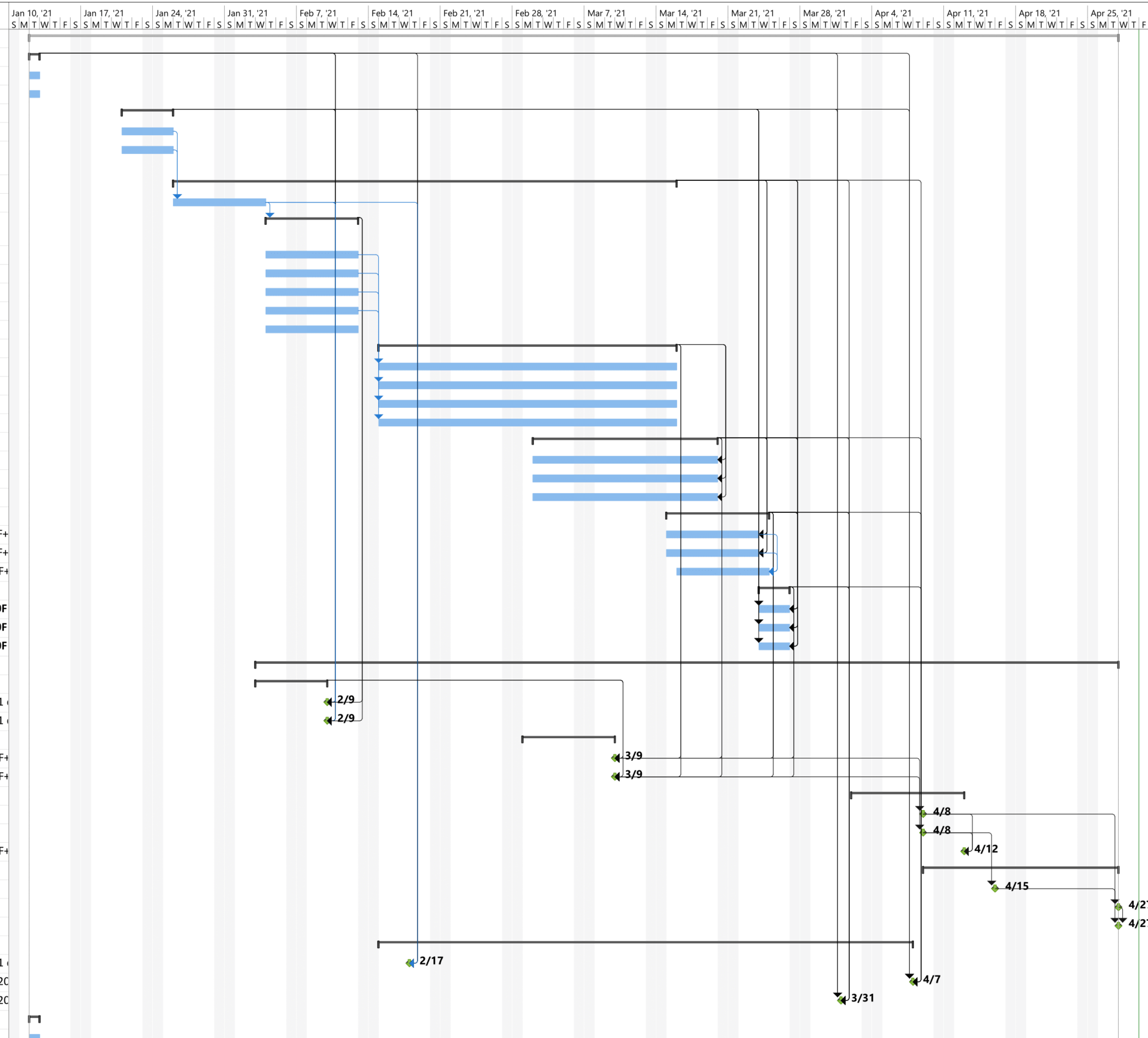


Project: Project1
Date: Sun 11/22/20

Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone	Critical Split
Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline	Progress
Milestone	Inactive Task	Manual Task	Manual Summary	External Tasks	Critical	Manual Progress

Appendix - N.2: Actual

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
0			**Updated Schedule**	**76 days?**	**Tue 1/12/2**	**Tue 4/27/2**	
1			**1 Prepare for Competition**	**1 day?**	**Tue 1/12/21**	**Tue 1/12/21**	
2			1.1 Research for Treatment Proces	1 day	Tue 1/12/21	Tue 1/12/21	
3			1.2 Registration	1 day?	Tue 1/12/21	Tue 1/12/21	
4			**2 Site Investigation**	**3 days**	**Thu 1/21/21**	**Mon 1/25/21**	
5			2.1 Analysis of Provided Data	3 days	Thu 1/21/21	Mon 1/25/21	
6			2.2 Treatment Plant Constraints/Criteria	3 days	Thu 1/21/21	Mon 1/25/21	
7			**3 Treatment Design**	**35 days**	**Tue 1/26/21**	**Mon 3/15/21**	
8			3.1 Design Capacity	7 days	Tue 1/26/21	Wed 2/3/21	5,6
9			**3.2 Evaluate and Select Treatment Options**	**7 days**	**Thu 2/4/21**	**Fri 2/12/21**	**8**
10			3.2.1 Primary Clarifier	7 days	Thu 2/4/21	Fri 2/12/21	
11			3.2.2 Secondary Clarifier	7 days	Thu 2/4/21	Fri 2/12/21	
12			3.2.3 Disinfection	7 days	Thu 2/4/21	Fri 2/12/21	
13			3.2.4 Filtration	7 days	Thu 2/4/21	Fri 2/12/21	
14			3.2.5 Solids	7 days	Thu 2/4/21	Fri 2/12/21	
15			**3.3 Design Treatment Options**	**21 days**	**Mon 2/15/2**	**Mon 3/15/2**	
16			3.3.1 Primary Clarifier	21 days	Mon 2/15/21	Mon 3/15/21	10
17			3.3.2 Secondary Clarifier	21 days	Mon 2/15/21	Mon 3/15/21	11
18			3.3.3 Disinfection	21 days	Mon 2/15/21	Mon 3/15/21	12
19			3.3.4 Filtration	21 days	Mon 2/15/21	Mon 3/15/21	13
20			**4 Hydraulics**	**14 days**	**Tue 3/2/21**	**Fri 3/19/21**	
21			4.1 Site Layout	14 days	Tue 3/2/21	Fri 3/19/21	15FF+4 days
22			4.2 System Analysis	14 days	Tue 3/2/21	Fri 3/19/21	15FF+4 days
23			4.3 Pump Selection	14 days	Tue 3/2/21	Fri 3/19/21	15FF+4 days
24			**5 Cost of Project**	**8 days**	**Mon 3/15/2**	**Wed 3/24/2**	
25			5.1 Construction Costs	7 days	Mon 3/15/21	Tue 3/23/21	7FF+2 days,20FF+
26			5.2 Maintance and Operation Cost	7 days	Mon 3/15/21	Tue 3/23/21	7FF+2 days,20FF+
27			5.3 Adjust Costs to Common Year N	7 days	Tue 3/16/21	Wed 3/24/21	25FF+1 day,26FF+
28			**6 Project Impacts**	**3 days**	**Wed 3/24/2**	**Fri 3/26/21**	
29			6.1 Environmnetal Impacts	3 days	Wed 3/24/21	Fri 3/26/21	**4,7FF+2 days,20F**
30			6.2 Evonomical Impacts	3 days	Wed 3/24/21	Fri 3/26/21	**4,7FF+2 days,20F**
31			6.3 Societal Impacts	3 days	Wed 3/24/21	Fri 3/26/21	**4,7FF+2 days,20F**
32			**7 Project Deliverables**	**60 days**	**Wed 2/3/21**	**Tue 4/27/21**	
33			**7.1 30% Completion**	**5 days**	**Wed 2/3/21**	**Tue 2/9/21**	
34			7.1.1 30% Report	5 days	Wed 2/3/21	Tue 2/9/21	1FF+1 day,4FF+1
35			7.1.2 30% Presentation	5 days	Wed 2/3/21	Tue 2/9/21	1FF+1 day,4FF+1
36			**7.2 60% Completion**	**7 days**	**Mon 3/1/21**	**Tue 3/9/21**	
37			7.2.1 60% Report	7 days	Mon 3/1/21	Tue 3/9/21	15FF+1 day,20FF+
38			7.2.2 60% Presentation	7 days	Mon 3/1/21	Tue 3/9/21	15FF+1 day,20FF+
39			**7.3 90% Completion**	**7 days**	**Fri 4/2/21**	**Mon 4/12/21**	
40			7.3.1 90% Report	5 days	Fri 4/2/21	Thu 4/8/21	37
41			7.3.2 Practice Presentation	5 days	Fri 4/2/21	Thu 4/8/21	38
42			7.3.3 90% Website	7 days	Fri 4/2/21	Mon 4/12/21	40FF+1 day,41FF+
43			**7.4 100% Completion**	**13 days**	**Fri 4/9/21**	**Tue 4/27/21**	
44			7.4.1 Final Presentation	5 days	Fri 4/9/21	Thu 4/15/21	41
45			7.4.2 Final Report	5 days	Wed 4/21/21	Tue 4/27/21	40
46			7.4.3 Final Website	5 days	Wed 4/21/21	Tue 4/27/21	44,45
47			**7.5 Competition Deliverables**	**38 days**	**Mon 2/15/2**	**Wed 4/7/21**	
48			7.5.1 Project Plan	3 days	Mon 2/15/21	Wed 2/17/21	1FF+1 day,4FF+1
49			7.5.2 Presentation	7 days	Tue 3/30/21	Wed 4/7/21	1,4,7FF+2 days,20
50			7.5.3 Final Report	7 days	Tue 3/23/21	Wed 3/31/21	1,4,7FF+2 days,20
51			**8 Project Management**	**1 day?**	**Tue 1/12/21**	**Tue 1/12/21**	
52			8.1 Meetings	1 day?	Tue 1/12/21	Tue 1/12/21	



Project: Updated Schedule
Date: Wed 4/7/21

Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone	Manual Progress
Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline	
Milestone	Inactive Task	Manual Task	Manual Summary	External Tasks	Progress	