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Decentralized Wastewater Treatment Plant in Bangalore, India

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Department of Civil Engineering

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ENTITLED

DECENTRALIZED WASTEWATER TREATMENT PLANT IN BANGALORE, INDIA

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By

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SENIOR DESIGN PROJECT REPORT

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Abstract

The Vrishabawathi River in Bangalore, India, has high levels of pollution due to untreated wastewater discharges from the city. The city requires significant expansion of its wastewater treatment infrastructure. Smaller-capacity plants spread throughout the city, known as decentralized treatment plants, provide an alternative to centralized treatment plants that can meet these demands. This project involved the design of one decentralized plant. This plant is located in the Kengeri district of the city, a mostly residential area in the outskirts of Bangalore. The designed treatment facility includes two primary clarifiers, two biotowers, and two secondary clarifiers. Plants like these can help solve Bangalore's environmental and water resource difficulties.

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Project Background

Project Location

The project is located in Bangalore, India (Figure 1). Bangalore is the third largest city in India, with a population of 8.4 million as of 2011. Bangalore is in the state of Karnataka, in the inland southern portion of the country.

Figure 1: General project location.

Bangalore's climate is relatively mild. It has three seasons: winter, summer, and the monsoon season. Winter temperatures never drop below freezing and summer temperatures rarely exceed 90° F. The monsoon season includes significant rainfall.

The project focuses on the Vrishabawathi River (Figure 2), a major river that runs through

Bangalore. The Vrishabawathi flows southwest to the Cauvery River, which eventually flows to the ocean. This project is located in Kengeri, a district on the southwestern outskirts of the city. A centralized plant that currently discharges a treated effluent into the river is located closer to the center of Bangalore than Kengeri. Both plants are shown in red in Figure 2.

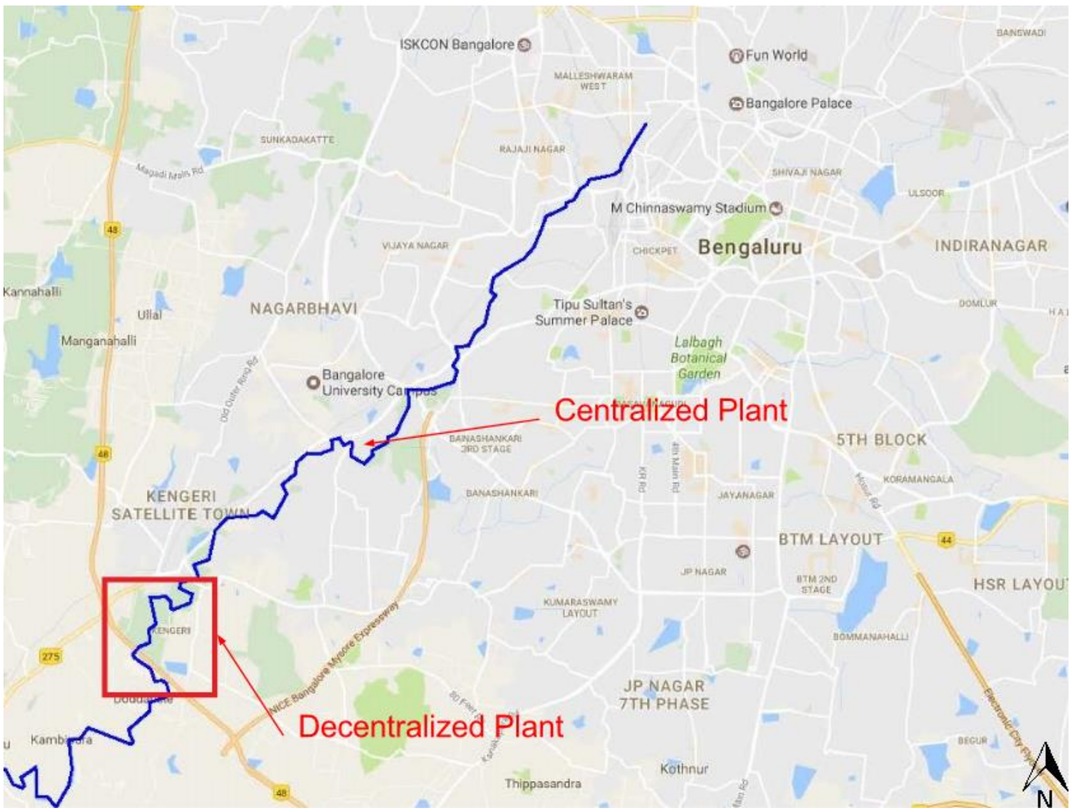


Figure 2: Project location and tributary area. Streamflow is to the southwest. Centralized plant location for reference.

Kengeri is a mostly residential area now, although future development could include industrial and commercial buildings. The tributary area for this proposed facility includes roughly half of Kengeri, located on the eastern side of the Vrishabawathi River. This part of the region has a projected population of 45,000 in 20 years, which was the basis of the design. The proposed location for the plant is located on the banks of the Vrishabawathi River, across a highway from the tributary area, shown in Figure 3.

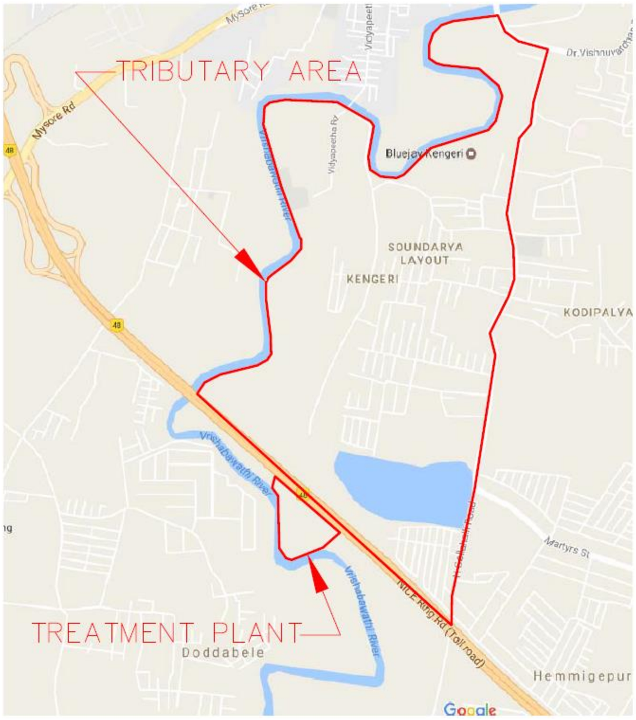


Figure 3: Tributary area and site location.

Project Need

Bangalore has seen rapid expansion in the past 50 years, with its population growing by roughly 20-30% per five years (Figure 4). The World Population Review projects that this expansion will continue to increase. This expansion has led to a significant demand on the existing potable and wastewater treatment infrastructure, leading to a growing potable water shortage and direct discharge of untreated wastewater. The untreated wastewater discharge has led to the pollution of bodies of water like the Vrishabawathi River, which in turn has decreased the supply of potable water since the Vrishabawathi River can no longer be used as potable water or for any application.

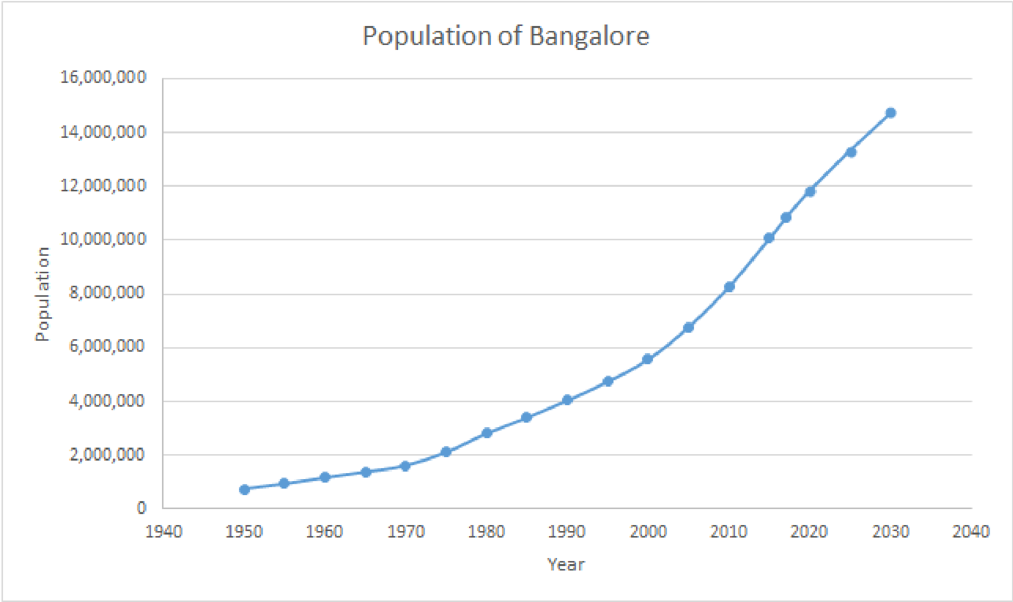


Figure 4: Recorded and projected populations for Bangalore (World Population Review 2017).

Bangalore's expansion has occurred in both its population and its area. In addition to the central, older parts of the city increasing their population density, areas like Kengeri are developing outward rapidly. The footprint of the city is getting larger, and the areas in the outskirts are gaining industrial and commercial components that further increase the need for wastewater treatment.

The needs of Bangalore's wastewater treatment infrastructure are twofold. First, the city's treatment plants need a higher capacity, giving them the ability to treat a larger quantity of wastewater. Second, the city's collection systems must collect wastewater from a larger area than they currently do. This development must occur at a pace which can keep up with the rapid population increase.

Current Conditions

As mentioned earlier, the Vrishabawathi River is highly polluted. It has a layer of visible white foam on top, and brown sludge in its depths (Figure 5).

Figure 5: Image of the Vrishabawathi River.

The bulk of the pollution in the Vrishabawathi is organic. This fact is evidenced by its dissolved oxygen content, which is low throughout the river and almost zero in some parts (Ahipathy 2006). Dissolved oxygen is a major indicator of stream quality because it determines whether marine plants and animals can survive in a stream. Low dissolved oxygen occurs when microbes consume the oxygen that other organisms need. These microbes thrive in streams with high quantities of organic matter, since they use it for food. Additionally, the five-day biochemical oxygen demand (BOD_5), the most common indicator of organic pollution, in the Kengeri section of the Vrishabawathi River ranges from 40 to 70 milligrams per liter (mg/L) (Ahipathy 2006), while the Bureau of Indian Standards (BIS) set a maximum of three mg/L for a treatable drinking water source. From this, two separate studies on the water (Ahipathy 2006, Jayadev 2013) concluded that there is organic pollution in the Vrishabawathi River that significantly exceeds the guidelines set by the BIS.

Although organic pollution is a significant problem, heavy metals are also found in the Vrishabawathi in harmful quantities. Lead, chromium, nickel, manganese, and iron are all found in the river in quantities that exceed BIS recommended standards (Jayadev 2013). This can lead to heavy metal accumulations in local wildlife (bioaccumulation), the ground around the river (geoaccumulation), and indirect spread from predators eating contaminated organisms (biomagnification).

The pollution in the Vrishabawathi River is spreading downstream and into Bangalore's groundwater, making the problem larger than just the Vrishabawathi. The Vrishabawathi River feeds into the Cauvery River (Figure 6), which is a major river that flows into the neighboring Indian province of Tamil Nadu. The Vrishabawathi accounts for 50% of the pollution in the Cauvery, making it unsuitable for drinking and for aquatic life (Begum 2009). This has caused political tensions between Tamil Nadu and Karnataka, the province that Bangalore is in. Additionally, a study of the groundwater that many of Bangalore's residents rely on has directly linked pollution in the groundwater to the pollution in the Vrishabawathi, since water from the river recharges the groundwater (Shankar 2008).

Figure 6: Map showing the Vrishabawathi River (red) and Cauvery (spelled Kaveri here) River (blue) (Wikipedia 2016).

The cause of the pollution comes largely from untreated wastewater. Roughly 66% of wastewater goes untreated in the area and is discharged directly into the Vrishabawathi River (Shankar 2008). This raw sewage comes from both residential and industrial sources and is responsible for the vast majority of the pollution. This fact also explains the large amounts of organic matter in the river mentioned previously.

The large discharge of untreated wastewater is caused by the fact that the facility that was built to treat the wastewater in the area; the Vrishabawathi Valley Treatment Plant, was not designed to accommodate the rapid increase in population in Bangalore (“Sewage Treatment” 2016). Although the Bangalore Water Supply and Sewerage Board is currently building new centralized treatment plants, they are not being constructed fast enough to serve the new population (“About BWSSB” 2016). The current rate of development is insufficient to meet demand, meaning that new developments must be proposed to meet the wastewater treatment needs.

Type of Treatment

One of the first roadblocks the group encountered was deciding between using a centralized or decentralized wastewater treatment plant. As seen in Table 1, a centralized treatment plant is most suited for a high density city with a large amount of available land. The benefit to using a centralized system is its large treatment capacity, however, a negative is its extensive infrastructure. Due to the size of this location, the team decided to use a decentralized treatment plant. This type of treatment can easily be implanted in a smaller, growing location with relatively low density.

Due to the fact that the team decided to team up with another group working on a centralized treatment plant (re-design of current treatment system), this project focused on smaller tributary areas along the Kengeri River. The project goal was to treat wastewater further away from the current (main) centralized treatment plant in Bangalore, near the industrial area known as the “Silicon Valley of India.” A decentralized system is necessary for smaller locations because the long pipes distributed treated water from the main centralized treatment plant creates a large inconvenient in the everyday lives of the surrounding community members.

Table 1: Centralized vs. Decentralized Treatment Plant.

Centralized Treatment Plant	**Decentralized Treatment Plant**
Large amount of land required	Small amount of land required
Large tributary area	Small tributary area
Suitable for high density cities	Suitable for low density cities
Large treatment capacity	Small treatment capacity
Extensive piping system (to distribute reclaimed water)	Simple piping system (to distribute reclaimed water)

Benefits of Decentralized Treatment

Some of the benefits of using a decentralized wastewater treatment plant that the group highlighted included: fast implementation, shorter pipelines, lower cost, and simplicity of the system. The other group being worked with will not have their treatment plant working for approximately two and a half years, and, knowing that the population and need for a wastewater treatment is quickly growing, this group needed to design a system that can be quickly implemented. Decentralized treatment plants can be created and working at a quicker rate than centralized plants, giving the local communities reclaimed water sooner. With decentralized plants comes shorter pipelines which will provide less inconvenience to the public than a centralized plant with relatively long pipelines would. Due to the fact that this group worked in a developing country, it was desired to reduce costs for the local government by selecting a less expensive treatment option. Finally, decentralized treatment plants are simpler to operate and maintain than centralized plants, which is crucial for an area which may not have many experienced treatment plant operators.

Selection of Secondary Treatment

As a team it was decided that because of the severity of the waste current in the stream, secondary treatment was necessary to treat all of the effluent and set the stage for tertiary treatment. The next step in the pre-design phase was selecting a secondary treatment system. As can be see in Table 2 below, the team chose biotowers because they provided necessary treatment levels, has a low process complexity, and a moderate tolerance to variable flows.

Table 2: Secondary Treatment System Options.

Secondary Treatment System	*Base Level Treatment*	*Enhanced Treatment*	*Process Complexity*	*Tolerance to Variable Flows*	*Aerial Efficiency*
Conventional Activated Sludge	30/30	Nitrification + Denitrification + Bio-P Removal	High	Low	Moderate
Biotower	30/30	30/30 + Nitrification	Low	Moderate	Moderate
Conventional SBR	30/30	Nitrification + Denitrification + Bio-P Removal	Moderate	Moderate	High
Oxidation Ditch	30/30 + Nitrification	Denitrification + Bio-P Removal	Moderate	High	Low

Site Location and Layout

The most important criteria for location was a site which can utilize gravity as much as possible to decrease the complexity of the design and construction phase. The team also looked for a site that may become a future industrial location. With the exponential growth of the population comes a growth and expansion of the industrial area (currently in the center of Bangalore), so the team looked to select a site that may become a possible future industrial area. Finally, the team looked at the Bangalore Water Supply and Sewage Board (BWSSB) website which had a list of proposed decentralized treatment plant locations, and selected a site on that location which had all of the desired attributes. In terms of treatment level, the team looked for a base secondary treatment of 30/30 mg/L of BOD_5 and total suspended solids (TSS).

General Design Criteria

Discharge Standards

Since it is known that the United States has strict guidelines regarding the effluent quality of a flow leaving a wastewater treatment plant, it was decided to follow these guidelines when designing the main treatment components of the plant. Table 3 lists the standards set by the NPDES that should be followed for secondary treatment plants.

Table 3: NPDES Standards.

Parameter	Avg. Monthly Limit	Avg. Weekly Limit
BOD_5	30 mg/L	45 mg/L
TSS	30 mg/L	45 mg/L
BOD_5 & TSS removal (concentration)	>85%	N/A
pH	Within 6.0-9.0 at all times	

For the scope of this project, the relevant values used to guide the design were the average monthly limits for BOD_5 and TSS. Henceforth, these limits shall be referred to as 30/30 (a standard nomenclature for these limits).

Service Population

As it is intended for this treatment system to work for a growing population, a forecasted 20 year population was used in order to determine the daily flow that the plant would need to treat. Furthermore, since this plant is only treating half of the Kengeri area, the total population in that area was determined, and then a rate of growth applied. The relevant values for this calculation are indicated in Table 4.

Table 4: Projected 20 year Population.

Parameter	Value
Total Current Kengeri Population	45,000
Population in Tributary Area	23,000
Population Growth Rate (per five years)	20.0%
Projected 20 year population	45,000

The population growth rate was determined by using the overall growth of the city and applying that same percent to Kengeri.

Base Flow Rate

Once the design population was determined, a base flow rate for the serviced area could also be calculated. Table 5 tabulates the values used for this calculation.

Table 5: Base Flow Rate.

Parameter	Value
Service Population	45,000
Per Capita Wastewater Production	150 L/D
Base Flow Rate	6.75 MLD

The amount for per capita wastewater production is a standard value used in India (Narain 2012).

Peaking Factor

During certain times of the day, there is much higher usage of utilities such as electricity and water. This fact also applies to the production of wastewater. Since many people are on the same general daily schedules, there are certain hours where the treatment plant will be receiving higher than average flows. This increase in flow can be accounted for with use of a peaking factor. There are a variety of peaking factor calculations, all based upon the design population, and they all give quite similar values. For this project, the Babbitt equation was used. Its form is noted in EQ 1.

(EQ 1)

$$PF = \frac{5.0}{(\frac{P}{1000})^{0.2}}$$

In EQ 1 above, P is the tributary population. The resulting Peaking factor (PF) from this equation is 2.34. The base flow is multiplied by this value to design the capacity of the treatment plant.

Influent Quality

As mentioned previously, the treatment plant is designed to treat the wastewater down to acceptable levels of BOD_5 and TSS. As such, it is necessary to know what the influent values for these parameters are. Table 6 indicates the design influent values for TSS and BOD_5.

Table 6: Influent Wastewater Quality.

Parameter	Value
BOD_5	225 mg/L
TSS	510 mg/L

These values were obtained from a treatment plant also located in Bangalore that is subject to similar conditions (personal correspondence).

Site Layout

Site Layout

The natural topography of the land was taken into consideration, which is shown in Figure 7. The contour lines indicate a gentle slope to the site, which has about a 1% grade. With its proximity to the Vrishabawathi River, the site most likely sits upon fairly soft soil and could potentially be subject to periods of flooding. With proper site protection systems such as a berm (the design of which is not within the scope of this project), flooding of the site can be prevented, as well as runoff into the Vrishabawathi River from construction.

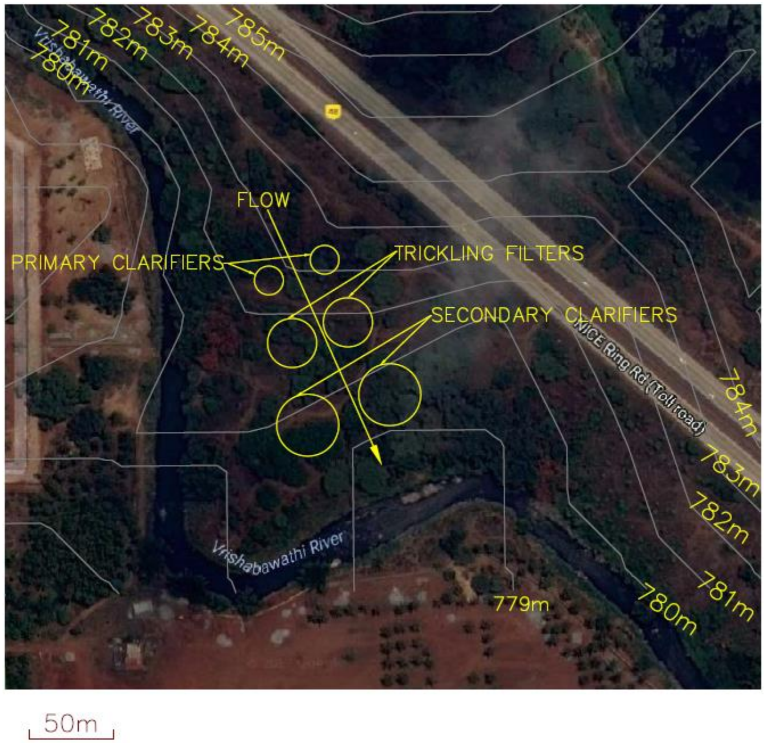


Figure 7: General Site Layout and Site Topography.

Plant Schematic Layout

With the main processes selected, a plan for how the wastewater would travel through the site was determined, and this is indicated in Figure 8.

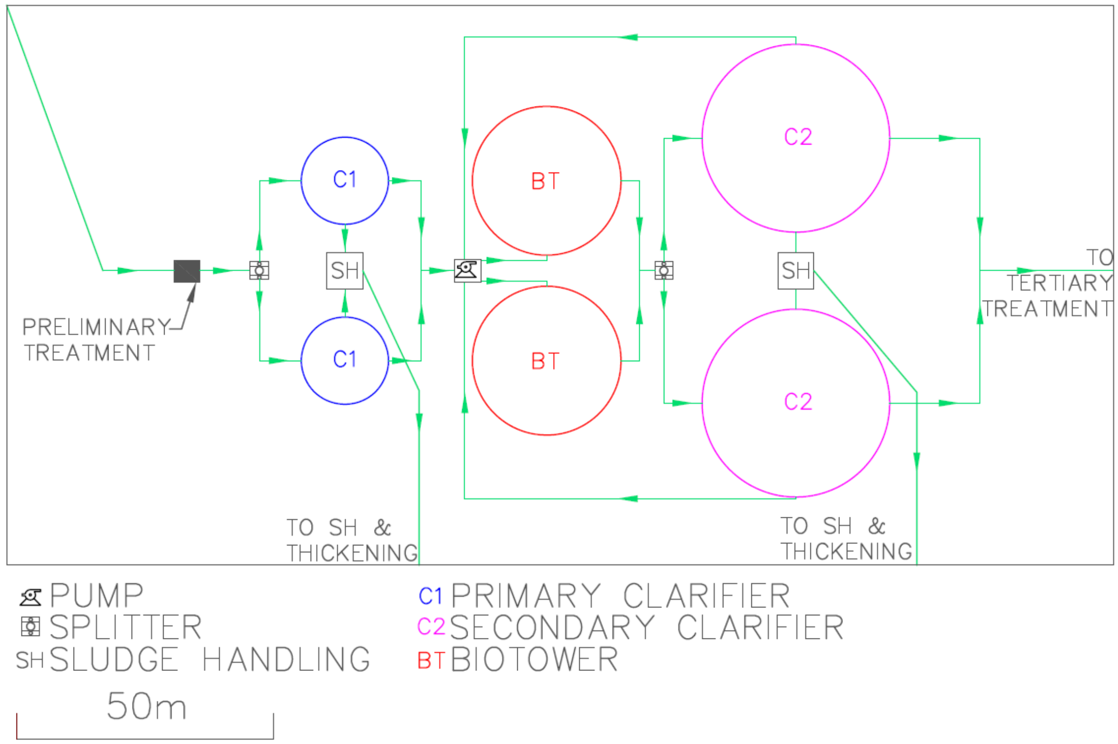


Figure 8: Site Schematic Layout.

The green lines are pipes connecting the plant, with arrows in the direction of flow. The need for preliminary treatment was recognized, which could include things such as grit removal and screening, but this was not within the scope of the project. The main components of the design were the primary clarifiers, biotowers, and secondary clarifiers, of which there are two each for redundancy. These components are all sized to handle the total flow, so that if one must go offline for maintenance, its counterpart can continue running with no interruption in service. Other key components of the site were the splitter boxes before each set of clarifiers which will disperse the flow evenly, and the pumps preceding the biotowers which will pump the wastewater up to the tops of the biotowers. Sludge handling and thickening would have to occur after primary and secondary clarification, but were not within the scope of this project. Also, as the effluent leaves the plant, it can either proceed to disinfection and be released into the river, or, in the future, could be directed to tertiary treatment for reuse.

Systems Design Criteria

Primary Clarifier

The treatment plant design uses primary sedimentation to remove large solids from the effluent. This process involves allowing heavy solids to settle and floatable solids to rise to the top, which are both removed as sludge. Cleaner water is then sent to the next element for further treatment.

Standard performance criteria were selected in order to allow a sufficient solids removal efficiency, as shown in Table 7. These values include a range of possibilities that have been used successfully. Dimensions for the clarifier needed to be chosen such that the performance criteria would be met, while using dimensions that would support commercially available equipment.

Table 7: Design criteria for primary clarifier (Metcalf 1979).

Description	***Value***
Overflow Rate (Average Flow)	30-50 $m^3/(m^2\ d)$ 800-1200 $gal/(ft^2\ d)$
Overflow Rate (Peak Flow)	80-120 $m^3/(m^2\ d)$ 2000-3000 $gal/(ft^2\ d)$
Detention Time	1.5-2.5 hrs
Weir Loading Rate	120-500 $m^3/(m\ d)$ 10000-40000 gal/(ft d)
Solids Loading Rate	<10.2 $kg/(m^2\ h)$ <2 $lb/(ft^2\ h)$

Circular clarifiers were chosen over rectangular clarifiers because they are easier to maintain and build. Rectangular clarifiers are more space-efficient, but site space was not a significant limitation for this project. Redundant design needed to be incorporated so that one tank could be taken offline for maintenance and the plant could continue to function; therefore, two tanks were designed, with each capable of handling the full flow.

Table 8 shows the selected dimensions for each primary clarifier. Calculations can be found in Appendix A. An overflow rate of 40 $m^3/(m^2\ d)$ was used to calculate a baseline diameter, which was then rounded to 15 m in order to support commercially available hardware. The detention time was used to calculate the volume, and therefore side water depth, which was designed to be four meters. The Smith and Loveless HS-50 equipment package was selected for the hardware for this clarifier, which includes a feedwell diameter of 2.1 meters. The sludge hopper uses a standard volume of one cubic meter.

Table 8: Designed dimensions for primary clarifiers.

Dimension	***Value***
Diameter	15 m
Side Water Depth	4 m
Feedwell Diameter	2.1 m
Sludge Hopper Volume	1 m^3

The calculated values for overflow rate, detention time, weir loading rate, and solids loading rate are shown in Table 9. All values fall within design criteria, meaning that the design is viable.

Table 9: Performance criteria for selected dimensions.

Description	***Value***
Overflow Rate (Average Flow)	38.2 $m^3/(m^2\ d)$ 938.5 $gal/(ft^2\ d)$
Overflow Rate (Peak Flow)	89.4 $m^3/(m^2\ d)$ 2196.1 $gal/(ft^2\ d)$
Detention Time	2.5 hrs
Weir Loading Rate	143.2 $m^3/(m\ d)$ 11551.6 gal/(ft d)
Solids Loading Rate	8.1 $kg/(m^2\ h)$ 1.7 $lb/(ft^2\ h)$

The selected internal components of the Smith & Loveless HS-50 include a scraper-type system. Two scraper arms push the settled solids into an offset sludge hopper, and a single skimmer arm removes floating solids. Figure 9 shows a schematic of this system.

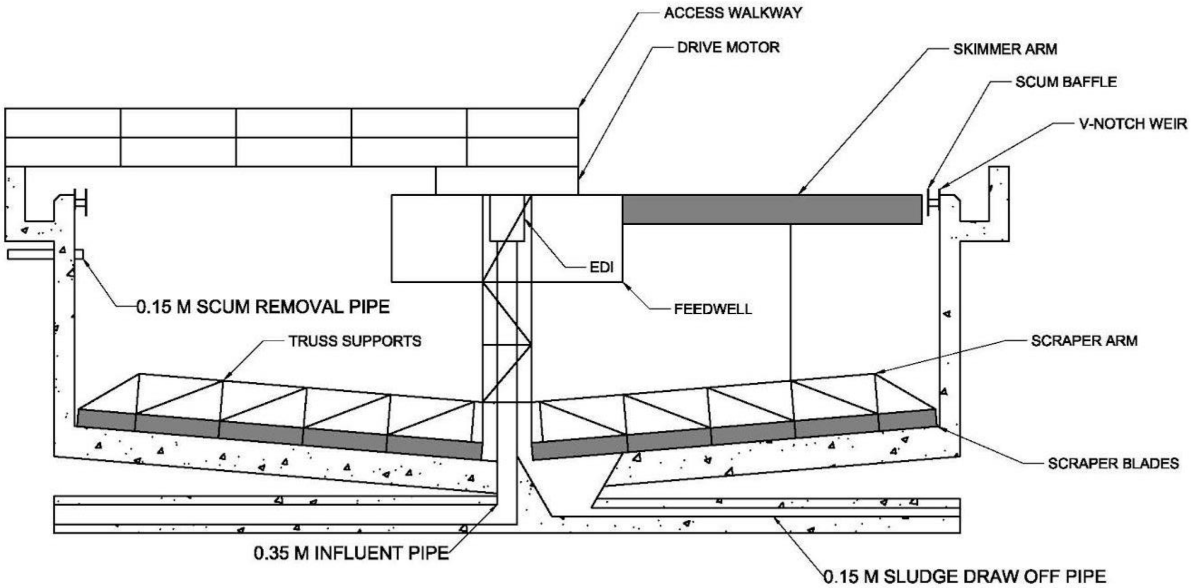


Figure 9: Schematic cross-section of primary clarifier design. Not to scale.

The dimensions for the sludge hopper were determined using Excel Solver (Appendix A). Wall and foundation thicknesses for cast-in-place reinforced concrete were based off of existing designs to be 0.35 m wall thickness and 0.55 m foundation thickness. The clarifiers are mostly below grade, with only one meter extending above grade. The concrete dimensions are shown in Figure 10.

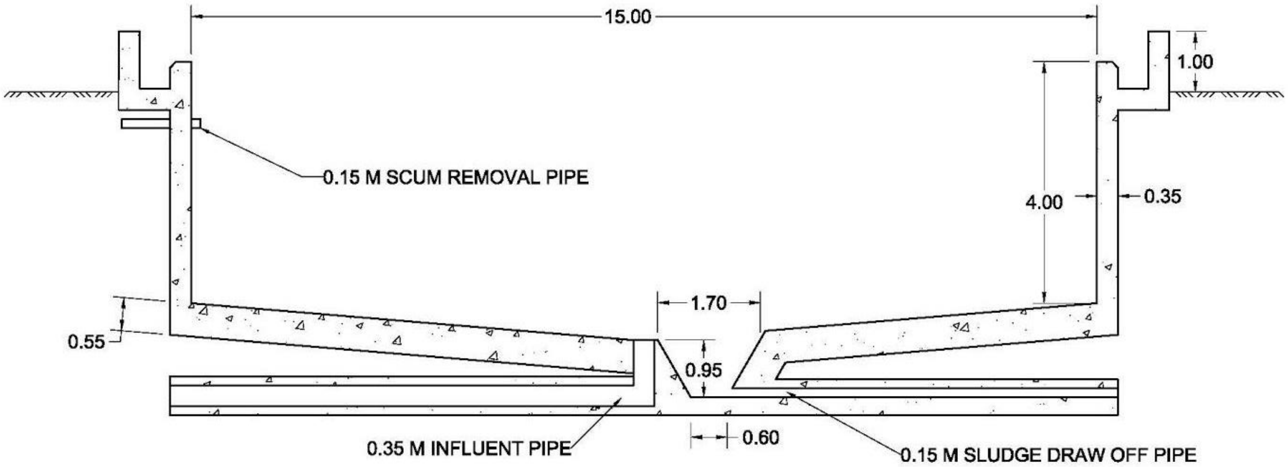


Figure 10: Concrete dimensions for primary clarifiers (all dimensions in meters).

Clean water passes under a scum baffle and exits through a v-notch weir, both of which are not included in the Smith & Loveless HS-50 package. This water exits into an outboard concrete weir, and is then sent to secondary treatment. The steel v-notch weir and concrete are shown in Figure 11.

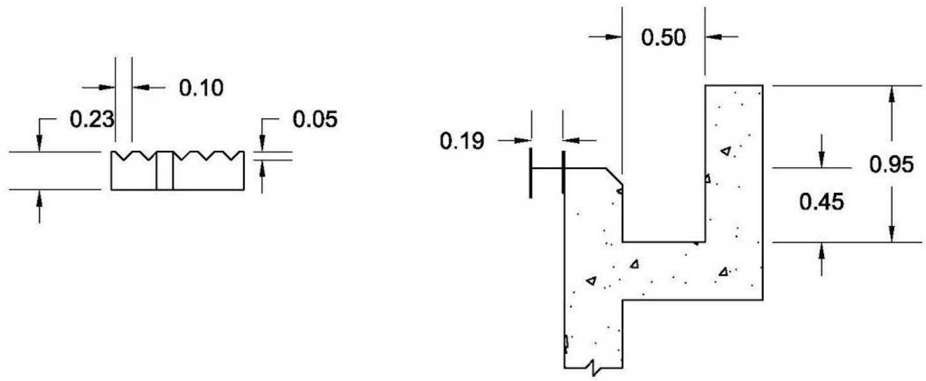


Figure 11: Steel and concrete detail for v-notch weir (left) and concrete outboard weir (right).

Biotower Design Criteria

The biotower was intended to be designed for a high loading rate of wastewater, since plastic filter media is being used rather than traditional gravel media. The standards guiding the design are noted in Table 10. These values were obtained from Wastewater Engineering by Metcalf & Eddy (Metcalf 1979).

Table 10: Biotower Design Standards.

Parameter	Value
Hydraulic Loading Rate (Peak Flow)	40-200 $m^3/(m^2\text{-d})$
Organic Loading Rate (Peak Flow)	0.8-6.0 $kg/(m^3\text{-d})$
Recirculation Ratio	1-4
Media Depth	4.5-12 m
Media	Synthetic
Sloughing	Continuous

The hydraulic loading rate is a measure of wetting the surface of the media, because in order to keep the system working properly, the media must be continuously wetted to promote the growth of and sustain the micro-bacteria population within the tower. The organic or volumetric loading rate is a measure of the amount of solids that are passing through the system, and must be closely controlled as well, as too high of a rate can lead to clogging of the system, and too low of a rate will decrease the efficacy of the system. The recirculation ratio ties back into the hydraulic loading rate, and helps to make up for periods of low flow so that the media is constantly wetted. The design of the biotower aims to achieve consistent sloughing through the hydraulic shear provided by the recirculation ratio and hydraulic loading rate.

Biotower Design Summary

The resulting design values and dimensions are noted in Table 11. The calculations can be found in Appendix A.

Table 11: Biotower Design Summary.

Parameter	Value
Hydraulic Loading Rate (Peak Flow)	73.5 $m^3/(m^2$-d)
Organic Loading Rate (Peak Flow)	1.3 kg/(m^3-d)
Recirculation Ratio	2
Media Depth	8.5 m
Media Diameter	29 m

The design values all comfortably remain within the ranges previously shown.

Biotower Design

A biotowers' primary purpose is to remove organic material through the use of bacteria and other microorganisms in order to treat wastewater. It is a relatively simple form of treatment that has existed for many years, although it was traditionally used with gravel media. The use of synthetic media in newer designs, including this one, allows for higher rates of treatment and also allows for wastewater to flow more smoothly through the tower. Figure 13 presents a schematic section view of the biotower.

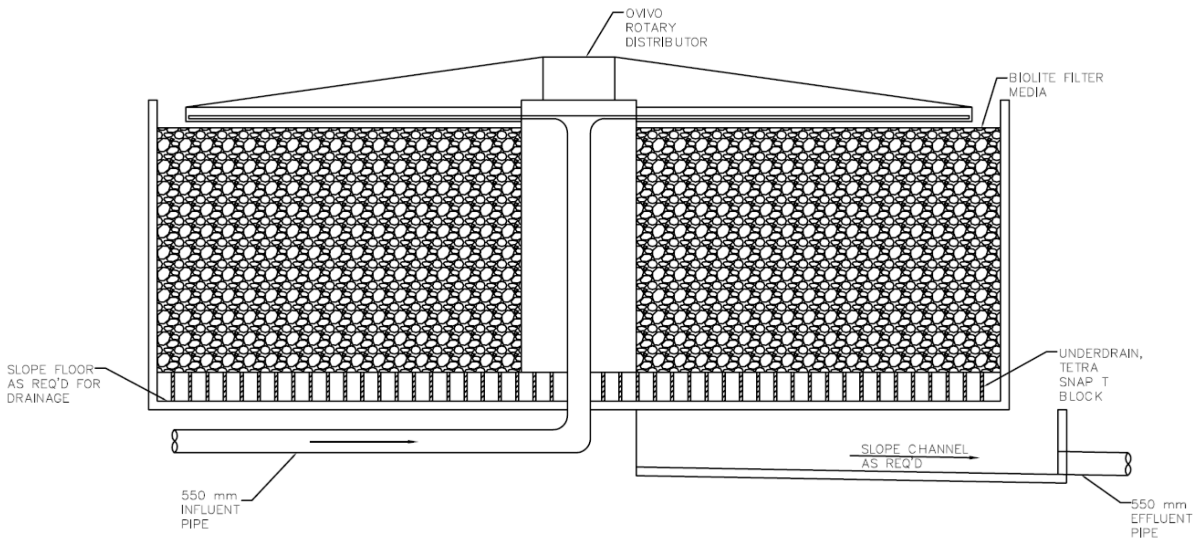


Figure 12: Biotower Section Drawing.

As the wastewater moves through the influent pipe coming in from the left, it rises to the top of the rotary distributor, which was selected to be speed controlled rather than hydraulically driven, as this provides greater control in the loading rate of the system. Plastic media was selected due to its higher void ratio and surface area, allowing for higher loading rates and greater efficacy. As the flow diffuses through the system, biomass becomes attached to the media due to bacteria in the wastewater consuming the organic matter. Once the flow exits the media, it passes through an underdrain system, which was selected to be modular block media, as it is less prone to clogging than spray nozzles embedded in monolithic underdrain systems. A modular block media underdrain also helps to provide an even distribution of air throughout the system, which is provided by passive air flow from the bottom the biotower. The flow is then directed into a channel by sloping the floor of the tower, and directed towards the next process. Furthermore, the use of lightweight plastic media means that there is less sidewall pressure exerted on the tower, enabling the use of steel walls, constructed out of steel columns and corrugated metal sheeting rather than traditional thick concrete walls. The erection of pre-fabricated steel components rather than cast in place concrete will save time and cost during construction.

Secondary Clarifier

After the water has been treated in the biotowers, it is sent to secondary clarifiers. These remove fine solids and microorganisms from the biotowers. The clarifiers send part of the clean effluent back to the biotowers as recycle flow in order to shear microorganisms in the biotowers. Because of this recycle flow, the secondary clarifiers treat the base flow plus the recycle flow, which is 20.25 MLD in this system.

As with the primary clarifiers, standard design criteria for secondary clarifiers were established. The design criteria are shown in Table 12. The overflow rate, weir loading rate, and solids loading rate are higher than in primary clarifiers, while the detention time is longer, since the secondary clarifiers need the water to spend more time in them than in primary clarification so that solids will be removed more effectively due to the smaller particle sizes and density.

Table 12: Design criteria for secondary clarifiers.

Description	***Value***
Overflow Rate (Average Flow)	15-25 $m^3/(m^2\ d)$ 400-600 $gal/(ft^2\ d)$
Overflow Rate (Peak Flow)	40-50 $m^3/(m^2\ d)$ 1000-1200 $gal/(ft^2\ d)$
Detention Time	3-4 hrs
Weir Loading Rate	120-500 $m^3/(m\ d)$ 10000-40000 gal/(ft d)
Solids Loading Rate	3-5 $kg/(m^2\ h)$ 0.6-1.0 $lb/(ft^2\ h)$

Like the primary clarifiers, the diameter was found from the overflow rate, and the side water depth was found from the detention time. A diameter of 36.6 m and side water depth of 3 m were selected. These values were checked with the weir loading rate and solids loading rate to ensure that the removal efficiency would be high enough for the effluent to meet the 30/30 mg/L BOD_5 and TSS requirements. The Smith & Loveless HS-120 equipment package was selected, with the optional three m diameter feedwell in order to manage the higher flow rate. The sludge hopper was scaled linearly to three cubic meters (m^3). The design dimensions are shown in Table 13.

Table 13: Secondary clarifier dimensions.

Description	***Value***
Diameter	36.6 m
Side Water Depth	3 m
Feedwell Diameter	3 m
Sludge Hopper Volume	3 m^3

The design dimensions were used to calculate the overflow rate at base and peak flow, detention time, weir loading rate, and solids loading rate (Table 14). These also fell within the design parameters.

Table 14: Performance criteria for selected dimensions for secondary clarifiers.

Description	***Value***
Overflow Rate (Average Flow)	19.2 $m^3/(m^2\ d)$ 472.9 $gal/(ft^2\ d)$
Overflow Rate (Peak Flow)	45.0 $m^3/(m^2\ d)$ 1106.6 $gal/(ft^2\ d)$
Detention Time	3.7 hrs
Weir Loading Rate	176.1 $m^3/(m\ d)$ 14202.8 gal/(ft d)
Solids Loading Rate	3.2 $kg/(m^2\ h)$ 0.7 $lb/(ft^2\ h)$

The schematic cross section for the secondary clarifiers is shown in Figure 14. Like all other components, there must be two identical secondary clarifiers so that one can be taken down for maintenance without taking the facility offline.

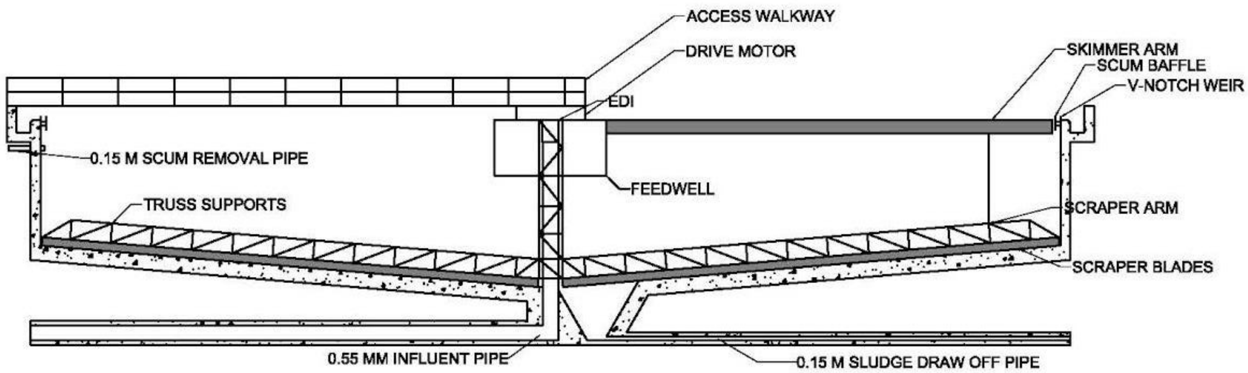


Figure 13: Schematic cross section for secondary clarifiers.

The concrete design for the secondary clarifiers is similar to the primary clarifiers, with 0.35 m wall thickness and 0.55 m foundation thickness and one meter above grade. The influent pipe is larger at 0.55 m diameter due to the larger flow. The sludge hopper is a right frustrum of three cubic meters volume. The sludge hopper's dimensions were calculated using Excel Solver. The concrete cross-section is shown in Figure 15.

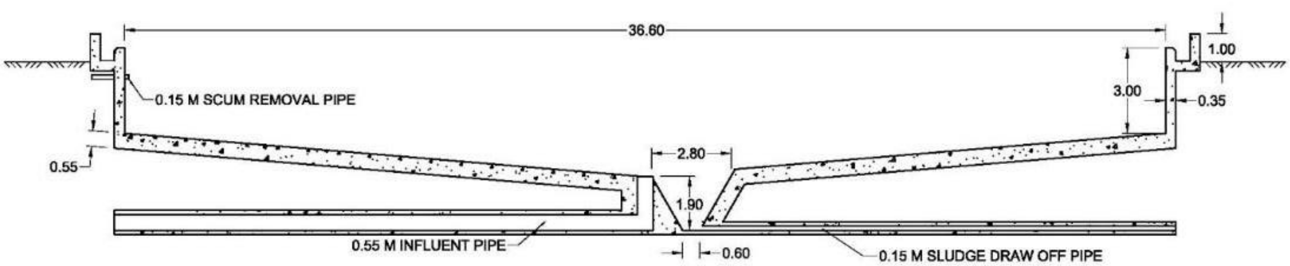


Figure 14: Concrete dimensions for secondary clarifiers (all dimensions in meters).

The secondary clarifiers use the same type of scum baffle, v-notch weir, and concrete outboard weir as the primary clarifiers. This will make construction easier, since the scum baffle and v-notch weir can be one order each to the supplier, and crews will have experience with the concrete weir. Details for the weir components are shown in Figure 15.

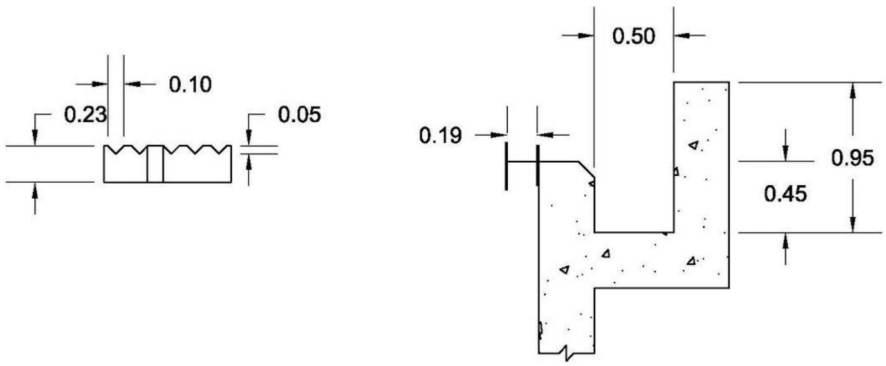


Figure 15: Steel v-notch weir detail (left) and concrete outboard weir cross-section (right)

Splitter Box Design

The purpose of a splitter box is to evenly distribute an influent flow to multiple effluent flows. In this plant, the splitter boxes are located prior to entering both the primary and secondary clarifiers. Figure 16 is a cross section of the splitter box

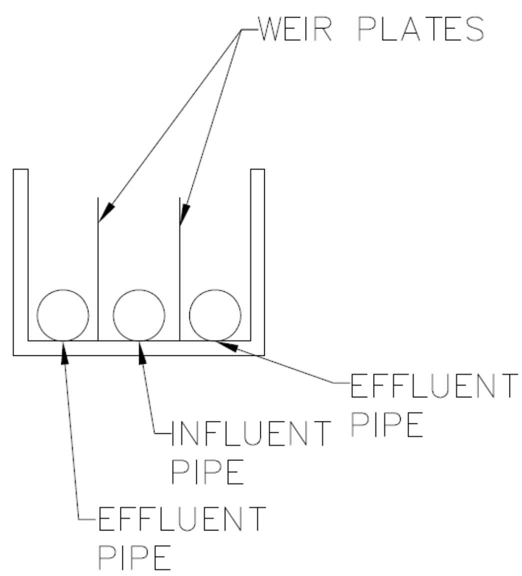


Figure 16: Splitter Box Section View.

As wastewater enters the splitter box through the 550 mm influent pipe, the center column fills up, and once it reaches a certain height, spills over the weir plates on either side of the column. The wastewater then flows out of the two effluent pipes to one of two clarifiers. The walls of the splitter box shall be constructed of reinforced concrete.

Pump Design

Another integral component of the system are the pumps preceding the biotowers, which provide the energy to overcome losses in the system due to friction, minor and static losses. There are three pumps in the pump station for redundancy. Although the primary clarifier is efficient, there is still the possibility of sizeable solids being present in the effluent, thus a solids handling pump is critical so that the pumps do not become clogged and halt operations. In order to pick a pump, it was necessary to calculate the amount of flow that the pump must be able to handle, as well as the head loss that it needed to overcome. Since there are certain components of the plant that were not within the scope of this project, such as preliminary treatment and sludge handling processes, the determination of head loss throughout this system is an approximation of what the final head loss would actually be if this design were to be constructed. The requirements for a single pump are noted in Table 15.

Table 15: Solids Handling Pump Requirements.

Parameter	Value
Required Flow Capacity (average flow)	3708.3 gpm
Required Head Capacity	9.1 m

The Fairbanks Nijhuis Model 5430 vertical solids handling pump meets these requirements, and is capable of passing 10% to 25% more solids, long stringy material, and trash than a conventional two-vane impeller (Model 5430). Thus, it is an appropriate solution for this treatment plant.

Construction Planning

Cost Analysis

In order to begin the estimation and scheduling of this project, the team created a work breakdown structure which outlined necessary tasks that need to be completed for various phases of design and construction. This work breakdown structure was divided into nine categories: pre construction, site work, pipes, primary clarifier, secondary clarifier, Biotower, pump station, splitter box, and final site commissioning. After deciding which tasks belong to specific phases of the project, RSMeans 2017 Heavy Construction and Building Construction was used to attain values for units, daily output, material, crew, labor, and equipment. All of these values can be seen in Table 16 below, with material, labor, and equipment all being cost values in dollars per unit. In order to get costs and durations of tasks, the team performed many takeoffs to get quantities for every task The complete project estimation can be seen in Appendix B, Table B-2.

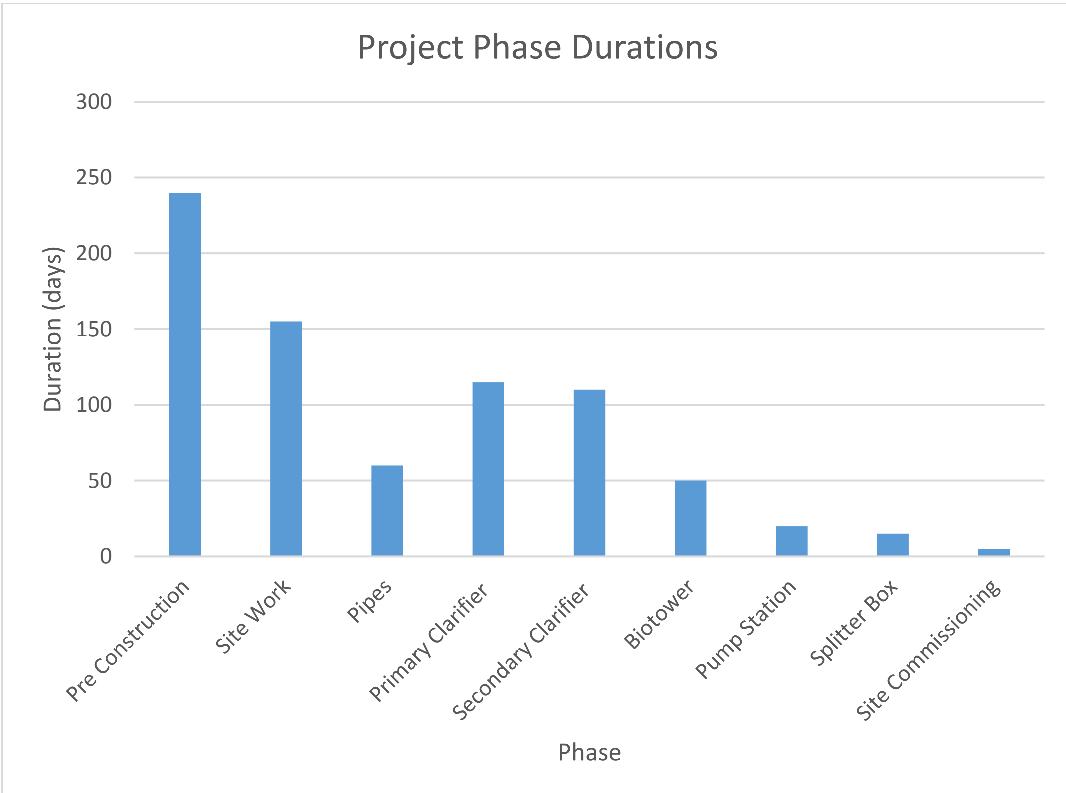
Table 16: Cost Estimation by Phase.

Phase	Cost
Pre Construction	$90,000
Site Work	$42,000
Pipes	$590,000
Primary Clarifier	$630,000
Secondary Clarifier	$1,120,000
Biotower	$1,770,000
Pump Station	$250,000
Splitter Box	$8,000
Site Commissioning	$90,000
Contingency (15%)	$676,000
Total Cost	$5,270,000

Project Scheduling

Based on the values attained for duration of time in the cost estimation, the team was able to start scheduling the project. In order to reduce the duration of the project, tasks were scheduled to happen simultaneously whenever possible, as well as extra crews being added to complete tasks that required a great deal of manual labor. The duration of days needed to complete the project was 660 days, a breakdown of this information per phase can be seen below in Figure 17. The complete project schedule can be seen in Appendix B, Table B-1.

Table 17: Project Duration per Phase.



Non-Technical Considerations

Although the proposed decentralized treatment plant will be extremely beneficial to the surrounding community, there remain some non-technical issues which need to be considered. The construction of this project will increase the traffic on the highway located near the site, almost inevitably, however, the goal is to reduce this traffic by doing the majority of the work outside of the peak traffic hours. Another possible public issue the team may encounter is constructing the treatment plant near a local temple, however the team proposes to use very large native trees and proper site landscaping to block visibility into the site in order to reduce possible disrespect to the local community.

The BWSSB and local government are separate entities and only the BWSSB could directly profit from the implementation of this project. Due to this fact, the local government will have to be convinced that although they do not directly profit from the project, they will indirectly profit through job opportunities for the public.

With every construction project comes possible environmental issues, especially with projects conducted on or near rivers. Some environmental issues the group expects to encounter are industrial waste and harm of the local wildlife. In order to mitigate these issues, the team looks to not allow any toxic materials into the river, clean up the site every day of any industrial waste, and construct a berm to reduce the harm to the wildlife in the river.

Project Takeaways

Learning how the various components of a treatment plant work together to produce an effluent that will have minimal impact on the environment was quite eye opening, as many people take proper wastewater treatment for granted and how important it is for the sustained and positive development of a society. The team was also exposed to the difficulties of international construction, and how many factors must be taken into consideration when designing for a location that is not easily accessible.

Conclusion

As discussed in the beginning of this document, the current state of water availability and quality, as well as the lack of sufficient wastewater infrastructure is what ignited the desire to prepare a treatment plant design like this one, plus could require the development of other solutions in the future. At present, a decentralized treatment plant is the best option to service quickly expanding areas that are not being properly serviced. Tying these areas into centralized treatment plants, as well as increasing the capacity of those plants, could take far too long to have a rapid enough impact in the lives of many. People and the environment do not have the time to wait, and they need quick and sufficient service. What the team is aiming to accomplish with this project is increase the health of people and the environment, and set the stage for future wastewater reclamation to address the shortage of water in the region. In biotowers, a fairly low-tech process that properly treats wastewater to the desired levels, has been selected.

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Appendix A

Table A1: Primary Clarifier Calculations.

Primary Clarifier Calculations			
Description	**Value**	**Unit**	**Excel Formula**
Q	6750.0	m3/m2d	6750.0
Qpeak	15795.0	m3/m2d	x=+D5*2.34
D	15.0	m	15.0
A	176.7	m2	x=+(D7/2)^2*PI()
OR avg	**38.2**	**m3/m2d**	**x=+D5/D8**
OR peak	**89.4**	**m3/m2d**	**x=+D6/D8**
OR avg	**938.5**	**gal/ft2d**	**x=+D9/0.0407**
OR peak	**2196.1**	**gal/ft2d**	**x=+D10/0.0407**
SWD	4.0	m	4.0
V	706.9	m3	x=+D8*D13
Detention Time	0.1	d	x=+D14/D5
Detention Time	**2.5**	**hr**	**x=+D15*24**
Weir Length	47.1	m	x=+D7*PI()
Weir Loading Rate	**143.2**	**m3/(md)**	**x=+D5/D17**
Weir Loading Rate	**11551.6**	**gal/(ftd)**	**x=+D18/0.0124**
TSS	200.0	mg/l	200.0
TSS	0.0	kg/l	x=+D20/100000
TSS	2.0	kg/m3	x=+D21*1000
Solids (avg)	13500.0	kg/day	x=+D22*D5
Solids (avg)	562.5	kg/hr	x=+D23/24
SLR (avg)	**3.2**	**kg/(hr m2)**	**x=+D24/D8**
SLR (avg)	**0.7**	lb/ft2 h	**x=+D25/4.8824**

Table A2: Secondary Clarifier Calculations.

Secondary Clarifier Calculations			
Description	**Value**	**Unit**	**Excel Formula**
Q	20250.0	m3/m2d	x=6750*3
Qpeak	47385.0	m3/m2d	x=+D4*2.34
D	36.6	m	36.6
A	1052.1	m2	x=+(D6/2)^2*PI()
OR avg	**19.2**	**m3/m2d**	**x=+D4/D7**
OR peak	**45.0**	**m3/m2d**	**x=+D5/D7**
OR avg	**472.9**	**gal/ft2d**	**x=+D8/0.0407**
OR peak	**1106.6**	**gal/ft2d**	**x=+D9/0.0407**
SWD	3.0	m	3.0
V	3156.3	m3	x=+D7*D12
Detention Time	0.2	d	x=+D13/D4
Detention Time	**3.7**	**hr**	**x=+D14*24**
Weir Length	115.0	m	x=+D6*PI()
Weir Loading Rate	**176.1**	**m3/(md)**	**x=+D4/D16**
Weir Loading Rate	**14202.7**	**gal/(ftd)**	**x=+D17/0.0124**
TSS	510.0	mg/l	510.0
TSS	0.0	kg/l	x=+D19/100000
TSS	5.1	kg/m3	x=+D20*1000
Solids (avg)	103275.0	kg/day	x=+D21*D4
Solids (avg)	4303.1	kg/hr	x=+D22/24
SLR (avg)	**4.1**	**kg/(hr m2)**	**x=+D23/D7**
SLR (avg)	**0.8**	lb/ft2 h	**x=+D24/4.8824**

Table A3: Biotower Calculations.

Description	Value	Unit
Total Inflow Calculated to be 6.75 MLD=	12.4956	MGD
Incoming BOD5=	140	mg/L
With high rate trickling filter containing Plastic Media, possible to treat 80 lb BOD		
Organic loading rate=	80	lb/1000 ft^3/day
Volume=	14589.86	lbs/day
V_Tot=	182373.3	ft^3
Depth=	28	ft
A_Tot=	6513.33	ft^2
Diameter=	95	ft
A_Tower=	7088.22	ft^2
# of towers=	0.92	
Round this up to one, and add one for redundancy		
Use 2 towers		
Use Ovivo Rotary distributor, or Sim.		
Use Biolite filter media, or Sim.		

Table A4: Splitter Box Calculations.

Description	Value	Unit
Flow Rate, Q=	20,214	m3/d
Q=	10107	m3/d-tank
Q=	0.116979	m3/s-tank
Assume a head(h_sc) over weir crest of 100 mm		
L=	2.052531	m
Round up L to 2.1 m		
Assuming Peaking Factor of 2.34		
Want to achieve 0.3 m/s at peak flow		
Thus, at peak flow with one tank out of service		
Q_peak=	0.547463	m3/s
A_pipe=	1.824875	m2
D_pipe=	1.524304	m
Choose 1520 mm		
Find standard Pipe size		
D_pipe=	1.54	m
Depth=	3.08	m
Add .6 m of freeboard		
Depth=	3.68	
Choose plan area of 3.5m x 3.5m		

Appendix B

Table B1: Construction Estimate.

RSMean #	Activity	Quantity	Unit	Daily Output	Duration (days)	Material ($/unit)	Crew	Labor ($/unit)	Equipment ($/unit)	Total
Pre Construction										
N/A	Detailed Design	30	day	1	30	N/A	N/A	512	N/A	$32,640.00
N/A	Construction Drawings	30	day	1	30	N/A	N/A	512	N/A	$32,640.00
N/A	Permit	180	day	1	180	N/A	N/A	512	N/A	$25,000.00
									Subtotal	**$90,280.00**
Site Work										
RSMean #	*Activity*	*Quantity*	*Unit*	*Daily Output*	*Duration (days)*	*Material ($/unit)*	*Crew*	*Labor ($/unit)*	*Equipment ($/unit)*	*Total*
02 21 13.13 0300	Survey	8	Acre	2	4.0	34	A-7	650	21	$5,640.00
31 23 16.50 0410	Cut	1553.8	CY	648	2.4		B-33F	1.07	2.57	$5,655.83
31 22 16.10 3100	Grading for Foundations (Fine)	3387	SY	1040	3.3		B-11L	0.71	0.65	$4,606.32
31 22 13.20 0270	Grading for Site (Rough)	1	EA	0.5	2.0		B-11L	1475	1350	$2,825.00
31 23 16.43 5300	Structural Excavation (Primary Clarifier)	1805.9	BCY	3400	0.5		B-14A	0.18	0.91	$1,968.43
31 23 16.43 5300	Structural Excavation (Bio Tower)	518.3	BCY	3400	0.2		B-14A	0.18	0.91	$564.95
31 23 16.43 5300	Structural Excavation (Secondary Clarifier)	13175.3	BCY	3400	3.9		B-14A	0.18	0.91	$14,361.08

31 14 13.23 0200	Strip Topsoil (Primary Clarifier)	178.1	CY	3000	0.1		B-10 M	0.2	0.63	$147.82
31 14 13.23 0200	Strip Topsoil (Bio Tower)	518.3	CY	3000	0.2		B-10 M	0.2	0.63	$430.19
31 14 13.23 0200	Strip Topsoil (Secondary Clarifier)	825.7	CY	3000	0.3		B-10 M	0.2	0.63	$685.33
31 23 23.14 3200	Backfill (Primary Clarifier)	814	LCY	670	1.2		B-10 W	0.87	0.91	$1,448.92
31 23 23.14 3200	Backfill (Bio Tower)	0	LCY	670	0.0		B-10 W	0.87	0.91	$0.00
31 23 23.14 3200	Backfill (Secondary Clarifier)	2308	LCY	670	3.4		B-10 W	0.87	0.91	$4,108.24
									Subtotal	**$42,442.11**
					Pipes					
RSMean #	*Activity*	*Quantity*	*Unit*	*Daily Output*	*Duration (days)*	*Material ($/unit)*	*Crew*	*Labor ($/unit)*	*Equipment ($/unit)*	*Total*
31 23 16.13 0062	Excavate (Pipes) (150mm)	44.9	BCY	270	0.2		B-12 F	2.81	2.5	$238.65
31 23 16.13 0062	Excavate (Pipes) (350mm)	123.1	BCY	270	0.5		B-12 F	2.81	2.5	$653.88
31 23 16.13 0062	Excavate (Pipes) (550mm)	752.0	BCY	270	2.8		B-12 F	2.81	2.5	$3,992.92
22 13 16.20 2200	Lay Pipe (150mm)	555.4	LF	*73*	7.6	*42.5*	*Q-2*	*18.95*		$34,132.07
22 13 16.20 3082	Lay Pipe (350mm)	866.1	LF	*40*	21.7	*178*	*Q-3*	*47*		$194,881.30
	Lay Pipe (550mm)	1141.7	LF	*40*	28.5	*246*	*Q-3*	*47*		$334,526.55

31 23 23.16 0050	Gravel Backfill (150mm)	7.7	BCY	150	0.1	21.5	B-6	6.9	2.44	$237.10
31 23 23.16 0050	Gravel Backfill (350mm)	27.1	BCY	150	0.2	21.5	B-6	6.9	2.44	$835.21
31 23 23.16 0050	Gravel Backfill (550mm)	261.9	BCY	150	1.7	21.5	B-6	6.9	2.44	$8,077.24
31 23 23.16 0200	Earth Backfill (150mm)	37.3	BCY	150	0.2	18.6	B-6	6.9	2.44	$1,040.90
31 23 23.16 0200	Earth Backfill (350mm)	89.9	BCY	150	0.6	18.6	B-6	6.9	2.44	$2,510.63
31 23 23.16 0200	Earth Backfill (550mm)	490.1	BCY	150	3.3	18.6	B-6	6.9	2.44	$13,692.09
									Subtotal	**$594,818.55**
Primary Clarifiers										
RSMean #	*Activity*	*Quantity*	*Unit*	*Daily Output*	*Duration (days)*	*Material ($/unit)*	*Crew*	*Labor ($/unit)*	*Equipment ($/unit)*	*Total*
31 23 16.13 0062	Excavate (Pipes)	3.5	BCY	270	0.0		B-12 F	2.81	2.5	$18.59
31 23 23.16 0050	Pipe Bedding	1.5	LCY	150	0.0	21.5	B-6	6.9	2.44	$46.26
33 31 13.13 2026	Lay Pipe (150 mm)	50	LF	84	0.6	38.5	Q-2	16.5		$2,750.00
33 31 13.13 2034	Lay Pipe (350 mm)	50	LF	49	1.0	162	Q-3	38.5		$10,025.00
03 31 13.70 2950	Concrete Backfill for Pipe	2	CY	400	0.0		C-20	6.75	2.16	$17.82

03 21 11.60 0600	Rebar (Mat Foundation)	9.5	Ton	2.3	4.1	940	4 Rodm	755		$16,144.88
03 11 13.55 0050	Formwork (Mat Foundation)	1680	SFCA	310	5.4	1.21	C-2	7.4		$14,464.80
03 31 13.70 2950	Pour Concrete (Mat Foundation)	254	CY	400	0.6		C-20	6.75	2.16	$2,263.14
03 21 11.60 0700	Rebar (Inner Walls)	6.2	Tons	2.3	2.7	940	4 Rodm	580		$9,348.00
03 11 13.85 4525	Formwork (Inner Walls)	7506	SFCA	355	21.1	0.52	C-2	6.5		$52,692.12
03 31 13.70 5350	Pour (Inner Walls)	164	CY	120	1.4		C-20	22.5	7.2	$4,870.80
03 21 11.60 0700	Rebar (Weir Base)	3.0	Tons	2.3	1.3	940	4 Rodm	580		$4,560.00
03 11 13.85 4350	Formwork (Weir Base)	766	SFCA	355	2.2	1.18	C-2	6.5		$5,882.88
03 31 13.70 5350	Pour (Weir Base)	80	CY	120	0.7		C-20	22.5	7.2	$2,376.00
03 21 11.60 0700	Rebar (Weir Inner)	0.8	Tons	2.3	0.3	940	4 Rodm	580		$1,140.00
03 11 13.85 4350	Formwork (Weir Inner)	912	SFCA	355	2.6	1.18	C-2	6.5		$7,004.16
03 31 13.70 5350	Pour (Weir Inner)	20	CY	120	0.2		C-20	22.5	7.2	$594.00

03 21 11.60 0700	Rebar (Weir Outer)	1.7	Tons	2.3	0.8	940	4 Rodm	580		$2,622.00
03 11 13.85 4350	Formwork (Weir Outer)	2234	SFCA	355	6.3	1.18	C-2	6.5		$17,157.12
03 31 13.70 5350	Pour (Weir Outer)	46	CY	120	0.4		C-20	22.5	7.2	$1,366.20
	S&L HS-50	2	EA	*0.05*	40.0	*100000*	*B-3C*	*100000*		$400,000.00
	Concrete Material Price	566	CY			*125*				$70,750.00
									Subtotal	**$626,093.76**
Secondary Clarifiers										
RSMean #	*Activity*	*Quantity*	*Unit*	*Daily Output*	*Duration (days)*	*Material ($/unit)*	*Crew*	*Labor ($/unit)*	*Equipment ($/unit)*	*Total*
31 23 16.13 0062	Excavate (Pipes)	8.3	BCY	270	0.0		B-12F	2.81	2.5	$44.07
31 23 23.16 0050	Pipe Bedding	3.3	LCY	150	0.0	21.5	B-6	6.9	2.44	$101.77
33 31 13.13 2026	Lay Pipe (150 mm)	60	LF	84	0.7	38.5	Q-2	16.5		$3,300.00
33 31 13.13 2034	Lay Pipe (550 mm)	60	LF	49	1.2	162	Q-3	38.5		$12,030.00
03 31 13.70 2950	Concrete Backfill for Pipe	5	CY	400	0.0		C-20	6.75	2.16	$44.55
03 21 11.60 0600	Rebar (Mat Foundation)	56.8	Ton	2.3	24.7	940	4 Rodm	755		$96,233.63

03 11 13.55 0050	Formwork (Mat Foundation)	6211	SFCA	310	20.0	1.21	C-2	7.4		$53,476.71
03 31 13.70 2950	Pour Concrete (Mat Foundation)	1514	CY	400	3.8		C-20	6.75	2.16	$13,489.74
03 21 11.60 0700	Rebar (Inner Walls)	14.7	Tons	2.3	6.4	940	4 Rodm	580		$22,401.00
03 11 13.85 4525	Formwork (Inner Walls)	1702	SFCA	355	4.8	0.52	C-2	6.5		$11,948.04
03 31 13.70 5350	Pour (Inner Walls)	393	CY	120	3.3		C-20	22.5	7.2	$11,672.10
03 21 11.60 0700	Rebar (Weir Base)	3.5	Tons	2.3	1.5	940	4 Rodm	580		$5,244.00
03 11 13.85 4350	Formwork (Weir Base)	166	SFCA	355	0.5	1.18	C-2	6.5		$1,274.88
03 31 13.70 5350	Pour (Weir Base)	92	CY	120	0.8		C-20	22.5	7.2	$2,732.40
03 21 11.60 0700	Rebar (Weir Inner)	0.9	Tons	2.3	0.4	940	4 Rodm	580		$1,368.00
03 11 13.85 4350	Formwork (Weir Inner)	207	SFCA	355	0.6	1.18	C-2	6.5		$1,589.76
03 31 13.70 5350	Pour (Weir Inner)	24	CY	120	0.2		C-20	22.5	7.2	$712.80
03 21 11.60 0700	Rebar (Weir Outer)	4.0	Tons	2.3	1.7	940	4 Rodm	580		$6,042.00

03 11 13.85 4350	Formwork (Weir Outer)	466	SFCA	355	1.3	1.18	C-2	6.5		$3,578.88
03 31 13.70 5350	Pour (Weir Outer)	106	CY	120	0.9		C-20	22.5	7.2	$3,148.20
	S&L HS-120	2	EA	*0.05*	40.0	*150000*	*B-3C*	*150000*		$600,000.00
	Concrete Material Price	2134	CY			*125*				$266,750.00
									Subtotal	**$1,117,182.53**
Bio Towers										
RSMean #	*Activity*	*Quantity*	*Unit*	*Daily Output*	*Duration (days)*	*Material ($/unit)*	*Crew (#)*	*Labor ($/unit)*	*Equipment ($/unit)*	*Total*
31 23 16.13 0062	Excavate (Pipes)	49.4	BCY	270	0.2		B-12F	2.81	2.5	$262.12
31 23 23.16 0050	Pipe Bedding	23.6	LCY	150	0.2	21.5	B-6	6.9	2.44	$728.56
33 31 13.13 2034	Lay Pipe (30")	47.6	LF	49	1.0	162	Q-3	38.5		$9,543.80
03 31 13.70 2950	Concrete Backfill for Pipe	8.5	CY	400	0.0	125	C-20	6.75	2.16	$1,133.18
03 21 11.60 0600	Rebar (Mat Foundation)	35.6	Ton	2.3	15.5	940	4 Rodm	755		$60,409.80
03 11 13.55 0050	Formwork (Mat Foundation)	2363	SFCA	310	7.6	1.21	C-2	7.4		$20,345.43
03 31 13.70 2950	Pour Concrete (Mat Foundation)	950.4	CY	400	2.4	125	C-20	6.75	2.16	$127,268.06

05 12 23.17 7150	Steel columns	630	LF	1032	0.6	72	E-2	2.92	1.62	$48,220.20
05 31 13.50 6000	Floor Decking (Used for walls)	21184	SF	2700	7.8	4.37	E-4	0.65	0.05	$107,402.88
Manufacturer	Filter Media	5791	m3	1158.2	5.0	104.95				$607,765.45
Manufacturer	Rotary Distributor	2	EA	0.2	10.0	187,325	*B-3C*	150000		$674,650.00
Manufacturer	Underdrain system	2	EA			56591.8				$113,183.60
									Subtotal	**$1,770,913.07**
Pump Station (Wet Well)										
RSMean #	*Activity*	*Quantity*	*Unit*	*Daily Output*	*Duration (days)*	*Material ($/unit)*	*Crew*	*Labor ($/unit)*	*Equipment ($/unit)*	*Total*
31 23 16.43 5300	Structural Excavation (Concrete Box)	26.1	BCY	3400	0.0		B-14A	0.18	0.91	$28.50
03 11 13.65 2050	Formwork (Concrete Box)	128.4	SFCA	250	0.5	1.45	C-1	6		$956.58
03 31 13.70 1600	Pour (Concrete Box)	8.6	CY	180	0.0		C-20	15	4.79	$169.31
03 21 11.60 0700	Rebar (Walls)	0.3	Tons	2.3	0.1	940	4 Rodm	580		$500.54
03 11 13.85 4050	Formwork (Walls)	476.3	SFCA	300	1.6	1.41	C-2	7.65		$4,315.28
03 31 13.70 5100	Pour (Walls)	8.8	CY	110	0.1		C-20	24.5	7.85	$284.08
	Install Pumps	3	EA			82783				$248,349.00
									Subtotal	**$254,603.30**
Splitter Box before secondary clarifier										

RSMean #	Activity	Quantity	Unit	Daily Output	Duration (days)	Material ($/unit)	Crew	Labor ($/unit)	Equipment ($/unit)	Total
31 23 16.43 5300	Structural Excavation (Splitter Box)	49.0	BCY	3400	0.0		B-14 A	0.18	0.91	$53.39
03 21 11.60 0600	Rebar (Mat Foundation)	0.2	Ton	2.3	0.1	940	4 Rod m	755		$305.10
03 11 13.55 0050	Formwork (Mat Foundation)	132.0	SFC A	310	0.4	1.21	C-2	7.4		$1,136.52
03 31 13.70 2950	Pour Concrete (Mat Foundation)	4.8	CY	400	0.0		C-20	6.75	2.16	$42.77
03 21 11.60 0700	Rebar (Walls)	0.7	Tons	2.3	0.3	940	4 Rod m	580		$1,064.00
03 11 13.85 4050	Formwork (Walls)	460	SFC A	300	1.5	1.41	C-2	7.65		$4,167.60
03 31 13.70 5100	Pour (Walls)	18.7	CY	110	0.2		C-20	24.5	7.85	$603.87
	Install Weir Plates	2	ea	2	1.0	175				$350.00
					0.012				**Subtotal**	**$7,723.24**
Site Commisioning										
										Total (2% of total project costs)
										$90,081.13
Contingency										
										Total (15% of total project costs)

										$675,608.48
									Project Cost:	**$5,269,746.18**

Table B2: Construction Schedule.

Task Name	Duration	Start	Finish
Pre Construction	**240 days**	**Fri 9/1/17**	**Thu 8/30/18**
Detailed Design	30 days	Fri 9/1/17	Thu 10/19/17
Construction Drawings	30 days	Fri 10/20/17	Thu 11/30/17
Permit	180 days	Fri 12/1/17	Thu 8/30/18
Site Work	**153 days**	**Fri 8/31/18**	**Tue 4/2/19**
Survey	4 days	Fri 8/31/18	Wed 9/5/18
Cut	3 days	Thu 9/6/18	Mon 9/10/18
Grading for Foundations (Fine)	4 days	Fri 9/14/18	Wed 9/19/18
Grading for Site (Rough)	2 days	Tue 9/11/18	Wed 9/12/18
Structural Excavation (Primary Clarifier)	1 day	Wed 9/12/18	Wed 9/12/18
Structural Excavation (Bio Tower)	1 day	Wed 9/12/18	Wed 9/12/18
Structural Excavation (Secondary Clarifier)	4 days	Wed 9/12/18	Mon 9/17/18
Strip Topsoil (Primary Clarifier)	1 day	Tue 9/11/18	Tue 9/11/18
Strip Topsoil (Bio Tower)	1 day	Tue 9/11/18	Tue 9/11/18
Strip Topsoil (Secondary Clarifier)	1 day	Tue 9/11/18	Tue 9/11/18
Backfill (Primary Clarifier)	2 days	Wed 12/26/18	Thu 12/27/18
Backfill (Bio Tower)	1 day	Fri 1/18/19	Fri 1/18/19
Backfill (Secondary Clarifier)	4 days	Thu 3/28/19	Tue 4/2/19
Pipes	**59 days**	**Mon 4/8/19**	**Thu 6/27/19**
Excavate (Pipes) (150mm)	8 days	Mon 4/8/19	Wed 4/17/19
Excavate (Pipes) (350mm)	22 days	Thu 4/18/19	Fri 5/17/19
Excavate (Pipes) (550mm)	29 days	Mon 5/20/19	Thu 6/27/19
Lay Pipe (150mm)	8 days	Mon 4/8/19	Wed 4/17/19
Lay Pipe (350mm)	22 days	Thu 4/18/19	Fri 5/17/19
Lay Pipe (550mm)	29 days	Mon 5/20/19	Thu 6/27/19
Gravel Backfill (150mm)	8 days	Mon 4/8/19	Wed 4/17/19
Gravel Backfill (350mm)	22 days	Thu 4/18/19	Fri 5/17/19
Gravel Backfill (550mm)	29 days	Mon 5/20/19	Thu 6/27/19
Earth Backfill (150mm)	8 days	Mon 4/8/19	Wed 4/17/19
Earth Backfill (350mm)	22 days	Thu 4/18/19	Fri 5/17/19
Earth Backfill (550mm)	29 days	Mon 5/20/19	Thu 6/27/19
Primary Clarifiers	**114 days**	**Thu 9/20/18**	**Tue 2/26/19**
Excavate (Pipes)	1 day	Thu 9/20/18	Thu 9/20/18

Pipe Bedding	1 day	Fri 9/21/18	Fri 9/21/18
Lay Pipe (150 mm)	1 day	Mon 9/24/18	Mon 9/24/18
Lay Pipe (350 mm)	2 days	Tue 9/25/18	Wed 9/26/18
Concrete Backfill for Pipe	1 day	Thu 9/27/18	Thu 9/27/18
Rebar (Mat Foundation)	5 days	Fri 9/28/18	Thu 10/4/18
Formwork (Mat Foundation)	6 days	Fri 10/5/18	Fri 10/12/18
Pour Concrete (Mat Foundation)	1 day	Mon 10/15/18	Mon 10/15/18
Rebar (Inner Walls)	3 days	Thu 10/18/18	Mon 10/22/18
Formwork (Inner Walls)	22 days	Tue 10/23/18	Wed 11/21/18
Pour (Inner Walls)	2 days	Thu 11/22/18	Fri 11/23/18
Rebar (Weir Base)	2 days	Thu 11/29/18	Fri 11/30/18
Formwork (Weir Base)	3 days	Mon 12/3/18	Wed 12/5/18
Pour (Weir Base)	1 day	Thu 12/6/18	Thu 12/6/18
Rebar (Weir Inner)	1 day	Thu 12/13/18	Thu 12/13/18
Formwork (Weir Inner)	3 days	Fri 12/14/18	Tue 12/18/18
Pour (Weir Inner)	1 day	Wed 12/19/18	Wed 12/19/18
Rebar (Weir Outer)	1 day	Thu 12/13/18	Thu 12/13/18
Formwork (Weir Outer)	7 days	Fri 12/14/18	Mon 12/24/18
Pour (Weir Outer)	1 day	Tue 12/25/18	Tue 12/25/18
S&L HS-50	40 days	Wed 1/2/19	Tue 2/26/19
Secondary Clarifiers	**109 days**	**Tue 1/1/19**	**Fri 5/31/19**
Excavate (Pipes)	1 day	Mon 1/21/19	Mon 1/21/19
Pipe Bedding	1 day	Tue 1/22/19	Tue 1/22/19
Lay Pipe (150 mm)	1 day	Wed 1/23/19	Wed 1/23/19
Lay Pipe (550 mm)	2 days	Thu 1/24/19	Fri 1/25/19
Concrete Backfill for Pipe	1 day	Mon 1/28/19	Mon 1/28/19
Rebar (Mat Foundation)	25 days	Tue 1/1/19	Mon 2/4/19
Formwork (Mat Foundation)	21 days	Fri 1/11/19	Sat 2/9/19
Pour Concrete (Mat Foundation)	4 days	Mon 2/11/19	Thu 2/14/19
Rebar (Inner Walls)	7 days	Wed 2/13/19	Thu 2/21/19
Formwork (Inner Walls)	5 days	Fri 2/22/19	Thu 2/28/19
Pour (Inner Walls)	4 days	Fri 3/1/19	Wed 3/6/19
Rebar (Weir Base)	2 days	Tue 3/12/19	Wed 3/13/19
Formwork (Weir Base)	1 day	Thu 3/14/19	Thu 3/14/19
Pour (Weir Base)	1 day	Fri 3/15/19	Fri 3/15/19

Rebar (Weir Inner)	1 day	Fri 3/22/19	Fri 3/22/19
Formwork (Weir Inner)	1 day	Fri 3/22/19	Fri 3/22/19
Pour (Weir Inner)	1 day	Mon 3/25/19	Mon 3/25/19
Rebar (Weir Outer)	2 days	Thu 3/21/19	Fri 3/22/19
Formwork (Weir Outer)	2 days	Mon 3/25/19	Tue 3/26/19
Pour (Weir Outer)	1 day	Wed 3/27/19	Wed 3/27/19
S&L HS-120	40 days	Mon 4/8/19	Fri 5/31/19
Bio Towers	**47 days**	**Mon 12/17/18**	**Tue 2/19/19**
Excavate (Pipes)	1 day	Wed 12/26/18	Wed 12/26/18
Pipe Bedding	1 day	Thu 12/27/18	Thu 12/27/18
Lay Pipe (30")	1 day	Fri 12/28/18	Fri 12/28/18
Concrete Backfill for Pipe	1 day	Mon 12/31/18	Mon 12/31/18
Rebar (Mat Foundation)	16 days	Mon 12/17/18	Mon 1/7/19
Formwork (Mat Foundation)	8 days	Thu 1/3/19	Mon 1/14/19
Pour Concrete (Mat Foundation)	3 days	Tue 1/15/19	Thu 1/17/19
Steel columns	1 day	Fri 1/18/19	Fri 1/18/19
Floor Decking (Used for walls)	8 days	Fri 2/1/19	Tue 2/12/19
Filter Media	5 days	Wed 2/13/19	Tue 2/19/19
Rotary Distributor	10 days	Fri 1/18/19	Thu 1/31/19
Underdrain system	5 days	Fri 2/1/19	Thu 2/7/19
Pump Station (Wet Well)	**22 days**	**Wed 12/26/18**	**Thu 1/24/19**
Structural Excavation (Concrete Box)	1 day	Wed 12/26/18	Wed 12/26/18
Formwork (Concrete Box)	1 day	Thu 1/3/19	Thu 1/3/19
Pour (Concrete Box)	1 day	Fri 1/4/19	Fri 1/4/19
Rebar (Walls)	1 day	Mon 1/14/19	Mon 1/14/19
Formwork (Walls)	2 days	Tue 1/22/19	Wed 1/23/19
Pour (Walls)	1 day	Thu 1/24/19	Thu 1/24/19
Install Pumps	0 days	Thu 1/24/19	Thu 1/24/19
Install Electrical Components	0 days	Thu 1/24/19	Thu 1/24/19
Splitter Box before secondary clarifier	**16 days**	**Wed 2/20/19**	**Wed 3/13/19**
Structural Excavation (Splitter Box)	1 day	Wed 2/20/19	Wed 2/20/19
Rebar (Walls)	1 day	Thu 2/28/19	Thu 2/28/19
Formwork (Walls)	2 days	Fri 3/8/19	Mon 3/11/19
Pour (Walls)	1 day	Tue 3/12/19	Tue 3/12/19
Install Weir Plates	1 day	Wed 3/13/19	Wed 3/13/19

Site Commissioning	**80 days**	**Thu 3/14/19**	**Wed 7/3/19**
Final Cut & Fill	2 days	Fri 6/28/19	Mon 7/1/19
Testing of Tanks	1 day	Thu 3/14/19	Thu 3/14/19
Testing of Pumps	1 day	Fri 3/15/19	Fri 3/15/19
Fencing & Painting	1 day	Tue 7/2/19	Tue 7/2/19
Final Site Clean up & Landscaping	1 day	Wed 7/3/19	Wed 7/3/19