Spring 2019

Design of a Denitrification Bioreactor for St. Francis Retreat Center

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I hereby recommend that the
SENIOR DESIGN PROJECT REPORT
prepared under my supervision by

MONIQUE HANSEN
&
ASHTON POLITZ

entitled

DESIGN OF A DENITRIFICATION BIOREACTOR FOR ST. FRANCIS RETREAT CENTER

be accepted in partial fulfillment of the requirements for
the degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

Advisor ______________________________ Date

6.10.2019

Chair of Department ______________________________ Date

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by

Monique Hansen
&
Ashton Politz

SENIOR DESIGN PROJECT REPORT

submitted to
The Department of Civil, Environmental, and Sustainable Engineering

of

SANTA CLARA UNIVERSITY

in partial fulfillment of the requirements
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Bachelor of Science Degree in Civil Engineering

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The team of Ashton Politz and Monique Hansen would like to thank Keith Warner OFM of Santa Clara University's Miller Center and resident of the St. Francis Retreat Center for introducing us to this project. We would also like to thank Edward de Groot who is the Director of Operations on the St. Francis Retreat Center for providing us with all the information we needed to put this project together. We would like to thank our faculty advisor Dr. Laura Doyle for guiding us throughout this project. Additionally, thank you to Professor Sukhmander Singh and Professor Edwin Maurer for their assistance in necessary calculations for the design of the bioreactor. Finally, we would like to thank the School of Engineering for providing funding for our project.

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ABSTRACT

The St. Francis Retreat Center located in San Juan Bautista, California has over 7000 visitors a year. The Retreat Center aims to provide a peaceful rejuvenating experience for its visitors through the opportunity to enjoy the natural beauty and landscape it has to offer. Unfortunately, the Retreat Center has a lake on its property that, primarily during the summer months, is dry due to the lack of rain. In effort to solve this problem and make the property more visually appealing, the Retreat Center would like to use the water from a well to recharge the lake. The well, however, is currently contaminated with high levels of nitrates. A sustainable, cost-effective, and aesthetically appealing solution to this problem is a denitrification bioreactor. This report designs a denitrification bioreactor for the Retreat Center. Included in this report is an analysis of the potential location of the bioreactor, the size of the bioreactor, the grade of the bioreactor walls, and flow rate and pipe size for the bioreactor. Additionally, this report addresses logistics for the construction of the bioreactor including the necessary cut and fill amounts, the cost estimate, and finally the schedule for construction. Ultimately, the Retreat Center would use the components of this report as the foundation for the construction of their denitrification bioreactor.

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INTRODUCTION

On September 26, 2018 the team of Ashton Politz and Monique Hansen met with Keith Warner OFM of Santa Clara University's Miller Center to discuss a potential senior design project. Brother Warner currently lives at the St. Francis Retreat Center which is surrounded by the Gavilan Mountain Range in San Juan Bautista, CA as seen in Figure 1. The St. Francis Retreat Center provides the opportunity for people of all faiths and religions, to escape from society and connect with their mind, body, and soul. In an effort to provide guests with a rewarding experience, a core value of the St. Francis Retreat Center is "Stewardship of the Earth." Furthermore, the Retreat Center claims, "In the Spirit of St. Francis of Assisi, the Center's staff commits itself to stewardship of the earth by honoring and preserving the Center's natural surroundings while extending hospitality and spiritual support to peoples of all faiths" (St. Francis Retreat Center - About Us, 2016). This core value echos Santa Clara University's Vision of "Santa Clara University will educate citizens and leaders of competence, conscience, and compassion, and cultivate knowledge and faith to build a more humane, just, and sustainable world" (Santa Clara University, 2019). Given how closely related St. Francis Retreat Center's core value is to Santa Clara University, this senior design project encompasses how this team of Monique and Ashton has fulfilled Santa Clara University's Strategic Mission.

Figure 1: Map of Northern California with the location of Santa Clara University and the St. Francis Retreat Center identified.

This senior design project is a continuation of two senior design projects from 2017 which consisted of a sustainable recharge of a dry lake on the Retreat Center property with water from a well contaminated with nitrates. Drew Highlander and Patrick Johnson, designed and tested the use of woodchips as a bioreactor to remove nitrates from contaminated water (Highlander and Johnson, 2017). Melene Agakanian and Cathy Cantoni designed a water distribution system to transport water from a well to the bioreactor and dry pond (Agakanian and

Cantoni, 2017). Using their research, this senior design project went one step further and designed a denitrification bioreactor specifically for St. Francis Retreat Center.

As of November 9, 2017, the St. Francis Retreat Center earned a water supply permit. This water supply permit is only applicable, however, to the water from the well and aquifer located on their property not the nitrate contaminated well located beyond the hill. The well that is located on their property which can be treated and distributed as potable water throughout their property can be seen in Figure 2 labeled "Aquifer and Potable Water Well." Further, the Retreat Center can filter and disinfect water from this well to be distributed for use throughout the property. With this system that meets state and federal requirements, they can provide safe drinking water throughout the Retreat Center. Since the St. Francis Retreat Center has this permit, they want to be able to utilize all water, including the contaminated well water, to distribute potable water throughout the Retreat Center. With that goal in mind, the Retreat Center needs the bioreactor to filter the nitrate contaminated water before it can infiltrate into the on site aquifer and be extracted to their existing filtration system.

Figure 2: Shows the two wells on the St. Francis Retreat Center property. The contaminated well will be filtered by the bioreactor to remove the nitrates. The aquifer and potable water well is the source of water currently that the St. Francis Retreat Center filters to distribute as potable water throughout the center's property.

Furthermore, the Retreat Center has a lake that is aesthetically appealing and used by the guests for healing purposes. Currently, however, the lake is dry. The denitrification bioreactor will help reduce the nitrate levels in the well water which will enable the Retreat Center to use the denitrified water to help fill the dry lake and recharge their groundwater aquifer used for drinking water.

As of April 5, 2019 the concentration of nitrate in the well water was 22 milligrams per liter (mg/L) which is two times the legal limit. Given this high level of nitrates, as described in the Design Criteria and Standards sections below, this design is aimed to effectively remove the nitrates to make the water below the legal limit of 10 mg/L according to the California Water Board ("California Drinking Water-Related Laws").

ALTERNATIVE ANALYSIS OF LOCATIONS

During site walks with Edward de Groot, the Director of Operations on the Retreat Center, two possible locations of the bioreactor were determined (Figure 3). The first potential location was on the plateau of a hill, located in between the well and the dry lakebed (Location 1). The second option was on an open flatland closer to the entrance of the Retreat Center (Location 2). In order to determine which location would be more ideal for residents and visitors to the center as well for ease of construction, an alternative analysis was conducted on the two locations. This alternative analysis included the total piping needed from the well to the bioreactor and to the lakebed, the type of soil, and the visual aesthetics for the Retreat Center.

Figure 3: The two possible locations for the bioreactor on the St. Francis Retreat Center in relationship to the well and lake.

In order to determine the length of piping required for the two possible locations, measurements were taken from a topographic map of the Retreat Center. For Location 1, approximately 2,300 ft. of piping is necessary to transport the water from the well to the bioreactor and then from the bioreactor to the well. For Location 2, the Retreat Center has an existing bioswale that could carry the water from the bioreactor into the lakebed. While the distance of the bioreactor is further from the well and the lakebed, the amount of piping needed would be comparable to Location 1, at 2,500 ft. of piping, and then the water would travel an additional 300 ft. down the bioswale into the lakebed. Location 2 is located across a road from the well, which would complicate the installation of piping, requiring road closure and repaving after installation.

The two locations have different soil characteristics, which impacts the excavation during construction as well as the sturdiness of the walls of the bioreactor. Location 1 is a clay soil, with a dense structure, allowing it to be very sturdy (Jamal, 2017). Clay soil will increase the rate of excavation during construction; however, it is still feasible with a backhoe. While this soil would be more difficult during construction, it would be stronger for the walls of the bioreactor by keeping a uniform shape after excavation. The clay soil can support the walls of the bioreactor without any additional reinforcement. In contrast, Location 2 consists of a sandy soil. Sandy soil allows for easier excavation of the soil; however, this second location is adjacent to trees and the roots could impact excavation and may lead to delays in construction. Sandy soil is not as strong after excavation, and the walls of the bioreactor may require extra reinforcements.

As previously stated, the aesthetics of the Retreat Center are very important to maintain the quality of their property. Thus, the aesthetics of the bioreactor is very important. In Location 1, the bioreactor would be located on top of a hill near the edge of the property line. Many visitors to the Retreat Center would not see the bioreactor, and the woodchips would blend into the natural landscape of the hillside. Location 2 would be seen more often, as it is directly next to the entrance of the Retreat Center. Visitors would be able to see the bioreactor on their right as they enter the property, and it could also be seen from the main building. Additionally, Location 2 is directly next to the location of a planned solar field and could impact the expansion of solar panels.

These variables included in the alternative analysis were discussed with Edward de Groot to reach the decision on the final location. After considering all the possibilities at both locations, Location 1 was chosen. As seen in the analysis in Table 1, Location 1 offers more ease of construction, allows for a less complicated design using only the natural land for the walls of the bioreactor, and limits the change in overall aesthetics to the Retreat Center. Location 1 was therefore used for the design of this bioreactor.

Table 1: Summary of the Alternative Analysis between Location 1 and 2.

	Location 1: Hillside Adjacent to Lake	**Location 2: Flatland near Retreat Entrance**
Piping Length Requirements	2,300 ft. total	2,500 ft. with and additional 300 ft. existing bioswale
Soil Characteristics	Clay soil- Dense, sturdy	Sandy soil- Loose
Visual Aesthetics	Near edge of property, away from guests	Could be seen approaching and entering the retreat center

WATER TEST RESULTS AND ANALYSIS

During a site visit to the St. Francis Retreat Center, water was collected from the well to test the nitrate level. The Hatch® Surface Water Test Kit was used to test the nitrate levels. Three test tubes were filled with the well water and five milliliters (mL) of nitrate reagent powder, as seen in Figure 4. The color of the test tubes were compared to the color chart to determine the level of nitrates. As seen in Figure 5, the first two trials showed a nitrate level of 22 mg/L, and the third trial showed a nitrate level of 20 mg/L. The average nitrate level found in the water was therefore 21.3 mg/L. A summary of the results is displayed in Table 2, below.

Table 2: The nitrate levels from three tests of water from the well on the St. Francis Retreat Center.

Trial Number	Nitrate Level Observed (mg/L)
1	22
2	22
3	20
Average	21.3

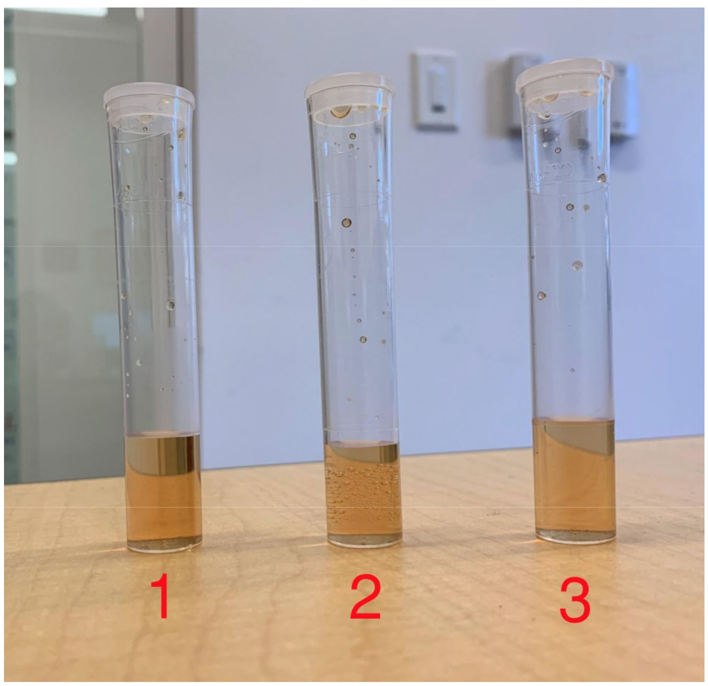

Figure 4: The three test tubes of water after the addition of five mL nitrate reagent powder.

Figure 5: The three test tubes being compared to the color chart, determining the nitrate level in the water.

According to the California State Water Resources Control Board , the maximum contaminant level of nitrate in water is 10 mg/L ("California Drinking Water-Related Laws", 2019). The maximum contaminant level is the legal limit of the concentration of a certain substance allowed in the water system. Since the legal limit of nitrate is 10 mg/L, the water from the well is in violation of the legal limit. From the test shown above, the nitrate level is about twice the legal amount of nitrates allowed in drinking water.

DESIGN CRITERIA AND STANDARDS

Bioreactor Size and Retention Time

There are several factors that must be considered when designing the size of the bioreactor: flow rate, retention time, length and width of bioreactor, and the location of bioreactor. As mentioned in the Alternative Analysis Location Section, it was determined that the bioreactor would be built in the Location 1. Location 1 is a large area as seen in Figure 3, therefore, it would not be a limiting factor when designing the bioreactor. Research revealed the two dominating factors that would determine the bioreactor size are the flow rate and retention time (Christianson et al, 2013).

In order to design a denitrification bioreactor that was both effective in nitrate removal and cost efficient, analysis was conducted on flow rate and retention time (Christianson et al, 2013). A short retention time in combination with a high flow rate would limit nitrate removal by inhibiting the full chemical reaction between the woodchips and nitrates. (Christianson et al, 2013). Therefore, it is imperative that the retention time be designed correctly in order to effectively remove the nitrates while also preventing negative side effects of high retention times which include sulfate reduction and mercury methylation. Christianson et al (2013) also revealed that the minimum retention time was four hours (240 minutes) and the maximum retention time was 31 hours (1860 minutes). To determine the optimal retention time for the bioreactor the following equation was used:

$$\tau = \frac{V p}{Q} \tag{1}$$

where τ = retention time (minutes), V = active flow volume of the bioreactor, p = porosity of the carbonaceous fill media (woodchips), and Q = flow rate (m^3/minutes) (Christianson et al, 2013). For the St. Francis Retreat Center bioreactor, the flow rate was known to be 12 gal/min (1.604 ft^3/min) which was obtained from the pump already installed at the well at the time of gathering data. Also, the porosity for woodchips was assumed to be 0.7 (Christianson et al 2013).

Table 3, uses Equation 1 to determine the optimal retention time and dimensions of the bioreactor based on the known flow rate and porosity of the woodchips. To ensure effective removal of nitrates, it was determined the ideal retention time would be 480 minutes or eight hours. With a retention time of eight hours, a flow rate of 12 gal/min (1.604 ft^3/min), and a porosity of 0.7, the bioreactor was designed to be 28 feet in length, five feet in width, and four feet deep as highlighted in Table 3.

Table 3: Evaluates the potential dimensions for the bioreactor as a result of varying the flow rate and retention time using equation 1. The highlighted row indicates the chosen design for the bioreactor.

Q, Flow Rate (ft^3/min)	**Retention Time (min)**	**Porosity, p**	**Flow Volume (ft^3)**	**Length (ft)**	**Width (ft)**	**Depth (ft)**	**Checking Flow Volume (ft^3)**
1.604	240	0.7	550.00	30	5	4	600
1.604	360	0.7	825.00	28	8	4	896
1.604	**480**	**0.7**	**1100.00**	**28**	**10**	**4**	**1120**
1.604	600	0.7	1375.00	34	10	4	1360
1.604	1860	0.7	4262.50	60	20	4	4800

Christianson et al (2013) suggests that the ideal length to width ratio for maximum removal of nitrates is 2:1 or 3:1. In designing the bioreactor, therefore, several variations of the length to width ratio were tested to determine the most efficient ratio. In Table 3, the column “Checking Flow Volume” is to ensure that the dimensions are adequate to achieve the actual flow volume shown in the column titled "Flow Volume." An overall representation of the bioreactor with the specific dimensions can be seen in Appendix A page A - 4.

Bearing Weight of Soil

In order to evaluate whether the type of soil located at the site was sturdy enough to support the bioreactor without reinforcements, Terzaghi's Bearing Capacity Theory was used. Professor Sukhmander Singh from the Santa Clara University Civil, Environmental, and Sustainable Engineering Department assisted with the theory and the correct assumptions to use for clay soil. In order to determine the ultimate bearing capacity of the clay soil, the following equation was used:

$$q_{ult.} = cN_c + \gamma D_f N_q + 0.5\phi B M_y \quad (2)$$

This equation is used to find the bearing capacity of strip footings; however, it can be applied to the bioreactor by treating the weight exerted by the bioreactor on the soil as the footing.

The first term in Equation 2 relates to the cohesion of the soil. The effective cohesion, c, can range from 250 pounds per square foot ($\frac{lb}{ft^2}$) to 2000 $\frac{lb}{ft^2}$ (Singh, 2019). Since the actual effective cohesion of the clay soil is unknown, a very conservative value of 300 $\frac{lb}{ft^2}$ was used. The bearing capacity factor, N_c, is a function of the soil friction angle. For clay soil, there is a negligible friction angle, so it is assumed to be 0°. When the soil friction angle is 0°, N_c is 5.7 ("Terzaghi's Method", 2015). The second term in Equation 2 relates to depth of the footing. For the bioreactor, the depth is assumed negligible as it is even with the natural ground. Finally, the third term relates to the friction and width of the footing. As stated above, the friction in clay soil is negligible; therefore, only the first term in Equation 2 is used to determine the ultimate bearing capacity of the clay soil on the site. A safety factor of three was used in the calculations seen below, resulting in an allowable bearing capacity of 570 $\frac{lb}{ft^2}$.

Given:

$$factor\ of\ safety = 3$$

$$assume\ no\ friction: \ \phi = 0$$

$$assume\ no\ depth: \ D_f = 0$$

Effective cohesion, c:

$$c_{min} = 250 \ \frac{lb}{ft^2}$$

$$c_{max} = 2000 \ \frac{lb}{ft^2}$$

$$\Rightarrow \ c = 300 \ \frac{lb}{ft^2} \text{ (for a conservative value)}$$

Bearing capacity factor, N_c:

For no friction, $\phi = 0$, $N_c = 5.7$

Terzaghi's Bearing Capacity Theory:

$$q_{ult.} = cN_c + \gamma D_f N_q + 0.5\phi B M_y$$

$$q_{ult.} = cN_c$$

$$q_{ult.} = 300 \ \frac{lb}{ft^2} \times 5.7$$

$$q_{ult.} = 1710 \ \frac{lb}{ft^2}$$

$$\frac{q_{ult.}}{FS} = \frac{1710 \ \frac{lb}{ft^2}}{3}$$

$q_{allowable} = 570 \frac{lb}{ft^2}$

In order to determine the actual weight exerted on the soil, the following equation (Singh, 2019) was used:

$$q_{actual} = (w_1 + w_2) \times d \qquad (3)$$

where w_1 is the weight of pure water, 62.4 $\frac{lb}{ft^3}$, w_2 is the weight of dry woodchips 23.72 $\frac{lb}{ft^3}$ (Convert Volume to Weight, 2019) , and d is the maximum depth of the water and woodchips, which is three feet (ft). A safety factor of three was used in the calculations seen below, resulting in an actual weight of 258.36 $\frac{lb}{ft^2}$ exerted on the soil.

Given:

$weight\ of\ pure\ water = w_1 = 62.4 \frac{lb}{ft^3}$

$weight\ of\ dry\ woodchips = w_2 = 23.72 \frac{lb}{ft^3}$

$maximum\ depth = d = 3\,ft.$

$factor\ of\ safety = 3$

Actual Bearing Weight:

$q_{actual} = (w_1 + w_2) \times d$

$q_{actual} = (62.4 \frac{lb}{ft^3} + 23.72 \frac{lb}{ft^3}) \times 3\,ft.$

$q_{actual} = 258 \frac{lb}{ft^2}$

Overall, the calculated allowable bearing capacity of the clay soil was 570 $\frac{lb}{ft^2}$, while the calculated actual weight of the bioreactor on the soil was 258 $\frac{lb}{ft^2}$. The clay soil will therefore be able to support the bioreactor without any reinforcements.

Stability of Slope of Walls

In order to determine the appropriate slope for the walls of the bioreactor, an equation from *Soil Mechanics in Engineering Practice* by Terzaghi and Peck was evaluated. Terzaghi and Peck (1996) state for any slope angle less than 53° in clay soil, the critical height of the slope can be found using the following equation:

$$H_c = 5.52 \frac{c}{\gamma} \tag{4}$$

where γ is the unit weight of clay and c is the effective cohesion. The unit weight of clay was found to be 105 $\frac{lb}{ft^3}$ (Lindeburg, 2015). The effective cohesion used was the same value used in the calculations for the bearing weight of soil, which was 300 $\frac{lb}{ft^3}$. A safety factor of three was used in the calculations seen below, resulting in an allowable wall height of 5.26 ft for any angle under 53°.

<u>Given:</u>

$$\gamma = unit\ weight\ of\ clay = 105 \frac{lb}{ft^3}$$

$$c = effective\ cohesion = 300 \frac{lb}{ft^3}$$

<u>For a slope angle less than 53° in clay soil:</u>

$$H_c = 5.52\,\frac{c}{\gamma}$$

$$H_c = 5.52\,\frac{300}{105}$$

$$H_c = 15.77\,ft.$$

$$\frac{H_c}{FS} = \frac{15.77\,ft.}{3}$$

$$H_{allowable} = 5.26\,ft.$$

Using Equation 4, it was found that an allowable height for the walls of the bioreactor was 5.26 ft. for a slope less than 53°. From the calculations above, the designed depth of the bioreactor was four ft. It was therefore concluded that a 45° angle would work for the designed height of four ft. From these calculations, the Grading Plan seen on A-3 was developed.

Pipe Size and Flow Rate

An analysis was performed in WaterCAD to model the water pump and piping system. This analysis ensured the designed water flow rate of 12 gallons per minute (gpm) would be delivered to the bioreactor. The system modeled in WaterCAD can be seen in Figure 6, where R-1 is the well, P-1 is the piping between the well and pump, PMP-1 is the pump, P-2 is 2,000 feet of PVC piping, and R-2 is the bioreactor.

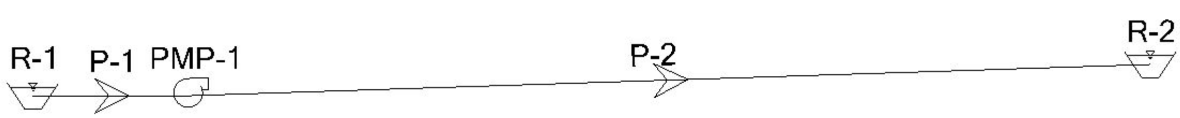

Figure 6: The WaterCAD model of the water pump and piping system into the bioreactor, where R-1 represents the well and R-2 represents the bioreactor.

The results of the analysis, displayed in Table 4, show a four inch (in) PVC pipe is capable of delivering a maximum of 14 gpm water into the bioreactor. The pump currently installed in the well has a capacity of 12 gpm. From this analysis, therefore, a four inch PVC pipe from the well to the bioreactor will deliver the required flow rate of 12 gpm used in the design of the bioreactor. From this analysis, the Piping Details seen on page A-6 were developed.

Table 4: The WaterCAD analysis showing a four inch PVC pipe has a maximum flow rate of 14 gpm into the bioreactor.

Label	Start Node	Stop Node	Length (ft)	Diameter (in)	Material	Flow (gpm)	Velocity (ft/s)
P-2	PMP-1	R-2	2,000	4	PVC	14	1.44

Water Facility and Control

To control the flow and residence time of the water in the bioreactor, there will be a four inch PVC pipe at the entrance of the bioreactor that transports the water from the well through the wall of the bioreactor. This four inch PVC pipe is connected to a six inch perforated PVC pipe that is placed horizontally across the width of the bioreactor as seen in Figure 7 Detail B. This horizontal placement of the six inch perforated PVC pipe across the width of the bioreactor is designed to evenly distribute the water throughout the bioreactor. The exit of the bioreactor will have a similar piping configuration. There is a six inch perforated PVC pipe placed horizontally across the width of the inside of the bioreactor wall to collect the water in the bioreactor. Connected to the six inch perforated PVC pipe is another four inch PVC pipe that transports the water through the wall of bioreactor. This four inch PVC pipe transports the water outside of the bioreactor through an Inline Water Level Control Structure. This is seen in Figure 7 Detail A. This control structure maintains the appropriate residence time of the water to ensure optimal effectiveness of the bioreactor.

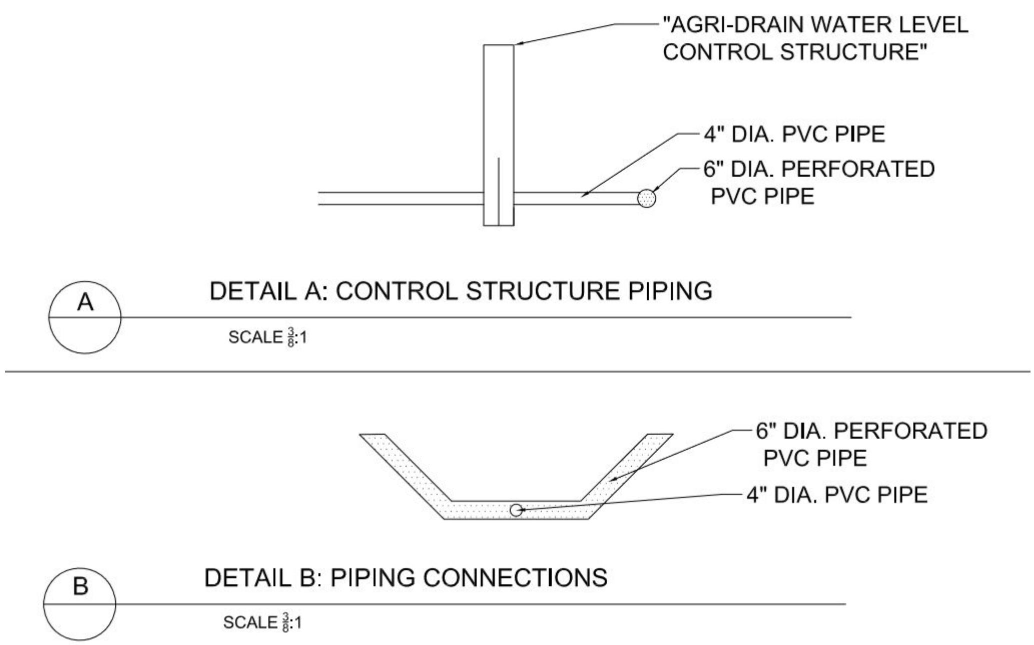

Figure 7: Detail A shows the water level control structure, located at the exit of the bioreactor, used to regulate residence time of the water which is connected to the four inch PVC pipe and the six inch perforated PVC pipe shown. Detail B shows the connection of the four inch PVC pipe and six perforated PVC pipe located both at the entrance and exit of the bioreactor.

Cut and Fill

To complete construction on the designed bioreactor, there will need to be cut and fill of soil in this location. For cutting purposes, there will need to be digging to obtain the proper depth of the bioreactor as well as additional digging to lay the piping that lies outside of the bioreactor. For filling purpose, there will need to be fill to build the walls of the bioreactor as well as filling for the area that was dug to lay the piping. The following sections show how the calculations for total volume of cut and fill. The total cut volume was 620 ft^3 seen in Table 5 and the total fill volume was 543.5 ft^3 seen in Table 6. The total cut is greater than the required fill so the remaining 76.5 ft^3 will need to be hauled from the site. It is important to note that the following calculations are not indicative of the order that the cut and fill operations should take place but, rather, they are broken into these categories for calculations purposes.

Part 1: Cut Calculations

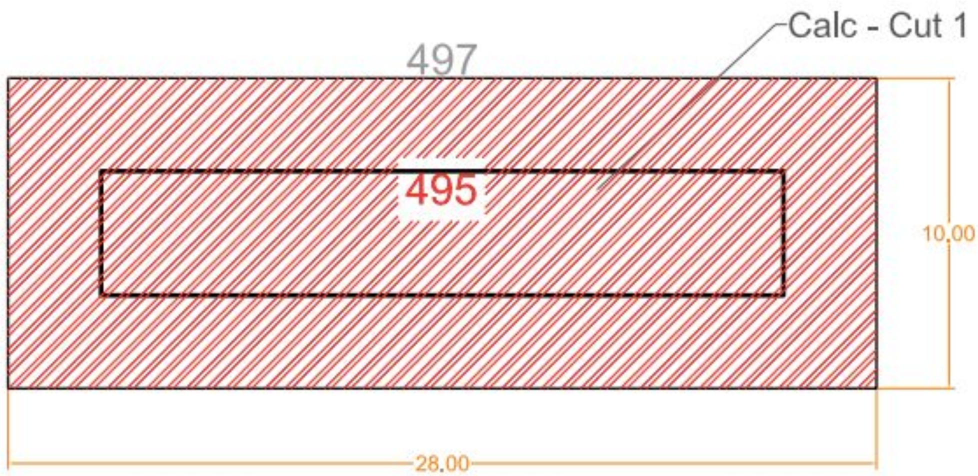

Figure 8: The area corresponding with Cut 1 calculations reported in Table 5. Grey numbers are current elevations and red proposed elevations. All dimensions are in feet.

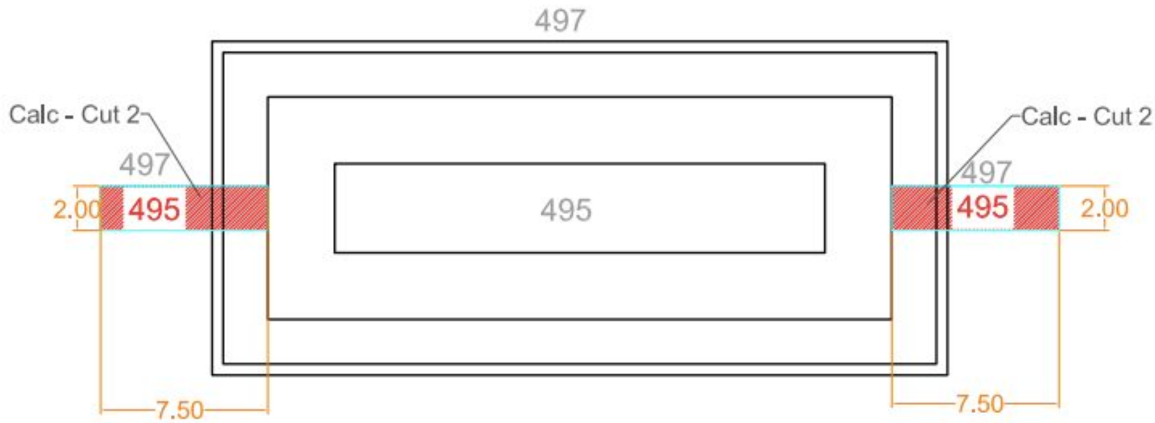

Figure 9: The area corresponding with Cut 2 calculations reported in Table 5. Grey numbers are current elevations and red proposed elevations. All dimensions are in feet.

Table 5: Calculations for the volume of soil removed for Figures 8 and 9.

Cut Calculations	**Volume Removed (ft^3)**
Cut 1	560
Cut 2	60
Total Cut	**620**

Part 2: Fill Calculations

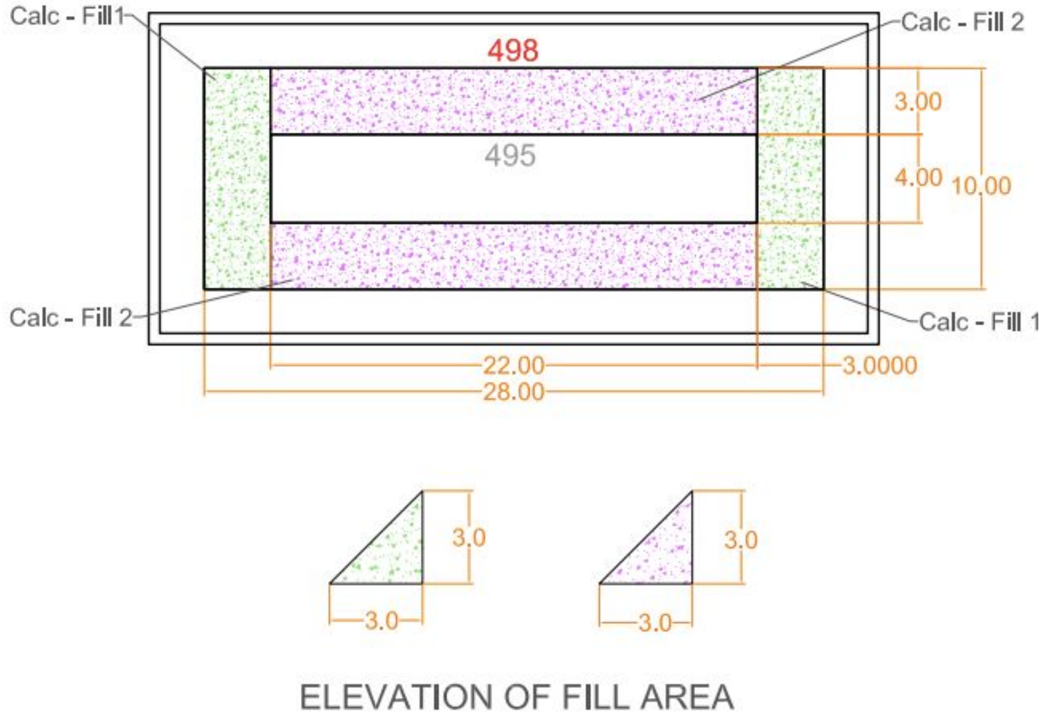

Figure 10: The area that corresponding with Fill 1 and 2 calculations reported in Table 6. Grey numbers are current elevations and red proposed elevations. All dimensions are in feet.

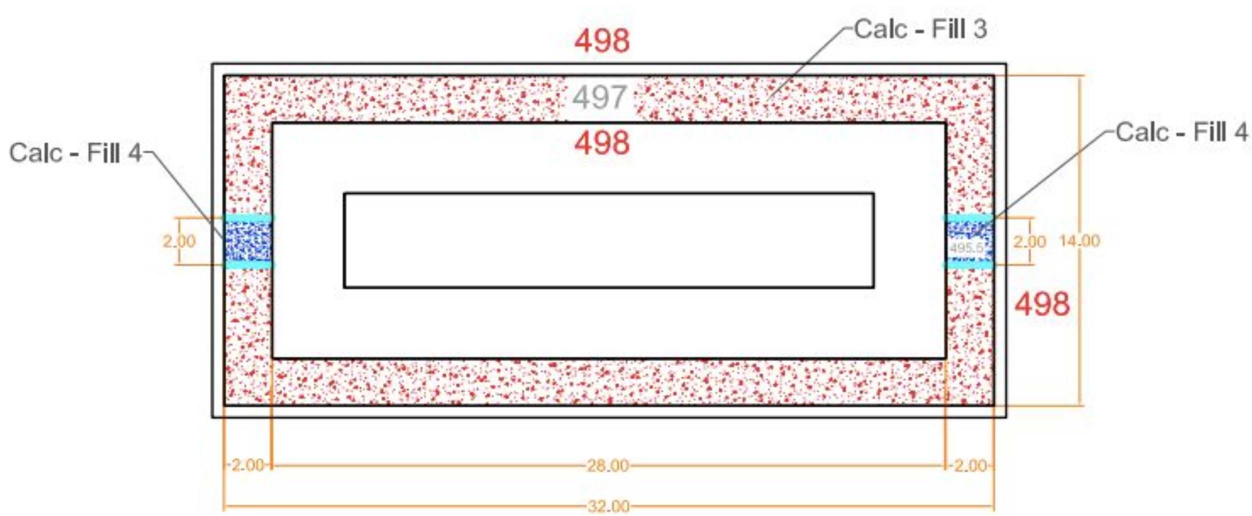

Figure 11: The area corresponding with Fill 3 and 4 calculations reported in Table 6. Grey numbers are current elevations and red proposed elevations. All dimensions are in feet.

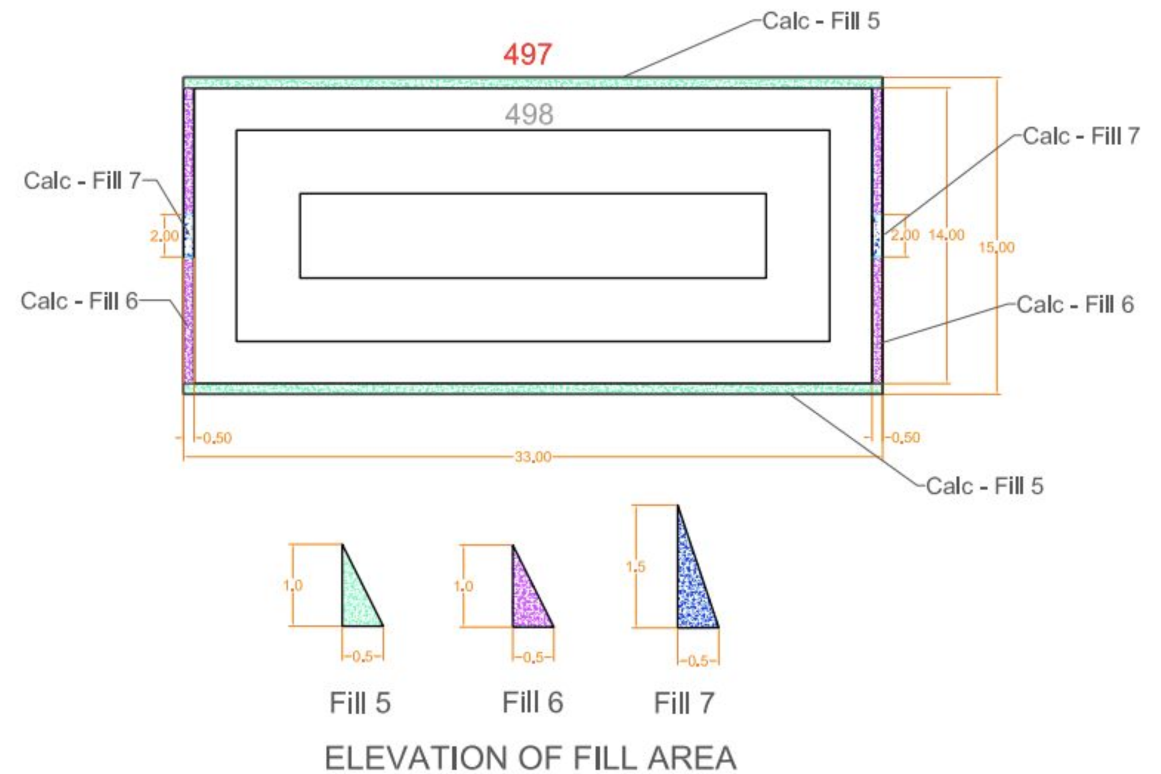

Figure 12: The area corresponding with Fill 5, 6, and 7 calculations reported in Table 6. Grey numbers are current elevations and red proposed elevations. All dimensions are in feet.

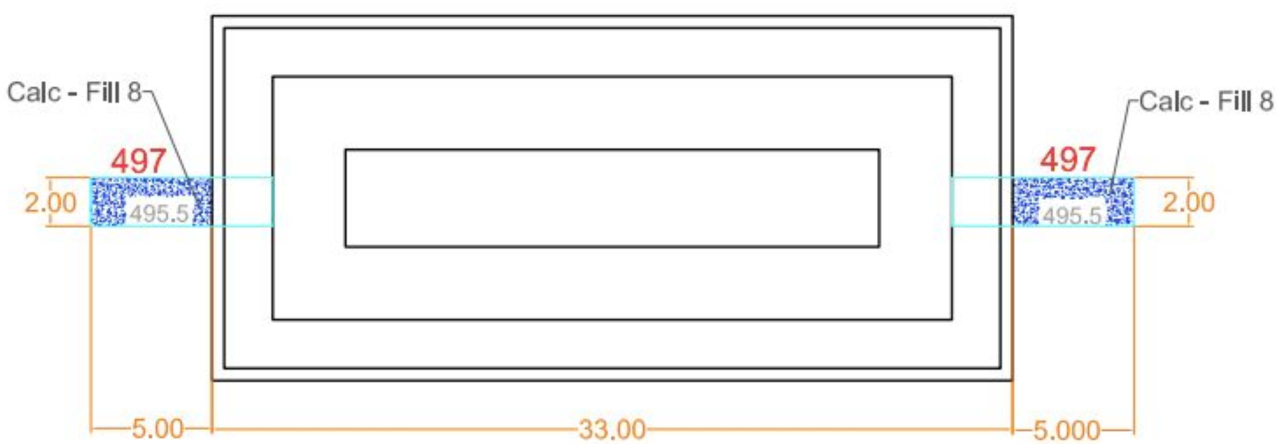

Figure 13: The area corresponding with Fill 8 calculations reported in Table 6. Grey numbers are current elevations and red proposed elevations. All dimensions are in feet.

Table 6: Calculations for the fill volume of soil for Figures 10-14.

Fill Calculations	Volume Filled (ft^3)
Fill 1	90
Fill 2	198
Fill 3	160
Fill 4	20
Fill 5	16.5
Fill 6	6
Fill 7	3
Fill 8	50
Total Fill	**543.5**

COST ESTIMATE

To provide the St. Francis Retreat Center with the overall cost of the denitrification bioreactor, Table 7 breaks down each material needed for the bioreactor and the associated quantity and cost. As shown in Table 7 the total cost for the bioreactor is $2,595.08.

Table 7: The cost breakdown for the bioreactor design including the material, quantity, unit cost, and total cost.

Material	Quantity	Unit	Unit Cost	Total Cost
6" Perforated PVC Pipe	24	LF	$1.69	$40.56
4" PVC Pipe*	21	LF	$3.20	$67.20
Surface Water Test Kit	1	COUNT	$365.00	$365.00
Inline Water Level Control Structure (Height 5 ft.)	1	COUNT	$590.76	$590.76
Woodchips**	70	CU FT	-	-
Wheelbarrow	2	COUNT	$54.98	$109.96
Backhoe	1	COUNT	$350.00	$350.00
Plastic Lining	280	SF	$0.97	$271.60

Labor for Piping Installation	16	HOURS	$25.00	$400.00
Labor for Cut/Fill	16	HOURS	$25.00	$400.00
TOTAL COST				**$2,595.08**

*The quantity of pipe includes five feet past the entry and exit of the bioreactor and also the quantity of pipe need in the bioreactor. Does not include total pipe length from the well and to the lake.
**The water test kit was used in testing the water and, since St. Francis Retreat Center already has a water testing company test their water, this will not be needed. It is is included in the overall budget however.
***Woodchips will either be from the St. Francis Retreat Center or donated. Both allow for no cost of woodchips. Please note according to research, the woodchips cannot come from cedar, oak, or high-tannin woods.
[1] (Menard, n.d.)
[2] (PVC Pipe Supplies, n.d.)
[3] (Hatch, 2019)
[4] (Agri Drain Corporation, 2019)
[5] (The Home Depot, 2019)
[6] (Cost Owl, 2019)
[7] (Anjon Lifeguard - Amazon, 2019)

SCHEDULE

A construction schedule for the bioreactor was created to give the St. Francis Retreat Center an idea about the duration of the project. Figure 14 displays the construction tasks and Gantt chart for the sequence of activities. Construction is estimated to last three days. The first day will consist of excavating for the bioreactor and trenching for the piping installation. The second day will include installation of the PVC piping, laying the geofilter fabric as lining for the bioreactor, and installing the PVC perforated piping. This piping will require testing and inspection prior to being covered. The third day will include backfill to create the slope of the bioreactor and covering the piping. Finally, on the third day the woodchips will be placed in the bioreactor. The bioreactor will then be functional and ready for continual use after the third day of construction.

ID	Task Name	Duration	Start	Finish
1	Construction Start	0 days	Mon 6/3/19	Mon 6/3/19
2	Excavate and Trench	1 day	Mon 6/3/19	Mon 6/3/19
3	Install PVC Piping	1 day	Tue 6/4/19	Tue 6/4/19
4	Lay Geofilter	1 day	Tue 6/4/19	Tue 6/4/19
5	Install Perforated Piping	1 day	Tue 6/4/19	Tue 6/4/19
6	Test and Inspect Piping	1 day	Tue 6/4/19	Tue 6/4/19
7	Backfill over Piping	1 day	Wed 6/5/19	Wed 6/5/19
8	Place Woodchips	1 day	Wed 6/5/19	Wed 6/5/19
9	Project Completion	0 days	Wed 6/5/19	Wed 6/5/19

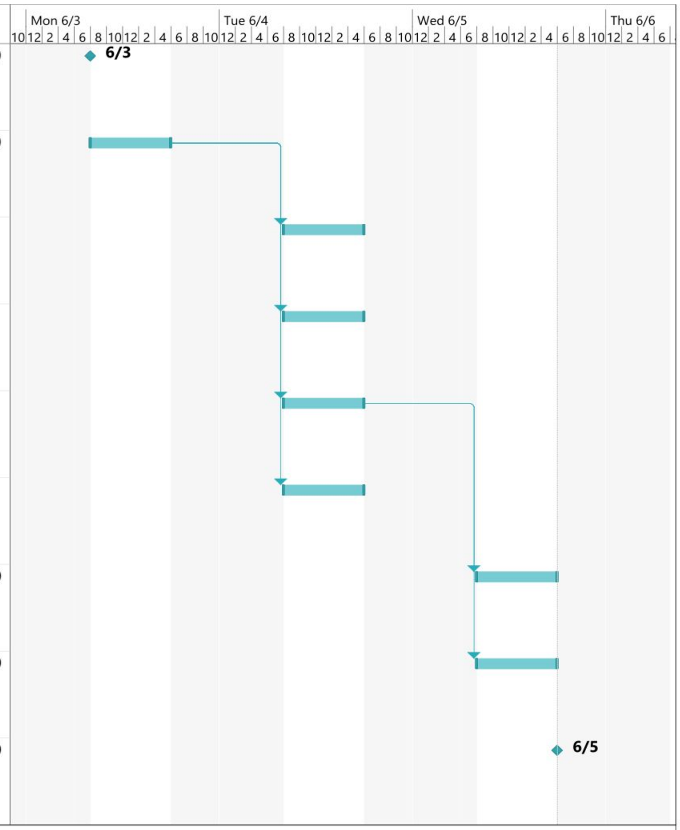

Figure 14: The construction schedule for building the bioreactor, with the scheduled tasks and Gantt chart displaying the order of tasks.

MAINTENANCE OF BIOREACTOR

One of the benefits of a woodchip bioreactor is that very little maintenance is required. Christianson and Helmers (2011) suggests that a woodchip bioreactor can last up to 15 to 20 years before the woodchips need to be replaced. Christianson et al. (2018) advise that the old woodchips be composted in an area where the regulations permit. Additionally, it is recommend that during the Retreat Center’s monthly facilities assessment, they test the water to ensure the bioreactor is running efficiently.

CONCLUSION

This project aimed to create a feasible design to construct a bioreactor at the St. Francis Retreat Center. The design drawings, cost estimate, and schedule can be used to plan and implement construction of the bioreactor. Implementation of the bioreactor will allow the Retreat Center to sustainably meet their water demands on site, as well as adding to the natural beauty of the area.

The project combined the St. Francis Retreat Center of "Stewardship of the Earth" (St. Francis Retreat Center - About Us, 2016) and Santa Clara University's Vision to "... cultivate knowledge of faith to build a more human, just, and sustainable world" (Santa Clara University, 2019). Currently, the Retreat Center has access to a well that is unusable due to the high level of nitrates in the water. As of April 5, 2019 the concentration of nitrates in the well water was 22 mg/L, twice the legal limit. If the nitrates were filtered out of this well water, the Retreat Center would be able to use it to replenish their dry lakebed, allowing for a more aesthetically appealing site for visitors. Additionally, the water in the lakebed would eventually infiltrate into groundwater, which the Retreat Center has a permit to filter and use as drinking water.

Overall, the design and construction of a bioreactor is a sustainable option for the St. Francis Retreat Center to be able to use the well water throughout the site. This design of a bioreactor, if implemented on the Retreat Center, can make a significant impact on the natural beauty of the land as well as the physical demands on the site.

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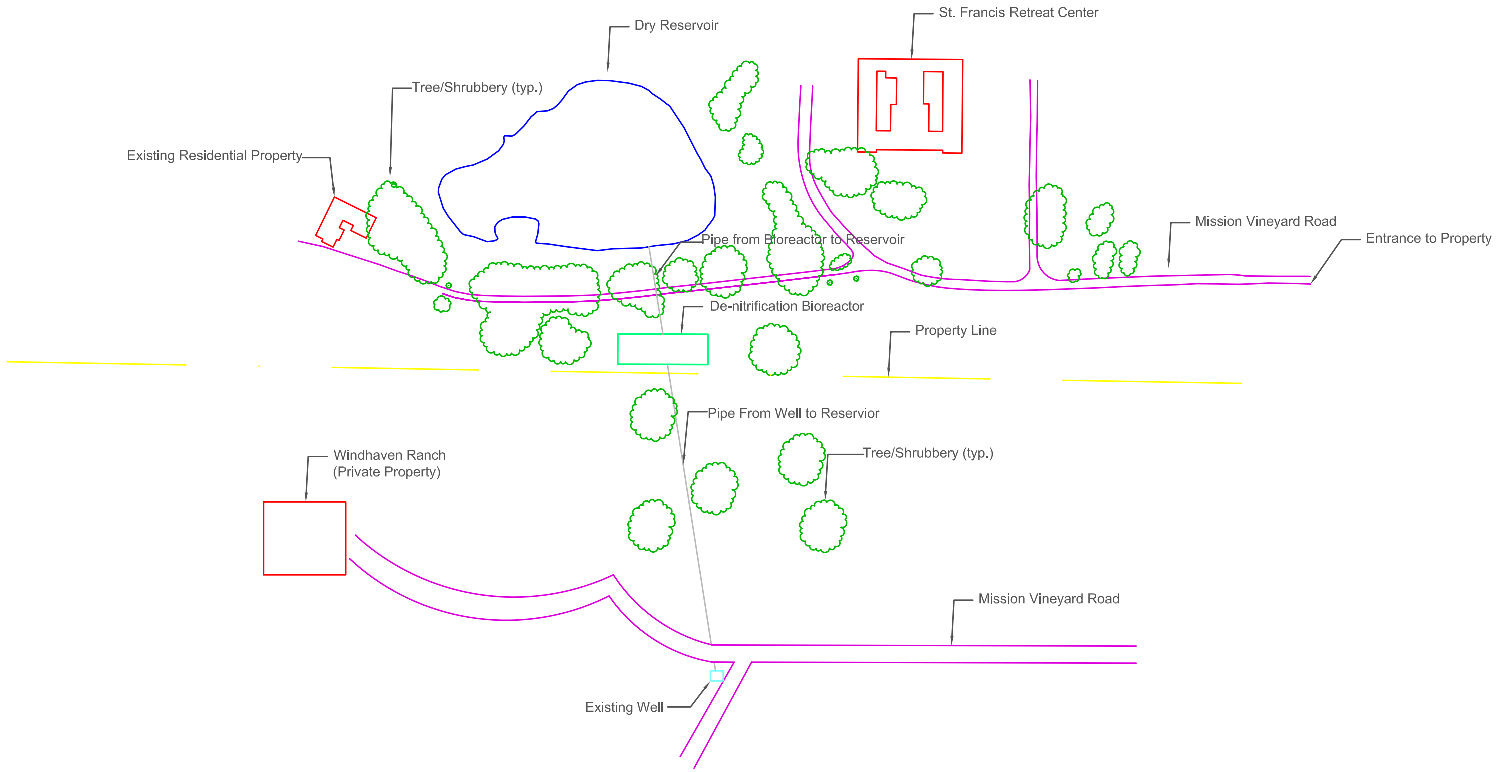
Appendix A

Design Drawings



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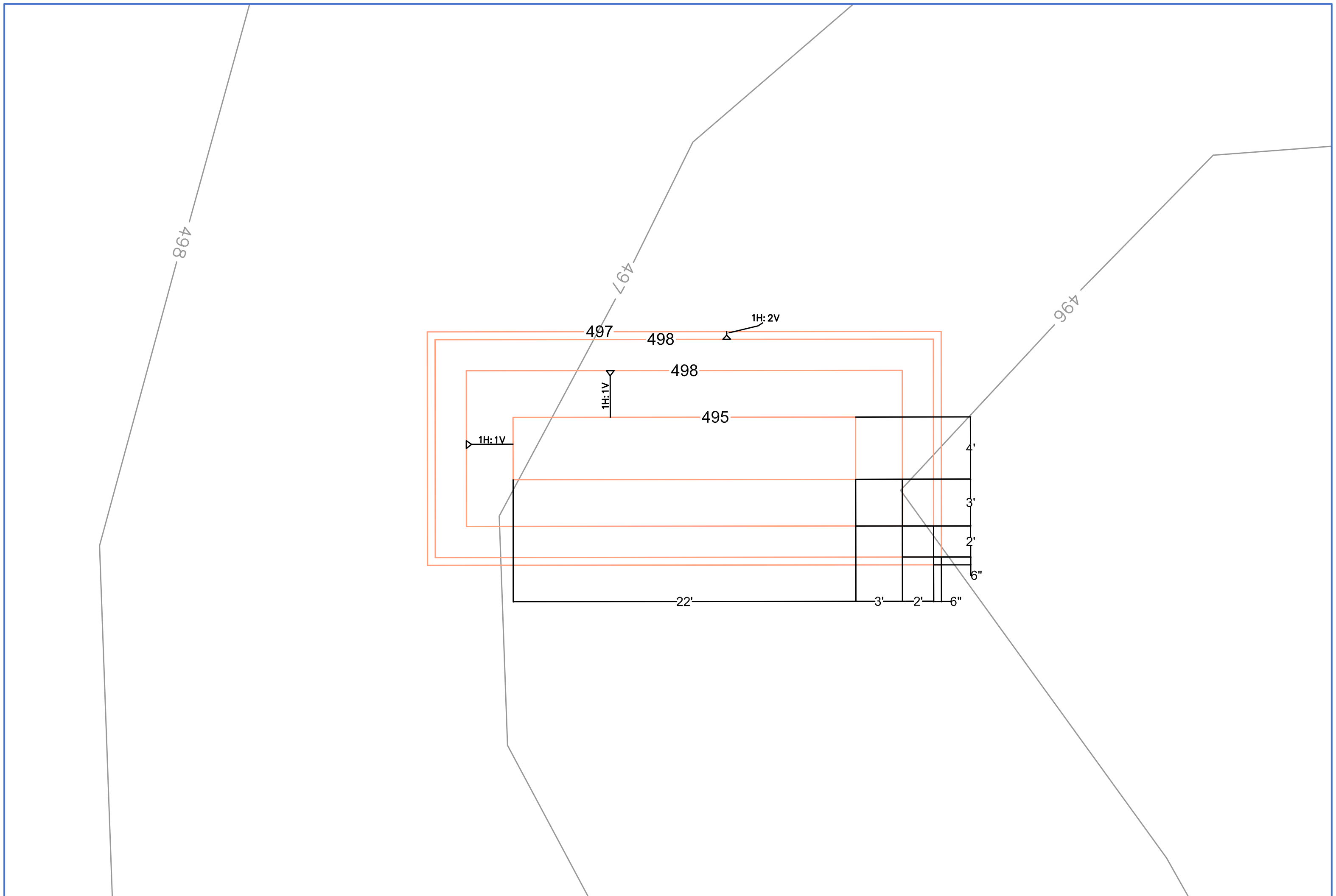
TITLE: St. Francis Retreat Center - Site Plan	N.T.S SCALE AT A4.	MH DRAWN.	AP CHECKED.	A REVISION.	



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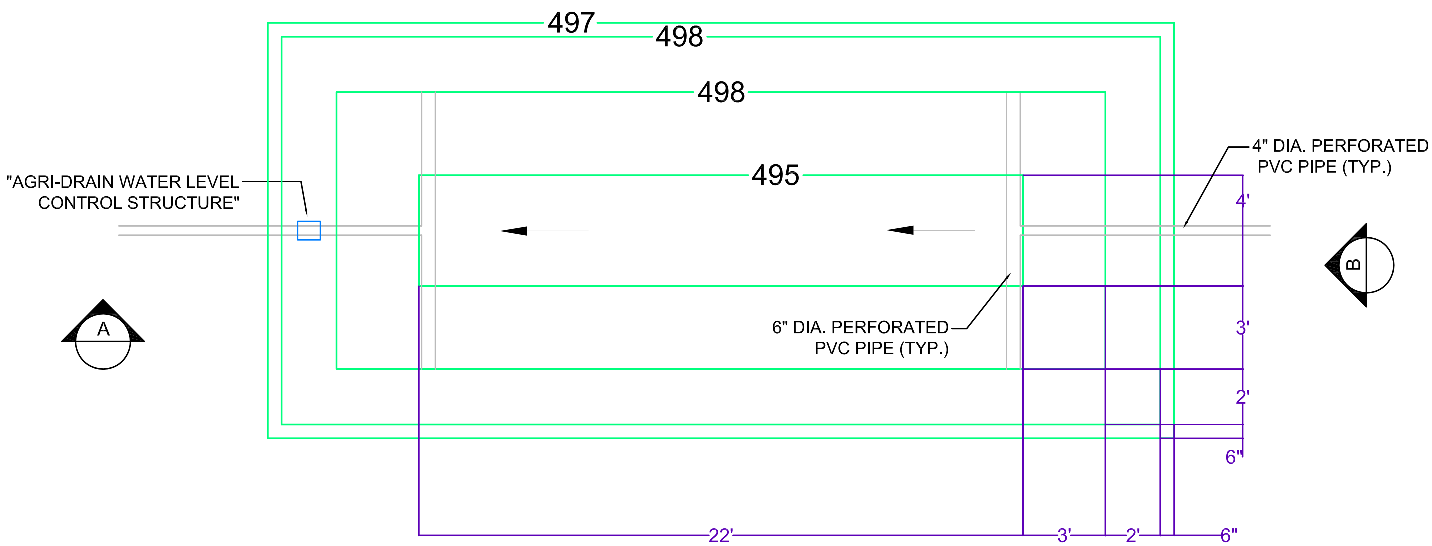
Hansen and Politz Design, Inc
500 El Camino Real
Santa Clara, CA 95053
(408)-303-5040



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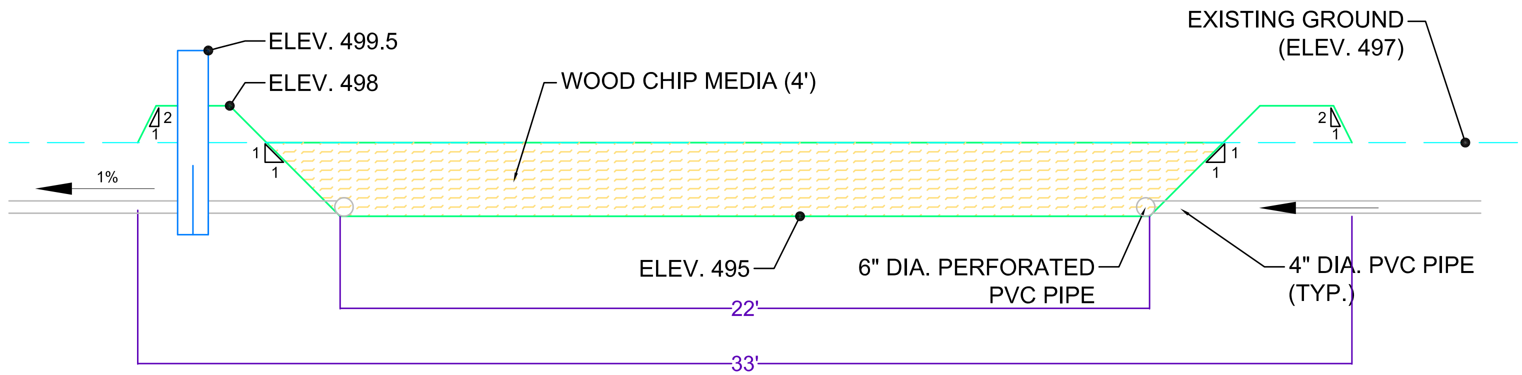
Hansen and Politz Design, Inc
500 El Camino Real
Santa Clara, CA 95053
(408)-303-5040



SECTION A

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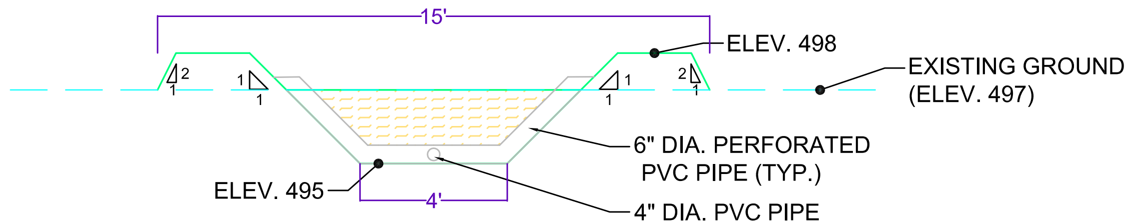

SECTION B

SCALE $\frac{1}{4}$:1

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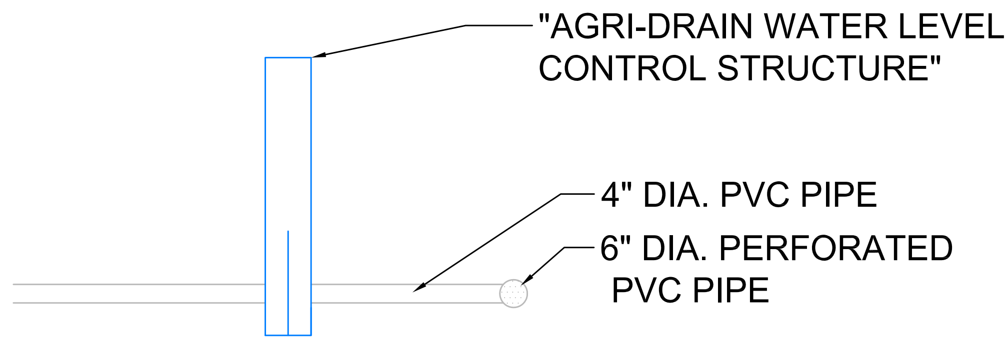
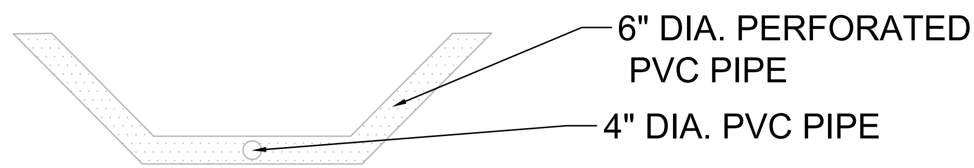


DETAIL A: CONTROL STRUCTURE PIPING

A

SCALE $\frac{3}{8}$:1



DETAIL B: PIPING CONNECTIONS

B

SCALE $\frac{3}{8}$:1

SITE: 549 Mission Vineyard Rd. San Juan Bautista, CA 95045	DRAFT (DRAWING NO.)		90603 (PROJECT NO.)	02/20/19 (DATE.)	Hansen and Politz Design, Inc 500 El Camino Real Santa Clara, CA 95053 (408)-303-5040
TITLE: St. Francis Retreat Center - Details	3/8" : 1' (SCALE AT A4.)	MH (DRAWN.)	AP (CHECKED.)	A (REVISION.)	