Sustainable Wastewater Treatment at La Escuela Agrícola San Francisco de Asís

An Interactive Qualifying Project Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In Partial Fulfilment of the Requirements for the Degree of Bachelor of Science

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Report Submitted to:

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Abstract

This project designed and implemented a sustainable treatment system for the wastewater at the Escuela Agrícola of the Fundación Paraguaya. Using site analysis, interviews, and water quality testing, the original state of the system was determined. From there a plan was made to repurpose an old pool into a ecological filter for the treatment of 11,000 liters of water a day, over 25% of the total wastewater the school produces. In conjunction with the pool, floating treatment wetlands were made to clean up the existing wastewater pond. Recommendations for future treatment and maintenance are included within this report.

Acknowledgements

During the length of our Interactive Qualifying Project, we have been fortunate to have many people assist us in the completion of our project. Without their help and support, our project would not have been nearly as successful.

First, we would like to thank general groundskeeper Virgilio Borges, agricultural engineer Amalio Enciso, and head school director Luis Cateura, for their constant guidance and assistance with each and every matter necessary.

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In addition to the aforementioned people, many others assisted in the success of our project. Students of both La Escuela Agricola and Worcester Polytechnic Institut provided us with ideas, labor, and encouragement for which we express our gratitude. We are very grateful for all those who contributed to the success of our project.

With gratitude,

Anna Gore

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Executive Summary

Project Overview;

La Escuela Agrícola San Francisco de Asis was developed by the Fundacion Paraguaya in order to teach impoverished youth entrepreneurship and the importance of sustainability. One area that lacks sustainability is the wastewater treatment system. This project addressed this issue by analyzing the current state of the system, sampling and measuring wastewater exiting the school, researching environmentally friendly wastewater treatment methods, and in the end designing and building a sustainable and efficient wastewater treatment system. More specifically, the team built a hybrid leach field and constructed wetland, implemented floating treatment wetlands, and recommended future improvements to the school's wastewater treatment system.

Methodology;

The group utilized meetings with experts, as well as water testing and additional site analysis in order to understand the current system. This allowed the group to find the most feasible and sustainable solution for the school.

The team also gathered data on the outflow of the system and the available space and resources. Based on the flow rate of the system and the resources readily available the group

chose the best tertiary treatment system for the wastewater at the school.

Calculations were performed based on research and on-site measurements to develop a design for the system. Ultimately two designs were created and given to the Fundacion Paraguaya, who chose one to be installed at the school.

Results;

On site, the team discovered that a portion of the school's wastewater was flowing from a septic tank directly into a pond, and from the pond into a nearby stream. Near the pond, the team found an old swimming pool with sufficient volume to be repurposed as a wastewater treatment system.

Ultimately the team designed a system very similar to a traditional leach field that used the pool as a basis for construction. The designed system has the potential to treat up to 11,000 liters per day, which is approximately 25% of the school's total wastewater. By the end of the project, the system was in the process of being built. (Add in exactly where we were once we leave the school…). Additional floating treatment wetlands were designed and partially installed to clean the water left in the pond.

Recommendations;

The team made the following recommendations to the school to further improve their wastewater treatment system:

1. Manage the primary treatment system (the septic tanks) and the ecological filter
2. System Additions
3. Remove pollution and repurpose pond
4. Landscape waste treatment area- pond, leach field, surrounding vegetation- into a park

Authorship

Anna Gore

Provided AutoCAD drawings, Calculations, Visuals

Stephanie Godding

Led research and construction of floating wetlands

Ann Marie Votta

Led research and calculations for constructed wetland/ leach field design and installation

Harrison Roy

Led the team in conducting Spanish speaking conversations

The entire team worked together to install the final system as well as to write and edit the final document.

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1 Introduction

Paraguay is a small, landlocked country in South America. Throughout its history, there have been many challenges. One of these challenges is poverty and the immensely inequitable distribution of wealth. This poverty stems from the lack of opportunity for the poorest Paraguayans to obtain a basic education. This education would ideally teach Paraguayans the skills necessary to elevate their economic status.

To address this poverty, Fundación Paraguaya provides educational and financial opportunities. La Escuela Agrícola San Francisco is a self-sustaining high school located in Benjamin Aceval. La Escuela was developed by Fundación Paraguaya to teach its students a variety of disciplines and skills. These skills include agriculture, management, and traditional education. By obtaining these skills, students are able to economically better the lives of themselves and their families.

Overall, the school has been and is extremely successful in achieving this goal. However, it continuously strives to increase its sustainability and improve the efficiency of its operations. The inadequacy of the school's wastewater treatment system is a major problem. The current system allows untreated wastewater to flow into the environment. In addition, the system is not ecologically sustainable (Belliard, Burns, & Golemo, 2016).

This project addressed the inadequacies of the current system by targeting primary location where untreated wastewater was flowing. A site analysis was performed at the school to identify and confirm problem-areas. A leach field was installed on campus to treat effluent from a portion of the school's wastewater.

2 Literature Review

2.1 Paraguay

Paraguay is a small, landlocked country in South America. It is bordered by Brazil, Argentina, and Bolivia, and has a population of about 6.8 million (World Factbook, 2017). Paraguay is a mostly subtropical region, divided by the Paraguay River which runs through the center of the country. Paraguay experiences hot summers and mild winters, with rain throughout every season. Paraguay contains a mix of terrains including savannahs, hilly regions, dense forests, and marshes (World Travel Guide, 2017). Paraguay is divided into 17 different departments, which are further divided into approximately 250 districts. Throughout its history, it has developed largely isolated from the rest of the world (Lambert & Nickson, 2013). Until 1989, Paraguay was run by dictator Alfredo Stroessner for 35 years, before he was overthrown by a military coup. Since then, Paraguay has had democratic rule (Encyclopædia Britannica, 2017), and its infrastructure is continuously developing.

2.1.1 Fundación Paraguaya

Fundación Paraguaya is a social enterprise that was founded in 1985. The goal of this organization is to decrease poverty in Paraguay. In order to decrease poverty, the Fundación gives people the resources and opportunities necessary to gain an income. This ideal, captured in the phrase "teach a man to fish," is one that fosters education and self-sufficiency rather than dependence. By giving the participants an education, the Fundación allows them to continue to earn an income even after it is done helping them directly.

Most Paraguayans helped by this organization participate in either a microfinance program, an economic education program, or an agricultural high school. The microfinance program uses micro loans and training to "strengthen precarious jobs, promote creation of new jobs, increase gender equality and raise family income" (Fundacion Paraguaya, 2016). The entrepreneurial education program "seeks to instill the spirit of entrepreneurship and creativity, as well as develop leadership qualities in children and youth" (Fundacion Paraguaya, 2016). The agricultural high school "promotes the spirit of entrepreneurship in rural youth and provides them with high quality and accessible education" (Fundacion Paraguaya, 2016). These schools allow students to attend a free high school that allows them to graduate with a high school diploma as well as a diploma in both Agriculture and Tourism. These three programs give their participants the ability to begin their journey as a functioning member of society rather than relying on handouts to survive.

2.1.2 La Escuela Agrícola San Francisco

La Escuela Agrícola San Francisco is the model for the other schools provided by Fundacion Paraguaya. Located in the small town of Cerrito, La Escuela Agrícola San Francisco has accepted students from all over Paraguay as well as from other South American countries. Its goal is to expose youth to entrepreneurship so that they have an opportunity to rise out of poverty. The school includes a hotel, farm, academic building, and dormitories, all run and maintained by the students who attend. Undergraduate students from Worcester Polytechnic Institute have been travelling to La Escuela for the past three years to help the students and workers improve the efficiency of the school. One problem encountered by the school is the treatment system for their wastewater. Last year, a team of three students mapped out and assessed the current system for wastewater. They concluded that the school could use a constructed wetland to deal with the untreated wastewater (Belliard, Burns, & Golemo, 2016). In addition to this project, there were five other teams working on similar projects such as a creating a biodigester and increasing tourism. The types of projects completed by the WPI students work to further the self-sustainability goals of the school.

2.2 Wastewater Treatment

Wastewater treatment is used worldwide to handle the waste generated by communities, industries, and even storms. The process of handling and treating wastewater varies greatly. Wastewater treatment, as defined by The World Bank Group (2017), " is closely related to the standards and/or expectations set for the effluent quality. Wastewater treatment processes are designed to achieve improvements in the quality of wastewater." Water quality is improved by the removal of various organic and inorganic contaminants. Treating wastewater is a common goal worldwide.

2.2.1 Types of Wastewater Treatment

While small communities and large cities both treat wastewater, the methods utilized vary. In general, there are two main methods of treating wastewater. The first method, centralized treatment, aims to reduce potential health risks by transporting the wastewater quickly away from residential areas. With the second method, decentralized treatment, the wastewater is treated onsite, making it often more ecologically sustainable and less resource intensive. (Zhang et al., 2014). Typically, large cities use a centralized approach because they have more people to manage and a higher risk of lingering contaminants. On a small scale, treating wastewater onsite is preferable because a centralized approach is more costly and poses a bigger threat to the environment.

2.2.2 Wastewater Treatment in Paraguay

Wastewater management is vital to the health of individuals. While in many industrialized countries a high standard of wastewater management exists, problems exist in less developed countries. In Paraguay, there is a lack of treatment facilities for the waste generated by its population (Bajak, 2013). However, recently there has been a surge of effort to change this. Although no centralized wastewater treatment plant currently exists in Paraguay, there is a plan to construct one in Asunción by 2018 (Paraguay.com, 2016). It is projects like this that can help to improve the infrastructure in Paraguay. Increased efficiency and operation will lead to a more sustainable future.

At La Escuela Agrícola wastewater is stored in cesspools and septic tanks. Cesspools are one of the simplest forms of wastewater management. Cesspools are constructed of brick siding and allow wastewater to flow in, separate, and then seep out into the surroundings. Septic systems are a more modern take on the cesspool approach. Septic systems utilize a single tank and naturally-occurring bacteria to separate and breakdown wastewater. This system allows incoming wastewater to flow in, separate, and flow out as effluent to the next step of the process (Belliard, Burns, & Golemo, 2016). There are measures that can be taken to improve these systems and make them more sustainable.

The group was tasked with examining the measures which can be taken to improve these systems and make wastewater treatment more sustainable for the school. In order to do so, the group needed to explore the different systems, both traditional and non-traditional. This included traditional leach fields and the more green option known as constructed wetlands. Through extensive research the functionality, design, and feasibility of each system will be compared. In the end, the best option for treating the school's wastewater was designed and implemented.

2.2.3 Leach Fields

A traditional way to treat wastewater is using a leachfield or drainfield. Leach fields can be used when a pretreatment system already exists and there is no intent for reuse of water. The system is a series of perforated pipes placed in trenches filled with gravel and topped with sand as shown in the diagram of figure 1 below. The effluent is dispersed throughout the field and percolates down through the sand and gravel for cleaning. This provides a safe way for wastewater to be discharged into the environment and rejoin the groundwater. The system allows the wastewater to be cleaned in two ways. While the sand and gravel physically filter the wastewater, bacteria in the sand removes organic matter as well. In the end, the pretreated wastewater that enters the system is clean enough to rejoin the water table as it exits the system (Eawag, Gensch, & Sacher, 2014).

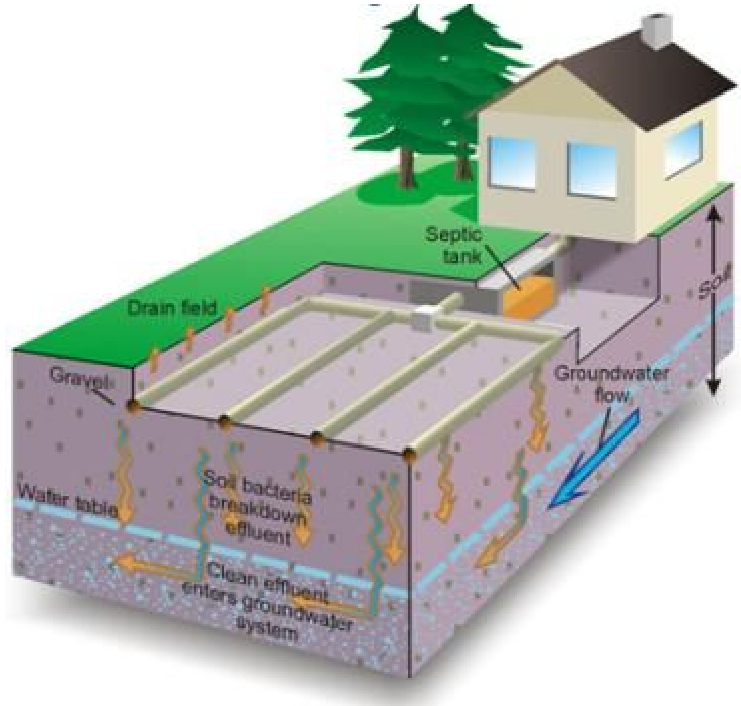


Figure 1. Design of a traditional leach field
(Eawag, Gensch, & Sacher, 2014).

The leach field system has its advantages and its disadvantages. This system can be used in mostly all climates and has a relatively long lifespan. There are minimum maintenance requirements as well as low costs. However, the design and construction requires a certain expertise and a large area. A primary treatment system is required and there is a risk of clogging. There is also the possibility that the surrounding soil and groundwater can be negatively affected.

2.2.4 Constructed Wetlands

Constructed wetlands are an ecological type of wastewater treatment system. “Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality (EPA, 2016).” Depending on the application, one of several wetland designs can be selected.

Constructed wetlands represent a low cost, low maintenance, and sustainable method of wastewater treatment. The affordability and ease of implementation make constructed wetlands especially popular in developing countries.

Plants naturally treat the wastewater in a constructed wetland. The natural process used by the plants to remove the contaminants is called phytoremediation. Biotic and abiotic remediation are two forms of this process. Biotic remediation deals with living organisms and organic waste. Abiotic remediation deals with inorganic substances.

Various plant species employ these remediation processes. Species that use these processes have similar root morphology and depth. As time passes, the roots mature. As the roots mature they become more effective biological filters (Bhatia & Goyal, 2014). Plant genuses that share these characteristics are *Typha*, *Juncus*, and *Phragmites* (Bhatia & Goyal, 2014). These species are commonly used in constructed wetlands, and studies have been completed to determine the effectiveness of different combinations. *Typha* is a form of cattails. *Phragmites* are a form of reeds. *Juncus* is part of the rush family of plants. *Phragmites*, *Typha* and *Juncus* are found in wetlands across North and South America, including Paraguay. However, *Phragmites* are considered an invasive species that is difficult to control (Blossey & Casagrande, 2016).

Tests have been developed to quantify the effectiveness of the wetland plants to remediate substances. The tests measure the reduction of certain contaminants. The contaminants include BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), nitrogen, phosphorus and pathogens (Bhatia & Goyal, 2014). The tests provide researchers with insights into what plants should be paired together in certain environments.

There are two main types of constructed wetland. The first type is called a free water surface constructed wetland (FWS system). The second type is a subsurface flow constructed wetland (SSF system). A FWS system is a constructed wetland that allows plants to grow directly in a body of water. Effluent flows from the initial treatment stage (the septic tank) into the body of water and slowly flows through it. A SSF system, in contrast, is a constructed wetland where plants grow in some medium, such as soil or gravel. Untreated effluent can flow either horizontally or vertically through the medium. (Zhang et al., 2014).

Both of these types of constructed wetland have a number of advantages and disadvantages over traditional wastewater treatment systems. A common advantage is having high removal efficiencies for organic and inorganic contaminants. In addition, they require less skill to operate and maintain, and are cheaper to construct and maintain than traditional wastewater treatment facilities. (Environmental Protection Agency (EPA), 2000). One common disadvantage is that both types require a large amount of land to ensure the proper treatment of water. They are also limited because they work inefficiently in colder temperatures, as they are reliant on plant growth.

The FWS and SSF systems also have many advantages and disadvantages in relation to each other. Regarding ecological impact, an FWS system typically introduces a more diverse ecosystem. However, the birds and other animals drawn to the wetland are likely to contribute more waste to the system. In addition, mosquitos and other insects are attracted more to FWS systems because there is a relatively small body of standing water. (EPA, 2000). Mosquitos are a concern in Paraguay because they are disease vectors. In SSF systems, there is no open water, so there is a much lower risk of attracting mosquitos (Mihelcic et al., 2009). In general, SSF systems require less space than FWS systems to remove most contaminants. On the other hand, SSF systems require large amounts of gravel or other medium, sometimes causing higher construction costs. This cost only becomes significantly higher for SSF wetlands that need to treat 60,000 liters/day or more. (EPA, 2000).

2.2.4.1 Subsurface Flow Constructed Wetland

There are two forms of subsurface flow (SSF) constructed wetlands: horizontal and vertical. In horizontal SSF systems, effluent flows horizontally through a single substrate, as shown in Figure 2 (top). The flow through horizontal systems is continuous and slow. In vertical SSF systems, effluent flows vertically through numerous layers of different substrates, as shown in Figure 2 (bottom). The effluent is fed into the system intermittently so that the water is allowed to slowly drain down through the layers. Vertical systems require higher construction, operation, and maintenance costs, and are more susceptible to system failure. However, horizontal systems generally require more land area and have lower removal efficiencies than vertical systems. (Zhang et al., 2014) (ENPHO, 2008).

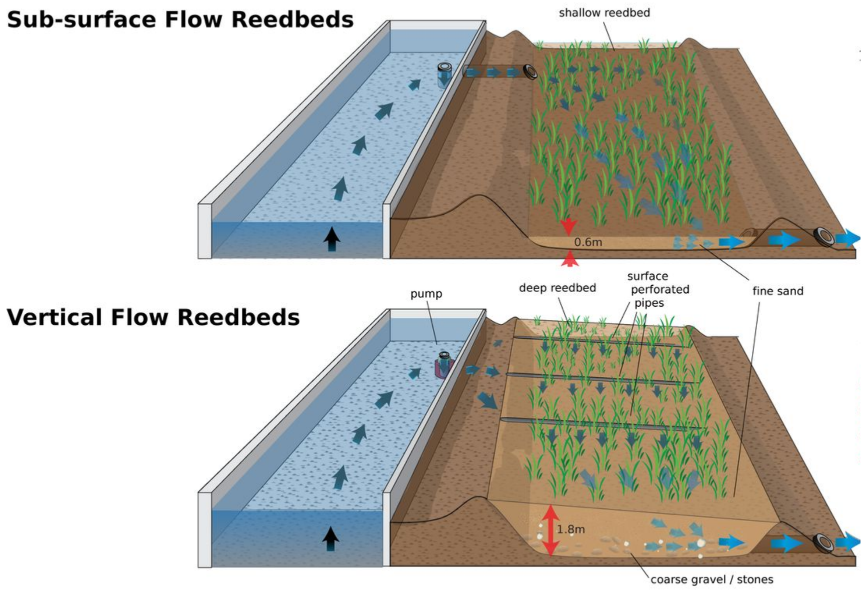


Figure 2. Horizontal vs Vertical SSF systems (Jkwchui, 2010)

2.2.4.2 Floating Treatment Wetlands

A new innovative type of constructed wetland is a floating treatment wetland. Floating treatment wetlands (FTWs) are comprised of floating mats of rooted emergent macrophytes as shown in the figure 3 below. These plants are similar to those utilized in traditional constructed wetlands, but they are floating on the water surface rather than being rooted in sediment. The exposure of the plants roots allows for greater biofilm accumulation and microbial growth. Together, these attributes allow for greater absorption of contaminants (Headley, Tanner, 2008). Contaminants such as total suspended solids, nitrogen, and phosphorus, have been proven to have a high removal efficiency with the use of the FTWs (Gunderson, 2015). This system also allows better tolerance of changing environmental conditions as well as better treatment efficiency.

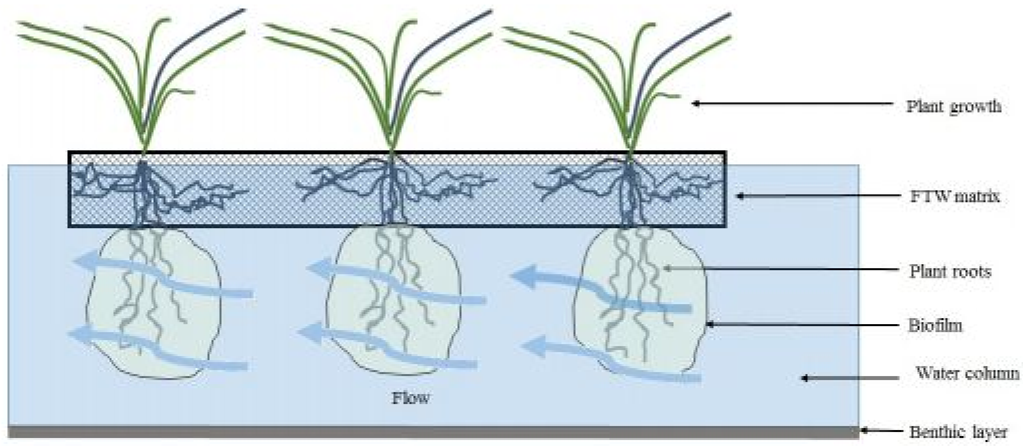


Figure 3. Schematic of a Floating Treatment Wetland System (Nichols, Lucke, Drapper, & Walker, 2016).

2.3 Design and Installation of Wastewater Treatment Systems

There are many options for the treatment of wastewater. Each option has different design considerations, construction techniques, and maintenance and operation guidelines. A traditional leach field and a constructed wetland work in very different ways and have varied materials and costs. While each design is a fair option for secondary treatment of wastewater, the implementation of either depends on many considerations. Environmental conditions, budget, available resources, and available space will affect the type of system which is chosen.

2.3.1 Design and Installation of Leach Fields

Typical leach field designs have dimensions that range from 0.3 to 1.5 meters in depth and from 0.3 to 1 meters in width. Typically, around 15 cm of gravel is laid on the bottom followed by distribution pipes. More rock is placed atop the pipes as well as a fabric to prevent clogging. The final layer is comprised of sand or topsoil which fills the system to ground level. The pipes are placed at least 15 cm under the surface to prevent effluent from being too close to the surface. Trenches are dug parallel in the system, are no longer than 20 m long, and should be at least 1-2 m apart. Leach fields are built at least 30 m away from a drinking water source to prevent contamination. Finally leach fields should be installed in areas where no future sewer lines or connections will be installed. (Eawag, Gensch, & Sacher, 2014).

Leach fields are relatively low maintenance and pose no health risk. The only problem that a leach field can face is clogging. It can take up to 20 years for the system to become clogged. If the primary treatment system is well maintained and functioning well, the leach field will remain unclogged for longer periods of time. If the system stops working efficiently, then the pipes need to be cleaned or replaced. Otherwise, leach fields are a fairly safe and effective option for secondary wastewater treatment. (Eawag, Gensch, & Sacher, 2014).

2.3.2 Design and Installation of Constructed Wetlands

The design of a constructed wetland includes the selection of plants and other construction materials. Plant and material selection, as well as daily wastewater production, influence the size of the wetland. The size of the wetland is the driving factor behind the cost and maintenance requirements of the system. Regardless of size, however, constructed wetlands provide a low maintenance option for wastewater treatment (Tanaka & Tanaka, 2011).

Materials including the plants, medium, base seal, and piping must be selected for the design of the wetland. The materials chosen directly impact the sizing and cost of the wetland.

Plant selection depends on the desired wetland application and geographical location of the wetland. Plants commonly used in the two types of constructed wetland are shown in Figure 4 below.

Common Name	Scientific Name	FWS	SSF
Bulrush	*Scirpus spp.*	X	
Cattail	*Typha latifolia*	X	
Common arrowhead	*Sagittaria latifolia*	X	
Papyrus	*Cyperus papyrus L.*	X	
Torpedo grass	*Panicum repens L.*		X
Common reed	*Phragmites australis*		X
Rush	*Juncus spp.*		X
Sedge	*Carex spp.*		X
Yellow flag	*Iris pseudacorus*		X
Umbrella palm	*Cyperus alternifolius*		X
Wild cane	*Gynerium sigattatum*		X

Note: Indigenous plants should always be given preference. The final use of a plant (e.g., animal fodder, roof thatch) may also be a consideration in plant selection.

Figure 4. Typical Plants used in FWS and SSF Wetlands. (Mihelcic et al., 2009)

There are many different types of substrate material that can be used in a wetland. The medium must be porous enough so that the water can pass through but absorbent enough so that the contaminants are filtered. The porosity of the medium contributes to the overall performance of the constructed wetland. Common choices for medium are gravel, sand and silt (Mihelcic et al., 2009).

Options for seals range from compacted clay to plastic liners. The base seal of the constructed wetland must be impermeable. Compacted clay should be installed carefully to prevent leakage, and additional testing is required to confirm impermeability. Plastic liners are difficult to install because they are thin and can be punctured on sharp rocks but generally increase the life of the wetland. Layers of sand are used in between plastic liners and sharp rocks to prevent puncture (Mihelcic et al., 2009).

General purpose PVC piping can be used to transport effluent to and from the constructed wetland. It is common to perforate the piping at the inlet of the wetland to provide an even distribution of the wastewater to the wetland. Grates are often used to prevent solid waste from entering the system and to prevent future blockages (Mihelcic et al., 2009).

2.3.3 Design and Installation of Floating Treatment Wetlands

Floating Treatment Wetlands are a great option for treating wastewater due to the ease of their design and installation. Because of the way a floating treatment wetland works, the design criteria is simple. The most important component of the system is the exposure of plant roots. Plants are chosen based on their ability to thrive in water and accessibility to the location of the system. Beyond that, the specific species of plant chosen is not all that important, because all water plants have emergent roots that can accumulate biofilm and grow microbes. The other component of the system is the floating mats on which the plants grow. First, the mat must float on the surface of the water. Common flotation devices used include sealed drain pipes or water bottles that circumference it. Both of these options are cheap and easy to use. The medium through which the roots emerge and the plants sit are usually made of a plastic mesh attached to the floatation device by zip ties or rope. The plants are placed in this mesh so that the roots are hanging into the water and the part above the stem remains above the surface of the water to allow for the access of sunlight and growth. The installation of this system is as simple as putting it on the surface of the water and attaching it to either the bottom or side of the water container. (Hillsborough County, 2014).

3 Methodology

This project aimed to design and implement a sustainable wastewater treatment system at La Escuela Agrícola. To reach this goal, the team completed a site analysis, devised a method to treat an existing body of wastewater, and designed a system to treat a portion of the school's wastewater.

3.1 Site Analysis

The current state of the system at the school was examined. Employees that are in daily contact with the system at the school were consulted, including Professor Virgilio, Professor Amalio, and Director Cateura. Meetings helped to determine the project goals of the school as well as the locations available for the treatment system. Before the site analysis was completed, the team thought that a horizontal constructed wetland would be the best option for the school. Upon arrival, the team was shown the existing site. The site consisted of two structures, a collection pond for the wastewater and an empty swimming pool. Both structures were considered for wastewater treatment. The site analysis and initial calculations revealed that multiple options for each structure should be considered.

3.1.1 Analysis of Pond

The pond was the main collection reservoir for the effluent coming from the boys dormitory at the school. There was no secondary treatment for this effluent, so it simply flowed into the pond and from there into a nearby stream. The team conducted water quality testing on water from both the inlet and outlet of the pond. This testing was performed to determine the levels of various contaminants in the wastewater at two different stages. Based on the results of this water testing, it was necessary to clean the contaminants from the pond. The effluent pipe flowing into the pond needed to be redirected to a treatment system. Redirecting the pipe would leave a pond full of effluent that needed to be cleaned. In order to clean the pond the team conducted research on efficient and easy ways to treat contaminated water. In alignment with the school's sustainability goals, the team chose to install Floating Treatment Wetlands due to their efficiency and ease in treating wastewater.

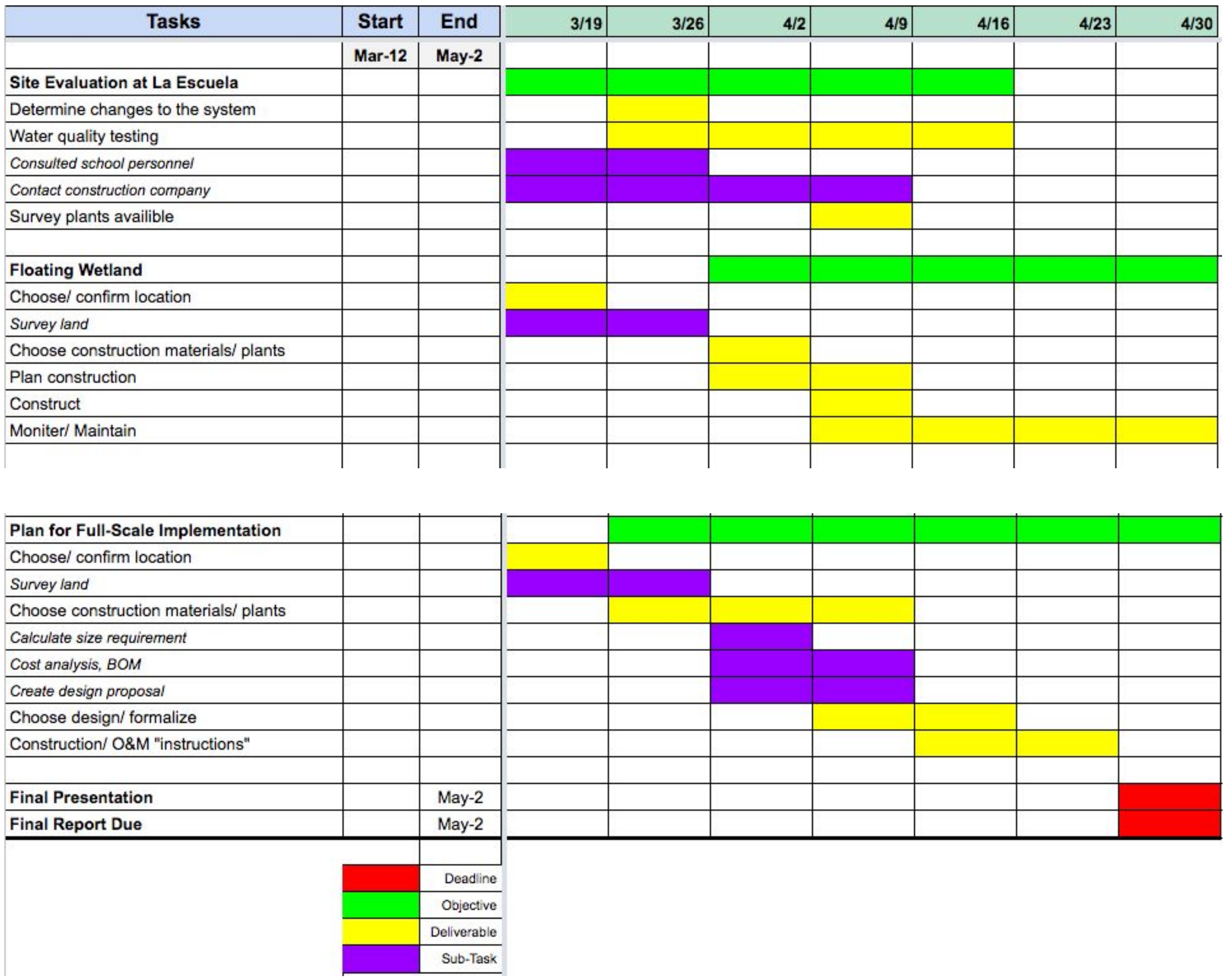
3.1.2 Analysis of Pool

The pool was created many years ago for recreation and has since been abandoned. Upon arrival, the team thought to use this space as the main structure for the treatment of the school's wastewater that currently flows into the pond. Measurements were taken of various components of the site, including distances, areas, and flow rates of the wastewater. The area of the pool was calculated based on a number of measurements taken.

At the start of the project, the team hoped to use constructed wetland technology for treatment. The group researched and analyzed different types of constructed wetlands including free-water surface, subsurface vertical, and subsurface horizontal systems. The team also researched more traditional leach fields treatment systems to examine their potential.

After initial measurements and calculations, the team determined that both the use of a vertical constructed wetland and a traditional leach field were viable options.

3.2 Methodology Timeline



4 Results

The project achieved the following results based on the methods of the team.

4.1 Site Analysis

The results of the site analysis were crucial to the design of both treatment systems that were partially implemented at the school. The area of the pool is about 190m^2, and its depth is 1.5m. The area of the pond is about 300m^2. The maximum flow rate of wastewater into the pond is 4800L/day, at 9pm, and the average flow rate is 3300L/day. The results for the water quality testing can be found in Appendix _. They generally show that the pond was cleaning the water to a certain degree, but not nearly enough to be considered same for re entering the groundwater.

4.2 Floating Treatment Wetland

Given the extremely poor quality of the water in the pond, a treatment system was devised to clean the pond. The treatment system chosen is a floating treatment wetland. There are many ways to build this system, and the cheapest and simplest design was chosen for installation in the pond. A picture of the wetland built is shown in Figure __ below.

(Insert pic of first floating wetland- with labels of materials/ etc.?)

Two such wetlands were installed in the pond, both of about the same size. The systems were monitored, and plants added as needed, until the team left. The two small wetlands will not be able to clean the pond on their own, but rather serve as an example for the school of how to build more in the future. Detailed instructions on how to build the system were given to the school.

4.3 Ecological Filter

The second component of the project was the implementation of a full-scale treatment system for a portion of the school's wastewater. Calculations performed determined that an area of ___m^2 was required to treat the water currently flowing into the system if a horizontal constructed wetland was installed. By comparison, a different calculation determined that $30m^2$ was required to treat the water if a traditional leach field design was used.

The team created two designs, one to treat only the water flowing into the system, and one utilizing the total area of the pool to treat as much water as possible. The designs were extremely similar to that of a traditional leach field. However the distribution system for the water was more similar to that of a vertical constructed wetland, as these are easier and cheaper to construct, and are less prone to failure with small misalignments.

The two designs were almost identical, and only differed in the amount of piping used and the treatment capacity. The smaller system, which would only treat 4800 L/day, only used 4 small distribution pipes, while the larger system, which would treat 11000 L/day, used 7 distribution pipes. Director Cateura and the Fundación Paraguaya chose the larger of the two systems.

The system designed uses layers of sand and gravel to filter the wastewater and a system of pipes to distribute the water evenly over the surface of the filter. There is a 10 cm layer of gravel at the top of the filter for drainage, followed by 70 cm of sand beneath it to actually filter the water, and another 20 cm of gravel at the bottom of the filter for drainage. The distribution pipes are 5 cm in diameter and have perforation holes at 5 and 7 o'clock, every 15 cm. The pipes ~~They~~ are spaced 1 m apart and span the length of the pool, as shown in Figure __ below. A 15 cm pipe is used to transport wastewater from its original source to the distribution system. Each small pipe has a valve at its inlet to allow water to collect in the larger pipe and flood each of the smaller pipes one at a time. (We have sources for this, we just need to go through them and figure out which one(s) we used…)

Once the design was approved by the Fundación Paraguaya, materials were ordered and the system was built. An operation and maintenance guide was created for the school so that they would know how to use the system in the future. (See Appendix __)

4.4 Maintenance Plan (?)

The team created a maintenance plan to give to the school detailing the required daily and long term maintenance for the ecological filter. In vertical constructed wetlands, water is distributed evenly by allowing it to collect in a large reservoir for some amount of time, and then releasing the water all at once to flood the pipes. A similar concept is used for the water distribution system in this ecological filter, where water is allowed to collect in the 15cm transportation pipe, and a valve on a single 5cm distribution pipe is opened at a time to allow that pipe to be flooded. With the current amount of wastewater being treated by the system, the 15cm pipe needs to be emptied 4 times per day, meaning 4 different pipes will be flooded each day. For this, a student needs to open one of the valves for 15 minutes, 4 times a day. A schedule was created for which valves should be opened at what times an don what days, to ensure that all pipes are "treating" approximately the same amount of water per week.

In addition to the daily operation, long term maintenance requirements were included in the maintenance plan. The most important aspect of long term maintenance is proper care of the primary treatment system, the septic tank. The septic tank needs to be emptied of solids every 3-6 months to ensure that the buildup of solids does not clog the filter and cause the system to fail. It was also stressed that it is important to check the pipes, if possible, for blockages, and to remove any plants whose roots may potentially grow into the pipes. Finally, in the maintenance plan, the team included instructions for how to build additional floating treatment wetlands.

5 Recommendations and Conclusions

The following recommendations will sustain and revitalize the system:

5. Manage the primary treatment system (the septic tanks) and the ecological filter
6. System Additions
7. Remove pollution and repurpose pond
8. Landscape waste treatment area--pond, leach field, surrounding vegetation-- into a park

5.1 Maintenance of the systems

In order to ensure proper and long term functionality of the wastewater treatment system, regular maintenance is required. This includes maintenance of the septic systems as well as the ecological filter.

As reported by the previous IQP team, septic system maintenance requires two actions. First the tanks must be emptied of their solids when they are nearly full. This should occur every three to six months. Second, monitoring is necessary to ensure that the system is not filling up faster than expected. (Belliard, Burns, & Golemo, 2016).

A detailed plan to operate and maintain the ecological filter has been developed and is located in Appendix C. It is crucial that the system is properly maintained and operated in order to avoid problems in the future. If the maintenance for both the septic systems and the ecological filter are followed accordingly, the system has the potential to operate for up to twenty years without problems. (Citation?)

5.2 Additions to the system

There is potential for the ecological filter system in the future. First it has the potential to become a more hybrid system that incorporates plants. Plants that have the potential to aid in further cleaning the wastewater. Second it has the capacity to process more wastewater than it currently receives. This means the school can add wastewater from other buildings to be treated by the system.

In combination with the existing leach field, plants can aid in the filtration of contaminants. The group recommends covering the surface of the leachfield with a thin layer of topsoil. Based on extensive research and expert consultation there are a series of species and plants which are favorable. Some of these species include cyperus, grasses, rushes, reeds, and canes. More detailed plant info can be referred to in Appendix E.

The new system has the potential to treat up to 11,000 liters a day of water. Currently, it is only treating water from the boys dormitory, which has a maximum flow rate of 4,800 liters a day. This leaves an additional 6,200 liters per day that can be treated by the existing system. Our team suggests that other buildings wastewater be treated by this system. Chosen buildings should be based on location relative to the ecological filter and daily flow rate. Some suggestions from our team include the kitchen or administration building. Once more wastewater is flowing into the system, it will be unfeasible to open and close the pipes the amount of times necessary to properly maintain the system. When this happens, our team suggests that a reservoir, floater, and microswitch system be added to the pipes for automatic water distribution.

5.3 Pollution removal from Pond

Due to the current use of the pond as a wastewater reservoir, it is severely polluted. Although the team redirected the wastewater away from the pond, the remaining pollution in the pond will not be removed unless additional measures are taken. An open body of water in this state of pollution is unsafe for humans and animals. Therefore, we recommend treating the water in the pond using natural means.

The group installed two floating treatment wetlands in the pond. The wetland plants in these systems will absorb pollutants in their roots. Over time these plants will rid the pond of unsafe pollutants. Based on research the group recommends that the surface of the pond be covered at least 20% with floating treatment wetlands.

5.4 Repurposing the Pond

A more permanent solution should be developed to fully remove contaminants from the pond. Due to the immensity of the pollution in the pond, the temporary solution for floating treatment wetlands will not fully solve the problem. The team recommends that for safety and efficiency purposes, the tilapia pond be drained, and converted into another ecological filter for the treatment of the rest of the school's wastewater. Further recommendations include using the soil at the bottom of the pond for compost to increase the school's sustainability measures.

5.5 Repurposing the Treatment Area

During a discussion with Director Cateura, he conveyed his hopes to repurpose and revitalize the water treatment area. He stressed the importance for the current generation to have a passion to clean the environment, specifically the correct treatment of wastewater. He hopes that by having this system implemented at the school, it will inspire students to continue the trend in later years.

The group recommends the future design and installation of a park. After the pond is cleared of pollutants then the area will be safe for human interaction. Some options for park components include benches, sports facilities, or playgrounds to be determined by a future IQP team.

5.6 Conclusion

The ecological filter system together with our recommendations, provides the school with an efficient and sustainable way to treat the wastewater it produces. The manner in which the wastewater is treated allows the students to be immersed in a new way of thinking that centers around environmental awareness. This awareness will allow the generations to come to work together with the environment to better their country.

Foto 01: Flores de *Ligaria cuneifolia* en ejemplar encontrado en el punto de mustreo F – Fl 25.

Foto 02: Flores en ejemplar de camara (*Lantana megapotamica*), encontrado en el punto de mustreo F – Fl 27.

Foto 03: Exemplar florido de *Ruellia coerulea* registrado en el punto de mustreo F – Fl 27.

Foto 04: Grupo de tallos de *Cyperus giganteus*, popularmente conocido como piri.

Foto 05: Plantas higrófitas, destacando los ejemplares de *Cyperus virens* (en el centro de la foto).

Foto 06: Ejemplares floridos de *Glandularia dissecta*, especie popularmente conocida como margarita poty, encontrados en el punto de mustreo F – Fl 25.

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Appendices