Wastewater Treatment at the Escuela Agrícola San Francisco de Asis

Penélope Belliard, Rebecca Burns, and Tyler Golemo

Advisors: Robert Traver and Dorothy Wolf

fundación paraguaya WPI

Wastewater Treatment at the Escuela Agrícola San Francisco de Asis

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

by
Penélope Belliard
Rebecca Burns
Tyler Golemo

Sponsored by:

Date: May 3, 2016

Report Submitted to:

Dr. Martin Burt
Fundación Paraguaya

Luis Cateura
Escuela Agrícola San Francisco de Asis

Professors Robert Traver and Dorothy Wolf Burt
Worcester Polytechnic Institute

ABSTRACT

This project improved the old and overwhelmed wastewater system of Fundación Paraguaya's Escuela Agrícola in Paraguay. Site assessments, interviews, and system integrity analysis were used and water usage data was collected to generate maps of the current structures and develop plans for a new system. The system fits the campus's needs and includes plans for proper maintenance, an ecological filter to treat wastewater, and a composting system to create fertilizer from solid remains. These plans provide the school with an integrated and sustainable waste treatment system.

ACKNOWLEDGEMENTS

Throughout the course of our Interactive Qualifying Project (IQP), we were assisted and advised by many who deserve recognition. The success of this project would not have been possible without their encouragement, assistance, and enthusiasm.

We would especially like to express our gratitude to Mr. Virgilio Borges, general maintenance and farm manager of the Escuela Agrícola, and Luis Cateura, the school's head director. Their patience, support, and assistance in the development of our project were invaluable.

We would also like to extend further gratitude to engineer Jose Luis Salomon and teachers Mrs. Marysabel Aquino and Mrs. Magdalena Guerra who made it possible to carry out our methodology and impacted the development and recommendations of our IQP.

We would like to thank Dr. Robert Traver and Mrs. Dorothy Wolf-Burt for advising our project. They provided us with exemplary guidance, constructive feedback, and a challenge that tested our talents.

Many others, including classmates from Worcester Polytechnic Institute and from the Escuela Agrícola San Francisco, also contributed to and shaped our project. Their critiques, ideas, and encouragement inspired us to improve our work. We thank all of those who helped us complete our assignment.

Penelope Belliard

Rebecca Burns

Tyler Golemo

EXECUTIVE SUMMARY

Project Overview

Fundación Paraguaya developed the Escuela Agrícola San Francisco in Benjamin Aceval to empower impoverished students in Paraguay by modeling self-sufficiency. Currently, the school's sewage system does not align with this self-sufficiency goal. The project addressed this problem by mapping the current system, identifying malfunctioning pipes and tanks, measuring system capacity, and ultimately recommending sustainable treatment of both liquid and solid waste. Specifically, the project proposed a wetland purification system, an on-campus human waste composting system, and overall upgrading of the physical infrastructure.

Methodology

Interviews, site assessment, and an analysis of system integrity were used to collect user knowledge, determine the components and function of the system, and identify system problems. Maps were developed to aid analysis and communication.

The team gathered data on the daily water use of the school and estimated the wastewater output of the students. Based on the waste produced in each bathroom, septic system capacity was calculated and a primary system treatment plan emerged. Ecological and biological treatment methods were investigated and evaluated in context of the school and its abilities. Concurrent construction was examined in order to create a comprehensive and cohesive plan for recommendation to the school.

Findings

The methodology generated four results:

1. The current waste management system is too old, too small, and inadequately maintained.
2. Even if the current system was adequate, it would not be ecological. There is not enough treatment of the wastewater due to the school's use of cesspools.
3. The campus has potential for ecological treatment of its wastewater. The school has enough resources to treat sixty-one percent of its waste by using a subsurface constructed wetland that would take up one-fifth of a hectare.
4. Current renovations will partially address waste treatment needs, but not in an ecological manner.

Conclusions

Based on our findings there are four recommendations to create a self-sustainable waste management system for the Escuela Agrícola San Francisco.

1. The extant and future systems need maintenance.
    a. All septic tanks need to be emptied every three to six months
    b. Chemicals, such as bathroom cleaning agents, that interfere with the biology of the septic tanks should never be flushed down the toilets.

2. Five new septic systems need to be installed--two at the hotel, two for the boys' dormitories, and one to service three chalets.
3. A subsurface constructed wetland should be built.

. It will ecologically treat the sixty-one percent of the school's wastewater that is not passing through the recent septic tank upgrades.

a. Water exiting it should be used for irrigation.

4. A human waste compost system should be installed.

Together, and with proper maintenance, these changes provide the school with an integrated and sustainable system. The school's wastewater will be treated in a safe and effective manner while also providing the school with additional resources to use on its farm. With greater self-sufficiency the school can continue contributing to the elimination of rural poverty in Paraguay by providing quality education for generations to come.

AUTHORSHIP

PENÉLOPE BELLIARD

Penélope led the team during interviews and other conversations conducted in Spanish, contributed specialty research of ecological filters, and provided visualization of current and future plans for the school.

REBECCA BURNS

Rebecca led the team's writing and editing efforts, contributed specialty research on human waste composting systems, and ensured clarity of the team's goals and objectives.

TYLER GOLEMO

Tyler created the final visual products the team used, including maps and presentations. He also organized and formatted the final paper.

The entire team came together to discuss the paper and project as a whole, and all parties contributed to the writing and editing of the final document.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Paraguay is a country located in the middle of South America. It has the highest proportion of rural inhabitants in the continent (Cerrutti & Bertoncello, 2003). Nearly a third live below the poverty line (International Fund for Agricultural Development [IFAD], 2013). Recent decreases in the national poverty rate have lowered this proportion, but it remains unacceptable (Godfrey, Kearney, Palmer, & Manwaring, n.d.; IFAD, 2013).

However, Paraguay is in a unique position to eliminate much of this hardship. Current data suggest that an amount equal to 1.4% of the country's GDP is all that's necessary to do so (World Bank, 2010). Essential to this is enhancing infrastructure and addressing the knowledge and services gap impoverished citizens face. With a concerted effort from the government and other organizations, this remediation is well within reach.

One such non-governmental organization is Fundación Paraguaya. The foundation provides programs that educate and supply resources to rural Paraguayans (Fundación Paraguaya, n.d.). One of its well-known efforts is the Escuela Agrícola San Francisco in Benjamín Aceval. The school teaches rural students how to effectively manage small scale farms and deliver basic hotel services alongside typical education (Godfrey et al., n.d.).

To show its students the connection between education, work, and income, and thus address the poverty that characterizes many of them, the school runs as a self-sustaining business. Profits from the school's farming and entrepreneurial efforts fund the children's education, room, and board completely. Therefore, the ability of every aspect of the school to align with its goal of self-sufficiency is critical.

One of the fundamental systems of the school is waste disposal. Like everything else in the school, the system should be self-sufficient--its cost minimized and potential maximized. The current system does not meet these criteria due to its age, the increase in enrollment at the school, and the increased popularity of the hotel. These factors have pushed the system beyond its original capacity. The result is two-fold. First, solid waste has accumulated within the system and is preventing it from functioning. Second, pathogen-containing wastewater is pooling at the surface across campus and being dispersed improperly in the environment.

The project addressed these problems by mapping the current system, identifying malfunctioning pipes and tanks, measuring overall system capacity, and ultimately recommending sustainable treatment of both liquid and solid waste. Specifically, the project proposed a wetland purification system, an on-campus human waste composting system, and overall upgrading of the physical infrastructure. An effective system will benefit the school, its community, and even the entire country by helping sustain the school and the students it educates.

CHAPTER 2: LITERATURE REVIEW

2.1: PARAGUAY

Paraguay is a developing country in central South America that has overcome many obstacles throughout its history. During its first one hundred and fifty years of freedom from Spanish rule, Paraguay was a country where power was centered on one man (U.S. Library of Congress, n.d.). Its history of domination by totalitarian personalities caused the nation to succumb to substantial economic losses. There was a concurrent weakness in education (U.S. Library of Congress, n.d.). Although Paraguay no longer suffers from dictatorial rule, there remain many poor people and less than acceptable levels of education (Central Intelligence Agency [CIA], 2016).

A large proportion of these poor people, as many as 30%, work in agriculture (World Bank, 2010). They also represent a large proportion of the under-educated. Learning how to properly monetize and market the products of their work is critical to their upward mobility. At the same time, education can serve this goal by transforming these rural farmers into entrepreneurs.

As part of this economic and educational transformation, the lives and resources of these uneducated poor must be materially improved. One of the most important material improvements is water--its sources, its uses, and its disposal.

Although a majority of Paraguayans have access to piped water, the proper disposal of said water leaves much to be desired (Inter-American Development Bank, 2014). Less than a quarter of Paraguay's wastewater is treated by any means (Oyamada, et al., n.d.). As a result, improved sanitation is an important goal for the whole country (World Bank, 2010). Unfortunately, the Ministry of Public Works and Communications, which oversees the subject, has not developed any relevant policies (LatinoSan, 2007).

The country's water contamination and inadequate means for waste disposal pose health risks (CIA, 2016). The risk comes from pathogens found in human waste (Wescot, 1997). These pathogens can survive a minimum of fifty days even when introduced to freshwater (Wescot, 1997). As a result, workers who come in direct contact with wastewater in the field and those who eat produce exposed to it can become sick and even die. Clearly, waste treatment is necessary.

2.2: WASTEWATER TREATMENT METHODS

One of the simplest forms of wastewater management is an underground containment system known as a cesspool (See Figure 1). In the past, cesspools were constructed similarly to wells (Stauffer & Spuhler, n.d.). They were made from brick siding and lacked a floor. These structures allowed waste to escape, enabling the cesspool to last a long time without overflowing. To enhance the lifetime of these systems, cesspools were leaked, a process that involved drilling a hole in the side of the pit and piping the waste to a ditch or field (Stauffer & Spuhler, n.d.). Nevertheless, these cesspools ultimately failed because solid waste built up, blocked the exit of liquid from the system, forced waste to overflow, and ultimately saturated the surface with wastewater (Stauffer & Spuhler, n.d.).

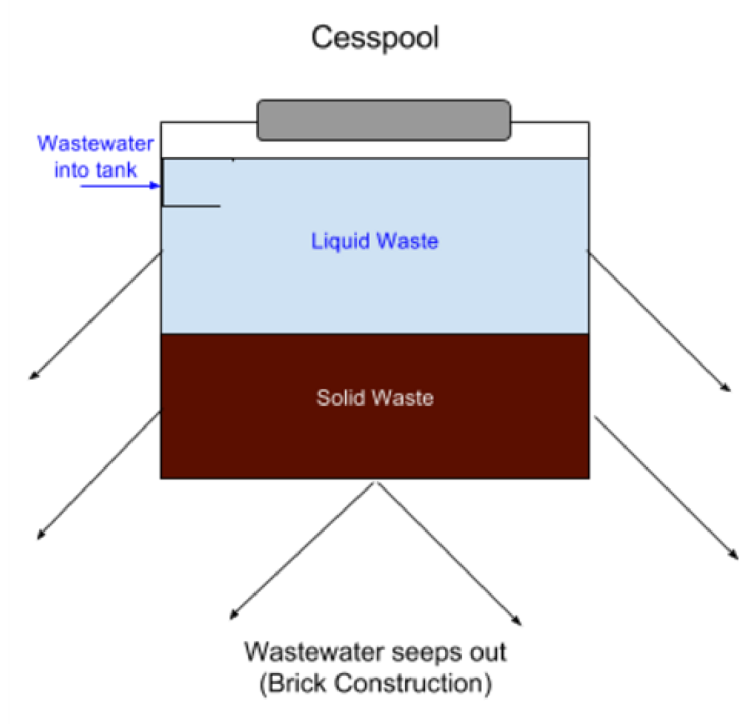


Figure 1: Diagram of a Cesspool

Cesspools are no longer the industry standard (Environmental Protection Agency [EPA], 2015). They are too prone to flooding, material decay, and contamination of groundwater (Stauffer & Spuhler, n.d; EPA, 2015). Certainly, they are a hazard where populations are dense. For these reasons, modern environmental regulations ban them in most of the developed world (EPA, 2015).

A more modern method of wastewater management and treatment is septic systems (See Figure 2). They are especially common in small, rural communities. Septic systems collect and purify household wastewater in one central tank. Inside the tank, naturally-found bacteria metabolize most solids, leaving the rest to settle to the tank's floor (EPA, 2002). As a result, the contents of the tank separate into three layers: the scum, effluent, and sludge. The scum consists of oils and fats that rise to the top of the wastewater; effluent is the contaminated water that continues through the system, and the sludge is the solid waste that settles to the bottom of the tank (EPA, 2002). As more wastewater enters the system, the tank maintains a steady volume because the force of incoming wastewater drives an equal amount of effluent out. This exiting water passes through a filter and into a leachfield.

A leachfield consists of a network of underground, perforated pipes (EPA, 2002). Within the leachfield, the the pipes distribute water into the surrounding medium where it is filtered. Filtration occurs through natural actions of soil chemistry and biology (EPA, 2002).

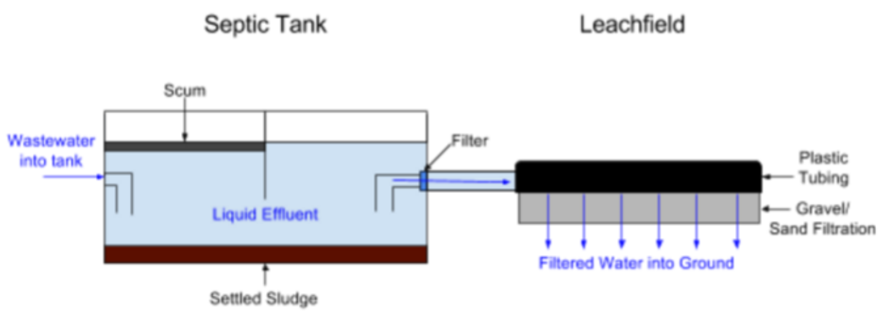


Figure 2: Diagram of a Basic Septic System

In developing nations, like Paraguay, it is common for these two waste management methods--cesspools and septic systems--to have some of their components combined into a third arrangement (Toro, personal communication, April 21, 2016). The arrangement might best be described as a septic tank connected to a leachfield which takes the form of a deep, cylindrical pool. As a result, this third arrangement functions as a septic system where a “leachpool” has replaced a leachfield. A cylindrical pool has far less surface area than a horizontal field, but it takes less room.

Piping must be considered wherever there are fluids. Modern wastewater treatment piping is usually composed of polyvinyl chloride (PVC), a durable plastic material. In the past, pipes were made from clay (Gladding, Mcbean, n.d.). Clay can last a long time, but roots and pressure, especially from vehicle traffic, can quickly damage it. Vitrified clay piping, which has an enamel coating, is much more durable. However, vitrification wasn’t common until around twenty years ago.

2.3: TROUBLESHOOTING

Problems are common in waste management systems, especially those serving large numbers of people. Most problems arise when the tank can no longer handle the volume of liquid entering it on a daily basis (Ready, 2008). Other problems arise from lack of maintenance. To operate at maximum efficiency, tanks must be pumped before they are full (Ready, 2008). Tree roots and other disturbances damage tank and pipe integrity (Ready, 2008). All these lead to contamination of the surface and groundwater (National Environmental Services Center, 2004).

The integrity of a septic system can often be analyzed with an indicator dye. An indicator dye shows where effluent has escaped the system. It does this by coloring effluent in a way that makes it easily seen. The dye is introduced into the system through a toilet or other point of disposal. Familiarity with the dye may be necessary because tests are not always conclusive. Commercially, these dyes are known as uranine dye or fluorisine #4 (The Center for Research Information, Inc., 2004).

.

2.4: PRODUCTS OF WASTEWATER MANAGEMENT

In addition to the human health and ecological benefits of wastewater treatment, there are practical uses for the sewage. Treated waste is nutrient-rich. The nutrients have agricultural applications. Wastewater can irrigate crops, and fertilizer can be made from waste solids. The safety of these byproducts requires special processes and attention.

2.4.1: ECOLOGICAL FILTRATION AND CONSTRUCTED WETLANDS

Ecological filtration is an environmentally friendly method of wastewater treatment. Ecological filters are low cost, easy to operate, and efficient. They can remove nearly ninety-nine percent of impurities from sewage and can produce water suitable for non-potable and even potable uses (Varón, et al., 2011).

The most common example of ecological filtration is the constructed wetland (Steinfield & Del Porto, 2004). A constructed wetland consists of layers of porous rock or sand and vegetation (Figure 3). Common vegetation is reeds, bulrush, cattails, and bamboo because they are good water purifiers. The wetland environment, working as an intact ecosystem, sustains bacterial and animal species that reduce the level of harmful bacteria found in septic effluent (Varón, et al., 2011).

There are two different kinds of constructed wetlands. The first type, free water surface wetlands, exposes the water's surface to the atmosphere, creating a visible pool (Steinfield & Del Porto, 2004). The second type, the subsurface flow wetland, maintains the water level below the surface of the gravel or other media placed in the bed of the wetland (Steinfield & Del Porto, 2004). The latter method reduces the risk of odors, exposure, and the breeding of insects such as mosquitos.

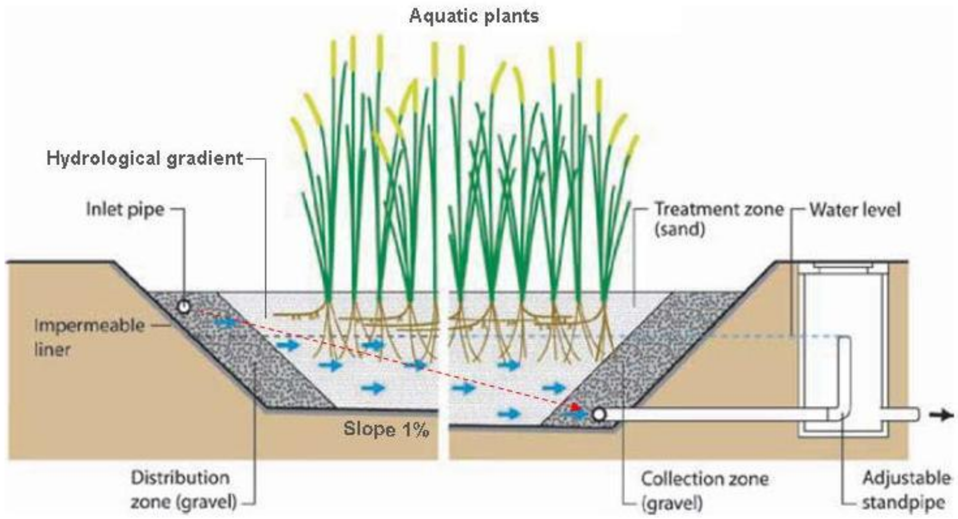


Figure 3: Diagram of a Constructed Wetland

The key difference between traditional leachfields and constructed wetlands, apart from wetlands being highly favorable to the environment, is the bacteria used to purify effluent. While septic tanks rely on anaerobic bacteria, constructed wetlands use aerobic species (Steinfield & Del Porto, 2004). Aerobic species use oxygen to transform and stabilize effluent ten to twenty times faster than anaerobic types (Steinfield & Del Porto, 2004). Additionally, plants in a constructed wetland can adapt to changing wastewater strengths (Steinfield & Del Porto, 2004).

2.4.2: COMPOSTING OF HUMAN WASTE

Human waste can be composted. Composted human waste is known as biosolids when used as fertilizer (Geiling, 2014). This fertilizer provides the kind of nitrogen and other nutrients needed to maximize crop production (Westcot, 1997). In addition, composted human waste improves the water-holding and iron-buffering capacity of soil (Morgan, 2003).

Composted human waste is culturally unappealing in most places. There is no evidence, however, that when properly handled, human waste is unsafe or adversely affects crop management and production (CTPBAL et al., 2002). In fact, biosolids are used for either agricultural or other fertilizing purposes (i.e. landscaping) in all fifty U.S. states (Stevens, 2015).

To ensure that composted human waste is safe, it must sit for at least one year in climate conditions such as those in Paraguay (Phi et al, 2004). Keeping the compost dry and at a relatively high pH eliminates dangerous human pathogens.

A simple, three bin compost system achieves acceptable safety levels (Jenkins, 2005). One bin serves as dry materials storage (leaves, grass, straw). The other two bins receive human waste. The first of the human waste bins receives a load of waste that is then covered with dry material. The alternation between human waste and dry material takes place until the bin is full. After which, it is covered and stands for a year. The second of the two human waste bins is filled in the same way, alternating human waste and dry plant material until it is full. Then, it is covered and left to stand for a year. At the end of a year of composting, the waste is safe to use. From time to time, the dry plant storage bin needs to be refilled. Should there be more human waste than the two human waste bins can hold, more bins can be added. If there are doubts about the safety of the compost, it can be aged for two years. Bin size can be based on estimates of human waste supply.

Once the compost is ready, it should still be handled with care (World Health Organization [WHO], 2006). Workers should wear gloves when handling it. Additionally, at least a month should pass between the application of the fertilizer and the harvest of the crop (WHO, 2006). Crops on which this fertilizer might collect, such as spinach, lettuce, kale, and swiss chard are not recommended for use with biosolids (WHO, 2006).

Both constructed wetlands and human waste composting systems can be used by farmers in rural Paraguay. The techniques, however, are not well known, though, if used, could contribute to self-sufficiency. Their cost is low and environmental footprint small. Poverty elimination organizations, like Fundación Paraguaya, might find it compatible with their mission to take the lead in teaching rural farmers how to use these techniques.

2.5: FUNDACIÓN PARAGUAYA

Fundación Paraguaya is a non-governmental organization attempting to eliminate poverty in Paraguay. The foundation supports a “teach a man to fish” philosophy, wherein it provides resources and education to communities, but let the communities lead themselves out of poverty (Fundación Paraguaya, n.d.). Additionally, the foundation revolutionized the conceptualization of poverty, by giving voice to the impoverished themselves through the creation of a self-diagnosis tool called a Poverty Stoplight.

This stoplight helps the organization’s employees put its three key programs to use where they are needed most. Fundación Paraguaya actually introduced the first of these programs, microcredit, to Paraguay and devotes most of its funding to the small businesses of women (Fundación Paraguaya, n.d.). The second key program is financial and entrepreneurial education, accomplished through community lessons and challenges. The final program is a system of self-sustaining farming high schools.

This initiative is exemplified by the Escuela Agrícola San Francisco, a high school located in Benjamín Aceval. The school takes children from rural communities and turns them into young entrepreneurs. Alongside a typical curriculum, students are taught to farm, produce cheese and jams, run the town’s hotel, Hotel Cerrito, as well as how to market these products and skills (Godfrey, Kearney, Palmer & Manwaring, n.d.). The school covers one hundred percent of its operating costs through the profits of the students' and professors' labor and studies (Godfrey et al., n.d.).

Due to this, it's important that costs not only be minimized, but that all byproducts of school and hotel activity be utilized. This project improved the current overwhelmed and outdated septic system of the school by creating designs for a new system that includes the use of septic tanks, an ecological filter, and a composting system. Together these will supplement the school's ability to sustain itself and provide more quality education to impoverished students, in keeping with the goal of Fundación Paraguaya.

CHAPTER 3: METHODOLOGY

The project adopted a methodology that allowed it to assess the current status of the school's human waste treatment system. Specifically, it sought information that allowed this system assessment to serve as a basis from which to make recommendations for improvements. Methodological objectives included:

1. Map the current system and identify its problems
2. Determine the features of a waste treatment system that respond to school goals

Traditional qualitative and quantitative techniques served these objectives.

3.1: MAPPING THE CURRENT SYSTEM AND IDENTIFYING PROBLEMS

To understand a system, its components and their functions must be known. An interview with the general maintenance manager and a tour of the campus identified the system's components, functions, and its problems, if present. The results were mapped, and septic tank and cesspool locations and the flow of water all appear in a one-page graphic.

In spite of the detailed map, important information was not available. The size and precise location of some waste containment systems were unavailable. Background research indicated that it would be unsafe to dig in the areas surrounding the cesspools in order to determine this information. Furthermore, some of these locations were not even exactly known.

A second interview with the general maintenance manager sought information related to problems within the system. The interview asked about the frequency and type of maintenance the system undergoes, the history of construction and repair, and the observed consequences of any its problems.

The answers indicated that a flow study of the system was warranted. The flow study utilized an industry standard indicator dye. There were eight test sites: the first and second year girls' dorm, the third year girls' dorm and administration building, the academic building, boys' dorms B and D, boys' dorm C, Mburucuya, the hotel front, and the hotel back. The results of the test were reported on a second map and served to indicate the school's primary problem areas.

3.2: DETERMINE THE FEATURES OF A WASTE TREATMENT SYSTEM THAT RESPOND TO SCHOOL GOALS

With school waste system and problem area maps in hand, the team devised a method to redesign the system so that it would fit school goals. The school's goals were conveyed in interviews and conversations with both its general maintenance manager and director. There were two goals: upgrade the system wherever necessary and design an ecological and biological treatment system.

Information needed to be gathered to address these goals. First, the team determined the daily water use of the school. Flow rates were metered and volumes were measured over a twenty-four hour period of time. Daily usage was deduced from industry standards and observations of personal behavior. With these numbers, the volume of each bathroom's waste was calculated. Based on the waste produced in each bathroom, a septic system capacity was calculated (Oxfam, n.d.b).

A further source of information related to the school's goals came from ongoing efforts to renovate the septic systems of the girls' dormitories. The team examined two septic systems designed along the lines of traditional Paraguayan waste management techniques. These waste treatment units handle about 34% of the school's waste.

An architect in charge of the waste treatment units for the dormitories provided the team with an overview of the function of traditional Paraguayan septic systems. In addition to general system logistics, two key points emerged. First, the systems can be ecologically sustainable if they are properly maintained. Second, if they are maintained, their effluent does not need to be merged with the rest of the school.

Based on the information gained from these methods and previous background studies, a map was developed to show how the school's whole waste treatment system can be dealt with ecologically. Once again, the map showed the location of all the system components, including the new treatment plants and proposed areas for large scale ecological wastewater treatment and human waste composting.

3.3: TIMELINE OF METHODS

The timeline seen below in Figure 3 was used to organize the many activities of the project (Figure 4).

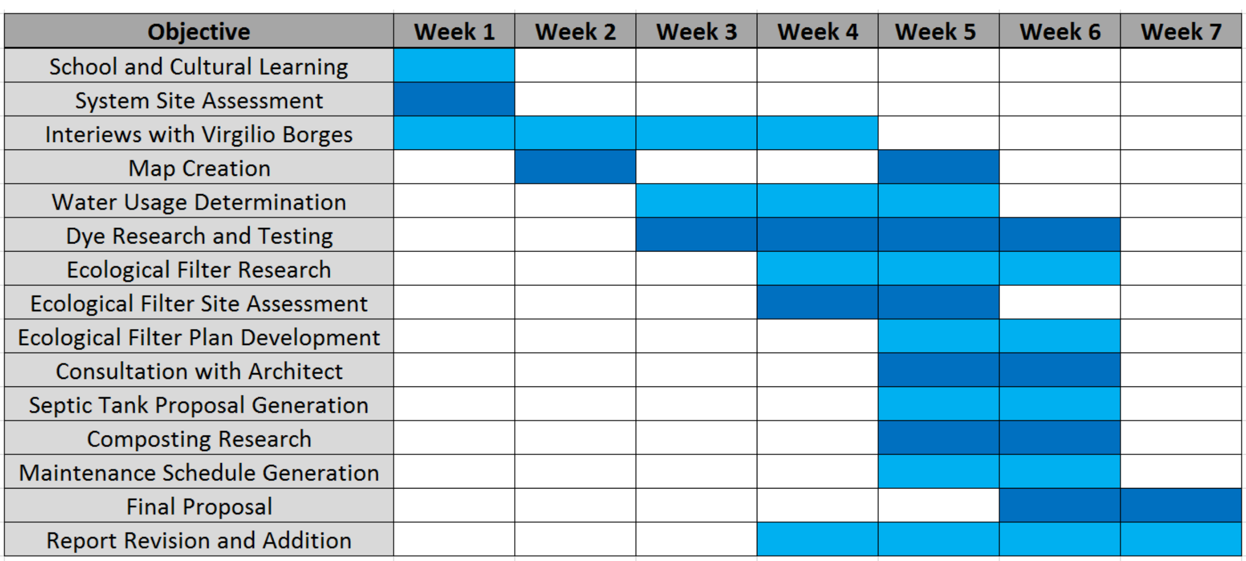


Figure 4: Gantt Chart

CHAPTER 4: FINDINGS

Our methodology generated the following findings regarding the current and future status of Escuela Agrícola San Francisco's wastewater management and treatment system:

1. The current waste management system is too old, too small, and inadequately maintained.
2. Even if the current system was adequate, it would not be ecological.
3. The campus holds potential for ecological treatment of its wastewater.
4. Current renovations will address waste treatment needs, but not completely ecologically.

4.1: THE CURRENT WASTE MANAGEMENT SYSTEM

The current waste management system is too old, too small, and inadequately maintained. The state of disrepair caused by its age was evident in our site assessment, where we saw broken, non-vitrified clay pipes and learned that it was over forty years old. Wastewater on the ground indicated that the system was too small or in some places did not exist. For example, there was neither a septic tank nor a cesspool connected to the boys' dormitories B and D bathroom. Here, waste flowed directly into a small stream. The kitchen and part of the hotel faced the same issue. Ground-level wastewater also indicated the tanks are not being properly maintained. School records corroborated this. Records indicated that, in a forty year period, only one septic tank had ever been pumped, and the cesspools had never been cleaned. Waste had built up within them to the extent that there was no more room for wastewater to enter.

The school's current waste management system appears in a map (Figure 5). Squares depict septic tanks, of which there are four. Circles on the map are cesspools; these accompany most buildings. Triangles are registers, which connect pipes throughout the campus. Arrows show the flow of water.

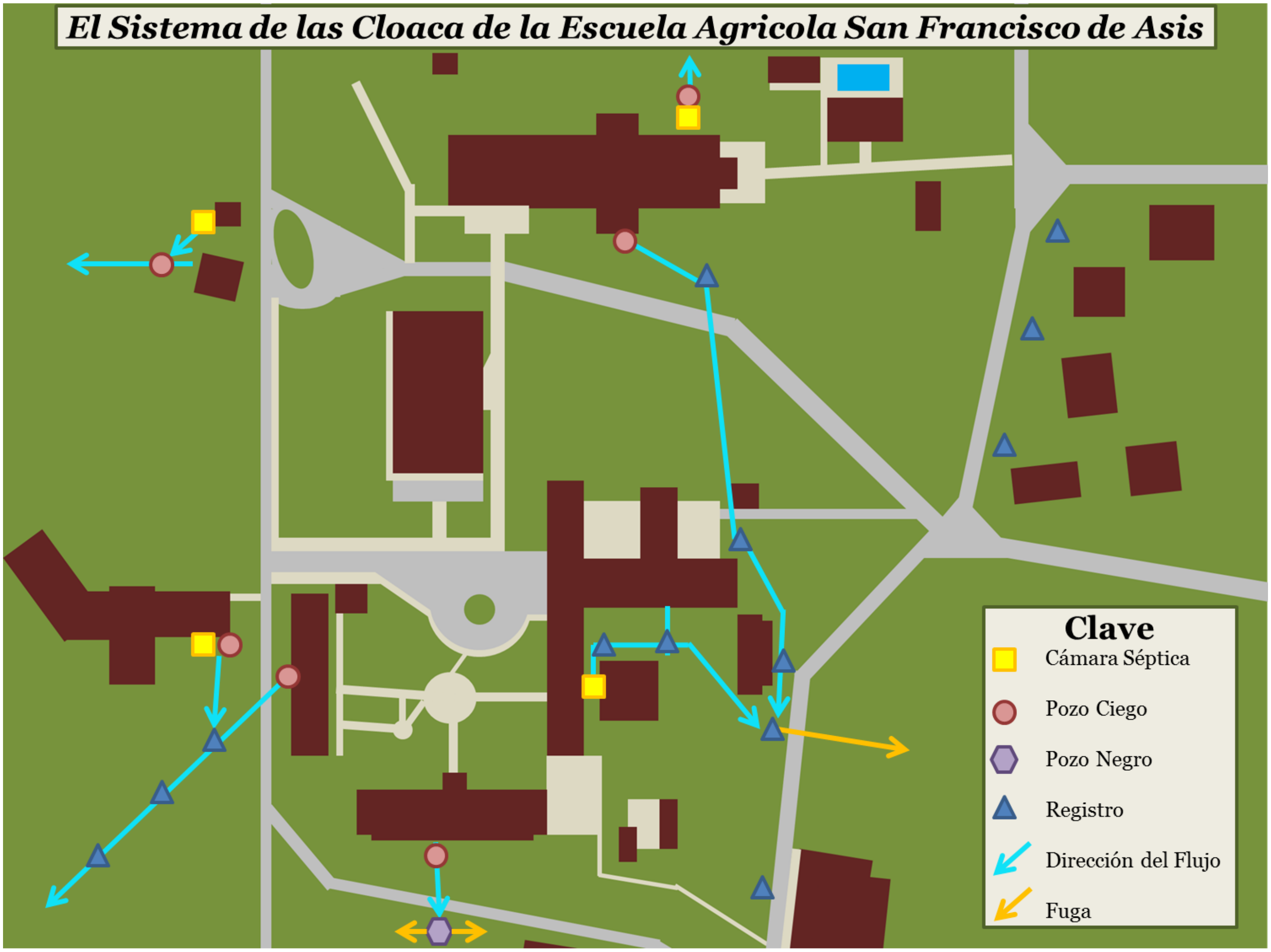


Figure 5: Map of the School's Current System

A second map depicts the functional and dysfunctional areas of the system (Figure 6). Areas that are orange show where waste has breached the surface. These areas are near the hotel and each dormitory. Areas that aren't depicted in orange have adequate systems.

<u>Figure 6: Map of Current System's Problems</u>

Further findings relate to the flow of wastewater on campus. Based on measurements and calculations, the volume, contents, and sources are known. The estimated total volume of wastewater is 41,099 liters a day. Of this, 11,020 liters are black water (bw) and 30,078 liters are greywater (gw). The hotel contributes 13,646 liters (4,059 L bw; 9,587 L gw), boys' dormitories B and D contribute 4,868 liters (1,514 L bw; 3,355 L gw), boys' dormitory C 5,422 liters (1,686 L bw; 3,736 L gw), first and second year girls' dormitory 8,408 liters (1,619 L bw; 6,792 L gw), third year girls' dormitory and administration 5,366 liters (1,032 L bw; 4,335 L gw), and the chalets contribute 2,313 liters (688 L bw; 1,624 L gw).

4.2: THE CURRENT SYSTEM IS NOT ECOLOGICAL

Even if the current systems were adequately maintained, there isn't ecological cleaning of the wastewater. This is evident with any of the broken systems, where wastewater on the ground is clearly unsanitary. For those systems which are intact or coming online, their cesspools utilize ground-based filtration, but this can still cause health problems through penetration to groundwater and seepage into surrounding soil.

4.3: POTENTIAL FOR ECOLOGICAL WASTEWATER TREATMENT

The school can treat its waste ecologically through the use of a subsurface constructed wetland. Such an ecological filtration system is well-documented in the literature, and the location of the school in terms of its hydrology, geology, soil, and vegetation lends itself to its application (Steinfield & Del Porto, 2004). Installation and maintenance of such a system are feasible because construction techniques are basic and student labor is readily available. Calculations suggest that a two-fifths hectare system can serve the school and has potential to treat nearly sixty-one percent of wastewater produced daily (Hoffmann, Platzer, von Münch, & Winker, 2011).

4.4: CURRENT RENOVATIONS

The school is building new septic systems for the girls' dormitories and the administration building. These are based on a modernized version of traditional Paraguayan design. The design utilizes a double pit structure. The first pit accumulates black water and is arranged to separate the solid from liquid waste. The second pit takes the liquid waste from the first and all grey water and allows them to percolate into the ground, in a "leakpool" structure. An effluent pipe from the second pit serves to carry away excess wastewater and, through perforations, let it drain into the surrounding soil. The crux of this system is that the first pit can fill up with waste and completely block the exit of effluent black water.

These new systems can treat thirty-four percent of the school's wastewater, but will not do so ecologically, as noted above, and without proper maintenance will likely fail after three months.

CHAPTER 5: RECOMMENDATIONS AND CONCLUSIONS

Based on our findings we have four recommendations to create a self-sustainable waste management system for the Escuela Agrícola San Francisco.

1. Regular maintenance of all extant and future septic systems.
2. Renovations and additions to the current wastewater system.
3. The implementation of a subsurface constructed wetland to ecologically treat sixty-one percent of the school's wastewater.
4. The construction and utilization of a human waste compost system.

5.1: MAINTENANCE OF THE SYSTEM

The currently existing, newly constructed, and proposed systems all require regular septic tank maintenance. Maintenance comprises two distinct activities: emptying the tanks when full and ensuring that chemicals harmful to their function do not enter them. The emptying schedule is unique to each tank, but attention will be required every three to six months. The concern for chemicals stems from the fact that many cleaning agents can poison the microbiological processes that break down solid waste in the first tank. These agents should never be emptied into the toilets. A commercial cleaner, Mr. Clean, however, appears to be compatible with the microbiology of septic tanks in Paraguay (Toro, personal communication April 21, 2016).

For a complete maintenance plan with information, see Appendix A.

5.2: NEW SYSTEM

Renovations and additions are required to create an integrated system. In addition to the ongoing construction, five new tanks are needed. The hotel needs two 7.65 m^3 tanks; the three chalets Tajy, Pacholí, and Jazmín together need a 3 m^3 tank; boys' dormitory blocks B and D require a 5.85 m^3 tank; and boys' dormitory block C requires a 6.75 m^3 tank. For recommended tank dimensions based on the team's calculations, see Appendix B. Additionally, Mburucuya should be connected to the already existing septic tank behind Alili, and the academic building's system should be connected to the filtration pipes of the first and second year girls' dormitories. Whenever the tanks are replaced or repairs are performed, the old clay piping of the system should be replaced with PVC pipes. The construction of new tanks to service the boys' dormitories is the most urgent, followed by hotel renovations, and finally chalet renovations.

Unlike the ongoing construction for the girls' dormitories and administration building, the proposed septic tanks should not have cesspools. Instead, along with the kitchen plumbing, they should be connected to an ecological filter located on campus.

5.3: ECOLOGICAL FILTER

The type of ecological filter best suited for the school is a subsurface constructed wetland. This holistic and sustainable system aligns with the school's desire for self-sufficiency and environmental friendliness. Additionally, it utilizes resources the school already has and reduces the risk of both odor and mosquito breeding.

Such a filter should be located behind general services near the old tilapia ponds. This location is large enough, downstream of all the systems to be connected to the filter, filled with plants, and already the receiving area for much of the school's wastewater. Like all septic systems, it must be maintained. Setty (n.d.) provides a definitive text on the construction and maintenance of such a system.

The constructed wetland just described need not be the only constructed wetland to serve the school. Additional wetlands could be used to handle all of the school's waste, either by rerouting all of the waste into the first system or building others. As mentioned in the previous chapter, the system currently being constructed is not completely ecological due to the use of "leakpools". If the school ever wants to make its systems completely ecological, it should cease using these components. A second ecological filter can be created in the area behind the administration and academic building to service the girls' dormitories, Alili, and Mburucuya. The filter could use many of the plants already growing in the area and would need to be around one-fifth of a hectare in size.

Water exiting either of these systems could be collected for later use for agricultural irrigation or could be allowed to enter a natural stream nearby.

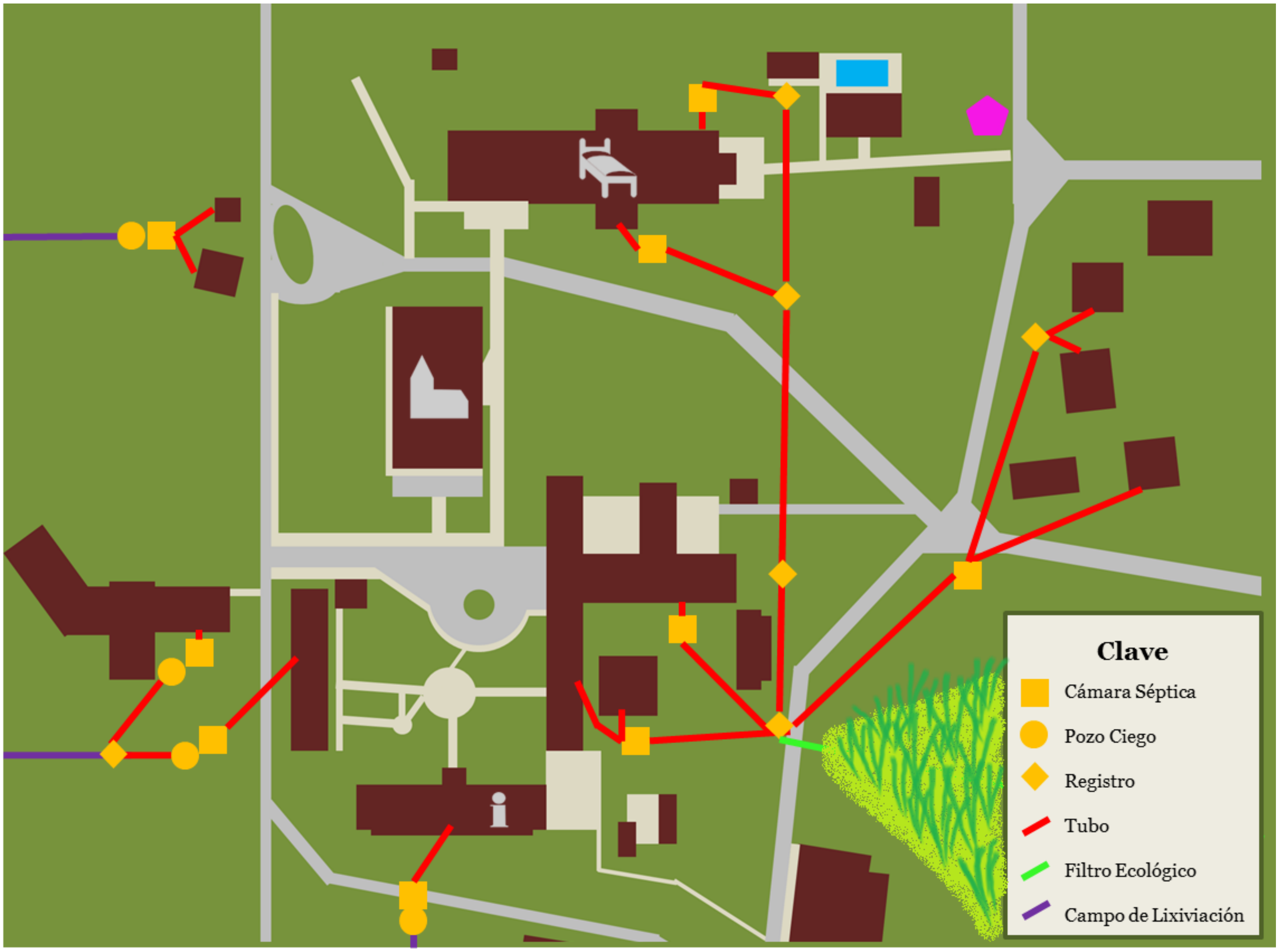
5.4: HUMAN WASTE COMPOST SYSTEM

Regular maintenance of the septic tanks will generate a large amount of solid waste that requires disposal. If the school wants to be entirely sustainable, this waste must be dealt with on campus. A compost system for creating fertilizer is the best use for this waste. A simple three-bin system, wherein one bin is filled to capacity and then allowed to compost for a year is recommended (See Appendix C for instructions).

Composting the waste will allow the school to eliminate the cost of disposing of the solids, and the fertilizer is safe to use on non-edible plants after one year in the holding bin and edible plants after two. A non-problematic use of the fertilizer for the school is on the eucalyptus trees.

5.5: CONCLUSION

Figure 7 shows the culmination of all the recommended changes, including new septic tanks to properly manage the school's waste as well as ecological and biological treatment of the solid and liquid remains through ecological filtration and composting, respectively.



Together and with proper maintenance, these changes provide the school with an integrated and sustainable system. The school's wastewater will be treated in a safe and effective manner while also providing the school with additional resources to use on its farm. Implementation of the system will therefore help the school achieve its self-sustainable goals. With greater self-sufficiency the school can continue contributing to the elimination of rural poverty in Paraguay by providing quality education for generations to come.

REFERENCES

Alliance for Water Efficiency. (c2016). Toilets. Retrieved from: http://www.home-waterworks.org/indoor-use/toilets

Central Intelligence Agency [CIA]. (2016). South America: Paraguay. *The World Factbook 2015-16.* Washington, DC: Central Intelligence Agency.

Cerrutti, M., Bertoncello, R. (2003, June). *Urbanization and Integral Migration Patterns in Latin America.* Paper presented at the Conference on African Migration in Comparative Perspective, Johannesburg, SA.

Committee on Toxicants and Pathogens in Biosolids Applied to Land, Board on Environmental Studies and Toxicology, Division on Earth and Life Studies [CTPBAL]. (2002). *Biosolids applied to land: Advancing standards and practice*. Washington, D.C: The National Standard Press.

Environmental Protection Agency [EPA]. (1994). *A Plain English Guide to to the EPA Part 503 Biosolids Rule*. Washington, D.C.

Environmental Protection Agency [EPA]. (2002). *A Homeowner's Guide to Septic Systems.* Cincinnati, OH: United States Environmental Protection Agency.

Environmental Protection Agency [EPA]. (2015). Large-Capacity Cesspools. Retrieved from https://www.epa.gov/uic/large-capacity-cesspools

Farm & Stable Projects. (c2013). O2Compost System. Retrieved from: http://farmandstables.com/project/o2compost-system-camden-nc/

Fundación Paraguaya. (n.d.). "Quiénes Somos". Retrieved from http://www.fundacionparaguaya.org.py/wp-content/uploads/2014/10/ LibroBYU.pdf

Geiling, N. (2014). The stink about human poop as fertilizer. *Modern Farmer*. Retrieved from http://modernfarmer.com/2014/07/stink-human-poop-fertilizer/

Gladding, McBean. (n.d.). Why clay pipe?. Retrieved from: https://www.gladdingmcbean.com/ sewer-pipe/why-clay-pipe

Godfrey, P. C., Kearney, R., Palmer, J., Manwaring, T. (n.d.). Fundación Paraguaya: The San Francisco School [Abstract]. Retrieved from http://www.Fundaciónparaguaya.org.py/wp-content/uploads/2014/10/ LibroBYU.pdf

Green Action Centre. (n.d.). Multi-Bin Composting System. Retrieved from: http://greenactioncentre.ca/content/multi-bin-composting-system/

Hoffmann, H., Platzer, C., von Münch, E., Winker, M. (2011). Technology review of constructed wetlands - Subsurface flow constructed wetlands for greywater and domestic wastewater treatment. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, Germany

Inter-American Development Bank. (2014). Water and sanitation system construction project for small cities and rural and indigenous communities in Paraguay. Retrieved from http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=39879104

International Fund for Agricultural Development [IFAD]. (2013). Rural poverty in Paraguay. Retrieved from http://www.ruralpovertyportal.org/country/home/tags/paraguay

Jenkins, J. (2005). Chapter 8: The Tao of Compost. *The Humanure Handbook.*

LatinoSan. (2007). Informe Paraguay. Primera Conferencia Latinoamericana sobre Saneamiento.

Morgan, P. (2003). *Experiments using urine and humus derived from ecological toilets as a source of nutrients for growing crops*. Paper presente at the 3rd World Water Forum, 16-23 March 2003 (http://aquamor.tripod.com/KYOTO.htm)

National Environmental Services Center. (2004). Maintaining your septic system: A guide for homeowners. *Pipeline*, 15(4): 1-8.

Oxfam. (n.d.a). Manual Desludging Handpump (MDHP). Retrieved from: https://d3gxp3iknbs7bs.cloudfront.net/attachments/c1f765714d94db35ac1

Oxfam. (n.d.b). Septic Tank Guidelines. Retrieved from: http://www.bvsde.paho.org/texcom/desastres/oxfamstg.pdf

Oyamada, J., Machado, K., Moreno, H., Páez, T., Stuzenegger, G., Sasaki, K., López, L., Monje, A. Chaverri-Suarez, A., Perales, M., de Egea, A., Morais, J. (n.d.). Water and sanitation system construction project for small cities and rural and indigenous communities in Paraguay.

Phi, D., et al. (2004). *Study on survival of* Ascaris suum *eggs in faecal matter inside the ecosan toilets built in Dan Phuong - Lam Ha - Lam Dong - Vietnam*. Nha Trang Pasteur Institute, University of Kyoto, NIPPON International Cooperation for Community Development Organisation (NICCO).

Ready, M. (2008). Top reasons for septic system failure and how to prevent them. *Barnyards & Backyards*, Summer 2008: 13-15.

Setty, K. (n.d.). Manual de construcción: Humedales construidos para el tratamiento de aguas negras. Retrieved from: http://www2.bren.ucsb.edu/~keller/courses/GP_reports/Diseno_Humedal_AguasNegras.pdf

Stauffer, B., Spuhler, D. (n.d.). Cesspit. Retrieved from: http://www.sswm.info/print/1830?tid=849

Steinfield, C., Del Porto, D. (2004). Growing away wastewater. *Landscape Architecture*.

Stevens, R. (2015). Frequently asked questions about biosolids. Retrieved from http://www.epa.gov/biosolids/frequently-asked-questions-about-biosolids

The Center for Research Information, Inc. (2004). Uranine Dye. Retrieved from: https://www.nationalacademies.org/hmd/~/media/Files/Report%20Files/2007/Long-Term-Health-Effects-of-Participation-in-Project-SHAD-Shipboard-Hazard-and-Defense/URANINEDYE.pdfv

U.S. Library of Congress. (n.d.). Paraguay - History. Retrieved February 04, 2016, from http://countrystudies.us/paraguay/2.htm

Varón, P., Van Ginneken M.R., Meike, Madera. (2011). Humedales de flujo subsuperficial: una alternativa natural para el tratamiento de aguas residuales domésticas en zonas tropicales. *Revista Ingeniería y Competitividad*, *5*(1), 27-35.

Westcot, D. W. (1997). *Quality Control of Wastewater for Irrigated Crop Production*. Retrieved 1/26, 2016, from http://www.fao.org/docrep/w5367e/w5367e00.htm#Contents

World Bank (2010). *Paraguay poverty assessment: Determinants and challenges for poverty reduction*.

World Health Organization [WHO]. (2006). *Who Guidelines for the Safe Use of Wastewater, Excreta and Greywater*. World Health Organization: Geneva, Switzerland.

APPENDICIES

APPENDIX A: SEPTIC SYSTEM MAINTENANCE PLAN

DEVELOPING A CLEANING SCHEDULE

- Each septic tank the school has needs to be emptied of its solid contents every three to six months.
- The project team recommends that the tanks first be emptied after three months.
    - Then, if it is discovered that a tank isn't full, the time between this cleaning and the next can be extended to four months, and so on.
    - However, no more than six months should ever pass before a tank is emptied.
- An individual cleaning schedule should be developed for each tank.
- Marking cleaning days on a calendar may help ensure that cleaning happens.

HOW TO EMPTY THE TANKS

Exact cleaning instructions should be provided by the manufacturer, but there are some common guidelines:

- Be sure to close off access to all bathrooms corresponding to the tank being cleaned.
- There should be a way to open the septic tank on the top.
- If necessary, it is possible to use a shovel to remove the majority of the solid waste.
    - Waste should be removed until it is too difficult to remove any more.
    - The shovel should never be used for any other purpose and should be well cleaned with disinfectant after use.
- Preferably, a pump would be used. Oxfam (n.d.) has developed picture instructions for the design and operation of such a hand pump.
- Emptied waste should be transferred into large plastic bins for transport to the compost site or other disposal site. These bins should never be used for any other purpose and should be well cleaned with disinfectant after use.
- Those emptying the tanks should use proper health precautions.
    - If possible, face masks should be worn that cover the mouth and nose.
    - Gloves, long pants, long sleeves, and closed-toe shoes are all essentials.

PREVENTING THE DISPOSAL OF CHEMICALS IN THE TOILETS

Most chemicals found in household cleaning supplies are harmful to the bacteria that break down waste within the septic tanks. Therefore, it is critical to ensure that none of these chemicals are flushed down the toilet. The main concern area for this is the morning cleaning. Students should be advised to dump buckets containing cleaning supplies down the shower drains, not into the toilets. Signs should be posted above every toilet in the dormitories as well as every other bathroom on campus. Students should be reminded at the morning clean-up for the first week after a new system is installed and then periodically after this. Hotel guests should be informed by signage as well.

In order to clean the toilets themselves, septic tank-friendly cleaning supplies should be used. These supplies use microbes and microbe-friendly chemicals to clean. An example is Mr. Clean.

APPENDIX B: CALCULATIONS

The following page shows Table 1 where the numbers are used to determine the volume of wastewater flow in the school Locations are color coded based on the system they correspond to--any two or more locations that are the same color share the same system. Shower length estimates were based on personal observation and split by gender. In areas where bathrooms are not gender specific, the longer shower time (ten minutes) was used. The volume of water used showering each day was based on multiplying the approximate flow rate of school showers (6.32 L/min) by the length of two showers per person, per day. Average toilet usage was estimated to be 34.4 liters per day, and average hand and face washing volume were estimated to be eight liters per person per day (Alliance for Water Efficiency, c2016). The academic building bathroom was calculated separately as its system has only one toilet that it's possible for many people to use each day. In total, the school generates 41,099 liters of wastewater every day.

Below that is Table 2, which shows the numbers used to determine the correct size for the school's septic systems. Calculations were based on instructions provided by Oxfam (n.d.). First, the total black water generated in each system every day was calculated by multiplying the number of people using a given system by an average toilet usage of 34.4 liters per day (Alliance for Water Efficiency, c2016). Ninety percent of this total was called the daily flow of the system. Sludge storage, the amount of sludge generated that would need to be stored in the tank, was the number of people using the system multiplied by time between emptying in years (.5 for twice a year), multiplied by the rate of sludge accumulation per person per year (25), multiplied by the sludge digestion factor (1 in warm climates, like Paraguay's) (Oxfam, n.d.). The results generated were the total tank volume necessary for each system, along with suggested dimensions (in meters) and the actual tank volume these proposed dimensions create. The status of construction is also listed.

Table 1: Volume of Wastewater Flow by Location

Location	Dorm A1	Dorm A2	Dorm A3 y Administration	Dorm B1	Dorm B2	Dorm B3	Dorm C1	Dorm C2	Dorm D1	Dorm D2	Alili/Mburucuya	Taji, Pacholi, Jazmin	Hotel
Number of people	28	19	30	10	10	13	24	25	6	5	8	20	118
Shower length estimate (min)	10	10	10	5	5	5	5	5	5	5	10	10	10
Shower volume estimate (L/min)	126.49	126.49	126.49	63.25	63.25	63.25	63.25	63.25	63.25	63.25	63.25	63.25	63.25
Toilet volume estimate (L)	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40
Hand/face washing (L)	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Total volume per day/person (L)	178.89	178.89	178.89	110.65	110.65	110.65	110.65	110.65	110.65	110.65	115.65	115.65	115.65
Total volume (L/day)	5,009.01	3,398.97	5,366.80	1,106.47	1,106.47	1,438.41	2,655.52	2,766.17	663.88	553.23	925.17	2,312.93	13,646.31
Total Volume per System (L/day)		8,407.99	5,366.80			4,868.45		5,421.69	Included in B1-B3 calculations		925.17	2,312.93	13,646.31
Academic Building Bathroom (L/day)	150												
Grand Total (L/day)	41,099.34												

Table 2: Septic Tank Size Calculations

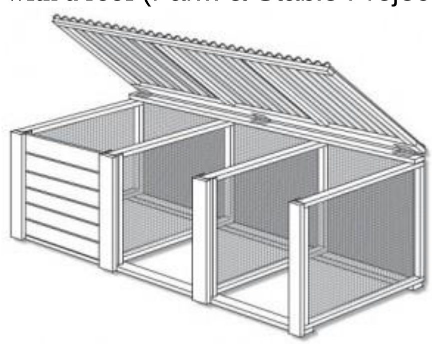
Location	Dorm A1	Dorm A2	Dorm A3 y Planta Alta	Dorm B1	Dorm B2	Dorm B3	Dorm C1	Dorm C2	Dorm D1	Dorm D2	Alili/Mburucuya	Taji, Pacholi, Jazmin	Hotel
Number of people	28.00	19.00	30.00	10.00	10.00	13.00	24.00	25.00	6.00	5.00	8.00	20.00	118.00
Toilet use per person (L/day)	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40	34.40
Total black water (L/day)	963.20	653.60	1,032.00	344.00	344.00	447.20	825.60	860.00	206.40	172.00	275.20	688.00	4,059.20
Number using system		47.00	30.00			44.00		49.00	part of B1-B3 calculation		8.00	20.00	118.00
Daily Flow (L/day)		1,616.80	1,032.00			1,513.60		1,685.60	-		275.20	688.00	4,059.20
Sludge Storage		940.00	600.00			704.00		980.00	-		160.00	400.00	2,360.00
Total Volume of Tank Necessary (L)		5,790.40	3,696.00			5,244.80		6,036.80	-		985.60	2,464.00	14,537.60
Length		2.80	2.00			2.60		3.00	-		1.50	2.00	3.00
Width		1.50	1.50			1.50		1.50	-		0.50	1.00	1.70
Height		1.50	1.50			1.50		1.50	-		1.50	1.50	1.50
Actual Proposed Volume (m^3)		6.30	4.50			5.85		6.75	-		1.13	3.00	7.65
Construction Status	Ongoing		Ongoing		Needed		Needed		-		Connect	Needed	2 tanks at this size

APPENDIX C: HUMAN WASTE COMPOST SYSTEM CONSTRUCTION AND MAINTENANCE

1. Build a three bin compost system. Each chamber should be approximately 5' wide, 5' deep, and 4' high. Wood is a suitable material; mesh can also be used for interior walls. Build a roof or lid to keep all materials underneath dry. Installing a rainwater harvesting system on top of roof can aid in cleaning the supplies that have touched human waste.

   The following are appropriate examples:

A system with a roof (Farm & Stable Projects, c2013)



A system with mesh walls and a lid (Green Action Centre, n.d.)

A System with rainwater harvesting system (Jenkins, 2005)

2. Designate the far left chamber as Bin 1. Create a thick layer of coarse, absorbent material such as hay, straw, grass, leaves, and other weeds. Make it so that this floor is over eighteen inches thick and is slightly concave.

3. Begin to collect extra coarse, absorbent material in the middle bin, Bin 2.

4. Fill Bin 1 with the contents of every septic tank for the first year each time the tanks are emptied. (Note: Any tools [i.e. shovels, transport bins, etc.] used to handle the waste should be cleaned immediately after use and should never be used for any other purpose.) Immediately cover any contents with dry material, such as straw, grass, leaves, etc. from the middle bin. This will help prevent odor and trap air in the compost.

5. Food scraps, cow manure, and even small dead animals can be added to this compost and covered with more coarse, absorbent material.

6. Once the bin is full, cover it with plenty of coarse, absorbent material. Let sit for all of one year.

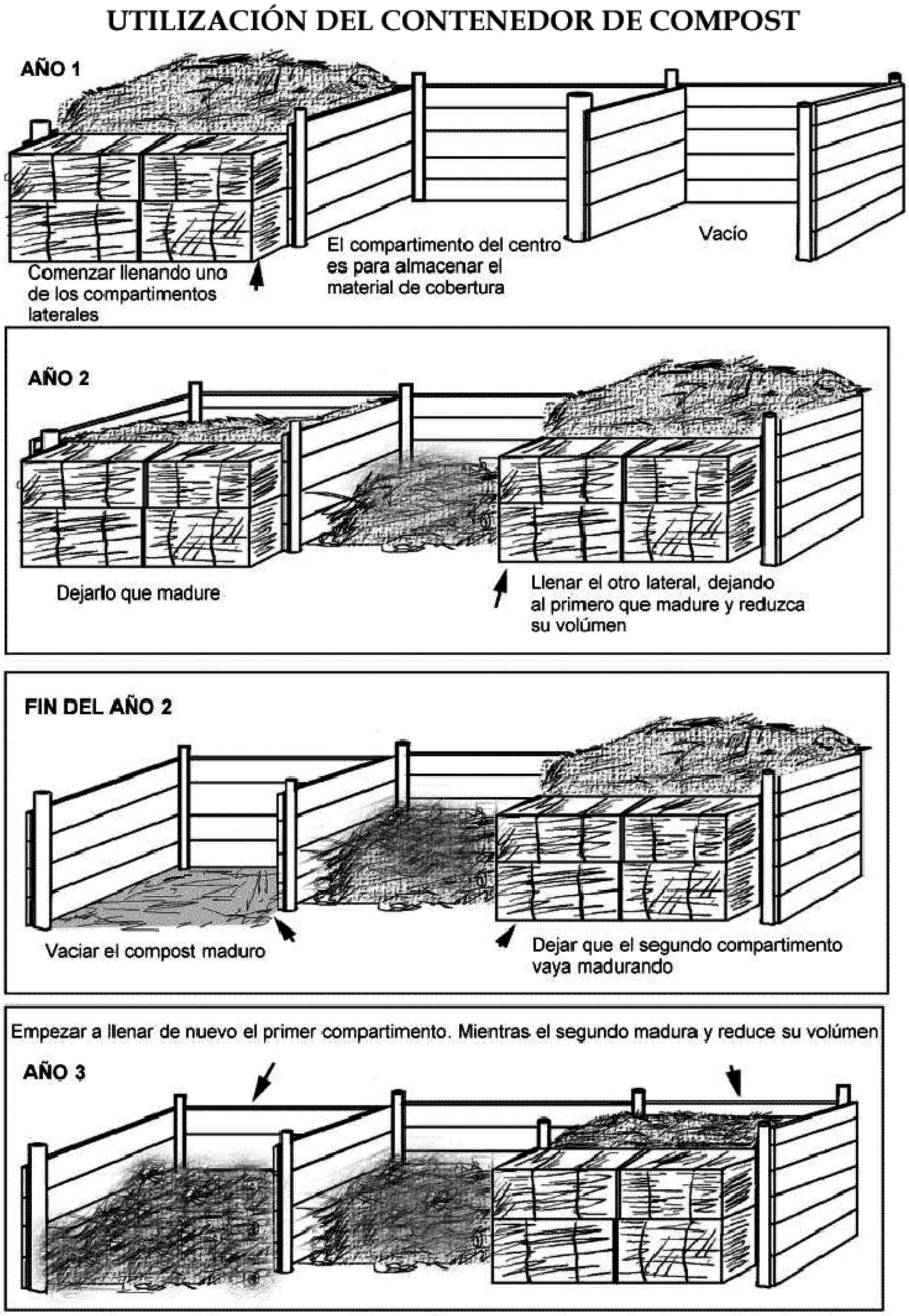
7. During this period, begin to fill the bin on the far right, Bin 3.

8. After one year, the compost of Bin 1 is ready for use.

9. After Bin 3 is full, begin to fill Bin 1 again and allow Bin 3 to sit for a year.

10. If Bin 3 fills before Bin 1 has sat for a year, another bin can be constructed or the bins can be made larger.

The above instructions are modified from the following infographic, presented in Spanish for the benefit of the staff and students of the Escuela Agrícola San Francisco (Jenkins, 2005).



Si queremos que el compost madure durante dos años en vez de uno, añadiremos un cuarto compartimento al sistema. No es necesario remover el compost.
Un tejadillo sobre el compartimento central mantendrá su contenido seco y a salvo de heladas.

<u>Tips for Using Human Waste Fertilizer</u>

- Leave at least one month between application of fertilizer to crops and the crops' harvest
- Irrigate the treated crops with clean, treated water

- Wash crops in a weak detergent solution to ensure elimination of helminth (parasitic worm) eggs. Then, rinse them in clean drinking water to clear off detergent.
- Crops that aren't for consumption, such as eucalyptus, are ideal for compost use.
- Crops that are always cooked before consumption are also suitable.
- Unsuitable crops include those with surfaces that easily retain water or those that are grown very close to the surface of the soil.
- The compost will also help with landscaping and can be used to help flowers and other decorative plants grow.
- Human waste fertilizer should always be handled with gloves, long pants, boots, long sleeves, etc. to protect the health of those distributing it.