Sustainable Water Treatment Prototype System for a Ghanaian Orphanage, School, and Hospital Campus

PROJECT DESCRIPTION

In 2016, a Ghanaian organization requested a wastewater sanitation system to be built on their campus, which contains an orphanage, school, and hospital. The existing system discharged untreated wastewater into the local river impacting downstream communities by contaminating their main source of water. Since then, design teams consisting of professionals, faculty, and engineering students have worked on the project as outlined in the Timeline in Figure 2. The solution selected by the design team was to implement a trickling filter system as the treatment method. This system utilizes a series of tanks that cycle wastewater through them until treated water is expelled. There are several benefits to this system, such as, low power usage, relatively simple construction, and utilization of locally available parts. The prototype system was implemented in May 2018 to treat 2,000 gal/day while the full system is set to be installed in May 2019 to treat 10,000 gal/day.

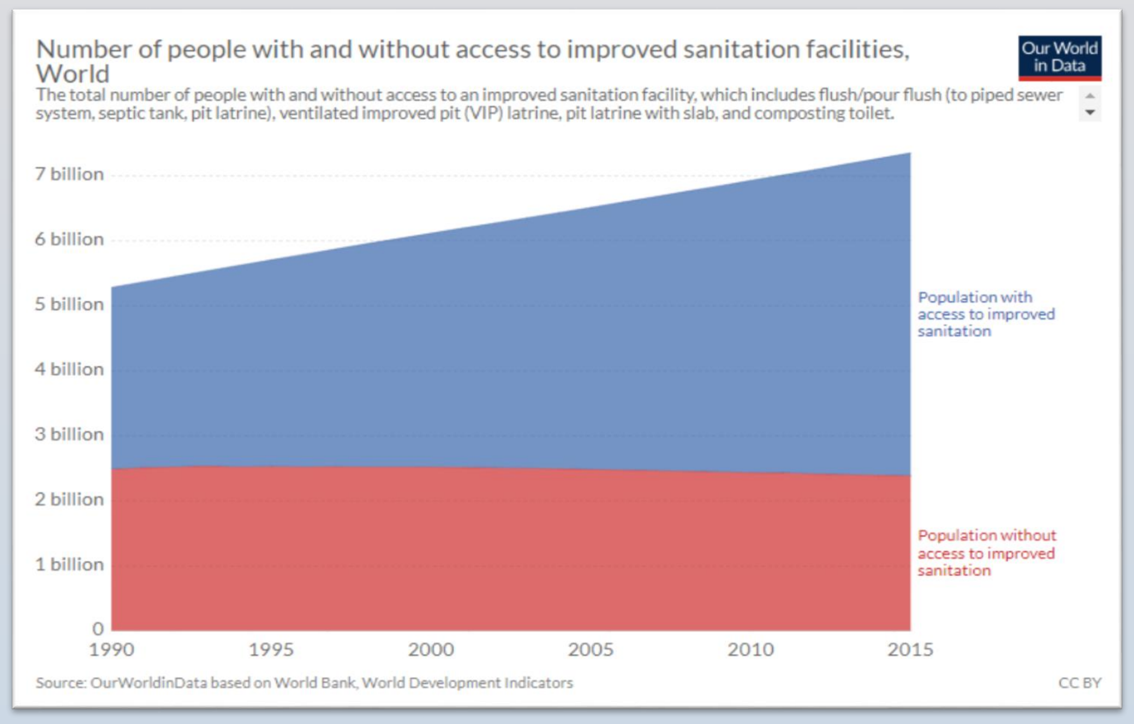

Figure 1: Of the approximately 7.4 billion people in the world, about 2.4 billion did not have access to modern sanitation facilities in 2015. That same year, 14.9% of the population of Ghana lacked access to modern sanitation.

INTERDISCIPLINARY WORK

The project involved a variety of aspects from multiple engineering disciplines:

- Civil and environmental engineering:
  - wastewater treatment quality and processing
  - tank sizing and weir design
- Mechanical engineering:
  - pump sizing and selection
  - dispersion nozzle design and testing
- Electrical and computer engineering:
  - controls process design
  - programming for pump dosing and fans

KNOWLEDGE/SKILLS GAINED

The nature of the project gave students involved the opportunity to practice:

- Engineering design process for a real-world project toward patenting
- Communication and cooperation across disciplines
- Implementation of technical knowledge alongside social, economic, and environmental impacts
- Professionalism including management, flexibility, and sustainable design

CHALLENGES FACED

- One week to build the prototype system
- Only 6-8 team members for construction
- Blown circuit shortly after construction (repaired in November 2018)
- Clarifier tank collapsed after significant rain (repaired in November 2018)
- Filter media was cut by hand, which was time-consuming and labor-intensive

TIMELINE

- **2016**: Initial Request for System
- **May 2017**: Trip to Measure Flow Rates and Install Solar Panels
- **September 2017**: Senior Design Team Tasked with Dispersion and Instrumentation Project
- **May 2018**: Prototype Construction Completed by Student Team
- **November 2018**: Post-Construction Issues Fixed
- **May 2019**: Full System Construction Upcoming

Figure 2: Timeline of project implementation since initial request in 2016

Samples (From Septic Tanks)	Alkalinity (mg/L)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	KN (mg/L)	NH_3- N (mg/L)
Academy	700	144	84.0	289	1.54	8.59
Hospital	950	116	208	417	4.09	8.11
Staff Housing	300	2.00	18.4	147	.34	13.9
College	750	150	265	1411	1.99	13.8
Girl Dormitory	850	142	90	431	2.52	8.95
EPA Guideline	**150**	**50.0**	**50**	**250**	**-**	**10.0**

Table 1: Wastewater quality before installation of the sanitation system compared to EPA guidelines

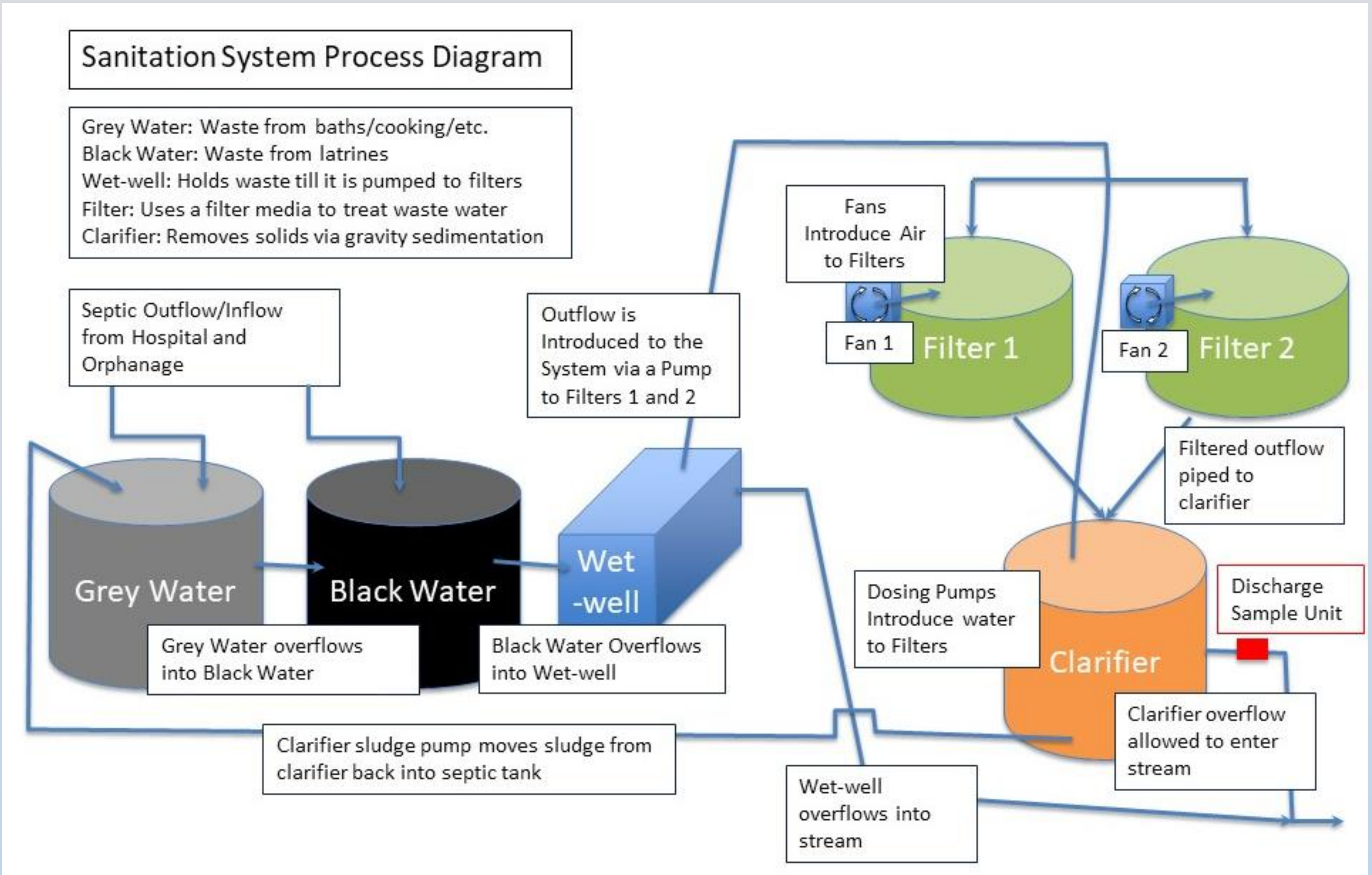

Figure 3: Flow process diagram of the wastewater treatment system

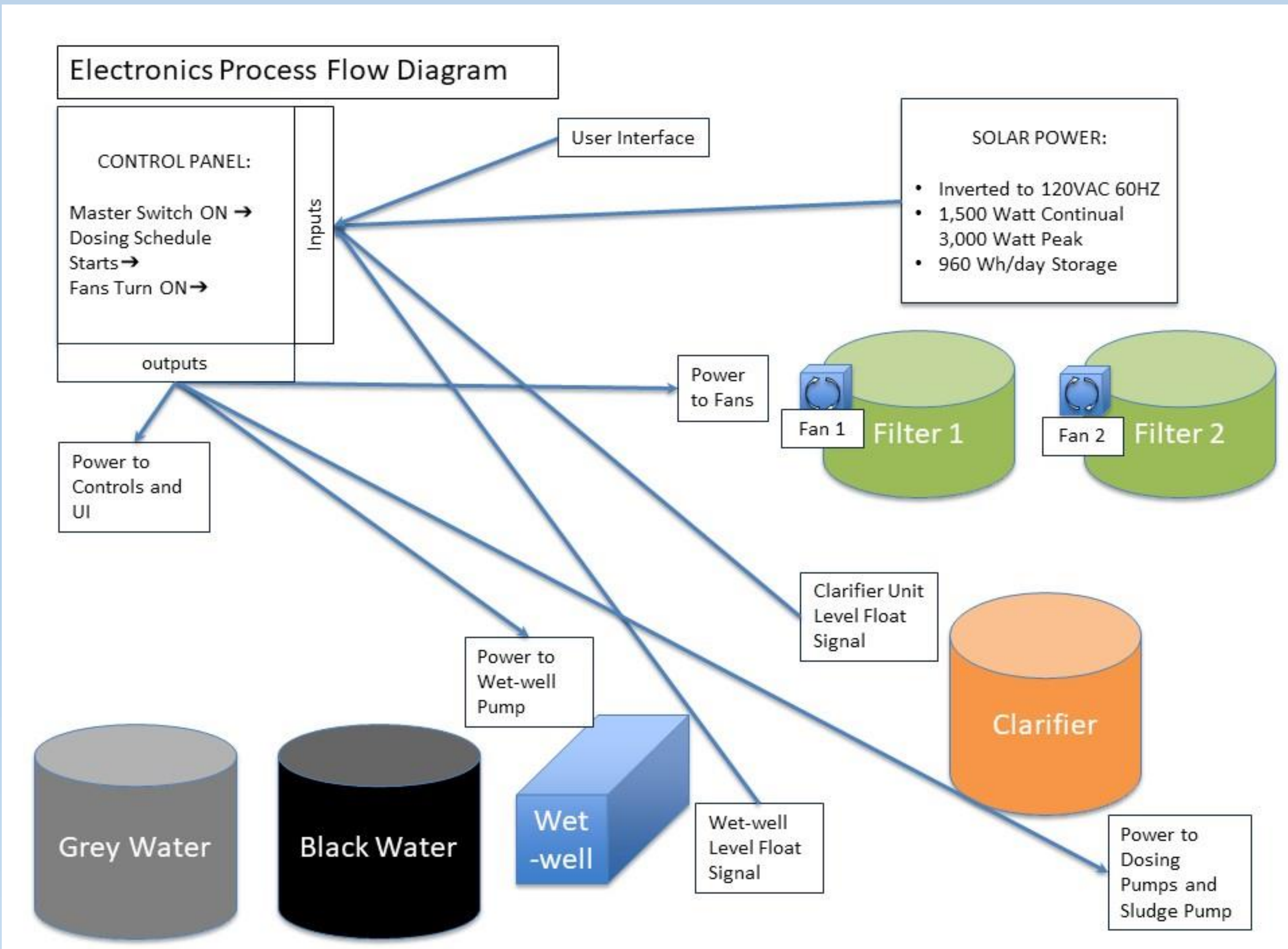

Figure 4: Controls and electronics process diagram of the wastewater treatment system

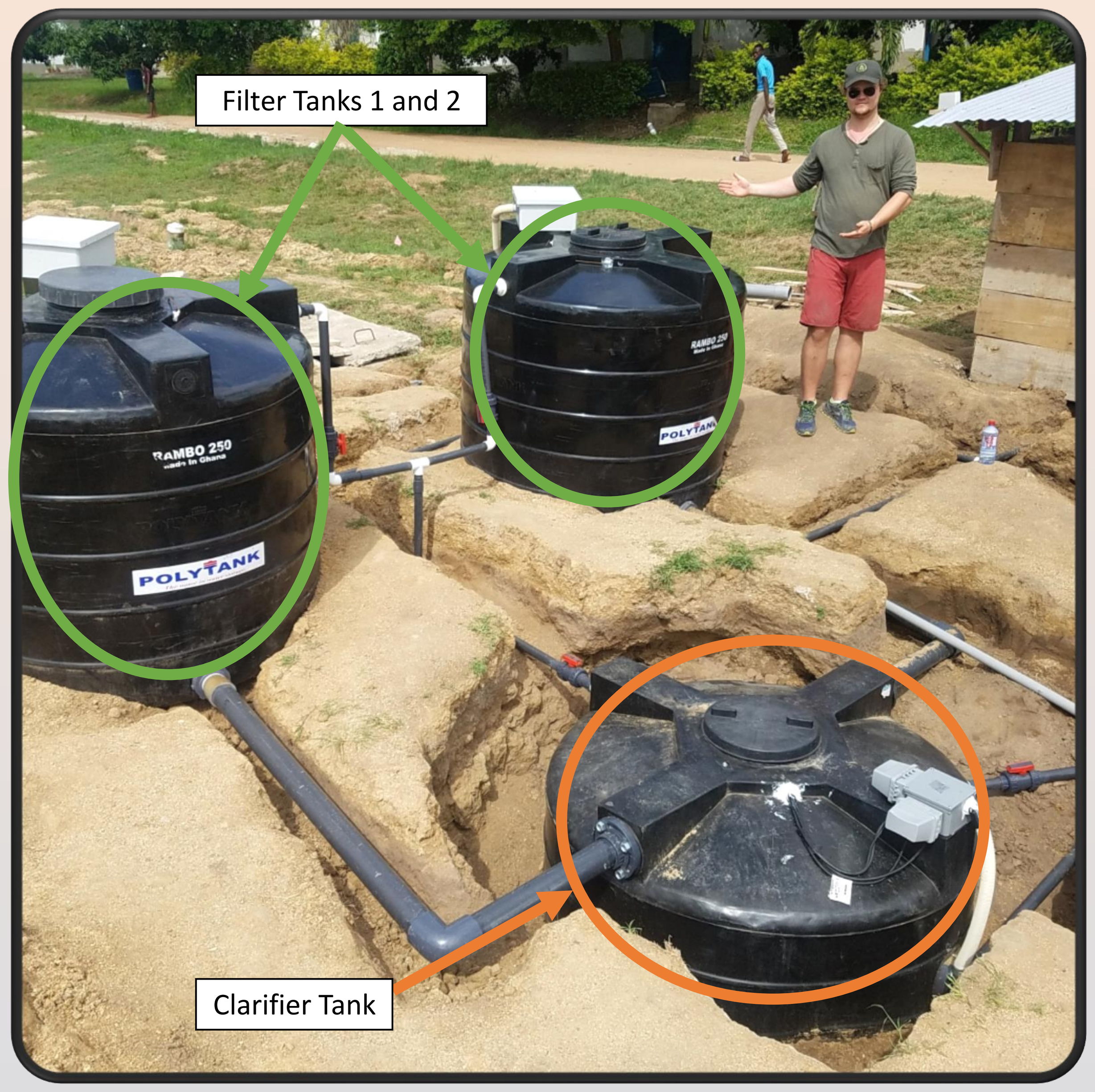

Figure 5: Filter tanks drain to the clarifier tank before exiting the system

Figure 6: Filter media inserted into the filter tanks for treating the wastewater

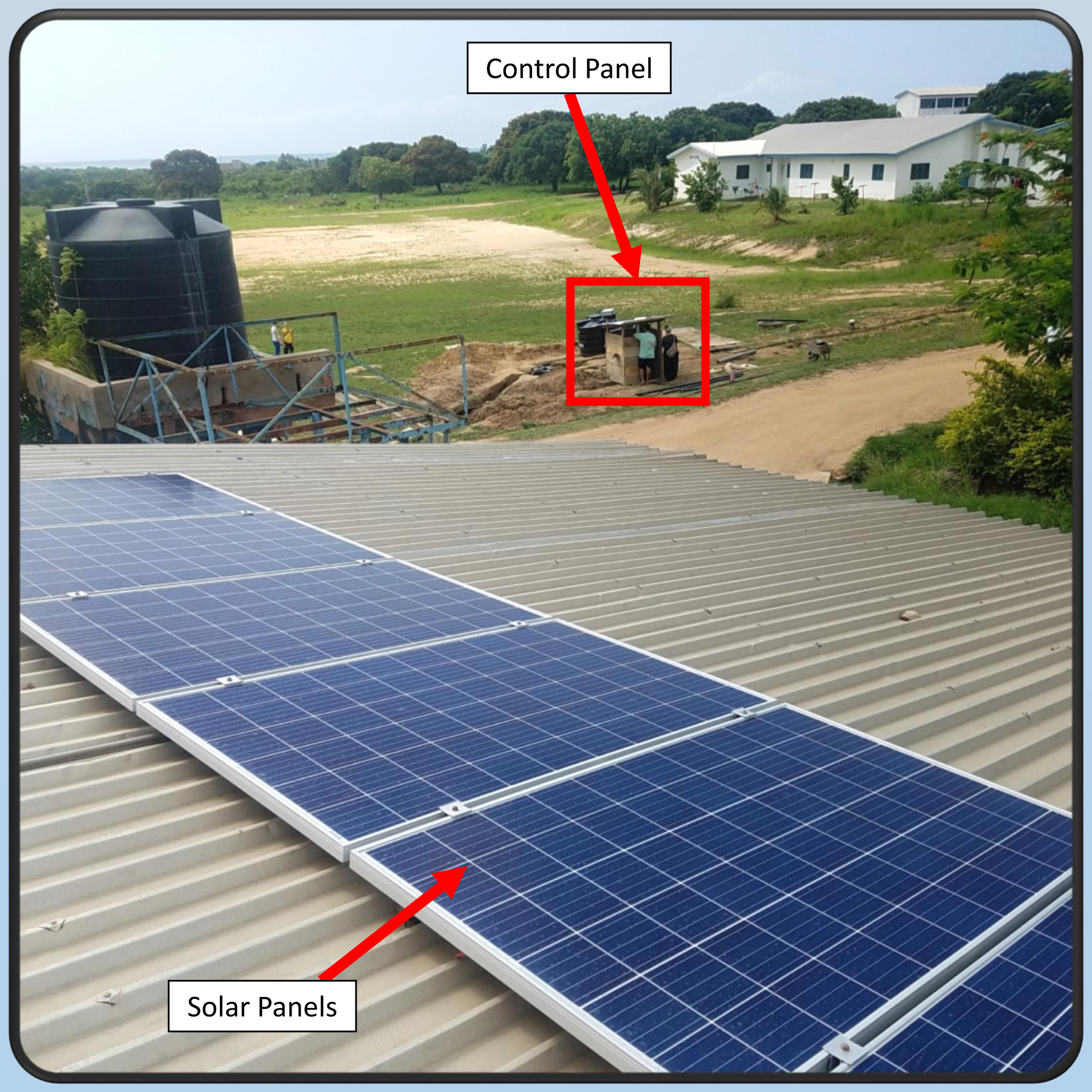

Figure 7: Solar panels mounted on a nearby building overlook the system

CONCLUSIONS/FUTURE WORK

The prototype system provided insight to design challenges and possible improvements. In May 2019, a team of engineering students and professionals will implement the full system at the Ghanaian compound. Upon completion and validation of the design, the design team will attempt to patent the system for mass production to reach a larger area in Ghana and possibly other rural sites worldwide.

Sustainable Water Treatment Prototype System for a Ghanaian Orphanage, School, and Hospital Campus

Abstract

A sustainable water treatment prototype system was designed and implemented by an interdisciplinary group of engineering students and professionals to serve a Ghanaian organization. The organization hosts a campus which includes an orphanage, school, and hospital. The project was initiated by a request made by the administration of the campus in 2016. The existing sanitation system was flawed and placed children at the orphanage, patients at the hospital, and the communities downstream at risk of contracting diseases or illnesses from the untreated water. To improve the system and protect these populations, professional engineers, faculty, and students have worked hard on designing a solution. The objective of the system is to treat all of the wastewater from the campus to EPA guidelines before dispelling it into the nearby river. Based on design constraints, the team selected a trickling filter treatment system as the possible solution.

The design team has iterated through the engineering design process by completing initial assessments at the site, including quality testing and flow rate measurements, developing a prototype design and testing it, and using the mistakes and flaws from the prototype to design the full system. The assessment of the existing system was completed in May 2017 at the same time solar panels were installed to power the system. During the following academic year, the design team developed various parts of the system including a dispersion nozzle, a measurement box, pump sizing and selection, control panel, and general assembly of the system. The prototype system including these components was constructed in May 2018 to handle 2,000 gal/day, only a portion of the total wastewater from the campus. The construction of the prototype system posed many obstacles for the design team, and two major systems failed within a couple of months. These challenges were addressed during the following academic year when the design team worked toward improvements and changes to the system. The full system capable of handling 10,000 gal/day is set to be implemented in May 2019 by a team of students and engineering professionals. Pending validation of the design, the team plans to patent the system for future expansion to other rural communities that lack access to modern sanitation facilities.

Going into this project, the team of engineering professionals and students had to account for several key design considerations. For instance, the system needed to be easy to construct and sustainable while also using locally sourced parts. Due to the lack of reliable electricity, the system was designed to be powered using solar panels, placing a limit on the overall power draw. These factors, and several others, made this design a unique challenge for the team. In addition to the technical challenges, the team faced numerous other obstacles throughout the project. Because the project relied on civil, mechanical, and electrical/computer engineering concepts, students and professionals from each discipline were required to work hand-in-hand with one another to complete the design. This cross-disciplinary nature of the project required effective communication by all team members.

Additionally, many of the design decisions made by the teams were not solely technical in nature. As a system to be built in a developing country on a school and hospital campus, the students were required to think outside the technical design to understand social, cultural, economic, and environmental impacts. In order to strategically consider the impacts of design decisions, students employed concepts like ethics, sustainability, and environmental effects. The team decided to treat the water to EPA guidelines, utilize solar power as the energy source, and employ local companies where possible. Looking forward, the team will implement the sustainable water treatment system in May 2019 with the hopes of patenting the design.

Sustainable Water Treatment Prototype System for a Ghanaian Orphanage, School, and Hospital Campus

1. Project Description

A sustainable water treatment prototype system was designed and implemented by an interdisciplinary group of engineering students and professionals to serve a Ghanaian organization. The organization hosts a campus which includes an orphanage, school, and hospital. The project was initiated by a request made by the administration of the campus in 2016. From this request, a feasibility study was used to determine the preexisting conditions and the possibility of these conditions being improved. The study results were positive, however, the solution had to take into account a number of special design considerations. For one, the system had to be simple to construct and, if possible, be built out of locally-sourced parts. Next, the entire system had to have a relatively low power draw, as the power delivery in the area is inconsistent and unreliable. According to a report from the Center for Global Development, the country's power grid is routinely overloaded causing major electricity supply challenges leading to daily blackouts[1]. To address this constraint, the system was designed to be powered with solar energy which is widely abundant in Ghana. Lastly, the system had to be highly sustainable and require little to no maintenance for the organization. With these considerations in mind, a volunteer professional engineer (PE) envisioned a possible design solution. Together, students and faculty alongside the PE (and other professionals) have been working on the wastewater treatment system design since the request in 2016.

The solution envisioned to address this issue was a wastewater treatment system designed around a trickling filter. A trickling filter was decided upon due to its relative simplicity, low power usage, and cost effectiveness. The preexisting system was designed to utilize soil as the filter medium. However, this design was flawed due to the high density and low permeability of the soil. Rather than filtering through the soil as expected, the wastewater stayed near the ground surface, which is a less than desirable condition. The reason this condition was unacceptable is that the wastewater would bubble up near the surface, which would pollute the air and eventually find its way to the local water supply, a nearby river. Additionally, the system was incapable of treating all of the wastewater from the campus so the overflow exited directly into the same river. Not only is this a hazard to those who depend on the river for drinking water but also anyone near the discharge. As the campus hosts an orphanage and school with children as well as hospital, the wastewater required a new treatment method away from these populations. The objective of the design team was to design a system that treats the wastewater to an acceptable point before discharging to the local river so as to protect children at the orphanage, patients at the hospital, and the communities who depend on the river as their primary water supply.

An initial assessment trip to determine requirements and constraints was completed in May 2017 where students measured the flow rate of the wastewater at the campus and installed solar panels for later use. During the following academic year (August 2017-May 2018), a team of undergraduate students worked with engineering professionals and faculty to design a prototype system. This team was responsible for the general design while a capstone senior design team focused heavily on two smaller, yet more advanced components. In parallel to the general team, the capstone senior design team was tasked with designing and testing a nozzle dispersion mechanism and a wastewater quality measurement box. These two components were installed alongside the prototype system in May 2018. The construction of the prototype system posed significant challenges for the team. Within a month of installation, the power system failed followed by the clarifying tank a few months later in September 2018. In November 2018, a small team traveled to the campus to make corrections to the system. These construction and design challenges provided new insight into the sustainable design of the full system. Since September 2018, another team of students led by the same PE has been working on improving the design and overcoming these challenges. The full system with major improvements from the prototype system is scheduled to be installed in May 2019.

The project had a profound impact on all involved, students, faculty, and professionals. The micro and macro applications of the system installed certainly piqued the student's awareness of the effects of modern engineering on the daily life of developing communities. Also, the realization that the issue addressed in the compound is not a localized phenomenon, but actually a quite common situation faced, was made more tangible for those involved. Because this is a worldwide challenge in developing communities, the solution settled upon for this specific scenario is one that could be adapted to many other areas. Due to this, it could be feasible to improve access to modern sanitation by a significant margin if this solution were to be produced on a large scale. After validation and testing of the full system, the design team plans to work toward patenting the solution.

2. Collaboration of Faculty, Students, and Licensed Professional Engineers

Various engineering students, faculty, and professionals were involved throughout the design, implementation, and testing of the system. The lead PE primarily led the overall design while the students completed smaller portions of the project. Faculty were involved as facilitators of the design where needed to help connect professional knowledge to concepts from the classroom. In its 2-year lifespan thus far, the project has involved at least 7 professionals or faculty and at least 21 undergraduate students. Five of the 21 students have been involved with the project since its inception in May 2017 and will be traveling to Ghana in May 2019 for installation of the full system. The design of the system is shown below in two diagrams, the flow process diagram in Figure 1 and the controls process diagram in Figure 2. The tanks, solar panels, and control panel are shown in Figures 3 and 4.

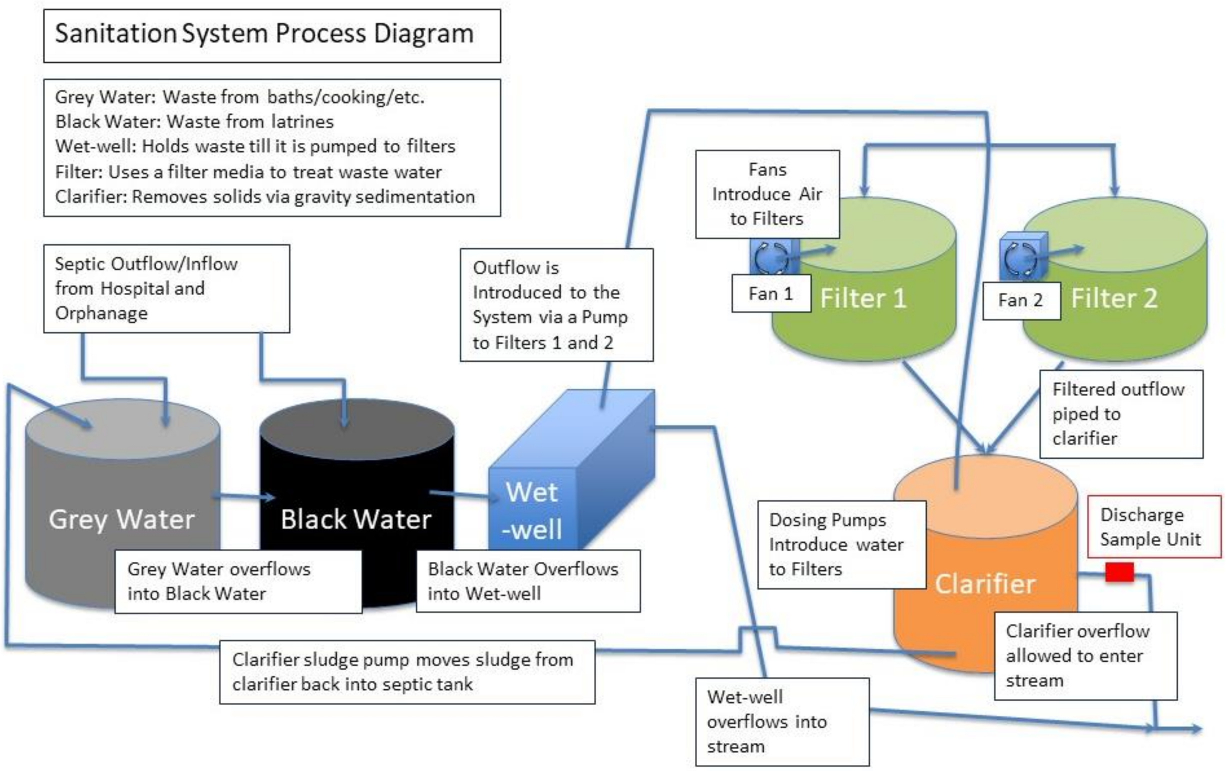

Figure 1: Flow process diagram for the wastewater treatment system

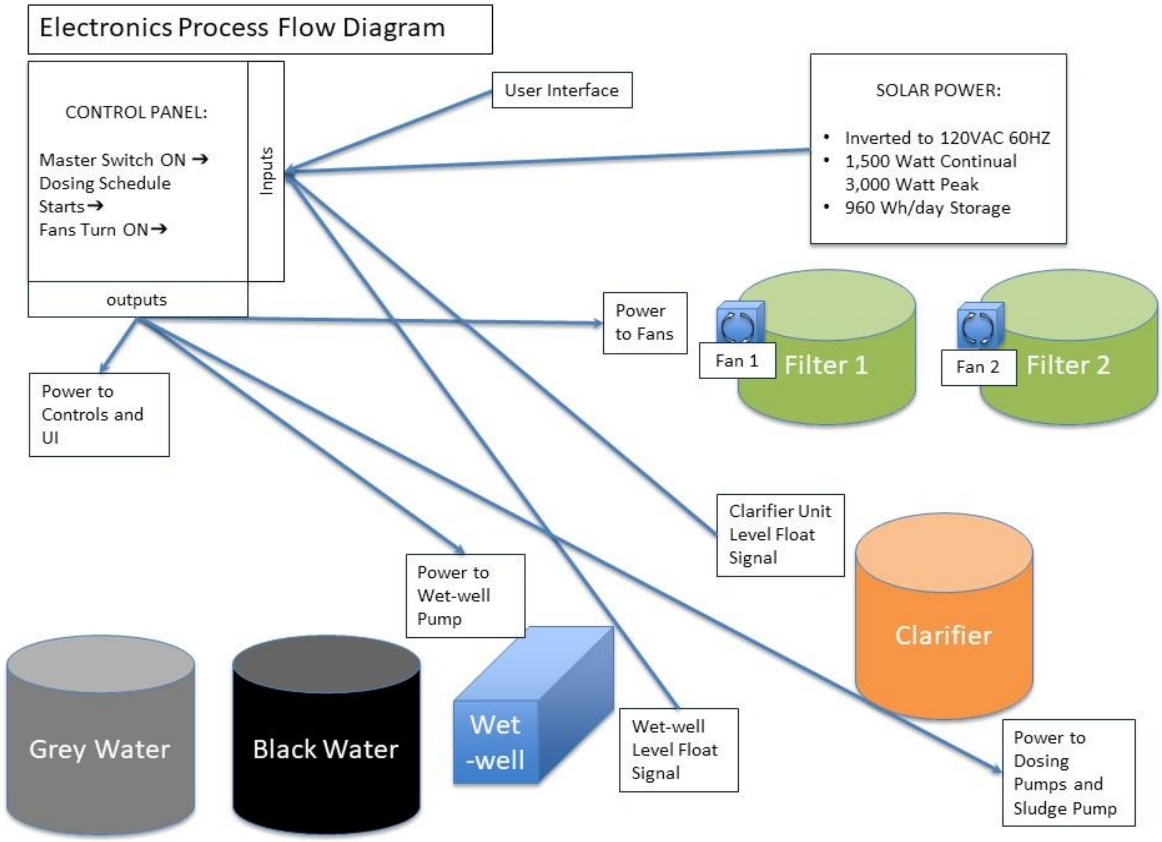

Figure 2: Controls and electronics process diagram for the wastewater treatment system

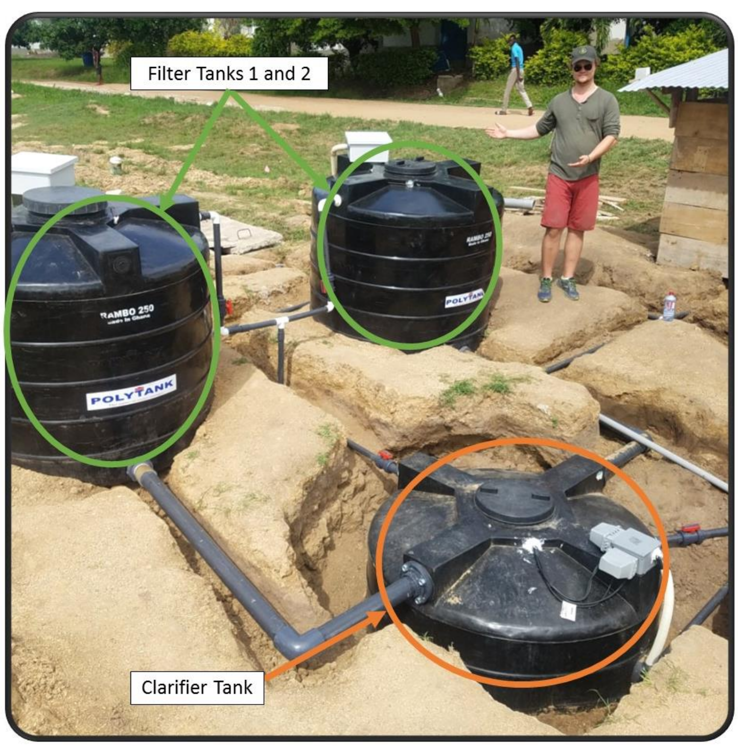

Figure 3: Filter tanks containing the filter media drain to the clarifier tank before treated wastewater exits the system

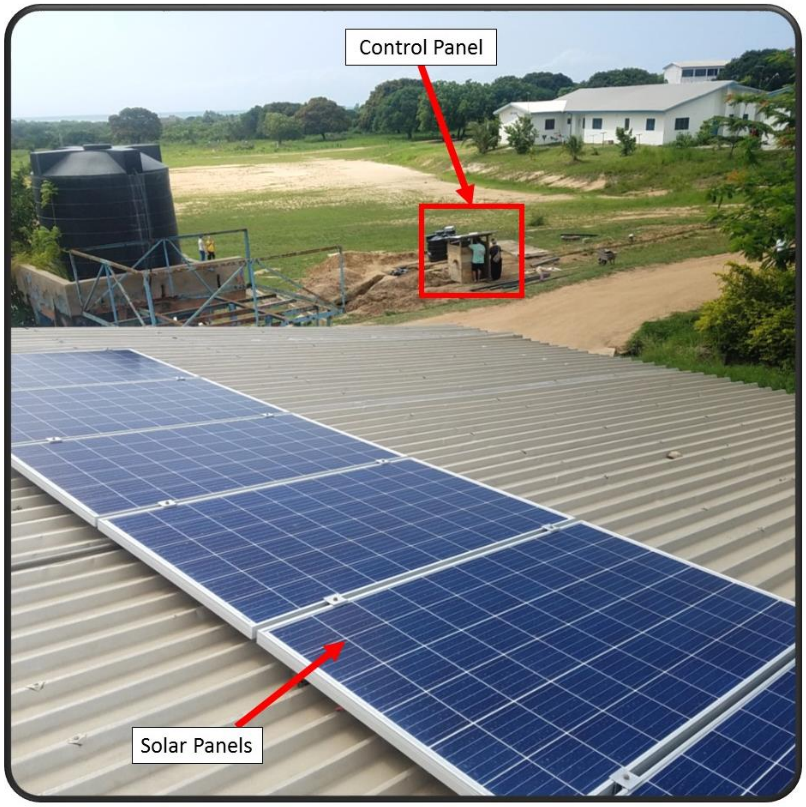

Figure 4: Solar panels mounted on a nearby building overlook the system and control panel

Engineering professionals were responsible for the conception and validation of the design while students were assigned tasks for completing the system. The senior design team (academic year 2017-2018) consisted of mechanical and electrical/computer engineering students. The mechanical engineering students designed, built, and tested the dispersion nozzle for the filter tanks as well as an instrumentation box installed after the clarifier tank to test the quality of the wastewater. The electrical/computer engineering students assisted with the instrumentation box and developed a program that sent the quality data to a webpage. This webpage was setup to be accessed freely by the Ghanaian organization or the design team in the United States to ensure the water was being treated effectively. Parallel to the senior design team, other engineering students guided by the lead PE worked on sizing and selecting the pumps, designing the assembly of the system, building a control panel for the pumps and fans, and developing a construction plan.

In country, the construction and assembly of the system proved very challenging. The design team spent numerous hours adjusting the design onsite to account for unexpected obstacles like misaligned connections or lack of appropriate tools. One of the most time-consuming and labor-intensive tasks was hand-cutting filter media to fill the filter tanks out of corrugated plastic piping. Wastewater enters the filter tanks through the dispersion nozzles and settles on top of the media. Over time, bacteria builds on the media which effectively treats the water by removing toxic chemicals. The corrugated plastic piping came in large rolls and was cut into approximately 1.5 inch pieces to create the filter media. As shown in the picture below (Figure 5), approximately 30 tubs of filter media were required to fill the two filter tanks. Though the team was able to develop new methods for cutting the media using available tools like pipe cutters, the task required over 140 person-hours for completion. As an improvement on this task, the design team has worked on new options for cutting the filter media. This solution is set to be implemented in May 2019 during the full system construction.

Figure 5: Approximately 30 tubs of filter media cut by hand was added to the two filter tanks

3. Public Health, Safety, and Welfare Impact

In the modern world, access to sanitation facilities is a major concern that must be addressed in order to improve public health. One major factor contributing to public health quality is the problem of sanitation and the discharge of wastewater into community water supplies. High population density cities suffer widespread disease primarily due to the lack of proper waste collection and treatment. Due to this, strides were taken to improve living conditions by improving public sanitation in an effort to promote proper hygiene. The United Nations, a leader in world development, has set a goal of ensuring availability to adequate sanitation and hygiene for all by 2030[2]. According to the World Bank, around 5 billion people have access to modern sanitation as of 2015, while 2.4 billion are without access[3]. This is great progress, however, there are still many who live in poor conditions and suffer from poor hygiene due to the lack of proper waste treatment. In Ghana alone, 14.9% of the population were estimated to still lack access to improved sanitation facilities in 2015[3]. The lack of sanitation facilities or treatment means waste eventually finds its way into the public water supply, which causes the spread of sickness. By addressing access to sanitation, this project will have a long-term positive impact on the public health of those at the orphanage, school, and hospital campus as well as the communities downstream.

The wastewater treatment project was undertaken in an effort to increase the sanitation conditions of the Ghanaian compound. Prior to the project, the compound's raw sewage was largely untreated by the preexisting sanitation system. Fundamental flaws in the design caused the sewage to be deposited into the local river. The contamination of the river eventually was a major problem as it affected downstream communities that depended on the river for drinking water. Additionally, the hospital as a part of the campus produces waste outside typical wastewater conditions. This posed a unique design challenge for the team to address. Because of the opportunity to improve both the compound and surrounding communities, the project had high potential to impact a large number of people. During the early stages of the project, several samples were taken from the septic tanks on site to determine the initial quality of the wastewater. The following table lists the sample data collected in March of 2017 as well as the guidelines for each quality indicator:

Samples (From Septic Tanks)	Alkalinity (mg/L)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	KN (mg/L)	NH_3- N (mg/L)
Academy	700	144	84.0	289	1.54	8.59
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EPA Guideline[4]	**150**	**50.0**	**50**	**250**	**-**	**10.0**

Table 1: Wastewater quality before installation of the sanitation system compared to EPA guidelines

The samples were tested in the CSIR-WRI Laboratories in Accra, Ghana. The data in Table 1 shows that the raw waste is above the standards set by the Environmental Protection Agency (EPA)[4]. Also, since the waste underwent minimal treatment, it was discharged at similar levels. Specifically, the Alkalinity, which is an indicator of the buffering capacity or ability of a water to neutralize an acid, is much greater than the specified 150 mg/L. The total suspended solids (TSS) is an indicator of how many solid particles are dissolved into the water. These dissolved particles would primarily be solid waste and soil particles. The biochemical oxygen demand (BOD) measures how much biomass is present in the water. Too high of a BOD will make the water uninhabitable by fish as the microorganisms in the water will have used up all of the oxygen present in the water. Next, the chemical oxygen demand (COD) shows how much oxygen is available to be consumed by chemical reactions. The Kjeldahl nitrogen (KN) and NH_3- N are both indicators of ammonia, ammonium, and nitrogen concentration in the water. All three of these are of importance as they are one of the determining factors of the health of the aquatic life in the water. Too much ammonia and the water will become toxic to fish. Too much Nitrogen and the aquatic plants will overtake the aquatic area and increase oxygen demand, which can potentially kill off the fish. In summary, the data collected indicates the discharged wastewater was at an unacceptable range and required treatment to satisfy EPA guidelines. With the newly installed system in May 2019, the design team will test the quality of the wastewater as it exits the system for comparison to previous values and the EPA guidelines.

4. Multidiscipline Participation

For the sanitation system, three disciplines of engineering were heavily involved in the design and implementation. Since May 2017, students and professionals from civil, mechanical, and electrical/computer engineering have been involved in the completion of the project. As related to the system, civil engineering concepts were used to determine the appropriate quality levels and general design of the wastewater treatment including weir design and tank sizing. Mechanical engineering concepts were used to size and select pumps, design the assembly of the system, and design and test the dispersion nozzle. Electrical and computer engineering concepts were employed in the design and programming of the control system. Throughout the design, installation, and testing, students and professionals from all three disciplines were required to practice effective communication. If a specification for treatment needed to be adjusted, this affected the pump selection which then impacted the power system and controls. As changes were made, the team met regularly to discuss impacts of those changes and updates to the design.

5. Knowledge and Skills Gained

By working on a real-world project, students gained valuable technical knowledge as well as professional skills. Much of the technical knowledge gained was highly dependent on the part of the system the student worked on and the related discipline. Overall, all of the students learned about the real-world function of the design process. Because the design and implementation of the system was completed in parts, the students experienced important steps of the engineering design process. Early in the process, students measured parameters like flow rate and quality to create constraints for the system. From those constraints, students examined design considerations and began building a prototype system with guidance from the lead PE. Then, the students installed and tested their prototype design onsite. Learning from the failures of the prototype, the students and PEs worked to improve the design and make strategic changes. Finally, the students will implement the new design and any changes in May 2019 for completion of the full system. Also, due to the nature of the project for possible expansion to other communities, the team is developing a patent for the system. Though the product development is still in the initial phases, the students have been learning about the patenting process from the PE who is guiding the development of the design.

With respect to professional skills, the demand of the project created a wide variety of opportunities for developing practical proficiency. Because the project involved multiple disciplines of engineering, sufficient and effective communication was a major obstacle. The students involved learned that more communication is always better than less and that even small adjustments to the design should be communicated to all parties. Managing tasks and responsibilities as an interdisciplinary team was also a challenge for the students. At times, the students found difficulty in communicating expectations or design constraints across the disciplines. In order to understand the cause and effect of design decisions, students were required to use critical thinking to view the project holistically throughout development. Many of the design decisions made by the teams were not solely technical in nature. As a system to be built in a developing country on a school and hospital campus, the students were required to think outside the technical design to understand social, cultural, economic, and environmental impacts.

In order to strategically consider the impacts of design decisions, students employed concepts like ethics, sustainability, and environmental effects. Though the primary client was the school/hospital campus, communities downstream of the system would be largely affected by the sanitation system. With this understanding, the teams decided that the system should treat the water to EPA guidelines as mentioned above to protect the health of the communities downstream. This decision was supported by the team’s development of a wastewater quality measurement box that tests the quality of the water before leaving the campus. In addition to the health of the communities downstream, the teams sought to design a sustainable system in a variety of ways. By utilizing solar power as the primary energy source, the system was not only environmentally friendly, but also not reliant on the unpredictable electrical power at the campus. The solar panels were bought from and installed by a local company, thus further supporting the community and providing sustainable options for maintenance in the future. As the system was developed, the long-term success of the design was considered. The installation of the prototype system revealed opportunities for major improvements toward this goal. For example, after a heavy rain, the plastic clarifier tank which had originally been buried floated out of its hole due to the lack of permeability of the soil to absorb the excess water. Though this region in Ghana rarely experiences that heavy of rainfall, the floating tank provided clear indication of a need to improve to accommodate unexpected weather. In response to this, the team decided to replace the plastic tank with a concrete tank poured on site, which will be completed during the upcoming trip in May 2019.

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