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Universidad Tecnológica de Panamá: Baseline Sustainability Study and Water Management Systems

Jason Michael Morgan
Worcester Polytechnic Institute

Universidad Tecnológica de Panamá: Baseline Sustainability Study and Water Management Systems

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Submitted by:

Abigail Ismail
Jason Morgan
Sabrina Napoli
Ana Restrepo

Project Advisors:

Dr. Aaron Sakulich
Dr. Tahar El-Korchi

Abstract

The goal of this project was to conduct a baseline study for a climate action plan for the Universidad Tecnológica de Panamá. The objectives were to develop a baseline sustainability inventory, propose a climate action plan with mitigation and adaptation strategies, and address water management needs on campus. A greywater recycling system was designed for the Engineering building, and recommendations were made regarding how to find and analyze the data required to design a stormwater management plan for campus.

Authorship

This report entitled Universidad Tecnológica de Panamá: Baseline Sustainability Study and Water Management Systems in Panama City, Panama, was collectively edited and revised by Abigail Ismail, Jason Morgan, Sabrina Napoli, Ana Restrepo. The Executive Summary was compiled from writing completed by all team members. The following lists the main author of the remaining sections of the report.

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Recommendations and Conclusions: Abigail Ismail

Design Statement: Ana Restrepo

Licensure Statement: Jason Morgan

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Juan Medina Sanchez
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Executive Summary

Climate change is the disruption of global weather patterns, including temperature, precipitation, and the likelihood of extreme events such as hurricanes, landslides, and floods. While Earth's climate has undergone periods of natural change, recent changes are likely due to human activity, particularly the release of CO_2 into the atmosphere from burning fossil fuels. There is a two-pronged approach to address climate change: mitigation and adaptation. Mitigation refers to reducing the release of greenhouse gases to prevent further changes to the climate, while adaptation refers to preparing for the changes to the climate that have already been set in motion. Climate Action Plans (CAPs) are a common framework for this approach. CAPs include a baseline inventory of greenhouse gas (GHG) emissions and strategies for mitigation and adaptation.

The goal of this Major Qualifying Project (MQP) was to conduct a baseline sustainability inventory and propose a CAP for the Victor Levi Sasso (VLS) campus of the Universidad Tecnológica de Panamá (UTP). The CAP proposal identified the most impactful measures to reduce GHG emissions, lower the campus's vulnerability to risks like floods and tropical storms, and improve sustainability education on campus. The selected measures included the development of a stormwater management design process and a greywater recycling system to reduce water consumption in the Engineering building. Additional recommendations for reducing GHG emissions and resource consumption on campus were developed to be included in a future CAP that includes input from UTP administration.

Methodology

The goal of this project was to provide UTP with recommendations regarding ways the university can become more sustainable. To accomplish this goal, three objectives were established:

- Develop a baseline sustainability inventory
- Propose a climate action plan
- Address water management needs

Information regarding the university's current GHG emissions and resource consumption was gathered by reviewing energy, transportation, water consumption, and waste management practices. The GHG emissions information was summarized into a baseline estimate using a three-scope framework established by the Intergovernmental Panel on Climate Change. Scope 1 includes direct emissions from sources that the institution owns or controls, such as UTP-owned vehicles. Scope 2 emissions are released indirectly by an institution, such as through purchased electricity. Scope 3 emissions include other indirect emissions from sources that the institution does not own, such as student and faculty vehicles. Water consumption data were determined through published averages and the campus population, since the university pays a flat monthly rate for water, and water consumption is not metered anywhere on campus. The published average used was 42

L/person/day (11 gal/person/day), which is the approximate consumption of a school with a cafeteria and no residents.

Once a clear understanding of sustainability practices on campus was obtained, areas where the university could improve were identified. Actions in each of these areas were compared to each other to determine which initiatives would have the largest impact on reducing GHG emissions and resource consumption. These recommendations were based on the actions of universities similar to UTP in their respective CAPs. While a full CAP involves a more thorough baseline sustainability inventory and involvement from campus administration, this proposed CAP serves as a starting point for future recommendations and sustainability developments on campus.

Along with this, a two-part water management design component was developed for UTP to implement. This design is focused on reducing water consumption through a greywater recycling system and planning for flood risks by developing a stormwater management design process for campus.

The stormwater management design process was developed by consulting hydrology resources, including the New Jersey Stormwater Best Management Practices 2004 Manual and publications from Malaysia's Department of Irrigation and Drainage. Information collected from UTP faculty and undergraduate theses was also summarized. The stormwater design elements and specifications were derived from the Massachusetts Department of Environmental Protection (DEP) Stormwater Handbook. The design process is intended to assist in the preparation of data by UTP faculty and administration to allow a future team to undergo the design process of a stormwater management plan.

The greywater recycling system was designed to reuse wastewater for building operations like toilet flushing. Appropriate sources of greywater to include were selected based on the desired level of water treatment. Then, the building for the design was selected, and the average daily load and maximum hourly load were estimated through a series of observational studies of bathroom utilization. The physical design of the tank was developed to ensure that the treated greywater would not be sitting for more than 24 hours and maintenance would be minimized. These factors were both considered before adding design components to the storage tank, such as locations of the inflow and outflow. Together, these water management measures will help UTP become a more sustainable university and adapt to the risks presented by climate change.

Results

In 2017, Scope 1 was the source of 25 tonnes (28 tons) of CO_2-equivalent, while Scope 2 contributed 1,637 tonnes (1,844 tons) of CO_2- equivalent. At 13,633 tonnes (14,995 tons) of CO_2-equivalent, Scope 3 was determined to be the highest source of UTP's GHG emissions, contributing nearly 90% of the total 15,295 tonnes (16,867 tons) of CO_2-equivalent released by UTP. Since there are 14,298 students and 139 faculty on the VLS campus, water consumption was estimated to be 606,354 L/day (158,807 gal/day).

Based on the common approaches of other universities, sustainability recommendations were made for UTP in the areas of energy consumption, transportation, water and waste management, and education. These recommendations can be incorporated into a full-fledged CAP in the future, in cooperation with UTP administration.

The stormwater design process was developed to assist in the design of a comprehensive stormwater management plan at UTP. It includes information on data collection specific to UTP, using the Rational Method to quantify runoff, and how to design redirected building downspouts, bioretention areas, grass channels, and green roofs. The VLS campus does not have much open space available for use, due to areas with high slopes and conservation restrictions. Accordingly, stormwater management components with high space requirements, such as retention ponds, are not suitable. Additionally, the campus has a lot of impervious surface area, which introduces contaminants into stormwater. Therefore, design elements that provide water quality improvement were preferred. The design components presented are suitable for UTP's constraints and stormwater management needs. However, they are not a comprehensive list of all potential stormwater management design components. This process should be used in combination with knowledge of any relevant advances in stormwater management practices when selecting design components.

Bathroom sinks and drinking fountains were selected as the only inputs to the greywater recycling system. Cafeteria sink water contains harsh chemicals and a high level of organic material and toilet water contains fecal contamination, requiring a more involved water treatment process. Slow sand filtration was selected as the treatment method due to its advantages in effluent quality, maintenance requirements, and operational costs. It removes turbidity, bacteria, and heavy metals. Slow sand filters have a lifespan of more than ten years and only require simple maintenance of the top sand level. Slow sand filtration can operate without electricity, which decreases cost. The required size of the storage tank was determined to be 6,629 L (1,751 gal) based on the results of the bathroom study. The influent pipe was placed halfway up the depth of the tank to encourage mixing and prevent water from remaining in the tank for more than 24 hours. The effluent pipe was placed at the bottom of the tank to ensure that the treated greywater can be used regardless of the water level in the storage tank. An overflow pipe that drains to the sewer system was placed at the top of the storage tank to discharge excess incoming water. A drainage plug was placed at the bottom of the tank for drainage at certain times, such as over weekends, to prevent water from sitting for more than 24 hours.

Recommendations and Conclusions

In general, UTP's sustainability goals would benefit from increased collaboration amongst groups and departments on campus. While there is an Office of Sustainability, their work is not widely known by students or faculty. This office should publish sustainability initiatives and data on UTP's website to improve transparency and knowledge sharing. They could collaborate with professors from various disciplines to coordinate the development and implementation of a full CAP in collaboration with UTP administration.

Additionally, there are many ways that UTP can improve the accuracy of the baseline sustainability inventory, particularly in the area of GHG emissions. Ideally, these recommendations will be acted upon as soon as possible in order to develop an accurate baseline against which UTP can measure future sustainability progress.

Due to time and data-availability limitations, there were sources that were not included in the GHG emissions estimate. For Scope 1, this includes gasoline or diesel consumption of all UTP-owned vehicles and use of HCFC-22 refrigerant for air conditioning. To improve the Scope 3 estimate, an updated traffic study should be conducted to reflect the growth in student and faculty population since 2014. This study should be conducted on days without special events to provide a more accurate estimate of the number of cars entering campus on an average day.

Prioritizing the work of the Office of Sustainability is vital for UTP to reach their sustainability goals. Publicizing sustainability initiatives will promote campus engagement and can help generate student interest on research opportunities or other ways to make UTP more sustainable. UTP has significant potential to become a sustainability leader, and the best way to achieve this is through internal and external collaboration and engaging students in the process.

CAPs help universities, organizations, and cities mitigate their environmental impact. At universities in particular, introducing sustainability concepts to campus exposes students to the importance of minimizing environmental impact. When students carry these lessons on to their future work, sustainability can influence diverse fields. If more universities implement CAPs, the impact on the environment and the influence on the world would be significant.

1 Introduction

Climate change is the disruption of global weather patterns, including temperature, precipitation, and the likelihood of extreme events such as hurricanes, landslides, and floods. While Earth's climate has undergone periods of natural change, recent changes are likely due to human activity, particularly the release of CO_2 into the atmosphere from burning fossil fuels. This activity increases a natural phenomenon known as the greenhouse effect where "greenhouse gases" (GHG) like CO_2 trap thermal radiation in Earth's atmosphere. Scientific models predict that heavy precipitation events will become more intense with climate change, with a global increase in heavy precipitation intensity of 16-24% by 2100. Warmer sea temperatures will also intensify tropical storms and cause them to occur more often (Fischer, et. al, 2014).

There is a two-pronged approach to address climate change: mitigation and adaptation. Mitigation refers to reducing the release of greenhouse gases to prevent further changes to the climate, while adaptation refers to preparing for the changes to the climate that have already been set in motion. Climate Action Plans (CAPs) are a common framework for this approach. CAPs include a baseline inventory of greenhouse gas emissions and strategies for mitigation and adaptation.

With climate change, the Central American country of Panama may be vulnerable to more frequent flooding or severe tropical storms. In many climate projections, Panama sits on the cusp of areas that will experience increased precipitation and areas that will become drought-prone. Therefore, adapting to climate change is essential. In 2016, The Universidad Tecnológica de Panamá (UTP) administration self-evaluated the campus based on a sustainability metric developed by the University of Indonesia, called the GreenMetric. UTP scored 3,638 out of a total possible 10,000 points, and the lowest-scoring categories were Energy & Climate Change and Water. In 2017, students analyzed the GreenMetric rating and found that implementing water and energy-efficient appliances and air conditioning systems could increase the score. However, no comprehensive plan was implemented to address UTP's sustainability or vulnerability to the risks of climate change.

The goal of this Major Qualifying Project (MQP) was to develop a baseline sustainability inventory and propose the development of a CAP for UTP. The CAP proposal identified the most impactful measures to reduce greenhouse gas emissions and lower the campus's vulnerability to risks like floods and tropical storms. These measures were evaluated based on impact on GHG emissions, impact on vulnerability to extreme weather events, and educational benefit to campus. The selected measures included the development of a stormwater management design process and a greywater recycling system to reduce water consumption in the Engineering building. In addition, recommendations for improving campus collaboration and implementing a full CAP with support from UTP administration were developed.

2 Background

The goal of this MQP was to conduct a baseline study for the development of a CAP for UTP. Starting the development of a CAP will allow for the university to become a more sustainable institution and reduce the campus's vulnerability to climate change. The effects, impacts, and reactions to climate change in Panama are first discussed. Next, it is discussed how CAPs can be used to respond to climate change by implementing mitigation and adaptation strategies. Finally, the setting and unique characteristics of UTP are presented.

2.1 Climate Change Effects, Impacts, and Reactions in Panama

Climate change presents risks to the tropical climate of Panama as the frequency of extreme weather events increases. Panama's average annual temperature between 1901 and 1930 was 25.1°C (77.2°F), and it has risen by 0.4°C (0.7°F) between 1991 and 2015 (The World Bank Group, 2018). While Panama's temperature does not change drastically throughout the year, with the lowest monthly average occurring in November at 24.4°C (75.9°F) to the highest monthly average occurring in May at 26.4°C (79.5°F), there are two very different seasons. The dry season runs from January to April, averaging just under 70 mm (2.76 in) of rain each month, and the wet season runs from May to December, averaging over 280 mm (11 in) of rain each month (The World Bank Group, 2018). The increased risk of floods, droughts, and landslides brought by climate change is exacerbated during the different seasons for the following reasons. In the dry season the flora is not prepared to absorb the precipitation, due to biological differences in plant behavior between the dry season and wet season. Increased extreme weather during the wet season could also lead to flooding as drainage infrastructure may not be prepared to handle increased loads of rainfall.

Severe weather has caused the majority of nationally reported economic losses in Panama. The annual average combined economic losses in Panama from 2005-2013 were more than $89.5 million (PreventionWeb, n.d.). With weather events such as floods, landslides, and droughts being the overwhelming contributor to economic losses, the possibility of increased extreme weather events is potentially detrimental to Panama's economy. Furthermore, flooding caused nearly 87% of mortalities due to natural disasters from 1990-2014, a number that could unfortunately spike if climate change increases the frequency of extreme weather events (PreventionWeb, n.d.).

While increased severe weather poses a serious threat to Panama, it is not the only threat climate change poses. Sea level rise will increase the damage from storm surges and threaten Panama's coastlines, which are where a majority of Panama's population resides, as shown in Figure 1 (World Population Review, 2018). Sea level has already risen by 85 mm (3.35 in) since 1993 and will keep rising as polar ice sheets and glaciers continue to melt and ocean water continues to expand with rising temperatures (Shaftel, 2018). The extent by which the sea is predicted to rise by 2100 varies depending on the modelling method used. Predictions range from 0.2-2 m (0.66-

6.6 ft), which presents risks to the population and infrastructure of Panama's coastal cities (Baynes, n.d.).

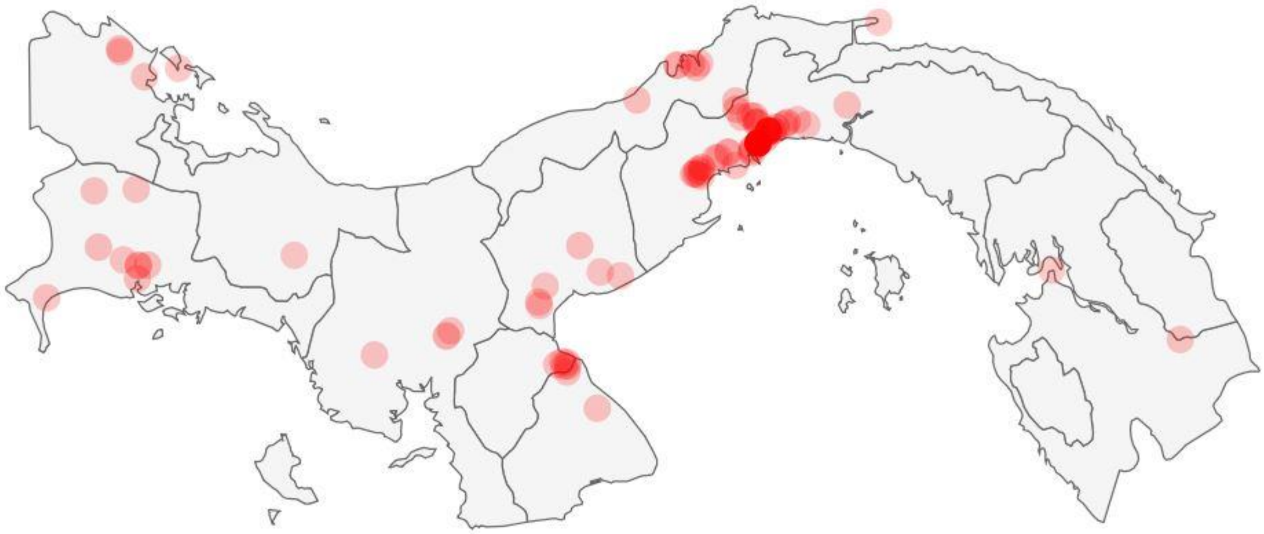

Figure 1: Panama's population heat map (World Population Review, 2018)

The importance of the Panama Canal to Panama's economy further compounds the risks caused by climate change, since increased extreme weather events and sea level rise could damage the canal. The service sector comprises nearly 65% of Panama's GDP, with transportation being the overwhelming contributor to the sector (Kiprop, 2018). Transit through the canal in 2017 brought in $2.7 billion (Panama Canal Authority, n.d.). Climate change affecting this revenue could be devastating to Panama. However, measures to avoid the negative impacts of climate change can be taken, and a CAP is a tool to outline these measures and set goals for an organization.

2.2 Climate Action Plans

CAPs have been implemented on many different levels, but they all have the same goals: reducing greenhouse gas emissions and adapting to the changes and extreme weather events caused by these emissions. The goals of a CAP are accomplished by focusing on mitigation and adaptation strategies. Mitigation aims to reduce or prevent greenhouse gas emissions causing climate change, whereas adaptation prepares a community for the unavoidable impacts of climate change. A Canadian public sector infrastructure magazine refers to mitigation as the globally responsible thing to do, by reducing contributions to climate change, while adaptation is the locally responsible thing to do, by helping the organization or community become more sustainable and less vulnerable to the risks of climate change (Renew Canada, 2009). Implementing a CAP is one of the first steps a community can take towards becoming more sustainable, as climate change becomes a more pressing issue each day.

Mitigation practices consider the growing population and economy while aiming to prevent climate change. One strategy is to reduce greenhouse gas emissions, which come from the generation of electricity, heat, and transportation (United States Environmental Protection Agency, 2018). This can be achieved through using renewable energy sources like solar panels, wind turbines, and hydropower, and/or energy-efficient appliances and lighting equipment. Other mitigation practices focus on sustainable waste management initiatives, like recycling and composting, since they play an important role in preventing air and water pollution. By composting, greenhouse gas emissions produced from fertilizer production and pesticide usage are avoided. In addition to reducing emissions, composting also helps revitalize exhausted farm soils by integrating organic matter, reducing erosion, and preventing stormwater runoff (Eureka Recycling, 2008). Recycling helps mitigate climate change by reducing greenhouse gas emissions from landfills and incinerators, as well as reducing the energy needed to extract new resources from the earth. Sustainable transportation practices can also reduce the amount of emissions from fossil fuels. Park-N-Rides, public transportation, and programs that encourage carpooling help reduce the carbon footprints of individuals, institutions, and cities alike. By adopting these sustainable practices, fewer fossil fuels will be burned, which will in turn reduce the amount of greenhouse gases emitted into the atmosphere.

In response to the impacts of climate change, groups worldwide are also looking toward adaptation, or increasing the capacity of environmental and societal systems to respond to extreme events (Barros, Field, 2014). These steps help the community minimize damage from extreme weather events caused by climate change. Adaptation measures should be built into all levels – local, national, and regional – to have the most impact (United Nations Foundation, n.d.). A common approach is upgrading a community's infrastructure to have a more effective stormwater management system. Redirecting rainfall that flows over impervious surfaces helps to reduce runoff and minimize pollution. Allowing stormwater to infiltrate into the ground prevents flooding and the associated property damage. It also decreases the volume of water entering municipal wastewater treatment systems, which reduces stress on infrastructure. Sustainable practices, such as green infrastructure or low impact development systems, can minimize erosion, downstream water pollution, and flooding (United States Environmental Protection Agency, 2017, February 3). These practices include green roofs, rain barrels, and constructed wetlands. These sustainable practices can be used for educational purposes that promote environmental education and continued research. Universities often include sustainability education and research components in a CAP. This promotes campus engagement with sustainability initiatives and encourages students to consider the applications of sustainability across various fields and on a global and local scale (Florida International University, 2009).

2.3 Universidad Tecnológica de Panamá

The Universidad Tecnológica de Panamá is a state university located in the Altos de Panama neighborhood of Panama City. Founded in 1975 as part of the University of Panama, it became its own school in 1981, with the support of President Dr. Aristedes Royo (Universidad Tecnológica de Panamá, 2018). There are three campuses in Panama City as well as regional research centers throughout Panama. The current project is limited to the Victor Levi Sasso (VLS) campus, the largest of UTP's Panama City locations. The VLS campus does not have any residential buildings or dormitories. All 14,298 students walk, drive, or use public transportation to reach campus. There are faculty parking lots available, but students typically park along the internal roads of campus.

There are multiple construction projects currently underway at the VLS campus, including a student center, a research laboratory, a teaching laboratory, and a new road (Edificar Empresa Constructora, 2017). These projects represent a total investment of nearly $40 million into the campus, and an opportunity to implement more sustainable building practices that will benefit campus for years to come.

Contextualizing the problem of climate change in Panama helps identify the most appropriate ways to mitigate and adapt to climate change. Additionally, obtaining background information about CAPs fosters an understanding of what goes into creating a thorough and effective CAP. Finally, understanding UTP's setting and circumstances allows for a tailored CAP proposal to be created for the university. With climate change becoming an increasingly urgent issue, UTP is in a prime position to implement a CAP to reduce their impact and adapt to changes in extreme weather events.

3 Methodology

The goal of this project was to provide UTP with recommendations regarding ways the university can become more sustainable. To accomplish this goal, three objectives were established:

- Develop a baseline sustainability inventory
- Propose a climate action plan
- Address water management needs

Due to the effects GHG emissions have on climate change, it was important to investigate the sources of UTP's emissions. Information regarding the university's current GHG emissions was gathered by reviewing energy, transportation, water consumption, and waste management practices. This information was summarized into a baseline estimate using a three-scope framework established by the Intergovernmental Panel on Climate Change (IPCC). Once a clear understanding of the origins of these emissions was obtained, areas where the university could improve were identified. Actions in each of these areas were compared to determine which initiatives to prioritize in order to have the largest impact on reducing GHG emissions and resource consumption. Along with this, a two-part water management design component was developed for UTP to implement. This design is focused on reducing water consumption through a greywater recycling system and planning for flood risks by developing a stormwater management design guide for campus. These measures will help UTP become a more sustainable university

3.1 Objective 1: Develop a Baseline Sustainability Inventory

The baseline sustainability inventory was used to collect information about the current status of mitigating GHG emissions and adapting to extreme weather events at UTP. Conducting an inventory now will allow UTP to make comparisons and measure progress in the future. CAPs from various universities around the United States were analyzed in order to understand what a CAP is comprised of and how to create one. Of the CAPs examined, all conducted a GHG inventory. This was done by either using a calculation tool, such as the Clean Air-Cool Planet Campus Carbon Calculator, or by having university officials calculate inventories internally. Internal calculations can be done by analyzing electricity consumption, utility bills, gasoline and diesel purchases for university fleets, and other sources of emissions. Each method of calculating GHG emissions followed the IPCC's Greenhouse Gas Emissions Protocol, which defines three scopes of GHG emissions. Scope 1 includes direct emissions from sources that the institution owns or controls, such as vehicles. Scope 2 emissions are released indirectly by an institution, such as through purchased electricity. Scope 3 emissions include other indirect emissions from sources that the institution does not own, such as student and faculty vehicles (Greenhouse Gas Protocol, n.d.). The sustainability inventory also included measuring adaptation practices, in order to track UTP's sustainability outside the context of greenhouse gases. Adaptation measures that were analyzed include water consumption and stormwater management, since Panama is vulnerable to both drought and increased storm intensity due to climate change.

Sources of Scope 1 emissions at UTP include UTP-owned vehicles. However, at the time of the research, the only shuttle service from campus to a public transportation stop had been terminated due to lack of use. Additionally, no data were found regarding university-owned vehicles other than waste transportation trucks.

The Environmental Maintenance Office at UTP collects monthly data about waste disposal volumes and the associated diesel consumption of UTP-owned garbage trucks. However, these data are reported as a combined total for the VLS, Tocumen, and Howard campuses of UTP. To determine the portion of waste contributed by the VLS campus, the populations of the three campuses were analyzed. Waste is generated by individuals (e.g. food wrappers and papers) or services that generate more waste when more people are involved (e.g. cafeteria operations). The proportion of the total population that the VLS campus comprises was estimated to be directly proportional to the waste generated by the campus, and therefore the diesel consumed for waste transportation. At the time of the research, the monthly totals of waste generated and diesel consumed from January 2016 to August 2017 were available. Since the 2016 and 2017 averages were similar, the 2016 data were used in order to analyze an entire year. Monthly emissions, M, were calculated by multiplying the CO_2-released per liter of diesel fuel with the amount of diesel consumed, D, each month, shown in Equation 1. The United States Environmental Protection Agency (US EPA) lists the amount of CO_2 emissions per gallon of diesel as 10,180 g CO_2 eq/gallon, which was then converted to g CO_2 eq/liter of diesel (United States Environmental Protection Agency, 2011).

$$M = 2689g\ CO_2\ eq/liter\ diesel \times D\ (liters) \times 1\ tonne/1{,}000{,}000g$$

Equation 1: Monthly emissions in CO_2 equivalent

Waste generation data were also used to inform recommendations about recycling and compost initiatives to help the university reduce the volumes of waste sent to landfills.

Scope 2 sources at UTP include electricity consumption, since the university purchases electricity from external sources. These emissions were calculated by reviewing monthly utility bills, provided by the Center for Electrical, Mechanical, and Industrial Research and Innovation at UTP. Monthly consumption data in kilowatt-hours (kWh) were available for January 2009 through May 2018. However, the most recent full year, 2017, was analyzed to provide more up-to-date data, since the student body size and operations of the campus have changed since 2009. Data regarding the sources of electricity in Panama in 2017 were collected from the National Dispatch Center, a Panamanian organization that oversees operations controls for the country, since data regarding electricity by source at UTP could not be obtained (Centro Nacional de Despacho, 2017). Along with these data, information regarding median carbon dioxide equivalents for each source of electricity was collected from the IPCC and other sources. IPCC values were used for solar at a utility scale. Additionally, equivalent values for onshore wind energy were used since Panama has a number of onshore wind farms. Because there are no available data on the fossil fuel use in thermal plants in the country, it was assumed that thermal energy came from 50% coal and 50% diesel sources (IPCC, 2015). CO_2 equivalents for diesel were also used for electricity produced from diesel generators (Jakhrani, et al., n.d.). Lastly, values for biogas containing 60% methane and combusted at 25% efficiency were used for calculations (Cuéllar & Webber, 2008). A value for CO_2-equivalent/kWh in Panama was calculated by weighing the percentage of each source of electricity (P, in %) with that source's CO_2-equivalent (E, in g CO_2 eq/kWh).

$$\text{National Emissions } (g\ CO_2/kWh) = P_{Hydro} \times E_{Hydro} + P_{FFPP} \times E_{FFPP} + P_{Biogas} \times E_{Biogas} + P_{Wind} \times E_{Wind} + P_{Generators} \times E_{Generators} + P_{Solar} \times E_{Solar}$$

Equation 2: National emissions equivalent for energy consumed

Then, the monthly emissions, M, in tonnes CO_2-equivalent, for UTP was found by multiplying the calculated national weighted emissions, N, in CO_2-equivalent/kWh, with the university's 2017 monthly electricity consumption, E, (kWh), and converting from grams to tonnes, shown in Equation 3. These data were converted to CO_2-equivalent and added to the total.

$$M = N \times E \times (1 \text{ tonne}/1{,}000{,}000 \text{ grams})$$

Equation 3: Monthly emissions at UTP

Sources of emissions in the Scope 3 category at UTP included student and faculty commuting and waste management. Information about commute emissions was gathered primarily by reviewing a 2014 undergraduate traffic study. This study analyzed traffic entering and exiting campus over three days from 6:00am to 11:00pm. The student body sizes at the VLS campus in 2014 and 2017, respectively, were compared to estimate the increase in drivers to campus, which was considered directly proportional to the increase in student body size.

Once the number of each type of vehicle entering campus was estimated, CO_2 emissions per kilometer (mile) for each vehicle type were calculated. This was used to calculate which vehicles emit the largest amount of CO_2. Using the average amount of CO_2 emissions from a liter (gallon) of gasoline and diesel, CO_2 emissions per kilometer (mile) were determined for each vehicle type. To do this calculation, kilometers per liter (miles per gallon) for the type of vehicle was determined. There were many limitations when calculating CO_2 emissions per mile. Information regarding the make and model of each vehicle entering campus was not available, so miles per gallon for each vehicle type was estimated using data from the United States Department of Energy on the average fuel economy of major vehicle types for both gasoline and diesel consumption

(United States Department of Energy, 2015). The US EPA and other agencies list the average CO_2 emissions to be 2347.9 g/L (313.5 oz/gal) of gasoline and 2689.4 g/L (359.1 oz/gal) of diesel (United States Environmental Protection Agency, 2011). Using the average amount of CO_2 emissions from a gallon of gasoline and diesel, CO_2 emissions per mile were then determined by dividing by an average miles per gallon for the vehicle type. The kind of fuel consumed was assumed based on typical consumption per vehicle type. After estimating the estimated kilometers per liter (miles per gallon) for each vehicle type, CO_2 emissions per kilometer (mile) were determined.

After obtaining information regarding CO_2 emissions per mile (km), this number was then multiplied by the number of vehicles to give the total amount of emissions coming from each vehicle type. Since personal vehicles were the most common type of transportation, CO_2 emissions from this sector were the largest. The amount of CO_2 emissions caused per mile per day was then totaled to see the overall CO_2 emissions caused per mile due to campus transportation. However, calculations still needed to take into account how far students typically commute. There were no specific data available regarding where students commute from, but the districts where most students live were provided. It was assumed students were commuting using a personal vehicle and CO_2 emissions per mile were determined accordingly. The percentage of students commuting from each district was determined by dividing the quantity of students from each district by the total quantity. Using the estimated total number of vehicles entering campus each day multiplied by this percentage, the total number of vehicles commuting from each district was found. The number of vehicles from each district was then multiplied by the number of miles from the district's geographical center to UTP. When the total number of miles from each district was obtained, this information was then multiplied by the average CO_2 emissions per mile. Lastly, the total emissions from the commute to campus was summed together and multiplied by two to get the total emissions per day to account for transportation to and from campus. Finally, using the number of working days per UTP's 2017-2018 calendar, the total number of CO_2 emissions per school year was then determined. To do so, CO_2 emissions per day were multiplied by number of working days.

In addition to GHG emissions, water consumption on campus was quantified in order to ultimately reduce the use of water resources as part of a climate change adaptation strategy. In 2016, UTP administration self-reported to a sustainability index called GreenMetric and found that their lowest-scoring category was water. However, the university pays a flat monthly rate for water, and water consumption is not metered anywhere on campus making it impossible to quantify the exact water usage on campus. Therefore, an estimate of water usage on campus was made using the student and faculty population as well as published averages of water usage. The published average used was 42 L/person/day (11 gal/person/day) and was for a school with a cafeteria and no residents (Alvarez-Corena, 2016). The VLS campus is home to 14,298 students and an additional 139 faculty (Ramirez, n.d.).

Due to Panama's vulnerability to more frequent storms and flooding due to climate change, stormwater management practices are another essential component of an adaptation strategy. Observations were conducted around the UTP campus to determine the extent of stormwater management practices. This information was necessary to assess UTP's vulnerability to risks presented by climate change.

3.2 Objective 2: Propose a Climate Action Plan

To ensure that the recommendations for UTP were in line with best practices worldwide, selected CAPs were analyzed to determine the common approaches of universities similar to UTP for reducing emissions. Universities were chosen based on their size and setting, the rigor of their CAP and GHG reduction goals, and having the explicit goal of carbon neutrality in the foreseeable future. This was important in order to assure that UTP holds itself to the same standard of emissions reduction. Once universities where chosen for analysis, their CAPs were reviewed to determine the common actions chosen to reduce emissions. The content of the CAPs was divided into five categories: Transportation, Water/Resilience, Energy/Utilities, Waste Management, and Education. Then, specific actions that each university took to improve sustainability in those categories were listed, and each university that also took that action was noted.

Based on the sustainability inventory from Objective 1, energy consumption, water use, transportation, and stormwater management were determined to be areas for improvement at UTP. These areas were compared to determine which actions are the best fit for UTP's sustainability goals.

Even within a single area, implementation costs can vary significantly based on how the problem is approached. For example, energy consumption could be improved by installing a solar array on campus, switching to energy-efficient appliances, or even simply placing signs around campus reminding students to turn off lights when they leave a room. Due to this variation, implementation cost was not considered when comparing the areas to one another.

Instead, the areas were compared based on their impact on mitigating GHG emissions, adapting to extreme weather events, and their benefit to sustainability education on campus. While these impacts also vary with the aggressiveness of the solution, CAPs from other universities were evaluated to gauge which areas generally have high impacts on mitigation, adaptation, and sustainability education.

Although this analysis was subjective, it synthesized best practices from other universities, which provides UTP with a reliable example to follow to achieve the campus's sustainability goals.

3.3 Objective 3: Address Water Management Needs

As discussed in the Results section, addressing water management practices on UTP's campus was the most suitable area of sustainability in which to implement changes. Therefore, a system was designed that focused on reducing water consumption through greywater recycling and reducing flood risks through stormwater management practices. The stormwater management component is a guide for data collection and analysis for a future design of stormwater components on campus. The greywater recycling component is a design for the Engineering building at UTP. Both contribute to the mitigation and adaptation goals of a Climate Action Plan at UTP.

The stormwater management design process was developed to assist UTP in gathering the data required for a future group of UTP students or a WPI MQP team to implement stormwater management practices on campus.

To develop the stormwater design process, hydrology resources were consulted, including the New Jersey Stormwater Best Management Practices 2004 Manual and publications from Malaysia's Department of Irrigation and Drainage (Blick, et. al, 2004; Department of Irrigation and Drainage, 2018). Information collected from UTP faculty and undergraduate theses was also summarized. The design elements and specifications were derived from the Massachusetts Department of Environmental Protection (DEP) Stormwater Handbook (Massachusetts Department of Environmental Protection, 2008). In order to address both stormwater and water consumption management, a greywater recycling system was designed.

The first step in designing a greywater recycling system for UTP was to identify the sources of greywater to recycle and what uses the recycled greywater can serve. The required level of treatment for certain greywater sources and uses, the space required for treatment, and the maintenance of the treatment system were the main factors in deciding the source and use of the system. The best option was one that could minimize all three of these factors. The potential sources of greywater for reuse that were considered at UTP were toilets, water fountains, cafeteria water, and sinks. The potential uses for treated greywater were the same as the potential sources. In order to determine the extent of treatment each of the potential sources would require, the sources were divided into three different categories; light greywater, dark greywater, and blackwater. Sinks and water fountains would fall under the light greywater category. Cafeteria water is classified as dark greywater. Toilet water is blackwater (Alfiya, et. al, 2015). Research on light greywater, dark greywater, and blackwater treatment was done to understand the extent of treatment systems required for each specific possible source. The possible uses of treated greywater were broken up into two separate categories, those that must meet unrestricted use standards and those that must meet restricted use standards set by the US EPA. Water must be drinking quality to meet unrestricted use standards and can be used for any purpose, whereas water does not have to be drinking quality to meet restricted use standards and can only be used for certain things, such as toilet flushing. Toilet flushing is the only considered use that is not required to meet unrestricted use standards, but still must meet restricted use standards (Fayyad, et. al, 2011). Research of required water qualities for restricted use and unrestricted use was done to identify the levels of treatment needed to meet each standard.

The next step was to determine which building was best suited for the greywater recycling system. While the methods of designing the system would be similar for all buildings, a specific building must be considered for design purposes. The constraints considered for which building to design the system for included which building the greywater system would have the biggest and lasting impact. In order to answer these questions, research on the specific buildings was done including the foot traffic through the building, whether water efficient appliances were present, and whether there were plans to remodel water appliances. These were answered through inquiring with UTP staff and observations of the buildings.

Once the scope and location of the greywater system was decided, the design process began. The design contained three components: treatment, storage, and transport. The treatment component was designed based on the required effluent water quality. Different options for water treatment, including coagulation, flocculation, filtration, and disinfection processes, were considered keeping in mind the requirements for the water effluent and other factors, including cost of implementation and maintenance. The treatment system was designed using a maximum hourly load. Typically, this could be quantified through the water metering system, as total load and maximum flows could be identified through those systems. However, UTP pays a flat utility rate for water regardless of consumption and there is no metering system. To quantify the maximum hourly load, a survey of the bathroom usage was done. The survey was done between 5:30-6:30 in the evening. This time was chosen because it is during the change from afternoon to evening classes and the cafeteria is also serving dinner, therefore it is the time of day that the highest number of students are present. The number of students entering each bathroom was counted and it was assumed that each individual entering the bathroom washed their hands. The number of individuals that used the bathroom was then multiplied by the faucet flow rate and the duration of the handwashing to find the maximum hourly load. The faucets did not have specified flow rates, so the published averages of sink faucet flow rates by the US EPA of 8.3 lpm (2.2 gpm) were used (United States Environmental Protection Agency, 2017, April 19). A duration of 4.87 seconds was used for the average hand washing duration, based on a study from Pace University in New York City (Peteroy-Kelly, Shanks, 2009). The flow from water fountains was not considered when calculating the maximum hourly load as it would be negligible in comparison to the load from sinks. The maximum hourly load was then used to calculate the size of required treatment systems. The treated greywater would then flow into a storage tank.

The storage tank's size and physical attributes were designed. For tank sizing, the average daily load was calculated. The average daily load was used because greywater is best used within 24 hours, as it has the potential to develop an unpleasant odor. The average daily load was found through a similar survey as above, but was conducted between 3:30-4:30 in the afternoon. This time was selected, because no special events occur during that time period that would increase load, such as a meal time. The same process outlined above was used to translate the number of people using the bathroom to the average hourly demand. Classes begin at 7:00 in the morning and continue until 10:00 at night. Therefore, students are present in the building for 15 hours a day, and the average hourly demand was then multiplied by 15 to estimate the average daily demand. The goal with the physical design of the tank was to ensure the treated greywater would not be sitting for more than 24 hours and to minimize maintenance. These factors were both considered before adding design components to the storage tank, such as inflow and outflow locations.

The transport of the water needed to be considered as well. The goal was to minimize energy consumption and maintenance. The transport required would be from the source to the treatment systems, between the treatment system and the storage tank, and then to the location of use. To minimize energy consumption and maintenance, the system was designed to maximize the use of gravity.

4 Results

In this chapter, the findings of the sustainability inventory are presented, including findings surrounding UTP's greenhouse gas emissions, waste production, and water consumption. Case studies were also analyzed and used to decide on best practices when proposing a CAP to UTP. Finally, the stormwater design guide for UTP and a greywater recycling system are described.

4.1 Objective 1: Develop a Baseline Sustainability Inventory

The baseline sustainability inventory included information that will assist in developing both mitigation and adaptation strategies. An inventory of GHG emissions was conducted in order to focus mitigation strategies on the categories with the highest emissions. Additionally, the campus's vulnerability to both drought and increased flood potential due to climate change was evaluated through assessing water consumption and current stormwater management practices. This analysis was conducted to allow adaptation strategies to consider the current practices on campus related to resource consumption and flood management.

To begin with the baseline estimate of greenhouse gas emissions, data were gathered to determine direct emissions from sources that UTP owns or controls. Waste disposal and campus census information was used in order to calculate Scope 1 emissions. According to data provided by the university, approximately 97% of students in the Panama City locations of UTP are located at the VLS campus. Therefore, it was assumed that 97% of all waste generated from the three Panama City campuses came from VLS, and that 97% of diesel consumed to transport the waste was specific to VLS. It was calculated that the VLS campus consumed approximately 9,731 liters (2571 gallons) of diesel fuel to transport waste in UTP-owned trucks, which emitted approximately 25 tonnes CO_2-equivalents (28 tons CO_2-equivalent). Approximately two tonnes of CO_2-equivalent emissions were released each month, with the exception of October, three tonnes (3.3 tons), and December, one tonne (1.1 tons).

Scope 2 emissions were calculated using data regarding UTP's monthly electricity consumption and data from the National Dispatch Center regarding national consumption of electricity. It was found that the majority– over 65%– of Panama's electricity is generated from hydropower with fossil fuels, biogas, wind, diesel generators, and solar power generating the remainder. By weighting the contribution of each source of electricity with its CO_2-equivalent, the national CO_2-equivalent/kWh was calculated to be approximately 225 g CO_2-equivalent/kWh (0.00233 oz CO_2 eq/BTU), as shown in Table 1.

Table 1: National sources of electricity and carbon dioxide equivalents per kilowatt-hour

Source	% of Electricity	Median g CO_2 eq/kWh	Median oz CO_2 eq/BTU**
Hydropower	65.22%	24	0.00025
Fossil Fuel Power Plants	25.90%	655	0.00677
Biogas	0.09%	1130	0.01168
Wind	4.50%	11	0.00011
Generators	2.95%	1270	0.01313
Solar	1.34%	48	0.00050
Panama g CO_2 eq/kWh (oz CO_2 eq/BTU)		**225**	**0.00233**

After calculating the national carbon dioxide equivalent, UTP's monthly emissions were calculated using their 2017 monthly electricity demand. UTP's total annual emissions was calculated to be approximately 1,673 tonnes CO_2-equivalent (1,844 US tons CO_2-equivalent), shown in Table 2.

Table 2: 2017 Monthly electricity consumption and emissions

	Monthly Electricity Consumption		Monthly Emissions	
	kWh	**BTU (billions)**	**tonnes CO_2 eq**	**tons CO_2 eq**
Jan	590,100	2.01	133	146
Feb	571,200	1.95	128	142
Mar	669,900	2.29	151	166
Apr	640,500	2.19	144	159
May	735,000	2.51	165	182
Jun	697,200	2.38	157	173
Jul	646,800	2.21	145	160
Aug	674,100	2.30	152	167
Sep	667,800	2.28	150	166
Oct	655,200	2.24	147	162
Nov	546,000	1.86	123	135
Dec	342,300	1.17	77	85
TOTAL	**7,436,100**	**25.37**	**1,673**	**1,844**

Scope 3 emissions were calculated using campus transportation data from 2014 and the growth in population at the university. From 2014 to 2017, the number of students enrolled on campus increased by 13.6% to 14,298. Using this percentage increase and the information from the transportation study conducted in 2014, an estimated number of vehicles entering campus in 2017 was determined by multiplying the number of cars entering by 1.136. The average number of vehicles entering per day increased from 5,234 in 2014 to 5,946 in 2017. It is important to note a few factors that influenced the 2014 study's findings which in turn influenced the 2017 results. There was an event on campus during two of the three days studied, contributing to an increase in vehicles entering campus. Additionally, there was a percent of error of 1.06% from the 2014 study from the number of cars entering campus not equaling the number exiting. This percentage of error was considered acceptable for the study as some vehicles may have been parked overnight at the university, such as service and institutional vehicles.

The transportation study from 2014 classified each type of vehicle (personal car, taxi, motorcycle, buses, service cars, trucks) entering and exiting campus and found the overall percentage of each type. Using the percentages for each type of vehicle entering from the study conducted in 2014, the number of each type of vehicle entering was estimated for 2017, as shown in Table 3.

Table 3: Estimated number of vehicles entering campus and total CO_2 emissions

Estimated Number of Vehicles Entering Campus Each Day (by Type) & Total CO_2 Emissions							
	Personal Vehicles	**Institutional Vehicles**	**Motorcycles**	**Taxis**	**Buses**	**Service Vehicles**	**Trucks**
Percentage	87.6%	1.3%	1.2%	8.4%	0.5%	0.8%	0.3%
2014							
# of Vehicles	4,585	68	63	440	26	42	16
CO_2 Emissions g/m	1,100	10	8	104	3	3	2
oz/mile	61,439	578	454	5,896	182	151	117
Total CO_2 Emissions: 1.25 kg/m (4,301 lbs/mile)							
2017							
# of Vehicles	5,209	77	71	499	30	48	18
CO_2 Emissions g/m	1,230	12	9	118	4	3	2
oz/mile	69,800	655	511	6,687	210	173	131
Total CO_2 Emissions: 1.38 kg/m (4,885 lbs/mile)							

The information obtained regarding the average number of vehicles entering campus in 2017 will be useful to UTP when assessing the need for on campus residency. Not only does this create an influx of vehicles on campus each day, but it also results in a larger contribution to greenhouse gas emissions from transportation.

Table 4: CO_2 emissions per vehicle type based on fuel consumption

Vehicle Type	**Gasoline**		**CO_2 Emissions Gasoline**		**Diesel**		**CO_2 Emissions Diesel**	
	mpg	kpl	oz/mile	g/km	mpg	kpl	oz/mile	g/km
Personal Vehicles	23.4	9.9	13.4	236	-	-	-	-
Institutional Vehicles	-	-	-	-	8.5	3.6	42.2	743.4
Motorcycles	43.5	18.5	7.2	126.8	-	-	-	-
Taxis	23.4	9.9	13.4	236	-	-	-	-
Buses	-	-	-	-	7	2.9	51.3	903.7
Service Vehicles	-	-	-	-	3.6	1.5	99.8	1.8
Trucks	-	-	-	-	7.3	3.1	49.2	866.6

In 2017, UTP produced an estimated 1.38 kg/m (78,167 oz/mi) of CO_2 per day. Furthermore, it was found that UTP produces 61.14 tonnes (67.24 tons) of CO_2 emissions per day due to transportation. To help conceptualize this number, a typical passenger vehicle produces 5.1 tonnes (5.62 tons) of CO_2 per year (United States Environmental Protection Agency, 2011).

Table 5: Total CO_2 emissions per day by district

District	**Quantity**	**% of Students Commuters**	**Vehicles from District**	**Average Distance to UTP**		**Total Distance**		**Total CO_2 Emissions**	
				km	**mi**	**km**	**mi**	**tonne**	**ton**
Chepo	106	0.74%	44	60.4	37.5	2,660	1,653	0.628	0.692
Panamá	8,201	57.33%	3,412	16.6	10.3	56,514	35,116	13.34	14.7
San Miguelito	3,351	23.43%	1,395	9.7	6	13,449	8,357	3.18	3.5
Arraiján	1,904	13.31%	792	28.5	17.7	22,577	14,029	5.33	5.87
Capira	39	0.27%	16	68.6	42.6	1,102	685	0.36	0.287
Chame	26	0.18%	11	86.9	54	930	578	0.2	0.242
La Chorrera	657	4.59%	273	115.1	71.5	31,453	19,544	7.4	8.18
San Carlos	13	0.09%	5	106.7	66.3	571	355	0.13	0.149
Total Emissions from Commute to Campus								**30.568**	**33.62**
Total Emissions per day (to and from UTP)								**61.136**	**67.24**

An estimated total amount of CO_2 emissions per year was then determined using the number of working days per the UTP 2017-2018 calendar. In 2017-2018, the number of working days was 223 days. Total CO_2 emissions per day due to commuting was found to be 61.136 tonnes (67.24 tons). Therefore, it was calculated that 13,633.3 tonnes (14,994.5 tons) of CO_2 are released per year.

Due to not knowing the exact vehicle types or number of vehicles entering in 2017, this estimate could be higher or lower than UTP's actual emissions from transportation. Since there have not been any active changes to more sustainable transportation practices, such as Park-n-Rides or an actively used shuttle system, transportation emissions from the university have increased significantly since 2014. This is due to the student body population increasing and therefore causing more people to be commuting to and from campus.

To summarize, UTP's emissions in 2017 equaled a total of 15,295 tonnes (16,867 tons), as shown in Figure 2. Twenty-five tonnes (28 tons) came from Scope 1; 1,637 tonnes (1,844 tons) came from Scope 2; and 13,633 tonnes (14,995 tons) came from Scope 3. Evidently, the scope that released the most CO_2 emissions into the air per year was Scope 3, which focuses on indirect emissions. UTP's emissions from electricity consumption was on the lower end comparably due to most of Panama's electricity coming from hydropower.

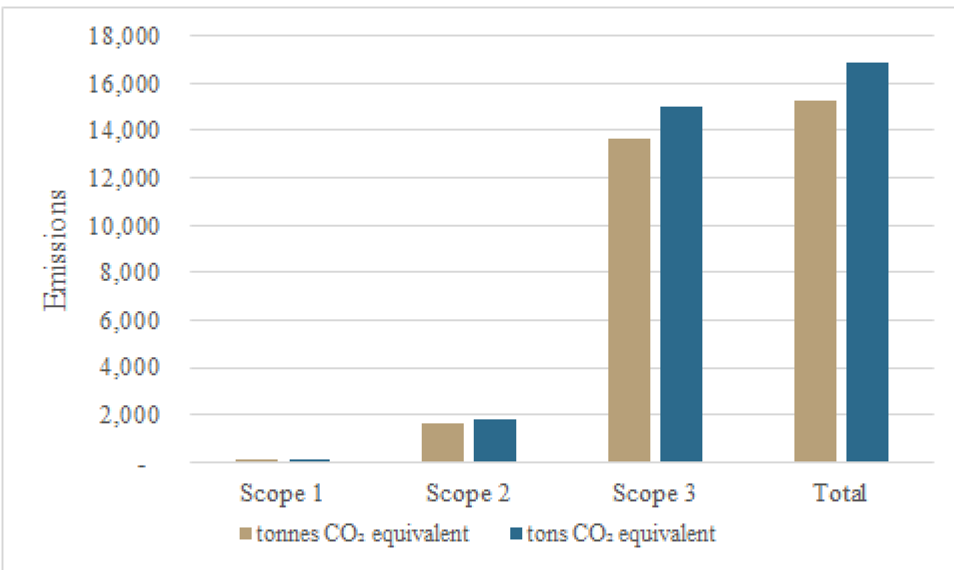

Figure 2: Total emissions in 2017 by scope

Water consumption estimates were then made for the VLS campus using the published water usage average and campus population outlined in the methodology. The calculation of daily water usage can be found in Equation 4.

$$\text{Daily Water Consumption} = 42\ L/person/day\ (11\ gal/person/day) \times 14,437\ people = 606,354\ L/day\ (158,807\ gal/day)$$

Equation 4: Estimated daily water consumption

In terms of existing adaptation strategies on campus, some stormwater management components were observed, including culverts and a retention pond. However, there was no observed effort to treat stormwater or reduce stormwater volumes. Downspouts on buildings empty onto impervious surfaces, rather than being redirected to storage for non-potable use.

4.2 Objective 2: Propose a Climate Action Plan

Results for Objective 2 include a summary of CAPs and proposed areas of focus for UTP based on research and the baseline sustainability inventory completed for Objective 1. In order to understand how a CAP works, four universities' CAPs across the United States were analyzed; Boston University, University of Louisville, University of Miami, and Florida International University. The universities are all located in urban or suburban areas and have high student populations, ranging from approximately 17,000 students to over 57,000 students (University of Miami, 2018 & Florida International University, 2018). Three of the schools are primarily residential campuses, whereas commuter students make up the majority at Florida International University (Florida International University, 2018).

The climate action plans that were studied all shared common approaches to addressing climate change and greenhouse gas emissions. To start, all of the universities had the goal of greenhouse gas emissions reduction, with the eventual goal of carbon neutrality. For example, Boston University has three reduction scenarios; "BU Bold", their most aggressive approach, plans to reach carbon neutrality by 2040 (Boston University, 2017). All of the universities focused on mitigation in transportation, the use of renewable energy and the encouragement of energy efficiency, waste management, and education. Transportation mitigation initiatives seek to cut down on transportation related emissions by offering more sustainable options for students and staff to use instead of commuting. For energy, the schools encouraged the use of green energy alternatives and green building principles in new construction and renovation projects wherever possible. In terms of managing waste, many of the universities plan to perform waste audits to quantify what their waste is composed of, reduce the amount of solid waste produced, and increase the rate of recycling. Finally, the universities also use academics as a way to encourage sustainability by incorporating sustainability principles in the classroom and expanding sustainability research in their labs. Table 6 summarizes the common initiatives for each area of focus.

Table 6: Summary of common approaches in CAPs for four universities

	Boston University	Florida International University	University of Louisville	University of Miami
Transportation				
Campus Shuttle	✓	✓	✓	✓
Ride Sharing	✓	✓	✓	
Transit Passes		✓	✓	✓
Electric Vehicle Infrastructure	✓			✓
Bike Share	✓			✓
Valet Parking		✓		
Water/Resilience				
Flood Barriers	✓			
Energy/Utilities				
Green Construction	✓	✓	✓	✓
Efficient Appliances	✓	✓	✓	✓
Green Energy Use	✓		✓	✓
Energy Efficiency	✓		✓	✓
Waste Management				
Recycling		✓	✓	✓
Composting			✓	
Education				
Sustainability Research	✓	✓	✓	✓
Sustainability Curriculum	✓	✓	✓	✓

While many universities use similar strategies to reduce their GHG emissions, it is also important to tailor climate action plans to specific campuses and needs because no two campuses have the same circumstances. Universities may differ in their main sources of emissions and therefore approach mitigation in different ways. For example, more than half of the emissions from Florida International University (FIU) came from transportation, specifically commuters. Accordingly, transportation is one of the main parts of their reduction goals in their climate action plan. Their initiatives to reduce transportation-related emissions include using a carpool program, expanding their shuttle system, switching to a biodiesel powered fleet, and making discounted public transit passes available to students and staff (Florida International University, 2009). Like FIU, it would be beneficial for UTP to focus on their transportation-related emissions in their climate action plan, since commuters contributed nearly 90% of UTP's 2017 emissions.

Not only are mitigation strategies important, but also adaptation strategies. The University of Louisville's climate action plan has a very specific focus on stormwater management and resiliency due to their history of flooding, which, in 2009 alone caused more than $21 million dollars in damage to campus buildings. Their stormwater plan includes rainwater harvesting for irrigation, vegetated bioswales, rain gardens, pervious pavements, green roofs, and underground infiltration basins (University of Louisville, n.d.). As UTP is located in a tropical location, it will also be beneficial to include adaptation strategies that focus on stormwater management.

Mitigation and adaptation strategies specific to UTP will help achieve the sustainability targets set for the university while also keeping the university's concerns at the center of their climate action plan.

After analyzing various case studies, it became evident that similar strategies could be implemented by UTP in a future CAP. These include strategies, not to just reduce emissions, but also to reach the eventual goal of carbon neutrality. Because Scope 3 emissions were the major source of emissions at UTP, specific strategies should be implemented to target commuters. However, decreasing the emissions from all three scopes is important.

The biggest impact in reducing GHG emissions will most likely come from implementing transportation related initiatives. Lowering commuter related emissions should focus on incentivizing more sustainable commuting options, such as public transportation, ride sharing, and university shuttles. Additionally, implementing paid parking may encourage students to seek more cost effective and sustainable options to get to campus, such as public transportation. As far as university-owned vehicles, it would be beneficial for UTP to invest in electric vehicles. The implementation of these options could result in significant decreases in emissions.

Although the majority of Panama's electricity comes from hydropower and other green energy sources, it is still important to lower UTP's electricity consumption and encourage efficiency on campus. This can be done by installing energy efficient fixtures, such as LED light bulbs. Installing efficient chillers would also save electricity for air conditioning and replace the need for HCFC-22, a greenhouse gas refrigerant. Additionally, UTP could continue to explore the option of installing solar panels. Since UTP has plans to continue expanding campus, future construction should be completed with green building principles in mind. This could be achieved by obtaining green certifications, such as LEED Certification, or by generally incorporating these principles into their plans.

Water consumption on campus is another major component of a CAP. At UTP, water is purchased at a fixed rate because of the abundance of water in the region. However, it is still important to conserve this resource. UTP's water demand can be lowered by recycling water on campus, such as in an expanded greywater recycling system. Rainwater can also be harvested for non-potable use around campus. Additionally, fixtures such as dual flush toilets and water efficient faucets can be installed.

Waste management is another important part of a CAP. In UTP's case, waste is transported off of campus by university owned vehicles. Although not a significant portion of UTP's emissions, as discussed in Section 4.1, the diesel used to transport waste emits greenhouse gases. Additionally, if transported to a landfill, solid waste releases methane. Methane released at landfills was not calculated for the baseline inventory study, but this is more reason for UTP to address their waste generation. A waste audit can be performed to understand what types of waste UTP generates and how much. This is the first step to decreasing waste generation because composting, recycling, and other waste management initiatives can be implemented depending on the results of the waste audit. Additionally, UTP currently has single stream waste bins, which causes them to send all of their waste to the landfill. Implementing multiple stream waste bins would allow them to maximize their recycled waste as well decrease the amount of waste they dump in landfills.

Lastly, UTP's future CAP can benefit from including sustainability education as a focus, and this can be done on many different levels. Educating students, faculty, and staff can be as simple as hanging posters around campus displaying different initiatives. For example, if a composting initiative is implemented, information on what can be composted can be displayed on a poster near trash bins. Additionally, if a building has a special feature like solar panels, information can be displayed on that initiative and its benefits. However, it is also important to teach students how to incorporate sustainability in their work, especially in a school that specializes in engineering, technology, and other sciences. Currently, very few courses at UTP focus on sustainability. However, sustainability principles can be incorporated into curricula across many topics, and departments. This is important so that students take these principles into their future careers. UTP would benefit from consulting other universities that incorporate sustainability into all parts of their curriculums.

Sustainability can also become a major part of research at UTP. UTP already has research projects on the topic of sustainability, with laboratories like the Center for Electrical, Mechanical, and Industrial Research and Innovation (known as CINEMI in Spanish) on campus. However, the university would benefit from fostering additional collaboration and communication between departments so that there is more transparency and accessibility regarding sustainability research. It was evident that UTP faculty was already making great strides in sustainability research, but many people did not have access to these impressive findings. Overall, incorporating sustainability education on campus will benefit UTP in many different ways.

A CAP is a great tool for UTP to become a more sustainable institution and become a leader in Panama and in the region in general. While a full CAP involves a more thorough baseline sustainability inventory and involvement from campus administration, these proposed CAP components serve as a starting point for future recommendations and sustainability developments on campus.

4.3 Objective 3: Address Water Management Needs

High water consumption and a lack of stormwater management practices were indicated as the UTP's most urgent sustainability needs. This section includes a stormwater management design process and the design of a greywater recycling system to address these water management needs at UTP.

The stormwater design process was developed to assist the design of a comprehensive stormwater management plan at UTP. It includes information on data collection, data analysis, and design, with each design component accompanied by a description of which circumstances it is best-suited for. The process is intended to assist in the preparation of data by UTP faculty and administration to allow a future team to undergo the design process of a stormwater management plan.

Based on a review of hydrology resources and other stormwater management plans, there are two categories of data that need to be collected prior to beginning the design process: geographic and climate. Geographic data is in the form of GIS files, AutoCAD files, surveying maps and/or observations. Climate data comes from nearby weather stations or rain gauges at the university. Ideally, geographic data analysis should be conducted in AutoCAD or ArcGIS. Much of the available information is contained in AutoCAD (.dwg) files, but, depending on the user, ArcGIS may be preferred for geoprocessing applications. AutoCAD files can be converted to a format that is compatible with ArcGIS with georeferencing tools or paid ArcGIS plugins. The goal of geographic data analysis is to determine where stormwater will flow, collect, and gain pollutants. Climate data analysis provides insight into how much stormwater is expected for a certain design storm (Department of Irrigation and Drainage, 2018). The following geographic and climate data analysis procedures must be completed in order to design appropriate conveyance, storage, and treatment methods.

First, drainage basins and subbasins must be delineated using elevation data. Distinguishing between drainage basins is the first step in identifying individual land uses and soil types. These areas can have different infiltration rates and pollutants which must be considered. Contours to a resolution of 1 meter for campus as a whole were available as an AutoCAD file from the Department of Topography at UTP. This AutoCAD file can be used to delineate drainage basins by identifying all local high points, then drawing a line perpendicular to each contour line to connect them.

Then, using symbology and measurement tools in ArcGIS or other methods, areas of impervious surfaces and various soil types can be marked and measured within each drainage basin. To facilitate future calculations, this information can be recorded in a table that records the value of impervious surface area and the area of each soil type both as a numerical value and in proportion to the total area of each basin.

Soil type data were only available for four areas of campus where construction was underway at the time of the research. To complete this dataset, soil testing should be conducted throughout campus. The location of buildings and impervious surfaces was available as an AutoCAD file from Professor Diana Laguna at CINEMI.

The Rational Method is a way to calculate the peak flow of stormwater runoff. It is appropriate for small drainage areas of less than 200 acres (80.93 hectares). It does not directly consider the antecedent moisture condition of the land, which can impact how much stormwater infiltrates. It is most accurate when the drainage area is fairly homogeneous in regards to land usage, and, similarly, when there is more impervious surface area. Since the campus has large swaths of both forested area and impervious surfaces, rather than small areas interspersed throughout, the Rational Method should be relatively accurate for the purposes of the study (Blick, et. al, 2004), which uses Equation 5.

$$Q = ciA$$

where Q = peak flow (ft^3/s)
c = runoff coefficient
i = rainfall intensity (in/hr)
A = drainage area (acres)

Equation 5: The rational method for calculating peak flow

The information collected about soil type and impervious surface area can be used to determine the runoff coefficient for each drainage area based on published values for each land use and soil type. The proportional relationships recorded for the soil type and impervious surface areas of each drainage basin can be used to perform a weighted average for the runoff coefficient (Department of Irrigation and Drainage, 2018).

Before determining the rainfall intensity (i), the time of concentration (t_C), which is the time it takes for water from the most "hydrologically-distant" point of the drainage basin to reach the outlet, must be determined. If the drainage subbasins on campus are smaller than 20 acres each, use the Kerby-Hatheway Method to determine t_C (Thompson, 2006). This method is appropriate for small urban watersheds like UTP where overland flow is a significant component of runoff. The Kerby-Hatheway Method uses Equation 6 to determine time of concentration.

$$t_c = \left[\frac{0.67NL}{\sqrt{S}}\right]^{0.467}$$

where t_C = time of concentration (min),
N = Kerby roughness parameter (dimensionless),
L = length of drainage area, and
S = overland slope (dimensionless)

Equation 6: Kerby-Hatheway method for calculating time of concentration

Overland slope can be derived from elevation data by dividing change in elevation by distance. The Kerby roughness parameter ranges from 0.02 for pavement and 0.8 for dense forest, and can be found in published tables.

The t_C value can be used as to find the rainfall intensity by consulting Intensity Duration Frequency (IDF) curves. IDF curves vary by location, and contain information on the intensity and duration of various design storms. Design storms describe the likelihood of a storm of a certain magnitude. For example, a 5-year design storm is of a magnitude that is likely to occur once every five years, while a 100-year design storm is likely to occur once every 100 years. Alternatively, the likelihood of each storm occurring in a given year can be found by dividing 1 by the return period. For example, a 5-year design storm has a 1/5 (20%) chance of occurring in a given year, while a 100-year design storm has a 1/100 (1%) chance. Stormwater management plans typically use a 100-year design storm when calculating the anticipated volume of stormwater, but this value can be selected with UTP administration based on a risk and cost analysis.

Local IDF curves for Panama are available in an undergraduate thesis completed at UTP in 2015 by Alcely Lau and Antonio Pérez. Once a design storm is selected, the t_C calculated using the Kerby-Hatheway method should be used as the duration, then used to find the corresponding rainfall intensity.

The location of storm drains and other existing stormwater management components should also be determined. This will allow the amount of runoff remaining after diverting to storm drains and other stormwater elements to be quantified, allowing for strategic placement of new stormwater management components. Storm drain locations were available on a paper map from a study conducted in 1993. This map should be updated to reflect construction that has occurred since 1993 and converted to an ArcGIS shapefile or AutoCAD file. The location of existing culverts, retention ponds, or other stormwater management components should be gathered from observations and inputted into a GIS or AutoCAD file.

The outlets of UTP's stormwater should be determined in order to select appropriate treatment methods. For example, if there is a stream on campus that drains to an environmentally sensitive area, stormwater management methods should be designed to remove pollutants from impervious surface area, such as oil. Information about the location of bodies of water on campus should be collected through observations and inputted into a GIS shapefile or AutoCAD file in order to be integrated with the rest of the data analysis.

In order to select appropriate treatment options, water quality testing should be conducted to understand which contaminants are present in the stormwater. Most contaminants and suspended solids will likely come from impervious surfaces, due to oils and other chemicals from vehicles, and construction sites, due to erosion and contaminants from construction vehicles. So, water quality testing should focus on these two types of areas. Tests should include Total Suspended Solids (TSS), heavy metals, nitrogen, phosphorus, and pesticides.

Once information about how much stormwater a given design storm will create and where stormwater will collect, flow, and gain pollutants is determined, the design process can begin. Due to UTP's level of impervious surface area and rainy climate, the goal of a stormwater management plan is twofold: to reduce the peak flow and runoff volume during a design storm and remove contaminants from runoff whenever possible.

The VLS campus does not have much open space available for use, due to high slopes and restrictions on construction near the high voltage lines that run through part of campus. So, stormwater management components with high space requirements, such as retention ponds, are not suitable. Additionally, the campus has a lot of impervious surface area, which introduces contaminants into stormwater. Therefore, design elements that provide water quality improvement are preferred.

The following design components are suitable for UTP's constraints and stormwater management needs. However, it is not a comprehensive list of all potential stormwater management design components. The group using this process should use their best judgement and knowledge of any relevant advances in stormwater management practices when selecting design components.

A simple option for reducing runoff volume is to separate rooftop runoff from surface runoff. Water from building downspouts can be redirected into storage and used for irrigation or other non-potable uses.

Bioretention areas utilize plants, microbes, and soil to treat stormwater before it infiltrates back into the ground. They can remove up to 90% of TSS and phosphorus and 50% of nitrogen, while infiltrating up to an inch of rainfall (Massachusetts Department of Environmental Protection, 2008). Bioretention areas require a space equal to roughly 5% of the area that drains to them, and can be interspersed throughout a large drainage area like UTP. When implemented in an area with a high concentration of oil and grease, such as roadways on the UTP campus, bioretention areas should be coupled with a pretreatment method such as an oil and grit separator (Massachusetts Department of Environmental Protection, 2008).

Grass channels are a stormwater conveyance method that provides water quality improvement. They can remove up to 50% of TSS through sedimentation and gravity separation. They receive water through sheet flow over land or pipe flow from other stormwater management components. Ideally, grass channels are located adjacent to roadways in order to receive runoff from impervious surfaces. The longitudinal slope of the channel should be as flat as possible in order to increase sediment removal (Massachusetts Department of Environmental Protection, 2008). In order to prevent erosion, the channel should be sized such that the velocity of the runoff will not exceed 1 foot (0.3048 meters) per second during the design storm. The channel can be constructed using soil from the area, unless the soil is highly impermeable (Massachusetts Department of Environmental Protection, 2008).

Green roofs are permanent rooftop installations containing vegetation in a soil medium. They can reduce the runoff volume of storms while also providing thermal and sound insulation for the building. Green roofs are relatively simple to retrofit or incorporate into the new construction on campus, and they take up very little additional space. Properly designed green roofs can intercept 40% of annual rainfall and reduce peak flows by 50-90% compared to conventional roofs (Massachusetts Department of Environmental Protection, 2008). Since the rain that falls on green roofs is lost to plant uptake and evapotranspiration, green roofs do not provide groundwater recharge, but that is not a concern in Panama's wet climate. Green roof design includes the following components: drainage layer, waterproof membrane, soil layer, and vegetation. The drainage layer can be constructed of a thin layer of gravel or perforated plastic sheets. The waterproof membrane is typically a synthetic material designed to prevent soil from clogging the drainage layer. The selected soil should have good water retention capacity, and increasing the depth of the soil layer allows the green roof to retain more precipitation. The plants should provide dense cover and be resistant to heat and wind (Massachusetts Department of Environmental Protection, 2008).

These stormwater design components can be combined and utilized to reduce the quantity of stormwater runoff at UTP and ultimately reduce the campus's vulnerability to flooding and other damages. While the stormwater design addresses stormwater runoff, a greywater recycling system addresses water consumption at the university.

The greywater recycling system was designed by deciding the sources of greywater, the uses of the treated greywater, the building to design the greywater system for, and the design of the greywater system itself. To decide the sources of greywater, the required treatment for the three classifications of greywater applicable to the possible sources were researched. Similar research was done to determine the uses of the treated greywater, which considered the required water quality for restricted and unrestricted uses. In order to decide for which building to design the greywater recycling system, the impact the system would have in each building was considered. The greywater system itself included three different facets, which were treatment, storage, and transport. To decipher the best treatment practice to design, rapid sand, slow sand, and active carbon filters were considered and compared based on their effluent quality, required space, and maintenance. The filtration system was then designed based on best practices and surveys completed. The storage system was also designed based on surveys completed. Finally, the transport of the greywater was designed with the goal of minimizing energy consumption.

The possible sources of greywater and the required treatment for those sources were researched. Through that research, three classifications of the possible sources for the greywater system that all require different levels of treatment were identified, as outlined in the methodology. The following are the findings of this research and the resulting decision made regarding the sources of greywater to implement in the designed system. Light greywater typically has the lowest contamination of all greywater sources and requires the least amount of treatment for reuse (Alfiya, et. al, 2015). Light greywater only requires a couple steps of treatment, typically filtration and disinfection, and does not need more intense treatment that require multiple reactor tanks. This decreases the space and maintenance required on the treatment system as well. Dark greywater typically has higher organic contamination than light greywater (Alfiya, et. al, 2015). Greywater from the cafeteria at UTP contains extremely high organic contamination, as it contains food waste particles. Furthermore, harsh chemicals are present in the cafeteria’s greywater from the soaps used to clean dishes. The harsh chemicals in dish soaps can not only add treatment steps, but also cause bubbling throughout the treatment process, which could decrease the efficiency of the treatment methods. The high organic contamination from the cafeteria would require further treatment as well. The treatment required for organic contamination includes aerobic and anaerobic reactors that not only require a lot of space but also require constant monitoring and maintenance to ensure organic compound levels are desirable in the reactors (Funamizu, et. al, 2009). The possibility of fecal contamination is always present when considering blackwater reuse, which requires full wastewater treatment. While dual flush toilets can be designed to avoid fecal contamination, a rinsing process must occur between each flush of solid waste, which requires the use of excess water. Furthermore, dual flush toilets are best suited for small scale projects where it can be ensured that all toilet users are informed of how to use the toilet and will use it correctly. Large scale projects using dual flush toilets must still have treatment processes assuming fecal contamination due to the possibility of a person using the dual flush system incorrectly. The increased required treatment for using toilet water in a greywater recycling system also increases the space and maintenance required for the treatment system. In conclusion from this research, light greywater minimizes treatment, space, and maintenance required and therefore was the best option for this project. Sinks and water fountains were used as the sources for the greywater recycling system.

Through research of the US EPA's quality requirements of restricted and unrestricted use, it was found that the possible sources of greywater require different quality levels. For example, the five-day biological oxygen demand (BOD_5) for unrestricted water usage set forth by the US EPA is ≤10 mg/L (0.0013 oz/gal) where the BOD_5 for restricted water usage set forth by the US EPA is ≤30 mg/L (0.004 oz/gal). Another important difference between the unrestricted and restricted water usage standards is the fecal coliform (FC) allowance levels. For unrestricted use, FCs may not be detectable where restricted use can have up to 200 colony-forming units per milliliter (Fayyad, et. al, 2011). These differences cause a difference in the required treatment for uses. For the unrestricted uses of treated greywater, the greywater would have to go through full wastewater treatment processes where the restricted uses of treated greywater would not require full treatment processes. The increased treatment processes for unrestricted uses also increases the space and maintenance required for the systems, further increasing their complexity. Therefore, the best option for UTP is to reuse the water for restricted uses only, which would be for toilet flushing.

Two buildings, Building 1 (Engineering Building) and Building 4 (VIPE Building), were considered for the design of the greywater recycling system, based on suggestions from UTP faculty. The two questions outlined in the methodology were researched on these two specific buildings. Building 1 has the most foot traffic of any building on campus, as it is home to four of the engineering departments and a majority of the classrooms on campus. Building 4 has the least traffic as it is a center for research departments and does not contain any classrooms. Water efficient appliances are not present in either building, so that did not affect the decision of which building to design a greywater system for. Implementing a greywater system in Building 1 would recycle more water due to it having more usage. There are currently no plans to renovate Building 1 or Building 4, so that did not affect the decision of which building to design a greywater system for either. Therefore, the determining factor in deciding which building to implement a greywater recycling system was which building the system will have a bigger impact on. Building 1 has more traffic than Building 4, so Building 1 was chosen.

The first step in designing the treatment system was to select the treatment type. Several different treatment systems were considered with the factors of effluent quality, required space, and maintenance in mind. Pretreatment is unnecessary in this case due to the generally clean quality of greywater from sinks and water fountains. Therefore, a filtration system with no pre- or post-treatment was decided upon.

Only considering filtration for treatment eliminates unnecessary space requirements, cost of implementation, and maintenance as coagulation, flocculation, and sedimentation are all taken out of the treatment process. Three different filtration processes were considered for implementation;

activated carbon, rapid sand, and slow sand filtration. All three of these methods are widely implemented and have specific advantages and disadvantages.

When considering the effluent quality, slow sand filtration provides the highest effluent quality. It effectively removes turbidity as well as bacteria, viruses, protozoa, and heavy metals (Bruni, Spuhler, 2018, July 4). Rapid sand and activated carbon filtration techniques are effective against all of those contaminants (Bruni, Spuhler, 2018, May 31; Mazille, Spuhler, 2018). Treatment systems that treat water more slowly require more space when the same loading flow rate is applied, which it is for this greywater recycling system. Slow sand filtration requires the most space of the three options as it filters water more slowly (Bruni, Spuhler, 2018, July 4). Rapid sand and activated carbon filtration require similar amounts of space as they treat water at similar rates (Bruni, Spuhler, 2018, May 31; Mazille, Spuhler, 2018). Maintenance is the biggest difference between the three filtration processes. Slow sand filtration has an extremely long lifespan of more than ten years and only requires maintenance of the top sand level that can be done simply and without skilled labor. Slow sand filtration can also operate without any electricity input, which decreases operational maintenance and cost (Bruni, Spuhler, 2018, July 4). Rapid sand filtration requires backwashing every 24-72 hours. The backwashing process not only deems the system nonfunctional, but requires high energy consumption. The energy input required for rapid sand filtration increases operational maintenance and cost (Bruni, Spuhler, 2018, May 31). Activated carbon filters must be replaced regularly, which also must be done by skilled labor, increasing cost and maintenance. They can operate without any input of energy, similar to slow sand filtration (Mazille, Spuhler, 2018). It was decided to utilize a slow sand filter for this greywater recycling system due to its clear advantages in effluent quality, low maintenance, and operational costs.

The first step in designing the slow sand filter was to identify the maximum hourly load, as the treatment system must be able to handle maximum loads. The outcome of the bathroom usage survey during peak usage hours was that 308 people used the bathroom on one of the four floors in Building 1 during peak usage hours. Using the assumption that the bathrooms on all four floors of the building are used an equal number of times and the other assumptions and estimates outlined in the methodology, Equation 7 was used to calculate the maximum hourly load.

$$\text{Maximum Hourly Load} = 308\ \text{persons/floor} \times 4\ \text{floors} \times 4.87\ \text{sec/person} \times 8.3\ \text{l/min}\ (2.2\ \text{gal/min}) \times 1/60\ \text{min/sec} = 832.8\ \text{l/hr}\ (220\ \text{gal/hr})$$

Equation 7: Maximum hourly load calculation

The maximum hourly load calculation was then used to determine the size of the slow sand filtration system. Slow sand filters typically operate between 100-300 l/hr per square meter (22.1-66.2 gal/hr per square yard) of surface area (Bruni, Spuhler, 2018, July 4). The decision was made to design the surface area of the slow sand filter using the 300 l/hr per square meter (66.2 gal/hr per square yard) based on the fact that this would make the filter smaller. Making the filter smaller serves two purposes. The first is that it decreases the space required for the filter. The second is that slow sand filters perform more effectively if they are not allowed to dry out and a smaller filter would treat less water, thus keeping the filter wet with the provided load (Bruni, Spuhler, 2018, July 4). Equation 8 was then used to size the surface area of the slow sand filter.

$$Surface\ Area\ =\ \frac{832.8\ l/hr\ (220\ gal/hr)}{300\ l/hr/m^2\ (66.2\ gal/hr/yd^2)}\ =\ 2.8\ m^2\ (3.3\ yd^2)$$

Equation 8: Slow sand filter surface area calculation

Next, the decision was made to use sand that has an effective size of near 0.15 mm, as this is the most effective grain size. However, tests have shown that effective removal of bacteria, turbidity, and color are not dramatically changed with effective sizes of up to 0.45 mm (ITACA, 2005). Therefore, while smaller sand size is slightly more effective, effective sand size of anywhere between 0.15-0.45 mm would be acceptable. The sand bed should be approximately 1.2 meters deep when the system is installed and that will decrease each time the filter is cleaned (ITACA, 2005). Beneath the sand layer is a gravel pack which is used to keep the sand from reaching the drain into the storage tank. For the sand size of 0.15 mm, with which this system is designed, four layers of gravel pack should exist. The gravel layers should have effective sizes from top to bottom of 0.4-0.7 mm, 2-4 mm, 6-12 mm, and 18-36 mm (ITACA, 2005). Underneath the gravel pack, a drainage system exists to carry water from the slow sand filter to the storage tank. The drainage system for this specific filter consists of standard bricks with 9 mm openings between them, as the bottom level of gravel pack should be at least twice the size of the openings in the drainage system (ITACA, 2005). The drainage system leads to a pipe that then carries the treated water to a storage tank.

The sizing of the storage tank was done using an average daily load, which was done because it is not desirable to allow greywater to sit in a storage tank for more than a day. To calculate the average daily load, an average hourly load was used. The average hourly load was found through the bathroom usage survey done from 3:30-4:30 in the afternoon outlined in the methodology. The findings of this survey are that an average of 164 people use the bathroom on one of the four floors in Building 1 in an hour. In addition to the assumptions that were used to calculate the maximum hourly load, one other assumption was made when calculating the average daily load, which is that Building 1 is active for 15 hours a day. These assumptions and the data from the survey were used to calculate the average daily load, shown in Equation 9.

$$Average\ Daily\ Load\ =\ 164\ people/floor \times 4\ floors \times 4.87\ sec/person \times$$
$$8.3\ l/min\ (2.2\ gal/min) \times 1/60\ min/sec \times 15\ hr/day\ =\ 6,629\ l/day\ (1,757\ gal/day)$$

Equation 9: Average daily load calculation

The tank size was decided to be the same as the average daily load, to avoid treated greywater remaining in the storage tank for more than one day. Therefore, the storage tank has a volume of 6,629 liters (1,757 gallons).

The physical attributes of the tank were designed as well. The shape of the tank does not have a specific impact on this project, and for the reason any storage tank shape would suffice as long as the volume is that of the average daily load. Four other things were considered for the physical design of the tank; the influent location, effluent location, overflow potential, and draining potential. The influent pipe location was placed halfway up the depth of the tank. This was done to encourage mixing and avoid water from becoming stagnant and possibly remaining in the tank for more than 24 hours. The effluent location was placed at the bottom of the tank. This was done to ensure that the treated greywater can be used regardless of the amount of water in the storage tank. An overflow pipe was located at the top of the storage tank that drained to the sewer system. This was done realizing that more water may flow into the storage tank than the volume of the storage tank. A drainage plug was placed at the bottom of the tank. This is necessary for drainage at certain times to avoid water sitting for more than 24 hours. Specifically, the storage tank should be drained every Saturday evening. This is because campus is not as active during the weekend as it is during weekdays. Therefore, water would build up in the tank over the weekend, which should be avoided.

The last portion of the greywater system design was the transport of the water from the sources (sinks and water fountains) to the treatment system, between the treatment system and the storage tank, and from the storage tank to the toilets that will utilize the treated greywater. The design utilizes gravity for the transport of water up until the water must be transported from the storage tank to the toilets. The treatment system is located at a lower elevation than all of the sources to ensure water naturally flows into the treatment system. The storage tank is then located at a lower elevation than the treatment system to allow water to freely flow into the storage tank. At the effluent flow of the storage tank, a pump exists. This pump would be used to transport water to the toilets where the greywater would be used. A full schematic drawing of the system can be seen in Figure 3.

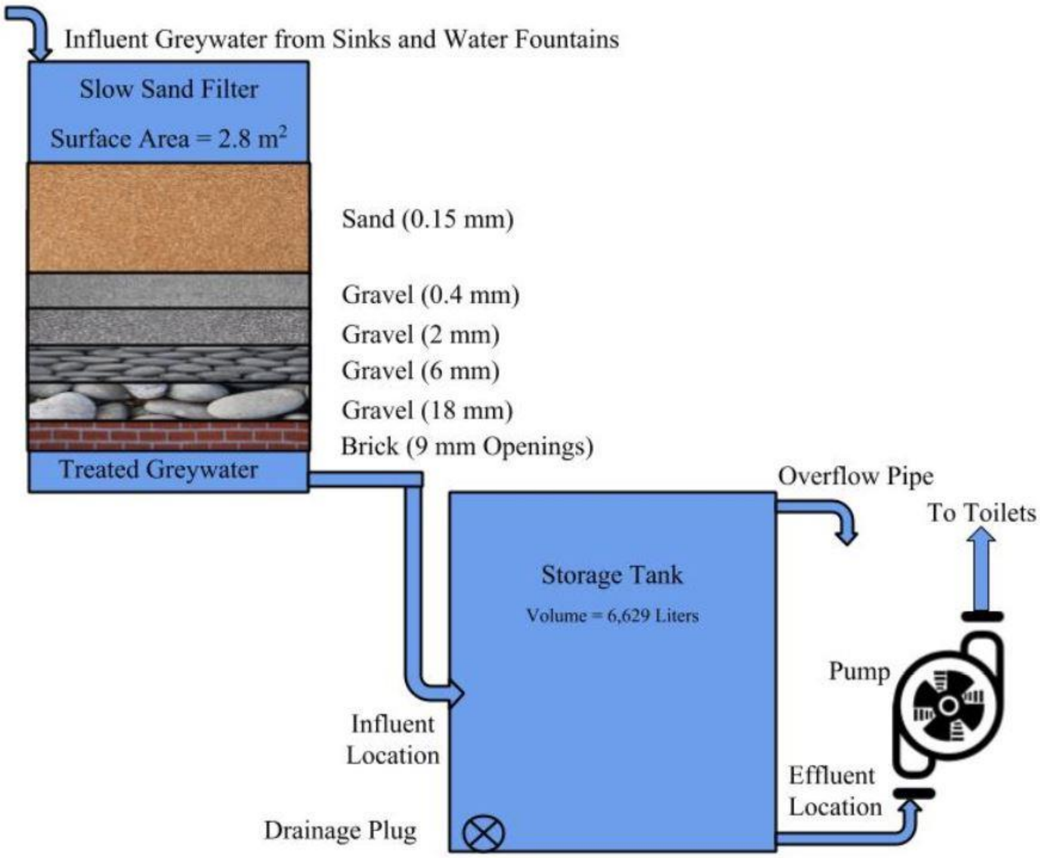

Figure 3: Greywater recycling system schematic

5 Recommendations and Conclusions

In general, UTP's sustainability goals would benefit from increased collaboration amongst groups and departments on campus. While there is an Office of Sustainability, their work is not widely known by students or faculty. This office should publish sustainability initiatives and data on UTP's website to improve transparency and knowledge sharing. The various UTP undergraduate theses completed each year in areas related to sustainability could be collected and archived by this office to assist future researchers. The office could collaborate with professors from various disciplines to coordinate the development and implementation of a full CAP in collaboration with UTP administration.

There are many ways that UTP can improve the accuracy of the baseline sustainability inventory, particularly in the area of GHG emissions. Ideally, these recommendations will be acted upon as soon as possible in order to develop an accurate baseline against which UTP can measure future sustainability progress.

Due to time and data-availability limitations, there were sources that were not included in the GHG emissions estimate. For Scope 1, a future inventory should track gasoline or diesel purchases of all UTP-owned vehicles, including campus shuttles. Purchases of HCFC-22 refrigerant, which is sometimes used for air conditioning, should also be recorded and used to estimate Scope 1 emissions. Scope 2 should include emissions from the cooling and heating of water, if these processes do not use the purchased electricity that was already recorded under Scope 2. To improve the Scope 3 estimate, an updated traffic study should be conducted to reflect the growth in student and faculty population since 2014. This study should be conducted on days without special events to provide a more accurate estimate of the number of cars entering campus on an average day.

Together, these recommendations for increased collaboration and developing an improved sustainability estimate will assist UTP in collecting sustainability information in order to make more targeted, impactful changes to campus GHG emissions and resource consumption in the future.

Prioritizing the work of the Office of Sustainability is vital for UTP to reach their sustainability goals. Publicizing sustainability initiatives will promote campus engagement and can help generate student interest on research opportunities or other ways to make UTP more sustainable. UTP has significant potential to become a sustainability leader, and the best way to achieve this is through internal and external collaboration and engaging students in the process.

CAPs help universities, organizations, and cities mitigate their environmental impact. At universities in particular, introducing sustainability concepts to campus exposes students to the importance of minimizing environmental impact. When students carry these lessons on to their future work, sustainability can influence diverse fields. If more universities implement CAPs, the impact on the environment and the influence on the world would be significant.

6 Design Statement

This project was completed in collaboration with the Universidad Tecnológica de Panamá (UTP) in order to develop a Climate Action Plan (CAP) proposal for the university and address water management needs on campus. A greywater recycling system and guidelines for designing a stormwater management plan were proposed, in accordance with the design requirements of a Major Qualifying Project at WPI, and with ABET criteria. As described below, engineering tools related to stormwater management and wastewater treatment learned in and out of the classroom were used in order to understand UTP's circumstances, and create new systems that meet the campus's needs. Furthermore, environmental, health and safety, and sustainability constraints were considered during the design process.

Water management practices are crucial to UTP in addressing the predicted risks associated with climate change. With climate change come extreme weather events such as hurricanes, droughts, floods and more due to the disruption of global weather patterns. The CAP recommendations included mitigation and adaptation strategies to reduce GHG emissions and adapt to the changes already brought on by climate change. A stormwater management design process was developed to reduce flood risk on campus, and a greywater recycling system was designed for the Engineering Building at UTP to reduce the university's overall water consumption. In order to create the stormwater management design process, hydrology resources describing how to characterize drainage areas and utilize the Rational Method to quantify runoff were consulted. Relevant data from UTP were collected through reviewing undergraduate theses and consulting with professors on campus. Any information that was not available was noted, and methods of obtaining this information were described. The design process will allow UTP to guide a future team in the implementation of a stormwater management system. The greywater recycling system was designed by identifying possible sources and uses of greywater, and investigating the required treatment level, the required maintenance, and the space needed for the system. The design was based on past greywater recycling studies as well as established water treatment requirements.

Environmental constraints were considered in the design of this project. The VLS campus does not have much open space available for use, due to high slopes and conservation restrictions. So, stormwater management components with high space requirements, such as retention ponds, were not considered. Additionally, the campus has a lot of impervious surface area, which introduces contaminants into stormwater. Therefore, design elements that improved water quality were preferential

Next, health and safety constraints were also considered. The inputs to the greywater recycling system were restricted to bathroom sinks and water fountains. Cafeteria sinks were not included due to the high levels of harsh chemicals and organic material, and toilets were not included due to the risk of fecal contamination. While these contaminants could be removed by a more complex treatment process, limiting the inputs to less-contaminated sources decreased health and safety risks. Slow sand filtration used in the greywater recycling system will provide high enough effluent quality to be used for non-potable reuse, such as flushing toilets. Because sustainability is essential to every CAP, it was an important constraint to consider for this project. Recycling greywater reduces UTP's freshwater usage, and the stormwater design process encourages the careful management of a valuable resource.

This MQP ultimately meets the design standards for both WPI and ABET criteria. This project addressed UTP's lack of a CAP by proposing recommendations for the development of a CAP. This was done by conducting baseline studies to measure UTP's emissions generation and resource consumption. Greywater recycling and stormwater management were also essential parts of this project by helping UTP manage their resources and plan for a future where climate change and environmental disasters will make water an even more valuable resource.

7 Licensure Statement

Professional engineering licensure allows an engineer to perform duties at their job and carry more responsibility that they otherwise could not. Several of those duties and responsibilities have been provided by the National Society of Professional Engineers:

- *"Only a licensed engineer may prepare, sign and seal, and submit engineering plans and drawings to a public authority for approval, or seal engineering work for public and private clients.*
- *Licensure is a legal requirement for those who are in responsible charge of work, be they principals or employees.*
- *In many federal, state, and municipal agencies, certain governmental engineering positions, particularly those considered higher level and responsible positions, must be filled by licensed professional engineers.*
- *Many states require that individuals teaching engineering must also be licensed."* (National Society of Professional Engineers, n.d.)

In order to obtain a professional engineer license, an individual must complete four specific steps. The first step is to graduate with a four-year engineering degree from an ABET accredited program. The next step is to pass the Fundamentals of Engineering (FE) Exam (National Society of Professional Engineers, n.d.). The FE Exam is a 110-question exam administered by the National Council of Examiners for Engineering and Surveying. The exam may be taken in any of seven disciplines, which are Chemical, Civil, Electrical and Computer, Environmental, Industrial and Systems, Mechanical, and Other Disciplines (National Council of Examiners for Engineering and Surveying, n.d.). An individual must then practice as an engineer under a licensed Professional Engineer for four years. The final step to becoming a licensed Professional Engineer is to take and pass the Principles and Practice of Engineering (PE) Exam (National Society of Professional Engineers, n.d.). The PE Exam can be taken in 17 different disciplines as it is more specific to an individual's practice than the FE Exam (National Council for Examiners for Engineering and Surveying, n.d.).

Once an engineer has become professionally licensed, the engineer must continue to renew that license. Requirements to renew a professional license vary by state. In Massachusetts, renewal of a professional engineering license is required on June 30th of even years. Renewal can be done online and does not require any annual professional development or continued education (Massachusetts Society of Professional Engineers, n.d.). While Massachusetts does not currently have requirements of professional development or continued education, other states do and it is important to be aware of the renewal requirements in the state of licensure.

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