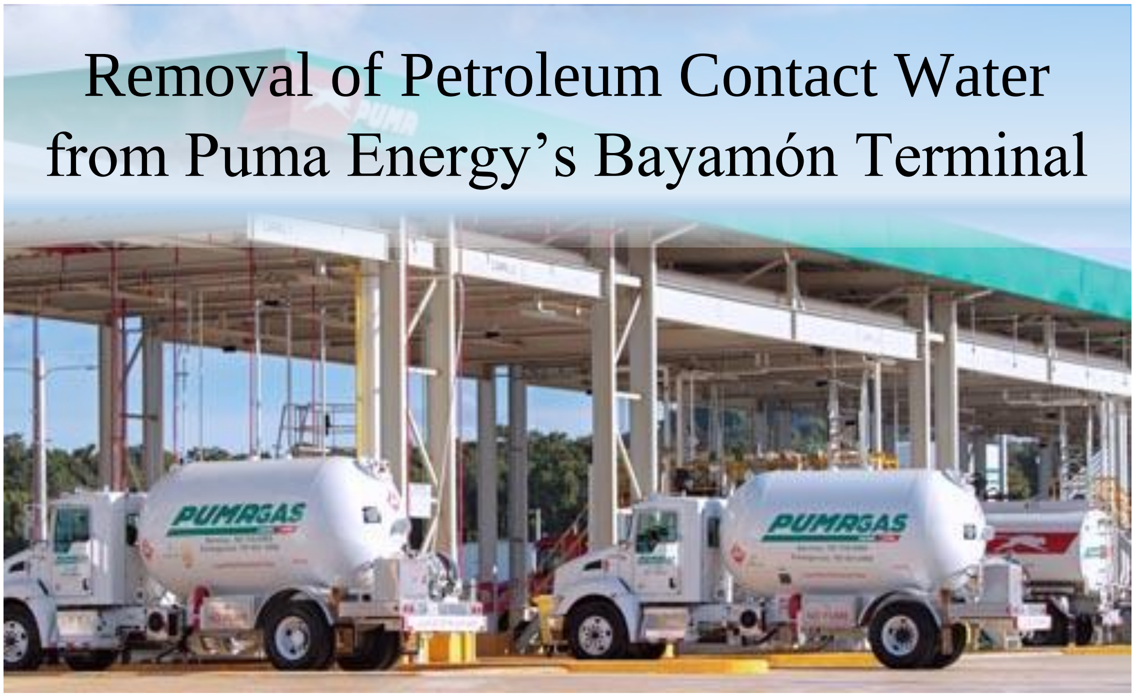
Removal of Petroleum Contact Water from Puma Energy's Bayamón Terminal



A collaboration between Worcester Polytechnic Institute and Puma Energy

Removal of Petroleum Contact Water from Puma Energy's Bayamón Terminal

An Interactive Qualifying Project

On behalf of

Worcester Polytechnic Institute

Sponsoring Organization: Puma Energy

Submitted to:

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Abstract

Puma Energy is a major petroleum provider in Puerto Rico. Their Bayamón facility is in need of a cost effective batch treatment system to remove contaminants from their petroleum contact water (PCW) for discharge to the sewer system. This treated water must meet discharge limits specified by the Puerto Rico Aqueduct and Sewer Authority (PRASA). We contacted batch treatment system manufacturers, generated cost estimates, and arrived at a proposed system to treat the PCW in a cost effective manner.

Executive Summary

Introduction

Puerto Rico relies heavily on the petroleum industry. Petroleum is used all over the island and provides fuel and energy to many of the major industries, especially tourism through cruise ships and airplanes. Also, petroleum dominates the power sector of the island by providing Puerto Rico with ⅘ of its energy and ⅔ of its electricity (U.S. Energy Information Association, 2015).

Puma Energy is a major supplier of petroleum products and deals with storage and distribution across much of Puerto Rico. Being such a significant contributor to the island's energy, Puma Energy has many large storage tanks for their products. These tanks require periodic cleanings, which generate considerable amounts of petroleum contact water (PCW). PCW is water that accumulates at the bottom of the storage tanks of Puma Energy's products and contains many harmful contaminants that could have a negative effect on the community if left untreated. Puma Energy's Bayamón terminal currently treats their PCW through physical and biological processes in a continuous flow system before discharging the treated water into San Juan Bay with a permit provided by the Environmental Protection Agency (EPA).

This continuous flow system is too large for the Bayamón terminal and is very expensive to operate. The goal of the project was to find a cost effective and environmentally friendly treatment method for the PCW at the Bayamón terminal. This PCW will be discharged into the sewer system of Puerto Rico after meeting the permit parameters from the Puerto Rico Aqueduct and Sewer Authority (PRASA).

Methodology

To successfully meet our project goal we:

- **Recommended** an effective treatment system
- **Presented** cost estimates
- **Proposed** a plan for discharge into the sewer system (PRASA)
- **Assessed** the current status of PCW
- **Evaluated** ethics and social aspects

Initial Investigation

From our initial research we investigated:

- Contaminants in PCW
- Effects of these contaminants
- PRASA discharge information
- Manufacturers

Research was the first major step that we took to complete the project. This began by exploring PCW and its contaminants. Each individual contaminant in PCW has a potential effect that could impact the population if not treated properly. We also needed to investigate batch systems and how they operate, which would aid us in identifying an efficient method. Researching PRASA was a necessary step to discover what limitations were required to discharge into the sewer system. Once we had this background knowledge, we conducted our investigation into potential manufacturers that produce batch systems capable of treating PCW.

Interviews

We conducted interviews with:

- WPI Professor
- Puma Energy
- PRASA
- Manufacturers

In our interview with the WPI professor, we inquired about batch systems and general information on contaminants in PCW. We asked a contact at Puma Energy's Bayamón terminal about their current PCW treatment process and details on contaminant levels in their water. These levels were compared to PRASA's limits for discharge. We then reached out to PRASA to get more information on the permitting process and associated fees. This knowledge narrowed our manufacturer search by giving us details into what Puma Energy would need in a new system. This information from PRASA was essential in our determination of the overall cost for Puma Energy to downsize. We reached out to ten vendors that manufacture batch treatment systems.

Rating Manufacturers

To rate manufacturers, we devised the following metrics:

- Cost of System
- Company Size
- Location
- Communication
- Years in the Market

Our analytical scale of five metrics was used to rate the manufacturers to propose the best system to Puma Energy. These five metrics included cost of system, company size in terms of employees, location for importation, communication with our team, and years in the market. The final manufacturer options were ranked from 1 to 5 in all of these five metrics to receive a final score out of 25 possible points. The company that received the highest score was recommended to Puma Energy. The name of each vendor was omitted to maintain their confidentiality.

Results

Through the completion of interviews and investigation, we proposed a batch treatment system that would fulfill all of Puma Energy's wastewater needs at the Bayamón facility.

Puma Energy & PRASA

From the interviews, we were able to learn more about the workings of batch systems and how they would benefit Puma Energy in their search for a more cost effective method to treat their PCW. We received a detailed water quality report from Puma Energy's Guaynabo terminal and obtained PRASA's local limits and regulations that must be met in order to discharge into the sewer system.

To fully understand the cost of the PRASA permit and accompanying discharge fees, Puma Energy would have to fill out a questionnaire about wastewater pretreatment and an application for a connection. We developed an alternative cost estimate using publicly available data from other areas of the United States to produce an average and annual discharge cost.

Rating Manufacturers

After reaching out to ten vendors, we learned that six did not have the means to treat Puma Energy's PCW sufficiently. Three vendors responded with cost estimates for a new treatment system. We rated these vendors using our five analytical metrics, to assign each company a score out of 25 possible points. We decided that the vendor with the highest score would be our primary recommendation to Puma Energy.

Vendor 1 scored a 19/25 on our metric scale and provided a system cost of $184,000 which included the cost of manufacturing and design, implementation, a new water test, and training for the new system. They proposed a system that would treat 2,000 gallons per day to match our local limits provided by PRASA. The system has an added pH meter and carbon filter to account for water contaminant changes in each batch.

Vendor 2 scored a 16/25 and provided a system cost estimate of $85,000. They proposed a system that would treat Puma Energy’s PCW with an oil skimmer and three ultra-filtration units. The vendor informed us that the waste from the filtration units would have to be disposed of through a third party organization.

Vendor 3 scored an 18/25 on our rating system. They provided a system cost estimate of $15,000. Their system encompassed a strictly physical treatment method, however it lacked a thorough process description. The vendor did not disclose how to clean the physical apparatus, but they did inform us that it would need to be cleaned after each use.

Recommendations and Conclusions

The following are the final recommendations we have outlined for Puma Energy:

- **Contact** Vendor 1 to follow up on their batch system quote
- **Take** water samples of PCW from the Bayamón terminal
- **Account** for new metrics including importation, construction, and maintenance fees
- **Complete** the PRASA application and questionnaire

After completing all of our research and interviews, we were able to outline these recommendations for Puma Energy. Because they had the highest score of the three manufacturers, we recommended Vendor 1's treatment system. Also, instead of using a neighboring terminal's water quality report, we recommended that Puma Energy perform a new water test at the Bayamón terminal. Due to time constraints of the project, we were unable to receive cost estimates on importation, construction, and maintenance fees for the proposed systems. We recommended that Puma Energy look into these additional expenses in order to evaluate all of their cost factors. Also, we recommended that Puma Energy complete the PRASA application and questionnaire to acquire cost estimates for a discharge permit.

By considering all of these factors, we believe that Puma Energy can benefit from a new batch treatment system that would sufficiently treat their PCW. We believe that this system would save Puma Energy money and promote a clean environment in Bayamón. With one of the island's main petroleum providers running more efficiently, there is assurance that energy will continue to reach the people of Puerto Rico.

Video

A video summary of our project can be found at the following link, or by clicking on the image:

https://www.youtube.com/watch?v=Ufhh3LrhUP8&feature=youtu.be

Acknowledgements

Our team received a lot of help throughout the duration of this project. Many people provided thoughts and assistance to aid us in delivering the final products. Without this guidance, we would not have been able to complete this project.

We would like to sincerely thank the employees and staff of Puma Energy's Bayamón terminal for their continued help throughout the project, specifically ***Carlos Ramos***, ***Raquel Velazquez***, and ***Luis Medina***. Carlos and Raquel steered us in the right direction in researching batch systems and treatment methods. Luis provided transportation to and from the office and was a significant morale boost for the entire facility.

We extend our gratitude to our advisors ***Fred Hart, Karla Mendoza-Abarca,*** and ***Anna Jaysane-Darr*** for assistance with our report, video, and presentation along the way. Fred helped us with our video production as well as technical edits to the report. Karla advised us with the business aspect of our project. Anna guided us through our proposal process prior to arriving in Puerto Rico. She helped shape our project and provided critical initial edits.

Finally we would like to thank ***Lauren Matthews*** and ***Beatriz Arsuaga*** for coordinating the Puerto Rico IQP center and making this project possible.

Authorship

For the duration of this project, all members of Team Puma pooled their efforts and contributed to the final deliverables. This involved writing and editing the report, working on the video, and assembling the final presentation.

Brendan focused on treatment strategies and contaminants in petroleum contact water, while also working on metrics for analyzing manufacturer results. He also was a primary contact for manufacturers and organized data received from them.

Erin concentrated on permitting and government regulations involved in sewer discharge and water quality. She was the primary team member in charge of formatting the final documents. Erin also produced the visuals and aided in editing for the final video.

Evan worked primarily in the background sections and ethics. He was also the primary team member in charge of the final video deliverable. He aided in the manufacturer interview process, and was the main contact for the Puma Energy representatives.

All members of the team helped compile final recommendations and conclusions for the report. They all worked together to produce the tables and figures throughout the document and presentation. The team edited the deliverables as a group to produce the final products.

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1.0 Introduction

Puerto Rico has a thriving island culture. Its economy is based mostly on tourism and manufacturing for exports. Energy is a necessity for the Puerto Rican economy to create and transport products and to handle the millions of tourists that come to the island annually. Petroleum dominates the power sector of Puerto Rico, providing the island with ⅘ of its energy and ⅔ of its electricity (U.S. Energy Information Association, 2015). Puerto Rico does not refine its own petroleum, but instead imports oil products and distributes them across the island. Puma Energy plays a critical role in Puerto Rico as the main fuel provider for the general public and major industries.

Puma Energy's business touches a variety of industries including marine, aviation, and the general public for the sale and distribution of petroleum products. Puma Energy deals primarily in standard oils, such as gasoline and diesel, lubricants, and specialty fuels for planes and sea vessels. Worldwide, Puma Energy serves upwards of 23,000 customers from their 2,212 retail sites. These sites span across 45 countries on 5 separate continents (Puma Energy, 2015).

Between Puerto Rico and the Virgin Islands, Puma Energy operates 349 retail sites to serve their customers daily oil needs (Puma Energy Puerto Rico & US Virgin Islands, 2015). In Puerto Rico, Puma Energy serves as a sign of change from old oil providers. After a large terminal explosion in 2009, Puma Energy stepped in as a safe and reliable petroleum provider for the island (Puma Energy Puerto Rico & US Virgin Islands, 2015). Puma Energy has a large global footprint, but plays an especially important role in Puerto Rico.

Being such a large company on the island, Puma Energy sets an example by promoting environmental preservation. One example of their environmental consciousness is their proper treatment and disposal of their petroleum byproducts. “Petroleum contact water” (PCW) is water that has accumulated at the bottom of storage tanks and "contains harmful contaminants from petroleum" (Florida Department of State, 1995). PCW contains contaminants that are not only harmful to the environment, but also harmful to human and animal life. Puma Energy currently processes their contact water through a large treatment facility. The water runs through physical and biological treatment, and is then discharged into San Juan Bay with a permit from the Environmental Protection Agency (EPA). This processing system promotes an environmentally friendly and safe way to dispose of the PCW while following government regulations.

Puma Energy's current continuous flow system properly treats their PCW, but it occupies a lot of physical space and is expensive to operate. The task assigned to our team was to research the costs and implications of a new system and present Puma Energy with several options that would fit their specifications. We focused on a batch treatment system as a solution to our problem as it is much smaller in size and cheaper, yet still maintains proper environmental regulations in regards to water quality.

Figure 1.1 outlines the goal and objectives that were utilized to complete this project.

Goals & Objectives Summary

Goal

Propose a cost efficient, environmentally friendly batch treatment method for Puma Energy that will discharge into Puerto Rico's sewer system.

Objectives

A) **Research:** contaminants in PCW, batch treatment systems, manufacturers, & PRASA
B) **Interview:** WPI Professor, Puma Energy, & PRASA
C) **Propose:** batch treatment system
D) **Provide:** cost summary and manufacturer information

Figure 1.1: Goal and objectives that were followed to complete the project

The goal of this project was to find a cost-efficient, environmentally friendly treatment method following government regulated standards to replace Puma Energy's current treatment system. The new method would discharge treated water to the sewer system, as opposed to San Juan Bay. Background research was conducted to completely understand the scope of the project and the potential impacts on the community. We also obtained knowledge and gathered advice from experts in the field by conducting interviews with WPI professors, Puma Energy representatives, and Puerto Rico Aqueduct and Sewer Authority (PRASA) officials. These discussions helped us to better understand the technicalities of the project and business of our sponsor. By completing these objectives and researching system costs, we presented three options to Puma Energy that would treat the PCW while meeting sewer discharge regulations.

2.0 Background

This chapter will evaluate the current status of Puma Energy and its surroundings in Bayamón, Puerto Rico. Also, the general treatment strategies of wastewater contaminants and the legal aspects behind discharge will be discussed. To treat wastewater, all pathogens, hydrocarbons, organics, and chemical pollutants must be reduced to safe concentrations as dictated by the permitting organization for the site of discharge. Each of these contaminants can harm human and animal health, deplete natural oxygen levels, and generally damage the environment in the surrounding areas of the disposal site. The petroleum driven industry of Bayamón relies on clean waterways, as seen in Appendix I. Our sponsor, Puma Energy, proves to be a significant corporation on the island of Puerto Rico because of their role as a large petroleum provider.

2.1 Our Sponsor

The following section addresses our sponsor, Puma Energy, and their goals as a company in terms of expansion and globalization.

2.1.1 Puma Energy

Puma Energy has restored some faith in the petroleum industry in Puerto Rico after obtaining land for their terminal in Bayamón. In 2009, at the Bayamón facility, there was a large explosion and an immense fire caused by years of neglect from Capeco, the main oil provider on the island prior to Puma Energy (Puma Energy Puerto Rico & US Virgin Islands, 2015). After this explosion, many Puerto Ricans lost all faith in large oil companies. Years of mistreatment from Capeco ended up forcing locals to aid in the cleanup of the surrounding area. Lack of support from locals coupled with the explosion forced Capeco to go bankrupt. Puma Energy took advantage of this bankruptcy and won a bid for the Bayamón terminal. The goal of Puma Energy after winning the rights to the terminal switched focus to affirming their image and gaining support from their future customers (Puma Energy, 2015).

Society lacks faith in large oil companies like Puma Energy because they see the negative reports of the petroleum industry through news of explosions, oil spills, and oil leaks. In the eyes of the public, Puma Energy may be seen as more of a danger to the environment than as an asset to the island. To account for the lack of initial support, Puma Energy strives to work well with local communities through the Puma Energy Foundation. In 2014, they spent $1.5 million on local projects in many communities worldwide. Specifically in Bayamón, the Puma Energy Foundation has made a conscious effort to work with the locals to recover from the 2009 terminal explosion by investing domestically and maintaining high safety and environmental standards. This sincerity was proven when Puma Energy signed four agreements with the U.S. Environmental Protection Agency to remediate the old explosion site, as well as 147 other gas stations throughout Puerto Rico (Puma, 2013). It is critical to our project that Puma Energy maintain environmental standards, invest time and money into continuing safe treatment methods, and remain conscious of these efforts as they expand globally. More information on Puma Energy can be found in Appendix II.

2.2 Petroleum Contact Water

In this section we address petroleum contact water, common contaminants found within it, and the potential impact of these contaminants on humans and the environment.

2.2.1 Introduction to Petroleum Contact Water

Petroleum contact water (PCW) is defined as "any water containing product [petroleum]" or "any water that has come in contact with a petroleum or oil source" (Florida Department of State, 1995). In the case of Puma Energy, petroleum contact water is understood to be excess water accumulated in the petroleum storage tanks. This water tends to enter the tanks from seepage of rain and from groundwater in the surrounding environment near the storage tanks. Water is also used to clean the inside of the tanks when the product being stored is switched with a new product. For example, if a tank holds diesel one week, it is entirely possible for it to hold standard fuel oil the next week. When switching between products, the tanks must be properly washed. There is some residual water left from the cleaning of the tanks, which also contributes to the PCW at hand. The accumulation of PCW presents a potential issue with its composition of harmful contaminants that could negatively impact the environment over time.

2.2.2 Contaminants in PCW

Due to the nature of petroleum and its complicated and diverse chemical makeup, contaminants in PCW vary. The most important factor in the treatment of PCW is the volume of each contaminant present. Though each case is unique, there exist some standard pollutants in petroleum based wastewater. These contaminants are categorized in Table 2.1.

Potential Contaminants in Petroleum Contact Water
Suspended Solids
Heavy Metals
Organic Compounds
Biological Compounds

Table 2.1: Common contaminant groups in PCW

Physical suspended solids, chemical biodegradable organics, refractory organics, heavy metals, dissolved organics, biological pathogens and hydrocarbons are the leading contaminants in water that has come in contact with petroleum (Bahadori, 2013). Suspended solids typically have a high volume of organic compounds, which tend to group together into larger masses. To be considered a suspended solid, particles must be larger than one micrometer (10^{-3} mm) (Bahadori, 2013). Heavy metals are another contaminant that commonly arise in petroleum based wastewater. Cations with an atomic weight greater than twenty three are considered a heavy metal (Bahadori, 2013).

Organics, in all various forms mentioned above, contain some level of carbon. Hydrocarbons, a special type of organic pollutant, are often found in water that has come in contact with petroleum products. Hydrocarbons are defined as chemical compounds composed of a varying mix of carbon and hydrogen (Reeves, 1999). Specific contaminants and different volumes of these contaminants play the most significant role in determining how to handle the wastewater at hand. Unique filtration methods exist, however some methods must be combined to effectively treat each contaminant. PCW has unique pollutants with particular impacts on humans, animals, and the environment, which helps to reinforce the necessity for a sound filtration method.

2.2.3 Impact of Contaminants in PCW

As stated above, each case of petroleum contact water is unique; different contaminants have different treatment methods and similarly have differing impacts on people, wildlife, and the environment. A summary of the effects of these contaminants can be seen in Table 2.2.

Contaminant	Effects
Suspended Solids	• Aesthetically unappealing • Sludge deposits
Heavy Metals	• Accumulate in soft tissues • Cause vomiting • Headaches • Dizziness • Motor Deficiency
Organic & Biological Compounds	• Deplete oxygen levels in environment • Block natural cycle of oxygen in water • Carcinogenic

Table 2.2: Various effects of contaminants commonly found in PCW

Suspended solids tend to be more of an aesthetic issue in the environment. When enough suspended solids group together, they begin to build up and form sludge deposits which can wash onto the shorelines of surrounding water ecosystems. Though these sludge deposits can be easily seen and avoided, they are an issue with the clean appearance of the natural environment (Bahadori, 2013). Too much sludge buildup could have a very negative effect on the image of Puerto Rico, which could in turn affect tourism by causing a decrease in desire to visit the island.

Heavy metals exist as smaller particles in wastewater, and have proven to be detrimental to human health. Arsenic, cadmium, lead, and chromium are all classified as heavy metals and are frequently found in PCW. Accumulation of these heavy metals in the soft tissue of the human body can cause vomiting, headaches, and in extreme cases motor deficiency and impaired speech (Thivierge & Frey, 2011). Heavy metals do not decay, which poses an issue in the filtration of PCW. Removal of heavy metals is essential to providing a safe environment for the general population.

Organics, in contrast, pose a threat to the surrounding environment in terms of available oxygen. Plants and animals in ocean habitats need oxygen to thrive. A high accumulation of organics in wastewater tends to block the natural cycle of oxygen into the water from the surrounding atmosphere. This poses a risk to wildlife inhabiting a highly contaminated zone. To avoid oxygen depletion, organics must be effectively treated (Taylor & Yahner, 2015).

Carcinogens also fall under the broad category of organics in wastewater. A variety of organic compounds that are known to be a factor in the development of cancer cells can be found in wastewater that has been exposed to petroleum (Bahadori, 2013). If enough of these carcinogens build up in areas of high population, cancer rates in the area are more likely to increase. Efficient treatment of contaminants in petroleum contact water is a necessity to maintain environmental friendliness as well as to keep the population healthy.

Whether it is a direct effect on the natural state of the environment, a detrimental effect on human health, or a significant impact on the wildlife, contaminants in PCW need to be treated in a safe and controlled way to provide the cleanest possible water to recirculate into the surrounding regions.

2.2.4 Current Disposal Strategy of Puma Energy

As it currently stands, Puma Energy does not have a cost effective method for treating and disposing of their petroleum contact water. The Bayamón facility used to be a refinery, prior to Puma Energy's facility takeover after the 2009 Capeco explosion. The refinery sized wastewater treatment facility is too large for Puma Energy to maintain and operate at a low cost. Under permits, Puma Energy is able to discharge their treated water into San Juan Bay by maintaining proper water quality regulations, addressed in the following section.

2.3 Water Quality

Water needs to be safe and free of pollutants to keep a community healthy and thriving. Puerto Rico, as a US territory, must abide by regulations set by the US Environmental Protection Agency (EPA). Therefore, companies must go through efforts to treat their waste before releasing anything into the environment. In 2006, the Puerto Rico Aqueduct and Sewer Authority (PRASA) was fined $9 million dollars for 15 felonies in violation of the Clean Water Act. This charge to PRASA was the largest fine in history for violations against the Clean Water Act. It is now a priority of PRASA to better the water of Puerto Rico (Rodriguez, 2006). To abide by these regulations, many permits and standards are now in place and are all focused toward keeping the community safe.

2.3.1 PRASA and Permitting

PRASA is a government owned agency that aids in the cleaning and the delivery of potable water, as well as receiving and treating wastewater. PRASA requires companies to obtain a permit to allow the discharge of its wastewater into the Puerto Rico sewer system.

Under the permit, which follows the regulations of the EPA, wastewaters with grease and oil concentrations must meet certain guidelines. Petroleum can never be discharged into waters. For petroleum wastewater to be released into the sewer system, it must have a concentration below 100 milligrams per liter (Commonwealth of Puerto Rico Aqueduct and Sewer Authority, 2003). PRASA has generally applicable limits and site specific local limits that give parameters to follow before discharge. A summary of these general limits can be seen in Table 2.3.

Parameter	**Generally-Applicable Local Limits* (mg/L unless otherwise noted)**
Temperature	60 °C (140°F)
pH (Minimum)	5.0
pH (Maximum)	10.0
Copper	1.0
Mercury	0.05
Nickel	0.5
Chromium	1.0
Silver	0.05
Cadmium	0.1
Zinc	0.5
Lead	0.2
Selenium	0.2
Manganese	4.00
Cyanide	0.1
Phenols	1.00
Oil and Grease	50
BOD**	
Total Suspended Solids**	

* All limits are based on 24-hour composite samples except for temperature, pH, cyanide, and oil and grease. Grab samples shall be taken for temperature, pH, cyanide, and oil and grease unless, upon request by the user, the Authority approves use of a mathematically calculated "composite sample," based on individual grabs that are analyzed separately. The Authority shall specify the manner in which these grab samples will be collected and mathematically combined.

** Generally-applicable local limits are not established for these parameters; however, limits may be set in a user's discharge permit or authorization, based on the capacity of the treatment works. The Authority will typically use a default value of 250 mg/L in a permit or authorization unless the user demonstrates a higher limit will not cause pass through or interference.

Table 2.3: Generally applicable PRASA limits for water discharge

It is important to follow these regulations and permits to treat and release wastewater in an appropriate and safe manner to better the community of Bayamón and its waterways.

Pollution to water causes degradation of the community. It negatively impacts recreational activities such as fishing and swimming. The National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution through regulations of point sources that are responsible for discharging pollutants. Municipal and industrial facilities must obtain permits if they are discharging pollutants directly into surface waters. NPDES permits are typically given by the state in which each facility resides (US EPA Water Permits Division, 2014). Under the Clean Water Act (CWA), it is against the law to release pollutants into navigable waters without a permit. More information on CWA and other federal regulations can be found in Appendix III. The NPDES is responsible for controlling the discharge of contaminated water into local waters (US EPA RMD, 2015). Puma Energy currently uses a NPDES permit for their constant flow treatment system, in which they dispose their treated water into San Juan Bay.

NPDES only handles treated water to be discharged into the bay and coastal waters but does not include water released into the sewer system. With the new treatment method, a PRASA permit would be used to dispose of the treated water into the sewer system and the NPDES permit would no longer be necessary. Though special permits allow Puma Energy to choose where to discharge their PCW, the contact water must first be thoroughly treated to abide by PRASA's specified regulations.

2.4 Current Treatment Strategies

Due to the varying contaminants that PCW could contain, there are many treatment methods that help remedy the wastewater. Treatment methods include physical filtration, using screens and sieves of varying sizes and grades; chemical filtration, using different chemicals and their reaction properties; and biological treatments, targeting organics. These treatment methods are used in a series, typically starting with physical filtration to remove large masses, then continuing on to chemical or biological treatments to remove the smaller particles from the wastewater. A visual summary of this series treatment can be seen in Figure 2.1.

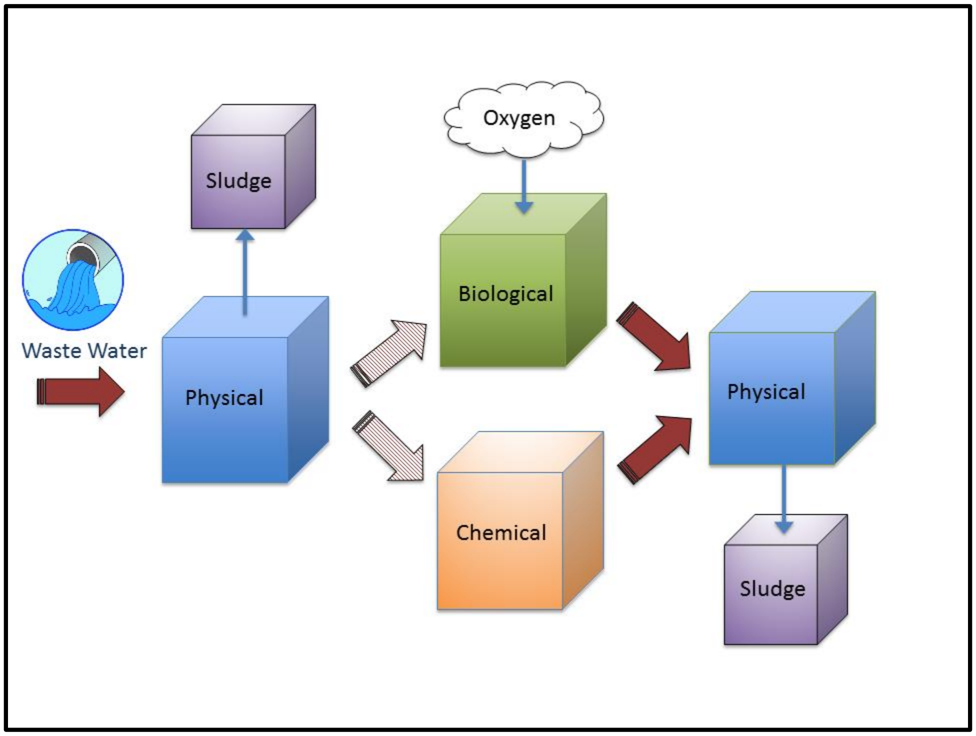


Figure 2.1: Typical treatment strategies for wastewater

As illustrated by Figure 2.1, wastewater initially enters a physical treatment phase, where solids are separated out using screens. After the initial solid separation, water can either go to a biological phase or a chemical phase. In the biological phase, oxygen is added and gravity forces more solid matter to the bottom of the tank. During the chemical phase, the wastewater is mixed with chemical reactants to help solids coagulate. For both phases, solids can then be removed by physical separation. After the second physical separation, the water is discharged.

2.4.1 Physical Treatment Methods

Typically, physical filtration is the first step in treating various forms of wastewater. Suspended solids and dissolved inorganic solids are the leading contaminants targeted by physical means of treatment. Using different grades of metal screens, clumps of solid matter are removed from wastewater. Table 2.4 depicts the typical size of various contaminants.

Particle Classification	Particle Size (mm)
Dissolved	Less than 10^{-6}
Colloidal	10^{-6} to 10^{-3}
Suspended	Greater than 10^{-3}
Settleable	Greater than 10^{-1}
Supracolloidal	10^{-3} to 10^{-1}

Table 2.4: Varying size of contaminant particles (Bahadori, 2013)

As seen in Table 2.4, suspended particles are particles greater than 1 micrometer in size. This is the smallest size that can be efficiently filtered from the water using strictly physical filtration. The typical practice for suspended solids is to run the wastewater through a 0.45 micrometer screen and after enough material is caught in the screen, it is dried at 103 degrees Celsius. Any leftover material on the screen is considered suspended solids and is safely removed from the water (Bahadori, 2013). Dissolved inorganic solids are run through the same screen, but they are dried at 550 degrees Celsius. Any material left after this drying process is considered dissolved inorganic solids.

2.4.2 Chemical Treatment Methods

After conducting the physical screening to remove larger particles, chemical treatment can begin to target smaller particle matter. Reactions of various chemicals allow for the removal of smaller particles that pass through the spectrum of screen sizes used for physical filtration. Chemical coagulation and chemical precipitation are two common chemical treatments for petroleum based wastewater. Chemical precipitation is the process by which one reagent is added to wastewater and another reagent is added to an adjacent apparatus. These reagents are combined through a spraying process, hence the name chemical precipitation (one reagent is rained down upon the other). When the two reagents meet, a reaction occurs in which the small particles are bonded together to form larger masses. This is similar to chemical coagulation in the sense of bonding small particles into larger matter (Bahadori, 2013). The overall goal is to create larger particles that are heavy enough to sink to the bottom of the wastewater and, in turn, be physically filtered out using similar techniques to physical filtration.

Chemical stabilization is another process that exists in the realm of chemical treatment. This process takes an oxidizer, such as chlorine or hydrogen peroxide, and applies it to solid sludge waste. These oxidizers force the water out of the sludge and leave a purer form of the contaminant that can be physically filtered out (Bahadori, 2013). Chemical filtration alone would not target the suspended solids and therefore is a good method to use after a physical screening of the wastewater. By combining the two methods, more particulate matter can be filtered out and the PCW would become cleaner to release into the sewer system.

2.4.3 Biological Treatment Methods

Biological treatments have been used for many years as an effective way to filter wastewater. The method involves the use of bacteria and microorganisms to remove particulate matter. Biological treatment requires much more knowledge about the specifics of the wastewater. Each case is unique and the biological treatment methods are different for each contaminant. There are a wide variety of methods, and they all have specific calculations to determine effectiveness (Bahadori, 2013). Biological treatment can be used as an alternative to chemical treatment. It is an effective method to give the wastewater one final screening before it is discharged.

2.4.4 Puma Energy: Bayamón Facility

Puma Energy uses a combination of physical and biological treatments to remedy the PCW at their Bayamón facility. The PCW being treated goes through phases including a physical and a two-step biological phase with a lagoon stage. A diagram of Puma Energy's current treatment process can be found in Figure 2.2.

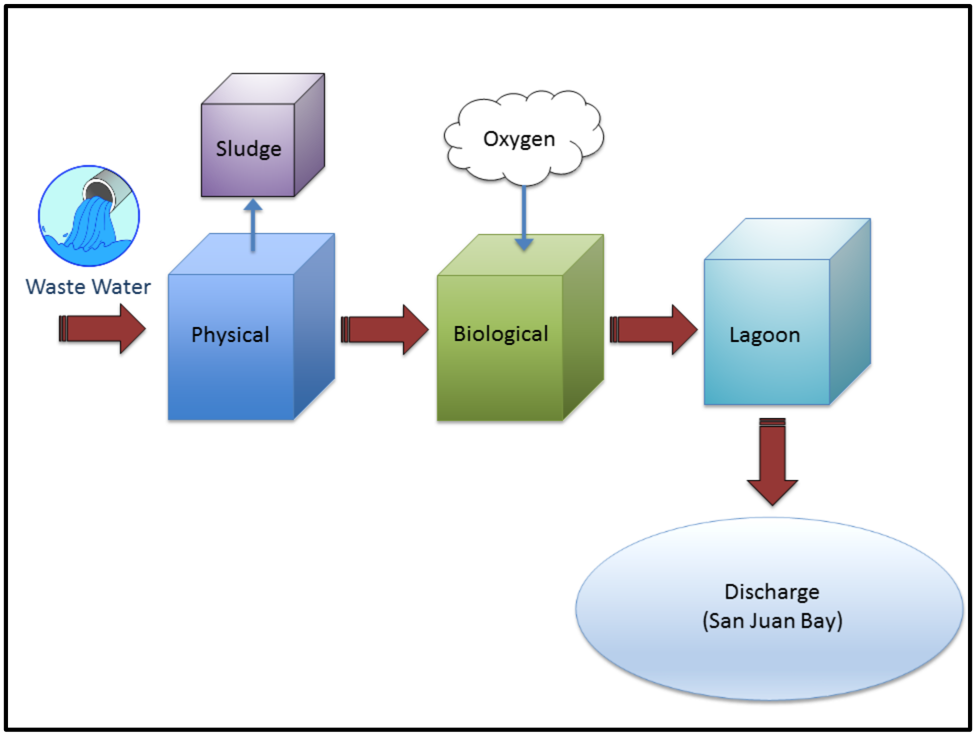


Figure 2.2: Puma Energy's current treatment facility

Physical treatment begins at each individual storage tank. A petroleum recovery unit (PRU) is attached to each storage tank as a means used to separate the water from the fuel being stored. The PRU acts as a decanter by allowing the petroleum product and the water to separate due to their varying densities. The contact water sinks to the bottom of the PRU and is moved through underground pipes to a storage tank with PCW from the 17 other storage tanks around the facility. After the water is physically separated from the storage tanks in phase one, phase two begins the biological process. This process takes place in two separate but related steps. Step one of phase two involves two biological reactors and two clarifiers to begin treating for organics and non-solid matter. After running through the reactors and clarifiers, the PCW enters step two of the biological phase: the lagoon. The lagoon provides an area for the treated water to stabilize before discharge. The treated water is currently discharged into San Juan Bay at safe levels. As Puma Energy moves towards a new treatment system, they plan on removing phases from their treatment facility in preparation. They will start with the removal of physical treatment and then move into the removal of biological treatment once a new system is decided upon.

2.5 Summary

To safely release treated PCW into the sewer system we aided Puma Energy in devising a strategy for appropriate treatment options. After identifying individual contaminants, Puma Energy must sufficiently treat their water through a combination of physical and chemical or biological filtration in a batch system model. This treatment ensures that the water released back into the sewer system is safe and free of contaminants. The environment is a major focus in the design and implementation of this new facility as well as the overall costs charged to Puma Energy. In terms of legality, Puma Energy will need to comply with PRASA regulations for a permit to discharge their treated water into the local sewer system. By assessing all contaminants and regulations, Puma Energy can begin to implement a new system to treat their PCW.

3.0 Methods

The goal of this project was to devise a cost effective strategy to properly treat and dispose of petroleum contact water at Puma Energy's terminal in Bayamón, Puerto Rico. To achieve this goal, we developed a plan that addresses the various levels of contaminants in the water, researched different treatment methods, and considered the cost effectiveness and permit process for the overall project. Figure 3.1 provides a visual representation of our methods section.

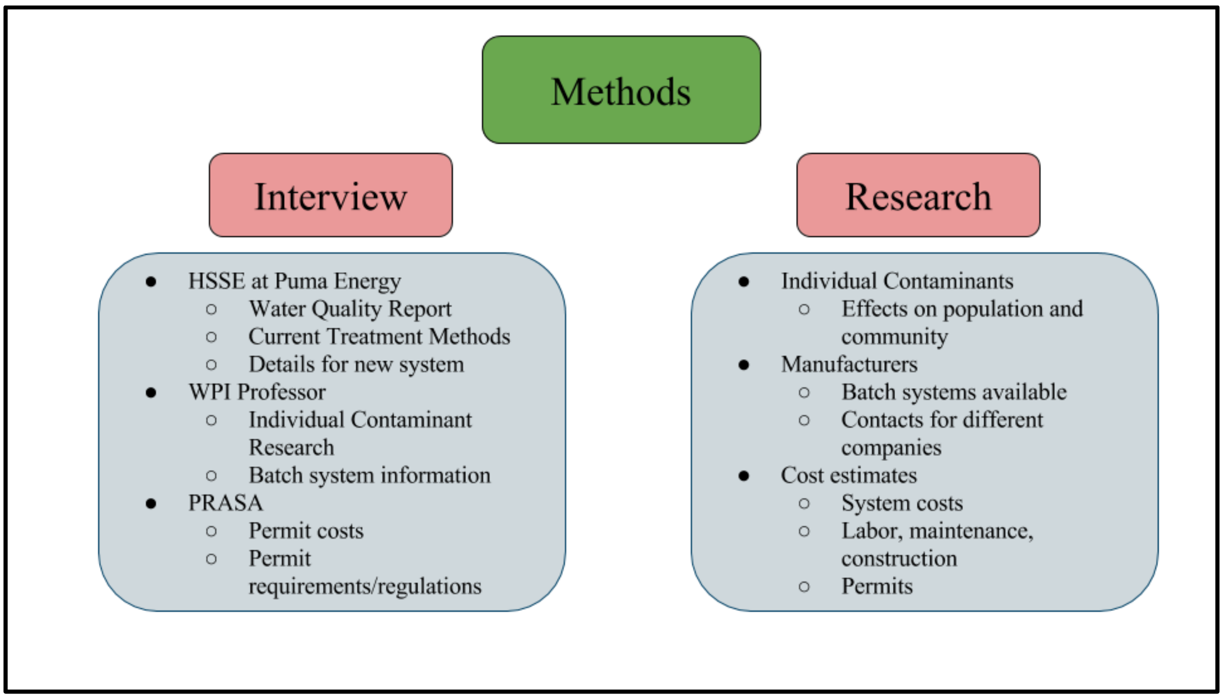


Figure 3.1: Our methods utilized to complete the project

To complete the project, we had to meet certain objectives. Our objectives were as follows:

- **Recommend** an effective treatment system
- **Present** cost estimates
- **Propose** plan for discharge into sewer system (PRASA)
- **Assess** current status of PCW
- **Evaluate** ethics and social aspects

We found volumes of individual contaminants in the petroleum contact water (PCW) at Puma Energy. This contaminant summary allowed us to target specific methods to treat the water. Once a proper treatment method was determined, we proceeded to evaluate cost estimates by obtaining permit fees and manufacturing quotes.

3.1 Finding Major Contaminants in PCW

To achieve our goal of devising a cost effective treatment method, we first had to fully understand what was in the water that we were dealing with. We understood that to propose the most effective treatment methods, we needed a detailed water quality report labeling all the volumes of individual contaminants in the PCW from Puma Energy. This data would allow us to research each group of contaminants and determine the most effective strategy to treat them.

To obtain the data pertaining to the volumes of contaminants, we consulted our sponsor and ask for their information on the topic. We interviewed a supervisor in Puma Energy's Health, Safety, Security, and Environment Department (HSSE) at the Bayamón terminal to get the information we needed. The water quality report obtained is in Appendix IV and presented in the results chapter.

3.2 Analyze Individual Contaminants

By looking into individual contaminants from the water quality report, we hoped to fully comprehend the composition and risks associated with Puma Energy's PCW. This helped us decide the best processes to treat such water. We found major groups of contaminants and were able to research associated treatment options for them. Each contaminant has a specific method to best remove it from the water. Some contaminants require physical treatment, while others need biological or chemical treatment. Until we received a water quality report, we did not know which method treated each contaminant. With this new information, we made a plan to research the contaminants in groups, such as heavy metals and volatile organic compounds. This research was necessary because we needed to be sure that the new system had the proper methods necessary to treat the PCW to a level that would meet discharge parameters.

3.3 Devise Effective Treatment Methods

As previously stated, each individual contaminant requires a unique treatment method for removal. We evaluated each pollutant and its effect on the environment and humans. Once we identified the contaminants, we looked into the three most common forms of treatment: physical, chemical, and biological. Each method has unique features to remove pollutants to allow clean water to be discharged into the sewer system.

We consulted various experts on the PCW we analyzed. Our method of contact was through interviews; primarily in-person, on Skype, or by email. We interviewed a WPI professor, employees at Puma Energy, and a PRASA representative to help lead us towards proposing an effective treatment method.

3.3.1 Interview: WPI Professor

Before we departed for Puerto Rico, we conducted interview on the WPI campus with a professor in the environmental engineering field. We held this interview to get more understanding on the process of wastewater treatment, and how it related to the treatment of PCW. Prior to the interview, we came up with a list of topics to discuss including the various methods of treating contaminants and more specifics on batch systems. This interview helped in the process of evaluating each contaminant and getting insight on which methods treat which pollutant. The WPI Professor helped us to focus on a few methods of treatment to effectively remove contaminants from the water. After this interview, we opened more communication with Puma Energy to help further our understanding of the problem at hand.

3.3.2 Interview: Puma Energy

When we arrived in Puerto Rico and went to the Bayamón terminal, we were able to speak to the HSSE supervisor at this Puma Energy location. The HSSE, mentioned in Section *3.1 Finding Major Contaminants in PCW*, had given us preliminary information and the water quality report that was used to research individual contaminants. This interview was conducted to get more information on the current treatment method at the terminal and to get more details on the new system and discharge plan. We hoped that after speaking with the HSSE, we would be able to better grasp how Puma Energy handles their PCW. We were unsure about the specifics of their system or how much PCW had to be treated. From this interview, we also needed information on a contact that they had with PRASA. We were hoping that Puma Energy would be able to provide us contact information at PRASA. We were also curious if Puma Energy had any manufacturers in mind for the new system. We knew that large companies sometimes have better experiences with certain manufacturers. We wanted to provide the best possible system to Puma Energy, while also trying to accommodate their needs. The HSSE supervisor continued to aid us in the process of finding a solution to our problem and was able to answer any questions we had regarding the details of our project.

3.3.3 Interview: Puerto Rico Aqueduct and Sewer Authority (PRASA)

In addition to a WPI professor and a Puma Energy HSSE supervisor, we interviewed a representative of the Puerto Rico Aqueduct and Sewer Authority, known as PRASA. We consulted PRASA to get more information on the requirements and legalities behind the discharge permit. The topics discussed included cost estimates for the permit that Puma Energy would need to obtain. We intended on asking about the initial cost of the permit and the price per gallon to discharge wastewater. The PRASA permit would allow Puma Energy to dispose of their wastewater into the sewer system, as opposed to discharging it into San Juan Bay. Discharge through PRASA was one of Puma Energy's requirements throughout the project. They intended on discontinuing their current EPA permit, and obtaining the PRASA permit. Puma Energy provided us with contacts at PRASA to acquire this necessary permitting information.

3.4 Cost Estimates

A major component of this project was the expense needed to treat Puma Energy's PCW. Although no direct budget was put in place, our goal was to create strategies that efficiently treat the water, but are also cost effective.

The PRASA permit required for Puma Energy's facility presented an important cost factor to our project. We were informed, from the HSSE at Puma Energy, that for each new facility added to their terminal to treat water, a new permit must be approved. While searching for a treatment method for the PCW, we planned to take into account permit costs to meet wastewater disposal regulations. These permit expenses apply to all systems we proposed and costs are compounded. The PRASA permit is a necessity for Puma Energy's new system.

In our evaluation of cost, we looked particularly into the price of each individual system as well as the expenses of implementing the system. A visual representation of our cost map is found in Figure 3.2.

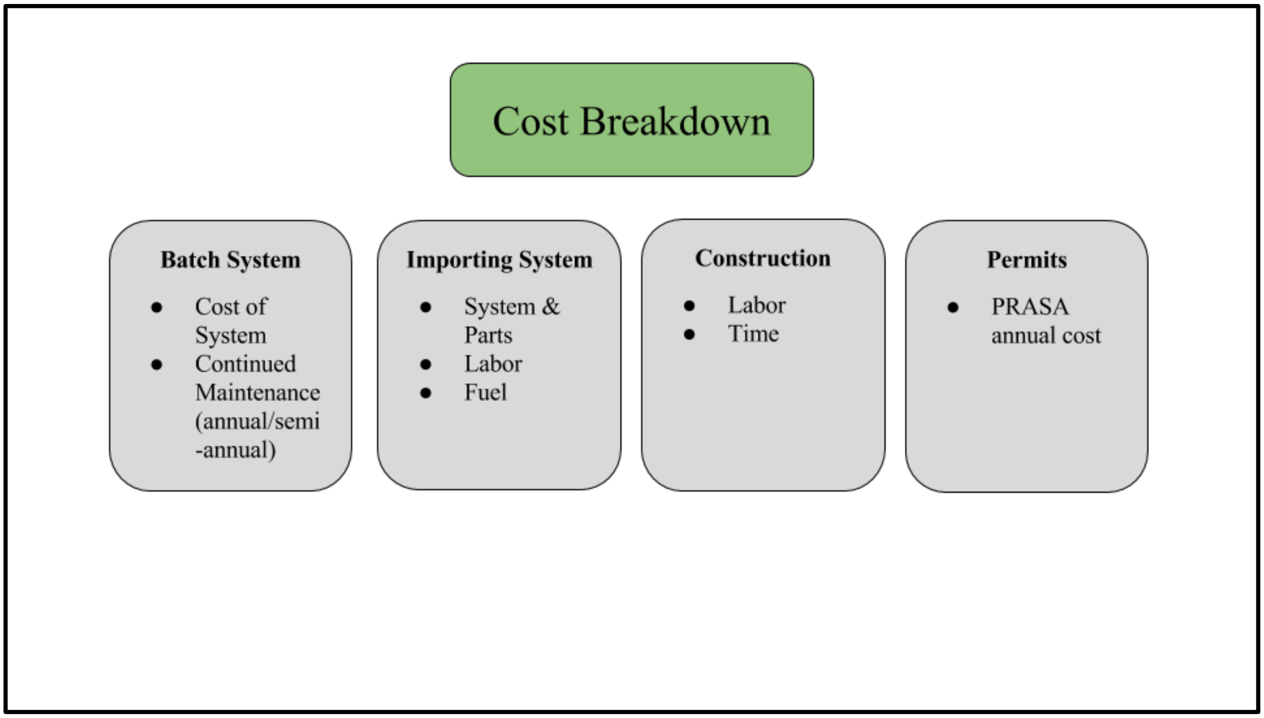


Figure 3.2: Expense factors in overall cost estimate

Puma Energy asked for a batch system so that they can treat their PCW at their convenience. A batch system requires multiple treatment methods and typically operates at a lower cost. We investigated companies that could implement these systems, and how much they would charge.

3.5 Manufacturers

To assess costs for this project, we reached out to various batch system manufacturers to receive estimates. After investigating numerous companies, we reached out to ten in hopes that all of them would reply with a cost estimate. Unfortunately, six of the manufacturers were eliminated from our search. These six companies did not have the technology nor the means to implement a system to treat Puma Energy's PCW at the Bayamón terminal. We were left in contact with four vendors to discuss batch treatment systems with. We were able to send to the vendors a summary of the water quality report from Puma Energy and the PRASA local limits that would need to be met to safely discharge into the sewer system. The vendors were able to determine if their batch system would be sufficient in handling Puma Energy's situation. We received cost estimates and rated each vendor using analyzing metrics to propose the best manufacturer to Puma Energy.

3.5.1 Metrics of Analysis

As previously stated, each manufacturer that we received a cost estimate from was rated using a system of metrics that we selected. We devised five separate factors to rate each company including: cost of system, company size in terms of employees, location of manufacturer for importation, communication level with our team, and years in the market. Each metric corresponded to rating number, between 1 and 5, to allow us to assign each manufacturer a final score out of 25. The company that produced the highest score in our metrics analysis would be proposed as the primary solution to Puma Energy.

We chose these metrics because they are critical in all business decisions. 'Cost of System' related directly to our problem statement, as we were tasked with finding a cost effective treatment system. In terms of 'Company Size', we presumed that the more employees a vendor had, the more assistance they could provide to Puma Energy. 'Location' was chosen to account for the cost of importation and shipping of the system. 'Communication' is a large factor in any business decision. We had many questions about proposed systems and needed a company that would be willing to help us understand them. 'Years in the Market' was our final important metric. We suspected that the more experience a company had, the more prepared they would be to better serve their clients.

3.5.1.1 Cost of System

The metric for system cost was scored based on a range of prices for the systems. For a more expensive system, the manufacturer received a lower score. For a more cost effective system, the manufacturer received a higher score. A score of 1 occurred if the system costs above $100,000, while a score of 5 occurred for a system costing less than $25,000. Scores of 2, 3, and 4 occur when the system cost falls within a range of $25,000 to $100,000 with $25,000 increments. A summary of the system cost metric can be found in Figure 3.3.

Cost of System

1	2	3	4	5
> $100,000	$75,000 - $100,000	$50,000 - $75,000	$25,000 - $50,000	< $25,000

Figure 3.3: 'Cost of System' metric used to score manufacturers

3.5.1.2 Company Size

Another metric used to help analyze each manufacturer was company size. This metric was scored in terms of employees at the company. A company with less employees was scored lower. We decided that the more employees a company had correlated with the amount of help and time we would be able to receive from the manufacturer. A vendor having between 1 and 5 employees scored a 1, while a vendor with over 45 employees scored a 5. A graphic of the company size metric can be found in Figure 3.4.

Company Size (Employees)				
1	2	3	4	5
1-5 employees	5-15 employees	15-30 employees	30-45 employees	>45 employees

Figure 3.4: 'Company Size' metric used to score manufacturers

3.5.1.3 Location

Location of the manufacturer was another important metric that we considered. After investigation of the vendors, we learned that there were no companies already in Puerto Rico that would be able to provide us a system. This prompted the question about cost to import a batch system to the Puma Energy facility. The location metric provides a scale from 1 to 5, with a score of 1 being companies located over 5,000 miles away from the terminal. A score of 5 occurs with a company located less than 500 miles away. We presumed that a company that was farther away would have a higher importation cost. A higher importation cost would raise the overall cost estimate of the system. A graphic of the location metric can be found in Figure 3.5.

Location (Distance to import)				
1	2	3	4	5
>5000 Miles	3500-5000 Miles	2000-3500 Miles	500-2000 Miles	< 500 Miles

Figure 3.5: 'Company Location' metric used to score manufacturers

3.5.1.4 Communication with Our Team

Communication with companies was a very important factor to us. In order to receive cost estimates, it was crucial that companies were willing and able to talk and communicate with us. This metric was based on a scale of weekly communication. Every week varied in terms of communication with companies, but we took this metric as an average level of communication from each manufacturer. A score of 1 occurred if manufacturers had no communication, while a score of 5 occurred with companies who called or emailed us daily. A graphic of the communication metric can be found in Figure 3.6.

Communication with Our Team				
1	**2**	**3**	**4**	**5**
No Communication	Below Average Communication (> one week to respond)	Average Communication (One response per week)	Above Average Communication (Multiple responses per week)	Great Communication (emails or phone calls daily)

Figure 3.6: 'Communication with Our Team' metric used to score manufacturers

3.5.1.5 Years in the Market

The final metric we considered to rate manufacturers was 'Years in the Market'. We suspected that a company with more experience in the market would be able to provide more assistance and a better overall product than a company that is new to the market, simply based off of experience. A score of 1 occurs for a manufacturer with less than 1 year of experience in the market of batch systems. A score of 5 occurs for manufacturers with greater than 40 years of experience with batch systems. A graphic of the years in the market metric can be found in Figure 3.7.

Years in the Market				
1	**2**	**3**	**4**	**5**
<1 year	1-5 years	5-20 years	20-40 years	>40 years

Figure 3.7: 'Years in the Market' metric used to score manufacturers

3.5.2 Summary

We reached out to ten initial manufacturers and, based on system abilities and communication levels, we were able to narrow the final options down to three vendors. Each vendor was ranked with a variety of metrics including: cost of the system, size of the company, location that the system would be imported from, communication with our team, and the number of years the company has been in the market. After compiling the scores, the vendor with the highest score was presented to Puma Energy as our primary solution and the other two vendors were presented as backup options.

3.6 Ethics

Ethics were very important to consider when working in the professional field. Maintaining proper ethical standards was critical to develop a strong working relationship with Puma Energy. In this section, we analyzed each component of our methodology from a moral standpoint. Our methods involving human subjects were approved by the Worcester Polytechnic Institute Review Board (IRB). We were declared exempt from all ethical conflicts, but to avoid any confidentiality issues, all names of interview subjects have been omitted from our report.

3.6.1 Finding Major Contaminants in PCW

When conducting our research with Puma Energy, we considered how our investigation of the major contaminants in the PCW could impair our ethical approach. First, improperly reporting water conditions to the public would defy an ethical standard. If there are health concerns with the water involving contaminants, then the public could be directly impacted.

Also, we looked into every possible contaminant and the associated consequences involving the local population to avoid ethical issues. It would be problematic to ignore any possible negative health consequences to Bayamón and the Puerto Rican population.

3.6.2 Determining Methods of Treating the Water

We understood what ethical conflicts we could potentially run into during our search for an effective treatment method. Issues could arise if we had neglected the treatment of some contaminants in our resulting methods selections. Omitting treatment of contaminants would have had a significant impact on the surrounding environment and inhabitants of the local area, putting the blame on Puma Energy for not sufficiently treating their water.

3.6.3 Cost Efficiency

In our investigation of how to save Puma Energy money in their new treatment system, we had to be wary of how we dealt with the topic of cost efficiency. One major ethical flaw would have been to lie about the price of the treatment system to make it more appealing. Also, omitting treatment of certain contaminants to lessen the overall cost would have been an ethical problem. Our priority had to be meeting environmental standards, as opposed to finding the cheapest solution. Every aspect of the contaminant treatment(s) had to be considered before we moved forward with cost assessment.

3.6.4 Interviewing

While interviewing different experts and professionals throughout this project, we remained mindful of the questions that we were asking and how they affected the interviewee. It was possible for us to ask questions that pertained to sensitive company information and therefore could not be reported. We structured our questions so that we could acquire the necessary information while preserving the integrity of the interviewee. We reviewed our questions thoroughly so we would not encounter any conflict with the company and receive all necessary information.

3.6.5 Manufacturers

When reaching out to different manufacturing companies to receive cost estimates, we had to be aware of sensitive information. We needed to preserve the confidentiality of the companies' names in our report, so we referred to them as Vendor 1, 2, and 3. That way, we did not associate their company name with cost estimates to the public because this is private information. When relaying information to manufacturers, we preserved Puma Energy's security by summarizing the data from their documents instead of sending the original confidential reports. That way, we were able to keep from sharing private information from Puma Energy.

3.7 Summary

To reach our goal of recommending a cost effective system for Puma Energy to treat their PCW, we had to meet all of our objectives. We identified the major contaminants in the water and their effects on the surroundings. We proposed a cost effective, environmentally regulated method to treat Puma Energy's wastewater. PRASA was contacted to fully understand their regulations so that Puma Energy could discharge the water into the sewer system with their new treatment method. Finally, the ethics of our decisions had to be factored in to conduct a fair, informational, and detailed product without harming Puma Energy's image or our relationship with the company.

4.0 Results

Effectively providing Puma Energy with the proper advice and recommendations required us to weigh all of the proposed treatment options. We used information obtained from interviews with the WPI Professor, Puma Energy, and PRASA to communicate our needs to manufacturers for a new treatment method. We represented Puma Energy as engineering consultants by understanding their current treatment system and addressing outside manufacturers to retrieve cost estimates. The results from the manufacturing companies were evaluated and analyzed, allowing us to recommend a new system to the Bayamón terminal.

4.1 WPI

From the interview with the WPI professor, found in Appendix V, we gained better insight into how to analyze the water quality report from Puma Energy. We reviewed typical contaminants in the PCW such as organic and inorganic compounds. These are commonly found in wastewater and can be removed by methods including activated carbon filtration and chemical treatment. The WPI professor suggested that we look into the specific effects that each individual contaminant could have on humans and the surrounding environment.

We learned basic knowledge of batch treatment systems and methods to remedy contaminated water. According to the WPI professor, physical treatment is an important first phase, especially in Puma Energy's case of dealing with petroleum byproducts. Physical treatment occurs when oil is separated from water using membranes. Since many oil byproducts are not soluble in water, they get caught in the membrane and can then be manually removed. Devices called decanters are also commonly used in physical treatment. Because of different densities, gravity separates the oil and water into two different layers. The settled water on the bottom can be taken out and treated. We were advised to look into decanters as means of physical treatment to extract the water from the storage tanks. With the information we provided, the WPI professor mentioned that we should focus more on physical and chemical based systems because, for our purposes, biological treatment may not be the best option. We followed the professor's advice by looking into physical and chemical systems, but we found that many batch systems include biological treatment instead of chemical. Based on availability of systems and treatment methods for specific contaminants, we concluded that a biological system would sufficiently manage Puma Energy's PCW.

4.2 Puma Energy

Throughout the course of this project, Puma Energy provided us with a large amount of information and answered any questions we had. We received a detailed water quality report of contaminants in the PCW, learned about the isolation of PCW at the terminal, and were given contact information for the PRASA permitting organization. All of these deliverables from Puma Energy were a great asset to our team to propose a new treatment system.

4.2.1 Water Quality Report

During our interview with the HSSE at the Bayamón terminal, we requested a water quality report to help us in our research. Our contact offered to send us detailed data from Puma Energy's Guaynabo terminal. The information from this report is summarized in Figure 4.1 and the transcript of this interview can be found in Appendix VI.

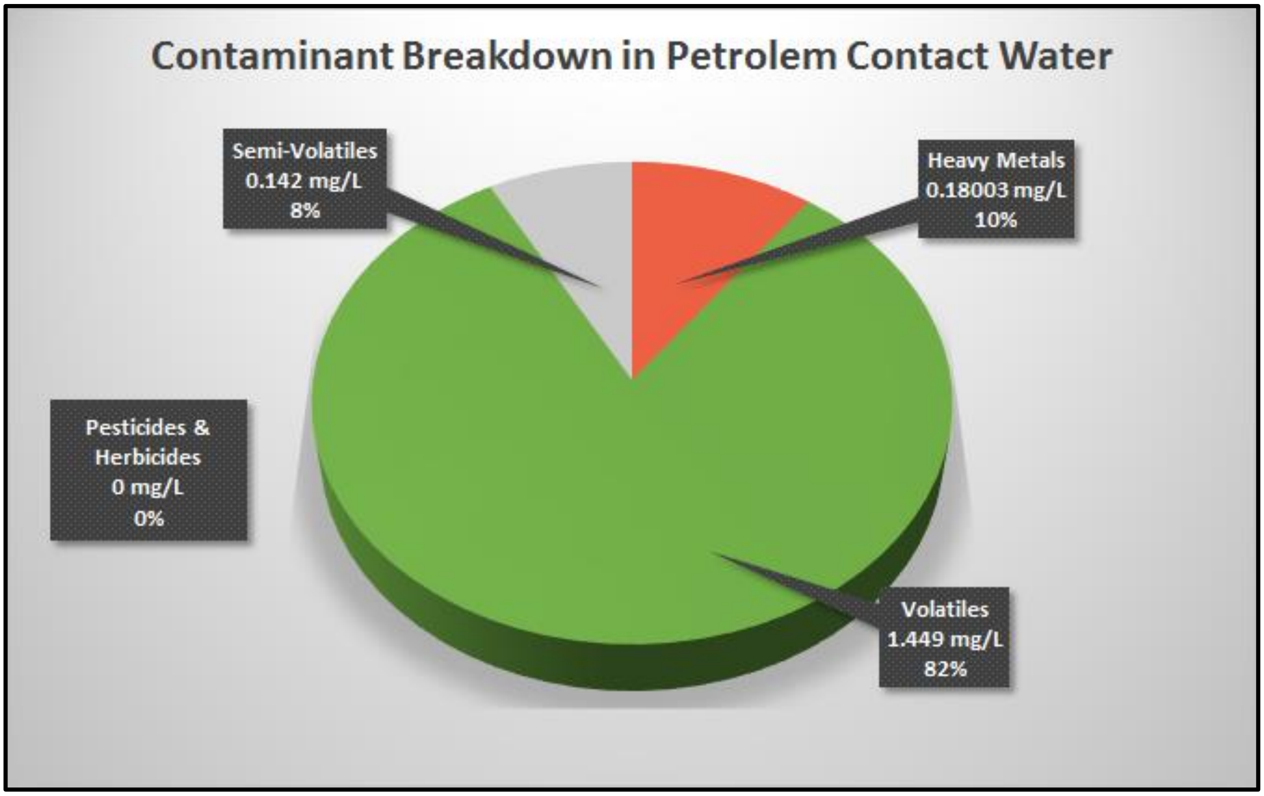


Figure 4.1: Major contaminants from the Guaynabo water quality report

From this interview with the HSSE, we gathered that there are heavy metals, volatiles, semi-volatiles, pesticides and herbicides in the PCW. The data received allowed us to analyze each individual contaminant in the PCW, which helped us to narrow our search for proper treatment methods as we advanced through the project.

4.2.1.1 Analyzing Contaminants

The report categorized each contaminant into five major divisions, including: heavy metals, volatiles, semi-volatiles, pesticides, and herbicides. We looked into the effect that each division has on humans and the environment near the disposal site.

4.2.1.1.1 Heavy Metals

Heavy metals present in Puma Energy's PCW, such as cadmium, chromium, lead and mercury, impact humans and the environment. Cadmium can damage the lungs if it is inhaled in significant amounts. Ingestion of chromium can cause skin irritation and ulcers. This is common in areas such as San Juan Bay because water can easily enter the mouth while swimming. Lead and mercury can impact every organ in the body causing major brain and kidney damage if the exposure is significant enough (S. Martin & Griswold, 2009).

4.2.1.1.2 Volatiles

Volatiles (VOCs) are organic compounds that easily vaporize. At Puma Energy's Guaynabo terminal, some VOCs include benzene, tetrachloroethylene, and chloroform. As a whole, VOCs can have varying effects on humans depending on exposure levels. Short term exposure can cause eye irritation, headaches, and dizziness. Long term exposure can cause liver, kidney, and central nervous system damage. Also, some VOCs such as benzene and tetrachloroethylene are known human carcinogens, leading to the growth of cancer cells in the human body (U.S. National Library of Medicine, 2015).

4.2.1.1.3 Semi-Volatiles

Semi-Volatiles, known as SVOCs, were also found in Puma Energy's PCW. Most of the compounds that were tested for were not at detectable limits but o-cresol, m-cresol and p-cresol were present. As a whole, SVOCs are similar to VOCs in the sense that they are compounds that easily vaporize. Less is known about SVOCs because they are more challenging to measure than typical VOCs ("SVOCs and Health," 2015). Cresol, the only SVOC detected in the water quality report, has some minor human impacts if the exposure is large enough. Respiratory issues and skin irritation are the two leading reactions to cresol exposure (US EPA, 2015).

4.2.1.1.4 Pesticides and Herbicides

Pesticides and herbicides were grouped together in the water quality report, and both categories turned up a series of “no detect” compounds meaning they were not at high enough levels to measure. In general, pesticides pose more issues to humans and herbicides have more environmental damage potential. Pesticides have varying effects including birth defects, carcinogenic tendencies, and eye and skin irritation (U.S. National Library of Medicine, 2015). Herbicides on the other hand tend to interfere with plant enzymes and have a larger effect on aquatic organisms (Lah, 2011).

4.2.1.1.5 Summary

A summary of the contaminants in the PCW and their effects can be found in Table 4.1.

Contaminant	Effects on Humans
Heavy Metals	• Lung Damage • Skin irritation • Ulcers • Brain Damage • Kidney Damage
Volatiles	• Eye irritation • Headaches • Dizziness • Liver Damage • Kidney Damage • Central Nervous System Damage • Carcinogenic
Semi-Volatiles	• Respiratory issues • Skin irritation
Pesticides	• Birth Defects • Carcinogenic • Eye Irritation • Skin Irritation
Herbicides	Environmental Problems • Interfere with plant enzymes • Affect aquatic organisms

Table 4.1: Contaminants and their effects on people and the environment

Analyzing each group of contaminants was a necessity to grasp the scale of the Puma Energy's problem. Without knowing the side effects of the contaminants, we could not fully comprehend the importance of removing them with a sound treatment method.

4.2.2 Isolating PCW

The HSSE at the Bayamón terminal supplied us with information on their current constant flow system and the contact water that Puma Energy accumulates. After arriving at the terminal, we learned of the petroleum recovery units attached to each tank which act as decanters. The water and oil separate because of gravity and the decanters remove the contact water from the storage tank. The water is stored in a separate tank with a maximum capacity of 25,000 gallons. The frequency of treatment varies with weather and stored products. Heavy rain will produce more PCW through seepage. Also, if the petroleum product in the storage tanks needs to be changed, the tanks must be thoroughly cleaned. This cleaning leaves residual water in the tanks, leading to more PCW. Our sponsor informed us that this PCW would then need to be treated by the proposed batch system approximately once a month, as opposed to the current constant flow system.

4.2.3 PRASA Contacts

The HSSE supervisor helped us obtain PRASA contacts and regulation documents to get the permits needed to discharge to the sewer system. The regulation information, found in Appendix VIII, was especially helpful along with the water quality report, found in Appendix IV. When we reached out to manufacturers of batch systems, we were able to supply them with a summary of this information so they could provide us with a proposed treatment system to meet the regulations.

4.2.4 Summary

Puma Energy supplied us with valuable information to complete the project. The water quality report was important because it outlined the contaminants in the PCW. With this information we could research the effects of these pollutants on humans and understand the importance of a new treatment option for the terminal. The HSSE supervisor at the terminal explained their current method for removing the PCW, the accumulation details, and potential frequency of the new batch treatment system. The HSSE also provided us with a contact at PRASA so we could start communication regarding the discharge of treated PCW into the sewer system of Puerto Rico.

4.3 PRASA

In our interview with PRASA, found in Appendix VII, we were informed that our cost questions could be answered only after Puma Energy fills out an application to get an official PRASA connection. The cost of the permit varies depending on the amount of water released into the sewer. We could not move forward in obtaining PRASA permit cost estimates until Puma Energy fills out the application and questionnaire regarding the water they are planning to dispose of into the sewer system. Because of this lack of information, we decided to research discharging fees in other states.

We found that in Salt Lake City, Utah it costs $0.00116 per gallon while in Atlanta, Georgia it costs $0.0174 per gallon for sewer discharge (Walton, 2010). In Puget Sound, Washington it costs $0.003579 per gallon (King County Industrial Waste Program, 2015). We analyzed these expenses to come up with a cost estimate that Puma Energy could expect to pay per gallon discharged. The estimates we found were averaged to $0.0074 per gallon. This average does not reflect the direct expense from PRASA to discharge water. After computing the average cost per gallon of the locations we researched, we were able to arrive at an estimated monthly and yearly fee to discharge to the sewer system. To discharge 25,000 gallons, based off of our estimate, it would cost Puma Energy $185 per month. This equates to a yearly fee of $2,220. Our calculations can be found in Figure 4.2.

Salt Lake City, Utah: $0.00116 /gallon

Atlanta, Georgia: $0.0174 /gallon

Puget Sound, Washington: $0.003579 /gallon

Average cost for sewer discharge = [Σ (Salt Lake City + Atlanta + Puget Sound)] / 3

Average cost for sewer discharge = [($0.00116 + $0.0174 + $0.003579)] / 3

Average cost for sewer discharge = $0.0074 /gallon

Monthly Cost = (Average cost for sewer discharge) * (gallons discharged per month)

Monthly Cost = ($0.0074) * (25,000 gallons)

Monthly Cost = $185.00

Yearly Cost = (Monthly Cost) * (Months per year)

Yearly Cost = ($185.00) * (12)

Yearly Cost = $2,220.00

Figure 4.2: Calculations for permit expense estimates

In addition, our connection at PRASA sent us the local limit regulations for Puma Energy's terminal. The PRASA permit has particular regulations to follow based on location, meaning many parts of the island must follow different standards. For Puma Energy's Bayamón terminal, the treated PCW will have to follow the regulations of the Puerto Nuevo Regional Waste Water Treatment Plant. These water quality regulations can be found in Appendix VIII. A summary of these local limits can also be found in Table 4.2.

Local Limits for **Puerto Nuevo RWWTP** [Effective since April 1, 2003]

Parameter	Local Limit (mg/L)
Oil and Grease	50.0
Arsenic	0.75
Biochemical Oxygen Demand (BODs)	250
Cadmium	0.077
Cyanide	MO
Zinc	MO
Copper	0.50
Chromium (hexavalent)	MO
Chromium (Total)	0.50
Mercury	0.02
Nickel	0.50
Silver	MO
Lead	0.10
Phenols (mg/L)	MO
Selenium	0.306
Thallium	13.3
Total Suspended Solid (TSS)	250

Additionally Generally-Applicable Local Limits

pH	6.5-9.0
Temperature (°C)	40
Flashpoint (°F)	>140
Total Toxic Organics (TTO) (mg/L)	MO

MO – Monitoring Only

Table 4.2: Local limits for discharge of Puma Energy's PCW

By providing a summary of these local limits to manufacturers, they were able to ensure that their system would meet Puma Energy's needs.

4.4 Manufacturers

As stated in the methods section, we reached out to a number of manufacturers in order to get cost estimates on a batch treatment system for Puma Energy. After receiving cost estimates from three companies, we conducted an analysis on each vendor based off of 5 metrics: cost of system, company size in terms of employees, location of manufacturer, communication with our team, and years in the market of batch systems. These metrics allowed us to assign each manufacturer a numerical score out of 25 possible points.

The three companies that provided cost estimates were then ranked using our devised metrics. Due to the confidentiality mentioned in our IRB form, names of companies have been omitted and replaced with the titles 'Vendor 1', 'Vendor 2', and 'Vendor 3'. Information on manufacturers can be found in Appendix IX.

4.4.1 Vendor 1

Vendor 1 received an overall score of 19/25 on our rating scale. After reaching out to us, the vendor requested to see Puma Energy’s water quality report to understand if their system could meet the local limits. We sent them a spreadsheet summary of the report and received a cost estimate for a batch treatment system. Vendor 1 produced a cost estimate of $184,000, giving them a score of 1 on our metric rating scale. This cost estimate included the design, manufacturing, implementation, and training fees associated with the new system. In terms of company size, Vendor 1 scored a 5 on our metric scale. After some research, we learned that Vendor 1 employs well over 50 people, making them one of the larger companies that we reached out to. More employees allowed for us to have easier communication with the company because they were able to devote one contact to us to answer any and all questions we had pertaining to the company and their system.

Vendor 1 scored a 4 on location as well. The company is located approximately 1,500 miles away from the Puma Energy terminal. The manufacturer expressed that they would be able to ship a system to us but was unable to present a cost estimate for the importation. The proximity to the terminal made this system a feasible option. Communication with Vendor 1 was also considered to be above average, leading to another score of 4 on our rating scale. We were able to discuss the system on the phone multiple times with our contact at Vendor 1. After discussing the system, we sent multiple emails and received responses to our questions in a very timely fashion. Vendor 1 also scored highly on the 'Years in the Market' metric. Their score of 5 comes from being experienced in the industry for over 40 years. A summary of the overall scores of Vendor 1 can be seen in Figure 4.3.

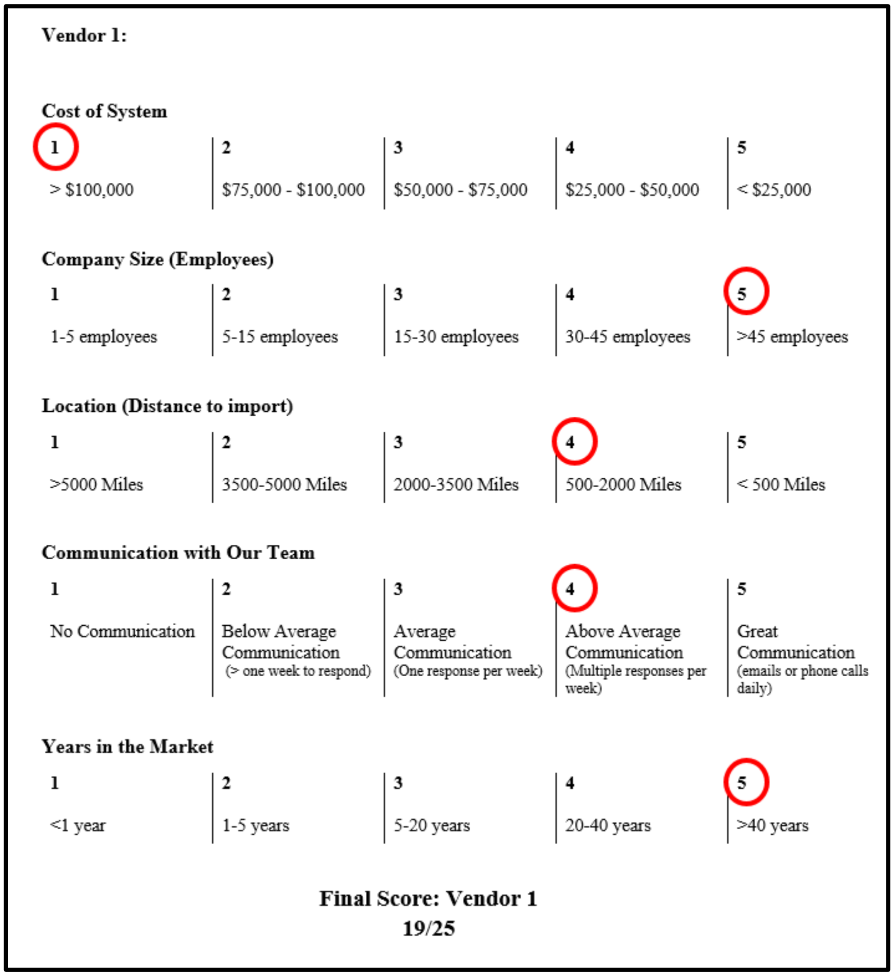


Figure 4.3: Metric rating scores for Vendor 1

The batch treatment system proposed by Vendor 1 would treat Puma Energy's water to sufficient levels to meet the local discharge limits at the Puerto Nuevo facility. Vendor 1 suggested a system that treats 2,000 gallons of PCW per day. The water would go through a physical treatment phase where solids are filtered out and excess oil is separated from the water. The PCW would then move to a carbon filter to remove any organics, oils, and greases. The added carbon filter feature would also help to remove extra VOCs and any odor from the treated water. Finally, the system would contain a pH meter that would allow for the adjustment of the acidity of the water to meet limit requirements. Overall, the system from Vendor 1 provides room for adjustments on each individual batch of water to be treated. Should the pH levels of PCW from each batch be drastically different, the system provided would have the capability to adjust it. Vendor 1 proposed a very adaptable system to be able to treat a wide variety of contaminants in Puma Energy's PCW.

4.4.2 Vendor 2

Vendor 2 received a final score of 16/25 based on our metrics analysis. The manufacturer provided us with a cost estimate of $85,000, earning a score of 2 for the 'Cost of System' metric. In terms of company size based off of employees, Vendor 2 scored a 5. They employ over 50 people, which is an acceptable number for our metrics. Vendor 2 is located very far away from the Puma Energy terminal. Because the system would need to travel just over 4,600 miles to get to the Bayamón facility, the cost for importation would be quite high. This location gave Vender 2 a score of 2. Communication with Vendor 2 was initially quick and informative, but as the process of system research continued communication began to decline. Vendor 2 received a score of 2 for communication with our team. They responded within a day after our initial contact, and provided a cost estimate within a week. After we received the cost estimate, we reached out with questions and never received answers. Communication was considered below average. Vendor 2 scored high on the 'Years in the Market' metric. Because they have been designing and producing batch systems for over 50 years, Vendor 2 received a 5 on this metric. A summary of the overall score for Vendor 2 can be seen in Figure 4.4.

Vendor 2:

Cost of System

1	(2)	3	4	5
> $100,000	$75,000 - $100,000	$50,000 - $75,000	$25,000 - $50,000	< $25,000

Company Size (Employees)

1	2	3	4	(5)
1-5 employees	5-15 employees	15-30 employees	30-45 employees	>45 employees

Location (Distance to import)

1	(2)	3	4	5
>5000 Miles	3500-5000 Miles	2000-3500 Miles	500-2000 Miles	< 500 Miles

Communication with Our Team

1	(2)	3	4	5
No Communication	Below Average Communication (> one week to respond)	Average Communication (One response per week)	Above Average Communication (Multiple responses per week)	Great Communication (emails or phone calls daily)

Years in the Market

1	2	3	4	(5)
<1 year	1-5 years	5-20 years	20-40 years	>40 years

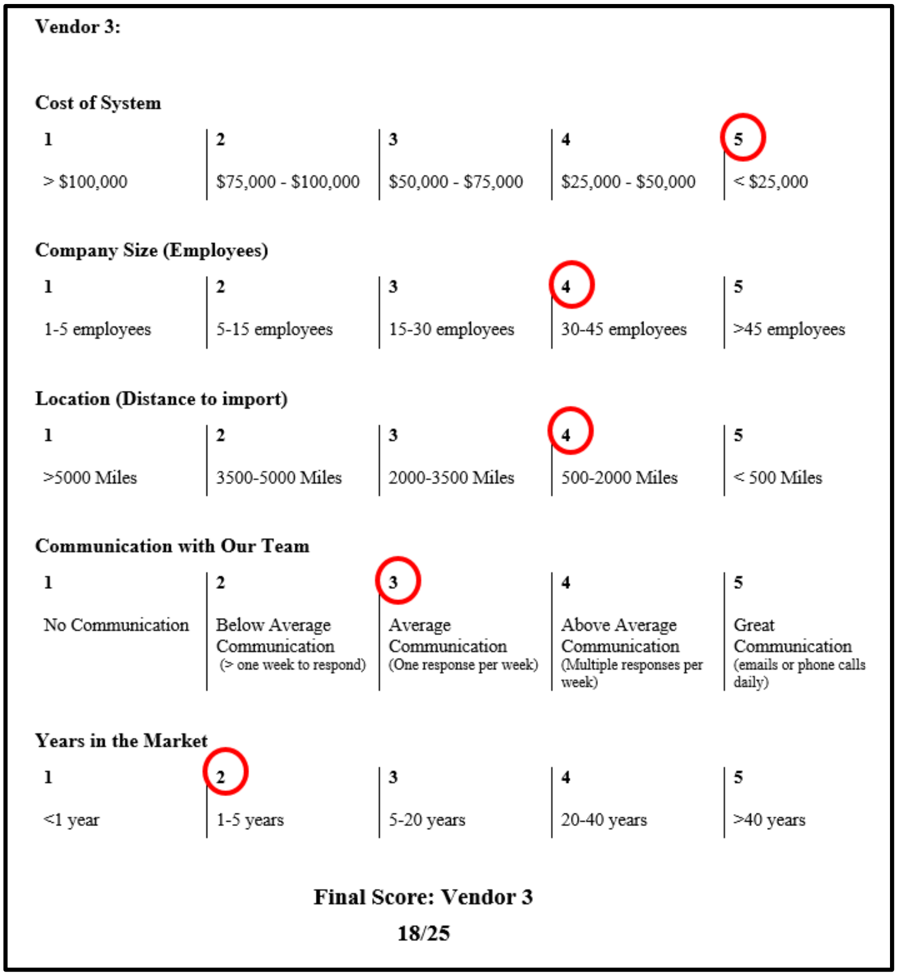
Final Score: Vendor 2
16/25

Figure 4.4: Metric rating scores for Vendor 2

Vendor 2 suggested one of their sequencing batch reactor treatment systems. The system would be able to treat our 25,000 gallons per month, but a flow rate was not specified. The PCW would enter the system and free oil and grease would be removed with an oil skimmer as a means of physical treatment. Dissolved oil would then be removed with three "ultra-filtration units." Vendor 2 guaranteed that the oil level in Puma Energy's PCW would be below 20 mg/L, meeting the local limits. The solids removed from the PCW would need to be removed by an external waste management company as oil sludge.

4.4.3 Vendor 3

Vendor 3 received a final score of 18/25 based on our metric rating system. This manufacturer presented us the cost estimate of $15,000, leading to a score of 5 for the 'Cost of System' metric. In terms of company size, Vendor 3 received a score of 4 because they employ approximately 40 people. Similar to Vendor 1, Vendor 3 scored a 4 in the 'Location' metric. The system would need to be shipped just over 1,900 miles to the Puma Energy terminal. Vendor 3 provided average communication with our team. They did not respond at first, but after we reached out multiple times we received our first contact with the company. After sending them a summary of the water quality report and the local limits that we had to meet, we received the $15,000 cost estimate and a system summary. We responded with follow up questions that were never answered. Essentially, we received average communication for about two weeks, then no communication. This led to a score of 3 for the 'Communication with Our Team' metric. Vendor 3 scored the lowest of the three rated manufacturers in the 'Years in the Market' metric. Because they have only been an established company for just under 5 years, Vendor 3 received a score of 2. A summary of the rating score for Vendor 3 can be seen in Figure 4.5.



Vendor 3:

Cost of System

1	2	3	4	5
> $100,000	$75,000 - $100,000	$50,000 - $75,000	$25,000 - $50,000	< $25,000

Company Size (Employees)

1	2	3	4	5
1-5 employees	5-15 employees	15-30 employees	30-45 employees	>45 employees

Location (Distance to import)

1	2	3	4	5
>5000 Miles	3500-5000 Miles	2000-3500 Miles	500-2000 Miles	< 500 Miles

Communication with Our Team

1	2	3	4	5
No Communication	Below Average Communication (> one week to respond)	Average Communication (One response per week)	Above Average Communication (Multiple responses per week)	Great Communication (emails or phone calls daily)

Years in the Market

1	2	3	4	5
<1 year	1-5 years	5-20 years	20-40 years	>40 years

Final Score: Vendor 3

18/25

Figure 4.5: Metric rating scores for Vendor 3

Vendor 3 suggested a specific model of their treatment systems that would process 2.6 gallons per minute for 8 hours a day for 20 days a month. At this flow rate, the system would be able to sufficiently handle Puma Energy's 25,000 gallons of PCW per month. This flow rate could be achieved with Vendor 3's smallest system. The system uses primarily physical filtration to meet all limits. The downside to this batch treatment system is that it must be manually cleaned after use. The filters must be taken apart and there is no information on what to do with the material that is removed from the filters.

4.4.4 Summary

Each manufacturer that we received a cost estimate from was given a score on a scale of 25. This score came from five metrics that we devised to analyze each company. A summary of the final scores can be seen in Table 4.3.

Manufacturer	Final Score
Vendor 1	**19/25**
Vendor 2	**16/25**
Vendor 3	**18/25**

Table 4.3: Final scores for each vendor

After rating each company, we decided that the vendor with the highest score would be the system that we recommended to Puma Energy.

We had initially intended on providing a cost summary of many aspects of a new system to Puma Energy. We planned on getting expense estimates on importation, maintenance, and labor required for installing and continuously running the system. Due to the time constraints of the project, we were unable to receive any estimates on these factors from Vendors 2 and 3. We were not provided enough data on each system to be able to calculate an import cost. We also were not provided data on maintenance requirements or labor requirements to implement the system. Because of these factors, we could not present thorough cost of system metrics. The cost estimates are solely based on the expenses for the systems themselves from Vendors 2 and 3. Vendor 1, on the other hand, provided an extremely high estimate. However, it contains certain factors that the other quotes do not. Vendor 1 provided a detailed list of what the $184,000 would entail. This quote included the cost of the system, manufacturing, implementation, water testing, and operator training for the system. The proposed system from Vendor 1 does seem very costly, but it includes many special factors that the other vendors did not offer.

5.0 Recommendations

In this section, we provide our overall recommendations for Puma Energy based on our results from this project. Our final conclusions were drawn from analysis and comparison of the results from the manufacturing companies that we reached out to. We also outlined future steps for Puma Energy to take in order to make a decision for future treatment of PCW at the Bayamón terminal.

5.1 New Water Quality Report

We recommend that Puma Energy ***take water samples of PCW from the Bayamón terminal***. In order for Puma Energy to implement our strategies, they should perform a water quality analysis from these samples. Initially, we received data from the neighboring Guaynabo terminal. Although we were told the data from the Guaynabo terminal was taken from an identical process to that of the Bayamón facility, it is in the best interest of Puma Energy that a new water quality test be performed. This data collection would ensure that the results from Bayamón are identical to those from Guaynabo. All of our research was performed with the water analysis from Guaynabo. If the contaminants do not match up perfectly with Bayamón, a different system may need to be considered which could affect system cost. Puma Energy must prove to PRASA that their contaminant levels are satisfactory to the local limit parameters outlined in Appendix VIII. We recommend that Puma Energy take water samples of PCW from the Bayamón terminal in order to ensure that our proposed system will meet PRASA regulations.

5.2 PRASA Permit Forms

We recommend that Puma Energy ***complete the PRASA application and questionnaire*** before initial discharge. Based on the interview we conducted with PRASA, we learned that the only way to receive a cost estimate for the discharge permit is to fill out these documents. The questionnaire is necessary to provide PRASA with more specific information on pretreatment of the PCW, and the application is necessary to receive a connection with PRASA and a more accurate cost estimate for a permit to discharge. These are to be completed in order to compare to the price of discharging with the NPDES permit to determine if discharging into the sewer system is a cheaper option. By completing these forms, Puma Energy will be able to get a definitive cost to discharge the PCW in their 25,000 gallon tank. We were only able to provide estimates on the monthly and annual cost to discharge the PCW. Completing the PRASA application and questionnaire is a critical step that we recommend Puma Energy takes in their decision process for a new batch treatment system.

5.3 Manufacturer's Scores

We recommend that Puma Energy ***contact Vendor 1 to follow up on a batch system quote***. We compiled each vendor's metric scores, and recommend Vendor 1 as the best option for Puma Energy. In terms of cost, Vendor 1 proposed a quote of $184,000, Vendor 2 proposed a quote of $85,000 for the system, and Vendor 3 proposed a quote of $15,000. Vendor 1 provided a reasonable cost estimate in relation to the overall product that they provided. Vendor 1 received a score of 19/25 on our metric scale, whereas Vendor 2 scored 16/25, and Vendor 3 scored 18/25. The communication level of Vendor 1's employees set them apart from the other manufacturers. They were very open with us about any questions or concerns we had, which we determined to be a great asset to Puma Energy moving forward. Vendor 1's responses from both phone and email were made in above-average time, which we believe would be a great help to a large corporation such as Puma Energy. In terms of location, Vendor 1 was the closest of the three manufacturers to the Bayamón terminal. Their proximity to the terminal should provide a more cost effective importation expense. Also, we were reassured by the fact that Vendor 1 had been in the market for over 40 years, proving that they have been able to maintain their business for a substantial amount of time. We firmly believe Puma Energy would have a good relationship with a company who knows the wastewater treatment market well.

Along with Vendor 1's system scoring the highest on our metric scale, it also has ability to meet the local discharge limits of the Puerto Nuevo facility. The systems that Vendors 2 and 3 provided would sufficiently treat the water to the specifications of PRASA's local limits, but extra costs and concerns make these options less favorable. Vendor 2's system would require the removal of the oil sludge from the PCW by an external waste management company. Exporting physical waste has an additional cost factor involved. Vendor 3 would require extra maintenance to manually clean the system after each use. We were not provided with information on how to properly dispose of the excess material, leading to questions about environmental issues. Vendor 1's flexibility in pH adjustment lead to a more versatile system. Their added carbon filter removes extra VOC's and eliminates odor, which is another added advantage of the system. These additions help to solidify Vendor 1 as our primary recommendation to Puma Energy.

We also recommend that Puma Energy ***account for new metrics including importation, construction, and maintenance fees***. In the time frame that we had to complete the project, we were unable to obtain these cost estimates, which would impact the overall price. Going forward, we recommend that Puma Energy take these new metrics into account before coming to a decision about their treatment system. Without having this data, the information that we received from Vendor 1 was the most in-depth of all the manufacturer's systems. Overall, Vendor 1's willingness to communicate with us, as well as the added benefits of their system and expertise in the market, make them a very clear primary recommendation.

5.4 Summary

The following are the final recommendations we have outlined for Puma Energy:

- **Take** water samples of PCW from the Bayamón terminal
- **Complete** the PRASA application and questionnaire
- **Contact** Vendor 1 to follow up on their batch system quote
- **Account** for new metrics including importation, construction, and maintenance fees

Should Puma Energy follow these recommendations, they could implement a system to satisfy all of their specifications.

6.0 Conclusion

We believe that Puma Energy can benefit from a new batch treatment system that will sufficiently treat their PCW. This batch system could save Puma Energy money and promote a clean environment in Bayamón. By following our recommendations, Puma Energy could implement this new system while following all government regulations. Success of this system could lead to implementation at other Puma Energy terminals, prompting an overhaul in wastewater treatment throughout the corporation. With the island's main petroleum provider running more efficiently, there is assurance that the people of Puerto Rico will continue to meet their energy needs for years to come.

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Appendix I: Industry and Waterways in Bayamón

Industry

Petroleum governs the power sector of Puerto Rico, as ⅘ of the energy usage on the island stems from it. The main users of this petroleum are the electrical and transportation divisions (U.S. Energy Information Association, 2015). However, Bayamón used to be a common growth area for sugar, tobacco, grapefruit, vegetables, and coffee (Rivera, 2015). The first hydraulic sugar mill in Puerto Rico was built in 1548, and was a crucial asset to the city. It was Bayamón's number one industrial establishment, above iron foundries, brickyards, ice plants, dairies, and an oil refinery (Rivera, 2015). When the mid-20th century came about, modern industries started to replace the older agricultural economy (U.S. Energy Information Association, 2015). The use of hydraulics throughout history shows Bayamón's heavy reliance on water as an energy source to power the more modern industries of Puerto Rico, such as tourism, manufacturing, and aviation. The waterways of Bayamón, and Puerto Rico as a whole, must be clean and up to standards to maintain the critical industries of the island. In terms of our project, Puma Energy must properly dispose of their petroleum contact water to maintain the health and wellbeing of the industry of Bayamón.

Waterways

Waterways must be properly maintained and cleaned to avoid contamination of the surrounding environment and aquatic organisms. There are five main rivers in Bayamón: the Bayamón, Hondo, Minillas, Bucarabones, and Cuesta Arriba (Rivera, 2015). Past issues with sewer runoff into such waterways has forced the island to take more action in cleaning rivers. To promote cleaner waterways, the Puerto Rico Aqueduct and Sewer Authority (PRASA) has come to an agreement with the U.S. Department of Justice and the U.S. Environmental Protection Agency (EPA) to upgrade, clean, and better inspect their sewer systems and facilities throughout the island. These upgrades and inspections will include improvements to wastewater treatment plants, as well as sludge treatment systems (J. Martin, 2015). This is directly related to the goal of our project because we want to dispose of the treated water into the sewer system. With cleaner waterways, the treated water would not be contaminated and would only benefit Bayamón, promoting a better industry in the city. With minimal runoff from sewer systems, the rivers would be cleaner and safer to use, thus maintaining the health of employees and customers, as well as the biodiversity that inhabits these waters.

Appendix II: Puma Energy

Puma Energy is a privately owned petroleum company with operations in both midstream and downstream business. They work closely with three shareholders and are funded mainly through retail services. These services focus on gas station and oil product sales, as well as sales to other independent distributors, retailers, and customers. Puma Energy has influence on many aspects of the petroleum business, including: storage units, marine systems, retail, aviation, lubricants, and liquid petroleum gas (LPG) (Puma, 2013). The company aims for global business and growth through high performance to promote their brand. They strive for less corporate influence by allowing local divisions to operate themselves in a style of management entitled “light touch” (Puma, 2013). Along with this method, they also aim to be transparent and accountable in all matters of business. Maintaining transparency and keeping open lines of communication helps gain the trust of customers, who can find putting faith in such a large oil company difficult.

Puma Energy is located on five different continents: Africa, South and Central America, Asia, Europe, and most recently Australia (Puma, 2013). Puma Energy has built a foundation that is quickly growing from a financial standpoint. In the past year, before tax, Puma Energy’s profits have risen 18%, from $551 million to $650 million. In general, Puma Energy is looking for more business opportunities, specifically larger markets with a need for substantial volumes of supply (Hoffman, Kennedy, Griffiths, & Monteiro, 2015). To reach such markets, Puma Energy is expanding globally. Recently, Puma Energy bought the British Petroleum aviation business in Puerto Rico. This purchase stems from Puma Energy’s partnership with many other world-leading airlines and their work with over 45 airports. These locations all have airport and into-plane operations that conform to regulations from both the JIG (Joint Inspection Group) and the IATA (International Air Transport Association) (PR Newswire, 2015). Success in the aviation business has aided in Puma Energy's global expansion by making them a more versatile petroleum company. If Puma Energy is involved in a large variety of business, new doors open in industry and expansion becomes an easier process.

Appendix III: Clean Water Act and Federal Regulations

Clean Water Act

Starting in 1948 with The Federal Water Pollution Control Act, the US government began regulating waste management and discharge into national waters. More specifically, the federal government assisted local governments with funding to take care of water pollution problems. The Clean Water Act (CWA) was established in 1972 to regulate pollution discharges into United States waters to better public health (US EPA RMD, 2015). Today, the Clean Water Act is made up of two distinct parts: provisions that authorize financial assistance for sewage treatment plant construction of municipal facilities, and regulations for industrial and municipal dischargers. Our proposed system for Puma Energy treats the contact water to a degree that follows parameters for it to be safely and properly disposed. Regulations such as the CWA are a necessity to promote cleanliness of the overall environment and to assure companies are in line with governmental regulations.

Federal Regulations

Puerto Rico and the United States Environmental Protection Agency have many regulations regarding national water quality. The Puerto Rico Water Quality Standards Regulation states that "the waters of Puerto Rico shall be substantially free from floating non-petroleum oils and greases as well as petroleum derived oils and grease." The Board of the EPA has the right to conduct tests of the discharges and polluted water of Puerto Rico whenever they feel necessary, and can intervene in the discharge of pollutants if they are affecting the quality of the water they are being released into (Commonwealth of Puerto Rico Office of the Governor Environmental Quality Board, 2014).

Appendix IV: Water Quality Report

Heavy Metals					
Parameter / Unit	**Result**	**Method**	**Method Detection Limit**	**Regulatory Limits (EPA)**	**Date of Analysis**
Arsenic, mg/L	<0.028	SW 846-6010	0.028	5.0	30-Jul-13
Barium, mg/L	0.18	SW 846-6010	0.035	100.0	30-Jul-13
Cadmium, mg/L	<0.033	SW 846-6010	0.033	1.0	30-Jul-13
Chromium, mg/L	<0.032	SW 846-6010	0.032	5.0	30-Jul-13
Lead, mg/L	<0.037	SW 846-6010	0.037	5.0	30-Jul-13
Mercury, mg/L	0.00003	SW 846-7470A	0.00001	0.2	26-Jul-13
Selenium, mg/L	<0.024	SW 846-6010	0.024	1.0	30-Jul-13
Silver, mg/L	<0.031	SW 846-6010	0.031	5.0	30-Jul-13

Hazardous Characteristics			
Ignitability	Sample does not exhibit the characteristics of ignitability according to the U.S. Envrionmental Protection Agency, Manual SW 846, "Test Mehtods for Evaluating Solid Wastes."	Method	Regulatory Limits
	Not Falmmable > 140°F	SW-846-1010	> 140°F
Corrosivity	Sample does not exhibit the characteristics of corrosivity according to the U.S. Environmental Protection Agency, Manual SW846 "Test Methods for Evaluating Solid Wastes"	Method	Regulatory Limits
	pH 6.15 S.U. at 20°C	SW-846-4500/9045/9040	2-12.5 (S.U)
Reactivity	Sample does not exhibit the characteristics of reactivity according to the U.S. Environmental Protection Agency, Manual SW846 "Test Methods for Evaluating Solid Wastes"	Method	Regulatory Limits
	Sulfide <10.0 ppm	SW-846-9030 / EPA 376.1	500
	Cyanide <1.0 ppm	SW-846-9030 / EPA 335.2	250

Contaminant	Result	Method	Method Detection Limit	EPA Hazardous Waste Number	Regulatory Limits (EPA)	Date of Analysis
Volatiles (mg/L)						
Benzene	0.119	SW 846-8260	0.01	D018	0.5	2-Aug-13
Carbon Tetrachloride	ND	SW 846-8260	0.01	D019	0.5	8/2/2013
Chlorobenzen	ND	SW 846-8260	0.01	D021	100.0	8/2/2013
Chloroform	ND	SW 846-8260	0.01	D022	6.0	8/2/2013
1,4-Dichlorobenzene	ND	SW 846-8260	0.01	D027	7.5	8/2/2013
1,2-Dichloroethane	ND	SW 846-8260	0.01	D028	0.5	8/2/2013
1,1-Dichloroethylene	ND	SW 846-8260	0.01	D029	0.7	8/2/2013
Methyl ehtyl ketone	1.33	SW 846-8260	0.5	D035	200.0	8/2/2013
Tetrachloroethylene	ND	SW 846-8260	0.02	D039	0.7	8/2/2013
Trichloroethylene	ND	SW 846-8260	0.01	D040	0.5	8/2/2013
Vinyl chloride	ND	SW 846-8260	0.01	D043	0.2	8/2/2013
ND = Not Detected						

Contaminant	Result	Method	Method Detection Limit	Regulatory Limits (EPA)	EPA Hazardous Waste Number	Date of Analysis
Semivolatiles (mg/L)						
o-Cresol (2-Methylphenol)	0.052	SW 846-8270	0.011	200	D023	7/30/2013
m+p Cresol (3-Methylphenol+4-Methylphenol)	0.09	SW 846-8270	0.032	200.0/200.0	D024/D025	7/30/2013
1,4-Dichlorobenzene	ND	SW 846-8270	0.013	7.5	D027	7/30/2013
2,4-Dinitrotoluene	ND	SW 846-8270	0.052	0.13	D030	7/30/2013
Hexachlorobenzene	ND	SW 846-8270	0.013	0.13	D032	7/30/2013
Hexachlorobutadiene	ND	SW 846-8270	0.016	0.5	D033	7/30/2013
Hexachloroethane	ND	SW 846-8270	0.02	3	D034	7/30/2013
Nitrobenzene	ND	SW 846-8270	0.014	2	D036	7/30/2013
Pentachlorophenol	ND	SW 846-8270	0.05	100	D037	7/30/2013
Pyridine	ND	SW 846-8270	0.037	5	D038	7/30/2013
2,4,5-Trichlorophenol	ND	SW 846-8270	0.02	400	D041	7/30/2013
2,4,6-Trichlorophenol	ND	SW 846-8270	0.037	2	D042	7/30/2013
ND = Not Detected						

Contaminant	Result	Method	Method Detection Limit	EPA Hazardous Waste Number	Regulatory Limits (EPA)	Date of Analysis
PESTICIDES (mg/L)						
Chlordane	ND	SW 846-8081	0.005	D020	0.0	30-Jul-13
Endrin	ND	SW 846-8081	0.00007	D012	0.0	8/1/2013
Heptachlor (and its OH)	ND	SW 846-8081	0.00007	D031	0.0	8/1/2013
Lindane	ND	SW 846-8081	0.00009	D013	0.4	8/1/2013
Methoxychlor	ND	SW 846-8081	0.00006	D014	10.0	8/1/2013
Toxaphene	ND	SW 846-8081	0.005	D015	0.5	7/29/2013
HERBICIDES (mg/L)						
2,4-D	ND	SW 846-8151	1.0	D016	10.0	7/30/2013
2,4,5-TP Silvex	ND	SW 846-8151	1.0	D017	1.0	7/30/2013
TOX, ppm	100	SW 846-9077	100	--	--	7/31/2013
ND = Not Detected						

Appendix V: Interview with WPI Professor

Date: October 15, 2015, 12:00 PM

Participants:
WPI (Interviewers): Evan Pereira, Brendan Johnson, and Erin LaBounty
PROF: WPI Professor

WPI: Alright now we're back, so that is the report from the Guaynabo terminal. So they [Puma Energy] have three terminals on Puerto Rico and that is one of the three. She [HSSE at Puma Energy] didn't have the info from our terminal at the time we talked to her.

PROF: Let me just look at these numbers here. Ok they are in milligrams per liter. So these are all low. And where does this come from? This is water that they use to rinse a tank?

WPI: So in their tanks, water accumulates in the bottom of them through seepage and different things, I'm not sure if they actually wash the insides of the tanks but there is a certain film of water on the bottom

PROF: Is it sea water?

WPI: We're not too sure. They have just said it is water that builds up on the bottom of a storage tank. Like it rains and it basically leaks in.

PROF: And this is fuel oil?

WPI: Yes, well they do a lot of petroleum products. They do lubricants, aviation fluid, marine fluid, and standard diesel and gas.

PROF: Ok so it could be any of those things?

WPI: Right so it could be any combination of those. But the way they have it right now is they have a refinery style system, which processes 500 gallons/minute which is pretty expensive to run for what they actually have for contact water. So they want us to come in and design a batch system.

PROF: Ok so just looking at these numbers the problem is…So what do you want to know, how can I help you? I have a lot floating around in my head but what questions do you have?

WPI: We could not make heads or tails of that analysis, We know common water contaminants in contact water just from research but we don't necessarily know what all of it means. We know for example suspended solids form a lot of buildup and create sludge and its unappealing but not necessarily harmful and we know hydrocarbons are not a good thing to mess with and a lot of carcinogens come out of the water and we don't know what levels are actually dangers and at what levels we start running into issues

PROF: Well in all of these chemicals here looking at the analysis, all of the chemicals have different hazards and different concerns. So arsenic has different concerns and cadmium, chromium all have different concerns. I meant they all have different concerns that would raise red flags if they are discharged. I mean looking at the analysis here, these numbers are pretty darn good. I mean obviously you want to remove more stuff before discharge but I mean I don't see anything huge. We're talking about things that are non-detects, a fraction of a milligram per liter. I mean there's some barium, 180 micrograms/ liter, yeah that might be a little high. And then some of these other things…cresol, that's one of the things that's detected but at low values. So you could do a search for each one of these to try to determine…I guess I would focus on the things that weren't non detects, the things that you picked up. You could do a search on each of these to figure out what is the concern with them. Health, environment etc. I mean some of these are carcinogens, lead has its own special concern but you're below detection limit. So that would be my advice. You're just going to have to do your digging. It's out there, it's in the literature so it shouldn't be that hard to find. It's on the EPA website so you can go and search for these.

WPI: Right and figure out all the impacts of each.

PROF: Yes and that would be good background research for your report.

WPI: Right so initially, before we had this [water quality report] we had to say it could be any of these six major pollution categories. Like we had to be very broad about what we were talking about. Like we looked into other case studies and we had to see how they interpreted their data.

PROF: See I would think that the VTEC compounds, benzene etc. are typically found in gasoline and I would expect them to be in a lot of petroleum products. I would have thought that those would have been here but it doesn't look like they checked for those. Did they not look into those?

WPI: We're not sure if they looked for them or if they don't want us to know if they are in there. That's our other issue is a breach of confidentiality. We're not sure what they will actually share with us and what we can in turn share in our report.

PROF: Yes I know I understand that.

WPI: Yes they sent us different disclaimers about confidentiality

PROF: Yeah I understand. But those VTEC compounds have some significant water solubility that's where if you have water in contact there you'd have some of those going into solution. You could look at a masters student I had a few years ago that looked at gasoline dissolution into water. If you search under master's graduate work under my name as the advisor you can find their work. Lewandowsky did the work. His was part experimental work and part modelling. And then looking at, that's when they were talking about using ethanol, so we were concerned about the co-solvent effects. I know you have a variety of petroleum products that could be in this tank but it could give you some of the things that can go into water from gasoline and maybe draw some parallels to what you're doing, so I would suggest that as a background information source.

WPI: Yes with break coming up that's a little easier to dive into right now too. Another question was can you give us a basic outline of what a batch system might be and how it would function? So they have an open flow system now.

PROF: For what?

WPI: I believe right now they categorize it as an open flow system. They weren't very specific as to what system they have now.

PROF: so like a decanter, oil separation tank style with oil on the top and water on the bottom? And it's a flow through continuous system?

WPI: I believe that is what they described. They have some basic screens, some clarifiers, and a bunch of different big machinery to help process. Essentially we believe they are looking to downsize to save money.

PROF: So they want to get away from that [big continuous system]?

WPI: Something they can treat as they see fit. Essentially a big oil company looking to save money where they can. They told us that the current system will process 500 gal/min and they don't need that much processing because they're not building up water at that high of a rate. I think they want to store it and run it through on their own power.

PROF: (pulls out book for more info on decanters) Flow through continuous decanters, centrifugal decanters and gravitational decanter. All are ways to help separate liquids of different specific gravity.

WPI: Ok great we will look into those.

PROF: So they want to go to a different process? Do they want a different process or a scaled down version or?

WPI: I guess that's where we come in. They want to scale down the process they have now, but we need to figure out what they actually want/need in their system.

PROF: There are a couple concerns. The first being an efficient scaled down separation process where you separate the two phases you have a petroleum phase and a water phase. You could certainly look at a decanter type of thing if they still wanted to go with it. I believe that they use membranes that would allow the water to pass and capture the petroleum product on the other side. I believe that there is ways that they do that. I've never worked with them so I don't have any first-hand experience but I believe you could do that just fine. You're looking for an oil water separator. You could just do a general search and see what is out there because you're not going to build a new technology you're going to see what's out there and what works. So that would be my recommendation for one part. But the other thing is the stuff that's dissolved in the water. So you separate the two phases which is a fairly easy thing to do, it's a physical separation, but now you have the petroleum products dissolved in your water. And there are various ways to address that. You have organics as well as inorganics. And a fairly limited list that they [Puma Energy] shared with you. So you need to figure out if you need to add a new process to remove things dissolved in the water and I would recommend that you talk to the treatment plant that it will be discharged to. Look into the discharge limits given by the sewer organization because they are going to have to follow the NPDES permit regulations, so see what they need in order to take their next step. They will tell you "here's what you can discharge and cannot discharge any higher". So I think you need a dialogue with them saying it will all be water waste with no petroleum products, but here are some of the things that could be there what should we do? Then you can look at what specifically do you need to do, if anything, to remove those things. So if it's some of the organic compounds, maybe activated carbon. If its inorganics maybe a bit of arsenic needs to be taken out, then you may be looking at ion exchange. I guess in my mind that is the direction I would go in if I were you.

WPI: Ok so chemical, biological treatments, see what takes what contaminants out?

PROF: Yeah, personally for this kind of stuff I would avoid biological. It sounds like it's going to be an intermittent type of thing. When they have a significant amount of water they are going to run it through and you're not going to keep a biological process viable for the time set that there's nothing going in there. So you're looking more physical/chemical.

WPI: Ok so our other factor is cost and we need to keep the system cost efficient. So we need to keep everything very efficient at low cost and give them a variety of solutions so they have some options so that will be another hard part to research. The cost of these batch systems, the cost of certain tanks and what not.

PROF: By batch system you mean they will have continuous flow once they start it but they are able to turn it off?

WPI: Yes like a big storage tank with a valve that you can open up when you need to run water and close it once you're finished. We don't know how long it will take them to build up enough water so for all we know it could take them a day or a month just to get enough buildup to make the system worth it. We just know the system they have now is continuous and the amount of PCW they produce is not worth it to run the way they do now.

PROF: Yep that makes sense. So these are my thoughts and I hope they have been helpful or at least steered you in the right direction.

Appendix VI: Interview with Puma Energy

Date: September 23, 2015 2:00 PM

Participants:
WPI (Interviewers): Evan Pereira, Brendan Johnson, and Erin LaBounty
PUMA: HSSE at Puma Energy

PUMA: Nice to meet you. Okay, [Bayamón terminal contact] is working, so he asked me to be here. So I work with the wastewater treatment plant stuff. You can talk to me about the project that you have.

WPI: Ok, so are you familiar with the project or do you want a little background first?

PUMA: Ok, I know (inaudible) but I don't know anything else. So you'll have to explain it.

WPI: Ok that would probably be helpful just to give you a little background. So, what we were tasked to do was come up with an environmentally sound solution to dispose of petroleum contact water while remaining cost efficient. So coming up with a few solutions to the problem and presenting them to Puma…and so we had a few questions in regards to the project. Our first question I guess is, we'd like to know more about the company in regard to Puerto Rico and the role the company plays in Puerto Rico. Just so we can get a little more familiar.

PUMA: Okay, we are a petroleum…..deal with petroleum products via storage of gasoline diesel and jet fuel. In the future maybe more, not sure. So we have storage of propane as well. We ship the products in tank trucks to the service stations that we have here. We distribute product to vessels at the dock. We have a private dock in Puerto Rico. That's mainly what we do

WPI: Ok. Uh so the project description mentioned that there were certain contaminants in the water and we were wondering if you had any more details as far as what contaminants you are dealing with and what volumes if you could add any specifics on that

PUMA: Ok actually we have an NPDES permit because we discharge the water into San Juan Bay. That permit is granted by the EPA which is still in Puerto Rico. We have an environmental quality board that regulates laws. Ok I have some parameters in that permit. I addition, we are in the process of reapplying for that permit through the EPA. And we are in that process now. So we have already some new parameters. If we start a new facility for treatment then we need to again apply for a permit to them. I already have some data about the parameters that we test right now. They are on file and I can send you some of them. Mostly the parameters that we have are grease, some metals such as mercury, but I can check the new parameters versus the old ones and send.

WPI: Ok that would be very helpful. Ok so, another question we had for you was what either current methods or past methods have you used as water treatment at your terminals?

PUMA: We have a tank that we separate the oil from the water, that's the physical treatment that we have. (Inaudible) API and CPI. And then we have two bioreactors, three clarifiers. And we have some bacteria for basically hydrocarbons. Then we have the (inaudible) [something about sulfates 6:35-6:40] and then we discharge the water.

WPI: Ok so is the issue that those methods, or part of that method isn't working? or…

PUMA: Well we are closing the wastewater treatment plant at this moment because in the past it was a refinery. So the plant was very big for our operation right now. Because it processed 500 gal/min right now. We never reach that flow. We are hoping for a batch unit, a small unit that we can operate in batch.

WPI: Ok so it wouldn't be a constant flow of water it would be more of a 'take it in doses' filtration system. Not a continuous flow system, but as the buildup occurs run it through?

PUMA: Yes more like that. We want to switch to batch because we are going to generate all the contact water at times. So we don't need the constant flow rate.

WPI: So it sounds like you're looking for something to use on site as opposed to using an outside source as far as using an outside company or agency to come in and help.

PUMA: Maybe. I mean perhaps yes we would like the facility to be on site

WPI: Are you, or have you been working with PRASA the Aqueduct and Sewer Agency in Puerto Rico?

PUMA: We were thinking that the new facility that we are going to have, this new treatment plan we are going to have, discharge into the aqueduct. That's what we hope for. Not to discharge into a lake or bay or something.

WPI: Ok do you have a contact with them or is it a basic collaboration?

PUMA: Well we need to apply for a permit with them to discharge the water. So it's like we want to discharge to your facility. I know some persons there but we need to apply for a permit.

WPI: Ok also we're curious as to roughly how many customers do you serve? Or your terminal serve? Just a rough estimate if you know. If not that's not a problem. Don't worry if you don't know.

PUMA: I really think that is something for [Bayamón terminal contact].

WPI: Ok yeah for sure. Is there any way we could get the emails from the Aqueduct and Sewer Authority as well just so we can ask questions and other stuff?

PUMA: I can check with the person that I know and maybe he can send me some contacts. For treatment because they have different agencies so can contact the person in that division.

WPI: Do you have any questions for us at the moment?

PUMA: Ok so you are going to work with and eventually propose a system with the treatment here. That is basically the project. I do not have a question right now. I need to send you the parameters that we have, the new permit, and some background of the resources that we already have. Do you need these right now?

WPI: As soon as possible would be great.

Appendix VII: Interview with Puerto Rico Aqueduct and Sewer Authority (PRASA)

Date: November 23, 2015, 9:30 AM

Participants:

WPI (Interviewers): Brendan Johnson, Evan Pereira and Erin LaBounty

PRASA: PRASA representative

PRASA: How can I help you?

WPI: We just had a couple questions in regards to the PRASA permit.

PRASA: Okay so Puma is trying to discharge to PRASA?

WPI: Correct.

PRASA: It's a process with water?

WPI: Correct. We're working for Puma trying to design a new batch system for them and they want the discharge from this batch system [to go to PRASA].

PRASA: Right now how does Puma discharge that water? Through NPDES?

WPI: Yes. So right now they have a continuous flow system and they want to change it to a batch system because they don't build up that much water so they want to run it at their own pace.

PRASA: Okay well first of all you have to fill out the questionnaire. Do you have it?

WPI: I do not.

PRASA: Okay so I can send it to you through email. There's a questionnaire that we call AAA715, it's a pretreatment questionnaire, where you put all the information that we need to know about that discharge. And the most important information there is what kind of water you use. Do you use water from PRASA or does Puma have a well. And then, how do you discharge it? How do you plan to discharge it? So Puma already has a connection with PRASA?

WPI: Right now no they're just in the beginning stages of trying to figure the whole process out.

PRASA: Puma doesn't discharge sanitary wastewater?

WPI: Not to PRASA no.

PRASA: So everything goes through the NPDES?

WPI: Correct and they want to switch that process.

PRASA: Okay, first of all you have to apply for a connection because you don't have it. The first step is to apply for a connection and that is with another office of PRASA. It is the public and private project office. I don't know if you are aware of that.

WPI: That's okay we'll look into it.

PRASA: They have an application and that is for the connection. You have to first get an approval connection and then we can apply for the treatment for the product discharge.

WPI: Okay I just have a couple quick questions just in general about the permit itself. Is there a rough cost to obtain the PRASA permit?

PRASA: For pretreatment, no. For connection, yes. There are some charges for the location so you pay one amount for the location depending how many gallons you need and the flow you need too to discharge. That information you can get from that office. I can tell you that they charge $500 per gallon. For example there is no fee to submit the application. For treatment, for the discharge permit, at this moment, we don't have any fees. For the connection, if Puma is not connected to PRASA to discharge the wastewater, that has a fee.

WPI: Okay. Alright, so I guess in order to figure out our specifics we need run through this application?

PRASA: First for the connection and second for the discharge permit.

WPI: Okay so we'll look into that and then we'll be in touch with any questions.

PRASA: Okay I will send you, if you want to, I can send you the application for the connection and the pretreatment questionnaire so you can have that information. And be aware that if you want to discharge to PRASA, the discharge has to comply with the local limits. If you are there you have to comply with the Puerto Nuevos wastewater treatment plant. The quality of the water you want to discharge to PRASA has to comply with the local limits so I can send you the parameters with the limits so you can have that information also.

WPI: That would be very helpful too. Thank you.

PRASA: Just to be clear I will send you the two applications, one for connection the other is pretreatment questionnaire for the discharge permit. I will send you also the local limits for Puerto Nuevo wastewater treatment plant.

WPI: Yes sir that would be very helpful. Thank you very much for your time.

Appendix VIII: Puerto Nuevo Wastewater Facility Local Limits

Autoridad de Acueductos y Alcantarillados

604 Barbosa Avenue
Hato Rey, PR 00917-4310
P.O. Box 7066, San Juan PR 00916-7066
Phone No. (787) 620-2277 Ext 2453, 2489
Fax (787) 620-3787

PRETREATMENT PROGRAM

LOCAL LIMITS FOR **PUERTO NUEVO RWWTP** EFFECTIVE SINCE APRIL 1, 2003

PARAMETER	LOCAL LIMIT (mg/l)
Oil and Grease	50.0
Arsenic	0.75
[1] Biochemical Oxygen Demand (BOD_5)	250
Cadmium	0.077
Cyanide	MO
Zinc	MO
Copper	0.50
Chromium (Hexavalent)	MO
Chromium (total)	0.50
Mercury	0.02
Nickel	0.50
Silver	MO
Lead	0.10
[2]Phenols (mg/l)	MO
Selenium	0.306
Thallium	13.3
[1]Total Suspended Solid (TSS)	250

Additional Generally-Applicable Local Limits

pH (E.U.)	6.5 - 9.0
Temperature (°C)	40
Flashpoint (°F)	>140
Total Toxic Organics (TTO) (mg/l)	MO

MO – Monitoring Only

1. The BOD and TSS limit is subject to a sewer surcharge for the excess above 250 mg/l in accordance with Article 2.10 of the PRASA Rules and Regulations.

2. Phenols will be calculated as the sum of the individual concentrations of toxic phenolic substances on the list of priority pollutants, analyzed using procedures in accordance with 40 CFR 136, Table 1C.

SEDE

Appendix IX: Manufacturer List

Antech-Gütling

Antech-Gütling provides integrated and environmentally sustainable solutions for water treatment and recycling. Their services start with system planning with pre and final assembly and extend to maintenance and service for their systems. They sell new plants, reliable sewage chemicals, service and training. They offer consultations as well as sale and production of the systems. They have experience in the market having sold over one thousand systems (Antech-Gütling, 2015).

US Centrifuge Systems

US Centrifuge Systems build, sell, and service centrifuge systems. These systems are for liquid-liquid separation, liquid-solid separation, liquid filtrations, and fluid clarification. Their machines are durable because they can generate forces up to 7,500 times gravity. Their products have the ability to remove solids at sub-micron levels. Their 700 operational centrifuges can be found in more than 30 countries (US Centrifuge Systems, 2015).

Beckart Environmental

Beckart Environmental supplies wastewater treatment systems worldwide. They assess clients to provide sufficient systems for their specific needs and further extend their services to supply chemicals and ongoing maintenance to keep their products fully functional. They have staff on five different continents (Beckart Environmental, 2013).

DMP Corporation

DMP Corporation provides lab services, engineering equipment, and a large variety of wastewater solutions. Their products use processes such as chemical and biological filtration and separation. They consult with clients and test the wastewater to create a system specific to the needs of the customer. After the installation process, they contact their clients at least two times a year to check on the system and provide maintenance when necessary (DMP Corporation, 2015).