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Improving Drinking Water Quality on Barro Colorado Island, Panama

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Improving Drinking Water Quality on Barro Colorado Island, Panama

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Abstract

This project was sponsored by the Panama Canal Authority in the Republic of Panama. The Panama Canal Expansion Project includes dredging, which has resulted in increased turbidity in the drinking water source for Barro Colorado Island, in Lake Gatun. This project's goal was to recommend a solution for providing potable water to the island. Through water quality testing and site investigations, alternatives were analyzed based on water quality, quantity, cost, and environmental impact. Importing water from the mainland was recommended.

Executive Summary

This project investigated water quality issues on Barro Colorado Island (BCI), located in Lake Gatun (part of the Panama Canal). The Smithsonian Tropical Research Institute (STRI), a research foundation on BCI, has reported problems with drinking water quality on BCI as a result of the Panama Canal Expansion Project dredging activities. In particular, the drinking water source at the intake in Lake Gatun has elevated levels of turbidity. STRI has been investing more than $20,000 annually to import potable water for drinking purposes. The objective of this project was to examine the current drinking water quality on BCI and assess the water supply needs of STRI in order to provide a feasible solution for their water quality problem.

Construction of the Panama Canal was started in 1881 by France, but was eventually abandoned due to design problems, lack of funding, and diseases affecting workers. The partially completed canal was eventually sold by France to the United States, who took over construction in 1904 and finished the project in 1913. The United States owned and operated the canal until 1999, when it was officially turned over to the Panamanian Government.

The Panama Canal is 83.7 kilometers (52 miles) long and is the shortest route to travel from the Pacific Ocean to the Atlantic. The canal is Panama's largest economic resource because it has become a center for world trade, transportation, and logistics. The canal consists of two channels on either side of Lake Gatun. Locks lead into each channel and control their water levels, raising ships up to Lake Gatun's height and then back down to sea level.

The Panama Canal is currently undergoing an extensive expansion project which began in 2007 and is expected to be completed by 2014. The expansion project is estimated to cost $5.25 billion. The goals of the expansion project are to: 1) achieve long-term economic sustainability and growth, 2) maintain competitiveness, 3) increase capacity, and 4) enhance the productivity, safety, and efficiency of the canal.

As part of the canal construction, the Chagres River was damned in 1914, which flooded the Chagres River Valley, and created Lake Gatun. BCI was formerly a hill in the valley, and then became an island after the valley was flooded. After the canal began operating, BCI became a permanent biological reserve. STRI was established in 1923 to provide research opportunities for long-term ecological studies of a variety of flora and fauna on BCI.

STRI draws water from Lake Gatun for their potable water needs. Periodically, the turbidity level of the raw water has been elevated, presumably due to the dredging in the canal. High turbidity in drinking water is a potential problem because particles may harbor microbiological contaminants that are harmful to human health or that decrease disinfection effectiveness. In Panama, turbidity measurements are used by drinking water utilities for process control and regulatory compliance and the maximum turbidity level for drinking water is 1.0 NTU. At BCI, the high turbidity caused failure of the drinking water treatment system, and forced STRI to import water from the mainland in five gallon jugs for drinking purposes.

Three alternative solutions for STRI's turbidity problem were proposed to the group by the Panama Canal Authority (ACP, Spanish acronym). The first alternative involved moving the water intake to a location where the source water would be least adversely affected by the dredging activities of the Canal Expansion Project. The second alternative entailed adding a system of sedimentation ponds before the filtration units in the water treatment system. Both alternatives would result in a lower turbidity in the influent. Also, they would both utilize the current water treatment system and no further improvements to reduce turbidity were expected to be necessary. The third alternative was to continue the transport of water from Gamboa to BCI, utilizing an improved transport system.

Specific Data were collected to evaluate the proposed alternative solutions to STRI's turbidity problem through reports from ACP and STRI, interviews and conversations, and field data collection. The reports contained information about: water quality testing data for Lake Gatun, water quality regulations, current BCI water quality issues, and the potable water transport system. The group held interviews and conversations with various members of ACP and STRI, as well as an engineer from E. T. Engineering Enterprises, Inc. Lastly, the group collected data in the field through water quality testing and a pipeline route investigation.

STRI's water treatment system consisted of a water intake near STRI's docks. From here, the water was pumped to a prefilter for removal of particulate matter, and then to a concrete storage tank. Next, the water flowed through filters and then was chlorinated and pumped into a metal storage tank, where it was stored before being distributed to STRI's facilities. Currently, STRI's filtration units are not operational because of the increased turbidity, so the water is only being chlorinated. This practice does not produce potable water for STRI. Therefore STRI has been spending $21,000 annually to import drinking water from Gamboa on the mainland.

Water quality testing in the Panama Canal channel in Lake Gatun showed high turbidity levels (up to 100 NTU) from August 2003 to December 2005, from January to December 2007, and in late 2009. The group conducted its own water quality testing at STRI’s current water intake location and three proposed intake locations. These alternative locations had turbidity levels of approximately 1 to 2 NTU, significantly lower than those for the current intake location and the channel in Lake Gatun (20 NTU). Possible pipeline routes that would connect the proposed intake locations to the current water treatment facilities were evaluated through field reconnaissance. The shortest route started at Wheeler Cove, in the south east region of the island, and traveled through the island to the treatment facilities.

The three alternatives were analyzed and compared based on the expected water quality, water quantity, cost of implementation, and environmental impact on the island. Moving the water intake would greatly improve the raw water quality. The cost of new piping and other construction materials would be approximately $67,000, and this alternative would have a significant negative environmental impact on the island from land clearing and construction. While installing sedimentation ponds would likely improve the raw water quality, the group was not able to acquire basic design data for this alternative. Transporting water from Gamboa would provide STRI with their minimum potable water needs (drinking water only) and, would not have any negative environmental impacts on BCI. However, water needs, including showering and laundry, would not be met with this alternative. ACP has supplied materials valued at $15,600 to import water in 200 gallon containers. The cost to construct this system is currently being estimated. While importing water currently costs STRI approximately $21,000 per year, the improved transport system is expected to have a significantly lower annual cost.

The group initially recommended moving the water intake to Wheeler Cove so that STRI would have access to a sustainable, better quality raw water supply in Lake Gatun that would meet all of STRI’s water quality needs. It was anticipated that STRI’s current treatment system on BCI would be able to treat the lower turbidity water. However, due to future dredging activities (expected to be completed by 2014), Wheeler Cove could be subject to increases in turbidity and these levels were unknown.

The group was informed in February 2010 that STRI had rejected the option of moving the water intake due to the significant adverse environmental impacts associated with construction of the pipeline on BCI. As a result, the group recommended that STRI implement the improved water transport system designed by ACP.

Acknowledgments

The group would like to thank Mr. Daniel Muschett of the Panama Canal Authority for agreeing to be the project sponsor. Professor Jeanine Plummer, of the Civil and Environmental Engineering Department of the Worcester Polytechnic Institute, is acknowledged for her guidance as an advisor. Additionally, the group would like to thank Professor Guillermo Salazar of the Civil and Environmental Engineering Department of the Worcester Polytechnic Institute for his assistance. The group would like to thank Hortensia Broce, Tomás Edghill, Melissa Alvarado, Luis Ferreira, Jorge Urriola, Guadelupe Ortega, Vielka Quijada, Jose Simmonds, Giancarlo Ciniglio, Marta Small, Denia Barrios, and Itzenith Vargas of the Panama Canal Authority. The group would also like to thank Oris Acevedo, Carlos Tejada, Walter Dillon, Sotero Campos, Apolonio Valdés, and Ricardo Racines of the Smithsonian Tropical Research Institute. Additionally, the group would like to thank Azu Etoniru of E.T. Engineering Enterprises Inc. The group would like to thank the WPI Alumni in Panama for making this project possible. Lastly, the group would like to thank its friends and family for their support over the course of the entire project.

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Chapter 1: Introduction

Construction of the Panama Canal was started in 1881 by France, but eventually was abandoned due to design problems, lack of funding, and diseases affecting workers, such as malaria and yellow fever. The construction project resulted in a large death toll and debt for the French Government. The partially completed canal was eventually sold by France to the United States, who took over construction in 1904 and finished the project in 1913. The United States owned and operated the canal until 1999, when it was officially turned over to the Panamanian Government.

The Panama Canal is currently 83.7 kilometers (52 miles) long. The canal is the shortest way to travel to and from the Pacific and Atlantic Oceans by eliminating travel around South America’s Cape Horn. It consists of two channels on either side of Lake Gatun, with locks leading into each channel. These locks control the water level in each channel, raising ships to the elevation of the lake and lowering them back down to sea level.

The Panama Canal is the country’s largest economic resource because it has become a center for world trade, transportation, and logistics. An expansion project began in 2007 and is expected to be completed in 2014 at a cost of $5.25 billion. The goals of this expansion project are to achieve long-term economic sustainability and growth, maintain competitiveness, increase capacity, and enhance productivity, safety, and efficiency of the canal. The expansion project consists of constructing two new lock complexes and new lock approach channels, and raising the maximum operating level of Lake Gatun. It is expected that the canal expansion will improve the national economy resulting in an improved quality of life for Panama’s citizens. While the canal expansion will provide many economic gains for Panama, the project introduces some environmental concerns.

One location that has been adversely affected by the expansion is Barro Colorado Island (BCI), located in Lake Gatun. The Smithsonian Tropical Research Institute (STRI) is located on the island and houses 200 to 400 researchers per year. In addition to these residents, the island receives about 4,000 visitors each year. Since the dredging activities for the canal expansion started, increased turbidity and color levels in the BCI drinking water intake have been reported. These measurements are indicative of high concentrations of solids. A pre-filter has been installed at the water intake to mitigate the problem, but the suspended solids levels remain problematic. As a result, BCI has been importing drinking water from the city of Gamboa at additional expense.

The purpose of this project was to evaluate alternatives for providing high quality water to BCI during the canal expansion. Several alternatives had been proposed, including: (1) moving the water intake to a location such that the water supply would not be directly affected by dredging activities, (2) installing a system of sedimentation ponds to allow for the settling of suspended solids prior to water treatment, and (3) maintaining the importation of drinking water from Gamboa. The following chapters provide background information relevant to this project, the methods and analyses used to gather data on water quality issues on BCI, and details on a recommended alternative for improving drinking water quality on the island.

Chapter 2: Background

This chapter contains background information about the Panama Canal. Topics include a history of the Panama Canal, the current canal, the expansion project, and Barro Colorado Island.

2.1 Panama Canal History and Construction

A canal in South America connecting the Atlantic and Pacific Oceans was envisioned as early as the 16th century. In 1513, Spanish explorer Vasco Nuñez de Balboa discovered that a narrow strip of land separated the Pacific and Atlantic Oceans at the Isthmus of Panama and would be an excellent location to construct a canal. Charles I of Spain initiated the first attempt to build a canal in Panama in 1534 by ordering a survey of a possible canal route through Panama along the Chagres River. Upon completion of the survey, the Spanish felt that it was not possible to build the proposed canal given contemporary technology of the time. It would not be until the late 19th century that construction of a canal would be attempted (Panama Canal Authority, 2009a).

2.1.1 French Construction Period

Towards the end of the 19th Century, French interest in a canal connecting the two oceans peaked and the Geographical Society of Paris organized a committee in 1876 to study the building of such a canal. The committee was lead by Ferdinand de Lesseps, a French diplomat with no engineering background. De Lesseps was the principal director of the Suez Canal in Egypt and his successes there earned him command of the new canal's construction (Panama Canal Authority, 2009a).

Many engineers and experts offered advice for the design of the canal transecting Panama. One such engineer was Baron Godin de Lépinay, the chief engineer for the French Department of Bridges and Highways. Lépinay thought a canal using locks and dams was the best alternative because it allowed minimal digging and minimized the danger of the Chagres River flooding during excavation. De Lesseps disagreed. His previous canal, the Suez Canal, had been a sea level canal. Because of its success, De Lesseps believed a canal in Panama could be a sea level canal as well (Gause, 1912). He didn’t take into account the differences in the tides of the Pacific and Atlantic Oceans and the fact that the Isthmus was not flat, but its elevation in the center was higher than its coasts. This proved to be a costly error for De Lesseps.

In a speech at the Geographical Society on May 23, 1879, De Lesseps revealed that there was no doubt in his mind that Panama was the right place to build the canal connecting the two oceans and a sea level canal was the only choice. He convinced the committee that his plan was the best option. On February 14, 1880, the International Technical Commission submitted a report verifying de Lesseps’ surveys and designs. Later it was realized that the review was conducted too quickly for such a large project and was technically insufficient but at that point it was too late (Panama Canal Authority, 2009a).

Construction on the canal began in 1881, but the project soon was plagued by inadequate equipment and work organization. The French excavation equipment was not adequate for the excavation work and disposal of the spoil (rock and soil) was handled inefficiently. Dump locations were too close to the excavation areas and slid back into the dug channel whenever it rained. As the channels were dug deeper, the steep walls began to slide into the channels. To solve this problem, the slope of the walls was decreased but this meant more soil needed to be excavated. Rock and stone were getting caught up in excavators, rendering them inoperable. To add to these difficulties, many workers were falling ill to yellow fever and malaria, leading to thousands of deaths (Panama Canal Authority, 2009a).

As the project progressed and continued to encounter problems, it became clear that the sea level canal was not going to succeed. Many engineers advised de Lesseps to adopt a canal system with 10 locks connecting a series of pools. After a great deal of stalling, de Lesseps agreed to adopt a design incorporating the locks in 1887. By 1888, portions of the canal were nearing completion and the first lock was almost ready for installation. However, the French resources for the canal ran out and de Lesseps could not secure any more money from the French public, so the shareholders decided to dissolve the company. Work on the canal ended in 1889 and the French abandoned the incomplete canal which had resulted in the deaths of over 20,000 workers (LaFeber, 1978). The partially completed canal remained unused for over 10 years until the United States took over construction of the canal (Panama Canal Authority, 2009a).

2.1.2 American Construction Period

President Theodore Roosevelt was responsible for American efforts to construct a canal in South America connecting the Pacific and Atlantic Oceans. Roosevelt saw the canal as a strategic naval necessity, allowing American fleets to quickly travel between the two oceans. He believed this would allow the United States to become a global power by achieving American naval supremacy. The U.S. considered many locations for a canal, including Nicaragua, New Granada, and Mexico, but they decided on Panama because of the already existing partial canal and the French eagerness to sell off their assets there. The Spanish-American War gave Roosevelt a prime example of the necessity of a canal. With the outbreak of hostilities in Cuban waters, the Battleship Oregon, stationed in San Francisco, was ordered to sail at once to the Atlantic to reinforce the American Fleet there (Major, 1993). The voyage took sixty-seven days and brought the Oregon from the Pacific Ocean, down around the Cape Horn of South America and into Atlantic waters just in time to participate in the Battle of Santiago Bay. This event demonstrated the need for an American controlled canal in South America so that the U.S. Navy could efficiently respond to threats in the Atlantic or Pacific Oceans (Panama Canal Authority, 2009a).

Roosevelt used Panama’s independence movement from Columbia to secure land on which to construct the canal. Roosevelt ordered American Naval forces to both coasts of Panama to prevent Colombian seaborne invasions and landed troops on the Isthmus to prevent land forces from invading Panama. Panama declared Independence from Columbia on November 3, 1903 with the signing of the Hay-Bunau-Varilla Treaty. The Panamanian government had little choice but to grant the United States a strip of land 10 miles wide on the Isthmus for the canal, over which the U.S. had complete sovereignty, because they required American military support to maintain their independence. Without this American support, Panama’s independence from Columbia is unlikely to have succeeded (Major, 1993).

In 1904, the U.S. bought the equipment and infrastructure that the French had left in Panama and immediately began construction. President Roosevelt appointed American Engineer John Findley Wallace as Chief Engineer for the project. Wallace discovered the remnants of the French equipment and facilities to be in complete disarray along the already excavated canal sections. Nevertheless, Wallace continued the work that the French had abandoned and began to encounter the same disease problems, namely malaria and yellow fever that began killing off his workers. For fear of his life, Wallace reluctantly resigned within a year and was replaced by John F. Stevens, a railroad builder. Stevens immediately stopped all excavation efforts and worked to build up a sufficient infrastructure to support the project and control the spread of malaria and yellow fever (The Panama Canal Museum, 2009).

Medical researchers of the day made the connection that the mosquito was a carrier of malaria and yellow fever in South America, so the key to fighting these diseases was to remove the mosquitoes. The U.S. efforts included screening windows and doors, fumigating houses in Panama City, and applying oil to stagnant water to kill the mosquito larvae. Large areas of swampland were drained, vegetation around the work sites was cut down, and insects and animals that fed on the mosquitoes and their larvae were released to destroy the mosquito breeding grounds (Panama Canal Authority, 2009a).

Stevens realized that Panama was not developed enough to support the laborers he needed to construct the canal, so he would have to bring all of the supplies, equipment, and food to Panama to sustain the project. Stevens utilized the Panama Railroad to distribute manpower, materials, and supplies and to haul excavated spoil from the canal. He also replaced the insufficient French equipment with the best available rolling stock. The entire railroad was overhauled to accommodate the canal’s demands and American railroad workers were brought in to operate it. Stevens also developed a complex, but highly efficient, train system comprised of tracks at various levels of the canal that hauled off the spoil on timed schedules coordinated with the level at which the excavation was taking place, allowing the steam shovels and trains to run as efficiently as possible (Panama Canal Authority, 2009a).

Stevens had entire communities constructed to house his work force. These communities included housing units, dining facilities, hospitals, hotels, schools, churches, storage, clubs, and laundries. Dirt roads were paved and city water and sewage systems were installed in Panama City and Colón, two major cities at both ends of the canal (Panama Canal Authority, 2009a).

Stevens was a major advocate of a lock canal in Panama rather than a sea level canal. He was able to successfully convince President Roosevelt to adopt the lock design for the Canal and worked to convince Congress of the same. Stevens spoke before the House of Representatives’ committee on Interstate and Foreign Commerce using his experiences of the Chagres River during flooding and advocated the need to be able to control the river, an ability that a sea level canal would lack. He also assisted Senator Philander Knox in preparing an address before the Senate on June 19, 1906 in which the canal's lock plan was the major subject. The Senate and House voted in favor of the lock design by a small margin and the design was put into place by Stevens (Panama Canal Authority, 2009a).

While construction progressed, President Roosevelt began to have a change in attitude towards the canal. He had begun the project with the feeling that the canal was of strategic importance for the United States, but he was now beginning to view it as a romantic battle that held the honor of the nation and its workforce in the balance. Roosevelt made a visit to the work site to personally inspect the progress of his project in November of 1906, being the first U.S. President to leave the States during his Presidency (Panama Canal Authority, 2009a).

Work on the Panama Canal was finished in 1913, during Woodrow Wilson's Presidency, as the locks were completed and the canal channel was finished (The Panama Canal Museum, 2009). The first complete passage of a ship through the Panama Canal occurred on January 7, 1914, when an old French crane boat used during construction, the Alexandre La Valley, travelled from the Atlantic side to the Pacific side using the locks (Panama Canal Authority, 2009a).

With the end of the canal construction, the workforce amassed for the canal was dissolved, the communities that were built for the workers were abandoned, and hundreds of buildings were disassembled or demolished. The Panama Canal was put under the authority of the Canal Zone Governor, an American confirmed by Congress to run the canal. The canal's construction cost 5,609 lives due to disease and accidents during the American involvement, and a total of over 25,000 including the French construction period. The Panama Canal cost the United States $375 million, making it the single most expensive construction project undertaken by the U.S. to date, and an extra $12 million was spent on the construction of fortifications. A total of 268 million cubic yards of spoil was excavated for the Panama Canal; 238 million by the Americans and another 30 million by the French (Panama Canal Authority, 2009a). The Panama Canal was officially opened to traffic on August 15, 1914 with the voyage of the SS Ancon (The Panama Canal Museum, 2009).

The Panama Canal stayed under U.S. control for many years. In 1977, President Jimmy Carter began negotiations with Panama for the eventual transfer of the canal from the United States to Panama. In 1978, the U.S. Senate voted in favor of turning the canal over to

Panamanian control on December 31, 1999 but immediately turning over the Canal Zone to Panama. On December 31, 1999, the Panama Canal was officially turned over to Panama who continues to operate it to this day (The Panama Canal Museum, 2009).

2.2 The Current Panama Canal

Today, the Panama Canal is an 83.7 kilometer (52 mile) long waterway connecting the Atlantic and Pacific Oceans at the Isthmus of Panama (The Panama Canal Museum, 2009). The canal runs from the Pacific Ocean, entering the Isthmus near Balboa and Panama City at the Miraflores Locks, through the Gaillard Cut and the Pedro Miguel Locks into Lake Gatun. From Lake Gatun, the canal travels through the Gatun Locks, then through another cut reaching the Cristobal Harbor in the Atlantic Ocean near Colón (see Figure 1). The canal utilizes three sets of locks to lift ships eighty-five feet above sea level to the Continental Divide, transport them across the Isthmus, and then lower them down to the sea level of the opposite ocean (LaFeber, 1978). No pumps are used in the Panama Canal; instead, culverts let water in and out of the canal. When water is let in, it raises the water level in the lock and lifts the ship. Water is also used to generate electricity to run motors which open and close gates, valves, and the lock locomotives (Panama Canal Authority, 2009a).

It takes about 8-10 hours for a ship to pass through the Panama Canal, compared to the 67 day journey the Battleship Oregon took around South America during the Spanish American War. At the end of the fiscal year 2006, over 900,000 vessels had traveled through the Panama Canal. Ships pay tolls to pass through the canal. These tolls are based on the type of vessel and the vessel’s volume (Panama Canal Authority, 2009b).

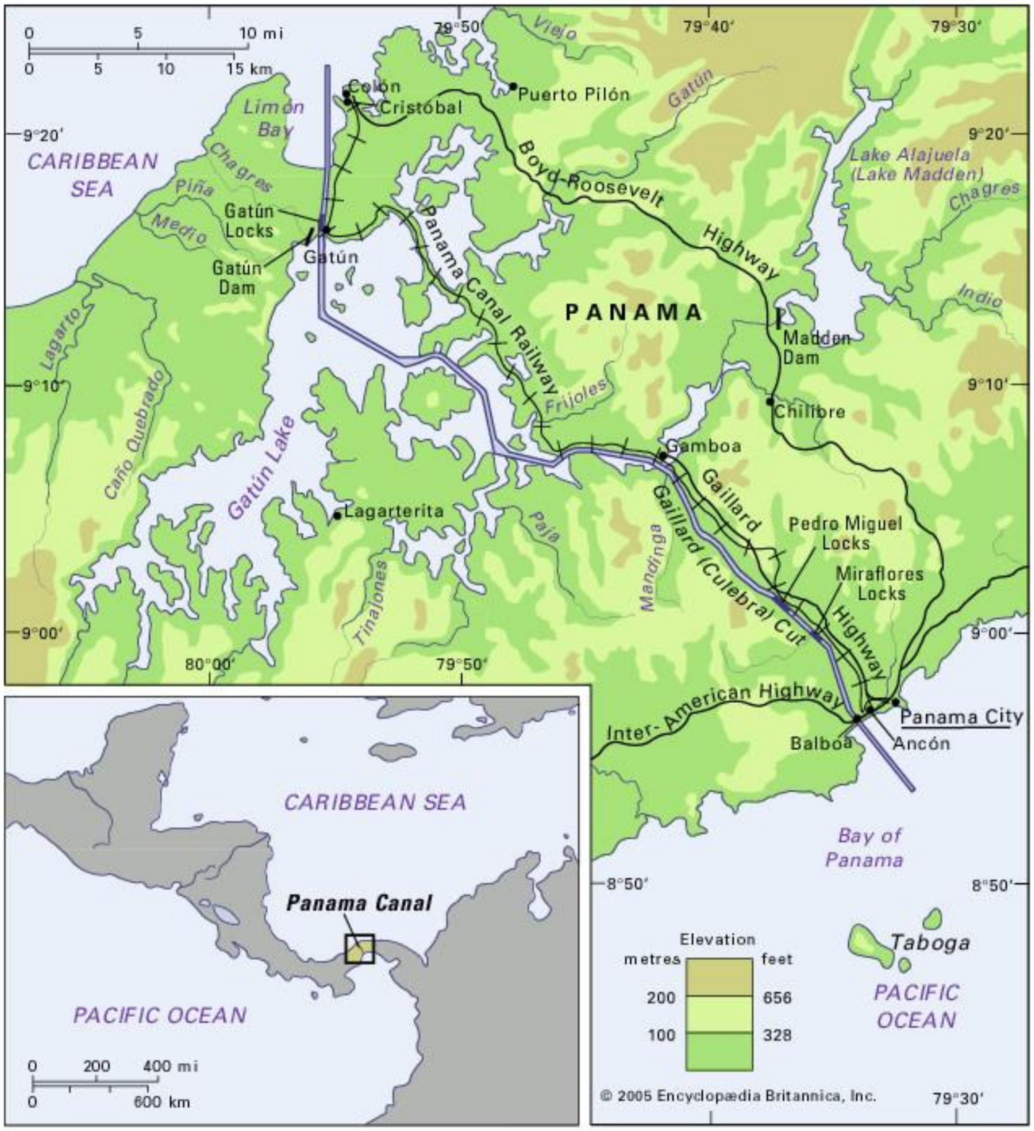

Figure 1: Map of the Panama Canal (Encyclopaedia Britannica, 2010)

2.2.1 Operation

There are three sets of locks in the Panama Canal: the two-stage Miraflores Locks, the single stage Pedro Miguel Locks, and the three stage Gatun Locks. Each lock has gates at both ends. These large miter gates are 64 feet wide and 7 feet thick. Their heights vary between 47 to 82 feet high depending on their location. A system of gears and an electric motor operate each lock. They operate by closing the main valves at the lower end of the chamber and opening the valves at the upper end, the side closest to Lake Gatun. Water enters the lock from the lake through culverts leading to the chamber floor. To release water from the locks, the upper valves are closed and the lower valves are opened, allowing the water to flow towards the ocean. Electric locomotives tow vessels through the canal as they travel through the locks. All the locks are managed by a computer program that controls the operation of each lock (Panama Canal Authority, 2009a).

2.2.2 Canal Expansion

The Panama Canal is currently undergoing an expansion project which began in 2007. The goals of this expansion project are to achieve long-term sustainability and growth, maintain competitiveness, increase capacity, and make the canal more productive, safe, and efficient. The Panama Canal is the country's largest economic resource because it has become a center for world trade, transportation, and logistics. It is hoped that the canal expansion will improve the national economy resulting in an improved quality of life for Panama's citizens (Panama Canal Authority, 2006a).

The expansion project consists of adding two new sets of locks to the canal system as well as approach channels for the new locks (see Figure 2). One set of locks is on the Pacific side of the Canal, east of the Gatun locks. The second set of locks will be on the Atlantic side south west of Miraflores Locks. The new locks will use gravity to bring water in and out of them, like the existing locks, but will have water basins to reduce the quantity of water released to the ocean when the locks are drained, thus reducing the volume of water needed from Lake Gatun. The new set of locks will use tug boats to position and move vessels instead of locomotives. The expansion project also includes the widening and deepening of all the existing channels of the canal and a proposed bridge or tunnel at the Atlantic end of the canal. Lake Gatun's water level will also be raised resulting in an increase in its useable water reserve capacity, allowing the locks to be used more frequently so that the canal can handle more traffic (Panama Canal Authority, 2006a).

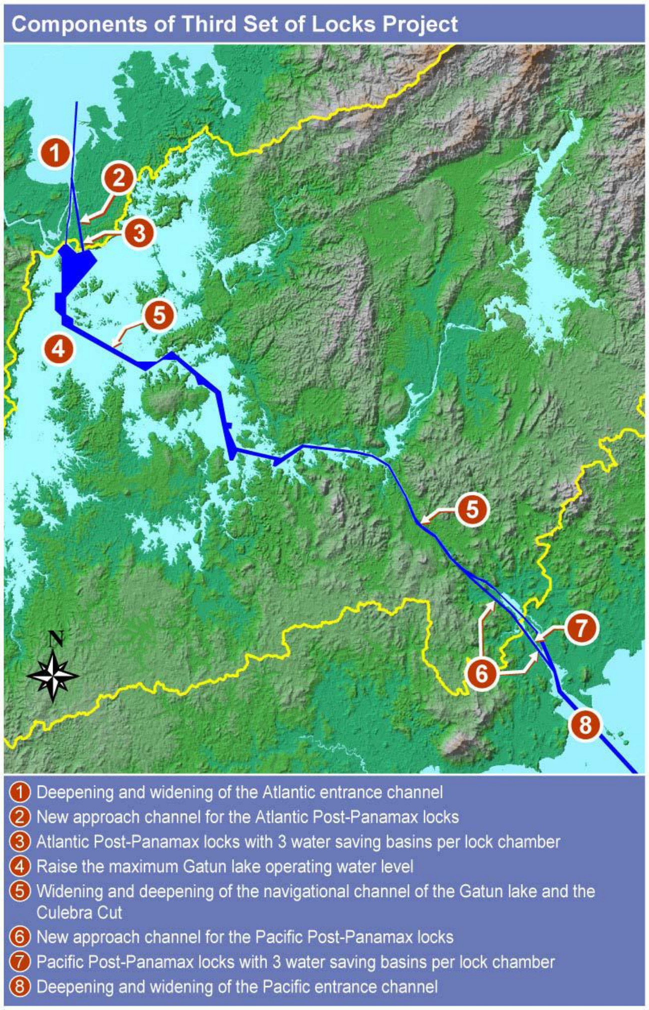

Figure 2: Panama Canal Expansion (Panama Canal Authority, 2006a)

The canal expansion project began in 2007 and is estimated to be completed by 2014. It will allow more ships and wider ships to travel through the canal (Panama Canal Authority, 2009c). Excavation and dredging began in 2007 and will last for seven or eight years. The construction phase of the expansion includes the lock construction, which began in 2008 and should take five to six years. Finally, once Lake Gatun’s level has been raised, the existing locks and facilities adjacent to the lake will need to be adjusted to account for the lake’s water level increase, which should take about four years. It is estimated that the expansion project will cost about $5.250 billion (Panama Canal Authority, 2006a).

Economic benefits of the canal expansion include increased profitability and increased tolls. The Panama Canal Authority (ACP, Spanish acronym) is financing the project itself, separate from the government. The canal expansion is estimated to produce a 12% internal rate of return, effectively double the capacity of the canal, and increase its operational efficiency. The canal will charge tolls that will double over the next 20 years, resulting in loans for the project being repaid while keeping the canal a competitive alternative to other maritime navigation routes. Since the ACP is financing the lock project separate from the government, any loans they take out will not be endorsed or guaranteed by the state. Based on traffic demand forecasts, the canal will make enough revenue to repay all its loans within eight years of completion (Panama Canal Authority, 2006a).

2.3 Barro Colorado Island and the Smithsonian Tropical Research Institute

The following sections detail the history of the Barro Colorado Island and the Smithsonian Tropical Research Institute

2.3.1 Barro Colorado Island

Barro Colorado Island (BCI) is located in Lake Gatun, 30 kilometers Northwest of Panama City, in the center of the Isthmus of Panama (Smithsonian Tropical Research Institute, 2010a). BCI was originally a large hill, called West Hill, in the Chagres River Valley. In 1914, engineers working on the Panama Canal constructed a dam blocking the outflow of the Chagres River. The dam altered the path of the river, flooding the Chagres River Valley, and lead to the creation of new lakes, including Lake Gatun. The former hills of the valley became the Islands of the Lakes. Thus, West Hill transformed into Barro Colorado Island (NASA, 2009). The island is 1,500-hectares in area. BCI, along with five adjacent peninsulas, form the 5,400-hectare Barro Colorado Nature Monument (BCNM) as shown in Figure 3 (Smithsonian Tropical Research Institute, 2009).

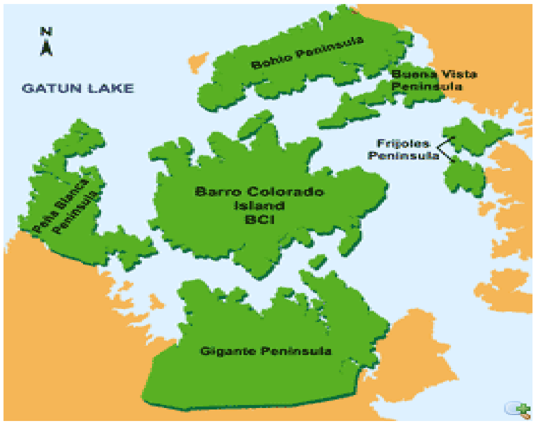

Figure 3: Map of BCI (Smithsonian Tropical Research Institute, 2010b)

2.3.2 Smithsonian Tropical Research Institute

The Smithsonian Tropical Research Institute (STRI) was officially developed in 1923 and is dedicated to understanding biological diversity. It first started in the 1910s, when scientific interest in understanding the flora and fauna of the area grew with the purpose of controlling insect diseases such as yellow fever and malaria. This was due to the increasing number of canal construction workers dying from these diseases. Once the canal began operating, entomologists and biologists decided to establish a permanent biological reserve on BCI. First starting as a small field station, STRI has since transformed into one of the leading research institutions in the world (Smithsonian Tropical Research Institute, 2009).

The STRI facilities on BCI provide a unique opportunity for long-term ecological studies in the tropics, specifically for the numerous species of animals, birds, reptiles, insects and plants that live there. According to Oris Acevedo, manager of STRI staff, up to 66 research scientists reside on the island in the high season, May through September (Acevedo, 2010a). In addition to these residents, BCI receives approximately 90 visitors per week, who commute daily. Ten Barro Colorado personnel provide all of the necessary support for the scientific staff and visitors and apply all of the regulations for the management of the Nature Monument as a field research station. Roughly 900 scientists visit the island to perform studies and academic research from institutions in the United States and around the world, and nearly 4,000 visitors travel to the island, annually (Smithsonian Tropical Research Institute, 2010c). The Field Research Station features the necessary infrastructure, including offices, laboratories, growing houses, a dark room, a computer room, a dining hall, a conference room, and a visitor’s center, as well as internet access, telephones, and boat rental services. A current picture of BCI is shown in Figure 4.

Figure 4: BCI Dock, Present (Worsham, 2010)

2.4 Water Quality

The following sections address the water quality concerns on BCI and the current Panama drinking water quality regulations as set forth by the General Directory of Standards and Industrial Technology and the Panamanian Commission of Industrial Standards and Techniques (DGNTI and COPANIT, respectively, Spanish acronyms).

2.4.1 Water Quality Parameters of Concern

The current water quality concern is particulate matter, such as suspended solids, which is associated with the turbidity level of a water source. Turbidity and suspended solids are the principal parameters that are analyzed in this report.

Solids in water can be classified as colloidal or suspended. Colloidal particles are kept in suspension by physical and chemical forces of attraction and range from 0.001 to approximately 1 µm in diameter. Suspended solids are large enough to settle out of solution or be removed by filtration. Suspended particles range from 0.1 to 100 µm in diameter. High solids concentrations in drinking water are a potential problem because particles may harbor microbiological contaminants that are harmful to human health or that decrease disinfection effectiveness (Davis & Masten, 2009).

There are multiple options for quantifying solids in water. Suspended and dissolved solids are measured by passing water through a filter and drying the retained matter and filtrate, respectively. Turbidity is an aggregate measure of solids and refers to the interference of light passage by particles in water. The scattering of light caused by suspended particles varies with the size, shape, refractive index, and composition of particles. Thus, turbidity can vary depending on the water source characteristics (MWH, 2005). In Panama[1], turbidity measurements are used by drinking water utilities for process control and regulatory compliance (Hernandez, 2010). On BCI, an increased turbidity in the drinking water supply has been reported which reflects a declining water quality for activities being conducted on the island.

2.4.2 Panama Drinking Water Quality Regulations

The DGNTI and COPANIT work in conjunction to establish the drinking water quality standards and the required water testing procedures to ensure that potable water in Panama meets these standards.

2.4.2.1 Standards

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[1] This also applies to the United States (MWH, 2005).

The Gaceta Oficial N^o 23,942, a report published on December 7, 1999, provides the official Panama drinking water quality standards as established by the DGNTI and COPANIT (DGNTI; COPANIT, 1999a). The standards for pH and turbidity are given in Table 1. The Gaceta Oficial does not specify a standard for suspended solids.

Table 1: Panama Drinking Water Quality Standards for Parameters of Concern

Water Quality Parameter	Standard
pH (standard units)	6.5 – 8.5
Turbidity (NTU)	1.0

2.4.2.2 Water Testing Procedures

The Gaceta Oficial N^o 23,941, a report published on December 6, 1999, provides the official testing methods for determining water quality as established by the DGNTI and COPANIT (DGNTI; COPANIT, 1999b). The required methods for collecting water samples are as follows:

- Note current conditions of testing site
- In lakes, consider factors such as: depth, current flow, and distance from the shore
- Obtain each sample with a minimum volume of 50 mL for pH testing and 100 mL for turbidity testing and place in a plastic container
- For each sample, rinse the container and lid with a portion of the sample water and proceed to collect the sample
- Refrigerate the containers promptly after collecting the water samples

Chapter 3: Methods of Data Collection

The goal of this project was to investigate problems with drinking water quality on Barro Colorado Island due to dredging, and recommend alternatives for providing high quality water in a cost effective manner. Currently, high solids concentrations in the BCI water intake have caused the treatment system to fail, and water is imported from Gamboa for drinking and cooking. ACP has proposed three alternatives for improving drinking water on BCI. Alternative 1 involves moving the water intake to a location that is least adversely impacted by the dredging. Alternative 2 includes installing a system of sedimentation ponds to reduce solids prior to treatment. Alternative 3 is continuing the transport of water from Gamboa to BCI.

This chapter discusses the methods used to evaluate the current water treatment system on BCI and to evaluate alternatives. The primary data collection efforts were three site visits to BCI and interviews with staff members of STRI. During the first visit, the group became familiarized with the water quality problems that STRI experienced and the current water treatment system. During the second visit, the group collected water samples in various areas around BCI to test for turbidity and suspended solids. During the third visit, the group conducted a field investigation to identify possible locations for a pipeline connecting a potential new water intake to the existing water treatment facilities on the island. Additional information was gathered through reports that were provided by ACP and STRI.

3.1 Information Resources from ACP and STRI

A considerable amount of information for this project was obtained through various reports. The group acquired these reports by requesting specific information from various members of both ACP and STRI. These reports may be categorized under the following subjects: Panama drinking water quality regulations, water quality data, current water quality issues on BCI and the actions taken by STRI to mitigate them, and potable water transport system details.

3.1.1 Panama Water Quality Regulations

The Panama drinking water quality regulations include a report on the standards and a report which discussed the required procedures for testing, as presented in section 2.4.2. The group acquired these reports from ACP.

3.1.2 Water Quality Data

Data for various water quality parameters was obtained through reports from ACP. Each report provided values of turbidity, temperature, and pH for different locations in Lake Gatun near BCI. These reports are:

- Water Quality Report of the Panama Canal Hydrologic River Basin 2003 – 2005, prepared by ACP
- Water Quality Report of the Canal River Basin 2007, prepared by ACP
- Supplement Report: Environmental Monitoring of the Dredging Activities of Lake Gatun and the Gaillard Cut for the Panama Canal Expansion Project, Water Quality June 2009, prepared by Aquatec Testing Laboratories
- Supplement Report: Environmental Monitoring of the Dredging Activities of Lake Gatun and the Gaillard Cut for the Panama Canal Expansion Project, Water Quality August 2009, prepared by Aquatec Testing Laboratories
- Supplement Report: Environmental Monitoring of the Dredging Activities of Lake Gatun and the Gaillard Cut for the Panama Canal Expansion Project, Water Quality October 2009, prepared by Aquatec Testing Laboratories

3.1.3 Current Water Quality Issues

Both ACP and STRI provided reports about the current water quality issues being experienced on BCI. These reports contained information on the actions taken by STRI and ACP to mitigate the turbidity problem and general observations about STRI's water treatment system. These reports are:

- Barro Colorado Island Inspection Report, June 5, 2008, prepared by ACP's Department of Environment, Water, and Energy: Water Division (provided by ACP)

- Report on ACP's Visit to Barro Colorado Island, April 3, 2009, prepared by ACP (provided by ACP)
- Sales Analysis of Products, October 2008 – December 2009, prepared by Agua Cristalina, (provided by STRI)

3.1.4 Potable Water Transport System

ACP designed a system to transport potable water from Gamboa to BCI in order to eliminate STRI's need to purchase water in 5 gallon jugs from Agua Cristalina. Reports and documents provided by ACP include information on the overall design of the transport system, design drawings, and cost estimates. These reports and documents are:

- Cost Estimate Request: Solution to Water Quality Problems, STRI, Barro Colorado Island, April 7, 2009, prepared by ACP Engineering Division
- Electrical Design Specifications, February 12, 2010, prepared by ACP's Engineering Division.
- Mechanical Design Specifications, April 24, 2009, prepared by ACP's Engineering Division.
- Design Documents for extending a potable water line from ACP's Dredging Division docks to the STRI dock in Gamboa, date and author not provided.
- Email correspondence between Herbert H. Sedelmeier (STRI) and Daniel Muschett (ACP) concerning the estimated cost of the transport system, March 2, 2009.

3.2 Interviews and Conversations with ACP and STRI

The group met with various people from ACP and STRI during the month of January, 2010. Through interviews and conversations, the group acquired valuable information regarding the turbidity problems that STRI had experienced and measures taken to mitigate the water quality issues. On January 13, the group conducted their first visit to BCI, accompanied by Hortensia Broce and Tomás Edghill from ACP. While on site, they met with Oris Acevedo, manager of STRI staff, and discussed the current turbidity problems that are being experienced on the island. Based on conversations with Ms. Broce and Ms. Acevedo, the group obtained preliminary information about the water transport system from Gamboa to BCI which was designed by ACP, as discussed in section 4.3. Sotero Campos, a maintenance worker on BCI, showed the group the existing water treatment system and how it operates.

During February 2010, the group met with Vielka Quijada, a civil engineer from ACP, and conducted a second visit to BCI. The group interviewed Ms. Quijada on February 2 about the design of the water transport system and obtained a detailed report about this system. During the second visit to BCI on February 12, the group met with Walter Dillon, the head of maintenance of STRI. Mr. Dillon explained how the temporary small filters operated and discussed how effective they have been in treating BCI's water source. On February 23, the group conducted a third visit to BCI in order to identify possible routes for a pipeline associated with moving the water intake. One of STRI's maintenance workers, Apolonio Valdés, led the group on trails leading through the proposed pipeline site.

In order to obtain supplemental information about STRI's water treatment system and to acquire STRI's budget for implementing a solution, the group contacted Carlos Tejada, the Director of Facility Maintenance, by telephone on February 24, 2010.

3.3 Field Data Collection

Data were collected during the group's visits to BCI. During the second visit, the group collected water samples in various areas of Lake Gatun around the island to test for turbidity and suspended solids. During the third visit, the group conducted field investigations to identify possible locations for a pipeline connecting a potential new water intake to the existing water treatment facilities on the island. Also during this visit, the group intended to identify possible locations for a system of sedimentation ponds, but was not able to due to time constraints.

3.3.1 Water Quality Testing

In order to determine a suitable location to move the water intake, water quality testing was performed at four locations along the shores of BCI. The first three testing sites were located at Harvard Cove, Shannon Cove, and Wheeler Cove. These were the proposed alternative locations for the new water intake, which are located in the southeast region of the island, off

Harvard Point. These locations are indicated by red arrows in Figure 7 in section 5.2.2. The fourth test site was located at the end of STRI's dock, approximately 10 meters away from the current intake location and was used as a basis for comparing the data from the other tests sites.

In order to conduct the water testing, the group used a small motorboat to travel from STRI's dock to the test sites. With the aid of José Simmonds, a water quality specialist from ACP, the group collected samples from the three sites off of Harvard Point and near the intake. Conditions at the testing sites were recorded, such as depth, water characteristics, and distance from the shore. At each site, a Van Dorn sediment sampler was used to collect water samples at the following depths: 1.0 meter from the bottom, the middle of the total depth, and 0.5 meters from the surface. As per the Gaceta Oficial N^{o} 23,941, each sample container was rinsed with the water sample prior to collection (DGNTI; COPANIT, 1999b). Upon returning to the dock, the samples were stored on ice in a cooler and then transported to ACP's water quality laboratory located in one of their main offices. From the laboratory report, the group acquired temperature, pH, turbidity, and TSS concentration results for each sample.

3.3.2 Site Investigation for Pipeline Routes and Sedimentation Ponds

Site investigations were conducted on BCI in order to identify and evaluate possible routes for a pipeline connecting a potential new water intake to the water treatment system. Due to time constraints, the group did not identify potential sites for a system of sedimentation ponds.

3.3.2.1 Pipeline for New Water Intake Location

Possible routes for a pipeline connecting an alternative intake location to the existing treatment facilities were identified using a trail map of BCI provided by STRI. This map contained contour intervals showing the topography of the island, allowing possible routes for the pipeline to be identified. While on the island, the group walked through trails to gain a better understanding of the terrain.

3.3.2.2 System of Sedimentation Ponds

The group intended to identify potential sites for a system of sedimentation ponds by touring STRI's existing facilities and the area surrounding them. The group acquired maps of BCI from ACP and STRI. However, these maps could not be used to identify possible locations on the island because the maps lacked sufficient detail. Due to time limitations during the visit, the group was compelled to decide between focusing on identifying a pipeline route or a location for a system of sedimentation ponds. The pipeline route was chosen because the group had more valuable data to use in the analysis of the first alternative of moving the water intake, as discussed in section 5.3.1.

3.4 Challenges during the Data Collection Period

The group encountered specific challenges during the data collection period. These challenges include time constraints and resource limitations.

3.4.1 Time Constraints

Time constraints were a major issue for the group. Background information on the project was compiled prior to the group arriving at the project site. However, the group was given eight weeks to accomplish the following: schedule site visits, gather information on site, interview contacts, request information from ACP and STRI, analyze the data, and write the report. As some of these activities were delayed, or took longer than expected, other activities were forced to be performed in less time than originally planned for.

3.4.2 Resource Limitations

Resource limitations were another major issue for the group during the project. The group encountered difficulty obtaining certain information that would have been pertinent to the analyses. This information either did not exist, or was not accessible to the group. The information included: STRI's actual water consumption, the canal expansion project dredging schedule, data about the material dredged (volume, sediment particle size and distribution) for design of a system of sedimentation ponds, water quality testing data for the alternative water intake locations while dredging activities were impacting the water surrounding BCI, and reports of environmental impacts observed during the expansion project[2].

The group would have benefited from information regarding STRI’s water supply needs and water quality for Lake Gatun over a long period of time. With the ability to determine STRI’s potable water needs, the group would have been able to determine the flow required to design the pipeline from the new water intake and the required capacity for a system of sedimentation ponds. With the use of ACP’s dredging schedule for the Canal Expansion Project, the group would have been able to investigate possible correlations between dredging activities in specific locations and their turbidity levels and total suspended solids (TSS) concentrations. Hypotheses drawn from these relationships would have been useful tools in analyzing the proposed alternatives. For Alternative 1, turbidity levels and TSS concentrations for various locations around BCI, from the start of the project to present, would have been utilized to determine the best location for the water intake. For Alternative 2, the dredging volume and particle size and density distribution within the source water would have allowed the group to design a system of sedimentation ponds. Although this information would have been valuable, the group was able to evaluate the problem by resorting to other methods of analysis. These methods are more conceptual than originally expected.

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[2] There was an Environmental Impact Statement published prior to the expansion project, but it has not been updated. Therefore, the group decided that this report was not relevant to this project.

Chapter 4: Current Situation on Barro Colorado Island

During the first visit to the island on January 13, 2010, the group became familiarized with the BCI water treatment system. This chapter discusses the components of the drinking water treatment system and their current conditions. Because the source water has had elevated levels of turbidity, STRI has implemented a short term solution for providing potable water that is currently in place.

4.1 Problem Statement

STRI has reported problems with drinking water quality on BCI as a result of the Panama Canal dredging activities. In particular, the drinking water source at the intake in Lake Gatun has elevated levels of turbidity. According to Oris Acevedo, manager of STRI staff, higher levels of turbidity were observed in BCI's water source at approximately the same time that the dredging associated with the expansion project began. As a result, the filtration units in their water treatment system have experienced operational malfunctions and are currently not working (Acevedo, 2010a). STRI has been investing more than $20,000 annually importing potable water for drinking purposes (Panama Canal Authority, 2009d). The objective of this project was to examine the current drinking water quality on BCI and assess the water supply needs of STRI in order to provide a feasible solution for their water quality problem.

4.2 Barro Colorado Island Water Treatment System

The water treatment system on BCI was originally installed in 1923, when STRI's facilities were first built. The source for this system is surface water from Lake Gatun. The pipe material for distribution of water starting from the intake location throughout the system is PVC Schedule 40. The general layout of the system is as follows (see Appendix A for photographs of the system):

- Water intake located near STRI main facilities
- Automatic pumps carry the water uphill
- Prefilter unit for removal of particulate matter (not in operation)

- Concrete storage tank with 15,000 gallon capacity
- Filters for removal of particulate matter (not in operation)
- Chlorine tank for chemical disinfection application
- Metal storage tank with 16,000 gallon capacity for chemical mixing
- PVC pipes for distribution

The water intake is in the same cove that STRI's dock and main facilities are located. It consists of a 2 inch diameter PVC pipe that starts from a location about 100 meters from the entrance dock, with two stakes that hold the pipe in place. The intake is about 1,200 meters from the canal channel in Lake Gatun (Panama Canal Authority, 2009d). The intake pipe reaches an automatic electric pump station that contains two centrifugal pumps in operation, each 80 gallons per minute, 25 HP, with a pressure gage (Flores, 2008). The pipe then leads to a prefilter mechanism that is currently not in operation. The prefilter system was installed between May and June of 2009 in order to mitigate the suspended solids content in the water before it enters a concrete storage tank (Broce, 2010). STRI began using a 25 micron pore size for the prefilter, but since this size was not adequate to collect dissolved solids, it was changed to a 10 micron filter which was provided by ACP. For this filter pore size, the influent flow had a turbidity reading of 100 NTU and the effluent flow had a reading of 53 NTU (Panama Canal Authority, 2009d), which is well above the Panama drinking water quality standard of 1.0 NTU.

After the prefilters, the water enters a concrete storage tank with a 15,000 gallon capacity. The effluent location of the concrete tank was originally at the top of a 1.5 foot vertical PVC pipe extending from the bottom of the tank (Dillon, 2010a). This allowed some solids to settle to the bottom while water from the middle portion of the tank, above the pipe (that had less suspended solids), was taken through the pipe for further treatment. Over time, the PVC pipe has deteriorated and is no longer present. There is a buoy in the concrete tank that senses when the tank is full, at which point the pumps, as previously mentioned, automatically stop operating. While water fills the tank, the pumps alternate in operation. The buoy also senses when the tank is low enough to accept more water (Campos, 2010). The water flows from the concrete tank through a 2 inch diameter PVC pipe to an Amiad Type AMF 36 filtration system consisting of three units, which can handle flows up to 30 cubic meters per hour (approximately 7,900 gallons per hour) (Amiad Filtration Systems Ltd., 2010). The filters were installed between May and

June of 2009. These filters are currently out of operation due to the high turbidity levels; specifically, the filter units were inoperable for water with 53 NTU or higher (Panama Canal Authority, 2009d). The water is then chlorinated for disinfection in a metal tank with a 16,000 gallon capacity. The effluent from the metal tank flows through a 6 inch diameter vertical PVC pipe into 4 inch PVC pipes and is distributed to STRI's facilities by gravity (Tejada, 2010). Appendix A provides the layout of the treatment system and pictures of the different units of the system.

The water from Lake Gatun is currently not being filtered; it is only chlorinated. According to Ms. Acevedo, the institute is using the unfiltered, chlorinated water for tasks such as dish washing, laundry, and showering. There are small filters at critical locations, but these do not filter the entire water supply. These filters, Intelifil UV 610 ultraviolet filters, were installed in November 2009 (Dillon, 2010b) in STRI's cafeteria ice machine, kitchen, dock water fountain, and distilled water unit in their laboratory; photographs of these filters are shown in Appendix B. These filters have been working properly since installation, but are expected to stop working once the dredging activities resume (Acevedo, 2010a). The unfiltered, chlorinated water from the lake will also be affected by the recommencement of dredging, making it less suitable for dish washing, laundry, and shower use.

4.3 Water Imported from Gamboa

Due to the high turbidity in the water intake and the ineffectiveness of the prefilter and filters of the water treatment system on BCI, water is being imported from Gamboa for drinking purposes only. As a short term solution, STRI has been importing 5 gallon jugs from Gamboa since October 2008, but STRI is trying to implement a more viable option. Gamboa is a town along the canal where STRI has their mainland pier. It is from here that the daily visitors to the island board an STRI boat for BCI. The water is currently being transported to the island from STRI's mainland pier in Gamboa by boat (Broce, 2010).

ACP has been assisting STRI with their water quality problem. So far, ACP has supplied the institute with two 550 gallon tanks and all the materials and equipment necessary for the implementation of a potable water transport system from Gamboa to BCI, as discussed in detail in section 5.3.3. The ACP has also extended a potable water line from its Dredging Division

Facilities in Gamboa to STRI's mainland pier for easier accessibility to water. STRI's intent is to fill two 250 gallon tanks from the potable water line at their pier in Gamboa and transport them to BCI by boat. Once at the island, the water will be transferred to the 550 gallon tanks for further chlorination of the water and then for drinking use. ACP and STRI have yet to negotiate a price for using ACP's water (Broce, 2010). Photographs of the equipment provided by ACP are shown in Appendix C.

4.4 Barro Colorado Island Water Requirements

As stated in section 4.3, STRI is importing drinking water from Gamboa. According to the sales records provided by STRI, they have purchased almost $21,000 worth of potable water from October 2008 through December 2009. An average of 400 jugs was transported to the island monthly at a cost of $3.50 each to provide all residents with potable water. This corresponds to an average of 2,000 gallons of water per month for drinking at a cost of approximately $1,400 per month. In the peak season, which was from May until August of 2009, 506 jugs were transported to BCI per month, resulting in 2,530 gallons of potable water used and $1,771 spent. The cost data are summarized in Table 2. Before the turbidity problem, the residents of BCI used about 31,000 gallons of water per day for their entire water needs (Agua Cristalina, 2010). This amount of water is based on the fact that the two water tanks on BCI (15,000 gallons and 16,000 gallons) would each fill up every morning and empty out every evening (Campos, 2010).

Table 2: Cost of Importing Potable Water

Time Period	Number of 5 Gallon Jugs	Number of Gallons	Cost in Dollars
Average Month	400	2,000	$1,400
Peak Season Month	506	2,530	$1,771

Chapter 5: Results and Analyses

This chapter provides the data acquired by the group through visits to BCI and documents obtained from ACP and STRI. The data include water testing results from various locations in Lake Gatun, space and terrain constraints on BCI, and a layout and cost estimate of the plan for transporting water from Gamboa. The group utilized these data to analyze the three proposed alternatives in section 5.1. Two alternatives - moving the water intake and importing water from Gamboa - were determined to be feasible.

5.1 Alternative Solutions

ACP has proposed three alternatives for improving the drinking water quality on BCI. Alternative 1 is moving the water intake to a location that is least adversely affected, or not affected, by the dredging activities of the Canal Expansion Project. Alternative 2 involves adding a system of sedimentation ponds before the filtration units in the water treatment system. Both alternatives would result in a lower concentration of solids in the influent. Also, they both utilize the current water treatment system and no further improvements to reduce turbidity are expected to be necessary. Alternative 3 is continuing the transport of water from Gamboa to BCI, utilizing ACP’s improved system.

5.2 Data Collection Results

The following sections provide relevant data for the alternatives and discussions of the results relating to the water quality testing, the pipeline route investigation, and the water transport system. For the water quality testing data, dredging schedules would have been used to draw correlations between the peak turbidity levels and specific dredging events, but were not available to the group.

5.2.1 Water Quality Testing

ACP provided the group with water quality data for Lake Gatun. ACP performed water testing for samples that were collected approximately 0.75 kilometers northeast of STRI's water intake on BCI, as indicated by the orange diamond shown in Figure 7. Samples were collected almost monthly from January 2003 to December 2005 and once every month from January to December in 2007. ACP hired Aquatec Testing Laboratories to perform water testing in the same location in Lake Gatun for June, August, and October of 2009. The water quality data, including temperature, pH, turbidity levels, and TSS concentrations, for the site near STRI's water intake for these time periods are shown in Appendix E. Month in which data are not available are noted

Turbidity data for this location near the surface of Lake Gatun for the available dates in 2003 to 2005 are shown in Figure 5. Throughout this time period, the turbidity levels varied greatly and were generally well above the Panama drinking water quality standard of 1.0 NTU. Peak turbidity levels occurred between March and April 2004 (44.0 and 39.5 NTU, respectively), in February 2005 (96.4 NTU), and June 2005 (85.1 NTU).

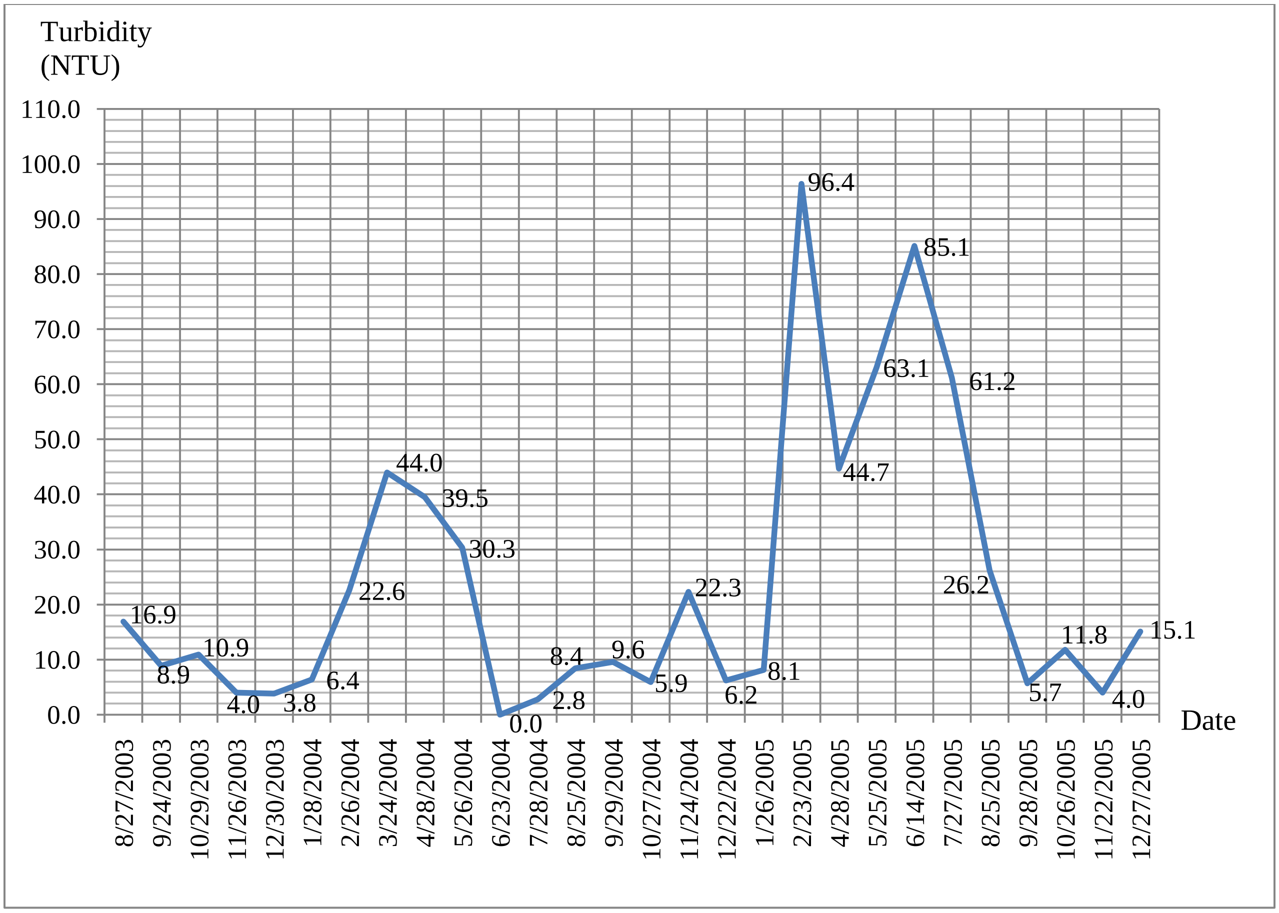

Figure 5: Graph of Turbidity Data in Lake Gatun at ACP Water Testing Point, August 2003 – December 2005

The turbidity levels and TSS concentrations for 2007 are given in Table 3. The turbidity levels near the surface do not vary greatly from those near the bottom of Lake Gatun. In January, October, and November, the water was more turbid near the surface than near the bottom. However, the surface and bottom TSS concentrations were the same in January and in November. The surface and bottom TSS concentrations were 3.0 and 2.0 mg/L, respectively, in October.

Turbidity data for this location near the surface of Lake Gatun for 2007 are shown in Figure 6. The turbidity levels near the water intake near the surface of Lake Gatun varied from 1.3 NTU to 10.4 NTU. Peak turbidity levels occurred in January (7.4 NTU), May (8.5 NTU), and November (10.4 NTU). These peak levels are significantly lower than peaks observed from 2003 to 2005.

Table 3: Turbidity Levels and TSS Concentrations of Lake Gatun at ACP Water Testing Point, 2007

Date	Depth[3]	Turbidity	TSS Concentration	Date	Depth	Turbidity	TSS Concentration
		(NTU)	(mg/L)			(NTU)	(mg/L)
1/25/2007	s	7.4	2.0	7/18/2007	s	6.2	1.0
	b	2.3	2.0		b	7.3	3.0
2/14/2007	s	1.9	0.0	8/23/2007	s	3.7	1.0
	b	1.8	1.0		b	5.6	3.0
3/28/2007	s	1.3	1.0	9/19/2007	s	2.5	1.0
	b	1.5	1.0		b	5.0	3.0
4/18/2007	s	3.3	0.0	10/24/2007	s	3.8	3.0
	b	4.2	1.0		b	2.6	2.0
5/16/2007	s	8.5	2.0	11/21/2007	s	10.4	6.0
	b	10.4	3.0		b	9.2	6.0
6/20/2007	s	6.4	2.0	12/19/2007	s	3.3	4.0
	b	11.5	2.0		b	5.0	7.0

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[3] s = 0.5 meters below lake surface; b = 1.0 meters above lake bottom

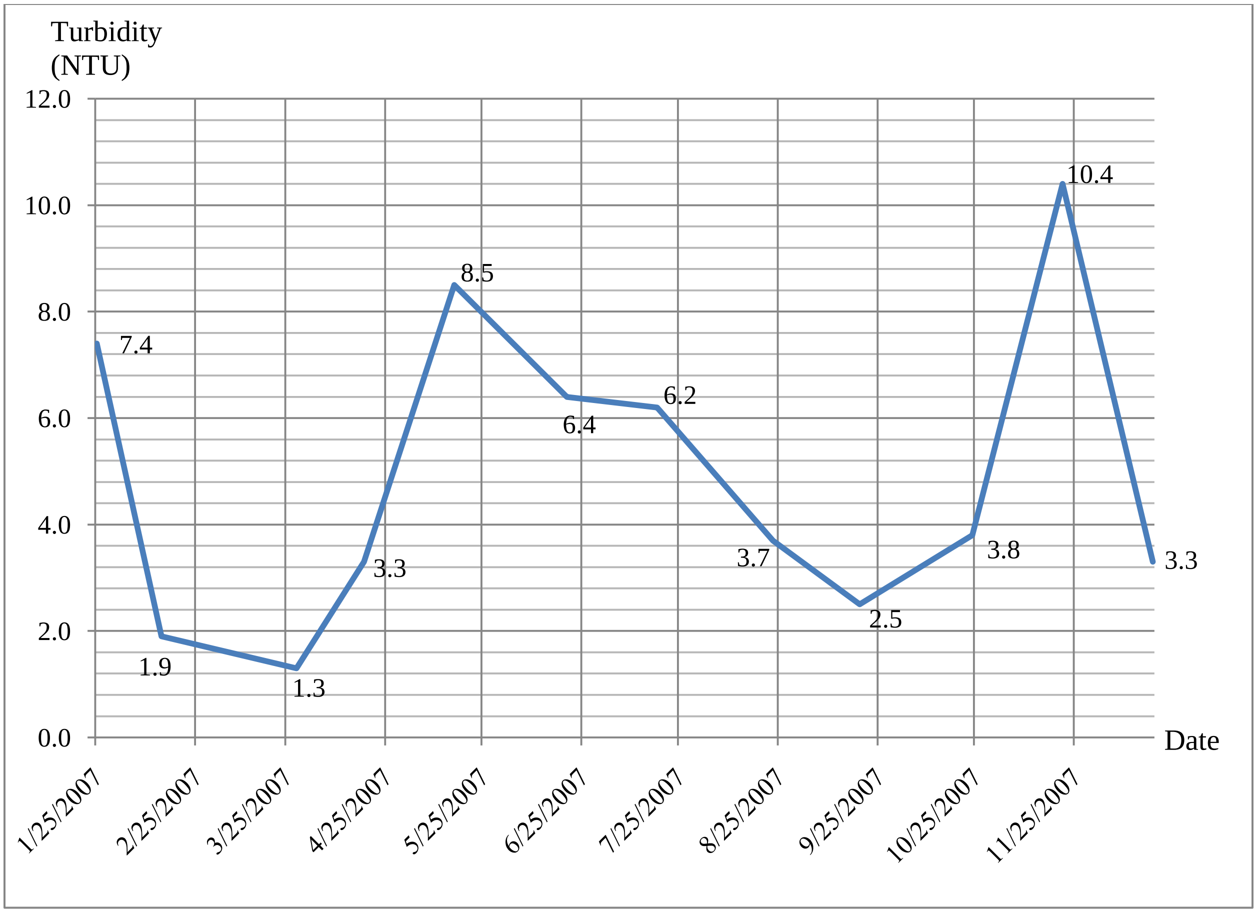

Figure 6: Graph of Turbidity Data in Lake Gatun at ACP Water Testing Point, January 2007 – December 2007

The measured values for turbidity and TSS concentration at the surface, middle, and bottom of Lake Gatun for 2009 are given in Table 4. In June 2009, there is little variation between the turbidity levels for the different depths in the lake and the TSS concentrations for each depth were each found to be below 5.0 mg/L. In August, the turbidity level at the surface and middle of the lake had decreased by approximately 10 NTU and the turbidity at the bottom of the lake had increased significantly within the 2 to 3 months. Over this time, it is hypothesized that sediments from the dredging activities of the canal expansion project may have settled to the bottom of the lake, and significantly contributed to the increase in turbidity in that location.

Table 4: Turbidity Levels and TSS Concentrations in Lake Gatun at ACP Water Testing Point, 2009[4]

Date	Depth[5]	Turbidity (NTU)	TSS (mg/L)
6/2009[6]	s	46.16	< 5.0
	m	45.79	< 5.0
	b	42.26	< 5.0
8/27/2009	s	34.12	14.0
	m	34.09	< 5.0
	b	112.70	12.0
10/20/2009	s	17.28	6.0
	m	17.61	6.0
	b	21.60	10.0

As mentioned in section 3.3.1, the group collected water samples from four sites around BCI. Dredging was not taking place near BCI during the sampling. The turbidity levels and TSS concentrations for these sites are shown in Table 5. Turbidity and total suspended solids were highest at the end of STRI's dock, which is approximately 10 meters away from the current intake location. Turbidity was approximately 36 NTU and TSS 20 mg/L. In comparison, turbidity and TSS were significantly lower at Harvard Cove, Shannon Cove, and Wheeler Cove. At these coves, turbidity ranged from 1.85 to 2.58 NTU and TSS ranged from 0.3 to 1.5 mg/L (over an order of magnitude less than by the STRI dock). In general, turbidity was lowest 0.5 meters from the lake surface.

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[4] Adapted from (Panama Canal Authority, 2006b; Aquatec Testing Laboratories, 2009b) (Panama Canal Authority, 2008) (Aquatec Testing Laboratories, 2009a)

[5] s = 0.5 meters below lake surface; m = middle depth of lake; b = bottom of lake (no specific measurement)

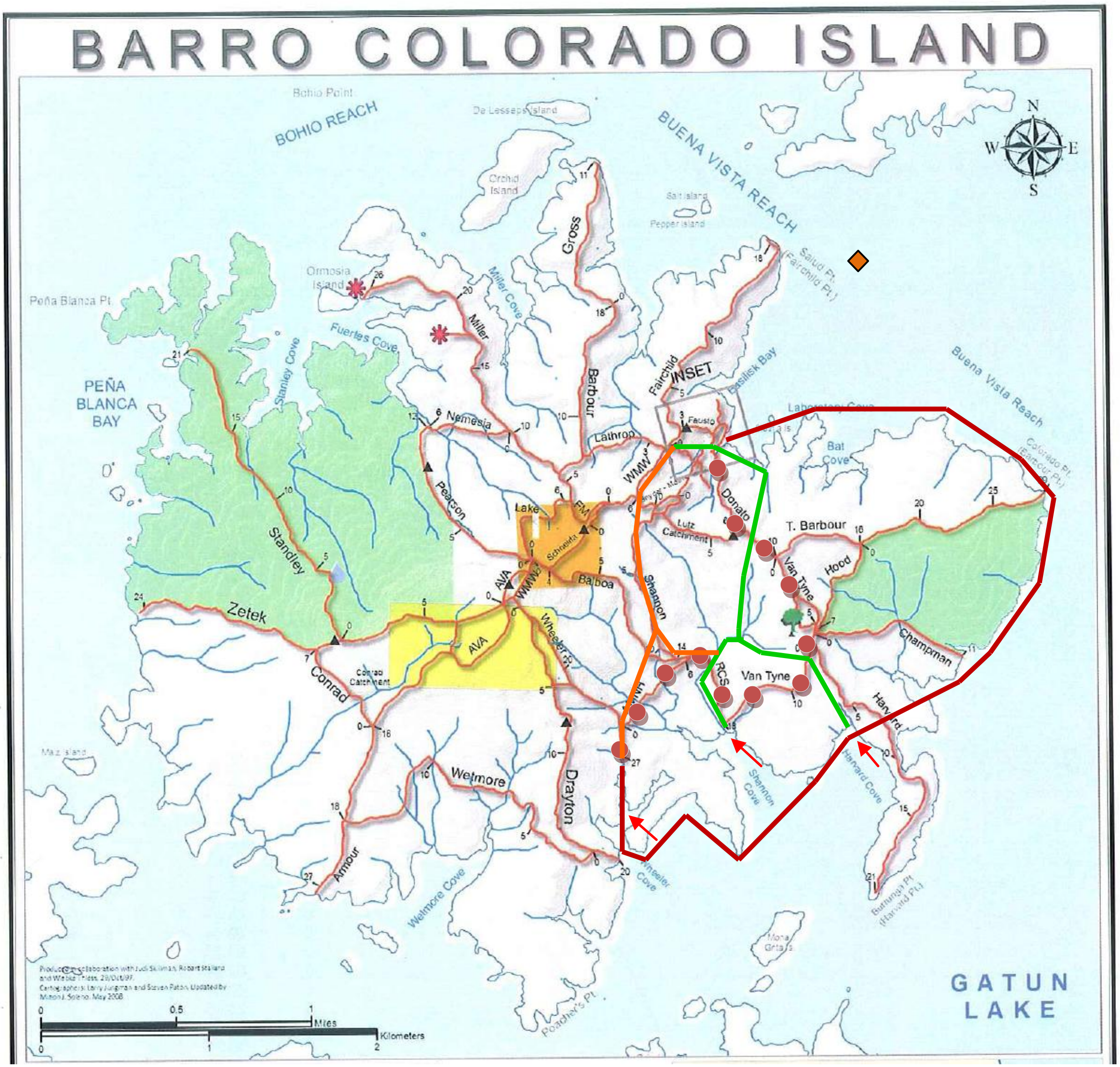
[6] No specific date provided for June

Table 5: Turbidity Levels and TSS Concentrations in Lake Gatun
At Various Sample Sites around BCI, 2010

Sample Site		Approximate Distance from Shore	Depth from Lake Surface	Turbidity	TSS Concentration
		(meters)	(meters)	(NTU)	(mg/L)
Proposed Alternative Locations	Harvard Cove	10	0.5	1.85	0.3
			2.5	2.08	0.9
			4.0	2.34	1.4
	Shannon Cove	10	0.5	2.33	1.0
			1.9	2.38	0.6
			2.9	2.36	1.5
	Wheeler Cove	12	0.5	1.97	1.0
			4.4	2.32	1.5
			7.7	2.58	1.2
End of Dock		15	0.5	35.10	20.4
			3.3	36.50	18.1
			5.5	36.20	20.6

5.2.2 Pipeline Route Investigation

During the third visit to BCI, the group conducted an investigation of possible routes for a pipeline connecting a potential new water intake to STRI's current water treatment facilities. Accompanied by STRI's Head of Trail Maintenance, Apolonio Valdés, the group traveled along Donato Trail, Van Tyne Trail, Shannon Trail, and American Museum of Natural History Trail as shown in Figure 7. The three proposed intake locations were visited, and the terrain over which a new pipeline would travel was viewed first hand. The group verified that the initial proposed pipeline routes, as shown in Figure 7, were suitable. The valley that the pipelines would follow was viewed from the trails that the group traveled and proved to be the lowest elevation in the area. Mr. Valdés suggested another alternative route, as indicated by the orange lines on the map of BCI. This route establishes Wheeler Cove as the intake location. Mr. Valdés suggested this intake location because it has experienced less impact from the dredging activities than the other proposed locations. Mr. Valdés has been working on BCI for nearly 30 years and as a result, he is knowledgeable about the terrain on the island. His advice concerning pipeline routes was given much weight by the group.



Key

● Group Trail Route

— Initial Proposed Pipeline Route

— Alternate Proposed Pipeline Route through BCI

— Alternate Proposed Pipeline Route following BCI Coast

→ Water Testing Locations

◆ ACP Water Testing Point

Figure 7: Map of Pipeline Routes on Barro Colorado Island[7]

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[7] Adapted from Barro Colorado Island trail map (Solano, 2008)

5.2.3 Transport of Water from Gamboa

STRI solicited a water treatment specialist from ACP to visit the island, evaluate the current potable water treatment system, and recommend possible alternatives for improvement. The first visit was conducted on June 3, 2008, in which various people from both organizations collaborated. Following this visit, ACP personnel made the following recommendations to STRI (Flores, 2008):

- Move the water intake away from the shore 150 linear meters from its current position
- Eliminate the valve that separates the raw water system from the treated water system and replace it with a PVC cork. This measure will eliminate the possibility of these two water sources from combining.
- Add a 25 micron prefilter in line with the water pumps to reduce the turbidity of the water before it enters the microfilters. This will result in water with a lower turbidity level, allowing the microfilters to operate effectively.

According to Hortensia Broce, the third recommendation was accepted and ACP provided STRI with a 25 micron prefilter. However, the prefilter malfunctioned due to a large increase in turbidity in Lake Gatun, as discussed in section 4.2. On March 25, 2009, STRI requested that ACP provide them with a cost estimate for the following works: 1) extension of the potable water line from ACP's Dredging Division Facilities in Gamboa to STRI's mainland dock and 2) a pumping system that transfers the water from the boat to STRI's drinking water distribution system. In order to investigate possible alternatives to the turbidity problem, ACP conducted a second visit to the island on April 3, 2009 (Panama Canal Authority, 2009d).

STRI and ACP agreed on a temporary solution that would supply 550 gallons of potable water per week to BCI. ACP's improved water transport system was based on STRI's potable water needs, as discussed in section 5.3.3. The agreement specified that ACP would provide the design and materials for the system and STRI would be responsible for construction costs. The proposed system consists of the following:

- Extend a potable water line from ACP's Dredging Division Facilities in Gamboa to STRI's mainland dock. It is estimated that 250 meters of 2" PVC, SDR 40, and all required accessories will be installed. With access to the potable water line, STRI will be able to refill the two 250 gallon tanks that are going to be used to transport the water from Gamboa to BCI.

- A mechanical system for the storage and provision of water to STRI's kitchen. The system will consist of the following:
    - Centrifugal pump, 30 gallons per minute, 1 HP
    - Centrifugal pump, 10 gallons per minute, 1.5 HP
    - Two 550 gallon plastic tanks
    - 35 gallon hydropneumatic tank
    - Pressure switch
    - 1.5" PVC pipe, SDR 26
    - 0.5" Hose keys
    - Pipes and valves accessories
    - Tablet chlorinator

The design and materials that ACP provided STRI for the construction of their temporary water treatment system included the mechanical system, electrical system, and the plumbing for the potable water line to STRI's dock. According to the cost estimate, the total cost of the system was $15,600 (Briceño & Bustos, 2009).

5.3 Analyses of Alternatives

Specific criteria were used to evaluate the different alternatives. These include: water quality, water quantity, cost, and environmental impact. Any alternative that was expected to produce inadequate water quality was eliminated. However, the group was not able to obtain sufficient data in order to determine the resultant turbidity level for each alternative. The quantity of water that could be produced for each alternative was considered. Each alternative must meet BCI's water supply needs. The environmental impacts of implementing each alternative were also considered. This was a major concern for the group when analyzing each alternative because BCI, along with its surrounding peninsulas, is a nature monument and the environmental impacts would have to be extremely low, if any. Lastly, the cost of the alternatives was important so that STRI could have an affordable water source. The alternative that would bring the best water quality to BCI at a reasonable cost would be the most desirable. Based on available data, a qualitative evaluation of the alternatives was possible.

5.3.1 Alternative 1: Move the Water Intake

The first proposed alternative was to move the water intake from its current location to an area near BCI that was less adversely affected by the dredging activities. This was determined to be a feasible option and was expected to result in improved water quality on BCI and meet STRI's potable water needs. However, moving the water intake would have a considerable impact on the island's environment. The estimated cost for this system ranged from approximately $63,000 to $67,000.

There were three proposed locations for a new water intake: Harvard Cove, Shannon Cove, and Wheeler Cove. Based on the water quality data discussed in section 5.3.1, all three locations would result in lower raw water turbidity than STRI's current intake location. These coves were located farther away from the channel in which dredging had taken place. Historical data demonstrated unacceptable turbidity levels at the current raw water intake. During the months of February, May, June, and July in 2005, the turbidity levels were above 53 NTU, as shown in Figure 5. This level was too high for STRI's current filtration system (Panama Canal Authority, 2009d). The turbidity levels were generally lower in 2007, with a maximum of 10.4 NTU. However, increases in turbidity were identified in 2009, with levels reaching approximately 45 NTU in June and a maximum level of 112.70 NTU in August. In the proposed water intake locations, the turbidity levels remained below 3.00 NTU. Thus, the group conducted a site investigation in order to determine which of the three sites would be preferred as a new water intake location.

The group learned about the terrain of the proposed routes for a pipeline on BCI, as discussed in section 5.2.2. The two shortest routes were considered for hydraulic flow analysis and are indicated by orange in Figure 7. One intake location is in Shannon Cove and the other is in Wheeler Cove, and the corresponding routes will be referred to as Shannon Route and Wheeler Route, respectively, in this report. The group assessed the topography of the terrain for both routes with the aid of the map shown in Figure 7[8]. Profiles for each pipeline route showing the elevations and required pipe lengths are shown in Appendix F. After the pipeline profiles were analyzed, the hydraulic characteristics for each route were determined using Pump System Improvement Modeling (PSIM). The input and output data for the Shannon Route and Wheeler Route pipeline systems are shown in Appendix F. The required pump output power for both routes was approximately 5 HP. The pumps that STRI used to draw water from the current intake location to the existing water treatment system are 25 HP each. Therefore, these same pumps would be adequate for either of the two proposed pipeline systems.

5.3.1.1 Cost Estimate

The cost estimate of the pipeline system was determined by using information from a construction cost index (R. S. Means, 2010). A cost estimate was prepared for the two proposed pipeline routes, referred to as Shannon Cove Estimate and Wheeler Cove Estimate in this report. Each estimate was divided into Piping Estimated Cost, Concrete Estimated Cost, and Total Cost. These estimates included material and labor costs for construction.

The Piping Estimated Cost was determined for “Piping, Water Distribution, PVC, Class 160, 2” diameter”, and would cost $6.31 per linear foot. The Concrete Estimated Cost was determined by estimating the amount of reinforced concrete that was needed for the construction of the system and multiplying that number by the cost per cubic yard. The support structure for the pipeline consisted of columns that will be placed every 40 feet, with dimensions of 8” x 8” x 12”. The beam supported by the columns would have a cross-section 6” tall and 8” wide. The estimated cost for a cubic yard of concrete was $300.

Shannon Route is approximately 1880 meters in length. The piping cost was estimated at $39,000 and the concrete at $24,000, for a total of $63,000. Wheeler Route is just over 2,000 meters in length and therefore has slightly higher overall costs, $67,000. Calculations to support these estimates are presented in Appendix F. As mentioned in section 5.2.2, the water quality in Wheeler Cove is expected to be better than that for Shannon Cove and the cost increase to use

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[8] The topographical lines are not visible in Figure 7.

Wheeler Cove is 6.4%. Therefore, the group decided that Wheeler Route would be used for the final cost estimate.

5.3.1.2 Impacts on the Surrounding Environment

A noteworthy aspect of Alternative 1 was the possible environmental impact that it could have on BCI. If a new water intake was installed on Wheeler Route, pipeline would have to be constructed along the island's trails. Construction activities for this system would likely disrupt the flora and fauna on BCI and as a result, adversely affect STRI's research efforts. Also, after construction is completed, the electrical power facilities for the pump at the new intake could create noise pollution. Lastly, the system could be aesthetically displeasing to the residents and visitors on the island.

STRI has expressed interest in constructing a pipeline along the coast of BCI, as shown by the red line in Figure 7. This route would have a significantly lower negative environmental impact on the island than the other routes because the pipeline would follow BCI's coastline, underwater. The pipeline's construction would involve minimal forest clearing and disruption of flora and fauna, only crossing a small portion of land near Harvard Point. However, this route would be approximately 7,750 meters long and would likely cost much more than the other pipeline routes, so it was initially rejected by the group.

5.3.2 Alternative 2: Install a System of Sedimentation Ponds

Alternative 2 involved installing a system of sedimentation ponds on BCI. Sedimentation ponds would improve the water quality by stopping or slowing the water flow long enough for the solids to settle out of the water (Best Manufacturing Practices, 2009). This would decrease the water's suspended solids concentration before entering STRI's water treatment facilities, allowing their filtration system to operate effectively. This alternative would supply STRI with sufficient quality water to meet their needs, provided that adequate space was available to install ponds of sufficient size.

While sedimentation ponds may greatly increase the quality of BCI's drinking water, they would likely have a negative impact on the island's environment. Implementation would likely require land around the existing STRI facilities to be cleared and this would destroy some natural habitat of fauna. While this is not the best outcome and STRI would prefer to keep activities involving clearing land to a minimum, they realize that such activities may be necessary. If this alternative was to be implemented and land needed to be cleared, it would require a formal request filed with STRI's Board of Directors for approval (Acevedo, 2010b). A final design for ponds would be necessary to determine the amount of land that would need to be cleared.

Azu Etoniru, of E.T. Engineering Enterprises Incorporated, was contacted by the group for assistance in evaluating sedimentation ponds as an alternative. Mr. Etoniru advised the group that sedimentation ponds in series with filtration check dams and a controlled outlet would be most effective. The number, size, configuration, and routing of the ponds would depend on the following information: the Canal Expansion Project's daily dredge volume, the composition of sediments in the source water, and the daily water demand of STRI (Etoniru, 2010). Through both ACP and STRI staff, the group inquired about this information, but was not able to obtain it. Without these data, the system of sedimentation ponds could not be designed and a cost estimate could not be calculated. Therefore, sedimentation ponds could not be evaluated as a potential alternative on BCI.

The group had visited three water treatment plants, two of which used alum and polymers as coagulants and flocculation tanks to treat the source water for turbidity[9]. According to Ms. Acevedo of STRI, the research institute consulted an outside designer for the development of coagulation and flocculation processes to ultimately reduce the turbidity in the source water, but these designers were not hired (Acevedo, 2010a). The process of coagulation in water treatment usually involves adding hydrolyzing chemicals such as alum and organic polymers in order to destabilize small suspended and colloidal particulate matter (MWH, 2005). Destabilization of particles in water allows adsorption and reaction between portions of these particles so that they aggregate, forming flocs in the flocculation tank. Since these flocs settle out of the water more quickly than the particles prior to aggregation, the required settling time would be decreased, and as a result, the required size for a sedimentation system would be reduced.

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[9] These treatment plants are called Miraflores and Mendoza, and were visited on the 20th and 22nd of January 2010, respectively.

The coagulant dose would depend on the composition of particulate matter in the source water, such as dissolved, suspended, or colloidal solids. The size of a flocculation tank would depend in the required settling time and the daily water demand of STRI. If STRI were to install a flocculation tank in their current water treatment system, they would need a system in which they can contain the solids that are separated from the treated water so as to not pollute BCI and Lake Gatun.

5.3.3 Alternative 3: Transport of Water from Gamboa

Transporting water from Gamboa is a feasible solution to the current water quality problem on BCI because it has already been designed and STRI has all the materials needed for the construction of the system on site. Although this is a temporary solution to the problem, it is one that can be established promptly at a reasonable cost and bring a significant improvement to the water quality on the island causing minimum harm to the environment. Also, this system would not be affected by the dredging activities caused by the Canal Expansion Project.

The total cost of the transport system is still to be determined because STRI is currently waiting for the construction cost estimate of the system. STRI is expecting to receive the cost estimate in March 2010 and promptly start the construction of the system (Tejada, 2010). Also, STRI would be charged on a unit basis by ACP for using their potable water (Broce, 2010).

The transport system can provide water that is high quality to the island and in sufficient quantity. The system was designed so that potable water would be transported to the island, and then, chlorinated again for disinfection on-site, so that it would be safe for human consumption (Tejada, 2010). ACP consulted STRI for their water needs and agreed that 550 gallons of potable water per week was sufficient for their kitchen and drinking purposes (Quijada, 2010).

This transport system would be desirable because it is not expected to cause any harm to BCI's environment. In addition, the water quality would not be affected by the dredging activities that are causing the high turbidity in the source water. Once STRI has their temporary transport system working effectively, they could focus on other solutions to fix their current water treatment system, which is currently not fully operational.

Chapter 6: Conclusions and Recommendations

This chapter discusses conclusions based on the analyses of the proposed alternatives. It also presents recommendations for an alternative solution to STRI's water quality problem and for further research that should be conducted.

6.1 Conclusions

The Smithsonian Tropical Research Institute, located on Barro Colorado Island, reported an increased turbidity and suspended solids concentration in their potable water intake. This was presumed to be a result of the Panama Canal Expansion Project's dredging activities because STRI reported that the problem began when the dredging started in Lake Gatun. As a result, the filtration units in STRI's water treatment system were clogged from the increased sediments and are currently not operational. STRI was forced to invest more than $20,000 annually to import potable water for drinking purposes. This practice continues to the present day. The objective of this project was to examine the current drinking water quality on BCI, assess the water supply needs of STRI, and provide a feasible solution for their water quality problem.

The Panama Canal Authority proposed three possible alternative solutions to STRI's problem for the group to investigate. Alternative 1 was to move the water intake to an area that would be less adversely affected by the dredging activities. Alternative 2 involved installing a system of sedimentation ponds before the filtration units of the water treatment system. Both of these alternatives would result in fewer solids in the influent, allowing the treatment system's filters to operate efficiently. Alternative 3 was to continue to transport water from Gamboa to BCI, but in larger containers than currently being used.

The three alternatives were analyzed and compared based on the resultant water quality, water quantity, cost to implement, and environmental impacts. Moving the water intake would greatly improve the raw water quality. The cost of new piping and other construction materials would be approximately $67,000, and this alternative would have a significant negative environmental impact on the island. While installing sedimentation ponds would likely improve the raw water quality, the group was not able to acquire basic design data for this alternative. Transporting water from Gamboa would provide STRI with their minimum potable water needs (namely, drinking water) and, would not have any negative environmental impacts on BCI. The cost of this system is currently being estimated and construction is expected to begin in March 2010.

Of the three alternatives, moving the water intake and importing water from Gamboa are both feasible with current data and are expected to provide STRI with satisfactory water quality. They each have specific advantages and disadvantages. While moving the water intake would meet all of STRI's potable water needs, it would have significant negative environmental impacts on BCI. This could seriously disturb the flora and fauna that inhabit the island, and as a result, the research being conducted there. This alternative would cost STRI approximately $67,000 to implement. Conversely, importing water form Gamboa would have very minimal negative environmental impacts. However, this alternative only meets STRI's drinking water needs. Currently, importing water costs STRI approximately $21,000 per year. Once the improved transport system (designed by ACP) is constructed on BCI, the annual cost is expected to decrease significantly.

6.2 Recommended Alternative

Based on data provided in reports and collected, the group initially recommended moving the water intake to Wheeler Cove so that STRI would have access to their own raw water supply in Lake Gatun. It is anticipated that STRI's current treatment system on BCI would be able to treat the lower turbidity water. However, due to future dredging activities (expected to be completed by 2014), Wheeler Cove may be subject to increases in turbidity and these levels are unknown.

The group was informed by Carlos Tejada in February 2010 that STRI has discarded the option of moving the water intake due to its significant adverse environmental impacts on BCI (Tejada, 2010). As a result, the group is left with no other option but to recommend that STRI continue importing water from Gamboa, using the new equipment provided by ACP.

6.3 Recommended Further Research

The group recommends that further research be conducted concerning a sedimentation system. In order to design such a system, specific information regarding the source water characteristics is necessary, such as: the Canal Expansion Project's daily dredge volume (for example, percent of dredged material in source water on a volume basis), the composition of sediments in the source water (particle size and density distributions), and an accurate required flow rate (as opposed to the estimate that was used for analyzing Alternative 1[10]). Based on the amount of dredge material in the source water and the particle size and density distributions in that water, as well as the desired percent reduction of suspended solids, the required settling time can be computed. Then, the required pond dimensions can be determined. The system needs to be in a location to allow the source water to be easily pumped from the intake to the ponds, and then to the existing treatment units for filtration and chlorination. Further research could be conducted to evaluate the implementation of a sedimentation tank rather than a pond system. The location for such a system would be limited to the area surrounding STRI's current facilities.

Additional research could also be conducted regarding a pipeline route being constructed along the coast of BCI. This alternative was initially rejected by the group because of its much longer length compared to the other pipeline routes and would likely cost much more to construct because of its length. However, STRI has expressed interest in pursuing a pipeline around the coast of BCI because it would have a significantly lower negative environmental impact on the island. Construction of the pipeline would have minimal disruption of the island's flora and fauna because the pipeline only crosses through forest over a small portion of Harvard Point as shown in Figure 7. Also, this pipeline would require that a new support structure be designed. The structure used for this project was for an overland pipeline, but the proposed pipeline following the coast of BCI would be sub-aquatic, so an overland pipeline support structure may not be appropriate.

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[10] The group used 48.61 gal/min, which was based on information obtained during the first visit to BCI (Campos, 2010)

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Appendix A: Photos of BCI Water Treatment System Layout

Jan. 13, 2010

Figure A-1: Water Intake in Lake Gatun

Figure A-2: Pipeline Leading from Intake to Pumps

Figure A-3: Water Pumps at Docks

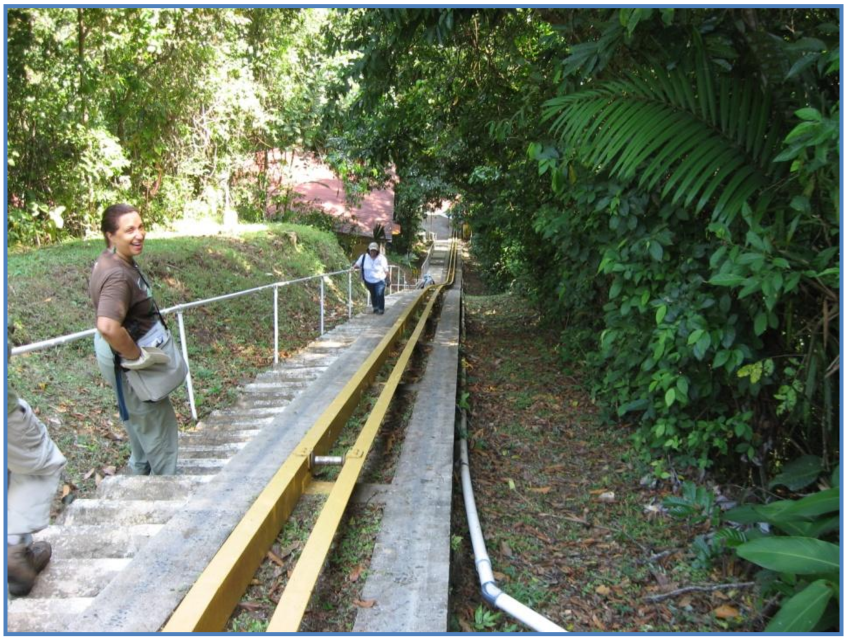

Figure A-4: Pipeline leading from Dock Pumps to Prefilter

Figure A-5: Prefilter

Figure A-6: 15,000 Gallon Concrete Tank

Figure A-7: Buoy Water-level Sensor in Concrete Tank

Figure A-8: Filter for Water after Concrete Tank

Figure A-9: Chlorine Testing Equipment

Figure A-10: Chlorine Powder (blue lid) and Chlorine Mixing Barrel (grey)

Figure A-11: 16,000 Gallon Metal Tank on Top of Filter Shed

Figure A-12: Pipeline Leading to the Distribution System for STRI

Appendix B: Photos of Small Filters Installed for Temporary Use

Jan. 13, 2010

Figure B-1: Filter for Ice Machine

Figure B-2: Filter for Water Fountain at Dock

Figure B-3: Filter in Kitchen

Appendix C: Photos of Materials for Transport of Water from Gamboa

Various Dates

Figure C-1: Potable Water Line Extended from ACP Dredging Division, Jan. 13, 2010

Figure C-2: 250 Gallon Tanks for Potable Water Storage for Transport, Feb. 12, 2010

Figure C-3: Photo of 550 Gallon Tanks for Storage of Potable Water on BCI, Jan. 13, 2010

Appendix D: Water Quality Testing at Harvard Cove, Shannon Cove, and Wheeler Cove

Feb. 12, 2010

Figure D-1: Photo of Harvard Cove

Figure D-2: Photo of Shannon Cove

Figure D-3: Photo of Wheeler Cove

Figure D-4: Photo of Hydrolab DataSonde 4a Turbidimeter

Figure D-5: Van Dorn Sediment Sampler

Figure D-6: Water Sample Collection Performed with Van Dorn

Figure D-7: Collection of Water Sample

Figure D-8: Transferring Water from Van Dorn to Sample Container

Appendix E: Water Quality Data for Lake Gatun

Table E-1: Temperature, pH, Turbidity, and TSS Concentration for STRI's Field Station in Lake Gatun, 2003[11]

Date	Depth[12]	Temperature	pH	Turbidity	TSS Concentration
		(°C)	(standard units)	(NTU)	(mg/L)
1/23/2003	s	n.a.	n.a.	n.a.	0.0
	b	n.a.	n.a.	n.a.	1.0
3/26/2003	s	29.5	7.26	n.a.	n.a.
	b	29.0	7.25	n.a.	n.a.
4/29/2003	s	30.2	7.31	n.a.	n.a.
	b	29.6	7.21	n.a.	n.a.
5/27/2003	s	n.a.	n.a.	n.a.	n.a.
	b	n.a.	n.a.	n.a.	n.a.
6/24/2003	s	29.7	7.91	n.a.	3.0
	b	29.1	6.83	n.a.	4.0
7/29/2003	s	n.a.	n.a.	n.a.	5.0
	b	n.a.	n.a.	n.a.	6.0
8/27/2003	s	29.4	8.53	16.9	4.0
	b	28.7	8.53	20.8	0.0
9/24/2003	s	29.7	8.35	8.9	5.0
	b	29.2	8.24	10.8	4.0
10/29/2003	s	30.1	8.26	10.9	3.0
	b	29.3	8.23	17.4	4.0
11/26/2003	s	29.1	8.20	4.0	5.0
	b	28.8	8.36	5.0	5.0
12/30/2003	s	28.6	8.02	3.8	n.a.
	b	28.2	8.27	6.9	n.a.

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[11] Adapted from: (Panama Canal Authority, 2006b)

[12] s = 0.5 meters below lake surface; b = 1.0 meters above lake bottom

Table E-2: Temperature, pH, Turbidity, and TSS Concentration for STRI's Field Station in Lake Gatun, 2004[13]

Date	Depth	Temperature	pH	Turbidity	TSS Concentration
		(°C)	(standard units)	(NTU)	(mg/L)
1/28/2004	s	28.5	8.34	6.4	8.0
	b	28.2	8.07	16.6	7.0
2/26/2004	s	29.1	7.91	22.6	6.0
	b	28.5	8.19	25.3	8.0
3/24/2004	s	28.4	7.84	44.0	8.0
	b	28.3	7.95	44.8	6.0
4/28/2004	s	28.9	7.81	39.5	5.0
	b	28.7	7.80	41.1	5.0
5/26/2004	s	29.3	7.74	30.3	9.0
	b	29.2	7.67	34.1	3.0
6/23/2004	s	29.7	7.74	0.0	2.0
	b	29.1	7.58	8.9	2.0
7/28/2004	s	29.7	7.77	2.8	1.0
	b	28.9	7.63	2.8	1.0
8/25/2004	s	29	7.66	8.4	3.0
	b	28.9	7.45	9.2	3.0
9/29/2004	s	29.8	7.76	9.6	2.0
	b	29.4	7.35	11.8	2.0
10/27/2004	s	29.6	7.65	5.9	1.0
	b	29.3	7.43	7.8	2.0
11/24/2004	s	28.2	7.36	22.3	8.0
	b	26.8	7.29	79.3	24.0
12/22/2004	s	28.7	7.83	6.2	1.0
	b	28.3	7.82	7.7	4.0

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[13] Adapted from: (Panama Canal Authority, 2006b)

Table E-3: Temperature, pH, Turbidity, and TSS Concentration for STRI's Field Station in Lake Gatun, 2005[14]

Date	Depth	Temperature	pH	Turbidity	TSS Concentration
		(°C)	(standard units)	(NTU)	(mg/L)
1/26/2005	s	28.2	7.75	8.1	3.0
	b	28.1	8.10	35.9	2.0
2/23/2005	s	27.7	7.29	96.4	41.0
	b	27.4	8.24	132.0	64.0
3/23/2005	s	29.6	7.19	n.a.	29.0
	b	29.0	7.32	24.1	41.0
4/28/2005	s	29.5	7.81	44.7	27.0
	b	29.3	6.97	10.6	31.0
5/25/2005	s	29.8	7.68	63.1	19.0
	b	29.2	7.87	61.4	24.0
6/14/2005	s	30.5	7.68	85.1	33.0
	b	29.7	7.97	88.7	29.0
7/27/2005	s	30.8	7.70	61.2	25.0
	b	29.6	7.72	108.6	42.0
8/25/2005	s	29.7	7.67	26.2	9.0
	b	29.4	7.65	28.1	10.0
9/28/2005	s	29.4	7.67	5.7	3.0
	b	29.2	7.45	7.3	2.0
10/26/2005	s	29.1	7.34	11.8	4.0
	b	29.1	7.35	11.5	4.0
11/22/2005	s	28.8	7.53	4.0	3.0
	b	28.7	7.43	4.3	4.0
12/27/2005	s	28.8	7.48	15.1	3.0
	b	28.4	7.41	17.2	5.0

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[14] Adapted from: (Panama Canal Authority, 2006b)

Table E-4: Temperature, pH, Turbidity, and TSS Concentration for STRI's Field Station in Lake Gatun, 2007[15]

Date	Depth	Temperature	pH	Turbidity	TSS Concentration
		(°C)	(standard units)	(NTU)	(mg/L)
1/25/2007	s	28.5	8.29	7.4	2.0
	b	28.3	8.42	2.3	2.0
2/14/2007	s	28.6	8.38	1.9	0.0
	b	28.3	8.48	1.8	1.0
3/28/2007	s	29.2	7.98	1.3	1.0
	b	28.8	7.82	1.5	1.0
4/18/2007	s	29.9	8.03	3.3	0.0
	b	29.6	7.83	4.2	1.0
5/16/2007	s	30.0	8.11	8.5	2.0
	b	29.5	7.83	10.4	3.0
6/20/2007	s	29.8	7.44	6.4	2.0
	b	29.6	7.21	11.5	2.0
7/18/2007	s	29.7	7.62	6.2	1.0
	b	29.3	7.49	7.3	3.0
8/23/2007	s	29.8	7.69	3.7	1.0
	b	29.0	7.37	5.6	3.0
9/19/2007	s	29.5	7.76	2.5	1.0
	b	28.9	7.51	5.0	3.0
10/24/2007	s	30.0	7.63	3.8	3.0
	b	29.2	7.37	2.6	2.0
11/21/2007	s	28.5	7.17	10.4	6.0
	b	28.2	7.05	9.2	6.0
12/19/2007	s	28.3	7.51	3.3	4.0
	b	28.0	7.17	5.0	7.0

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[15] Adapted from: (Panama Canal Authority, 2008)

Table E-5: Temperature, pH, Turbidity, and TSS Concentration for STRI's Field Station in Lake Gatun, 2009[16]

Date	Depth	Temperature	pH	Turbidity	TSS Concentration
		(°C)	(standard units)	(NTU)	(mg/L)
6/2009	s	30.6	7.57	46.16	< 5.0
	m	29.9	7.52	45.79	< 5.0
	b	29.8	7.50	42.26	< 5.0
8/27/2009	s	28.1	7.30	34.12	14.0
	m	28.1	7.30	34.09	< 5.0
	b	28.6	6.90	112.70	12.0
10/20/2009	s	28.3	7.20	17.28	6.0
	m	28.4	7.04	17.61	6.0
	b	28.2	6.80	21.60	10.0

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[16] Adapted from: (Aquatec Testing Laboratories, 2009a), (Aquatec Testing Laboratories, 2009b), (Aquatec Testing Laboratories, 2009c)

Appendix F: Cost Analysis for Alternative 1

Pipeline Route Calculations

In order to calculate the required length of the pipes for each route, the profiles shown in Figures F-1 and F-2 were created using AutoCAD 2010. Each route's elevations and horizontal distances were derived from the BCI trail map shown in

Figure 7. Note that each pipeline profile can be divided into individual segments. Each segment contains a triangle and rectangle (an example is outlined in red in Figure F-1), in which the hypotenuse of the triangle represents the required pipe length of each segment. The total required pipe lengths for the Shannon Route and Wheeler Route are 1,881.56 meters and 2,001.52 meters, respectively.

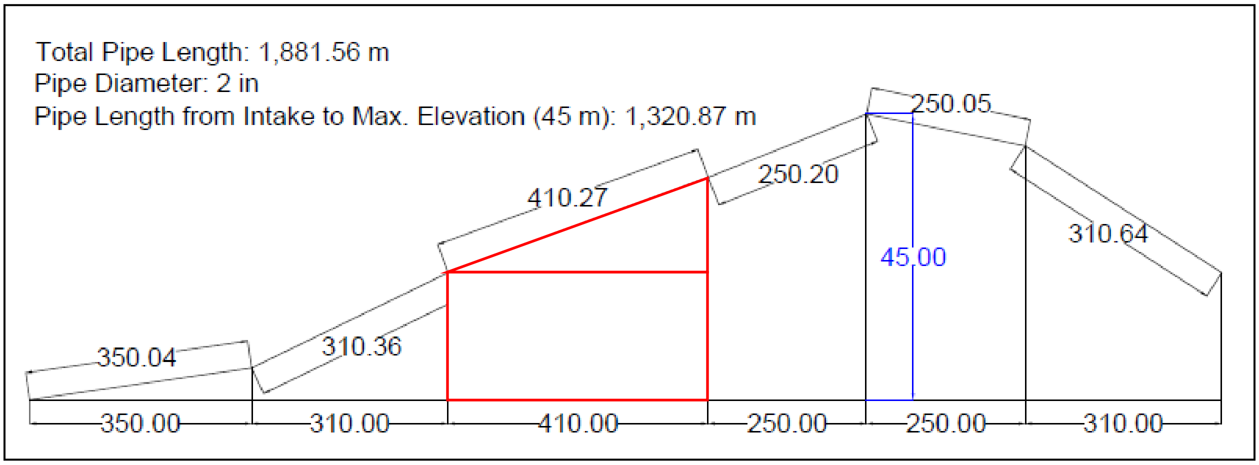


Figure F-1: Profile of Shannon Route

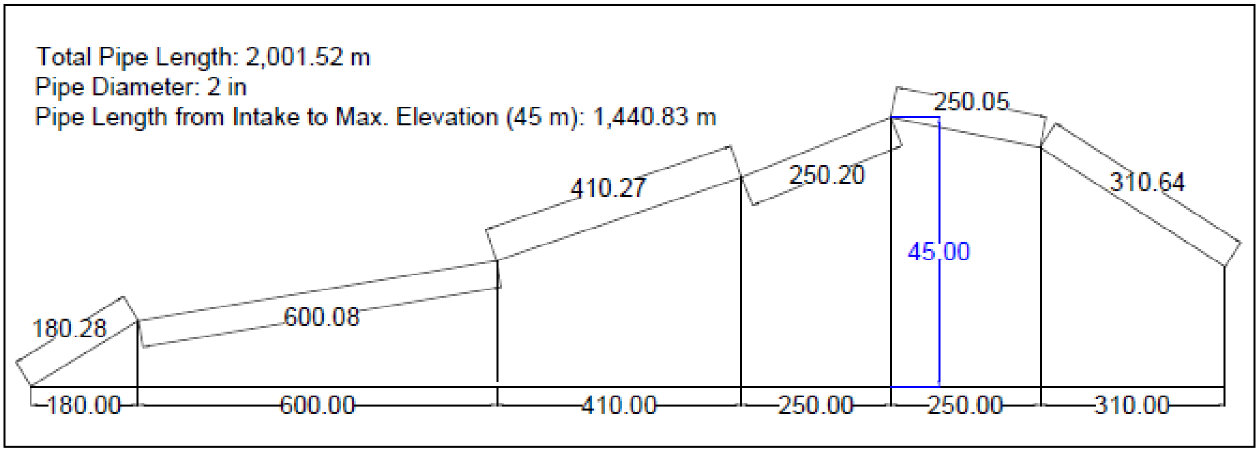


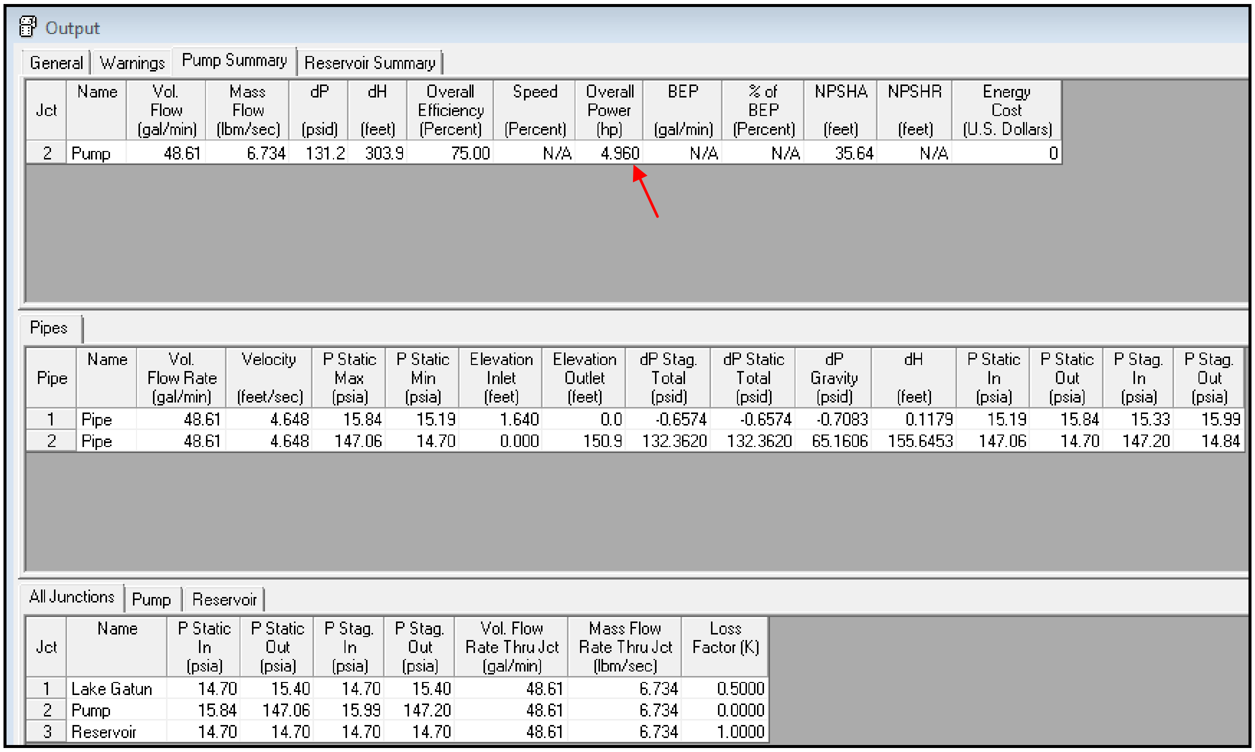
Figure F-2: Profile of Wheeler Route

The group utilized Pump System Improvement Modeling (PSIM), a software tool for modeling pipeline and pump systems, in order to obtain required pump characteristics for each profile. The group input specific information about the flow, pipe, and pump. These specifications are shown in Table F-1. The temperature was based on the water quality testing results for the proposed alternative intake locations. The fixed flow rate was based on the current water treatment system’s operating rate, which is approximately 2,916.67 gallons per hour. The pipe material is the same as that used in the treatment system and the pipe diameter is based on that of the current water intake. The group chose a sharp-edged flush and a pump efficiency of 75% based on default settings from the PSIM tool. The pipe length was derived from adding the distance from the intake to the highest peak on the profile. The pipe length after the highest peak was neglected from the pump analysis because it is assumed that the force of gravity propels the flow down the pipe. The pipe height was the highest peak on the profile, the elevation relative to the water source. After this information was input, the program provided the required horsepower for both systems’ pumps.

Table F-1: Input Data for PSIM Analysis

Characteristic	**Input**
Water Source Temperature	29.5 ˚C
Fixed Flow Rate	48.61 gal/min
Pipe Material	PVC, schedule 40
Pipe Diameter	2 in
Pipe Type	Sharp-Edged Flush
Pipe Length	1440.83 m (Wheeler)
	1320.87 m (Shannon)
Pipe Height (relative to source)	45 m (Wheeler and Shannon)
Pump Efficiency	75%

Figures F-34 and F-5 show the output data, including the pump summary and pipe flow details, for each profile. The required power for the Shannon Route was 4.960 HP and for the Wheeler Route was 5.191 HP, as indicated by red arrows in the figures.

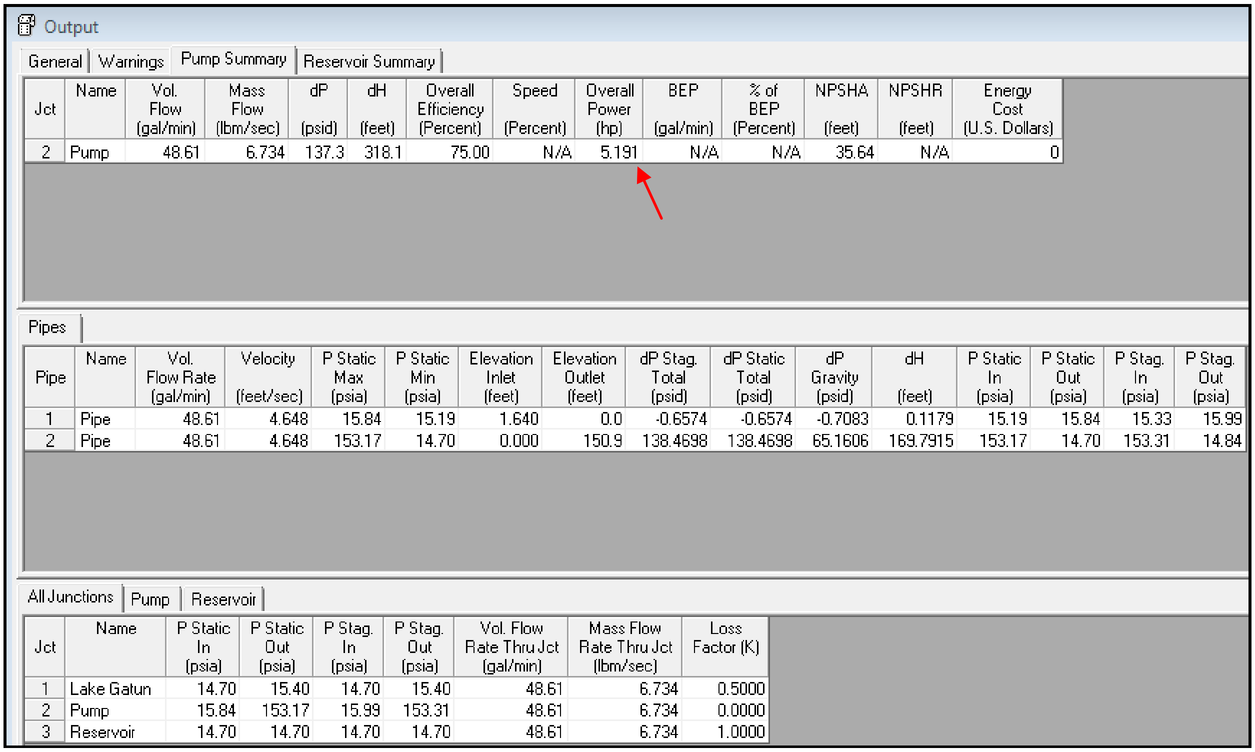


Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)	NPSHR (feet)	Energy Cost (U.S. Dollars)
2	Pump	48.61	6.734	131.2	303.9	75.00	N/A	4.960	N/A	N/A	35.64	N/A	0

Pipe	Name	Vol. Flow Rate (gal/min)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)	dH (feet)	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)
1	Pipe	48.61	4.648	15.84	15.19	1.640	0.0	-0.6574	-0.6574	-0.7083	0.1179	15.19	15.84	15.33	15.99
2	Pipe	48.61	4.648	147.06	14.70	0.000	150.9	132.3620	132.3620	65.1606	155.6453	147.06	14.70	147.20	14.84

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (gal/min)	Mass Flow Rate Thru Jct (lbm/sec)	Loss Factor (K)
1	Lake Gatun	14.70	15.40	14.70	15.40	48.61	6.734	0.5000
2	Pump	15.84	147.06	15.99	147.20	48.61	6.734	0.0000
3	Reservoir	14.70	14.70	14.70	14.70	48.61	6.734	1.0000

Figure F-3: Shannon Route Pipeline Data Output



Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)	NPSHR (feet)	Energy Cost (U.S. Dollars)
2	Pump	48.61	6.734	137.3	318.1	75.00	N/A	5.191	N/A	N/A	35.64	N/A	0

Pipe	Name	Vol. Flow Rate (gal/min)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)	dH (feet)	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)
1	Pipe	48.61	4.648	15.84	15.19	1.640	0.0	-0.6574	-0.6574	-0.7083	0.1179	15.19	15.84	15.33	15.99
2	Pipe	48.61	4.648	153.17	14.70	0.000	150.9	138.4698	138.4698	65.1606	169.7915	153.17	14.70	153.31	14.84

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (gal/min)	Mass Flow Rate Thru Jct (lbm/sec)	Loss Factor (K)
1	Lake Gatun	14.70	15.40	14.70	15.40	48.61	6.734	0.5000
2	Pump	15.84	153.17	15.99	153.31	48.61	6.734	0.0000
3	Reservoir	14.70	14.70	14.70	14.70	48.61	6.734	1.0000

Figure F-4: Wheeler Route Pipeline Data Output

Cost Estimates

Shannon Route:

Length of System: 1,881.56 meters, equal to 6,173.1 ft

Piping Estimated Cost: 6,173.1 ft x \$6.31 = \$38,952.26

Concrete Cost Estimate:

Beam: 6” x 8”

0.5’ x 0.667’ = 0.335 ft^2

0.3335 ft^2 x 6,173.1 = 2,058 ft^3

2,058 ft^3/27 = 76.25 Cubic Yards

Columns: 8” x 8”

0.667’ x 0.667’ = .4449 ft^2

.4449 ft^2 x 1 ft x 155 columns = 68.96 ft^3

68.96 ft^3/27 = 2.55 Cubic Yards

Total Cubic Yards: 76.25 + 2.55 = 80 CY

Concrete Estimated Cost: 80 CY x \$300 = \$24,000.00

Pump Cost: \$0 (using existing pumps)

Total Cost: \$38,952.26 + \$24,000.00 = **\$62,952.26**

Wheeler Route:

Length of System: 2,001.52 meters, equal to 6,566.67 feet

Piping Estimated Cost: 6,566.67 ft x \$6.31 = \$41,435.69

Concrete Cost Estimate:

Beam: 6” x 8”

0.5’ x 0.667’ = 0.335 ft^2

0.3335 ft^2 x 6,566.67 = 2,190 ft^3

2,190 ft^3/27 = 81.11 Cubic Yards

Columns: 8” x 8”

0.667’ x 0.667’ = 0.4449 ft^2

$0.4449\ ft^2$ x 1 ft x 165 columns = $73.41\ ft^3$

$73.41\ ft^3/27$ = 2.72 Cubic Yards

Total Cubic Yards: 81.11 + 2.72 = 84 CY

Concrete Estimated Cost: 84 CY x 300 = $25,200.00

Pump Cost: $0 (using existing pumps)

Total Cost: $41,435.69 + $25,200 = **$66,635.69**