An Environmental Analysis of Pollution in the Informal Settlements Surrounding Rio Burunga

Interactive Qualifying Project Report completed in partial fulfillment of the Bachelor of Science Degree at Worcester Polytechnic Institute
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Table of Contents

ABSTRACT

This project assessed the pollution of Rio Burunga in the informal settlements of Arraiján, Panama. Our team conducted water quality tests, held interviews with representatives from the national water utility of Panama (IDAAN), and integrated demographic and infrastructural data, identifying relationships between waste management practices, insufficient wastewater infrastructure and the concentrations of domestic effluent in the river. Our results emphasized the importance of wastewater infrastructure and suggested that wastewater reuse and pollution prevention methods will encourage better waste disposal practices.

AUTHORSHIP PAGE

Each member of this team was involved in conducting research, performing water quality tests, and reviewing each section of this paper. We analyzed our results together to present our findings and suggest recommendations to our client, IDAAN. Although we worked equally towards our project's success, we each took on different initiatives in order to efficiently reach our goals:

Samantha Moriarty

Samantha was primarily responsible for the research pertaining to the management of wastewater and types of wastewater treatment techniques in Latin America. Her contribution of the research behind wastewater reuse methods helped to craft our recommendations. She informatively communicated and organized our project objectives, while elaborating on each step of our methodology as our approach developed throughout this project. Samantha also took on the role of a sampler and chemist in the collection of water quality samples. The main structure of this report and the visual representation of our data can also be attributed to her efforts.

Lauren Morgan-Evans

Lauren was primarily responsible for the research regarding The Burunga Project and our client, IDAAN, setting the scope for the proper development of our work. Her thorough research pertaining to the current state of Burunga allowed us to develop a stronger focus for our project. She served as the primary editor of the paper, continuously reviewing chapters for readability, accuracy, and grammar throughout the course of the project. Lauren also took on the role of the data collector and chemist in the collection of our water quality samples. Her ability to compose the analytical deductions of the team helped us to construct recommendations from our findings.

Jada Plummer

Jada was primarily responsible for the research concerning the wastewater crisis in Latin America and Panama, providing us with a better understanding of the scope of contamination in the region. Her research regarding the obstacles contributing to the persistence wastewater issues allowed us to account for these impedances in the development of our recommendations. Jada also formatted and transcribed the interviews with our IDAAN representatives, calculated flow rates along Rio Burunga, and created visual models of the river at each sampling point. She continuously inspected the project for the accuracy of our techniques and explanations.

EXECUTIVE SUMMARY

Project Background

Improper wastewater disposal and treatment are increasingly recognized as leading contributors to the Latin American Water Crisis. The impact of the water crisis extends to Panama, where various bodies of water are regularly utilized as locations for the disposal of domestic wastewater, industrial effluent, agricultural waste and garbage. Communities become more vulnerable to the adverse health and environmental effects of wastewater discharge when their population growth exceeds that of the available wastewater infrastructure. Burunga is the fastest growing area in the district of Arraiján, with only 9 percent of its populace connected to a wastewater treatment plant (WWTP). For the parts of Burunga that have connections, there have not been any significant infrastructural repairs in almost 8 decades. The remainder of the population depends mostly on latrines and septic tanks. These methods of waste disposal often lead to discharge entering the nearby river, Rio Burunga. IDAAN, Panama's national water utility, is responsible for supervising the Burunga Project, which aims to prevent further pollution of the region's waterways with domestic effluent. In order to support the efforts of IDAAN in forwarding the Burunga Project, our team partnered with Footprint Possibilities, a non-profit community improvement organization. We assessed the contamination of Rio Burunga and provided recommendations to help reduce environmental pollution and rehabilitate waste collection and treatment services.

Project Objectives and Methodology

The goals of this project were to assess the state of pollution in Rio Burunga through quantitative and qualitative analyses of the river water quality, to investigate the current challenges of community wastewater disposal, and to present pragmatic recommendations about wastewater reuse and pollution prevention methods. Our project assisted IDAAN in its goal to transition the local communities from informal waste management practices to modernized practices, minimizing the impacts of contamination. Our team established 4 main objectives to accomplish our goals:

1. Become familiar with Rio Burunga and develop a representative sampling scheme for the investigation of the river's water quality.
2. Perform physical, chemical and microbial tests to determine the type and amount of contamination in the river.
3. Acquire information from IDAAN representatives and partnering Census and Topographical WPI project teams to understand the domestic practices surrounding contamination of Rio Burunga.
4. Interpret results to make recommendations on wastewater repurposing and pollution prevention.

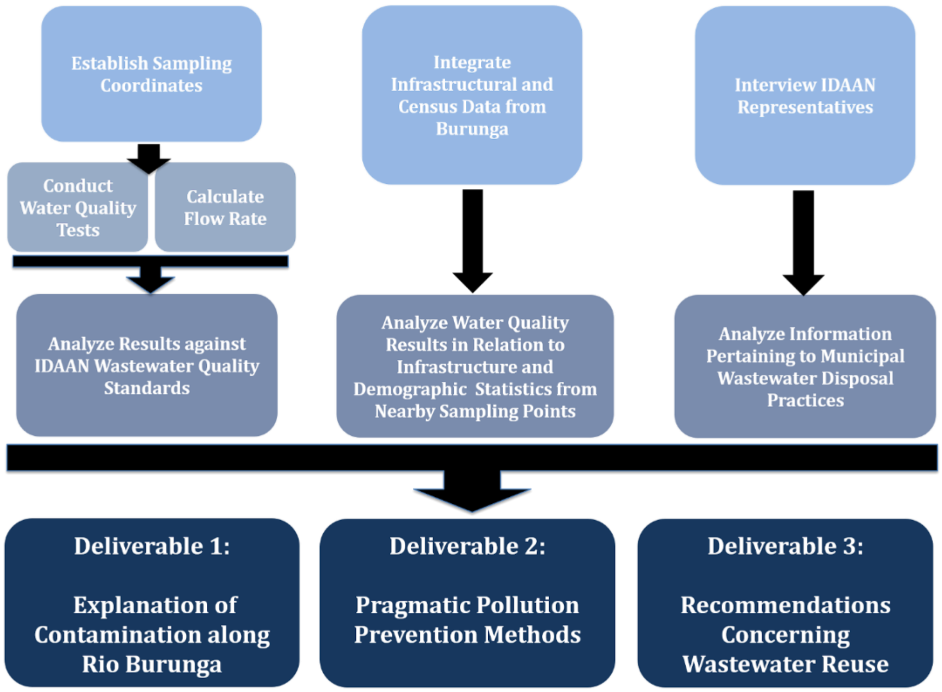


Figure 1-E.S. Overview of Project Methodology

To reach our first objective, we established sampling coordinates that would provide an accurate representation of the pollution along Rio Burunga. We identified 10 equidistant points using Google MyMaps and detailed maps from the Ministerio de Ambiente (Ministry of Environment). Then, based on location accessibility and recommendations from our IDAAN representatives, the 10 initial points were condensed and 6 final points were chosen for the purpose of conducting water quality tests.

We conducted a series of chemical, microbial, and physical tests to reveal contamination trends in the river. The chemical tests included nitrate, nitrite, and pH. The microbial tests included coliform, conductivity, resistivity, salinity, and dissolved oxygen. The physical tests included total dissolved solids, turbidity, and flow rate. The results of these tests were analyzed against the IDAAN standards for effluent entering receiving bodies of water.

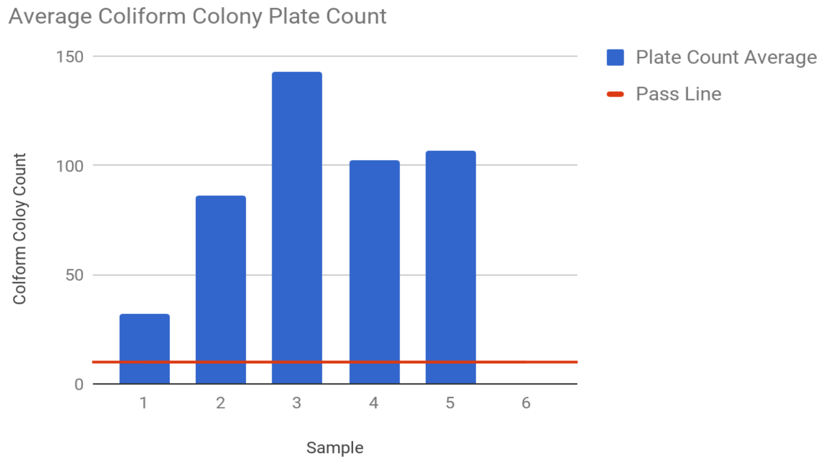
Data received from the two coordinating WPI project teams and the knowledge obtained from interviews with IDAAN representatives supplemented our evaluation of the contamination trends along Rio Burunga. This information allowed us to better understand the specific needs in the Burunga communities and, thus, frame our recommendations accordingly.

Findings

We concluded that there were four distinct relationships between pollution in Rio Burunga and the lack of reliable wastewater services in the area.

<u>Coliform is the Leading Parameter in Pollution Indication along Rio Burunga</u>

In comparison with the IDAAN standards for effluent entering receiving bodies, coliform showed the most recognizable results for contamination. It was the only water quality test for which results surpassed the permissible value at every sampling location except for Point 6. Some of the other tests, such as the nitrate and nitrite tests, also showed evidence of contamination at some points in the river. Interviews with IDAAN and our own visual observations of wastewater disposal malpractices additionally supported the notion that coliform is the most critical pollutant entering the river.



Graph 1-ES. Average Coliform Colony Plate Count

<u>Downstream Water Quality is Impacted by Upstream Disposal Habits of the Dense Populations</u>

Through the integration of the census data, visual data from the map, and the results from the water quality tests, we recognized a noticeable correlation between the size and density of the populace and the level of contamination. The increase in population upstream surrounding the river induced an accumulation of pollution downstream. Between points 1 and 3 there was a constant increase in the size of the population accompanied by a steady increase in the amount of coliform colonies, point 3 having the greatest amount. The nitrate and nitrite levels also spiked between points 1 and 3. Following point 3, there was a smaller amount of domestic effluent entering the river due to a significant decrease in population size. Yet, the coliform count at points 4 and 5 remained high. Along with the factors of flow rate and the type of effluent being discharged around points 4 and 5, this indicates that the wastewater disposal practices of the upstream populations have a large enough influence to sustain contamination in the downstream areas of the river despite a substantial population decrease.

Lack of Adequate Wastewater Infrastructure Prompts the Improper Disposal Methods

Data collected from the topographical WPI project team and information received from interviews with IDAAN employees revealed that there is currently no system in place for community sewage collection and treatment. All the residents in the communities examined by our partnering WPI project census team rely on using septic tanks and indoor or outdoor latrines as their main methods of wastewater disposal. These methods amplify the level of pollution of Rio Burunga since many of the people implement their own piping infrastructure to extend from their latrines to culverts which carry domestic influent into Rio Burunga. Additionally, some inhabitants detach themselves from their septic tanks and redirect the flow of their waste into the river. Until proper wastewater collection infrastructure is erected in the community and without an intermediate solution to the current waste disposal methods, the river will continue to be excessively defiled with household excrements.

The Absence of Communal Waste Management Services Promotes Detrimental Garbage Disposal Practices

Our analysis of Rio Burunga revealed that much of its pollution originates not only from domestic influent discharged into the river but also from the community's garbage. There are no garbage receptacles on the streets, and as such, community members resort to simple and easily accessible measures of waste disposal, where litter is simply tossed on the ground or in the waterway. This was highlighted by the abundance of organic and inorganic trash scattered throughout the community. We realized that residents may be unaware of the consequences of environmental pollution and concluded that resolving the problem of pollution in the region and its waterbodies should be coupled with the reformation of wastewater disposal and treatment management.

Recommendations

Based on our project findings, we decided upon the most advantageous and practical strategies for treated wastewater reuse and pollution prevention throughout the community. These are supplemental solutions to the previously established plans of the Burunga Project and should be used as methods to foster environmental sustainability within the community.

Reuse of Treated Wastewater

Construction Industry. As the infrastructure in Burunga develops, a great level of construction will be employed. In this industry, reclaimed water can be used as an acceptable and environmentally safe source for concrete mixing and dust control with specific standards for production.

Fire Hydrant System. One fire hydrant shared among a community consisting of close to 6,200 inhabitants is a severe safety hazard. The introduction of a hydrant system will require the need for a large volume of non-potable water which can easily be supplied by recycled water. It will also alleviate the safety concerns associated with its diminished presence, such as uncontrolled fires.

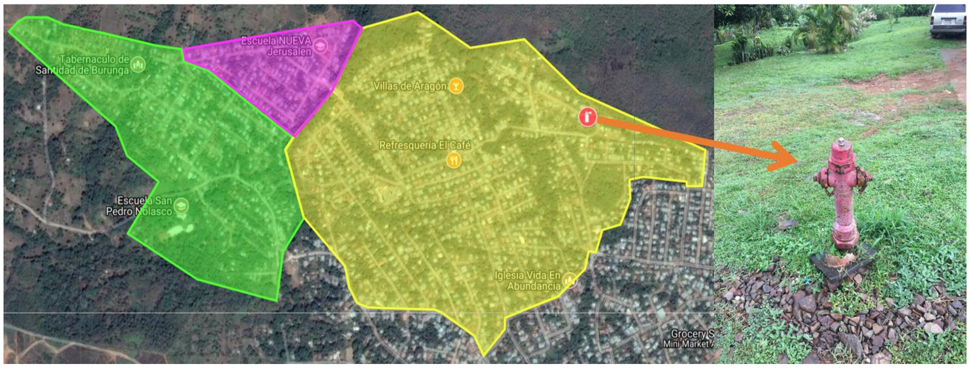


Figure 2-ES. Fire Hydrant in Upper Burunga Region

Landscape Irrigation. Within the communities of Burunga are many churches, cemeteries and school yards. Principally one person is assigned the duty of irrigating the land. This was seen in the case of a school yard, where an auxiliary member watered the school's flowerbeds with a hose. Landscape irrigation would simplify the process of land maintenance and employ the use of spickets and multiple hose systems allowing recycled water to cover a greater surface area in a shorter period of time. A regulated and consistent supply of the water to the land of these properties would hopefully add to their beautification.

<u>Prevention of Pollution</u>

Intermittent Sand Filters. A direct approach to pollution prevention is the introduction of sand filters in artery ways. Its design allows for the collection and filtration of effluent. Until all the infrastructure for wastewater treatment and collection is laid out, sand filters will act as an intermediate and extended resolve to pollution control. This suggested method is inconspicuous, easily accessible, affordable in construction cost and requires minimal skills to operate, making it a favorable solution.

Pollution Awareness Campaigns. Community involvement in the upkeep and improvement of their surroundings could be promoted through social interventions such as the implementation of community signs, waste collection and education programs. If community members develop a better sense of social responsibility for environmental protection and are advised of the implications of pollution, they may be motivated to take an active role in a pollution awareness campaign. Increasing the presence of waste prohibition signs and trash and recycling bins in the community will discourage inhabitants from littering and incorrectly disposing of their trash on the streets and in the river. Likewise, the implementation of environmental programs in schools and the communities will educate both youth and adults on the importance of environmental preservation, thus providing the population with resources to help the environment and enhance the goals of the Burunga Project.

ACKNOWLEDGMENTS

We would like to express our gratitude to our IDAAN representatives, Bolivar Duarte, Alonso Franco, Yamileth Quintero, and Natasha Vivas, for their assistance in selecting sampling locations, conducting water quality tests and expanding our knowledge on the Burunga Project. We also thank our advisors, James Chiarelli and Stephen McCauley, and our sponsor, Ricardo Montanari, for their constant dedication to our project's success. A special thank you to the other two Footprint IQP teams for their support and collaboration throughout this project and to Xylem Inc. for their generous donation of the Global Water Flow Probe.

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

CHAPTER 1. INTRODUCTION

While Latin America has the potential to store and yield more water per capita than any other part of the world, around one seventh of these rivers contain severe organic pollution (Koncagül, 2017). This region contains some of the largest lakes, rivers, and aquifers in the world, yet many communities lack reliable water delivery and treatment systems. Frequently, the high priority placed on supplying populations with potable water throughout Latin America has overshadowed the necessity to address the unsustainable situation of untreated waste (Idelovitch, 1997). In 2009, the Latin American and Caribbean region had an 85 percent coverage on potable water while treated wastewater was dramatically lower, at just 15 percent (Hernández, 2009). Communities and businesses have used various bodies of water as routine locations for the disposal of garbage, domestic wastewater, industrial effluent, and agricultural waste. The rapid urbanization and expansion of Latin America's biggest cities, such as Panama City, has increased the demand for water resources; a demand that is growing faster than the government and utilities can seem to manage or accommodate for (Barlow, n.d.).

Improper wastewater management and lack of infrastructure has become a growing environmental and health concern throughout Panama. Only 58 percent of Panama's rural population uses improved sanitation facilities (UNdata | Panama, 2016). Many of those who do not have access to sewerage services have built their own infrastructure, using domestic methods for the disposal of wastewater. These treatment methods have proven to be unreliable and the lack of maintenance on these systems has led to severe water pollution, posing significant threats to the health of the community. Panamá Oeste (West Panama) is the second largest province in Panama and is significantly in need of improved wastewater services evidenced by only 24 percent of the population having a connection to a municipal sewerage system (The World Bank, 2015). For the remainder of the population, half utilize domestic septic tanks and the other half utilize pit latrines or ground holes, many of which are non-functional or in need of maintenance (IDB, n.d.). In Burunga, the fastest growing corregimiento in the district of Arraiján, only 9 percent of the population is connected to a sewage system and the remainder have no connection to a wastewater treatment plant (The World Bank, 2015). The lack of effective wastewater disposal methods in such a rapidly expanding area has led the Government of Panama (GoP) to focus many of its improvement efforts within this region.

In March 2017, the GoP was approved a US $65 million loan from the World Bank to carry out the "Burunga Wastewater Management Project." This initiative aims to improve sanitation services and reduce the level of contamination in the Panama Bay and surrounding areas. The GoP intends to achieve this through the implementation of a new sewage system in Burunga, overseen by Instituto de Acueductos y Alcantarillados Nacionales (IDAAN). IDAAN is the national water and sanitation utility of Panama, part of whose mission is to improve the development of the community and the conservation of the environment through the safe collection and disposal of wastewater (IDAAN, n.d., Misión y Visión). Footprint Possibilities, a non-profit community improvement organization, has been authorized to assist IDAAN in obtaining census, topographical, and environmental data needed for the project's completion.

The work to be done in Burunga is extensive due to the challenge of introducing a modernized and regulated system in an area that has not had any major infrastructural repairs in about 80 years. Municipal pipes drain domestic effluent into the Burunga river (Rio Burunga), but little information has been gathered on the impact of these pollutants on the quality of the river. Developing a baseline understanding of the contamination in Rio Burunga is essential to the lasting success of the Burunga Project.

The goals of our project were to assess the state of pollution in Rio Burunga through quantitative and qualitative analyses of the river water quality, to investigate the current issues of community wastewater disposal, and to present pragmatic recommendations of wastewater reuse and pollution prevention methods. These recommendations will assist IDAAN in its mission to transition the community from informal waste management to modernized systems that minimize negative impacts.

CHAPTER 2. BACKGROUND

Improper wastewater disposal in Latin America is a multidimensional issue, making it difficult to control and implement effective reforms that protect communities and their water bodies from pollutants. This chapter will break down the major sources of pollution and their implications to provide a better understanding of the scope of contamination in the region. It will address the main obstacles contributing to the persistence of these wastewater related issues, allowing us to account for these impedances in the analysis of our results and development of our recommendations. This section examines the types of wastewater treatment methods used within the region along with an account of Chile's success in dealing with wastewater issues similar to those of Panama. This chapter also provides a dissection of Panama's governmental projects and initiatives related to our work, enabling us to better craft our deliverables around the needs of the existing plans for improvement in Burunga, Panama.

Wastewater Crisis in Latin America

The water crisis in Latin America is commonly identified by the unequal allocation of water resources, but another important manifestation of this crisis the high proportion of contaminated water, a key result of improper wastewater disposal. Across the region, pollutants are discharged from point sources and nonpoint sources. Point sources include wastewater from industrial and municipal pipes, channels, and runoff drains. Nonpoint sources include polluted runoff from agricultural areas into rivers (Rojas, 2011). The many environments where wastewater is poorly managed, the lack of effective treatment and monitoring, and the various governmental inefficiencies all promote the persistence of the wastewater crisis.

Water contamination is a widespread issue throughout the region with the major sources being agricultural, industrial, and municipal pollution. In Latin American provinces, domestic wastewater carries grease, detergents, bacteria, and dissolved solids into bodies of water through arteries. Agricultural runoff transports pollutants, such as "pesticides, organic matter, and salts," into bodies of water. Industry, on the other hand, uses less water than the municipal and agricultural sectors, but still contributes to pollution by way of untreated sewage. Pollutants like chemical residue, metal ions, and salts get transferred into bodies of water. The biggest contributor to industrial pollution is mining, where even concentrations of arsenic have been brought forth as an issue (Willaarts, 2014).

The lack of proper wastewater treatment facilities and monitoring programs throughout Latin America causes effluent to be a constant threat to bodies of water. According to the World Bank's Water and Sanitation Latin America Sewerage Document, because of the increasing expansion of urban areas coupled with the lack of investment into sanitation, on-site (domestic) methods have become popular in the outskirts of many Latin American cities (Rojas, 2011). These on-site systems have led to pollution from overflowing latrines and aquifers. In addition, health hazards have stemmed from inadequate and ill-monitored sewage storage tanks. Research has highlighted the repercussions arising from the lack of knowledge and skill in the domestic management of wastewater and construction of treatment systems, in addition to the need for regulation. The Dakar Declaration, written at the first International Symposium on Faecal Sludge Management, states that the construction of latrines alone is not enough to stop the threat of fecal contamination (The World Bank, 2006). According to the World Health Organization, pit latrines are the cheapest and simplest forms of improved sanitation. Although some people consider them improved, latrines require important maintenance and one must take caution when selecting their location to avoid the contamination of water bodies. Frequently, these preventative measures are overlooked because of the consequential financial and time constraints or lack of knowledge about them. For example, it is recommended that they are located downhill from water sources, at least 30 meters away from rivers and 6 meters away from houses (WHO, n.d.). The lack of communal enforcement, monitoring, and compliance with these recommendations could point to deficiencies in the scope of municipal management. Some research supports the idea that many municipalities have not been equipped to the level needed for the effective management of certain services (Idelovitch, 1997). The ambiguity of the responsibilities of municipalities shows a commonly recognized need for improved collaboration between levels of governance in Latin America. For effective treatment and monitoring programs to be implemented, the allocation of responsibility and structured plans should to be decided upon.

The selection of wastewater treatment plans and methods is a difficult and extensive process due to both technical, social, and governmental issues. The range and variety of treatment methods expand as the complexity of municipal wastewater and its standards for reuse and recycling continue to change. The economic aspects surrounding wastewater treatment play a major role in how countries select treatment methods. Governments not only need to implement treatment methods, but must decide where, when, and how much they want to invest in treatment systems (Mara, 2003). Most debates about the water crisis circulate around the process of construction and operation of infrastructure, privatization, and sanitation coverage in urban areas (Willaarts, 2014). A difficulty in ensuring the sustainability of the infrastructure is deciding which methods are both feasible and most reliable for each community. In many urban regions, the government has focused on implementing modernized infrastructure and treatment systems in areas that attract the most revenue and other areas have been deprived of these services leading to controversy. Within the past couple of decades, there has been a considerable amount of government focus and legislative reforms enacted regarding water allocation and sanitation.

It is safe to say that these reforms have been influenced by the bold demands of communities around Latin America. There have been numerous public demonstrations, such as Cochabamba, Bolivia's Water War (2000), advocating for greater efficiency and inclusiveness in governmental control of water and for the influence of international organizations in the governance of Latin America's water resources. Political movements in Latin America have been instrumental in encouraging municipalities to adopt upscale treatment programs. The people behind some of these movements include of public health officials, international businesses, consumers and governmental officials who wish to make major improvements in cities, smaller villages and the environment (Idelovitch, 1997). These series of reforms began around 1981 with the Chilean Codigo de Agua and continue up until today as populations throughout Latin America continue to grow and the demand for upgrades in wastewater infrastructure, expansion, and treatment, increase.

Wastewater Crisis in Panama

Although Panama, within the last two decades, has experienced a great economic boom due to its acquisition of the Panama Canal from the United States in 1999, there exists a significant disparity in the economic standing of the country, with the lower 40 percent suffering from a lack of infrastructure and weak service provision (Inter-American Development Bank, n.d.). As of 2012, only 42 percent of wastewater in Panama was treated (United Nations

Statistics Division, 2016). The formation of informal settlements in Panama and the recent attempts to improve wastewater treatment in these areas require new undertakings and introduce new struggles.

The coverage of water and wastewater services in Panama has reached a high level based on regional standards, but the allocation of these services to the low-income, peri-urban, and rural areas are in need of improvement (World Bank, 2009). Service continuity and water quality are limited in many peri-urban areas, so much that some communities still rely on water trucks to deliver potable water. Due to the country's continued economic development, there has been an upsurge in both foreign and local migration to certain areas, especially Panama City, where there has been a marked increase in the prices of real estate. Consequently, less prosperous incoming migrants have been pushed to the outskirts where informal settlements are formed (IDB, n.d.). The establishment of informal settlements arise for variety of reasons such as the low income of inhabitants, the divide between certain social societies and the urban environment**,** the lack of social housing available, strict financial obligations required for formal settlements, and the lengthy time period required to receive licensing for land (Fernandes, 2011). Many of the informal settlements and peri-urban areas have not received the benefits of formal governance including basic service provisions like water provision and wastewater treatment. It is believed that a main governance challenge for Panama is implementing individualized strategies for rural, urban, and other geographically specific areas in establishing infrastructure and treatment (Akhmouch, 2012). The lack of information that the government and utilities have on the state of wastewater infrastructure and maintenance in these informal communities also hinders their ability to effectively implement these strategies. Since water has been recognized as a human right, and the effects of insufficient treatment techniques are being increasingly acknowledged, reforms and modernizations have been underway to improve the wastewater crisis in many of these marginalized areas of Panama.

Panamá Oeste (West Panama) contains many marginalized districts and neighborhoods where wastewater treatment issues are rampant, prompting the government to focus many of its reform efforts in this area. Panamá Oeste is the newest province of the Republic of Panama, created in January 2014 due to the region's rapidly growing population. It includes the Districts of La Chorrera, Arraiján, Capira, Chame and San Carlos (Ministerio de Gobierno, n.d.). Based on the European Investment Bank's Environmental Assessment in 2015, a number of these disposal and treatment systems and facilities in this area are maintained poorly or are not working at all. Therefore, a portion of the population is expelling poorly treated wastewater into surrounding bodies of water. The use of these methods can lead to both surface and groundwater pollution, adversely affecting the health of the communities throughout the district. Along with the release of household waste into the region's waterways as a result of the domestic disposal methods, there were two recorded incidents of chemical contamination from 2011-2015, one of which defiled bodies of water. (Ministerio de Ambiente, n.d.).

When the GoP was considering areas to continue improvement projects, they chose to cover Burunga, a corregimiento (a small political subdivision; smaller than a district but larger than a neighborhood) in the district of Arraiján. Arraiján is one of the most populated districts in the province of Panamá Oeste and Burunga is the third largest and fastest growing corregimiento in Arraiján, having a population of 39,000 as of 2010 and annual population growth estimated at 17 percent (IDB,n.d.). The Project Coordination Unit (Unidad Coordinadora del Proyecto) of the Ministry of Health (Ministerio de Salud) recognized that only a "small amount" of wastewater is treated and the current infrastructure is not able to support any additional connections (World Bank, 2015). A practical plan is required to overcome the distinct challenges posed within Burunga.

An Overview of Wastewater Management and Treatment in Latin America

Wastewater management is built on the foundation of biological, chemical and physical processes that allow human and industrial effluents to be disposed of without danger to human health or cause perpetual damage to the environment (Jason, 2016). In terms of management, wastewater treatment systems need to be controlled not only with technology but through the involvement of communities as everyone is responsible for the failures as well as the successes of such a system (Eddy, 2000). In this context, how the community handles their waste, such as actions they take to conserve resources such as drinking water and their water recycling habits, contribute to the efficiency and longevity of the system. As Latin American countries continue to develop, advancements in their technology, treatment and management of waste need to be made in order to maintain a healthy, municipal water supply.

The main objective of wastewater treatment is to transform effluent into a liquid and a solid byproduct that complies with standard guidelines for discharge into water bodies. If the effluent is to be recycled, its quality and quantity must reach standards set for its specific purpose such as irrigation, industrial and recreation use and as groundwater recharge (Idelovitch, 1997).

Wastewater treatment methods vary due to the uniqueness of each situation, meaning that there is no universal treatment. Conventional wastewater treatment processes are broken into four methods: preliminary treatment, primary treatment, secondary treatment and tertiary treatment. Preliminary treatment is used to remove large particles from wastewater through coarse screening and grit removal. By removing large solids and materials from the water, operation and maintenance of following treatments will be amplified. Primary treatment is used to remove settable inorganic and organic solids through sedimentation and skimming material that floats on the surface. In this treatment, some of the incoming biochemical oxygen demand, total suspended solids and oil and grease is removed. In many industrialized countries, primary treatment is the minimal treatment needed for wastewater irrigation reuse for crops not consumed by humans. Secondary treatment follows primary treatment and removes biodegradable, dissolved and colloidal organic matter from aerobic biological treatment processes. Microorganisms must be separated at this stage by sedimentation to produce secondary effluent. Processes within the secondary treatment are activated sludge processes, trickling filters, oxidation ditches and rotating biological contactors. Activated sludge generally produces an effluent of higher quality than biofilters or contactors. Tertiary/advanced treatment is used when specific wastewater components cannot be removed through secondary treatment (FAO, 1992).

In Latin America and the Caribbean, many countries have used a general ten step selection process described by Idelovitch (1997), designing the most appropriate treatment method. Each step is significant and helps projects develop through the construction and design of treatment plants. (1) Determining the flow of wastewater is important in understanding the investment behind such a project. In locations where the flow of wastewater is high, meters can be put in place to monitor how much waste is coming from each area. Wastewater is comprised of industrial, commercial and domestic contaminants. These contaminants include solids, organic groups, inorganic substances and microorganisms. By (2) determining the composition of the wastewater, mechanical, biological and chemical processes can be used to separate and treat the waste. (3) Setting up standards for disposing or reusing effluent is another important step in selecting treatment. Standards in wastewater management and treatment ensure that contaminants such as sludge, effluent and larger particles do not limit nor prevent systems from working efficiently to dispose of or recycle wastewater. (4) Identifying objectives and alternate processes for treatments is based on the quality of influent and the desired quality of the effluent. Within the treatment process, (5) sludge, a byproduct of treatment, must be optimized in stability and dryness and minimized in quantity. This by-product will represent the amount of solid and microbial waste in the water. (6) The disposal of sludge requires specific standards for global environment protection. By (7) finding alternative processes for treating sludge, (8) specific sites can be identified to house these treatment plants. (9) These steps are followed by the need for pilot studies and industrial pretreatment programs to test new treatments and equipment for systems. Finally, (10) technical and economic feasibility analyses must be taken into consideration when selecting a treatment plant.

<u>Wastewater Treatment Case Study: Chile</u>

One example of a country following these guidelines is Chile. Chile's ability to transform their wastewater infrastructure over the past couple of decades has had a tremendous influence on sanitation governance, how industry handles their waste and environmental protection.

In the 1980's, less than 10% of households had their wastewater treated (OECD/UN-ECLAC, Environmental performance Review, Chile, 2005). Without wastewater treatment, untreated waste would flow back into the system and be used again in other industries. One of the biggest industries affected by untreated waste in the 1980's was agriculture. Chile's economy relies heavily on its exports of fruit, fish products, paper and pulp (Economy Watch, 2010). During this time, typhoid fever devastated the economy. The spread of typhoid was due to poor irrigation systems that allowed untreated wastewater to feed vegetation (Idelovitch, 1997). Untreated wastewater from homes was a governmental problem in which funds for maintenance and treatment methods were not allocated equally (Gabriel A. Bitrán and Comparing Private and Public Performance Eduardo P. Valenzuela, 2003). In the 1980's, Chile enacted a law that allowed water rights to be separated from land ownership, meaning that landowners with water sources on their property could no longer claim the entirety of the water source to their own use. This separation allowed water companies to take over these water sources through a new water rights regime and distribute water to meet the demand for potable water sanitation in their service area (Gabriel A. Bitrán and Comparing Private and Public Performance Eduardo P. Valenzuela, 2003). As water companies rose to power, this privatization and separation from the government caused problems as companies would charge more money than their customers could afford. In 1988, the Chilean government tried to make new regulations where rates would have to reflect the actual cost required to provide potable and wastewater disposal services. Privatization of waste companies disbanded as the government reorganized the water sector into thirteen regional water companies (Gabriel A. Bitrán and Comparing Private and Public Performance Eduardo P. Valenzuela, 2003).

In the 1990's, the central government decided to improve wastewater management and made a huge investment in an infrastructure program with improved technology that superseded previous wastewater treatment methods. The government also decided to privatize 5 of the 13 regional water companies and, through partnerships with the government, these companies would allocate a portion of their revenue to the funds needed for this new project (OECD Water Governance Survey, 2010). To protect consumers, the government enacted a social policy preventing increases in the cost of water and wastewater services, due to the fact that privatized companies were losing profit (OECD/UN-ECLAC, Environmental Performance Review, Chile, 2005). The goal of this program was to treat all urban wastewater flows, with secondary treatment being decided for 80 percent of total wastewater in inland cities, and primary treatment planned for the remaining 20 percent of wastewater for coastal cities and sea outfall (Aquafed, 2012).

This program was executed in Santiago, Chile. In 1990, 15 cubic meters (m^3) per second of wastewater flowed out of the area without treatment into three watercourses that then fed canals that supplied irrigation water to other areas (Idelovitch, 1997). The Metropolitan Water Company within Santiago tackled this issue with the support of the government and instilled a plan for wastewater treatment plants. They set up a pilot demonstration plant for unconventional wastewater treatments including stabilization ponds and deep reservoirs. The results from this demonstration plant helped engineers design and construct future plants. The plants had some setbacks and, in the early 1990's, only 2 percent of the wastewater produced in Santiago was treated. With political support and the backing of loans, three of the country's largest wastewater treatment plants were built within 1992 and 1994, containing aerated lagoons and activated sludge treatment systems; two methods that are most efficient within Chile now (Idelovitch, 1997).

Through the last decade, the government in Chile has worked diligently to minimize untreated wastewater. The percentage of domestic wastewater that was treated in a treatment plant in Chile reached 30 percent in 2003 (The Swedish Embassy, 2007). In nine years' time, 100 percent of the population had their waste treated before discharge or reuse (OECD/UN-ECLAC, Environmental performance Review, 2014). The increase of wastewater treatment coverage represents around 1,000 million m^3 per year of sewage that is treated by 280 treatment systems in the entire country. Investments have risen to an average of US$ 340 million per year with 38 percent being allocated to wastewater treatment plants and 52 percent being allocated to the maintenance and upgrades of drinking water and sewerage infrastructure (ECD/UN-ECLAC, Environmental performance Review, 2014). Through the ten-step treatment process selection, much of the country was serviced under four wastewater treatment methods: stabilization ponds, trickling filter, aerated ponds and activated sludge. Of the 280 WWTP's, a little over 60 percent of them used Activated Sludge Treatment. Activated Sludge Treatment produces a high-quality effluent for reasonable operation and maintenance costs. This treatment is the most popular biological treatment process for larger installations because of its low construction costs and the relatively small land requirement (NESC, 2003).

An example of activated sludge treatment used in Chile is found within one of the country's largest industries and main exports, the Pulp Industry. Of the industries within Chile, a large amount of contamination in water resources is caused by the emissions of untreated water from the production of pulp (The Swedish Embassy, 2007). This industry has their own treatment systems within the production plants. Wastewater from pulp usually has high values of suspended solids and biochemical oxygen demand (BOD5). BOD5 is a water quality parameter expressed in milligrams of oxygen needed to break down the organic matter contained in a liter of water over five days (Futura Sciences, 2017). In order to meet standards of wastewater effluent, the treatment plant uses an active sludge process to reduce the BOD5 and chemical oxygen demand (COD). Water from this process is lead back to the first step of the treatment plant. Withdrawn sludge is disposed of by an external company which produces soil improvements (compost) (Employee A2, 2008). This has proven to be a successful treatment for both large industries and individual communities.

Wastewater Treatment in Panama

IDAAN took the first steps in addressing wastewater issues in 2006 with the construction of a new wastewater treatment plant for the Bay of Panama. The main processes for treating wastewater are preliminary, primary and secondary, where large solid particles will first be removed from the liquid, organic matter will be dissolved through sedimentation and formed sludge will be moved to a wet trench where biological degradation takes place through activated sludge.

The Panama City and Bay Sanitation Project (PCBSP) was started in 2014. The goal of the project was to construct and restore the sewage treatment system, interceptors, and collectors to improve water quality in the Panama Bay and surrounding water sources where pollution is severe. An established activated sludge and sludge disposal management alternative was found to best suit specific conditions in Panama City (JICA, 2017). The treatment plant takes water leaving the sewage facilities and treats it to meet domestic water discharge standards and later releases it into a designated area, avoiding adverse impact on the environment. Sludge produced by the facilities is disposed of in existing landfill sites after it is treated (Hazen, 2014).
Today, some 280,000 m^3 of wastewater are discharged across the Panama City Metro Area each day. Connected to two of the Panama City Watershed's eight rivers is the first wastewater treatment plant that has a maximum flow capacity of 2.2 cubic meters/second (m3/s). At present, it treats waste and storm water flows of between 1.5 m^3/s, releasing clean water into Panama Bay (Burger, 2014). The impact of this project is to be seen over the next decades as new projects arise with similar goals. In fact, an extended project of the Panama City and Bay Sanitation Project, the Burunga Project, hopes to continue developing wastewater systems in underdeveloped parts of the country with lower costs and maintenance needs (Water World, n.d.).

The Burunga Project

Infrastructure and service provision expands at a disproportionate rate to the population growth Burunga. As such, many of the residents live without adequate access to basic services such as water supply and sanitation (WSS). Inevitably, there arises a host of problems related to public health and environmental sustainability, especially due to the surrounding water bodies being constantly polluted by the Province's untreated sewage. The Burunga Project is the second phase of a previously established venture named the Panama City and Bay Sanitation Program (PCBSP). The PCBSP is a US $1.5 billion, 20-year endeavor devised by the GoP, and managed by the Panamanian Ministry of Health Ministerio de Salud (MINSA) to provide efficient sanitation access to over half a million citizens and rectify the issues associated with the WSS in Panama Oeste (Vargas-Ramirez, 2017).

The first phase of the PCBSP, which was completed in July 2013, focused on Panama City. This phase resulted in the extension of existing sewerage and the construction of the first stage of a wastewater treatment plant (WWTP) to serve the western population of the country. The second phase, which has been underway since 2014, will involve the construction of new sewage systems, two new WWTP and the completion of the previously instated WWTP. This phase was structured to include the districts of Arraiján and La Chorrera in the province of Panama Oeste. As such, the Project was renamed the Panama Sanitation Program (Programa de Saneamiento de Panamá, PSP) also referred to as the "Burunga Project" (IRBD, 2017)**.** The total amount invested in Burunga Project is US$81.2 million, financed through loans from the Inter-American Development Bank (IADB), the Development Bank of Latin America (CAF), the European Investment Bank (EIB), the China Fund, and the World Bank, who provided documentation of the project's three key components (Rodriguez, 2016).

The first component of the Panama Sanitation Program, or the Burunga Project, involves the construction of a new sewage system in Burunga, a sub-division in Arraiján. It includes the construction of secondary sewers, collectors, pumping stations, a tertiary network, as well as inter-domiciliary connections from households to the main sewage network. The network will provide service to an estimated 20,000 residents by 2020 and eradicate the use of onsite sanitation solutions (latrines and septic tanks), with each occupancy containing a working toilet connected to a sewage system. (Vargas-Ramirez, 2017)

The second component focuses on institutional strengthening of the Project Coordination Unit (PCU) of the PCBSP for Wastewater Management in the Panama Bay area. The PCU will be provided with the assistance necessary to improve their technical ability in successfully managing water pollution in Panama. By way of knowledge-exchange events, such as technical training and structured operational models for sewerage infrastructure and management, the efficiency of PCU administrators in the operation, maintenance, and management of wastewater facilities will be bolstered. Conjointly, to effectively ensure the maturation of the project, the

PCU will develop social interventions to encourage the involvement of local community-based organizations in support of the Burunga Project. An example of such social interventions would be the creation and strengthening of community management committees to monitor socio-environmental conditions.

The final component deals with project management and administration**.** This Component will finance the costs associated with the supervision, quality control, monitoring, inspection and procurement support for the project.

The implementation of the sewer system will provide for the collection, transportation, and treatment of wastewater that is introduced into rivers and ravines within Arraiján, La Chorrera and Burunga. The employment of improved sanitation systems in a region of high urban poverty, the reduction of contaminants in its water bodies, and the protection and sustainability of the region's water bodies will positively impact the communities of Panama Oeste. Subsidiary benefits include increased business development, as well as tourism and real estate investment, improved bay ecology, the reduction in the incidence of disease, and the elimination of foul odor originating from the water bodies (Hazen, 2017).

IDAAN

To maintain the economic advances of the country while guaranteeing a better quality of life for the population, the coverage of basic services is of top priority for the government of Panama. Drinking water and sanitation services, respectively, are identified as the two most important areas in public service (IDAAN Plan de Acción, 2016).

The Instituto de Acueductos y Alcantarillados Nacional (The National Institute of Aqueducts and Sewers - IDAAN) oversees the provision of potable water and wastewater disposal services in Panama City. It was formed in 1961 with the mission of

> *"Improving the health of the community, the well-being and progress of the country through the provision of potable water services, and the collection and disposal of wastewater, ensuring the conservation of the environment, with a view to reaching optimal levels productivity and efficiency."* (IDAAN, n.d., Misión y Visión)

IDAAN envisions itself as being the leading company of public service in Panama, reaching levels of productivity and profitability that allow a self-sustainable development. Although this vision is possible, IDAAN struggles to fulfill its mission due to the hindrances it faces as a public sector; it suffers major operational, commercial and financial challenges. Consequently, the GoP had to intervene to develop a 2015-2019 Action Plan for the agency. The plan originated from an analysis of IDAAN's performance, the needs of the company and its clients, as well as its potential to successfully execute its duties. The plan of action focuses on the areas of IDAAN that need most improvement, such as its operational issues, low coverage regarding service provision, the quality of its aqueduct and sewer service, and the lack of access to potable water. With reference to wastewater disposal services, IDAAN covers 33 percent of the entire Panamanian population (Sánchez-Bender, 2017). According to the 2012 benchmark report made by the Association of Water and Sanitation Regulatory Entities of the Americas (ADERASA), the average sewerage coverage of 12 comparable agencies was 73 percent, a significantly higher figure than that of IDAAN. Sewerage coverage is poor in the vast majority of Panama's regions. Eight of the eleven provinces have coverage below national standards. Improving regional coverage is critical to the health and well-being of the population. In 2015, only 4 percent of households in regions such as Bocas del Toro and Panama East, had sewage service (IDAAN Plan de Acción, 2016). Currently, there are regions where the population has access to sanitation (flush or pour-flush toilet/latrine, a septic tank or a pit latrine), but not to sewerage. This is not entirely reflective of IDAAN's functional ability to provide service, as these locations are rapidly becoming inhabited. It is infeasible for IDAAN to monitor this growth and remain consistent in supplying citizens. Instead, it tends to provide service to those who choose to establish contracts of service with them (A. Franco, personal communication, Sept 21, 2017).

IDAAN concentrates its efforts on increasing coverage of the country's urban areas, where a majority of their paying clients reside. IDAAN has recognized the multitude of areas without a sewage connection and has dedicated part of the Burunga Project plan to the provision of water services to these communities. It is working in conjunction with the Ministry of Health (MINSA) to increase sewerage in all communities with a population exceeding 1,500 inhabitants (IDAAN Plan de Acción, 2016).

IDAAN is seeking to not only improve its coverage, but also its wastewater quality standard and the volume of wastewater it treats according to National Authority of Public Services (ASEP) and international World Health Organization (WHO) standards. Treated sewage will be absent of infectious agents such as coliforms and suspended solids, toxic chemicals and maintain a balanced pH. At the end of the 2015-2019 Action Plan, 75 percent of the Panamanian population within IDAAN's jurisdiction is expected to have high quality sewerage and receive wastewater treatment and disposal services. The volume of treated wastewater will increase according to ASEP standards and the treated effluent will comply with Commission of Industrial and Technical Standards (DGNTI-COPANIT Regulation 35-200) (IDAAN Plan de Acción, 2016).

Footprint Possibilities Inc.

Footprint Possibilities is a volunteer based non-government organization that is focused on seeking funding and organizing local community efforts, mainly in and around Cerro Patacon, Ancon, Panama. Their goal is to enhance basic health conditions and supplying people with accessible clean drinking water is a big part of that goal. This organization, while focused in Panama, is based in St. Petersburg, Florida but has affect more than ten thousand lives throughout rural Panama. Although Footprint Possibilities is a nonprofit, non-governmental organization and is strictly operated by volunteers, closely affiliated companies help with most of the expenses. Caterpillar Corporation and Coselecto, two major contributors, provide tools and materials for larger projects that may need more than just human labor. Other affiliates, such as University of Panama and Engineers without Borders, offer student volunteers opportunities to work with Footprint Possibilities helping Footprint Possibilities complete projects, large or small. This project was conducted in close coordination with Footprint Possibilities founder, Rick Montanari, and two other WPI project teams working towards collecting demographic and topographical data in the same Burunga region.

CHAPTER 3. METHODOLOGY

The goals of this project were to assess the state of pollution in Rio Burunga, to investigate the pending issues of community wastewater disposal and, using a pragmatic approach, to present recommendations of wastewater reuse and pollution prevention methods to IDAAN. We used a pragmatic approach to take qualitative and quantitative evaluations of pollution in the river. We collected demographic, topographical and interview feedback from two partnering WPI project teams and IDAAN representatives and used this data to aide IDAAN in mediating wastewater management problems.

The following is a list of objectives that we set to accomplish our goals for this project:

1. Become familiar with Rio Burunga and develop a sampling scheme for measuring water quality in the river and tributaries in the Burunga community.
2. Perform physical, chemical and microbial tests to evaluate qualitative and quantitative results correlating to the type and amount of pollution in the river.
3. Conduct interviews with IDAAN representatives and interpret infrastructural and demographic data to understand the domestic practices surrounding contamination of Rio Burunga.
4. Interpret results to make recommendations on wastewater repurposing, pollution prevention and reference potential products and systems to impede further environmental damage to Rio Burunga.

Mapping Rio Burunga: A Sampling Scheme

The first step we took in approaching this project was to become familiar with the area we were working in. In our first week on site, we walked on foot and were driven around by IDAAN representatives to look at different parts of the river. Using two types of map resources, Google MyMaps and maps provided by the Ministerio de Ambiente (Ministry of Environment), 10 equidistant locations on Rio Burunga were identified as potential sampling points. The 10 estimated points ran from where the river first enters the Burunga region to the end, where Rio Burunga merges with two larger rivers, Rio Portero and Rio Caceres.

By having 10 estimated points, we were able to estimate the distribution of pollutants for the range of the river. For each point selected, the corresponding latitude and longitude coordinates and the UTM were recorded for compatibility purposes for both mapping techniques. Google Maps uses longitude and latitude coordinates while the Ministerio de Ambiente and our client, IDAAN, employs the UTM Coordinate System.

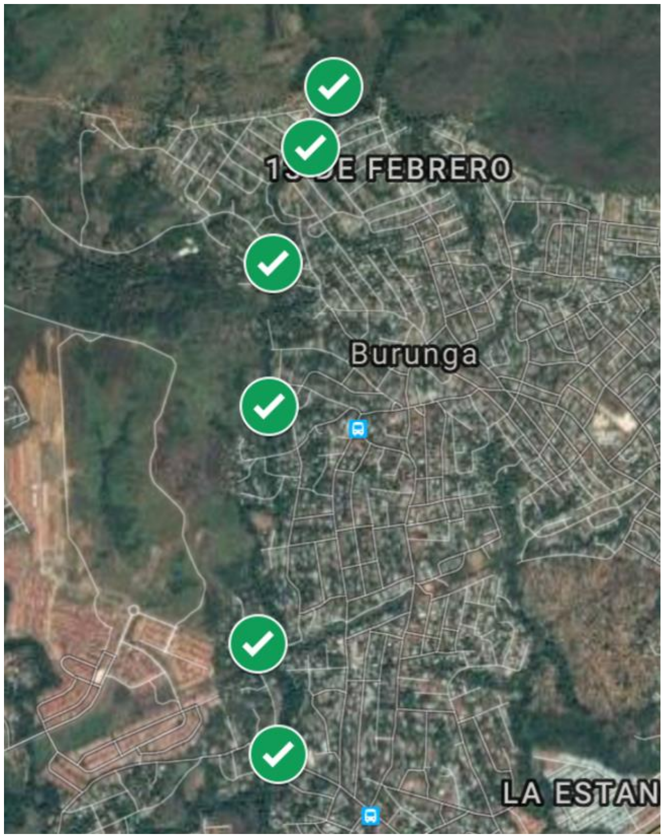


Figure 1. 6 Registered Sampling Points

With the assistance of our IDAAN representatives, including a chemist and an environmental engineer, we then validated our 10 estimated points and reduced our sample to 6 locations. Collectively, these 6 points were chosen because their range in distance and accessibility formed an accurate representation of the river. Individually, point 1 was chosen as our “control” for the water quality tests. At this point, the river water had not yet encountered communal discharge from the residents of Nueva Jerusalén, the first province Rio Burunga flows through. Points 2 and 3 were chosen near bridges. These bridges are central locations for the communities on both sides of the river, where culverts and outfalls channel influent into the waterway. Point 4 was chosen as the centrally located coordinate on the river. Here, arteries could be seen extending into the river, draining waste from the surrounding community. Point 5 was chosen because of its approximate distance between points 4 and 6. This part of the river had also extended in terms of width and was a central location for two communities. Point 6 was chosen because of its proximity to the convergence of Rio Burunga with Rio Cáceres and Rio Potrero.

Using the mapping instrument, MapPlus, coordinates of sampling locations were registered and photographed and then transferred to the desktop platform, Google MyMaps. The MapPlus application was chosen by the topographical team to map infrastructure and main roadways because it was fast, simple and accurate. With the registered points, we proceeded to take samples from the river.

La Chorrera Lab: Chemical, Physical and Microbial Analyses of Samples

Our next objective was to analyze the wastewater in the river utilizing chosen water quality factors and taking flow measurements. At each of the six designated sampling locations, we extracted two 100 mL sterilized bottles worth of river water. One of the sampling bottles was for physical chemical tests and the other bottle was for microbial tests. To take the samples, the bottles were opened and submerged in the water. This water was then returned into the river, so that the entirety of the inner bottle would be coated with the sample. The final sample was then taken at the surface with water flowing naturally into the bottle. Once the bottle was full, it was sealed and put into a cooler with ice packs to preserve the sample.

These samples were then taken to the laboratory at the Chorrera Water Treatment Facility and tested for nitrates, nitrites, dissolved oxygen, coliform, pH, conductivity, resistivity, dissolved solids, turbidity and salinity. Each of these water quality factors is important to our research. Simplified directions for each test can be found within Appendix C.

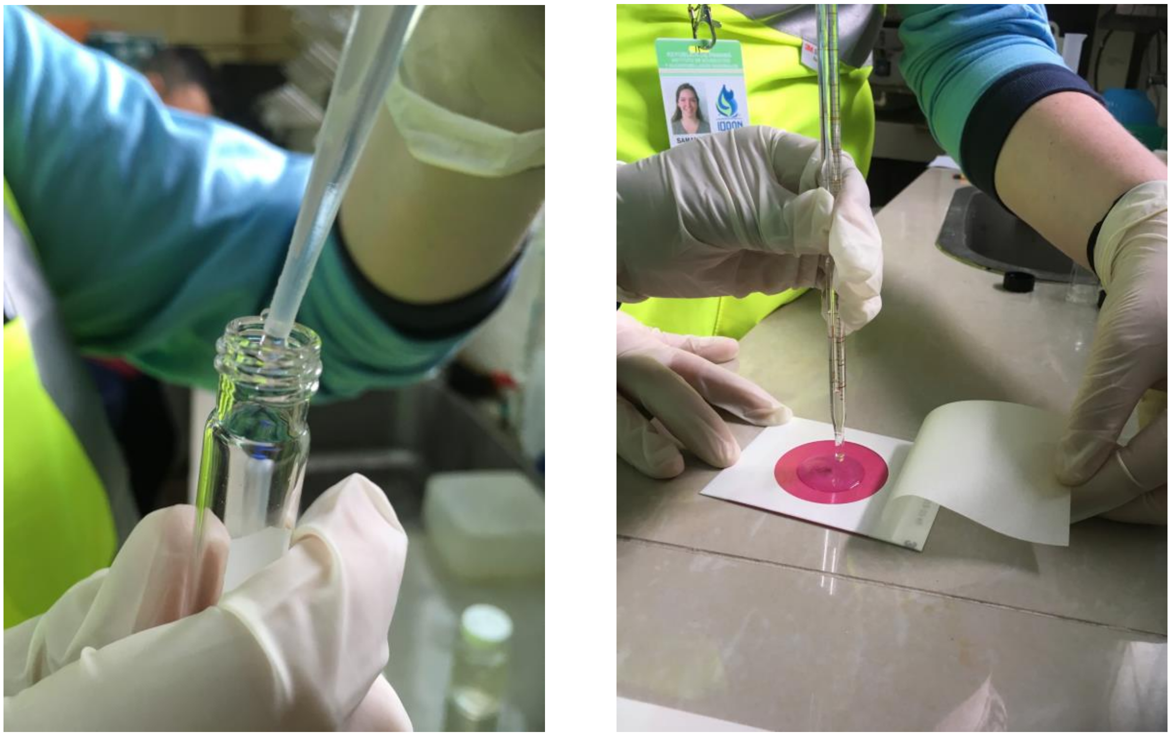
Figure 2. Sampling from Rio Burunga

Coliform Tests

The use of bacteria as indicators of the sanitary quality of water dates to the 1880's when microorganisms were found in human feces. The significance of coliforms was recognized by bacteriologists at the start of the twentieth century (Mario Snozzi, 1997). "Total Coliform" are a group of bacteria found in soil, on vegetation and in large numbers in the intestines of warm-blooded animals, including humans. Water is not a natural medium for coliform organisms and their presence in water is indicative of some type of contamination. Most coliform bacteria are not disease-causing organisms but do serve as effective water quality indicators (Eef, 2011).

In this situation, bacteria enter streams and rivers as wash from cities, overflown sewage, runoff from soil and vegetation, sewage treatment plant effluent, and as contaminated bottom sediments and sludge deposits (Schuettpelz, 1969). The number of coliform proliferates four to eight times its effluent number and reaches its maximum value in about one-half days' time (Kittrell and Furfari, 1963).

Two different test methods were used for coliform. A liquid test was performed to gather qualitative results, identifying if coliform was present within the samples. A petrifilm test was also performed for quantitative use, where bacterial colonies could be identified and counted as seen in Figure 3.



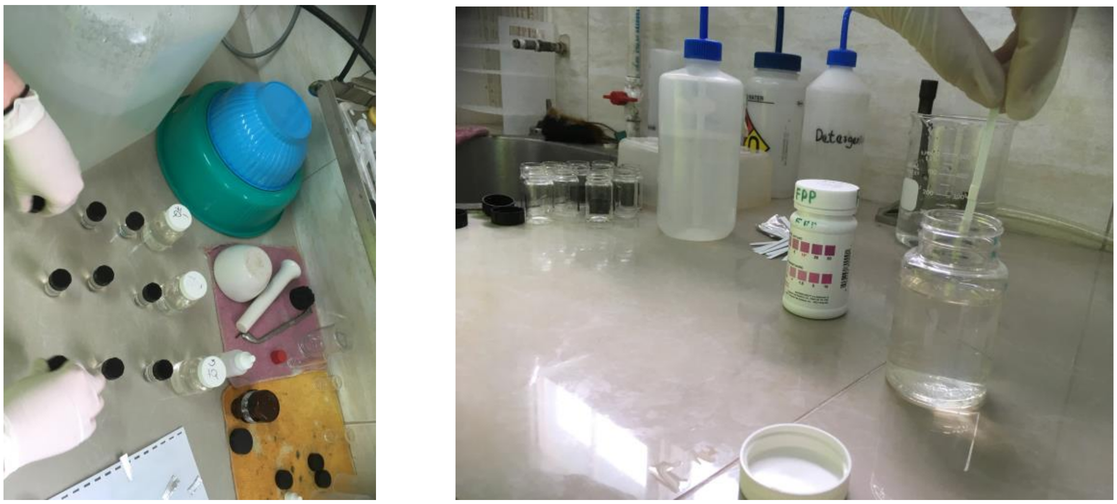
(a) (b)

Figure 3. Procedures of (a) Liquid Coliform and (b) Petrifilm Coliform Tests

<u>Nitrate/Nitrite Tests</u>

Nitrates and Nitrites are naturally occurring ions in the nitrogen cycle and a majority of them originate from animal and human waste (septic systems), crop residues, and fertilizers (Copeland, n.d.). Nitrite (NO2) is not ordinarily found in high concentrations in either surface water or in groundwater, but can exist as a medial step in the reduction of nitrate (NO3). Many effluents, including sewage, can lead to greater concentrations of nitrite in receiving bodies due to their high amount of ammonia. Fertilizer runoff, failing on-site septic systems, and industrial discharges containing corrosion inhibitors are also large sources of nitrates (Environmental Protection Agency, 2012). Therefore, high levels of nitrite in river waters may indicate pollution (Environmental Protection Agency, n.d.). In the environment, it is important to monitor the levels of nitrates and nitrites in water sources to prevent eutrophication. Excessive amounts of nitrate and nitrite will cause algae growth on surface water. When the algae die, the bacteria that helps decompose the algae will expend oxygen levels. Water then will become hypoxic, containing low levels of dissolved oxygen, and cause death in aquatic life (Vincent Summers, 2016).

In order to test for these two parameters, we used nitrate and nitrite test strips and also used programs in the Hach DR 6000 Spectrophotometer to test water quality through UV and visible spectrum wavelengths as seen in Figure 4 (a).



(a) (b)

Figure 4. Procedure of Nitrate and Nitrite Strips (a) and DR 6000 Program Testing (b)

Dissolved Oxygen Test

Dissolved oxygen (DO) refers the amount of free, non-compound oxygen that is present in water or other liquids and is expressed in milligrams per liter (mg/L). The level of dissolved oxygen present in a body of water directly relates the resource's health and its ability to support aquatic life. Water with DO levels less than 1 mg/L are considered hypoxic and usually devoid of life (EPA, 2016).

Dissolved oxygen content is affected by a number of factors, including but not limited to, aquatic life, elevation, salinity, temperature, turbidity and pollution. In the case of pollution, storm water runoff and wastewater discharge often carry oxygen-demanding wastes to streams and lakes which deplete the DO concentration. Animal wastes and other nutrients in rivers feed aquatic plants just as they would fertilize a farm or garden. Algae grow faster and more densely because of the presence of high amounts of minerals and organic nutrients. These well-fed plants require more oxygen for respiration and use up a great volume of DO when they decompose.

Wastewater from sewage treatment plants often contains organic materials decomposed by aerobic microorganisms. The amount of oxygen consumed by organisms breaking down waste is known as the biochemical oxygen demand or BOD. In aerated treatment ponds, dissolved oxygen is added to provide aerobic microorganisms with the content they need to convert organic wastes into inorganic byproducts. The amount of DO these organisms require ranges from 0.1 to 0.3 mg/L. (Water and Wastewater Industry, 2009)

Supplemental Water Quality Factor Tests

Several water quality factors were measured using the Hach HQ14D, a portable Conductivity and TDS meter that connects with conductivity Intellical smart cells for water quality, environmental and treatment process purposes. The Intellical probe automatically recognizes the testing parameter and stores the calibration history and method settings to minimize errors and setup time (Hach). This instrument was easy to use, as the only directions were to hold the probe still in a sample while a test was being done. The results of each test were displayed on the screen after a “beep” could be heard from the meter as seen in Figure 5. The tests performed using this meter are listed.

pH

pH is a measure of the acidity or basicity of a solution, ranked on a scale from 1.0 to 14.0 with acidity increasing as the pH gets lower. It measures the logarithmic concentration of hydrogen ions (hydrogen and hydroxide) which make up H_2O. Equal concentrations of these ions result in a pH level of 7.0 which is considered neutral. Atmospheric deposition (acid rain), surrounding rock, and certain wastewater discharges can cause changes in the level of acidity. pH varies based on the geology of the natural drainage pathways and catchment areas into the river. It also depends on river flow and on wastewater discharges, but is generally in the range 6 – 9. A pH level beyond the range of 6.5-8.0 diminishes the diversity of a stream by way of stressing the physiological systems of most aquatic organisms (Environmental Protection Agency, 2012). A low, or acidic, pH is especially harmful to young fish and insects and it hastens leaching of heavy metals which harm these organisms (DeBrosse, n.d.). Levels can also be affected by biological processes, most of which involve the uptake of carbon dioxide by vegetation during photosynthesis (Environmental Protection Agency, n.d.). Waters containing large amounts of dissolved organic matter from runoff and uptake, have acidic pH values (Allard, 2002).

Total Dissolved Solids

Total Dissolved Solids (TDS) describes the inorganic salts and small amounts of organic matter present in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonates (WHO, 2003). The test for total dissolved solids provides a qualitative measure of the amount of dissolved ions present but fails to identify the nature of ion relationships. Additionally, the test does not provide details about specific water quality issues. As such, it is classified as an indicator to determine the overall quality of the water (Oram, n.d.). TDS standards are typically set for drinking water but it has been found that at most, freshwater can have 2000 mg/L of total dissolved solids, and most sources should have much less than that. (American Water works Association, 1999). Depending on the ionic properties, excessive total dissolved solids can produce toxic effects on aquatic organisms (Fondriest, 2014). Moreover, high TDS water can have certain constituents at harmful levels that can cause adverse health effects (IWP, 2008).

Salinity

Salinity is the measure of all the salts (such as sodium chloride, magnesium and calcium sulfates) and bicarbonates, dissolved in water. It has many units of measurement, one of the more popular being ‘parts per thousand’ (ppt or ‰). The average river water salinity is 0.5 ppt which means that in every kilogram of river water, .5 grams are salt (URI, n.d.). There are 2 main types of salinity - primary and secondary. Primary salinity, also called natural salinity, is derived from natural processes such the accumulation of salt from rainfall over many thousands of years or from the weathering of rocks (WADOW, 2017). Secondary salinity, on the other hand, results from human activities such as irrigation and point source discharge which contains large levels of salts in effluent from municipal, agricultural and industrial wastewater (Queensland, 2003). An example of this is liquid detergent, a communal discharge which contains a high concentration of salts (The Guardian, 2014). Excessive amounts of dissolved salt in water can affect agriculture, drinking water supplies and ecosystem health (Water Education, n.d.).

Turbidity

Turbidity is a measurement of the extent to which suspended particulate matter interferes with the passage of light through the water. Silt, clay, organic material (sewage), industrial wastes, and microorganisms (plankton) all contribute to the level of turbidity. Soil erosion, excess nutrient and algae growth, and eroding stream banks are also activities leading to high turbidity. Dry weather can cause levels to spike when there are "earth-disturbing" activities in or around a stream without erosion controls. Turbidity can be an important indicator of the effects runoff from activities such as discharge, agricultural practices, logging, and construction (EPA, 2012). High turbidity levels increase the potential for bacteria growth by expanding the available surface area of suspended solids upon which they can multiply (EPA, n.d.). High turbidity also increases water temperature through the heightened heat absorption by particles in suspension. Consequently, this reduces the concentration of dissolved oxygen (DO) as water loses its ability to hold DO with increasing temperature (EPA, 2012). The effect of turbidity on the passage of light through water also reduces the concentration of dissolved oxygen. By preventing sunlight from reaching submerged plants, the rate of photosynthesis is decreased, thus lowering the levels of oxygen produced in the process.

Conductivity

Conductivity, in terms of water monitoring, refers to the capability of water to pass electrical flow. The ability for a water sample to do this is directly proportional to the concentration of ions in the water. Most bodies of water maintain a constant conductivity, which can serve as a baseline for comparisons of future measurements. In rivers, normal conductivity levels can be attributed to the geology of the land. Clay soils, as seen in Burunga, will ionize as they dissolve in water sources, increasing conductivity levels. Fluctuating levels of conductivity can indicate pollution. Agricultural runoff and sewage leaks will increase conductivity due to additional ions from chloride, phosphate and nitrates. Water sources have decreased levels of conductivity during periods of heavy rainfall and wet seasons due to dilution (Fondriest, 2014).

Resistivity

Resistivity is a measurement of water's opposition to the flow of current over distance. Resistivity decreases as ionic concentration increases. Water's ability to resist electrical current is proportional to the amount of dissolved salts in the water. Water with a large amount of dissolved salts will have low resistivity. When salts dissolve into water, there are free ions, which can conduct an electrical current. The less dissolved salts in the water sample, the purer the water. Resistivity is also the reciprocal of conductivity, where a low resistivity translates to a high conductivity. Resistivity is affected by natural factors, including urban and agricultural runoff, geology and rainfall (Fondriest, 2014).

Figure 5. Using the Hach HQ14D Meter

Recording Average Velocity and Calculating Flow

Aside from conducting chemical tests in the lab we also did a physical survey of Rio Burunga based on flow. The amount of streamflow, or discharge, is an important factor in interpreting water quality data because of the major effects it has on quality parameters (Erwin, 2005). Stream flow (Q) is the volume (V) of water moving past a fixed point (cross-sectional area, A) over a given amount of time. It is the function of the velocity and volume of the water:

$$\mathbf{Q = VA}$$

The velocity of water and volume of water increase at similar rates (EPA, 2012). The purpose of calculating average velocity is to compare and analyze the patterns in discharge along the length of the river. In some cases, more flow means that certain streams are carrying a greater amount of polluted effluent. On the other hand, rivers and streams with a large flow (large width, depth, and velocity) can receive discharge of pollution and remain mostly unaffected, in which case, streams with smaller flows, have less ability to dilute those pollutants. When these streams meet up with larger bays, the contaminants can be a huge threat to life (Erwin, 2005). The amount of sediment carried by the stream is also affected by streamflow. Sediment settles more quickly to the bottom of slow-flowing streams, while fast flowing streams causes higher rates of erosion and causes sediment to stay suspended for longer periods of time. Although sediment stays suspended longer, fast-flowing streams tend increase DO levels because they are more aerated (EPA, 2012). When water temperatures are high in low-flow streams, the DO levels can become critically low (WOW, 2008).

In order to calculate the flow rate at each of the 6 chosen water quality sampling points, we recorded the average velocity of the water and measured the width and depth of the river at each sampling location. For the first part of the process, we used the Global Water Flow Probe, donated to us by Xylem Incorporated, to measure average velocity (m^3 per hour). The flow probe that was given to us is ideal for storm water runoff studies, sewer flow measurements, measuring flow in rivers and streams, and monitoring water velocity in ditches and canals.

At each sampling point, we divided the river into 3 sections (A, B, and C) along its length and recorded the average velocity in each of the three sections. It was valuable to take velocity readings for each of the divided sections at each location because velocity varies throughout the stream's cross-section. The average velocity was recorded by slowly and evenly moving the Flow Probe up and down within each divided section for approximately 40 seconds. These actions were critical in decreasing the margin of error in our measurements by accounting for the varying velocities along the bottom and sides of the river. This is seen in Figure 6 (a).

Dimensions of the river were taken using a tape measure as seen in Figure 6 (b). Calculations of its cross-sections were derived from these dimensions and were used to determine the overall flow rate. Cross-sectional analysis enables one to investigate the shape of a river and to construct models assisting those investigations. It also enables the comparison of the river's morphology at different locations, aiding in the comparison of water quality factors and physical characteristics of the river.

At each sampling point location, the distance and depth across the river bank was measured in eight intervals. These measurements enabled us to create models of the river and calculate the flow. The first step in our flow calculations involved finding the cross-sectional area of each of the three divided sections (A, B, C) at every sampling location. We did this using trapezoid calculations (I-Study, n.d.): one trapezoid calculation equals the depth of the current point added to the depth of the following point, divided by two.

$$\textbf{Trapezoid} = (\textbf{Depth}_{\text{CURRENT}} + \textbf{Depth}_{\text{FOLLOWING}}) / 2$$

When drawn, the trapezoid is a line segment connecting the two depth measurements. The sum of all trapezoidal values in a section, multiplied by the distance between each of the eight intervals, results in the cross-sectional area. The flow (Q) was calculated by multiplying the cross-sectional area (A) by the section's recorded average velocity (V). Flow calculations were repeated for each of the three sections (A, B and C) at every sampling location along Rio Burunga. Each section's flow rates were added together to determine the total flow rate representing each sampling location. This resulted in 6 final flow rates for the 6 sampling point locations. These specific calculations can be found within Appendix B, along with models of the cross-sectional area of each sampling point.

(a)

(b)

Figure 6. Estimating Flow through (a) Average Velocity and (b) Measuring Distance

Burunga Communities: A Closer Look into the Wastewater Crisis

In order to fully understand the effluent entering the river, we researched the community demographics and infrastructure data supplied by the two other teams working within three of the Burunga communities: La Alameda, 13 de Febrero and Nueva Jerusalén. The census team collected data about the number of people living in each community and how they disposed of their waste (through septic tanks or latrines). The topographical team used MapPlus to document the existing infrastructure in these three regions. Our team analyzed this data for general patterns of wastewater disposal in the community and examined correlations between our water composition findings and the infrastructure and demographic data with three of our corresponding sampling points.

We conducted in-depth interviews with Alonso Franco, Yamileth Quintero and Natasha Vivas, employees from IDAAN appointed to our project. We asked them questions about the new project in Arraiján and how our findings will contribute to how this project will proceed. With the help of a Spanish-speaking WPI student from the census team, we communicated our ideas and questions concisely and gain valuable information on IDAAN’s contribution to the Burunga Project and how our results will prove to be useful for future project components.

The interview format was semi-structured. We asked a set of prepared questions, along with potential follow up questions, depending on the answer we received. As the representatives gave us more information about the project, social implication questions arose including how the community would be affected by project goals and how we could help the community understand the implications of pollution and the necessity for pollution prevention and wastewater reuse.

CHAPTER 4. RESULTS

The issues behind pollution in Rio Burunga can be organized into water component analyses and demographic, infrastructural and social findings. After conducting water quality factor tests and investigating infrastructural and census data in areas corresponding to sampling points, results were compared and relationships were formed between the levels of water quality and the surrounding environment. First, standards for water quality factors were discussed and established. Results were then organized by each sample point, having a physical description and a site analysis for each. Another factor that was taken into consideration was community culture. IDAAN representatives were willing to sit down with the team and answer questions regarding future plans and how our research can play a role in future initiatives and smaller projects surrounding community involvement and improvement through wastewater reuse methods and pollution prevention programs. This data was collected and separated by source.

To understand the science behind the contamination of Rio Burunga, standards for water quality needed to be put in place. These standards come from an IDAAN approved database, called Copanit 35-200. The table below gives maximum values of each factor allowed in liquid effluent discharged into receiving bodies of water, such as rivers.

Table 1. IDAAN Water Quality Standards

Test	**Maximum Permissible Values of Liquid Effluent Discharge to Receiving Bodies**
Coliform	1,000 Coli/100mL
Nitrate	1-6 mg/L
Nitrite	0.06 mg/L
D.O	5 mg/L * minimum permissible value
Conductivity	10000 [uS/cm]
Resistivity	10 [KΩ cm]
pH	5.5 - 9.0
T.D.S	500 mg/L
Salinity	350 ‰ Na
Turbidity	30 NTU

Point 1

The first point was considered the "control" of the six sampling points. This point came before the river reached the community in a wooded, secluded area. At this point, there was minimum flow and the water had a good clarity. The terrain was rocky and aquatic life could be seen thriving in the pockets of collected water, including fish and amphibians. There was also no visible inorganic waste in or around the river bed.

Table 2. Point 1 Data Results

Test	**Result**	**Pass/Fail**	**Location Data**	
Coliform [Coli/100mL]	3200	FAIL	Latitude:	8°58'49.21" N
Nitrate [mg/L]	0.3	PASS	Longitude:	79°40'31.54" W
Nitrite [mg/L]	0.012	PASS	UTM:	645609-992941
Dissolved Oxygen [mg/L]	7.49	PASS		
Conductivity [μS/cm]	160	PASS		
Resistivity [kΩ.cm]	6.14	PASS		
pH	7.54	PASS		
Dissolved/Total Solids [mg/L]	77	PASS		
Salinity [‰]	0.08	PASS		
Turbidity [NTU]	22.2	PASS		
Flow [m^3/s]	0.01824	LOW		

Site Analysis:

Because this point came before the start of any community, assumptions were made that this point would pass all the tests because there was no visible evidence of municipal waste entering the river at or before this point. In the table above, the only test that failed to meet the standards in Table 1 was coliform. The coliform count at this point was three times that of the maximum count allowed in effluent entering receiving bodies of water. This coliform bacteria growth can be attributed to the flow in the area. The flow was the lowest at this point and by having a low flow, sediment can settle in pockets where the water barely moves and can cause bacteria to grow.

Point 2

The second point was at a bridge that connected 13 de Febrero to Nueva Jerusalén. The bridge was still being built when the samples were taken. The sampling location was close to houses and a duck farm could be seen from the river edge. There were algae growing in small pockets along the riverbed and there was a foul odor coming from the arteries. This sample point was in the most densely populated area along the river.

Table 3. Point 2 Data Results

Test	Result	Pass/Fail	Location Data	
Coliform [Coli/100mL]	8612.5	FAIL	Latitude:	8°58'41.03" N
Nitrate [mg/L]	0.9	PASS	Longitude:	79°40'34.78" W
Nitrite [mg/L]	0.053	PASS	UTM:	645511-992689
Dissolved Oxygen [mg/L]	8.43	PASS		
Conductivity [µS/cm]	178.8	PASS		
Resistivity [kΩ.cm]	5.63	PASS		
pH	7.71	PASS		
Dissolved/Total Solids [mg/L]	84.5	PASS		
Salinity [‰]	0.08	PASS		
Turbidity [NTU]	15.7	PASS		
Flow [m^3/s]	0.334125	LOW		

Site Analysis:

The second point was much more polluted. The coliform count was almost nine times the maximum level. Another test that was close to failing the water quality standard was the nitrite test. The nitrite level at this point was less than a tenth of a mg/L away from failing. The flow at this point was also very low. The environment surrounding this point was much livelier, with densely populated communities on both sides contributing to the mass amount of effluent entering the river. Construction has moved sediment around and has caused more waste to enter the river on both sides. The foul odor could be due to the amount of bacteria that has grown. Many of the tests, including pH, dissolved oxygen and nitrates were the closest to the maximum permissible value levels at this point on the river.

Point 3

This point was at another bridge being constructed further down the river. This point it located downstream from the most densely populated area. Although there was not a lot of inorganic matter on site, the water was murky, muddy and the sediment at the bottom of the river was easily disturbed. The arteries leading into the river had foam and bubbles, suggesting that greywater was entering the river.

Table 4. Point 3 Data Results				
Test	**Result**	**Pass/Fail**	**Location Data**	
Coliform [Coli/100mL]	14263	FAIL	Latitude:	8°58'25.55"N
Nitrate [mg/L]	0.7	PASS	Longitude:	79°40'39.85"W
Nitrite [mg/L]	0.041	PASS	UTM:	645358-992213
Dissolved Oxygen [mg/L]	8.17	PASS		
Conductivity [µS/cm]	183.9	PASS		
Resistivity [kΩ.cm]	5.45	PASS		
pH	7.61	PASS		
Dissolved/Total Solids [mg/L]	87.3	PASS		
Salinity [‰]	0.09	PASS		
Turbidity [NTU]	22.1	PASS		
Flow [m^3/s]	0.249798	LOW		

Site Analysis:

The test results related to this point are like that of point two. The number of coliform colonies continued to climb. Turbidity was highest here, reaching a level that was merely 8 NTU away from the maximum permissible level. The water's murkiness and large amount of sediment was most prevalent and relatable to the amount of contamination in the area. The pollution from the two previous points had reached this area, contributing to the highest recorded amount of bacteria growth. The flow had started to increase, but did not have a noticeable effect on the amount of influent in the river.

Point 4

The fourth point was near a community a distance away from the main roads. At this point, there was visible inorganic waste seen not only in the river but in the trees surrounding the area. Arteries were mostly on the right side of the river, when looking at the map in Figure 1. The drainage arteries carried detergent discharge from the houses into the river. Although there was effluent entering the river, aquatic life did not seem to be threatened as tadpoles and small fish could be seen living in the river conditions.

Table 5. Point 4 Data Results

Test	Result	Pass/Fail	Location Data	
Coliform [Coli/100mL]	10,225	FAIL	Latitude:	8°58'6.46"N
Nitrate [mg/L]	0.7	PASS	Longitude:	79°40'40.38" W
Nitrite [mg/L]	0.022	PASS	UTM:	645344-991627
Dissolved Oxygen [mg/L]	7.48	PASS		
Conductivity [μS/cm]	193.7	PASS		
Resistivity [kΩ.cm]	5.16	PASS		
pH	7.34	PASS		
Dissolved/Total Solids [mg/L]	92.1	PASS		
Salinity [‰]	0.09	PASS		
Turbidity [NTU]	11.3	PASS		
Flow [m^3/s]	0.38128	HIGH		

Site Analysis:

The contamination of Rio Burunga at this point was much less than the points before. Although there was plenty of inorganic waste to be seen in and around the river, there was no direct effect on the river. Many of the tests, such as coliform, turbidity, pH, resistivity, nitrate, nitrite and dissolved oxygen started to decrease at this point. It had seemed that some of the effluent had started to dilute while traveling from point three to point four.

Point 5

Point 5 was the widest area seen in Rio Burunga. This part of the river was next to a community. There was a large amount of garbage and inorganic waste along the tree line and side of the river. This area was very shallow and very rocky. The water flowed over the rocks, which caused aeration and what is known as a “babbling” sound.

Table 6. Point 5 Data Results

Test	**Result**	**Pass/Fail**	**Location Data**	
Coliform [Coli/100mL]	10,675	FAIL	Latitude:	8°57'34.69" N
Nitrate [mg/L]	0.7	PASS	Longitude:	79°40'41.82" W
Nitrite [mg/L]	0.014	PASS	UTM:	645303-990651
Dissolved Oxygen [mg/L]	7.66	PASS		
Conductivity [µS/cm]	198.7	PASS		
Resistivity [kΩ.cm]	5.07	PASS		
pH	7.68	PASS		
Dissolved/Total Solids [mg/L]	94.3	PASS		
Salinity [‰]	0.09	PASS		
Turbidity [NTU]	11.1	PASS		
Flow [m^3/s]	0.644575	HIGHEST		

Site Analysis:

The results at this point were interesting. At point 5, the river was widest and had the highest flow. The decrease of levels in most of the tests can be attributed to this fact. With a wider mouth, the river can push more water out of this area. The area is shallow and rocky. The water flows with high velocity over these rocks creating air pockets for aeration to take place where sediment, ions and other small particles can be trapped and diluted. The specific point that the sample was taken was in the middle of this area. The environment’s ability to “clean” the water at this point is extraordinary. The coliform count is still high at this point and there is inorganic waste in this part of the river.

Point 6

The last point sampled was at another bridge. This was the last accessible point before the convergence of Rio Burunga with Rio Potrero and Rio Caceres. This area held the most aquatic life, with large and small fish, tadpoles and crayfish. The water was clearer than other sites and the river itself was rocky. There was not a very large community that had municipal effluent flowing into the river but it is important to note that the houses that were located on the river edge had pipes connected to their houses that allowed effluent to empty directly into the river.

Table 7. Point 6 Data Results

Test	Result	Pass/Fail	Location Data	
Coliform [Coli/100mL]	50	PASS	Latitude:	8°57'19.86" N
Nitrate [mg/L]	0.6	PASS	Longitude:	79°40'39.09" W
Nitrite [mg/L]	0.034	PASS	UTM:	645389-990195
Dissolved Oxygen [mg/L]	7.36	PASS		
Conductivity [μS/cm]	167.6	PASS		
Resistivity [kΩ.cm]	5.97	PASS		
pH	7.43	PASS		
Dissolved/Total Solids [mg/L]	79.5	PASS		
Salinity [‰]	0.08	PASS		
Turbidity [NTU]	7.54	PASS		
Flow [m^3/s]	0.61104	HIGH		

Site Analysis:

The least polluted sampling point was the last point. Most of the tests were at their minimum levels at this point, including coliform. In fact, this was the only location where the coliform count met the standards of Table 1. The low amount of coliform contamination has a parallel relationship with the results of all the other tests. Assumptions can be made about the previous point being the catalyst for the natural sanitization of Rio Burunga.

Social Dimensions of the Water Crisis

The water crisis in the Burunga Region must be understood not only through biochemical analysis of the river, but through cultural elements as well. Information from two teams working in the upper region of Burunga as well as information from interviews with IDAAN representatives gave the project social aspects that contributed to our overall conclusions and recommendations.

Integration of Demographic Data and Community Infrastructure

The integration of demographic data and community infrastructure data had influential impact on the findings and presumptions of pollution in the river. The census team and topographical WPI project teams worked in the Burunga region associated to the first three sampling points. Collectively, all teams coordinated and shared infrastructure, demographic and water quality data into one shared folder through a digital map on GoogleMaps. Once this data was stratified, analyses could be done to form relationships and correlation between water quality, infrastructure and census data and its effects on pollution in Rio Burunga.

The census team conducted surveys in three regions asking questions about the number of household occupants, how they disposed of their waste (septic tank or latrine), where they received potable water from and how long they have lived in the region. There were an estimated 6,000 people living within this region and about two thirds of the population used latrines (pink) and one third that used disconnected septic tanks (blue) to dispose of their waste. This statistic is seen through a visual representation on a map in Figure 7.

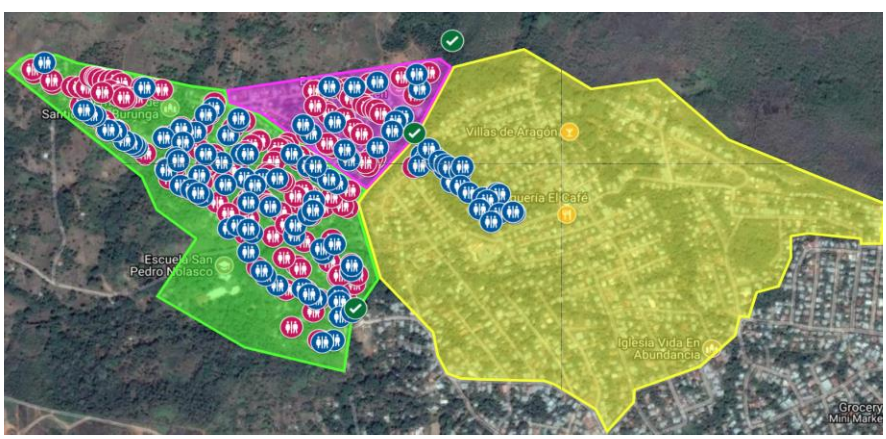


Figure 7. Household Water Facilities

The topographical team traveled through each of the communities, mapping roads, walking paths, bridges, culverts and other major pieces of infrastructure that was visible or important. From an environmental perspective, the most relevant infrastructure that has the most relevance to pollution factor determination are the culverts. Culverts are tunnels that carry a stream of drainage discharge above and under roads that lead to an open source. The number of culverts in each of the three regions of Burunga are seen below in Figure 8. Green icons represent ordinary culverts and red icons depict culverts that need maintenance. Of the culverts on this map, there is a large cluster near the river. The culverts are carrying effluent from houses through the community, building up nutrients, bacteria and inorganic matter, and dumping it into Rio Burunga.

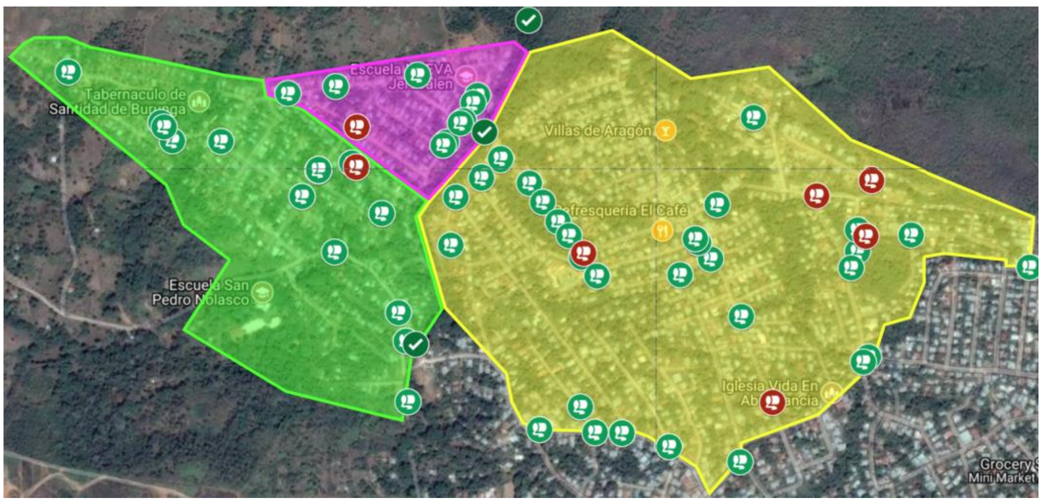


Figure 8. Infrastructural Data: Culverts

<u>Interview Analysis</u>

Alonso Franco, Yamileth Quintero and Natasha Vivas, representatives from IDAAN, gave the team valuable information pertaining to the Burunga Project and disclosed the plans of IDAAN in supplying these developing communities with water and waste management services. The representatives gave insight as to how this plan will be implemented and how the community will be impacted. All the information below can be found within our interview excerpts in Appendix E.

One of the components of the Burunga Project is dedicated to providing all of the households within this community with a connection to a wastewater treatment plant that is being built in Panama Oeste near Rio Cerro Silvestre. The treatment plant will pump potable water into houses and pump wastewater out of houses through a circulatory system. Once all the houses are connected to the treatment plant, there will be no need for septic tanks. The Panamanian government is in charge of the project's execution. IDAAN, acting as supervisor to the project, will have new contracts with every household in the community, making them the primary distributor and collector of water.

One of the social implications of this plan is the question of whether homeowners will be able to afford new sewage infrastructure. The government plans to solve this issue through the subsidization of sewage installation and monthly water bills. Since most of the citizens living in the Burunga region are of the lower economic status, deductions will be made so that the cost of these services are realistic and feasible. Each household will be responsible to pay a one-time $20 installation and IDAAN contract fee for the connection to the wastewater treatment plant. This installation fee also includes the sealing of any septic tanks on the property, to prevent future use. Monthly water bills will then be subsidized, costing on average $2.13 with a $1 fee for maintenance.

Another component of the Burunga Project is the "cleaning" of four rivers (Rio Burunga, Rio Cáceres, Rio Portero and Rio Perico) connected to the new treatment plant. The goal is to achieve water that is clean enough to swim in. Because of the premeditated plans to clean Rio Burunga, the aspect of the project changed from focusing on treatment plans for the river to more direct forms of pollution prevention and the necessity of wastewater reuse after treatment.

CHAPTER 5. KEY FINDINGS

Through our investigation of Rio Burunga along with the interpretation of data from the partnering Footprint project teams and interviews conducted with IDAAN Representatives, we were able to discern significant trends relating to the measure of contaminants in the river, the factors influencing its overall quality, and the perceived beliefs about the causes of the river's pollution. These conclusions regarding wastewater practices and Rio Burunga are organized into the 4 major findings from our study.

Coliform is the Leading Parameter in Pollution Indication along Rio Burunga

In comparison with the IDAAN Standards for effluent entering receiving bodies, the coliform tests had the most distinct results out of all the water quality parameters. It was the only test whose results surpassed the permissible limit at almost every sampling location. In the case of Rio Burunga, coliform seemed to be the most indicative of contamination and should be recognized as a critical water quality test in any follow-up investigations or monitoring activities carried out in the river.

It is true that some of the physical, chemical, and microbial parameters can create environmental conditions that support the growth of coliform, but many of these tests did not provide easily recognizable evidence of the river's contamination under the standards used by IDAAN. Point 3 had the highest count of coliform, which was about 14 times the permissible limit of 10 coliforms per mL. Out of the 5 points that surpassed the coliform count limit, point 1 had the smallest amount which was still about 3 times the permissible amount. In one of our supplementary artery examinations, near sample point 5 the influent was carrying an innumerable amount of coliform colonies referred to as TNTC (too numerous to count). The evidence of contamination from these coliform results can be clearly seen whereas all the other test results would require timely analysis to determine the presence and trends of contaminants along Rio Burunga.

It is not only the presence of coliform in our water quality results that makes it one of the best indicators of contamination in and around the river, but based on the wastewater disposal habits in Burunga, which were validated in our IDAAN interviews and data integration, it should be a key contaminant to test for. As noted from our background research, the use of septic tanks and latrines have contributed large amounts of fecal matter into bodies of water due to overflow and lack of maintenance. Out of all the houses surveyed by the census team in La Alameda, Nueva Jerusalén, and 13 de Febrero, everybody either had a septic tank or latrine. The topographical team found culverts. Although coliform bacteria can come from vegetation, it is more often a product of sewage effluent when found in excessive amounts within bodies of water and is related mostly to organic matter. With the lack of connections to a treatment plant, the numerous amount of septic tanks and latrines found in Burunga, and the many domestic pipes that our team visibly saw feeding into the river, coliform would show great evidence of the worsening or improvement of the wastewater systems in the community. The most indicative pollutant, coliform, should be used as the first indicator of progress in the quality of wastewater influent or infrastructure improvements.

Downstream Water Quality is Impacted by Upstream Disposal Habits of the Dense Populations

We found that the size of the populace surrounding the river had a strong relationship to the level of contamination downstream. Gathering population data from the census team and reviewing the patterns of houses surrounding Rio Burunga allowed us to determine trends between the upstream populations and the contamination downstream.

There was a consistent increase in contamination from points 1 through 3 which can be correlated to the increase in population. Point 1 is situated before the three communities surveyed by the census team, including La Alameda, 13 de Febrero, and Nueva Jerusalén. These 3 communities can be seen on the map in Figure 1. The coliform count at point 1 point was the second to lowest out of all of the sampling locations having an average of 32 colonies. Houses start to appear between points 1 and 2 where more effluent starts to discharge into Rio Burunga. The first two points are relatively close in proximity, so the number of houses and effluent between points 1 and 2 is smaller than between points 2 and 3. From point 2 to point 3 there is a rise in the amount of municipal pipes discharging effluent into the river. The spike in the level of coliform contamination from points 1 to 2 and 2 to 3 can be clearly seen in the Graph 2, located in Appendix A. There were 54 more coliform colonies located at point 2 than there were at point 1 and point 3 had 57 more coliform colonies than at point 2. The nitrate test results also showed a spike between points 1 through 3. The nitrate level was the highest at point 2, almost reaching the limit for freshwater bodies in the United States. The nitrite level also peaked at point 2 with a value of 0.053mg/L which is very close to IDAAN’s maximum permissible limit of 0.06 mg/L. The contamination levels at points 3, 4, and 5 were very close in value as seen in Graph 2 in Appendix A. Point 2 is located after Nueva Jerusalén and about half of 13 de Febrero, while point 3 is located almost at the end of all three communities, receiving a large amount of effluent from those areas.

After the accumulation of pollution at point 3, there was a significant decrease in the population, leaving only one side of the river populated. This caused a slight decrease in contaminants in sampling locations 4 and 5. Despite this slight decrease, the coliform counts at these points remained high. The dense populations at the head of Rio Burunga along with the incoming pollutants from one side of the river assisted in sustaining significantly high contamination levels at these locations. Data from the census team showed that out of the number of houses they surveyed in each community, 66 percent of the homes in La Alameda, 70 percent of the homes in Nueva Jerusalén, and 3.6 percent of the homes in 13 de Febrero used latrines without septic tanks. The prevalence of these latrines is dangerous due to their potential to transfer contaminants into bodies of water. The coliform levels at points 4 and 5 remained consistently higher, at counts of 102 and 107 colonies respectively. Also, the nitrate levels at points 4 and 5 remained very close to the levels at point 3.

Point 6 was an outlier in this finding. It was expected that there would be a higher coliform count at this location, but it turned out to have an average count of 1, which was the only point that passed the IDAAN standard. Our team has a few different hypotheses for the results at Point 6 based on physical aspects of the river. Rio Burunga’s converges with Rio Portero and Rio Caseres very nearby to Point 6 which could have caused a dilution of the pollution from backwash of the two other rivers. Also Point 6 had the second highest flow rate which increases the river’s ability to dilute incoming effluent on its own. It was very rocky in and around the river bed acting as a natural filter of pollutants. Lastly, although we did see pipes entering the river from houses, this area was not densely populated.

Lack of Adequate Infrastructure Prompts Improper Wastewater Disposal Methods

Although the Burunga Project has the intention of installing piping infrastructure connecting households to a wastewater treatment plant, at present, there exists no such connections. Residents rely on using septic tanks and indoor or outdoor latrines as their main methods of disposal. Through our research and personal observations, we found that these practices contribute to the impairment of the river. Some of the piping extending from the latrines, feeds into culverts which empty its contents into Rio Burunga. Of equal importance, we discovered that some inhabitants detach themselves from their septic tanks to conserve on water expenses. This perpetuates the flow of wastewater into the river as the sewage is redirected into the water. Through our survey of the community, the presence of soap residue with bubbles deposited from the mouths of ditches were indicative of greywater. The existence of drainage arteries reveal that it is a common practice for community members to use the river as a large ejection site. The fact that the people must resort to such measures of improper wastewater disposal raises the need for an intermediate solution for pollution prevention until all infrastructure can be installed. Due to the massive size of the region and its extent of underdevelopment, completion of installation is presumed to take years.

The Absence of Communal Waste Management Services Promotes Detrimental Garbage Disposal Practices

From our frequent visits to the river, we observed that the surrounding neighborhoods had an abundance of garbage deposited on the streets as well as in the waterway. We recognized that the focus of our project entailed the examination of the river, and it was discerned that its contamination stemmed not only from the domestic influent from the communities but also from the presence of various refuse. At point four, which is visually represented in Table 5, the surrounding area was teeming with residential waste, including fruit peels, discarded clothing, plastic bottles and other forms of biodegradable and inorganic debris. The amount of litter in the river and surrounding areas can be attributed to the lack of public receptacles throughout the communities.

Though there is clear interacting dynamic between the lack of disposal management services and waste removal practices among community members, it was apparent that community members may be unaware of the health and environmental risks of tainted water. Our claims were justified by the fact that many people use the river as a crossway. In certain areas where the waters were most shallow, and the river narrow, people would traverse the river, as they would a crosswalk, making direct contact with the water, despite its visible contamination. This may have been their only or most direct way of transport, nonetheless, it seems certain that the residents may be uninformed about the repercussions of pollution.

The current practices of the community members are prompted by their ability to employ the cheapest and seemingly most effective methods of disposal. Unloading garbage onto the streets and into the river are of no cost to homeowners, and there are no penalties for such actions. An example of how residents devise innovative tactics to live within their means is evinced by their collective sharing of potable water. In this practice, a household or a group of households receive a full supply of water and subsidiary houses without a tank nor water supply connect to that tank to form a network where the water can be divided.

We concluded that while rectifying the issues involving wastewater management and treatment is of utmost importance, tackling the problem of improper garbage disposal habits is an important corollary goal. It is our reasoning that if residents were cognizant of the negative implications of improper waste management, they would be more invested in improving and maintaining the cleanliness of their environs. However, it may be difficult to change waste disposal practices when established methods are seen as reliable and cost-effective.

CHAPTER 6: RECOMMENDATIONS

Project results concluded that the downstream water quality is impacted by upstream disposal habits from a dense population due to the lack of adequate wastewater and inorganic waste infrastructure. The planned Burunga Project will likely help a great deal in terms of providing needed services and revitalizing the environment from damage caused by pollution. The project is set to treat the river and connect all households in the area to sewerage to diminish contamination in the community. The projected plan for the region is insufficient alone without the cooperation and investment of the citizens it is impacting. Based on project findings, the most pragmatic way to enhance the Burunga Project is to recommend wastewater reuse techniques and pollution prevention methods that integrate and encourage the community.

Wastewater Reuse Methods

Recycled wastewater is treated wastewater from communities that is treated to meet standards of the treatment plant. In preliminary, primary and secondary treatment, suspended solids are removed, pathogens are disinfected and nutrients are reduced (Qian, 2006). The benefits of using recycled or reclaimed water include increased potable water quantity, decreased redirection of freshwater, reduced use of potable water by big industries, reduced amount of groundwater withdrawn from soil and increased water quality (Haering, 2009). Recycled water, although it may never reach standards to become potable, can be used safely within many industries. One of the most advantageous reuses of treated wastewater is urban reuse. Urban reuse encompasses many uses, including landscaping, fire protection and construction.

Landscape irrigation is an example of planned, direct non-potable reuse. Landscape irrigation requires control over the point of discharge from the treatment plant to a controlled area where used for irrigation (Keremane, 2017) such as through pipes that lead to spickets and hose systems. Landscape irrigation includes the maintenance of school grounds and cemeteries.

A successful example of wastewater reuse in cemeteries comes from a 700-acre cemetery in Southern California. The Rose Hills Memorial Park had used an estimated 293 million gallons of potable water a year to feed its grass. The switch from potable water to recycled water saved enough drinking water for 2,000 to 3,000 homes (AP, 2015). In the Burunga community, this same principle can be applied not only to cemeteries in the area but to school yards. Schools within the area can have recycled wastewater sent to their buildings to be used for landscaping purposes like grass, flowerbeds, bushes and anything else that will make the property more appealing to outsiders.

Industrial construction is another important aspect of urban reuse. As a developing region, Burunga can anticipate further construction with foundations of homes and paved roads. Reclaimed water sources can act as great resources for concrete mixing and dust control. Recycled water in concrete mixing has some limitations but its impact on the environment is much more significant. The limitations of using recycled wastewater in concrete operations are the standards the wastewater is held at. To avoid conflict with contractors, the quality of recycled water needs to meet criteria specific to the job site so that there is no diminished quality. The positive effects of using reclaimed water for concrete mixing are the simplicity of recreating batches of concrete and the increased ability to maintain the target solid content (Lobo, 2003). It was also found that the use of slurry, a semi liquid mixture or fine particles and water, had a faster setting time that mix that used purified water (Silva, 2010). Reclaimed water as a source of concrete mixing is an acceptable and environmentally safe practice if specific standards are met and kept through production.

Another way treated wastewater can be used is within the construction industry is for dust control. There are three types of construction dust. Silica dust, non-silica dust and wood dust. There are many harmful side effects of breathing in dust, including lung cancer, silicosis, chronic obstructive pulmonary disorder and asthma (HSE, 2006). The inhalation of dust particles causes damage to lungs and airways over time, often going unnoticed until the case becomes very severe and painful. Many tasks centered around construction produce dust, including the use of high energy tools, dry sweeping, working in an enclose space and the length of the work day. The most successful way to reduce the amount of dust in the air is to use water (HSE, 2006). Water dampens dust clouds down so there are less particles in the air. For this process to be productive, there needs to be a large enough amount of water to last for the whole project. This is attractive as a reclaimed water source purpose because it is more expensive to use potable water, the supply of treated wastewater is ceaseless, and there are few standards for the quality of treated wastewater (Keremane, 2017). The safety of construction workers within the Burunga region, as they continue to improve infrastructure, is an important factor to consider on wastewater reuse.

The most essential and advantageous way to use reclaimed water in the Burunga region is through the construction of a fire hydrant system. In the three communities that the topographical team investigated, the most striking note they made concerned the lack of fire hydrants in this region. In the three regions, home to thousands of civilians, there was a single fire hydrant (as seen in Figure 10). One fire hydrant to use for every house in the upper region of Burunga. A fire can erupt almost anywhere at any time, so it is important for fire services to have a large supply of water that is easily accessible, especially in an area like this where the river is the only large source of water running through the community. IDAAN planned to invest $ 1.5 million in hydrants around the country, including the maintenance of 700 damaged hydrants in the city (Diaz, 2012). The Panamanian government should become more aware of communities like La Alameda, Nueva Jerusalén and 13 de Febrero, who are left defenseless if there were ever to be a large-scale fire in the community. The construction of hydrant systems is not just a suggestion, but a necessity for the safety of the country's civilians. Hydrants fed with recycled water should be identified. By introducing hydrants supplied with recycled water around these areas, the risks of cross connection are reduced because all hydrants will come from the same non-potable source.

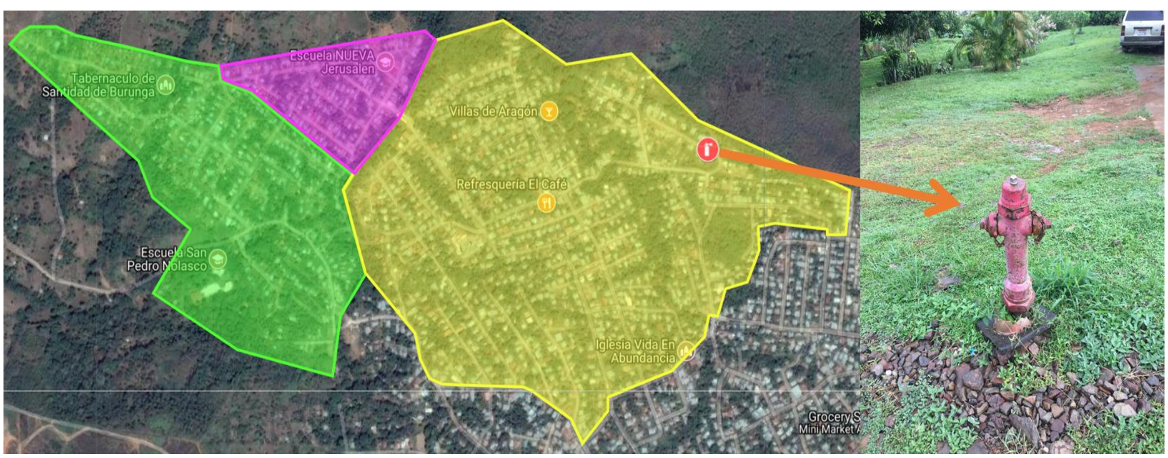


Figure 9. Fire Hydrant in Upper Burunga Region

Supplemental Pollution Prevention Infrastructure

Pollution prevention depends not only on social intervention but on methods that deal with the issues directly. A simple, yet tremendously helpful system of pollution prevention are intermittent sand filters. Historically, intermittent sewage filters have been known to produce effluent of high quality. These filters are designed to be placed in underdrains where effluent is collected and strained. Gravity discharge intermittent sand filters are used to allow treated effluent to flow out by gravity, which is much cheaper than inserting pumps to allow treated effluent to be released (EPA, 1999). Some advantages of using intermittent sand filters include low energy requirements, easily accessible, no chemicals, low construction costs and treatment capacity can be expanded. These sand filters can be installed to blend into the surrounding landscape and require close to no skill to operate or maintenance.

Until houses are able to have direct connection with wastewater treatment plants and the Burunga Project is under way, it is important for citizens and Panamanian government to initiate environmental transformation through social constructs. Society's ability to repair the damage is reflected on the mindset of the masses. With the recommendations on wastewater reuse and pollution prevention, IDAAN will act as the catalyst for a future of clean streets and rivers.

Pollution Prevention Methods: Awareness Raising Campaigns

Aside from wastewater reuse techniques, pollution prevention methods can encourage community members to adopt practices that further reduce pollution and have a lasting impact on the area. Social interventions such as community signs, implementation of waste collection and education programs, can have beneficial impacts. These pollution prevention method recommendations come from personal community observations of environmental damage from organic and inorganic waste.

One of the first acts the community can become involved in are grassroot campaigns. Community leaders can initiate campaigns that include placing signs around the community asking others to not dump their waste in the river or on the roads where runoff will carry it into the river and the implementation of communal receptacles. Signs can be placed around the river, on walkways and around any major infrastructure or buildings where community members congregate in large groups. These signs act as reminders to dispose of trash correctly, and will keep community members more alert about others who fail to comply. A second component of the anti-litter campaign is the implementation of public receptacles in each community. As referenced in the Findings chapter, there were no public methods of trash disposal. If public receptacles for waste and recyclable items were put on each street, the amount of inorganic waste floating around the community would be minimized.

The last recommendation for social intervention is the approval of an education program to be taught in local schools and for community members to have access to. Environmental education is used to inform the public to handle issues and problems regarding pollution from industry, agriculture and municipal sources. Programs, classes and pamphlets provide the public with the skills and information to take responsibility for their actions (Heimlich, 2002). The purpose of holding these classes and programs is to help others understand pollution to better protect the environment. By implementing environmental programs in schools, there is hope that the students will mature with a better sense for the need of environmental preservation.

CHAPTER 7. CONCLUSION

With plans to build a new wastewater treatment plant, connect all homeowners to a circulatory system for their water and efforts to clean Rio Burunga, Project Burunga encapsulates ideals protected under the bill of human rights from the UN; the necessity for potable water and sanitation. This project has the potential to help thousands of people in need of potable water and sanitation services. The pollution in Rio Burunga is extensive, with large amounts of bacteria growing, affecting aquatic life and raising health concerns for those who are impacted by the river's presence. The Burunga Project is hoping to treat the river and household waste through activated sludge treatment, a secondary method, and return the water through different applications. In order to heighten the success of the project goals, the regions in Burunga need direction as to how to handle their waste properly and responsibly as construction goes underway. The Panamanian government and IDAAN need to expand the network of industries that are able to use reclaimed water and understand the dangerous conditions people in the Burunga are living in without proper resources for combating domestic fires. The assessment of pollution in Rio Burunga as well as investigation into infrastructure and future investments has opened the opportunity for improvement for government and large industries to take advantage of as well as the necessity of community cooperation.

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APPENDIX A: LAB RESULTS

Table 8. Coliform Petrifilm Plate Tests				
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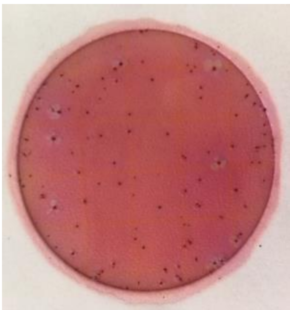
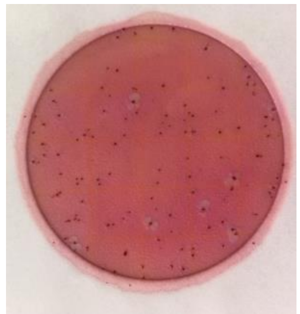
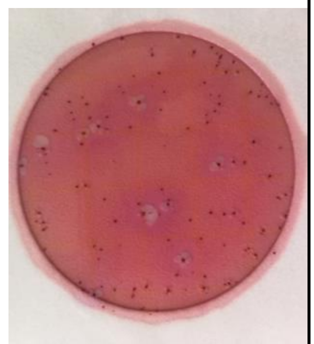
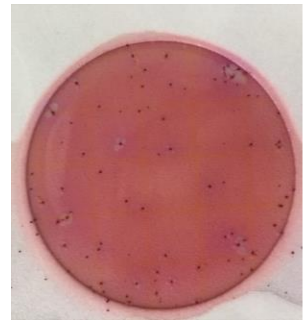
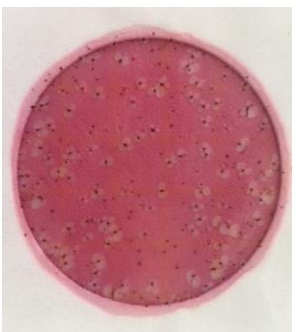
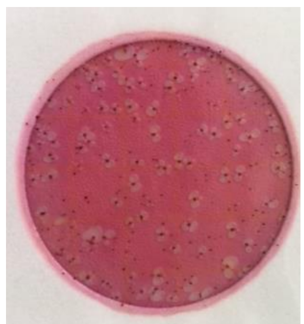
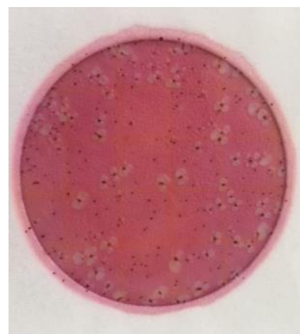
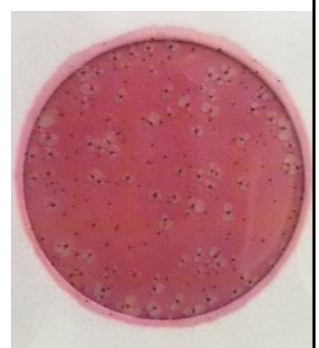
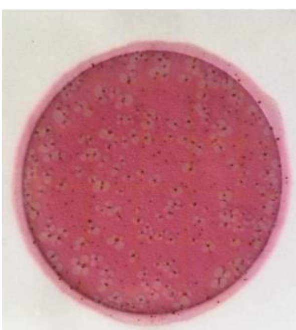
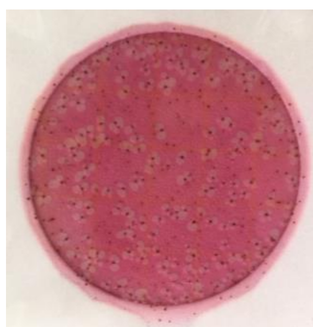
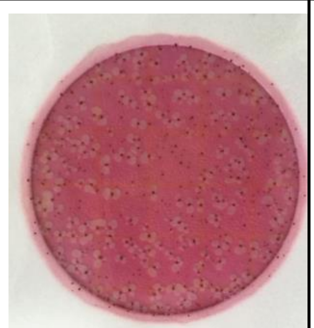
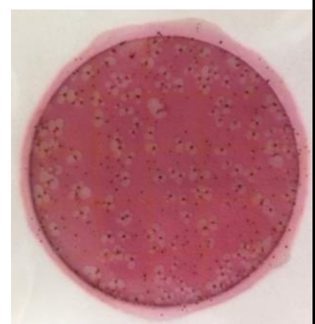
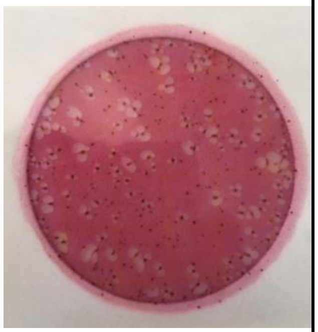
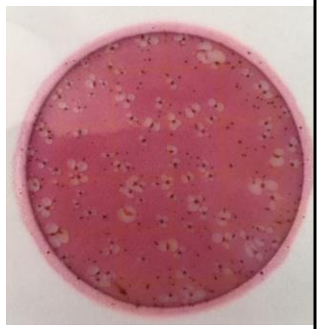
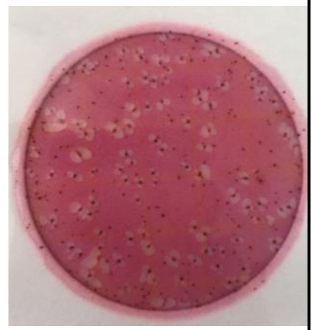
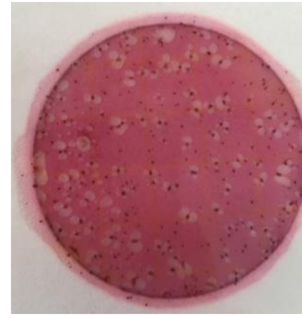
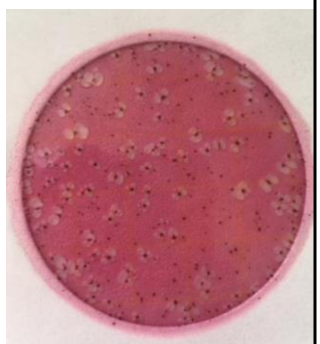
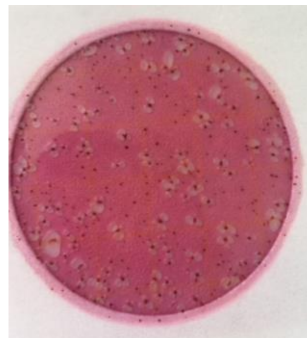
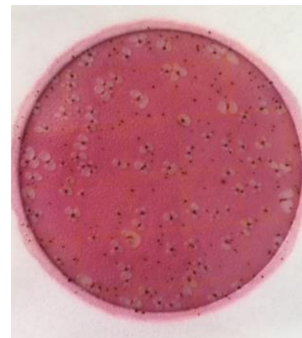
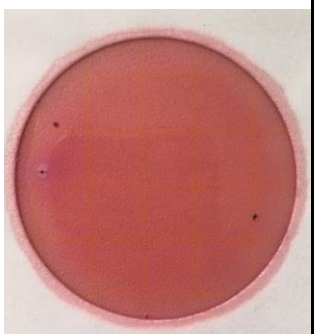
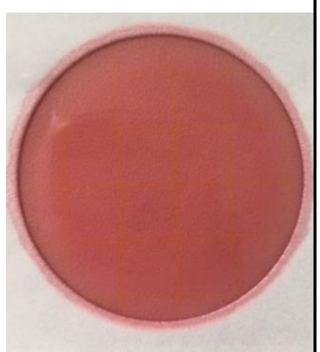
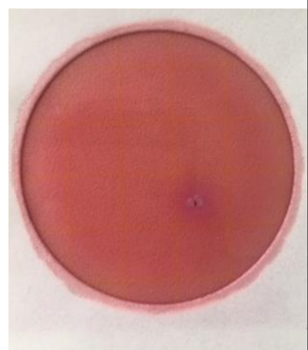
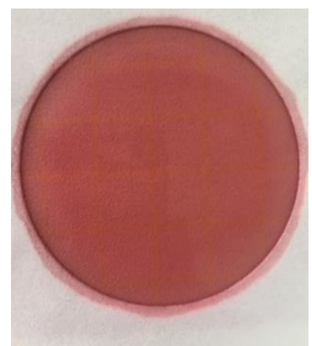
Sample 1				
Sample 2				
Sample 3				

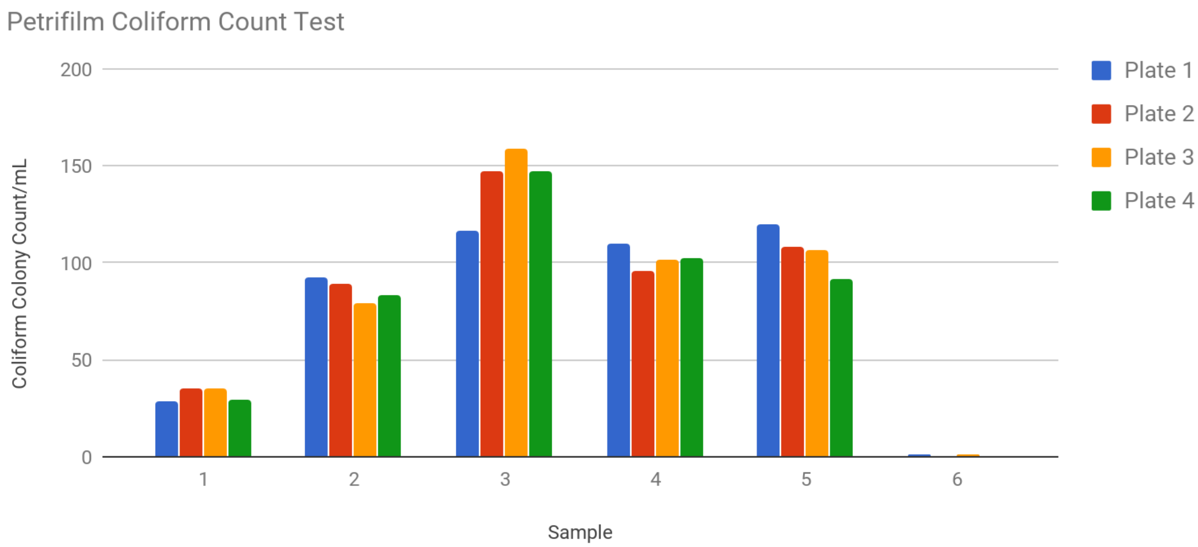
Sample 4				
Sample 5				
Sample 6				

3M™ Petrifilm Coliform Plates were donated to our research by the University of California; Burkeley team that completed a project in Panama before our arrival to the country. These plates were critical to our research and helped in our understanding of pollutants entering Rio Burunga. 1 mL samples from each sample point on the river were put on 4 plates and incubated for 24 hours. In the interpretation guide, the number of colonies on each plate can be counted using a microscope or magnifier. The identification of a colony is completely up to the interpretation of the person counting the plates. Colonies can be defined as “small red dots” with white gas bubbles connected, surrounding or near the red dot. These bubbles of gas are usually circular. Colonies were not counted if they had a smeared appearance or stood alone without and visible white bubbles. The darkening of the gel on the petrifilm also indicated the growth of coliform bacteria. This can be seen in all the plates for each sample. The gel darkens as more coliform grows on the plate. The two plates that differ within color and number of coliform are plates from sampling points 1 and 6. These plates are lighter in color and had much less growth on them. The next table quantifies the number of coliform on each plate.

Table 9. Coliform Petrifilm Count Data

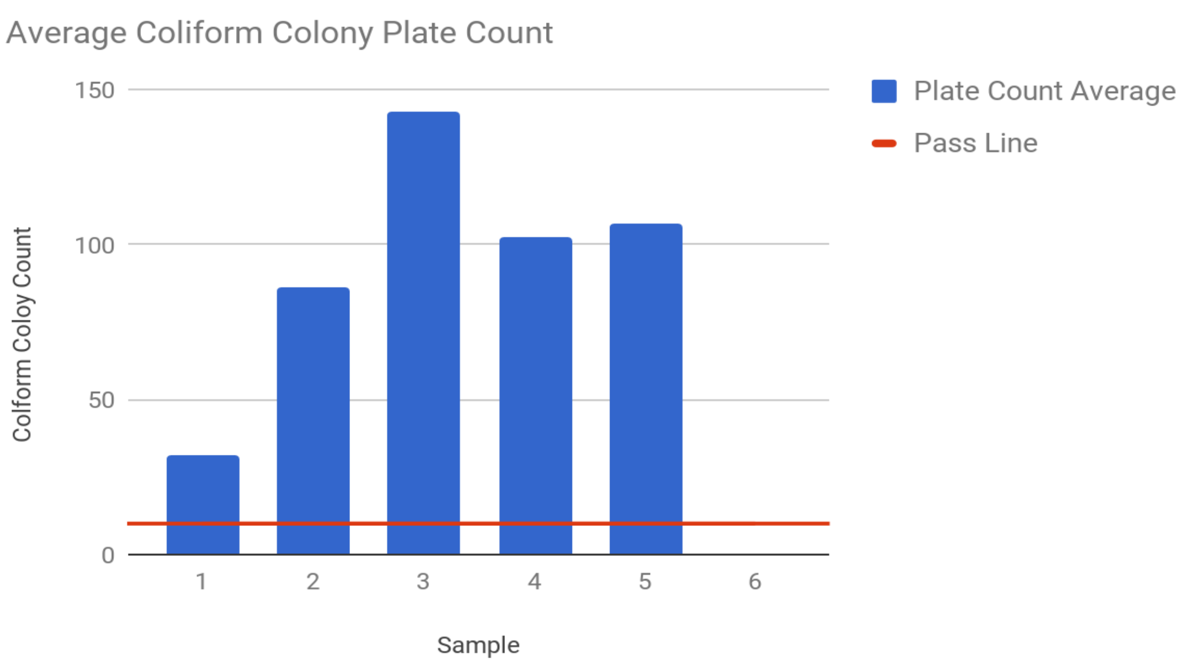
Sample	Plate #1	Plate #2	Plate #3	Plate #4	Avg Plate	Range
1	30	37	36	29	**33**	
	27	33	34	30	**31**	
Plate Count Average	**28.5**	**35**	**35**	**29.5**	**32**	**29-35**
2	93	89	71	78	**82.75**	
	92	90	87	89	**89.5**	
Plate Count Average	**92.5**	**89.5**	**79**	**83.5**	**86.125**	**79-93**
3	120	153	168	152	**148.25**	
	113	142	150	143	**137**	
Plate Count Average	**116.5**	**147.5**	**159**	**147.5**	**142.63**	**117-159**
4	106	95	100	99	**100**	
	113	96	103	106	**104.5**	
Plate Count Average	**109.5**	**95.5**	**101.5**	**102.5**	**102.25**	**96-110**
5	118	101	103	88	**102.5**	
	122	116	110	96	**111**	
Plate Count Average	**120**	**108.5**	**106.5**	**92**	**106.75**	**92-120**
6	1	0	1	0	**0.5**	
	1	0	1	0	**0.5**	
Plate Count Average	**1**	**0**	**1**	**0**	**0.5**	**0-1**

This table quantifies the number of coliform colonies on each of the plates for each river sample. Two different counts were taken for each of the four plates. The average for each count was taken as well as the two counts for the same plate. These two averages were also averaged to give a final coliform colony count average for the sample point. A range was also developed using the lowest and highest counts from the four plates.



Graph 1. Petrifilm Coliform Count Test

The graph above shows the four different petrifilm plate counts for each sampling point. It was important to test more than one plate for each sample to reduce error. The average petrifilm coliform count for the four plates were relatively close when compared to one another.



Graph 2. Average Coliform Colony Plate Count

The graph above takes the total average coliform colony count for the sampling points and compares them to themselves and to the passing line corresponding to the value of the water quality standard as mentioned in Table 1. Sample 6 was the only sampling point to pass this standard. Sample 1 had some coliform, but not nearly as much as sample points 2-5. It is important to note the difference between points 5 and 6, where the coliform count drops dramatically from over 100 colonies to almost 0.

Table 10. Liquid Coliform Test						
Control	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
						

Table 10. The Liquid Coliform Test was used to indicate the presence of Coliform within each sample. The control contains the liquid reagent. River samples from each point were put in test tubes with reagents and left in an incubator for 24 hours. The yellow color indicates the presence of coliform within the sample. As seen in samples 1 through 5, coliform is very clearly present. Sample 6 is a slightly lighter red than that of the control. This means that coliform can be detected, not enough bacteria can be found to completely change the liquid from red to yellow.

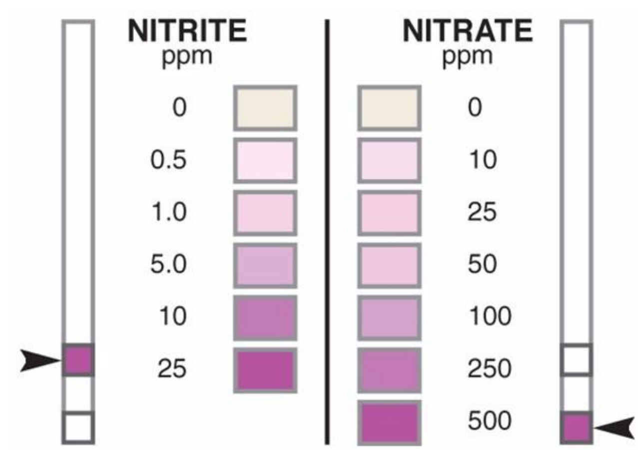


Figure 10. Nitrate/Nitrite Test Strip Chart

Figure 11 is the chart used for the nitrate and nitrite test strips. The strips were dipped into the sample from the river and left to develop. After the strips were developed, they were compared to this chart where the colors were matched up from the chart to the strip. This is up to the discretion of the person comparing the two.

Table 11. Nitrate Test Strips (NO_3^-)					
Sample	Strip 1 [mg/L]	Strip 2 [mg/L]	Strip 3 [mg/L]	Strip 4 [mg/L]	Average [mg/L]
1	0	0	0	0	0
2	0.5	0.5	0.5	0.5	0.5
3	0.5	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.5	0.5
6	0.25	0.25	0.25	0.25	0.25

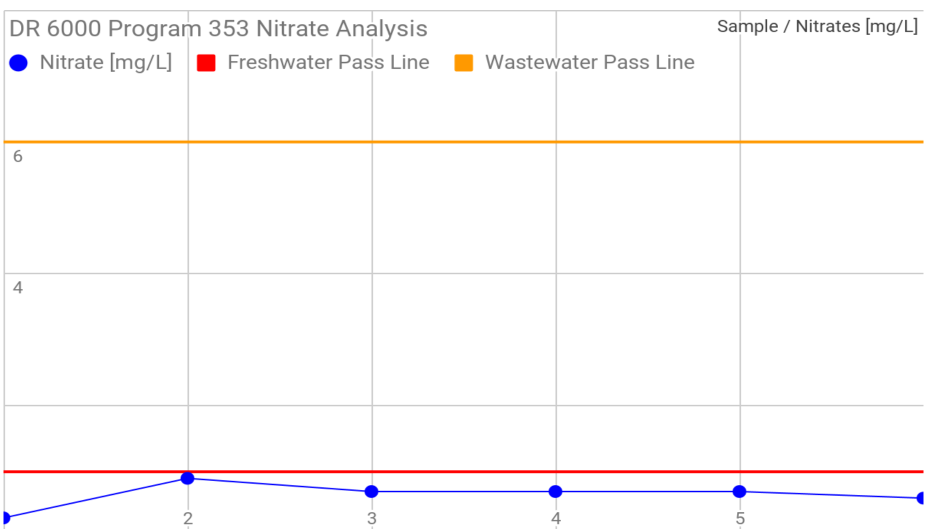
Table 11 shows the results of 4 strips developed and examined for nitrates in each of the sampling points. These results were then averaged.

Table 12. Nitrite Test Strips (NO_2^-)					
Sample	Strip 1 [mg/L]	Strip 2 [mg/L]	Strip 3 [mg/L]	Strip 4 [mg/L]	Average [mg/L]
1	0	0	0	0	0
2	0	0.15	0	0	0.0375
3	0.1	0.1	0.1	0	0.075
4	0.15	0.1	0.15	0.1	0.125
5	0.1	0.1	0.05	0.05	0.075
6	0.05	0.05	0.05	0.05	0.05

Table 12 shows the results of 4 strips developed and examined for nitrates in each of the sampling points. These results were then averaged.

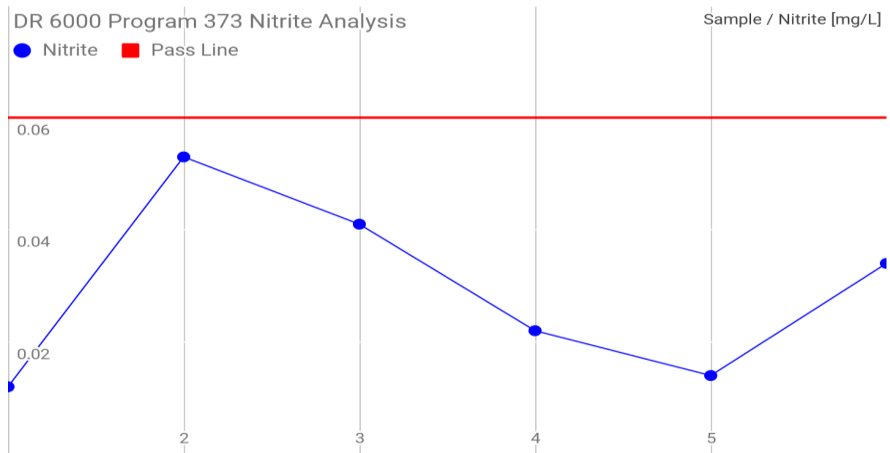
Table 13. DR 6000 Programs 353/373 Nitrate and Nitrite Results		
Sample	Nitrate [mg/L]	Nitrite [mg/L]
1	0.3	0.012
2	0.9	0.053
3	0.7	0.041
4	0.7	0.022
5	0.7	0.014
6	0.6	0.034

The DR 6000 was an instrument used to measure the exact Nitrate and Nitrite levels at the sampling points. Using a powder reagent, this chemical test took anywhere between 5 and 20 minutes to complete. Nitrate and Nitrite tests needed two different programs to analyze the samples. The levels did not vary much between all the samples but it is important to note that the water quality standards for each are very close to these results.



Graph 3. DR 6000 Program 353 Nitrate Analysis

The graph above correlates to the values in Table X. The pass lines in the graph represent the maximum values for both freshwater and wastewater. Although the nitrate results were well below the maximum levels for wastewater, it is important to note the similar levels of that to freshwater sources. Rio Burunga is considered a freshwater source and the levels of nitrate within the river almost surpass the maximum levels for freshwater sources. This can be attributed to inorganic and organic pollution.

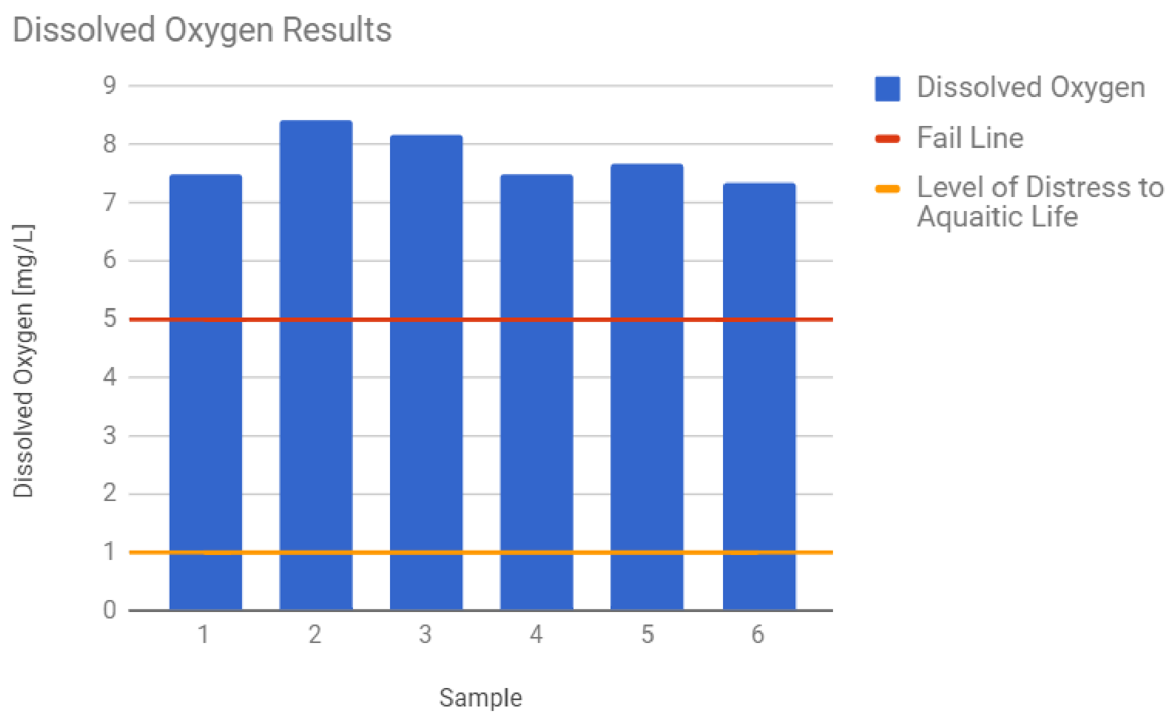


Graph 4. DR 6000 Program 373 Nitrite Analysis

The graph above correlates to the values in Table 13. The pass line in the graph represents the maximum values for wastewater disposal. The second sampling point had the highest level of nitrites, closest to the pass line. After this point, the levels start to drop until the sixth point. This decrease comes from potential organic waste being diluted through aeration and flow of the river.

Table 14. Dissolved Oxygen Results	
Sample	Dissolved Oxygen [mg/L]
1	7.49
2	8.43
3	8.17
4	7.48
5	7.66
6	7.36

The dissolved oxygen test, unlike all the other tests, was done on site. River water samples were taken and a probe was inserted into the sampling bottle to determine the dissolved oxygen results right from the source. This was an important step to take because as the water sits in a closed sampling bottle, more and more oxygen starts to dissolve, giving inaccurate results.



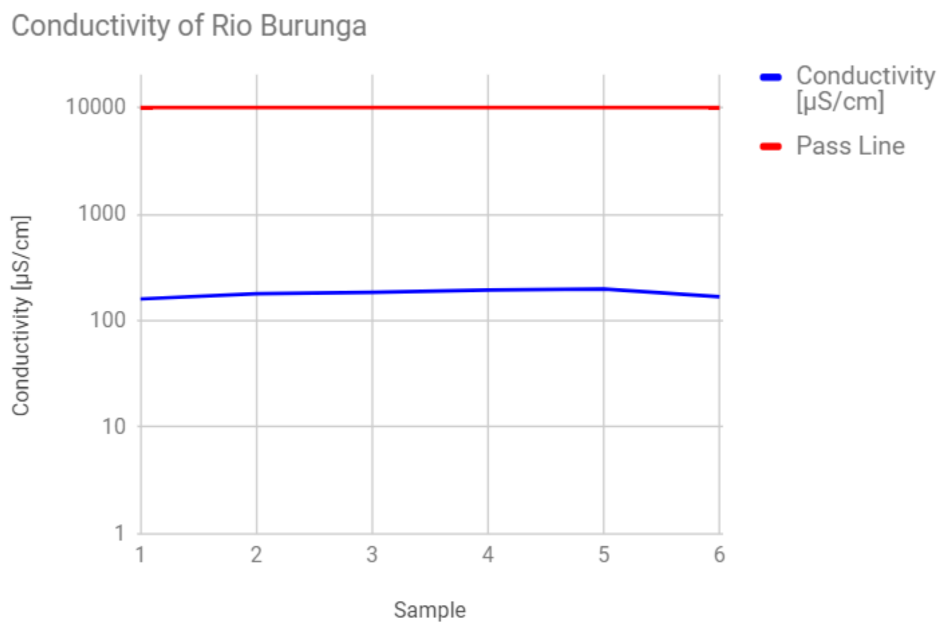
Graph 5. Dissolved Oxygen Results

The graph above compares the results of the dissolved oxygen test with the minimum level of dissolved oxygen allowed for use and the level of dissolved oxygen that inhibits life. The levels of dissolved oxygen surpass this minimum and are within "healthy" levels to hold life. This can be confirmed by the amount of aquatic life that was seen in each of the sampling points.

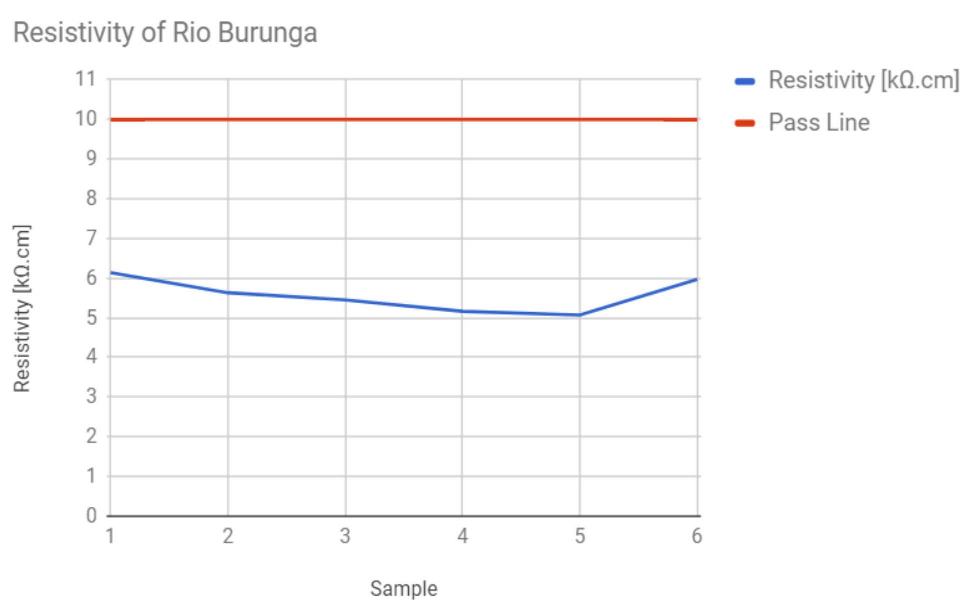
Table 15. Hach HQ14D Meter Tests

Sample	Conductivity [µS/cm]	Resistivity [kΩ.cm]	pH	Dissolved/Total Solids [mg/L]	Salinity [‰]
1	160	6.14	7.54	77	0.08
2	178.8	5.63	7.71	84.5	0.08
3	183.9	5.45	7.61	87.3	0.09
4	193.7	5.16	7.34	92.1	0.09
5	198.7	5.07	7.68	94.3	0.09
6	167.6	5.97	7.43	79.5	0.08

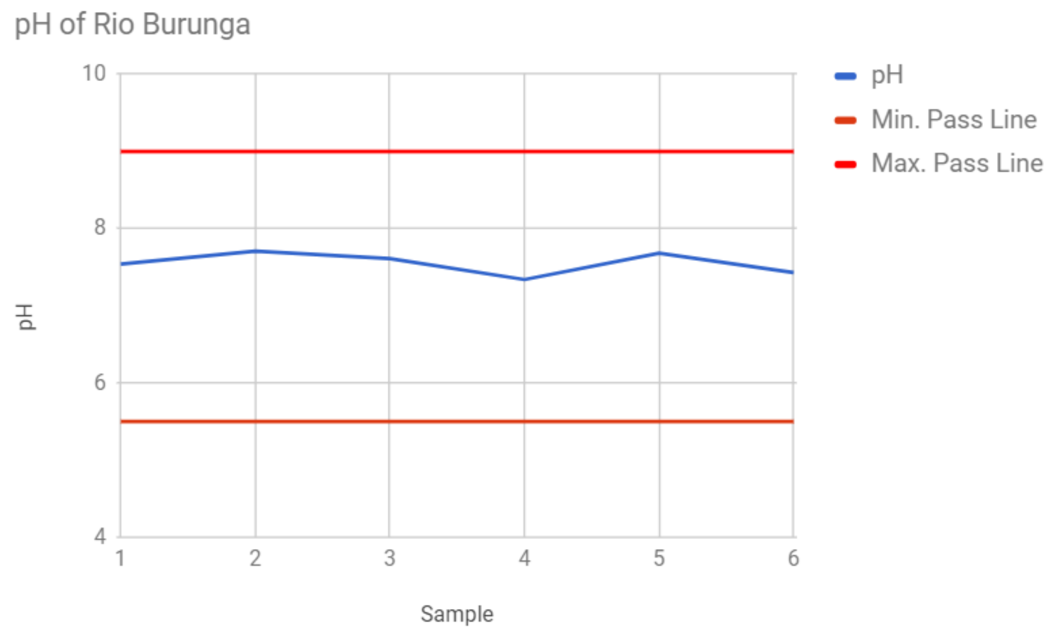
The Hach HQ14D Meter Tests used a probe and different internal instrument programs to test for these supplementary water quality factors. Each of the factors is important in determining the amount of pollution. Their corresponding graphs below indicate that all of the results for each sample fall within the "passing" level.



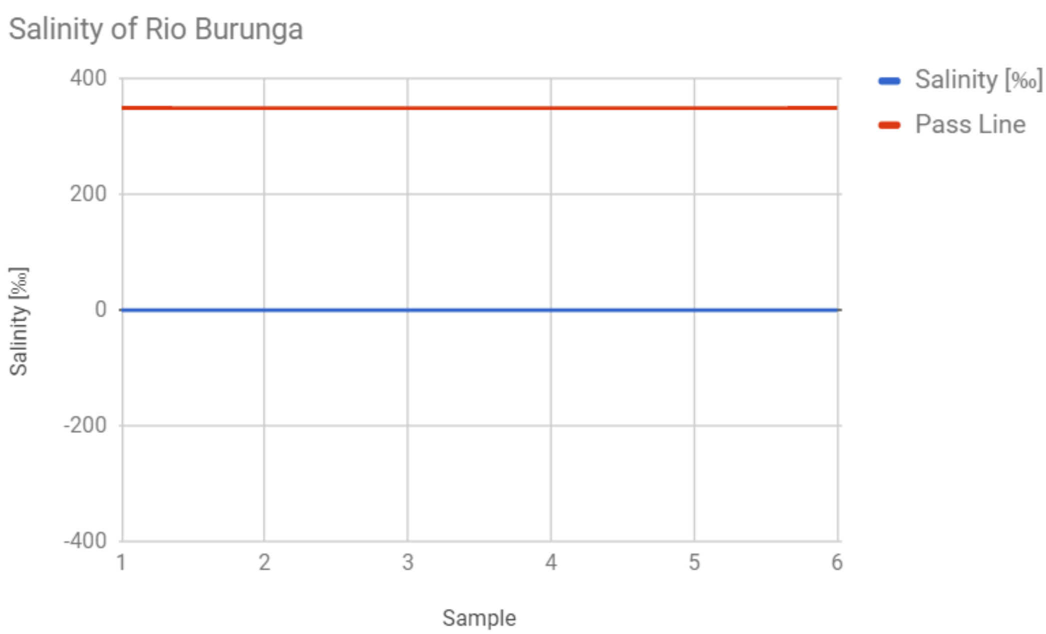
Graph 6. Conductivity of Rio Burunga



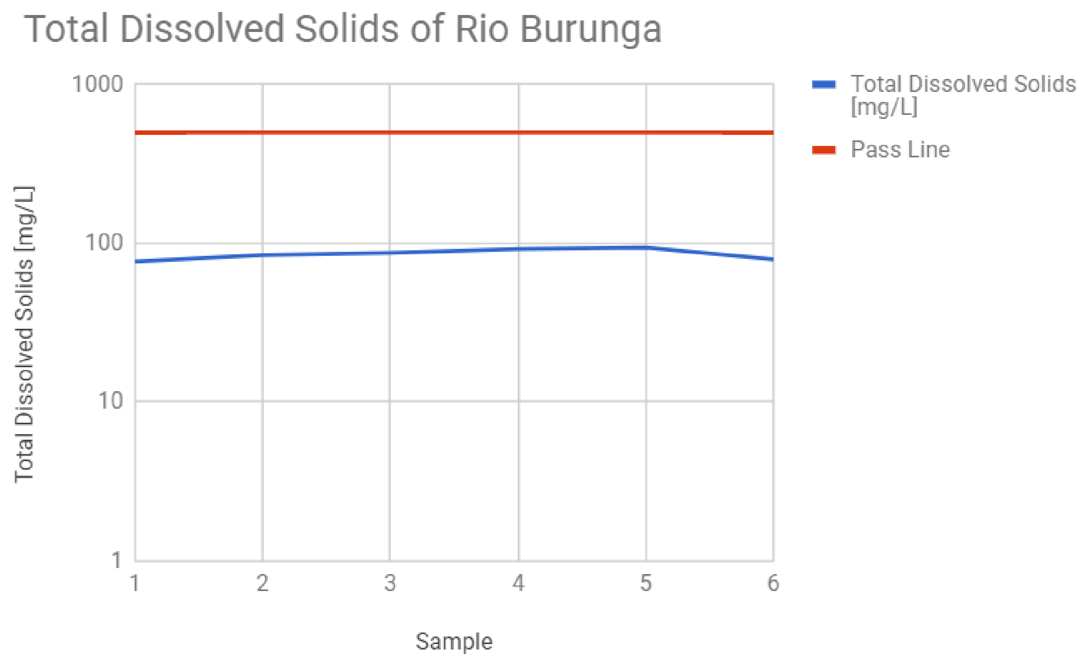
Graph 7. Resistivity of Rio Burunga



Graph 8. pH of Rio Burunga



Graph 9. Salinity of Rio Burunga



Graph 10. Total Dissolved Solids of Rio Burunga

APPENDIX B: FLOWRATE CALCULATIONS AND CROSS-SECTIONAL MODELS

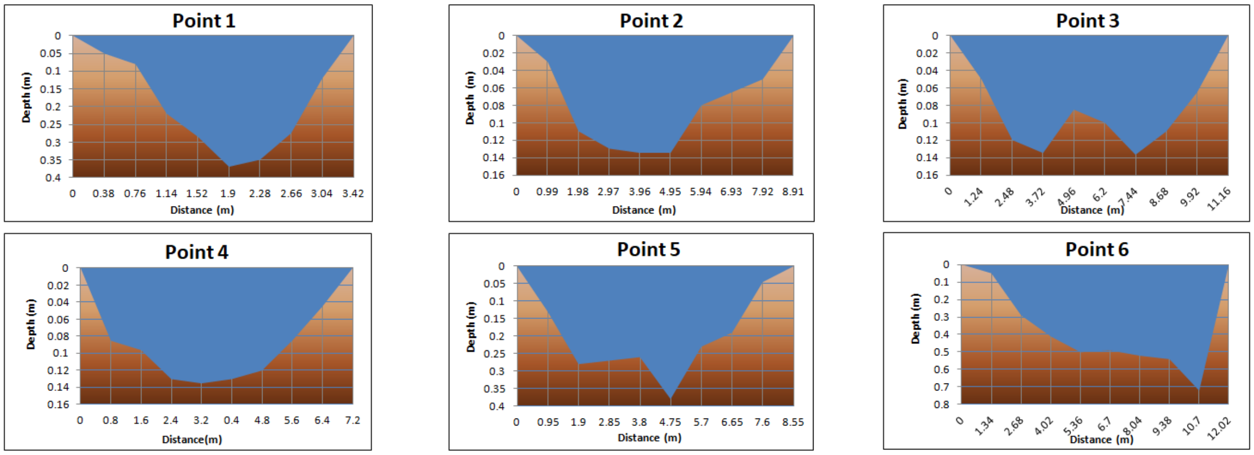
Table 16. Average Velocity (m/s)			
Point	Section A	Section B	Section C
1	0.2	0	0
2	0.6	0.2	0.9
3	0	0.4	0.3
4	0.6	0.6	0.5
5	0.3	0.5	0.2
6	0	0	0.3

Table 16 shows the average velocities recorded using the Global Water Flow Probe from Xylem Incorporated.

Table 17. Flow Rate Calculations

	River Mesurements (m)																	
	Sample Point 1			Sample Point 2			Sample Point 3			Sample Point 4			Sample Point 5			Sample Point 6		
	Width (m)	Trapezoid	Depth (m)	Width (m)	Trapezoid	Depth (m)	Width (m)	Trapezoid	Depth (m)	Width (m)	Trapezoid	Depth (m)	Width (m)	Trapezoid	Depth (m)	Width (m)	Trapezoid	Depth (m)
SECTION a	0	0.025	0	0	0.015	0	0	0.025	0	0	0.0425	0	0	0.065	0	0	0.025	0
	0.38	0.065	0.05	0.99	0.07	0.03	1.24	0.085	0.05	0.8	0.0905	0.085	0.95	0.205	0.13	1.34	0.17	0.05
	0.76	0.15	0.08	1.98	0.12	0.11	2.48	0.1275	0.12	1.6	0.113	0.096	1.9	0.275	0.28	2.68	0.35	0.29
SECTION b	1.14	0.2525	0.22	2.97	0.1325	0.13	3.72	0.11	0.135	2.4	0.1325	0.13	2.85	0.265	0.27	4.02	0.455	0.41
	1.52	0.3275	0.285	3.96	0.135	0.135	4.96	0.0925	0.085	3.2	0.1325	0.135	3.8	0.32	0.26	5.36	0.495	0.5
	1.9	0.36	0.37	4.95	0.1075	0.135	6.2	0.1185	0.1	0.4	0.125	0.13	4.75	0.305	0.38	6.7	0.505	0.49
SECTION c	2.28	0.3125	0.35	5.94	0.0725	0.08	7.44	0.1235	0.137	4.8	0.1025	0.12	5.7	0.21	0.23	8.04	0.53	0.52
	2.66	0.1975	0.275	6.93	0.0575	0.065	8.68	0.0875	0.11	5.6	0.065	0.085	6.65	0.1175	0.19	9.38	0.63	0.54
	3.04	0.06	0.12	**7.92**	0.025	0.05	**9.92**	0.0325	0.065	**6.4**	0.0225	0.045	**7.6**	0.0225	0.045	**10.7**	0.36	0.72
	3.42	0	0	8.91	0	0	11.16	0	0	7.2	0	0	8.55	0	0	12.02	0	0
	Cross Area 1a (m^2):		0.0912	Cross Area 2a (m^2):		0.20295	Cross Area 3a (m^2):		0.2945	Cross Area 4a (m^2):		0.1968	Cross Area 5a (m^2):		0.51775	Cross Area 6a (m^2):		0.7303
	Cross Area 1b (m^2):		0.3572	Cross Area 2b (m^2):		0.37125	Cross Area 3b (m^2):		0.39804	Cross Area 4b (m^2):		0.312	Cross Area 5b (m^2):		0.8455	Cross Area 6b (m^2):		1.9497
	Cross Area 1c (m^2):		0.2166	Cross Area 2c (m^2):		0.15345	Cross Area 3c (m^2):		0.30194	Cross Area 4c (m^2):		0.152	Cross Area 5c (m^2):		0.3325	Cross Area 6c (m^2):		2.0368
		Total Area:	0.665		Total Area:	0.72765		Total Area:	0.99448		Total Area:	0.6608		Total Area:	1.69575		Total Area:	4.7168
	Flow 1a (m^3/s):		0.01824	Flow 2a (m^3/s):		0.12177	Flow 3a (m^3/s):		0	Flow 4a (m^3/s):		0.11808	Flow 5a (m^3/s):		0.155325	Flow 6a (m^3/s):		0
	Flow 1b (m^3/s):		0	Flow 2b (m^3/s):		0.07425	Flow 3b (m^3/s):		0.159216	Flow 4b (m^3/s):		0.1872	Flow 5b (m^3/s):		0.42275	Flow 6b (m^3/s):		0
	Flow 1c (m^3/s):		0	Flow 2c (m^3/s):		0.138105	Flow 3c (m^3/s):		0.090582	Flow 4c (m^3/s):		0.076	Flow 5c (m^3/s):		0.0665	Flow 6c (m^3/s):		0.61104
		Total Flow:	0.01824		Total Flow:	0.334125		Total Flow:	0.249798		Total Flow:	0.38128		Total Flow:	0.644575		Total Flow:	0.61104

Table 17 shows the flow rate calculations for each sampling point. The flow rates were determined using the average velocity values in Table 16 and the calculated cross-sectional areas. We provided a thorough explanation of these calculations in Methodology: Recording Average Velocity and Calculating Flow.



Graph 11. Cross-Sectional Areas of Sampling Points

The graphs above show the cross-sectional area of each sampling point along Rio Burunga. These models were created using the depth and width measurements at each location.

APPENDIX C. TEST DIRECTIONS

Coliform Liquid Test

1. Add 1 ml of water sample to tube of broth
2. Put cap back on slightly loosened
3. Place test tube upright in 35-37° C incubator for 24 hours
4. Observe changes after 24 hours

If the color changed from red to yellow, there were coliforms present

Coliform Petrifilm Test

1. Place 3M Petrifilm E. coli/Coliform Count Plate on level surface. Lift top film
2. place 1mL of sample or diluted sample onto center of bottom film.
3. Roll top film down onto sample gently to prevent pushing sample off film and to avoid entrapping air bubbles. Do not let top film drop.
4. Incubate plates with clear side up in stacks of up to 20 at time and temperature 35C for 24 hours
5. Observe after 24 hours and use magnifying glass and backlight to count number of colonies on the film with 2 readings from 2 people to get average count

Nitrate/Nitrite Test Strips

1. Dip one strip into the labeled test tube for a couple seconds without noticeable movement
2. Remove from the sample and leave on a flat surface to develop for a minute
3. Compare the colors on the strip with those of the EPA USA standards

Hach DR 6000 Spectrophotometer- Nitrate Test

1. Start Instrument Program 353 N, Nitrate MR PP
2. Mix Water Sample and pour some into beaker
3. Fill a sample cell with 10 mL of sample water
4. Add the contents of one powder pillow to the sample cell
5. Put the cap on and vigorously shake the contents of the sample cell for one minute
    a. *Undissolved powder/solid material will not affect results*
6. Start a 5 minute reaction timer
7. Prepare a blank sample cell with 10 mL of sample
8. When timer expires, clean the blank sample cell and insert the blank into the cell holder

9. Push ZERO. The display shows 0.000 mg/L NO3 —N
10. Take out blank sample
11. Clean the prepared sample cell and insert the prepared sample into the cell holder
12. Push READ.. Results show in mg/L NO3- -N

Hach DR 6000 Spectrophotometer- Nitrite Test

1. Start program 373 N, Nitrite LR PP
2. Mix water sample and pour into beaker
3. Fill a sample cell with 10 mL of sample
4. Add the contents of one NitriVer 3 Reagent Powder Pillow
5. Swirl to mix. A pink color shows if nitrite is present in the sample
6. Start the instrument timer. A 20-minute reaction time starts
7. Prepare the blank l with 10 mL of sample without powder
8. Clean the blank sample cell and insert the blank into the cell holder
9. Push ZERO. The display shows 0.000 mg/L NO2 —N.
10. Take out blank sample
11. Clean the prepared sample cell and insert the prepared sample into the cell holder.
12. Push READ. Results show in mg/L NO2 —N.

APPENDIX D: TYPES OF WASTEWATER AND MANAGEMENT STRATEGIES

Storm Water and Best Management Practices

Storm water runoff comes from precipitation over land and other solid surfaces without soaking into the ground. The runoff picks up debris such as trash, chemicals, oils and sediment that can harm water sources like lakes, rivers, streams and coastal bodies of water (EPA, 2016). Best Management Practices (BMP's) in storm water management combat these problems by filtering out pollutants and preventing pollution by controlling it at its source. BMP's can be structural, vegetative or managerial.

Structural BMP's include wet/detention ponds, infiltration basins, porous pavements and water quality inlets. Wet ponds/detention ponds let runoff replace pond water. Pond water flows out and is replaced by stored runoff until the next storm. This type of systems lets pollutants settle to the bottom of the pond and although it prevents pollutants from entering the river, flooding cannot be avoided. Infiltration basins collect storm water and store it until it can filter into the soil. This system is good for fine grained pollutants but coarse-grained pollutants can clog these systems. Porous pavements, such as brick, allows storm water runoff to permeate into its surface and captures fine grain substances. Water Quality Inlets are known to separate oils and grease from parking lots before flowing into storm drains. (Rogue, N.D.)

(a) (b)

Figure 11. Structural BMP's: (a) Wet Pond and (b) Porous Pavement

Vegetative BMP's are landscaping practices that help reduce runoff in residential areas or highway medians. Through infiltration, storage and direction, storm water flows into grassed swales and ditches. Managerial BMP's include pollution prevention techniques like spill prevention and waste reduction practices (Rogue, N.D.).

Figure 12. Vegetative BMP: Grassed Swales

BPM's protect wetlands and aquatic ecosystems, improve quality of receiving waterbodies, conserve water resources, contribute to the protection of public health and aid in flood control (BMP). BPM's establish ideal environments for wildlife. Marshes and wet ponds can become home to waterfowl, marsh birds and different species of aquatic plants. Larger wet ponds can also be used for recreational swimming and fishing (Rogue, N.D.).

Although there are various types of Best Management Practices for storm water runoff, it is important to note the constraints of each system. The pros and cons of each system depend on the physical site, management goals and cost-effectiveness (Rogue, N.D.).

Greywater and Methods

Greywater is a secondary type of wastewater. Greywater is defined as "any domestic wastewater produced, excluding sewage." Greywater is known as wash-water because it contains pollutants apart from toilet and food waste (RUAF, n.d). With good management practices, greywater can be resourceful in horticulture, agriculture, landscaping and contractors through irrigation. Greywater contains many of the nutrients that makes vegetation thrive, such as phosphorous, potassium and nitrogen (RUAF, n.d.). Although greywater irrigation is popular and helpful to many consumers, management for greywater has created many problems with public safety consideration since better methods of management are hard to obtain, thus creating pollution (RUAF, n.d.). Greywater pollution can be measured in two categories: primary and secondary pollution.

Primary pollution was, historically, organic pollution. Stemming from industry, sewers, septic sewers, and livestock practices, organic compounds decomposed into the water and consumed the dissolved oxygen that fish and other aquatic animals use (RUAF, n.d.). To measure how much oxygen is extracted from the water by bacteria as waste decomposes, two tests are used; BOD5 and COD (RUAF, n.d.). BOD5 is a Five-day Biological Oxygen Demand. This test measures the amount of dissolved oxygen needed by organisms to break down the waste over a period of time (NPDES, 2017). COD is a Chemical Oxygen Demand test that indicates the amount of dissolved oxygen during two hours of decomposition (EPA, 2016). For both tests, the higher the chemical oxygen demand, the more pollution is in the test sample.

Secondary Pollution is a result of primary pollution. Algae and other plant species start to grow due to the lack of oxygen in water and in turn, these plants die and decompose, creating further turmoil for the water sources it is inhabiting (RUAF, n.d.). Secondary pollution is measured by how much fertilizer is added to the water (RUAF, n.d.).

Figure 13. Secondary Pollution: Algae Growth

There are several treatment technologies for greywater. Aerobic Pre-Treatment is used to treat water used for showers, hand-washing and laundry. A fiber filter technique removes large particles and fibers to protect infiltration pipes from becoming clogged. This technique allows micro and macro organisms to thrive. Stretch filters are a type of aerobic pre-treatment that catch larger particles in the water and allow the rest of the water to filter to the next stage. A disadvantage of this type of treatment is that if food waste gets trapped in the fibers, the effluent becomes malodorous and needs to be changed frequently. This will affect its cost-effectiveness and it will be high maintenance. (RUAF, n.d.)

Anaerobic to aerobic pre-treatments are needed when there is a significant amount of food waste. This waste can come from dishwashers and kitchen sinks, which receive not only food particles but cooking grease and other oils. An example of devices that can treat this kind of waste are grease-traps and septic tanks, sand filters and pump pits. A three-stage septic tank will first separate sludge, then the sand filter will restore aerobic conditions and then finally will be put in a pump pit to purify the water. This is an expensive solution but is one of the most effective and simply maintained solutions (RUAF, n.d.). From the pump pit, this treated greywater can be put into plant beds and used as a nutrient based water source to feed the plants and help with growth.

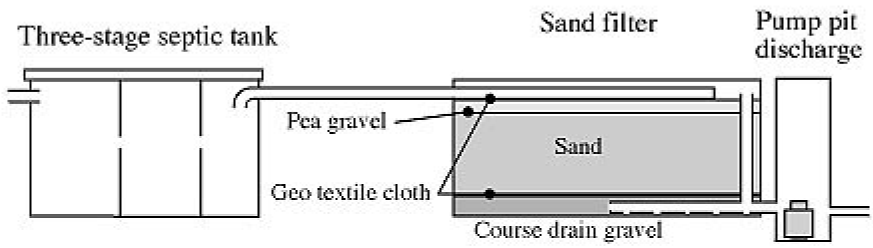


Figure 14. Three Stage Septic Tank

Unlike other types of wastewater, greywater can be reused and can be beneficial on many levels. Greywater contains many minerals and nutrients needed to support life. By reusing greywater, the need for fresh water is reduced. With less fresh water needed, consumers will have lower water bills and the broader community will use less of the water supply. The reuse of greywater will also reduce the amount of wastewater entering sewers and treatment systems which in turn will also help the community as a whole (NPDES, 2017).

Blackwater and Treatments

Blackwater is treated or raw waste from toilets that contains disease-causing bacteria and viruses that can result in human illness due to direct contact or consumption (EPA, 2016). Blackwater discharge creates an imbalance within the sensitive workings of ecosystems. Blackwater is usually discharged in small amounts but can be dangerous if left untreated. From a statistic from South Australia's Environmental Protection Agency, the "amount of bacterial pollution from one weekend boaters discharge of untreated sewage is equal to the amount from the treated sewage of 10,000 people during the same time period."

Before blackwater can be reused, it needs to be treated biologically and chemically for disinfection of bacteria (EPA, 2016). An example of how blackwater is treated is through the aqua cell unit. Water flows into a collection basin where it is then pumped into the aqua cell. The first step in the aqua cell is called screening. Here, waste is reduced between soluble and insoluble material. Soluble waste flows into the next stage while the insoluble waste is discharged into the sewer or turned into solid waste to be disposed of. Air is then diffused into the water so that "good" bacteria can consume all of the impurities in the water. This results in a sludge through a biological treatment. Ultrafiltration occurs as water passes through a microscopic membrane that traps bacteria and viruses and other particles from passing through.

APPENDIX E. IDAAN REPRESENTATIVE INTERVIEWS

<u>Interview with Franco: 9/21</u>

*All answers (ANS) have been paraphrased.

1. **The river is polluted. Would you want to treat the river or simply fix the issue of improper wastewater disposal in homes, which cause this pollution?**
   - ➢ ANS: The common Panamanian does not know how to dispose of waste. Part of the responsibility is of the people, who collect the waste at home. The other part of the responsibility belongs to the mayor of the city.
   - ➢ TEAM: What is the origin of the wastewater?
   - ➢ ANS: We do not know exactly.
   - ➢ TEAM: Do you want us to come up with recommendations on treatment of the river or, how to prevent further pollution?
   - ➢ ANS: Focus on waste water disposal from households. Waste disposal and collection, along with the lack of sewerage system is a social problem. We (team) should focus on both the inorganic n organic matter.
   - ➢ ANS: Problems include 1) Cultural issues 2) Waste disposal/collection 3) Lack of lack of sewers/sewage system
2. **Is IDAAN already planning to use the same methods of treatment in Burunga that they have been using in the Panama Bay Sanitation project?**
   - ➢ ANS: Yes, the plan is to bring the Panama Bay Sanitation Project methods to Burunga. (In an estimated three years the project will cover the areas of Burunga, Arraiján, and Cerro Silvestre)

   a. **This was activated sludge, right?**
   - ➢ ANS: Yes

   b. **How is that working?**
   - ➢ ANS: It has been so effective. The waste water quality is so good that you could swim in it!
3. **How is IDAAN planning to transfer and connect water from households to the wastewater treatment plant (plan of laying infrastructure)?**

- ➢ ANS: The plan is for the government to build treatment plants with vaults throughout the districts that pump water for the circulatory treatment. They plan to build the treatment plant near El Rio Cerro Silvestre (near the Centro de Salud?). The complementary project involves the installation of sewage systems to be connected to each household. Also, a part of the Sanitation Bay Project includes the cleaning of Rio Burunga, Rio Portero, Rio Caceres, and Rio Perico but it is not in my specialty so I do not know how it will be done.

4. **How are you planning to get everybody to comply with the installment of septic systems?**
    - ➢ ANS: People will have no need for septic tanks once they have sewerage.
    - ➢ ANS: IDAAN is responsible for the provision, not the execution, of the actions
    - ➢ ANS: The government plans to get rid of all septic tanks and people will be eventually fined if they still have one. (The census helps with this)

    a. **Will they have to pay for this installation?**
    - ➢ ANS: Everyone will have to pay for the $20 installment fee for *sewerage* (not septic tanks). This includes the installation and connection of the sewage system.
    - ➢ ANS: There are payment plans that people can set up for the one-time $20 installation fee.

    b. **Payments for maintenance?**
    - ➢ ANS: People who cannot afford it, will receive a subsidized fee on the required tax. So, instead of $4.26/month and $1 maintenance, those people will pay $2.13/month and $1 for maintenance.

5. **Is IDAAN the main contact for wastewater maintenance?**
    - ➢ ANS: It is not IDAAN's responsibility to service septic tanks. They only deal with the people who have/pay for sewerage.

    a. **What resources do the people in Burunga have to call?**
    - ➢ ANS: People call private companies and "backdoor trucks" to service their septic tanks.

6. **Does IDAAN reuse any of the treated wastewater for anything else? Why? If not, where does it go?**
    - ➢ ANS: Depending on the treatment plant, the treated wastewater is sent back to where it came from / discarded into a particular body of water.

- ➢ ANS: In the regions where it does not rain a lot, the treated wastewater is reused for pants.
- ➢ TEAM: Would you want us to make recommendations about how the treated wastewater could be reused in the Burunga area?
  - ○ ANS: Yes! It would be good to recommend methods for the reuse of treated wastewater. That could also be information that is transmitted to schools and to the Ministerio de Salud.

7. **Does IDAAN keep any record (electronic/paper) of the services they do in the Burunga.**
   - ➢ Franco (*an aside about the history of settlements*): In 1989, land was partially owned by the U.S. When they transferred the ownership, people took land and built up houses. The government gave them legal ownership of the land, but they do not do that anymore. People can no longer move to Burunga and take land illegally. The population can still grow in Burunga. People just have to pay for the land they take now. For IDAAN to know about who lives there, the people would need to get a contract with IDAAN. IDAAN is not seeking these people out.
   - ➢ TEAM: If IDAAN does not service septic tanks, where do their water tanks go? Do they use them to transfer water throughout the Burunga region?
     - ○ ANS: IDAAN has a contract with some of the people living in the Burunga region for water truck delivery to their water tanks. (& other people plug into those tanks and take water as well)
   - ➢ ANS: Yes, IDAAN has paper and electronic records/databases of the trucks used, the gallons of water administered, and which plants the water came from. The information is used to create a monthly report.
8. **Do you know what water quality standards IDAAN uses for wastewater?**
   - ➢ ANS: You will need to ask Natasha that question.
9. **(Added question) At the end of all of this, what should our deliverables to IDAAN consist of? Our maps, our testing results, and recommendations concerning wastewater reuse?**
   - ➢ ANS: Those three deliverables are good. Tell what testing results are good/bad and the maps and recommendations.

<u>Interview with Natasha Vivas and Yamilet: 9/27</u>

*All answers (ANS) have been paraphrased.

1. **Does anyone test the rivers for any reason?**
    - ➢ ANS: Yes, The EPA of Panama & Ministerio de Ambiente. Only the main river, the Camito River, is tested. Rio Burunga is too small.
2. **What main bodies of water does IDAAN get its potable water to treat and distribute? Any surface water? Any from rivers?**
    - ➢ ANS: Only the bodies of water that are part of the treatment plant... There are rivers, lakes, and wells that are used. For example, Rio Camito (used for Arraiján and Trapichito) and Lago Gatun. IDAAN only samples Rio Camito because Lago Gatun is private.
3. **Where do they transport the treated wastewater to?**
    - ➢ ANS: It depends on the place. It is not a united system (or the only system). There are multiple systems for residents. There is a current project for a treatment plant in Burunga. They are going to put the treated water into Rio Burunga after this project is completed. That is what they are constructing.
4. **Do you personally think that it would be more useful/save more money to reuse it near the plant?**
    - ➢ ANS: As of now, water reuse is not popular. There are not a lot of farms or things for people to use irrigation methods for in Burunga. But yes, reuse is not just possible. It is necessary!