Rio Piedras Conservation Management Plan

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Prepared for: The Conservation Trust of Puerto Rico

Prepared by: Craig Kennedy, Mark Kowaleski, Justin Pollard,
Kevin Zabinski

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Report Submitted to: Professor Ingrid Shockey and Professor Karen Lemone

Puerto Rico, Project Center

By:

Craig Kennedy

Mark Kowaleski

Justin Pollard

Kevin Zabinski

In Cooperation With:

Juan Rodríguez, Project Coordinator

The Conservation Trust of Puerto Rico

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

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Abstract

This report, prepared for the Conservation Trust of Puerto Rico, contains a conservation management plan for the Rio Piedras around Puerto Rico's first aqueduct. We assessed the ecological health of the watershed and identified flora to determine the best plan of action in order to restore and conserve the river basin. The plan includes recommendations for the conservation approach, the control of urban dumping, the prevention of erosion, and the introduction of native species.

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Authorship

This document was a collaborative effort between all team members. We each contributed to the primary writing and final editing of all sections within the report.

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Executive Summary

Our planet's natural environment is under pressure and damaged by continuing human expansion. Consequently, on small islands like Puerto Rico, there are only a few remaining areas left as natural sanctuaries. Communities and organizations in Puerto Rico are now working to restore the natural beauty that once characterized the island.

The Conservation Trust of Puerto Rico, or Fideicomiso, is an organization that acquires and protects properties across the island. Fideicomiso, known as "The Trust", currently owns over 18,000 acres of property in Puerto Rico. The lands acquired contain varying degrees of historical, cultural, and natural significance to the island.

Puerto Rico's first aqueduct, located in San Juan, is set in an urban environment and presents a unique set of challenges for conservation. The Trust is currently uncovering and restoring the aqueduct complex so that it can be opened to the public. Additionally, the organization will restore the Rio Piedras watershed surrounding the complex. The watershed serves as the aqueduct's source and is a valuable piece of natural land. The urban development bordering one side of the river contributes to its deterioration and therefore prevents the riparian zone from repairing itself naturally. The Trust asked our team to create a conservation management plan for the Rio Piedras around the aqueduct. The Management Plan includes an assessment of the ecological health, flora identification, and recommendations for a plan of action that The Trust can take. We achieved this goal through the following objectives:

- Assess ecological health of various zones in the region.
- Catalogue flora found in the region.

We accomplished our first objective by dividing the river into zones that contained similar features. To achieve this, we completed an interval health assessment sheet every thirty meters along each side of the river. The interval assessment sheet has qualitative descriptors for several categories, including shade cover, bank integrity, vegetation, algae, and debris. We then grouped similar intervals to form six zones on the urban side and seven zones on the side adjacent to the aqueduct complex. During this period, our team noted several key characteristics of the river:

- Substantial quantity of human and natural debris.
- Significant erosion.
- Insignificant fauna present.

Human and natural debris is present throughout the zones, with most of the human debris prevalent in zones next to the urban development. Our team found car tires, televisions, a car chassis, refrigerator, , and a large quantity of smaller garbage. While some of the items are deposited and carried downstream, others are dumped directly onto the embankment. Urban dumping damages the environment by decreasing the water quality. In addition, the trash adds pollutants to the soil and air. A majority of the encountered natural debris is composed of dead or damaged Bamboo that lies on the bank or in the river. The largest collection of natural debris is located in the river near the aqueduct. It is composed of dead Bamboo, which creates a natural dam that catches more debris flowing downstream. High concentrations of natural debris can inhibit vegetation growth and alter water flow paths.

Erosion is present in many zones, both on the side adjacent to the aqueduct and on the urban embankment. On the urban side, erosion seems to be more prevalent in the zones next to urban development. The buildings, fences, pavement, and other features increase the water run-off in the zone. This in turn creates sedimentation and prevents proper water filtration. The buildings also limit the width of the riparian zone, altering the vegetation growth. We found that in these areas, the tree growth was reduced, while varying types of undergrowth were more abundant. Our observations indicate that the undergrowth and scattered trees do not provide an adequate root structure to control erosion. On the aqueduct side, the banks suffering from erosion are those containing large amounts of Bamboo debris. The excessive growth of Bamboo and its unmonitored debris prevent the growth of native bank vegetation.

The only fauna found in the river were iguanas and small lizards, along with a few fish and birds. Due to the small amount of fauna, our team decided that they were insignificant to the scope of our study. Therefore we did not address them in our recommendations.

After forming the zones, we tested their ecological health with several experiments. Our team performed water quality tests to investigate the water temperature and the levels of pH, phosphate, and dissolved oxygen. The results display that the Rio Piedras water is in fair condition.

- Slightly basic pH levels ranging from 7 to 8 on the pH scale.
- Normal phosphate levels ranging from 1 to 2 parts per million.
- Low dissolved oxygen levels ranging from 0 to 41 parts per million.
- Temperature increases downstream.

We massed and analyzed soil samples from each zone's bank to determine the density and composition. The soil samples reveal several soil types and densities.

- Soil densities range from 0.478 to 2.296 g/cm^3.
- Average soil density is approximately 1.2 g/cm^3.
- Most soil samples were composed of hard packed clay.
- Nearly all samples contained varying degrees of organic matter, rocks, and roots.
- Zones of high biodiversity had greater bank integrity.

We accomplished our second objective by photographing the unique species in each zone, while noting their abundance. Fideicomiso employees helped us to identify 64 flora species that are present on the banks of the Rio Piedras. We researched the characteristics of the species, including their scientific and common names, family, life form, and origin.

We found that of the 64 species identified, 20 of them are invasive to Puerto Rico. However, of the eleven species receiving an abundance rating of localized (++) to widespread (+++), eight of them are invasive. The most abundant species found throughout the river include the invasive African tulip (*Spathodea campanulata*) and Bamboo (*Bambusa vulgaris*), as well as the native *Calopogonium coerulem* vine.

Recommendations

1. Approach

a. Use a hybrid of the classic, populist, and neo-liberal approaches.

2. Buffer Zone Expansion

a. Expand the buffer zone to an ideal 25 meters where possible.

i. Talk to building owners to educate them about the river restoration
ii. Offer incentives for owners to allow restoration on their land.

b. Where expansion is possible, address the grading issue to better control erosion.

3. Erosion Recommendations

a. Remove some urban features such as fences and pavement in order to improve ground runoff and filtration.
b. Implement a tiered native vegetation system.
c. Remove the rock collection in Zone 5 to allow for vegetation growth.
d. Address excessive grass growth in Zone 6.

4. Debris Recommendations

a. Organize and complete an annual or biannual river cleanup event through volunteer or professional work forces.
b. Remove existing fences and install a taller barbed wire fence, to prevent dumping and vandalism, with the following:
   i. Signage to display the conservation efforts on site
   ii. Motion sensor lights and cameras

5. Flora

a. Allow the growth of pre-existing African Tulip and Indian Almond species, yet prevent the further spread of the trees.
b. Maintain and control the growth of Bamboo and Elephant Grass.
c. Add twelve species to the first and second layer tiered vegetation system.

Through the implementation of these recommendations, Fideicomiso can allow the Rio Piedras around the aqueduct to achieve its full potential. Since it is located in the heart of urban San Juan, the site may become a benchmark for conservation efforts of natural land in an urban area.

Chapter 1: Introduction

Population growth and the overwhelming demand for natural resources, including land, is on the rise and threatens the remaining natural habitats. Deforestation, dredging, land reclamation, pollution, construction, urban sprawl, and other similar actions are some of the global activities that negatively impact the natural world. There are few remaining unspoiled natural environments to be found worldwide.

Puerto Rico is a small and densely populated island that has little natural land remaining. Protecting the precious remaining regions is important; however it is difficult and expensive. The Rio Piedras watershed is one of these important locations. Positioned within the city of San Juan, the river has been encroached upon by human development. The outlining features of the river bank include parking lots, buildings, roads, fences, farms, pastures, and river diversions (dams). In turn there is widespread pollution, flooding, sediment loss, invasive species growth, and damage to aquatic and terrestrial life.

Fideicomiso aspires to "save the beauty and richness of Puerto Rico…before it is too late" (Shapiro, n.d.). Also known as "The Trust", it protects and conserves pieces of land that are environmentally, culturally, and historically valuable to the island. Fideicomiso has begun a restoration of the aqueduct complex which also involves the conservation of the surrounding Rio Piedras. Fideicomiso has planned the repair of the machinery, repaired and demolished buildings, and uncovered the outline of the water basins.

The river and its features have not yet been incorporated in the Fideicomiso restoration plan for the aqueduct. Our team's goal was to create a conservation management plan for the river in the region of this aqueduct. The conservation plan includes an assessment of the riparian zone health, flora identification, and recommendations to restore the river's ecological health. The plan addresses the conservation approach, buffer zone expansion, erosion control, debris control, and the addition or removal of flora species. The Trust will incorporate this plan into the aqueduct restoration project to create a conservation site within the heart of urban San Juan.

Chapter 2: Literature Review

The following chapter describes conservation in Puerto Rico and the work of the Conservation Trust. It also emphasizes the importance of the riparian zone to the Rio Piedras. These topics build a solid foundation for the management plan of the Rio Piedras. To begin, we explored the theoretical models that inform modern approaches to land conservation.

2.1 Conservation

"Conservation is the integration of human needs with biodiversity" (Brown, 2002). Environmental destruction has provided human populations with the resources and capability to develop. In today's world, the environment relies on new generations to find ways to both protect and regenerate natural regions. This may explain why there is an urgent movement in many institutions toward environmentally friendly behavior. Gaston, Blackburn, and Goldewijk (2003) assert that the negative impact that humans have had on global diversity has been recorded in institutions and organizations during the past century. The importance of conservation and its implications cannot be reiterated enough.

Conservation involves carefully managing and preserving the environment and natural resources. This process, when effective, helps to maintain biodiversity. This means that the variation and abundance of species will be protected from human consumption or destruction. Biodiversity is a way to measure the well being of our environment. A decrease in biodiversity demonstrates that human selection has replaced natural selection as the determining factor of evolution. Although many agree that conservation is the next step, conservation practices vary from place to place.

There are several different conservation approaches. Conservation approaches are classified into the following three categories: "classic", "populist", and "neo-liberal" (Brown, 2002). In each case, a specific institution or group provides the motivation for certain conservation practices.

2.1.1 Classic Approach

The classic approach argues that the local people are responsible for the abuse of resources. Hunting season, fishing regulations, and logging limitations all are part of an attempt to protect threatened species from local populations. For example, there is Caribbean fishing regulations in order to protect aquatic life. Local regulations state "from December first through the last day of February each year, no person may fish for or possess red hind in or from the

Caribbean EEZ off the west coast of Puerto Rico" (Caribbean Fishery Management Council, 2009). However, according to Katrina Brown (2002), the traditional techniques involved with protecting areas and protective policies do not accomplish the goals of preservation. Instead, the environment and species remain an externality to the local people. This approach is limited by its lack of educational value, and consequently, it rarely stops the abusive human behavior.

2.1.2 Populist Approach

Contrarily, the populist approach utilizes this same local population as the source of conservation. The locals can provide their knowledge of the local species, resources, and habitat that can be utilized during the conservation effort. A method according to this paradigm might involve a certain tree species indigenous to the region. Native people would have knowledge of the plant and its requirements for survival. With such understanding, they could replant the tree in an area, help to develop it, and recreate at least part of the natural ecosystem that had once been there. Consequently, the conservation group can educate these people about the restoration, the environment, and its importance. This knowledge would motivate the population to act in a positive manner. Another aspect of this conservation approach is seen in the establishment of natural parks in urban areas. If local people are willing to integrate the ecology into their urban environment, parks can play home to important indigenous species. A perfect example of an urban park is New York City's Central Park, as seen in Figure 1. The park is a visible reminder of the local ecology, although it may or may not change the public's perception of ecological importance.

Figure 1: Central Park, New York City (http://www.states4u.com/Sfondi/Central%20Park%20New%20York%20Wallpaper.jpg)

2.1.3 Neo-Liberal Approach

The neo-liberal approach identifies the economic value of biodiversity as the key source of motivation for conservation. By finding monetary ways to appeal to people and businesses, conservation can be viewed as a beneficial component of social life. This approach identifies incentives to businesses as a key source of motivation, and it encourages businesses to create environmentally friendly policies. Countries that are in development stages with weak governing forces might find incentives useful if forming policies is not an effective form of management (Gaston et al, 2003). Countries with stronger governing forces will benefit from offering incentives as well as encouraging or forcing businesses to explore environmentally friendly policies. According to the EPA in 2001, "economic incentives have been increasingly used to control pollution and improve environmental and health protection "(National Center for Environmental Economics, 2009). The study shows that the United States has seen a dramatic increase in incentive motivation in recent years.

2.1.4 Conservation in Puerto Rico

The Puerto Rican ecology needs conservation intervention. The island was once characterized by rural lands, but its terrain has undergone several changes. These lands were abandoned during rural migration and allowed to grow into secondary forests. According to Aide and Grau (2004), forest cover on the island has increased from 10% to 40% in about 60 years. Fortunately, recovering forests are able to reduce erosions and floods, improve water quality, and provide habitats for recovering species (Myers, Mittermeier, Mittermeier, Fonseca, Kent, 2000). In comparison to other nations, however, Puerto Rico is well below in land area protection for the purpose of conservation. Below are a few countries in the vicinity of Puerto Rico and their percentage of land area protected for the purpose of conservation.

- **Puerto Rico (7.2%)**
- United States (25%)
- Jamaica (33%)
- Costa Rica (34%),
- Dominican Republic (42%)

- U.S. Virgin Islands (54%)

(Fideicomiso, 2009)

Many species have become endangered or extinct from human destructiveness and devastating storms. Recent environmental movements in Puerto Rico have helped to bring back the biodiversity which makes the island so wonderful. "The land in Puerto Rico has great ecological, aesthetic, and cultural value that are all motivating factors for reforestation" (Conservation Trust of Puerto Rico, 2007). At the same time, a vast number of invasive species appeared and flourished on abandoned and deforested lands. Native species that were once the backbone of Puerto Rican ecology now have to be reintroduced by organizations such as the Conservation Trust of Puerto Rico. The result is the rebirth of species populations and increasingly greater biodiversity.

Even with its altered landscape, Puerto Rico remains a diverse island. It is home to over 2,400 plant species, 200 bird species, and 80 species of reptiles (Grau, Aide, Zimmerman, Thomlinson, Helmer, Zou, 2003). Puerto Rico also houses "diverse ecological life zones that range from subtropical dry forests to subtropical rain forests" (Grau et al, 2003). The island

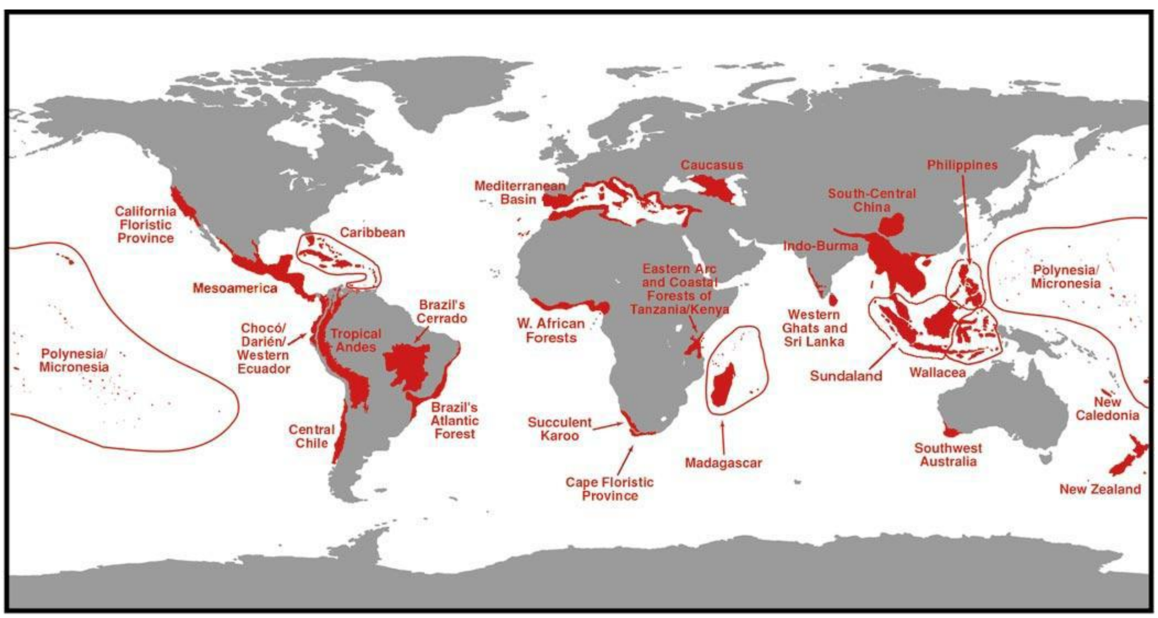

Figure 2: Conservation Hotspots around the Globe (Myers, Mittermeier, Mittermeier, Fonseca, Kent, 2000)

remains an essential area for conservation to take place. Figure 2 is an illustration of global conservation "hotspots" in the Caribbean (Myers et al, 2000). As shown in the map, hotspots are limited to island and coastal regions. Puerto Rico and the other Caribbean Islands are key locations for the global conservational effort.

2.2 Fideicomiso

Conservation in Puerto Rico has increased dramatically with the help of many organizations, including the Conservation Trust of Puerto Rico or "The Trust". The Trust was founded in 1970 by the combined efforts of the United States and Puerto Rican governments. It remains to this day a "private, nonprofit organization whose mission is to protect and enhance the Island's natural resources" (Fideicomiso, 2009). The Trust has helped to establish the Puerto Rico Conservation Easement Law in 2001 (Fideicomiso, 2009). This law

> "was created to achieve collaboration between the private sector, non-profit organizations and the Government, in order to promote the conservation of areas of natural, cultural or agricultural value by means of establishing conservation easements" (Policy and Law, 2008).

Thus far, The Trust has acquired over 18,000 acres of land for protection in Puerto Rico (Fideicomiso, 2009). These lands include properties of natural importance as well historical and cultural significance to the island. There are currently 20 sites that are protected by The Trust, including two sites which are currently open to the public. One of the newest sites is the target of this study, the Rio Piedras, which is home to the first aqueduct in San Juan.

2.2.1 Previous Conservation Sites

Figure 3: Hacienda Buena Vista in Ponce (www.anadon.biz/ponce/imagesp/buenav.html)

The Trust's long term goal for the Rio Piedras at the aqueduct is to open it up to the public, as they have done at previous sites. One of The Trust properties open to the public is Hacienda Buena Vista in Ponce, Puerto Rico. Hacienda Buena Vista started as a simple farm with a wide variety of crops. It developed into a plantation producing mainly coffee beans, with its own hydro-power supply (Shapiro, n.d.). Being rich in cultural and social history, Hacienda Buena Vista is used as an educational tool to the public today. Guides show the public the restored manor house, slave quarters, gardens, and trails throughout the property. This gives the visitors a perspective of the everyday life of those that lived and worked the plantation during the time of operation. The Trust also protects the Canas River and the forest that surrounds it. The Canas River is home to a large variety of flora and fauna.

The second of those sites open to the public is the lighthouse at Fajardo, known as Las Cabezas de San Juan Nature Reserve. This is a 316 acre protected land area, which is home to many unique species of plants and animals (Fideicomiso, 2009). Within this site there are multiple lagoons, which provide protected areas for fish and crustaceans to spawn. This site serves not only as spawning grounds for endangered sea turtles, but also as a haven for offshore underwater life such as coral formations (Shapiro, n.d.). At Las Cabezas de San Juan Nature Reserve, visitors are able to get a close look at the plants and animals that the property is home to. In the lighthouse there are displays of iguanas and hermit crabs as well as tanks of sea urchins. This provides the visitors with education about the creatures and their environments, which are in need of conservation.

Figure 4: Las Cabezas de San Juan Nature Reserve (tunapointlighthouse.homestead.com/prlights.html)

Although those are the only two sites open to the public, The Trust conserves and manages many other properties on the island. One of the more known is the Ramón Power and Giralt House in Old San Juan, which also serves as The Trust's headquarters (Fideicomiso, 2009).

2.2.2 Trust Operation and Programs

The Conservation Trust acquires these properties through various means. During the first ten years of operation the primary source for funding was U.S. tariffs paid by the petrochemical companies that were located in Puerto Rico (Fideicomiso, 2009). The Trust then invested in stocks and issued bonds as their financing. Currently The Trust receives portions of the Rum tax returns from the federal government. This has allowed The Trust to create its own fund and the ability to generate its own income. Cash contributions and land donations allow The Trust to continue to expand and preserve ecological and historical properties.

Figure 5: A+A Fair 2005 (www.fideicomiso.org/)

Árboles … Más Árboles (A+A), is a program started by the Conservation Trust in 1989 to help prevent and repair the massive amounts of deforestation that has occurred in Puerto Rico (Fideicomiso, 2009). In this program, The Trust's four nurseries grow and distribute native trees. To date over one million trees have been produced and replanted into Puerto Rico's forests (Fideicomiso, 2009). This program helps educate the public about the needs of the individual species of plants and the importance of the natural environment. This education includes tree planting sessions to ensure a better survival rate of the native plants produced. Prior to 2004, the reforestation program had produced many types of species of trees and focused primarily on the growth of flora in general. In 2004 The Trust had changed the program to specifically produce and distribute native species only (Fideicomiso, 2009). This change was caused by the realization of the biodiversity in Puerto Rico, and the numerous alien species that now populate the countryside. With the help of the A+A program, the Conservation Trust hopes to someday regenerate the native species across the island.

The Conservation Trust of Puerto Rico has played a large part in the conservation and the reforestation on the island. By conserving over 18,000 acres of historically, culturally, and ecologically significant land, The Trust has had tremendous success in their first 39 years of operation (Fideicomiso, 2009). The Conservation Trust of Puerto Rico continues to gain new properties for the purpose of conservation and education to the public. It hopes to one day set the standard on conservation for other Caribbean nations to follow. The Trust's recently acquired Rio Piedras water basin is the latest site for conservation and management review. For more information about Fideicomiso, refer to Appendix A.

As our team will work with The Trust to create a conservation management plan for the Rio Piedras watershed, we will be working in an area known as the riparian zone.

2.3 The Riparian Zone

The riparian zone is the region between the river and the upland. "Riparian vegetation is an important feature of the landscape because it connects terrestrial and aquatic systems and can function as [a] corridor" (Heartsill-Scalley, Aide, 2003). The riparian zone is a critical aspect of any ecosystem, and damaging this zone can result in drastic changes to the local environment. In order to conserve the riparian zone around the Rio Piedras, it is vital to comprehend its importance in conjunction with the ecosystem. The value of these areas is not generally appreciated by the public; as a result, the riparian zone is often destroyed or disregarded.

Figure 6: Riparian Zone (cstaf.ifas.ufl.edu/images/riparian.jpg)

2.3.1 Role of the Riparian Zone

The riparian zone plays many key roles in an ecosystem. The zone provides a home to a diverse set of species and is a key contributor to the hydrologic cycle. It also controls flooding, sedimentation, temperature, pollution, and water filtration in the region. Furthermore it acts as a carbon sink, a refuge for upland species, and a natural highway. The collaboration of all these roles results in its importance to a healthy ecosystem. The following sections will go into detail on certain aspects of the riparian zone.

2.3.2 Diversity in the Riparian Zone

The zone immediately surrounding a river is generally home to a more diverse set of species than the up-land area. (Sabo et al, 2005). While the bio-density is similar (+0.5% to riparian zones), the upland contains less biodiversity (Sabo et al, 2005). For example the riparian zone houses families of fish, reptiles, birds, mammals, and invertebrates, while the upland shelters mostly one or two set of families with different species. The riparian zone is a unique place where certain species will develop in niches specializing to those areas, promoting evolutionary changes. This is possibly due to "the interaction between the aquatic and terrestrial ecosystems, which only happens inside these zones" (Sabo et al, 2005). Therefore, conservation of the riparian zone is important to study and view the microevolution of species.

2.3.3 Hydrologic Cycle

The riparian zone plays a crucial role in the hydrologic cycle, as it contains many of the components used in the cycle.

"The movement and endless recycling of water between the atmosphere, the land surface, and underground is called the hydrologic cycle. This movement, driven by the energy of the sun and the force of gravity, supplies the water needed to support life. Understanding the hydrologic cycle is basic to understanding all water and is a key to the proper management of water resources." (Lusch, Wolfson, 1997)

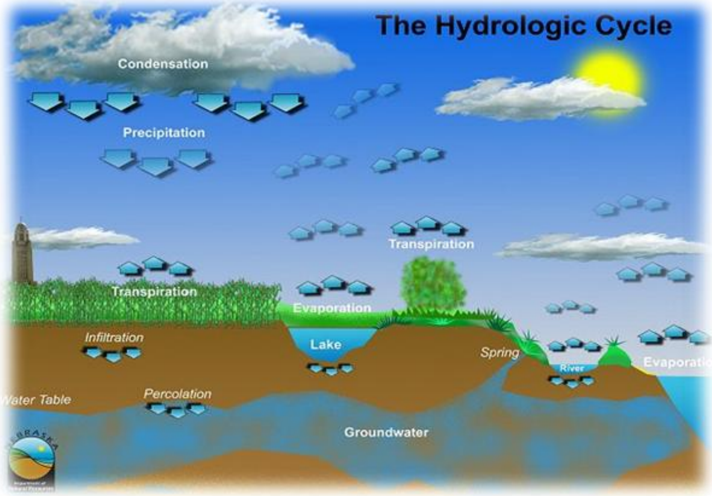

Figure 7: Hydrologic Cycle (http://www.dnr.state.ne.us/watertaskforce/Resourcematerials/HydrologicCycle.jpg)

As the process of the hydrologic cycle begins, the water is precipitated from the clouds to the earth. At this point, the water can take many paths. During precipitation, the water may be deflected in a different direction and taken up by plants. The water can also be stored in small basins or lakes, be absorbed by the soil, or end up as surface runoff that ends in rivers or other bodies of water (Lusch, Wolfson, 1997). The water then is recycled back into the atmosphere by evaporation and transpiration by the vegetation. The riparian zone is a key component in this process, as it contains many features that are included within the hydrologic cycle. The vegetation, rich soil, and the presence of a stream/river allow the cycle to operate successfully. An example of the hydrologic cycle is seen above in Figure 7.

2.3.4 Filtration

Vegetation plays a key role within the riparian zone because it performs various tasks. It acts as the zone's provider and regulator.

"At the local scale, riparian vegetation can influence in-stream habitat by providing shade, inputs of organic matter and wood, and aid in maintaining local bank and channel stability" (Teels, Rewa, Myers, 2006).

The vegetation also acts as a natural filter to help purify the water, perhaps for later use by humans. As a group, the leaves, sediments, and wood debris act as a filter to remove pollutants from the water.

> "They filter and process runoff, storm water, and drainage from lawns, roads and other urban sites. They also help hold water and control stream bank and in-channel erosion to help stabilize water corridors" (Allen, 2004).

By cleaning up the water, the zone helps to protect the habitat against the serious threat of pollution. The filtration also allows the fish and aquatic populations to survive, which in turn allows the aquatic predators on land to sustain life. Everything involved with the riparian zone has a chain effect that goes along with it. For example, the removal of vegetation would put fewer nutrients into the river, so during a flood the water would be less fertile to the flood plains. The consumers' survival chances are then hurt by weak vegetation growth.

Figure 8: Riparian Zone Canopy Cover (http://csc-s-maps-q.csc.noaa.gov/salmonid/html/salmonid/images/termper.j

2.3.5 Temperature Control

As mentioned above, the vegetation around a river provides shade to the area. The shade of the canopy helps to regulate the temperatures at the forest and stream floors. A study done by the University of Puerto Rico shows that the temperature greatly varies in the different riparian zones,

> " [the] watershed ranged from 21.7 °C to 23.6 °C in the forest site and from 22.2 °C to 25.0 °C in the mixed sites (secondary forest and original forest). Pasture sites had the highest values and largest range of temperatures (22.6 °C-26.5 °C). The peak in daily temperature was reached earlier in the day in the pasture cover sites, compared with mixed and forest cover sites." (Heartstill-Scalley, Aide, 2003)

This study was done on the Matón River in southern Puerto Rico and effectively shows how the canopy cover affects the ground temperature. The trees also serve as a carbon dioxide bank, which dampens the current problem of excess CO_2 in the atmosphere. The different temperatures promote distinctive life features. For example, in an area with little shade cover; grasses, invasive species, and algae tend to exist.

2.3.6 Refuge of Up-Land Species

Globally, the zone also serves as a shelter for upland plant and animal species during dry and glacial periods.

> "Moist tropical forest[s] survive as elongated forest fragments along rivers, where moisture supply is more continuous, fire frequencies are lower, and soil fertility is probably higher than elsewhere on the landscape"(Meave et al,1991).

The data collected from Belize and Venezuela indicate "large amounts of species can coexist in a riparian zone during times of extreme circumstances" (Meave et al, 1991). This is a very important discovery, as it reminds humans to limit damage of the zone because of its great value to the overall well being of the planet's ecosystem.

Figure 9: Deforestation in Puerto Rico (http://www.kingsnake.com/westindian/deforestation4.JPG)

2.4 Watershed Damage

A watershed is a fragile ecosystem; damage to any of the elements in a watershed can hurt the system as a whole. As mentioned above, the riparian zone serves many purposes and subjected to the "domino effect". The current problem is that the Rio Piedras water basin is lacking a true riparian zone and conservation plan. Present day "land use and land cover change (LUCC)" (Grau at el, 2003) is the leading cause of many environmental issues, including habitat destruction, soil degradation and introduction of invasive species. Effects of the LUCC are amplified on tropical islands, where limited space and increased populations create an urban sprawl effect, which invades forested lands.

2.4.1 Causes

The fertile land of the forests and river basins was converted into farmland for sugarcane, coffee, plantain, cotton, corn and rice. In 1899, 55% of the land was cultivated. 50 years later, the farming and ranching contributed to 45% of the gross national product (GNP) (Grau at el, 2003). Only 6% of the original forested land remained and 1% of the land remained unspoiled (Lugo, 2004). Before industrialization on the island, farmland covered 85% of the island, of which, a good number of farms were created along waterways in the lower elevations such as the Rio Piedras (Grau at el, 2003).

2.4.2 Implications

The wide scale deforestation in Puerto Rico resulted in severe damage to the Rio Piedras watershed. This had a drastic effect on the surrounding rivers and tributaries by changing the flow rates and pathways in which water enters and leaves the ecosystem. This, in turn, affects the flora and fauna of the area. In general, urbanization has decreased the width of the riparian zone. In some cases the zone was reduced to just the river bank, especially near the aqueduct site. An inadequate riparian zone causes sediment loss, down cutting, nitration, temperature increase, water pollution, invasive vegetation, and several other consequences. These topics are discussed in the following sections.

Sediment Loss

Wide scale deforestation exposes the delicate tropical soil to the extreme weather of the environment. A study from Puerto Rico "showed that a watershed dominated by agriculture (the Rio Grande de Loiza) yielded about 50% more landslides" (Grau at el, 2003). Another study in Puerto Rico of the Gaudiana watershed reveals the difference in erosion rates based on forest coverage and topography. In areas of bare soil, the erosion rate was 534 Mega-grams (Mgs) per year. While the opposite, closed canopy forests, yielded 8Mg per year. An erosion rate was measured in open canopy forests-26Mg, agricultural lands-22Mg, pastures-17Mg, and low-density urban areas-15Mg per year. This same study states that if "5% of the watershed with the highest erosion rates (bare soil, agriculture on steep slopes) is transformed into closed-canopy forest "that erosion would decrease by 20% (Grau at el, 2003). These studies show how riparian areas that were deforested, have significantly more sediment loss than the latter. This in turn fills the water-ways up with sediment, causing a loss of bank integrity, and making flooding more prevalent. The Rio Piedras is currently bordered by urban areas and pastures, resulting in a large erosion rate that has often flooded the river.

Down Cutting

Within the city, engineers often build stream channels and storm drain networks that bypass the riparian zone and empty right into the stream or river. The large amounts of water channeled into the streams change the hydrologic properties of the watercourse. Small amounts of sediment are no longer introduced in the river this results in a process called "down cutting". Down cutting is a process of sediment removal from large amounts of water. Sediment built up from agriculture or urban development creates an incision, or a narrow deep channel. Stream incision causes a lowering of the groundwater level, affecting the soil, plants, and microbial processes. Ground water level is a major factor in the function of riparian zones, which act as filters of pollutants from uplands. Riparian vegetation and microbes have been found to consume nitrate. Thus regulating its release into streams, without the ground water to keep the soil moist, the hydrophilic plants will die (Groffman at el, 2003).

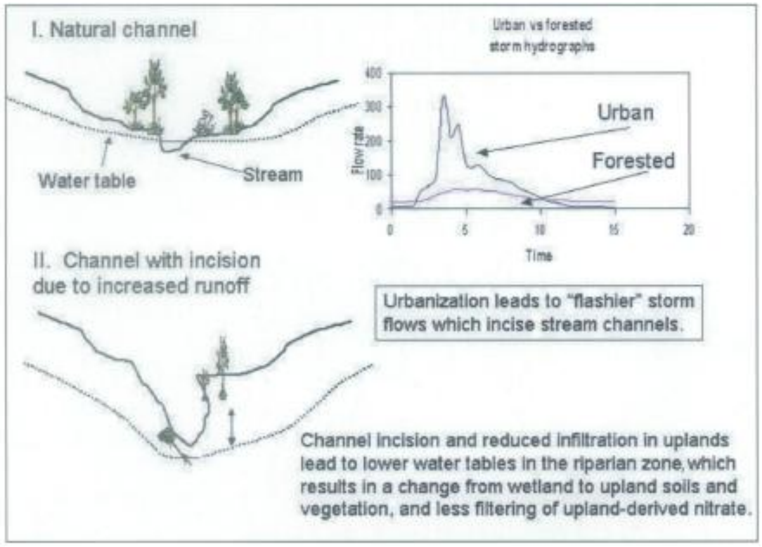

Figure 10: Down Cutting (Groffman, 2003)

Nitration

Agriculture has also caused an increase in Nitrate (NO_3^-) in the soil. Nitrate is "a byproduct of fertilizer use, human waste treatment, and fossil fuel combustion, is a highly mobile, ion and is the most common groundwater pollutant in the US" (Groffman at el, 2003). Nitrate in the soil washes into the streams with the eroded soil, polluting the rivers and streams. The island of Puerto Rico is also extremely susceptible to nitrate because short distance to coastal waters. The increased nitrogen in the water causes an influx of algae. In turn, the dead and decaying algae results in low levels of oxygen in bottom waters causing stress on aquatic species (Groffman at el, 2003).

Invasive Species

The soil left behind from farmlands was depleted of the nutrients necessary for native plant growth. Exposed fields also prevented the native plants that preferred shaded moist areas from reestablishing themselves. The dominance of invasive species is demonstrated in the growth of secondary forests on abandoned agricultural lands. There are up to 750 total individual tree species now on the island, of which many are non-indigenous. It has been shown that native species are growing in the understory of the secondary forests. As the shade intolerant plants compete for light, only some will survive leaving spaces for native plants to reclaim their spot in the canopy (Lugo, 2003).

Vegetation Removal

Vegetation removal in the riparian zone, due to the encroachment of houses and deforestation, makes the water unable to be used up by the vegetation around the river (Workman, Allen, 2004). In turn, the sediment becomes dry and loose. This causes the sediment to fall into the river and can create floods, narrow banks, polluted water, and shifting channels. A loss in sediment structure also hurts the ecosystem of the uplands. The riparian vegetation and sediments generally act as an energy sink and/or source of matter and energy. "As a sink, riparian vegetation dissipates the energy of flowing water while it retains and absorbs particles from upland areas" (Heartsill-Scalley, Aide, 2003). Therefore, harming the zone immediately around the river will also affect the greater regional habitat. Vegetation removal also leads to an increase in temperature, resulting in a change of habitat. New plants and animals (generalists/invasive species/algae) will likely occupy an area of higher temperature (pasture/farms), causing a change in watershed dynamics, such as water quality, as seen in Figure 11 (Heartsill-Scalley, Aide, 2003).

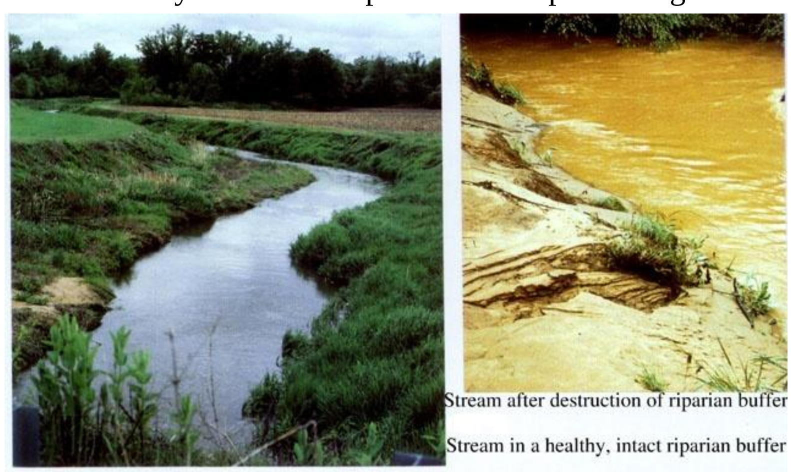

Figure 11: Riparian Zone-Health vs. Damaged (http://www.dof.virginia.gov/rfb/images/rfb-riparian-buffer-before-after.jpg)

Pollution

The lack of a riparian zone also allows dirty run-off and general pollutants to enter the stream. During a rainstorm, the runoff from the city streets will move into the watershed area. To prevent the dirty water from damaging the system, a riparian zone is needed to filter out the runoff (by way of roots, sediment, leaves, etc.). Agricultural runoff and manure is also a major problem in the damage of water systems. The manure leeches into the water, bringing damaging bacteria to the drinking water (Heartsill-Scalley, Aide, 2003).

2.5 Conservation Methods

The Rio Piedras riparian zone in San Juan is currently in a weakened state; there is a very small buffer between the river and the urban development's/pastures which surround it (as seen in Figure 12).

The river is bounded by open pastures and urban development, thus in numerous areas the riparian zone has limited width. This is a problem because as seen from a riparian vegetation study, "the amount of sediments from eroded soil was highest in pasture sites and decreased as forest cover increased" (Heartsill-Scalley, Aide, 2003). The combination of urbanization and open pastures has a devastating effect on the ecosystem of the river. To combat this, there are a few conservation methods available. The most common and effective method is to expand the buffer zone of the riparian vegetation to at least a distance of 50m from the river-bank (Freeman, Stanley, Turner, 2003).

Figure 12: San Juan, Puerto Rico: Rio Piedras River and Riparian Buffer Zone (google.map)

2.5.1 Buffer Zone

A buffer zone is a longitudinal band of natural vegetation and wildlife along the river's edge that will help to retain the riparian zone (Freeman, Stanley, Turner, 2003). The creation of a buffer zone around the body of water will help maintain the many important properties of the riparian vegetation, while still allowing for human activity outside the zone. An example of an urban buffer zone is seen in Figure 13. As the riparian zone acts as a highway for wildlife, the buffer zone will still allow travel of species from one habitat to another. Migratory routes will be left intact for many birds and others. The buffer zone will also vastly reduce the pollution to the

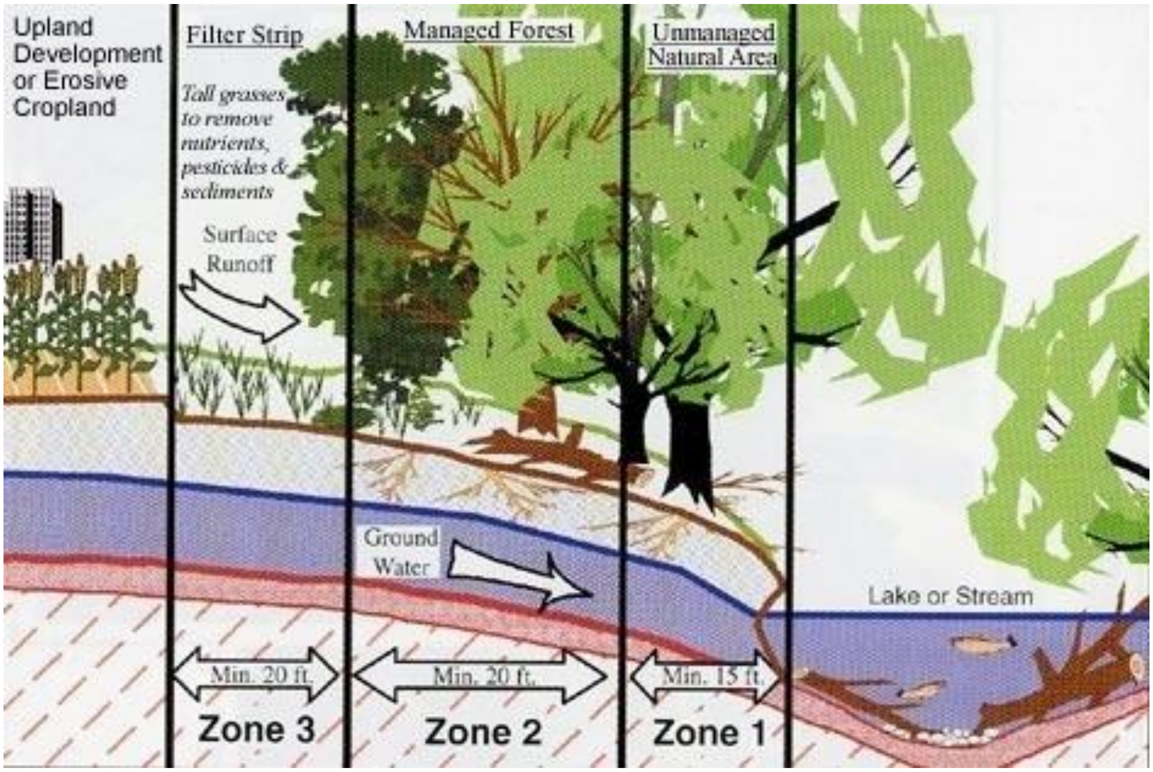

Figure 13: Example of Urban Buffer Zone (http://semircd.org/buffers/guide/pics/bufferzones.jpg)

water source, protect against floods, improve water quality, and allow safe recreation in the area. A study done in Wisconsin shows that a buffer zone of 50m will allow the riparian zone to function properly, while a zone of 100m will double its effectiveness (Freeman, Stanley, Turner, 2003). That is, the water quality, animal life, and overall health of the area were about two times more than the 50m zone. The Rio Piedras currently needs a buffer zone to bring the river back to the life it once had.

2.5.2 Connectivity

Another important aspect in the conservation of the river is the connectivity. That is, the link of a habitat or cover type across a landscape.

> "Functionally, habitat connectivity influences the case with which organisms or materials traverse the landscape between adjacent ecological units or land cover patches and intact vegetation patches are especially important to many birds and mammals activities. Within flood plains benefits of forest connectivity include provision of species habitat and movement corridors, enhanced species diversity, protection of water quality, and soil biogeochemical activities" (Freeman; Stanley; Turner, 2003).

The most common way to achieve the connectivity of the riparian vegetation is to fill in the gaps with native vegetation to stir growth. A gap would be all non-water, non-wetland holes in the riparian buffer (Freeman, Stanley, Turner, 2003). It is also important to keep the connectivity shape of the forests simple. This is hard to do with developments around the river, but a complex patch shape may hamper the benefits of an authentic connective buffer zone. A buffer zone with a complex shape can still alter the paths of wildlife migratory routes and cause irregular filtration and properties of the riparian zone (Freeman, Stanley, Turner, 2003). The conservation method of creating a buffer zone is proven to work. In a study done in Virginia on the effects of conservation, "buffer establishment improved stream bank cover, decreased sedimentation, manure, and nutrients, and improved water appearance" (Teels, Rewa, Myers, 2006).

2.6 Conclusion

In review, the literature has revealed the importance for conservation of the riparian zone around the aqueduct along the Rio Piedras. Puerto Rican development, followed by urban migration, has caused significant damage to the ecology of the island. As a result, the riparian zone of the Rio Piedras became, and remains, inadequate. Consequently, the Rio Piedras has suffered from the weakened riparian zone (i.e., flooding problems, sediment loss, rising temperatures, weak flora species diversity). A successful conservation effort will address the weaknesses, create a buffer zone, and realize the potential of the Rio Piedras.

Chapter 3: Methods

Our team's overall objective was to create a conservation management plan for the Rio Piedras around the aqueduct, in conjunction with the Conservation Trust of Puerto Rico. The Trust provided our team with a preexisting topographical and satellite map of the region. We divided the Rio Piedras watershed into zones based on ecological health. Our team identified each zone's biological and physical characteristics, and tests provided data regarding water and soil quality. Finally, we analyzed each zone's aspects in order to discover which zones needed focus for conservation measures.

3.1 Riparian Zone Identification

To begin, we divided the Rio Piedras region into smaller zones of similar ecological health. We surveyed along the river, filling out a river bank health assessment sheet (see Appendix I of the Management Plan) at thirty-meter intervals independently for each side of the river (urban and aqueduct bank sides). The dam of the aqueduct was used as a reference point for the start of the thirty-meter intervals. At each interval, a flag was placed with a reference number assigned accordingly. This gave our team an accurate idea of our location on the river. The assessment sheet included shade cover, vegetation, bank integrity, algae concentration in the river, both human and natural debris, and continuity from the previous interval. Each assessment sheet also contained a notes section to include the distinguishing features of each interval (ex: large river bank, water depth, vegetation, etc). After the initial interval assessments, we combined intervals of similar characteristics to form larger, continuous zones. We identified these regions as "Zone 1, Zone 2, etc." for easy referencing. Then, a brief description identifying the aspects of the zones was given for future reference in the report. This process is demonstrated in Figure 14, as team members are seen measuring out the thirty-meter intervals.

Figure 14: 30-meter Interval Measurement Process

After we identified the zones, we tied biodegradable marker ribbons to boundary trees to indicate the zone edge. This clarified the separation between zones for biological identification and measurements. Our team then marked each zone boundary, at the ribbon, using a GPS device with the help of a Trust employee. The GPS markings gave a very accurate measure of each zone's edge, and we uploaded the zone boundaries onto a digital map.

3.2 Zone Assessments

Upon completion of zone identification, we studied the ecological makeup of each individual zone. We recognized local flora and performed tests on the water and soil quality. These data gave information about healthy and unhealthy riparian zones that make up the Rio Piedras. This information was vital to the creation of a conservation management plan.

3.2.1 Identifying Flora

Our team's second objective was to describe the local biological features of this site. To achieve this objective, we explored the site with digital cameras. Photographs were taken of trees, shrubs, and grasses located in the riparian zone. To identify the plants, we took pictures of the subjects' leaves, flowers, buds, fruits, trunk, bark, and other characteristics. In some cases, the complete species was photographed. The photographs were compared with pictures and descriptions from botanical guidebooks and catalogues of island species. We also identified species with the help of The Trust employees. Figure 15 shows a team member documenting the species along the river's edge. This process was completed for the entire length of the river around the aqueduct complex.

Figure 15: Team Member Documenting Flora

3.2.2 Botanical Review of Species

After identifying the present species, we reviewed botanical literature to learn how each one contributes to or threatens the ecology. Our team created a flora classification spreadsheet, which describes the characteristics of each species uncovered from the literature review, as seen in the Management Plan Appendix IV. The characteristics in the spreadsheet include the following: a photograph, family and species, common name, life form, origin, abundance, and zone location.

3.2.3 Interviews

The importance of species to an area was found through research and review of literature. However, the members of the Conservation Trust of Puerto Rico had some of our group's most valuable information. The Trust had already established conservation practices in many areas.

Therefore, the employees understood whether a species was a threat, a contributor, or non-important for an area's biodiversity. There were too many irrelevant species so we recognized species of importance for biodiversity and conservation.

3.2.4 Water Quality Test

Pollution was also a contributing factor to the health of the ecosystem, and our group tested the water quality in each zone. Our group performed pH, nitrate, dissolved oxygen, and phosphate tests on the river. The tests were executed once for each zone at the downstream boundary. The test was performed at the end of the zone in order to demonstrate the effects of the entire zone on the water. Each test was performed in slower moving water as close to the bank as possible. The testing procedure can be seen in Appendix C for the respective trials.

3.2.5 Soil Density Test

We took soil density measurements twice per zone; however for the larger zone additional tests were performed. The measurements were taken approximately in the first and second half of each zone in accessible areas. Since each zone has a slightly different bank dynamic, our team attempted to take the measurements in similar areas. The density was measured by taking a 9 cm (3 in) inner diameter section of PVC pipe that is 8.2 cm (3 ¼ in) deep and hammering it into the ground. The PVC was hammered into the ground until the soil reached the half way lip. The volume of the cylinder to the lip is 261.32 cm^3 (15.94 in^3). A towel was then placed underneath the pipe to prevent soil loss during removal. The samples were placed into gallon sized freezer bags and dried out over a four-day period. After the drying period, each sample was placed in the microwave to completely dry the contents. The matter was weighed to determine the density of the soil. This measurement gave our group data to determine bank integrity and the possible erosion into the river.

3.3 Conservation Plan Creation

The ultimate goal for our team was to create a conservation management plan. The Management Plan is a located in Appendix B. The plan includes a detailed analysis of results and recommendations. Each zone has a comprehensive analysis for the flora found, water quality, and soil results. In addition, we placed pictures and discussed defining characteristics of each zone. The plan then includes recommendations and actions for Fideicomiso to take in order to restore the site. The recommendations involve information on the conservation approach, buffer zone expansion, erosion control, debris control, and the addition of flora.

Chapter 4: Results and Analysis

Upon completing our methodology, we were able to fulfill our objectives, which ultimately allowed us to accomplish our goal of creating a management plan. The following sections are a brief overview of the trends we observed throughout testing. In-depth results and analysis for each zone can be viewed in the Management Plan in Appendix B.

The only fauna found in the river were iguanas and small lizards, along with a few turtles, fish, and birds. Consequently, our team decided that the fauna were insignificant factors in the scope of our study. Therefore we did not further investigate the present fauna species or include them into the recommendations.

4.1 Interval Assessment

We divided ourselves into two groups and assessed opposite sides of the river. One group evaluated the side of the river adjacent to the aqueduct complex while the other worked on the side bordering the urban features. Forty-two individual assessment sheets were completed, 21 for each bank side. Our team visually addressed shade cover, vegetation, algae, bank integrity, continuity from previous zone, and a note section for specific comments corresponding to the interval. Our team members collaborated to decide upon the best qualitative descriptor in each section of the evaluation, based on a visual survey. The data was organized in a spreadsheet for interval comparisons. Refer to the Management Plan in Appendix B to view the assessment sheets. Some categories have little to no change throughout the intervals, such as algae abundance.

4.2 Zone Creation

Our team then analyzed the compiled spreadsheet data and arranged the 42 intervals into 13 larger zones as seen in Figure 16. A more defined map is seen in Figure 17, displaying a thick border for the zones and the property. The interval to zone correlation is shown in Chapter 3 of the Management Plan. The created zones are largely based upon the last category of the assessment sheet, “Continuity from Previous Interval”. This category allowed the intervals to merge together into continuous zones. Seven zones are located on the aqueduct side of the river while six are located on the urban side. On both sides of the river near the dam, the zones are smaller because the physical appearance varies between intervals. Further from the dam, intervals are similar are enough to create much larger zones.

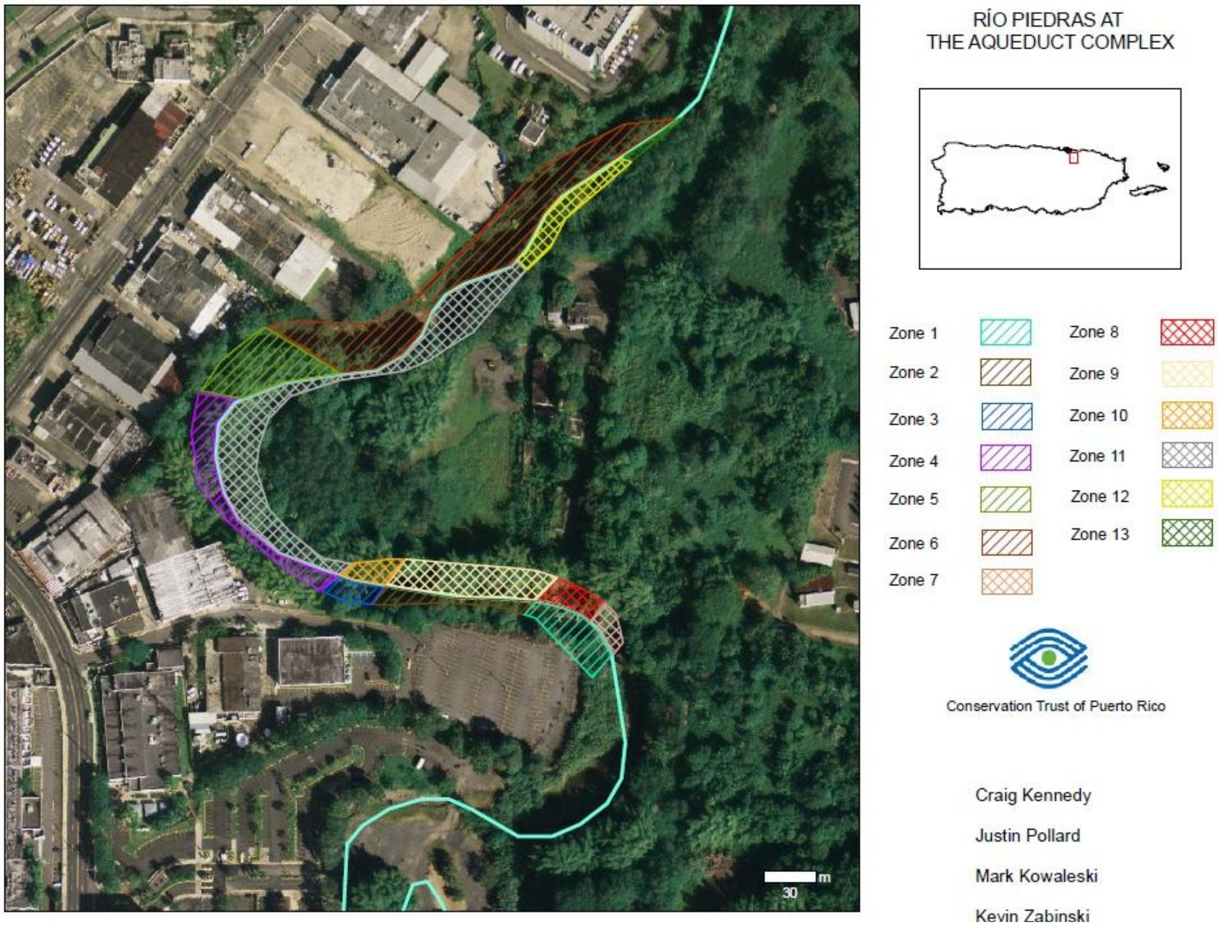

Figure 16: Map – Hatched Zone Identification

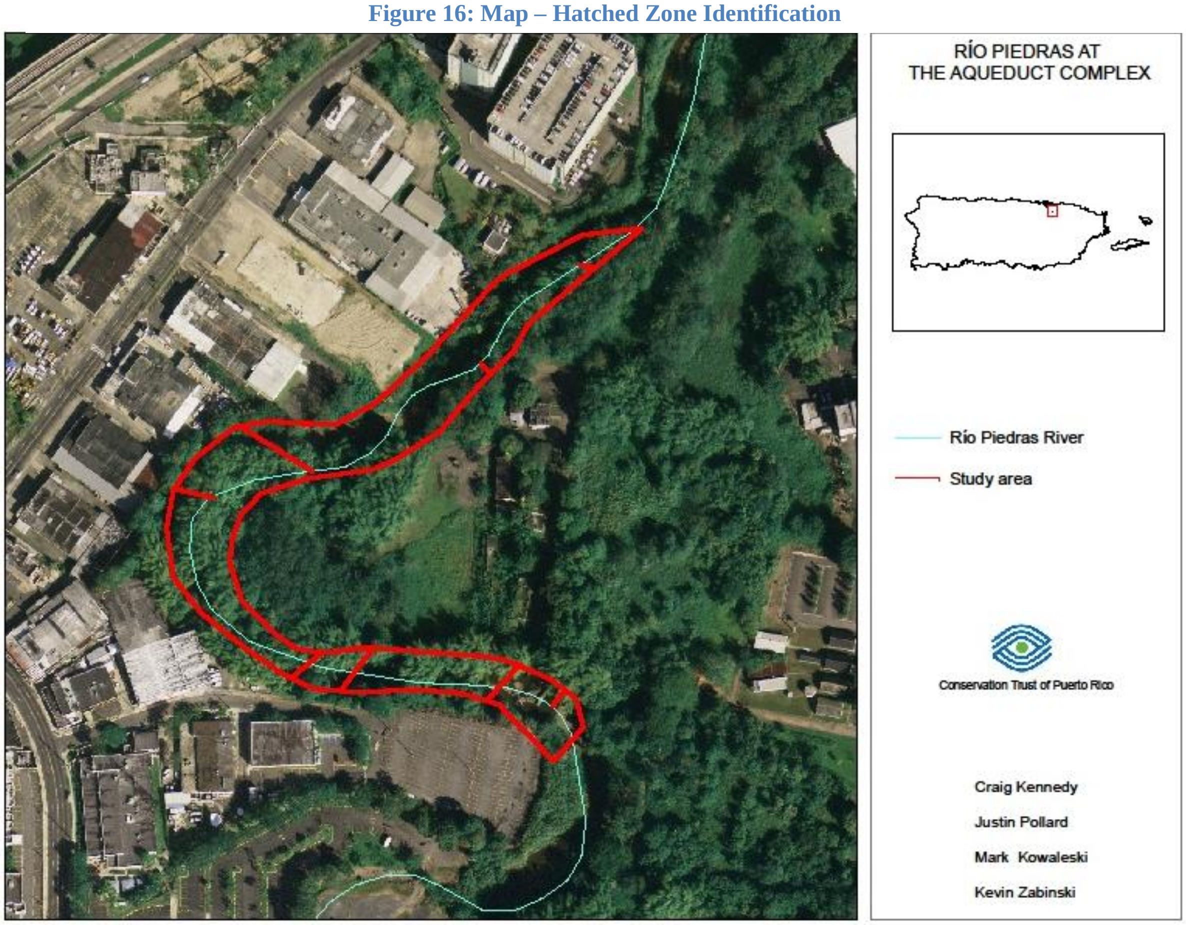

Figure 17: Map - Clear Zone Outline

4.3 Water Quality Testing

In testing the water quality at the end of each zone, we found little variances between testing locations. The experimental results are shown in Table 1. There are however slight patterns that we have discovered. The water temperature increased as each group proceeded downstream. This is primarily due to the decreasing amount of canopy cover. Based on the dissolved oxygen testing, the levels are not consistent with a healthy river. Yet, in speaking with Fideicomiso employees, we learned that the Rio Piedras possesses similar values to other San Juan water systems. In testing the phosphate levels, we found similar results in parallel zones. The first and last few zones on either side of the river had 1 part per million (ppm) concentrations while the central zones had 2 ppm. Overall the pH testing concluded that the water was slightly basic, but still at a healthy level throughout. Nitrate testing proved inconclusive as we found 0 ppm for each zone. The water quality testing concluded that the water of the Rio Piedras is in fair condition around the aqueduct.

Figure 18: Team Members Performing Water Testing

Table 1: Water Quality Test Results

Water Quality Test Results				
Zone Number	**Temperature °C**	**Dissolved O_2 (%)**	**Phosphate (PPM)**	**pH**
1	26	39	1	8.25
2	26	39	2	8.25
3	26	0	2	8
4	27	39	2	7.5
5	28	42	1	8
6	27	41	1	7.75
7	26	0	1	8.25
8	25	0	2	8
9	26	39	2	8.25
10	27	41	2	7
11	27	42	1	8
12	27	41	1	7.5
13	27	41	1	8

4.4 Soil Testing

Soil testing was conducted twice per zone with the exceptions of Zone 2 and Zone 11, as they were larger zones with a wider variety of soils. We found the majority of the samples were composed of clay with varying amounts of roots, rocks and organic matter. Our team observed that where there was a higher range of biodiversity, the samples contained a greater number of roots and were more difficult to extract. This demonstrates that those zones with a greater biodiversity have a solid bank integrity, which creates a larger resistance to erosion.

Figure 19: Team Member Performing Soil Collection

The density calculations range from 0.478 to 2.296 g/cm^3, with an average density of approximately 1.2 g/cm^3. This value of 1.2 g/cm^3 is the same as the average density value of clay which supports our observations of a mostly clay bank composition. The few outliers in the density results were samples that contained rocks, thus increasing the density. For a greater analysis of zone by zone soil results please go to the Management Plan. Also refer to the Management Plan Appendix III for the detailed density results.

4.5 Flora Identification

Flora photographs were given to Fideicomiso employees who helped in the identification process. A total of 64 individual species were identified, of which 20 are invasive to Puerto Rico. However, of the eleven species receiving an abundance of localized (++) to widespread (+++), eight of them are invasive. For details on the found flora and the respected information, refer to the Management Plan Appendix IV. The following is the life form breakdown of the 64 flora species:

- 27 species of trees – 10 of which are invasive
- 24 species of shrubs – 7 of which are invasive
- 5 species of vines – 2 of which are invasive
- 4 species of grasses – 2 of which are invasive
- 3 species of ferns – all native

The most abundant flora species in the Rio Piedras region is Bamboo (*Bambusa vulgaris*), as it appears in eight of the thirteen zones. Bamboo is widespread, in large thick clusters. On the aqueduct side it appears in every zone (7-13). Bamboo is an invasive species, but it can help prevent erosion with its matrices of small roots. Our team feels that Bamboo is a good species to have in a controlled manor, yet when the species grows excessively it can limit the growth of native vegetation. The positive qualities of keeping a controlled amount would outweigh the negatives of removing the entire species population.

One of the few widespread trees is the invasive African Tulip (*Spathodea campanulata*). The African Tulip exists in ten of the thirteen zones, however the population is much less than that of the Bamboo. The African Tulip exists in all zones on the urban side, with the exception of Zone 6. African Tulip is a good contributor to the canopy cover and is a rapidly growing species. The species does limit the growth of other large trees, as it can spread and grow quickly. Yet, the tree helps with sedimentation and filtration. Therefore, the tree's positive attributes prevail over its invasive and rapidly growing nature.

Elephant Grass (*Pennisetum purpureum*) is another widespread invasive species. As it grows so quickly, it chokes out the smaller shade intolerant vegetation. However, Elephant Grass does not contribute to the canopy cover which is important to maintain water temperatures. As this species can spread and develop much faster than most, it often occupies vast expanses of land along the river. Consequently, Elephant Grass is the second most abundant species our team discovered. Elephant Grass exists in nine of the thirteen zones and appears in large stretches of open land. Therefore, this species needs to be maintained and eliminated in order to allow other species to mature. A photograph of the grass is seen in Figure 20.

Figure 20: Elephant Grass

A common native vine is the *Calopogonium coerulem*. This species of vine is found in eight of the thirteen zones and is abundant in each. This species is found entangled within many of the trees and shrubs. This vine is shade tolerant and even able to grow well in that circumstance. Our team observed that the vine is able to survive in zones where the African Tulip is present because it can endure the tree's shade cover.

There are many other species along the river, some of which are unique to certain zones. For an in-depth look at the individual species that are present in each zone please refer to the Management Plan. There is a detailed table of the 64 species found, their scientific name, family, life form, origin, abundance, and zone location in within the Management Plan Appendix IV. There is also a table that shows their photos, common name, and scientific name that is found in the Management Plan Appendix XVIII.

Chapter 5: Recommendations and Conclusions

Our team's project goal was to create a conservation management plan for the Rio Piedras in the area of the aqueduct complex. The following sections include a summary of recommendations for The Trust. View the Conservation Management Plan, found in Appendix B, for the details of the recommendations and actions Fideicomiso should take.

5.1 Conservation Approach

As we outlined in Chapter 2, there are three approaches that The Trust can use. They are the classic, populist, and neo-liberal approaches. Due to the complexity of the river restoration, we recommend that The Trust use a hybrid of all three conservation approaches. The organization should continue to utilize the classic approach by keeping abusive people away from the site and finding ways to protect the site from them. We also recommend that The Trust use aspects of the populist approach by finding and involving local residents and organizations in the restoration process. Finally, The Trust should use aspects of the neo-liberal approach by offering incentives to the surrounding businesses for adopting environmentally friendly policies. This approach will best involve the people and businesses that were not reached by the populist approach. The restoration process will be successful if The Trust can utilize the people in these various ways while employing the classic approach to protect the site from misbehaving persons.

5.2 Buffer Zone Expansion

The riparian zone is very narrow in many places along the river. Our team advises the expansion of the riparian buffer zone to an ideal width of 25 m from the water's edge. To accomplish this, many urban features will need to be removed. Our team understands that this is not possible in many places because of the existing buildings and inhabitants. However, we suggest that The Trust removes the urban structures where possible. In these newly opened areas, we would like to address the grading issues of the river. Steps can be taken to reduce the drastic slope of the riparian zone.

5.3 Erosion Control

Figure 21: Erosion in Zone 1

Our group found excessive erosion in a majority of the zones. Erosion is seen evident in the upper riparian zone sheer cliff faces (Figure 21), fallen trees, Bamboo, and bank edges. We recommend that The Trust remove the scattered fencing at the top of the riparian zone. We also suggest that the pavement surrounding the river be replaced by gravel or any other water permeable surface. This will allow proper water filtration and to improve ground run-off that sends sediments into the water.

Throughout the Rio Piedras around the aqueduct, we suggest that a tiered vegetation system be implemented where possible. At the water's edge, large native trees with strong roots should be planted. Beyond the first layer, large shrubs and small trees should be planted. Finally, smaller shrubs and grasses should be planted further upland. This system allows the riparian zone to effectively filter the water while creating a strong root system in the area.

In Zone 5, the embankment is covered by very large rocks. We advise The Trust to remove the large rocks and reveal the soil. The tiered vegetation system should be used in this area along with the appropriate planting soil to increase growth. Once the vegetation is planted, we recommend that a geo-textile material be placed on the ground. This will prevent the newly exposed soil from eroding while allowing the plants to grow. The geo-textile material will eventually decompose into the natural habitat.

5.4 Debris

We identified extensive amounts of garbage and natural debris spanning the course of the river. We recommend that The Trust hold an annual or biannual river cleanup event with either volunteer or professional crews. Professional crews will be needed if large objects such as the refrigerator or car chassis need to be dismantled.

In order to control the dumping issue, we advise the building of an updated fence system. The fencing should surround the newly expanded buffer zone, and be integrated into the existing fence and guard station of the aqueduct complex. The new fence should include a tall heavy duty barbed wire fence that is placed at the outer extent of the expanded riparian zone. This fence system should include motion sensor lights and cameras. On the fence, there should be signage indicating the presence of cameras and explaining the site's importance. Finally, we suggest that the fence is covered in native vines and shrubs to increase the natural aesthetic. The fence will prevent vandals, polluters, and other abusive people from entering the river an unauthorized fashion. If they want to contribute to or be involved with the Rio Piedras, they can enter through the guard station and gate. This will prevent unwanted visitors from damaging the area.

5.5 Flora Recommendations

Six plant species received an abundance grade of widespread (+++), yet five of them are invasive species to Puerto Rico. Within this collection of plants, our group recommends controlling and limiting the growth of two plants. These two species are *Bambusa vulgaris* (Common Bamboo) and *Pennisetum purpureum* (Elephant Grass). Controlling the growth and spread of these plants will allow the native species, which we recommend be planted in the riparian zone, a chance to mature and thrive. We suggest that the other two invasive species, *Spathodea companulata* (African Tulip) and *Terminalia catappa* (Indian Almond) remain undisturbed because they have qualities that help the riparian zone. However, we suggest The Trust control the spreading by eliminating the saplings of these trees. For a more detailed report of the abundant species and their characteristics, refer to Chapter 4 of the Management Plan in Appendix B.

Figure 22: Tall Albizia

We also propose specific plants be used in conjunction with the implementation of the tiered vegetation system. A list of twelve plant species was chosen to be used in the vegetation system. They were chosen based upon their contribution to the riparian zone health, ease of growth, and The Trust's ability to obtain the plants. This list includes trees and shrubs such as the *Andira inermis* (Angelin), *Calophyllum calaba* (Maria) and the *Thespesia grandifora* (Maga). Nine of the trees are grown in The Trust nursery. One plant is an invasive species, the *Albizia procera* (Tall Albizia), but the positive characteristics of this tree prevail over the fact that it is invasive. The Tall Albizia can be seen in Figure 22. For a more detailed report of the suggested species and their characteristics, refer to Chapter 4 of the Management Plan in Appendix B.

5.6 Conclusions

A detailed plan of recommendations, results, and actions can be seen in the Management Plan of Appendix B. The Trust will utilize these recommendations in order to conserve and restore the Rio Piedras. Our team recognizes that the removal of buildings is a difficult task, but we feel this is one of the most important recommendations because it allows for buffer zone expansion and decreases urban effects.

In the future, the Conservation Trust of Puerto Rico will open the aqueduct complex to the public for historical and environmental education. The Rio Piedras surrounding the complex serves as the natural land portion of the site, and the restoration will allow for The Trust to educate the public about the environment and importance of conservation. In this way, people who once viewed the river as a dumping ground will see it as a natural sanctuary.

This site is a unique property for The Trust, because it is located both within urban San Juan and within the "Ecological Corridor" of Puerto Rico. This location both creates an obstacle and an opportunity for something magnificent. The successful restoration of the river will all but erase the years of abuse it has taken, but it must involve the positive contributions of local residents and businesses. Since the island has little natural land remaining, exploiting these opportunities will increase the ecological value exponentially. When completed, The Trust's restoration project will make other urban conservation opportunities visible in Puerto Rico.

We feel deeply privileged to have worked with The Trust on such an important restoration project. In the future, Fideicomiso can build upon our recommendations to restore the region and recreate one of Puerto Rico's most valued pieces of land. Consequently, we hope people who abuse the island will form a new set of values to respect their natural land. We are certain that the site restoration will be completed to The Trust's high standards and form a cornerstone for conservation in the face of urban development.

References

Aide, T. M., & Grau, H. R. (2004). ECOLOGY: Enhanced: Globalization, migration, and Latin American ecosystems. *Science, 305*(5692), 1915-1916. doi:10.1126/science.1103179

Brown, K. (2002). Innovations for conservation and development. *The Geographical Journal, 168*(1), 6-17. Retrieved from http://www.jstor.org/stable/3451218

Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning, 68*(1), 129-138. Retrieved from http://www.sciencedirect.com/science/article/B6V91-49PRHC3-1/2/8b5c67cddd8338652db86483ff9b55df

Clark, J. J., & Wilcock, P. R. (2000). Effects of land-use change on channel morphology in northeastern Puerto Rico. *Geological Society of America Bulletin, 112*(12), 1763-1777. doi:10.1130/0016-7606(2000)112<1763:EOLUCO>2.0.CO;2

David P. Lusch, Lois G. Wolfson. (1997). *The hydrologic cycle*.http://www.iwr.msu.edu/edmodule/water/cycle.htm

Dunn, C. P. (2008). Biocultural diversity should be a priority for conservation. *Correspondance, 456*

Fideicomiso de conservacion. Retrieved February, 10, 2009, from http://www.fideicomiso.org/

Francis, J. K. (1998), Tree Species for Planting in Forests, Rural, and Urban Areas of Puerto Rico. USDA Forest Service, International Institute of Tropical Forestry

Freeman, R. E., Stanley, E. H., & Turner, M. G. (2003). Analysis and conservation implications of landscape change in the Wisconsin river floodplain, USA. *Ecological Applications, 13*(2), 416-431. Retrieved from http://www.jstor.org/stable/3099908

Gaston, K. J., Blackburn, T. M., & Goldewijk, K. K. (2003). Habitat conversion and global avian biodiversity loss. *Proceedings: Biological Sciences*, *270*(1521), 1293-1300. Retrieved from http://www.jstor.org/stable/3558814

Godfrey, M. (2009). *Rainforests.*http://www.nature.org/rainforests/

Grau, H. R., Aide, T. M., Zimmerman, J. K., Thomlinson, J. R., Helmer, E., & Zou, X. (2003). The ecological consequences of socioeconomic and land-use changes in postagriculture Puerto Rico. *Bioscience*, *53*(12), 1159-1168. Retrieved from http://www.jstor.org/stable/1314687

Groffman, P. M., Bain, D. J., Band, L. E., Belt, K. T., Brush, G. S., Grove, J. M., et al. (2003). Down by the riverside: Urban riparian ecology. *Frontiers in Ecology and the Environment*, *1*(6), 315-321. Retrieved from http://www.jstor.org/stable/3868092

Heartsill-Scalley, T., & Aide, T. M. (2003). Riparian vegetation and stream condition in a tropical agriculture-secondary forest mosaic. *Ecological Applications*, *13*(1), 225-234. Retrieved from http://www.jstor.org/stable/3099961

Key facts at a glance: Puerto Rico. (2007). Retrieved February 07, 2009, from http://www.wttc.org/eng/Tourism_Research/Tourism_Satellite_Accounting/TSA_Country_Reports/Puerto_Rico/

Lugo, A. E. (2004). The outcome of alien tree invasions in Puerto Rico. *Frontiers in Ecology and the Environment*, *2*(5), 265-273.

Luquillo y Fajardo. *TO THE RECATE ANCIENT AQUEDUCT.*http://translate.google.com/translate?hl=en&sl=es&u=http://www.prfrogui.com/fortune/acueducto.htm&sa=X&oi=translate&resnum=1&ct=result&prev=/search%3Fq%3Dantiguo%2Baqueducto%2Bpiedras%26hl%3Den%26rls%3Dcom.microsoft:*

McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *Bioscience*, *52*(10), 883-890. Retrieved from http://www.jstor.org/stable/1314309

Meave, J., Kellman, M., MacDougall, A., & Rosales, J. (1991). Riparian habitats as tropical forest refugia. *Global Ecology and Biogeography Letters, 1*(3), 69-76. Retrieved from http://www.jstor.org/stable/2997492

Moskovits, D. K., Fialkowski, C. J., Mueller, G. M., & Sullivan, T. A. (2002). Chicago wilderness: A new force in urban conservation. *Annals of the Missouri Botanical Garden, 89*(2), 153-163. Retrieved from http://www.jstor.org/stable/3298560

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Fonseca, Gustavo A. B. da, & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*, 853.

O'Connor, P. J., Covich, A. P., Scatena, F. N., & Loope, L. L. (2000). Non-indigenous bamboo along headwater streams of the luquillo mountains, Puerto Rico: Leaf fall, aquatic leaf decay and patterns of invasion. *Journal of Tropical Ecology, 16*(4), 499-516. Retrieved from http://www.jstor.org/stable/3068690

Ortiz-Zayas, J. R., Lewis, W. M.,Jr., Saunders, J. F.,III, McCutchan, J. H.,Jr., & Scatena, F. N. (2005). Metabolism of a tropical rainforest stream. *Journal of the North American Benthological Society, 24*(4), 769-783. Retrieved from http://www.jstor.org/stable/4095629

Policy and law library. (2008). Retrieved February, 10, 2009, from http://www.surfrider.org/rincon/library.asp

Rodriguez, J. (2009).

Sabo, J. L., Sponseller, R., Dixon, M., Gade, K., Harms, T., Heffernan, J., et al. (2005). Riparian zones increase regional species richness by harboring different, not more, species. *Ecology, 86*(1), 56-62. Retrieved from http://www.jstor.org/stable/3450987

Shapiro, M. In Jane Clark Chermayeff Associates (Ed.), *The conservation trust of Puerto Rico.* San Juan, Puerto Rico: The Conservation Trust of Puerto Rico.

Sherer, P. M. (2005). The benefits of parks: Why America needs more city parks and open space. Retrieved from http://www.tpl.org/content_documents/parks_for_people_Jul2005.pdf

Sterba, O., Mekotova, J., Krskova, M., Samsonova, P., & Harper, D. (1997). Floodplain forests and river restoration. *Global Ecology and Biogeography Letters, 6*(3/4, Floodplain Forests: Structure, Functioning and Management), 331-337. Retrieved from http://www.jstor.org/stable/2997747

Teels, B. M., Rewa, C. A., & Myers, J. (2006). Aquatic condition response to riparian buffer establishment. *Wildlife Society Bulletin, 34*(4, Special Section: Farm Bill Contributions to Wildlife Conservation), 927-935. Retrieved from http://www.jstor.org/stable/4134301

Thompson, J., Brokaw, N., Zimmerman, J. K., Waide, R. B., III, E. M. E., Lodge, D. J., et al. (2002). Land use history, environment, and tree composition in a tropical forest. *Ecological Applications, 12*(5), 1344-1363. Retrieved from http://www.jstor.org/stable/3099976

The United States experience with economic incentives for pollution control. (2009). Retrieved April/20, 2009, from http://yosemite.epa.gov/EE/epa/eed.nsf/Webpages/USExperienceWithEconomicIncentives.html

Workman, S., & Allen, S. (2004). *The practice and potential of agroforestry in the southeastern united states.*http://cstaf.ifas.ufl.edu/whitepaper.htm#riparian

Young, O. R. (2008, February). The architecture of global environmental governance : Bringing science to bear on policy. *Global Environmental Politics,* , 14.

Appendix

Appendix A: Fideicomiso Background

Mission:

The Conservation Trust of Puerto Rico is a private, non-profit organization whose mission is to protect and enhance the Island's natural resources. The Trust carries out this mission through the acquisition and donation of lands of great ecological, aesthetic, historic and cultural value, and the establishment of conservation easements. As part of its mission, The Trust develops programs aimed at educating the public about environmental issues and the need to protect and conserve our natural resources. Through its reforestation program, Árboles… más árboles (A+A), The Trust produces and distributes native tree species that help promote the Island's biological diversity.

Origins:

In 1970, the governments of Puerto Rico and the United States founded the Conservation Trust of Puerto Rico. During its first ten years, The Trust received funds from U.S. tariffs paid by the petrochemical companies operating on the Island. Soon, The Trust began generating income through private financial transactions with companies operating under Section 936 of the U.S. Internal Revenue Code. Once the latter expired, The Trust began to invest in the stock and bonds market and to receive a portion of the rum tax returns from the federal government. These financial resources have allowed The Trust to create a fund with which to generate its own income and to acquire areas of high ecological and historic value.

Funding:

In addition to its federal funds and private financial transactions, The Trust also receives land and cash donations from its AMIGOS—individuals and corporations committed to the protection and conservation of the natural resources and beauty of Puerto Rico.

History:

During the first 33 years, under the leadership of architect Francisco Javier Blanco, The Trust managed to protect over 16.000 acres of land, among which stand out the lands at Parguera in Lajas, Las Cabezas de San Juan in Fajardo, Hacienda Buena Vista in Ponce, San Cristóbal

Canyon between Aibonito and Barranquitas, Hacienda La Esperanza in Manatí and Punta Guaniquilla in Cabo Rojo. Mr. Blanco directed important historic restoration projects such as the buildings at Hacienda Buena Vista, the lighthouse at Las Cabezas de San Juan in Fajardo and the Ramón Power and Giralt House in Old San Juan, currently The Trust's headquarters. The Trust has been the recipient of important recognitions for its restoration and historical preservation work. Also under Mr. Blanco's leadership, The Trust managed to establish important protection mechanisms for the conservation of lands in the Caribbean region, such as debt-for-nature swaps with the Dominican Republic and Jamaica and, in Puerto Rico, the Puerto Rico Conservation Easement Law of 2001. After Arch. Blanco's retiring in December 2002, The Trustees named lawyer Fernando Lloveras San Miguel as Executive Director of the institution. Under Mr. Lloveras's leadership, The Trust has acquired over 2,000 additional acres of land, including three conservation easements. In addition, Mr. Lloveras was responsible for implementing a native tree species production, distribution and reforestation policy in all of The Trust's tree nurseries in 2004. He is also responsible for moving forward a collaborative initiative between multiple government and educational entities focused on biodiversity conservation in Puerto Rico.

This information was taken directly from Fideicomiso.org

Appendix B: Conservation Management Plan

Conservation Management Plan

for

The Rio Piedras Around the Aqueduct Complex

May 2009

Prepared by:

Craig Kennedy

Mark Kowaleski

Justin Pollard

Kevin Zabinski

Prepared for:

The Conservation Trust of Puerto Rico

Advised by:

Ingrid Shockey

Karen Lemone

FIDEICOMISO

RIO PIEDRAS CONSERVATION MANAGEMENT PLAN

Prepared By: Craig Kennedy, Mark Kowaleski, Justin Pollard, Kevin Zabinski

Prepared For: The Conservation Trust of Puerto Rico

Advised By: Professor Ingrid Shockey and Professor Karen Lemone

May 2009

Abstract

This document was prepared for The Conservation Trust of Puerto Rico and contains detailed results, analysis, and recommendations for the Rio Piedras around the first aqueduct. The Management Plan contains an examination of the river's riparian zone. In order to complete the examination, our team performed an analysis of the watershed's flora, water quality, and soil densities and compositions. We found fair water quality and biodiversity, but there is an overwhelming amount of invasive species, debris, and erosion problems. Overgrowth, natural debris, and urban development are the three obstacles that The Trust needs to address to conserve the river. Our team's recommendations suggest a conservation approach, buffer zone expansion, erosion control, debris control, and the addition and removal of flora. The Rio Piedras will be restored to reduce flooding, increase ecological value, and to form the natural feature of the aqueduct complex.

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Chapter 1: Introduction

The Rio Piedras watershed is one of the rare natural regions in San Juan that requires conservation. Located within the city, the river has been encroached upon by human development. The outlining features of the river bank include parking lots, buildings, roads, fences, farms, and river diversions (dams). In turn there is widespread pollution, flooding, sediment loss, growth of invasive species, and damage to aquatic and terrestrial life.

We created the following Conservation Management Plan for the watershed around Puerto Rico's first aqueduct. The plan includes an assessment of the riparian zone health, flora identification, and recommendations to restore the river's ecology. These recommendations include addressing the urban features surrounding the river, adding and removing species, and improving the riparian buffer zone.

The Conservation Trust is faced with a unique situation because the river is located within the "Ecological Corridor" as well as within urban San Juan. We have discovered how abandonment and mistreatment of the region has hurt its ecology. Furthermore, we have suggested means to repair the damage that has taken place. By completing the restoration of the aqueduct and the surrounding river, The Trust will establish a cornerstone for site conservation in an urban area.

Chapter 2: Background

The following sections are a concise review of the supporting information relating to The Management Plan. This includes various theoretical approaches to conservation management, an understanding of functions of the riparian zone, and the implications of riparian zone damage.

2.1 Conservation Approaches

Conservation is the complex process of integrating “human needs with biodiversity” (Brown, 2002). When conservation is practiced, a unique strategy must be used because of varying ecosystems and surrounding communities. There are three categories that conservation approaches are categorized: the “classic, populist, and neo-liberal approach” (Brown, 2002).

Figure 1: Using the Classic Approach

The classic approach is used when local people are identified as abusive to the ecosystem. It is the most widely used approach because the surrounding communities are frequently to blame for the deterioration of an ecosystem. In the case of the Rio Piedras, for example, local residents and companies are dumping into the river. The solution under this approach is to prohibit access to the property to allow for restoration. The ideas and labor for the restoration would therefore be done completely by the company. Although keeping the damaging people away from the property helps to allow regeneration, the approach rarely assists in stopping the mistreatment. Fencing, as seen in Figure 1, is just one way of using the classic approach.

The populist approach is the opposite of the classic approach because the local residents and organizations are used for restoration. Since they dwell in the area, local people have knowledge and passion that can be utilized during conservation. In the case of rivers, for example, planning a restoration should involve upstream and downstream residents and organizations because they will see direct effects from major changes. People who live next to the river are important because they would like the ecosystem to achieve its potential.

The neo-liberal approach is used when economic incentives are offered to people who help further conservation efforts. Normally distributed by the government, incentives are perhaps the most effective way to make a company seek alternatives. Conservation becomes a beneficial component of social life when this approach is used. This is why the United States has seen such a large increase in incentives offered. In some cases, this approach forces companies to practice conservation. The neo-liberal approach can be effective, but it requires a significant amount of power to utilize.

2.2 The Function of the Riparian Zone

The riparian zone is the region between the river and the upland. "Riparian vegetation is an important feature of the landscape because it connects terrestrial and aquatic systems and can function as [a] corridor" (Heartsill-Scalley, Aide, 2003). A healthy zone can extend over 50 meters from the water's edge. It serves as a critical piece of the ecosystem because it houses a large diversity of species. The riparian zone also controls flooding, sedimentation, temperature, pollution, and provides water filtration for a region. The riparian zone of the Rio Piedras is displayed in Figure 2.

Figure 2: Rio Piedras Riparian Zone Downstream from the Aqueduct

A healthy riparian zone benefits the ecosystem in many ways. The combination of shade cover and water supply catalyze a large diversity of species. Water run-off enters the riparian zone from lawns, roads, and urban development, and the zone acts as a natural filter to purify the water. Tall trees in the zone contribute to shade cover, which maintains a low temperature at the forest and stream floors. Shade cover prevents growth of grasses, invasive species, and algae.

The wide scale deforestation in Puerto Rico resulted in severe damage to the Rio Piedras watershed. This had a drastic effect on the ecosystem by changing the flow-rates and pathways of surrounding rivers and tributaries. In many regions of the river, urban development has decreased the width of the riparian zone and even reduced them to the river bank. An inadequate riparian zone causes sediment loss, down cutting, nitration, temperature increase, water pollution, and invasive vegetation.

2.3 Riparian Zone Damage

Deforestation exposes the delicate tropical soil to the extreme weather of the environment. Deforested areas of the riparian zone have significantly higher sediment loss than closed canopy forests. The lost sediment comes to rest in the water ways. This in turn causes a loss of bank integrity and increases flood risks by decreasing the river depth. These effects are seen in the Rio Piedras, as it is surrounded by an urban environment that damages its riparian buffer zone. An example of sediment loss and erosion of the Rio Piedras is presented in Figure 3.

Figure 3: Erosion of the Rio Piedras

The urban development has also resulted in the down cutting of the Rio Piedras. Down cutting is the process of sediment removal by large amounts of water. A stream incision created in the river results in the lowering of the groundwater level. The entire ecology of the region is affected, including soil, plants, and microbial processes. The ground water level, which is a major factor in maintaining riparian zone stability, is also changed.

The soil composition has also been greatly affected by land use. The nutrients that once allowed for native species to grow have been depleted and invasive species, which do not require those nutrients, are able to now flourish. The dominance of invasive species is demonstrated in the growth of secondary forests on abandoned agricultural lands.

Chapter 3: Rio Piedras Characteristics

In order to assess the ecological health of the Rio Piedras around the aqueduct complex, we separated the river into zones of similar characteristics. Within each zone, we took soil samples, water samples, and identified the flora. The information allowed our group to make a specific management plan for the Rio Piedras. The following sections are a detailed analysis of each zone's characteristics and health.

3.1 Interval Assessments

The team completed a river health assessment sheet (see Management Plan Appendix I) in thirty-meter intervals, using the aqueduct base as a starting reference point. One interval was measured upstream from the aqueduct while twenty intervals were assessed downstream. In total, forty-two individual assessment sheets were completed, twenty-one for each bank side. The team visually addressed each category. The categories include shade cover, vegetation abundance, algae, bank integrity, continuity from previous zone, and a note section for specific comments corresponding to the interval. The team members collaborated with one another to decide upon the best qualitative descriptor in each section of the evaluation. These data from the assessment sheet were compiled into spreadsheets presented in Table 1 and Table 2. Some categories, such as algae abundance, have little to no change throughout the intervals while vegetation varies.

Table 1: Assessment Sheet Data Compilation Aqueduct Side

Assessment Sheet Data Compilation Aqueduct Side						
Date: 3/25/2009	Completed By: Justin Pollard & Kevin Zabinski			Fideicomiso Conservation Management Plan Data		
Interval Number	Shade Cover	Vegetation	Bank Integrity	Algae	Debris (Human/Natural)	Continuity from Previous Interval
-1	Good	Moderate	Stable	None	Little	Not Similar
1	Less	Less	Solid	None	Little	Not Similar
2	Somewhat	Moderate	Stable	None	Abundant	Not Similar
3	Less	Moderate	Less Stable	Little	Moderate	Similar
4	Good	Full	Less Stable	None	Abundant	Similar
5	Good	Full	Stable	Little	Little	Not Similar
6	Somewhat	Less	Less Stable	Little	Moderate	Not Similar
7	None	Less	Less Stable	Little	Moderate	Very Similar
8	Less	Less	Less Stable	Little	Abundant	Very Similar
9	Less	Less	Unstable	Little	Abundant	Very Similar
10	Less	Less	Unstable	None	Moderate	Very Similar
11	Somewhat	Less	Less Stable	Little	Moderate	Very Similar
12	Somewhat	Moderate	Less Stable	Little	Moderate	Very Similar
13	Somewhat	Moderate	Less Stable	Little	Little	Very Similar
14	Somewhat	Less	Less Stable	None	Moderate	Similar
15	Good	Moderate	Less Stable	Little	Little	Very Similar
16	None	Excessive	Unstable	Little	None	Not Similar
17	Good	Full	Less Stable	None	None	Simlar
18	Good	Full	Less Stable	Little	None	Very Similar
19	Somewhat	Moderate	Unstable	Little	Moderate	Not Similar
20	Somewhat	Moderate	Less Stable	None	Abundant	Simlar

Table 2: Assessment Sheet Data Compilation Urban Side

Assessment Sheet Data Compilation Urban Side						
Date: 3/25/2009	Completed By: Mark Kowaleski and Craig Kennedy			Fideicomiso Conservation Management Plan Data		
Interval Number	Shade Cover	Vegetation	Bank Integrity	Algae	Debris (Human/Natural)	Continuity from Previous Interval
-1	Less	Moderate	Less Stable	Moderate	Little	Very Similar
1	Less	Less	Stable	None	Moderate	Very Similar
2	Somewhat	Full	Stable	Moderate	Excessive	Not Similar
3	Good	Full	Solid	Little	Abundant	Similar
4	Somewhat	Less	Stable	None	Moderate	Very Similar
5	Good	Less	Less Stable	Little	Abundant	Not Similar
6	Less	Less	Less Stable	Moderate	Little	Not Similar
7	Somewhat	Less	Stable	Little	None	Very Similar
8	Less	Moderate	Stable	Little	Moderate	Very Similar
9	Somewhat	Less	Less Stable	Little	Excessive	Very Similar
10	Less	Moderate	Less Stable	Little	Abundant	Similar
11	Somewhat	Less	Stable	Moderate	Abundant	Not Similar
12	Somewhat	Less	Unstable	Little	Abundant	Similar
13	None	Moderate	Less Stable	Moderate	Abundant	Not Similar
14	None	Moderate	Less Stable	Little	Moderate	Very Similar
15	None	Excessive	Stable	Moderate	Little	Very Similar
16	None	Excessive	Unstable	Moderate	Little	Very Similar
17	None	Excessive	Less Stable	Little	Little	Very Similar
18	Somewhat	Full	Less Stable	Moderate	Little	Similar
19	Less	Moderate	Less Stable	Little	Moderate	Similar
20	None	Less	Unstable	Little	Little	Very Similar

The group then analyzed the spreadsheets and arranged the forty-two small intervals into thirteen larger zones as seen in the detailed map of Figure 4. Figure 5 displays a clear outline of the zones and area of the river that was surveyed. The detailed zone breakdown and general characteristics of each zone is seen in Table 3 and Table 4. The created zones are largely based upon the last category of the assessment sheet, "Continuity from Previous Interval". This category allowed the intervals to merge together into continuous zones. Seven zones are located on the aqueduct side of the river while six are located on the urban side. On both sides of the river near the dam, the zones are smaller because the physical appearance varies between intervals. The variance may be due to the presence of the dam, which has altered the riparian zone on the aqueduct side and changed the flow of the river. Further from the dam, intervals are similar enough to create much larger zones.

Table 3: Urban Side Interval to Zone Correlation

Urban Side Interval to Zone Correlation		
Interval Number	**Zone Number**	**Zone Description**
-1	1	Mostly grass and brush with a steep bank
1		
2	2	Human debris, water is slow moving at the start and fast at the end.
3		
4		
5	3	Large trees, no undergrowth, natural debris
6	4	Bamboo covered area with a small riparian zone. Buildings surround the top of the river bank. The bank is steep and eroding with a decent amount of human debris. Little undergrowth.
7		
8		
9		
10		
11	5	Bank is covered with rocks with little undergrowth and bamboo. Buildings present. Large human trash.
12		
13	6	Bank is covered by grass and fern vegetation. There are no trees and no shade cover, the area is significantly warmer. The grass is excessive with very steep banks. Erosion problems present and in interval 20 there is a mesh cover over the bank to slow erosion.
14		
15		
16		
17		
18		
19		
20		

Table 4: Aqueduct Side Interval to Zone Correlation

Aqueduct Side Interval to Zone Correlation		
Interval Number	**Zone Number**	**Zone Description**
-1	7	Bamboo and tree cover. Stable Bank.
1	8	Solid rock wall with bamboo at the top.
2	9	Bank is covered in bamboo and dead bamboo. The bank is eroding with a lot of natural debris. Grass Present.
3		
4		
5	10	A lot of shade cover from thriving bamboo, stable bank
6	11	The zone is mostly covered in fallen and dead bamboo. The bank is mostly steep with a small section that is flatened out. The vegetation is dominantly bamboo with a few scatered trees. Shrubs and grasses were also found in few places. There was a small amount of human debris. Erosion is significantly present.
7		
8		
9		
10		
11		
12		
13		
14		
15		
16	12	Grass and shrubs present with scattered trees. Little bamboo found, with a steep bank. Undergrowth can be found on the bank.
17		
18		
19	13	Good shade cover by the bamboo vegetation. There is little undergrowth present.
20		

Figure 4: Map – Detailed Zone Breakdown

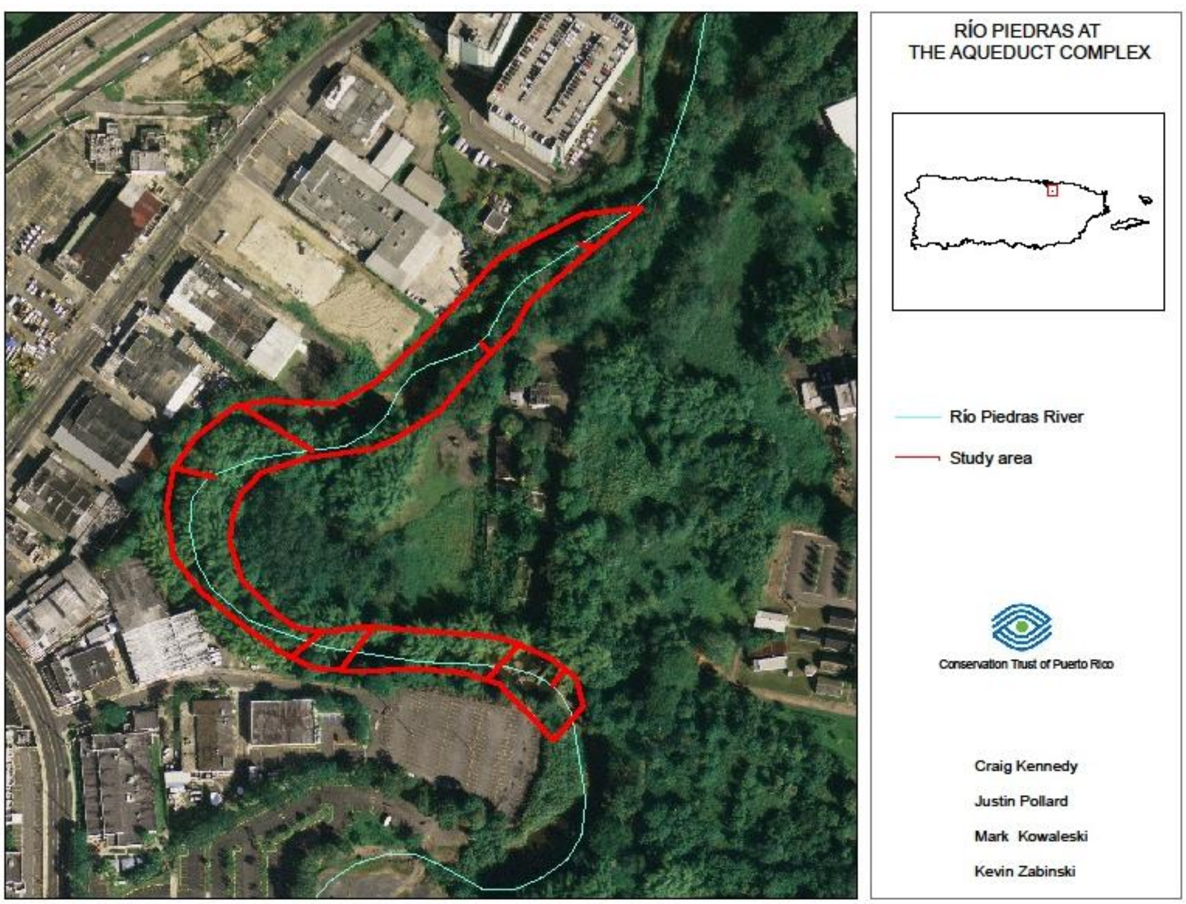


Figure 5: Map – Clear Zone Outline

3.2 Zone 1

Figure 6: Overview of Zone 1

On the urban side, intervals -1 and 1 are grouped together to form the sixty-meter Zone 1. The intervals contain areas of mostly grass and brush as demonstrated in Figure 6. There is relatively little shade cover since there are so few trees. Within the zone, clay, mud, and rock beaches make up the bank, which is steep and eroded. Little human debris is present in either interval other than the debris collection in the water. In the water of Interval 1, a collection of natural debris has created a dam which diverted water flow from its normal path that can be seen in Figure 7.

Figure 7: Natural Dam of Zone 1

Zone 1 houses one tree species, the African Tulip (*Spathodea campanulata*). It also contains a small amount of Papiro (*Cyperus imbricatus*) and an excessive amount of Elephant Grass (*Pennisetum purpureum*). Additionally, the zone holds two species of shrubs, one species of vine, and one species of fern. The shrubbery is abundant and integrated into the grass growth yet not overgrown. *Calopogonium coerulem* is a very abundant vine within the zone, covering many of the eroded bank overhangs. The Helecho (*Thelypteris sp*) is the most visible fern in the area. There are two invasive species within the zone, the African

Tulip tree and Elephant Grass. With just one tree species, Zone 1 consequently has little to no shade cover. To view the abundance and characteristics of species in Zone 1, see Appendix V.

The soil samples from Zone 1 are varied from point to point. The beginning of the zone has a sandy beach with small rocks and loose soil. The soil taken from this point had a high density of 1.722 g/cm^3 but this can be attributed to the rocks in the sample. As the zone progresses downstream, the bank becomes hard packed clay that is very slippery on the surface with a density of 1.244 g/cm^3. The typical density of clay is approximately 1.2 g/cm^3, and this sample is consistent with this value. The clay has many larger rocks within it and is extremely eroded. This clay sample covers a majority of Zone 1, from the start of the aqueduct to approximately fifteen meters after the natural dam. The eroded clay bank is almost vertical and covered by *Calopogonium coerulem* and in places by the Helecho fern, all of which is demonstrated in Figure 8. The complete Soil Density results can be found in Appendix III.

Figure 8: Erosion of Zone 1 and *Calopogonium coerulem* Overhang

The measured water temperature in Zone 1 was 26 ºC with a dissolved oxygen level of 39% O_2. The water's phosphate level was 1 ppm (part per million) and the pH level was 8.25. A healthy pH value is around 7, a neutral value. Therefore a value of 8.25 is slightly basic, but is still decent. The phosphate test in this zone was very good, as a phosphate level of 1ppm is "excellent" while a level of 2 ppm is "good". This indicates that the water is a good source for the vegetation. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is a little lower than the other zones, but the difference is not significant. All zone water quality results can be seen in Appendix II. The overall water quality can be described as fair.

3.3 Zone 2

Intervals 2, 3, and 4 are grouped together to form the ninety-meter Zone 2. There are many trees that have root structures reaching into the river. These trees provide good shade cover for the river bank. The bank was steep and difficult to traverse because of extending roots, dense undergrowth, and moss covered rocks. There is an abundant amount of natural and human debris, but there were no large objects found. This zone distinguishes itself because of its canopy cover and related vegetation, a deeper water level, and the presence of rocks along the bank. The features of the zone can be seen in Figure 9.

Figure 9: Zone 2 at Left

Zone 2 houses eight tree species that range in size from seedlings, to small trees/shrubs, to large canopy cover trees. The African Tulip tree is the major canopy cover contributor, along with the sparsely dispersed Indian Almond tree (*Terminalia catappa).* The remaining six tree species are relatively small consisting of the Yellow Sanders (*Buchenavia tetraphylla*), Santa Maria (*Calophyllum*), Maria (*Calophyllum calaba*), Areca Palm (*Chrysalidocarpus lutescenes*), Guineo (*Musa sp*), and the Rose Apple (*Syzygium jambos*) species. The zone also contains five evenly dispersed shrub species, none of which are particularly abundant. The Metallic Alocasia (*Alocasia plumbea*) and the Blue Day Flower (*Commelina diffusa*) are the significant shrubs, while the Dumb Cane (*Dieffenbachia seguine*), Star of Bethlehem (*Hippobroma longiflora*), and Wild Hops (*Hyptis capitata*) are also present. Zone 2

Figure 10: Invasive Papiro of Zone 2

contains two species of ferns, the Helecho and *Tectaria incise*. The Helecho is the more common of the two, yet is localized to a few areas within Zone 2. The area also holds the very abundant Papiro and Elephant Grasses. The African Tulip and Indian Almond provide good shade cover for the zone, resulting in lower temperatures and better undergrowth at ground level. Zone 2 contains seven invasive species. The Papiro Grass, Elephant Grass, and African Tulip are the major invasive species that play a role in the ecosystem. To view the abundance and characteristics of species in Zone 2, see Appendix VI.

The soil samples from Zone 2 are varied from the upstream to downstream locations. The upstream soil samples reveal a rocky, loose, and large granular soil that is found at the water's edge. Rocks in the sample resulted in a high density of 1.626 g/cm^3. The second sample is medium packed dirt that contains a few roots and no rocks with a density of 1.148 g/cm^3. The third sample is hard packed clay with moss along with a small amount of roots and rocks with a density of 1.052 g/cm^3. The last two samples demonstrate that there is a small root structure below the surface, helping to control the erosion in the zone. Yet, the roots are not large or plentiful enough to stop the erosion problem.

The measured water temperature in Zone 2 was 26 ºC with a dissolved oxygen level of 39% O_2. The water's phosphate level was 2 ppm (part per million) and the pH level was 8.25. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is a little lower than the other zones, but the difference is not significant. The overall water quality can be described as fair.

3.4 Zone 3

Interval 5 makes up Zone 3 because it is a distinct area. The bank is covered by moss and small plant life, making it slippery on top but stable to traverse. A large amount of natural debris is present in the zone, with a small amount of human debris. This zone distinguishes itself because there are large trees and little undergrowth. The typical biodiversity of the zone can be seen in Figure 11.

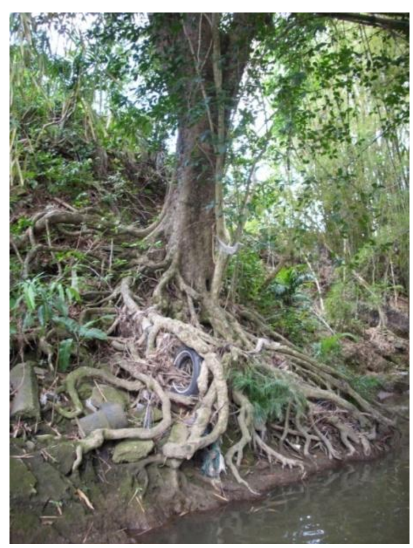


Figure 11: Indian Almond, Sparse Undergrowth, and Tire Debris of Zone 3

Zone 3 houses eight tree species, many of which are small trees or seedlings. The larger tree species that contribute to the shade cover are the African Tulip, Indian Almond, and Indian Padauk (*Pterocarpus indicus*). Though there is a variety of tree species, they are all sparsely located throughout the zone. The fairly abundant Areca Palm is the most populated tree species in the area. Zone 3 also contains Elephant Grass and Papiro grass, both of which do not have a significant presence. *Calopogonium coerulem* also appears within the zone, but is located in a few isolated places. The shade cover within the zone is good because of the large tree species contributing to the canopy. The team found a few seedlings of larger trees which are a good sign that the zone is recovering to help control the erosion and temperature. Zone 3 holds nine invasive species. Although they have a low population, the African Tulip, Indian Almond, Indian Padauk, McArthur Palm (*Ptychosperma macarthurri*), and Areca Palm are the major species contributing to the ecosystem. An example of the rare McArthur Palm and the other vegetation of Zone 3 can be seen in Figure 12. To view the abundance and characteristics of species in Zone 3, see Appendix VII.

Figure 12: McArthur Palm and Zone 3 (Building in Far Background)

The soil samples from Zone 3 are varied from place to place. The first sample, taken from the top of the bank, is a loose soil that contains rocks with a small amount of roots and organic matter. This soil is prone to erosion as there are not enough roots to hold the soil in place. The second sample was taken at the end of the zone and contains hard packed clay that was very slippery. The packed clay contains a few minute roots. The sample exhibits the zone's typical bank close to the water's edge. This type of bank allows for the growth of moss, small shrubs, and small grasses. Consequently, the bank is eroded and very steep. The first sample has a density of 0.765 g/cm^3 while the second sample has a density of

1.244 g/cm^3. The density of the clay is almost double that of the soil sample, demonstrating how tightly packed the bank is in the second half of the zone.

The measured water temperature in Zone 3 was 26 ºC with a dissolved oxygen level of 0% O_2. The water's phosphate level was 2 ppm (part per million) and the pH level was a slightly basic 8. The very low dissolved oxygen level is perhaps due to the slower stagnant water present where the sample was taken. The test is a good indicator that the water is damaged, but the result is not limited to this zone. The phosphate level of 2 ppm is a good level while the pH test shows that the water is at a slightly basic level. The overall water quality can be described as below average.

3.5 Zone 4

Intervals 6, 7, 8, 9, and 10 are grouped together to form the one hundred fifty-meter Zone 4. This zone marks the point where urban development meets the river's riparian zone. Consequently, an excessive amount of human debris characterizes the zone. At the end of the zone, items such as scrap metal, televisions, tires, and a car chassis are present. The canopy cover consists largely of Bamboo, positioned at the peak of the bank where the riparian zone meets a concrete foundation and fence. There are also scattered trees within the zone and little undergrowth. Some of the debris items, erosion, and bank composition can be seen in Figure 13. The resulting weak soil has caused Bamboo trees to upend and they are on

Figure 13: Features of Zone 4

the verge of falling into the river. The moss covered banks are very steep and house various sized rocks. This zone distinguishes itself because it accommodates Bamboo and is surrounded by numerous buildings. These features may be the cause of the severe erosion and urban dumping that also distinguish the zone. Recognizable features can be seen in Figure 14 and Figure 15.

Zone 4 houses seven tree species that range from small trees to large canopy cover species. The large tree species include the fairly abundant African Tulip and the scattered Indian Padauk. These two species provide adequate shade cover within the zone. The smaller species are less frequent and consist of the Angelin Tree (*Andira inermis*), Bottlebrush Tree (*Callistemon citrinus*), White Manjack (*Cordia sulcata*), Guineo, and the Rose Apple tree. Zone 4 also holds six shrubs, of which only Bamboo (*Bambusa vulgaris*) is widely populated in the zone. Bamboo is present at the top of the embankment near the urban development. Additionally the area contains three species of grass, one species of vine, and one species of fern. The grass species are not evenly distributed in Zone 4, as the area does not have much undergrowth. *Calopogonium coerulem* is found throughout the zone, as it hangs from many trees and eroded areas. The Helecho fern is the most abundant species in the zone. Zone 4 possesses seven invasive species. The found invasive species include Metallic Alocasia, Bamboo, Bottlebrush Tree, Elephant Grass, Indian Padauk, African Tulip, and the Guineo. To view the abundance and characteristics of species in Zone 4, see Appendix VIII.

Figure 14: View of Zone 4 from Aqueduct Side, Building and Fence Present

The soil samples from Zone 4 were taken at the beginning and end of the zone. Both samples reveal a very fine loose granule containing many roots. The roots vary in size and are all intertwined. Although the first sample has a lower density, 0.765 g/cm^3, than the second sample, 1.244 g/cm^3, the first sample has more roots than the second sample. A greater amount of roots allows less space for dirt resulting in a low density because roots weight less than dirt. Although the samples were taken from a steep slope, the presence of numerous roots is a positive aspect. The vegetation in the area has spread enough roots to create a solid bank, which can hold the nutrient rich topsoil. This results in more plant growth, creating a better root structure and increasing the ability for the bank to resist future erosion.

Figure 15: Zone 4 River Bank and Building

The measured water temperature in Zone 4 was 27 ºC with a dissolved oxygen level of 39% O_2. The water's phosphate level was 2 ppm (part per million) and the pH level was 7.5. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is a little lower than the other zones, but the difference is not significant. The phosphate level is noteworthy, allowing for good plant growth. The overall water quality for the zone can be described as fair.

3.6 Zone 5

Intervals 11 and 12 are grouped together to form the sixty-meter Zone 5. This zone has a steep bank composed of many large rocks, limiting the vegetation in the area. There are various trees at the top of the bank providing somewhat good shade, but there is no vegetation alongside the river. The zone also holds a lot of human debris, originating from the urban development at the edge of the riparian zone. The border of the zone is fenced in with numerous buildings at the top. The width of the riparian zone is noticeably small because the buildings are at the peak of

Figure 16: Zone 5 Rock Bank and Urban Development

the rock bank. This zone distinguishes itself because it has a rock embankment, close bordering urban development, no undergrowth, and large trees at the bank peak. Figure 16 and Figure 17 present the rock embankment of Zone 5, its main distinguishing feature.

Zone 5 houses six tree species that range in size from seedlings to large trees. There are four species that contribute to the good shade cover in the area. These species are the African Tulip, Indian Padauk, Tall Albizia (*Albizia procera*), and the Puerto Rican Royal Palm (*Roystonea borinquena*). The two smaller species found are the Santa Maria and Escoba Colorada (*Sida rhimbifolia*). Of the tree species, the African Tulip is widespread while the five other species are sparsely found. Zone 5 also holds Wild Hops and Castor Beans shrub species, both of which thinly populate the area. The area also contains two grass species, one vine species, and one fern species. Dense and tall Elephant Grass can be found at the downstream end of the zone. *Calopogonium coerulem* is fairly abundant, hanging from the larger trees at the top of the river bank. The Helecho fern populates the area where rocks are not present. Six of the twelve species found in the zone are invasive. They include the Tall Albizia, Papiro (*Cyperus involucratus*), Elephant Grass, Indian Padauk, Castor Bean, and African Tulip. The African Tulip is the most abundant of the invasive species, but it provides the most shade cover and bank stability to the zone. To view the abundance and characteristics of species in Zone 5, see Appendix IX.

Figure 17: Rock Embankment of Zone 5

The team was only able to take one soil sample from Zone 5 because of the rock embankment. The sample was taken in between two rocks and displays a clay consistency and a density of 1.435 g/cm^3. The hard packed clay displayed no roots or organic matter. This result demonstrates that the rock embankment damages the surrounding soil because the rocks create channels of fast moving runoff. These channels do not allow top soil to deposit. This combination of rocks and hard packed clay is unable to sustain life that will help the erosion problems.

The measured water temperature in Zone 5 was 28ºC with a dissolved oxygen level of 42% O_2. The water's phosphate level was 1 ppm (part per million) and the pH level was 8. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is slightly higher than the other zones, but the difference is not significant. The overall water quality can be described as fair.

3.7 Zone 6

Intervals 13-20 are grouped together to form the two hundred forty-meter long Zone 6, the largest and final zone of the urban side. The steep bank is totally covered by tall grasses and ferns, represented in Figure 18. There are scattered trees at the outer extents of the riparian zone, but they offer no shade cover for the river. There is loose sediment in the riverbed, resulting in deep mud. In Intervals 19 and 20, there is an erosion guard (mesh fence) covering the steep grade with vegetation growing through the holes. There is a fence and parking lot less than ten meters from the river's edge in these two intervals. The zone has little human or natural debris due to the barrier of excessive grasses. Our group also witnessed a stream of dirty runoff coming from one of the buildings into the river. This zone distinguishes itself because of the excessive grasses, lack of shade, and noticeable erosion. Examples of the zone characteristics are shown in Figure 19.

Figure 18: Typical Bank of Zone 6

Zone 6 houses five tree species, all of which sparsely inhabit the area. Tree species found are the Tall Albizia, Bottlebrush Tree, Guineo, African Tulip, and Triplaris (*Triplaris cumingiana*). Since the population of each species is so low, there is little to no shade cover in the zone. The only abundant tree species is the Guineo. The low frequency of trees results in a large quantity of undergrowth vegetation. This is displayed by the twelve shrub species, two vine species, and two grass species. Of the twelve shrub species, the Metallic Alocasia, Blue Day Flower, Wild Hops, and Cast Bean are the prevalent species. The two vines, *Calopogonium coerulem* and the Bejucco de Castillo (*Paullinia pinnata*), are equally distributed throughout the zone. Elephant Grass is the main distinguishing feature of the zone; it is extremely dense and tall, as seen in Figure 20. This makes it difficult for young trees to initially grow as the sun light is blocked by the grass. There are eleven invasive species in Zone 6. The invasive species include the Tall Albizia, Metallic Alocasia, Bottlesbrush tree, Volantines Preciosos (*Cleome speciosa*), Papiro (*Cyperus involucratus*), Elephant Grass, Castor Bean, African Tulip, Triplaris, and Rabo de Buey (*Vernonia cinerea*), and the Guineo. To view the abundance and characteristics of species in Zone 6, see Appendix X.

Figure 19: Parking Lot and Eroded Tree of Zone 6

Figure 20: Excessive Elephant Grass of Zone 6

The two soil samples that were taken from Zone 6 vary widely in consistency but have the same density 1.339 g/ cm3. The first sample is a moss covered hard packed clay. The soil contains few roots. The second sample was taken from a rocky beach at the end of the zone.

The sample consisted of large golf ball like rocks to small granule of sand. Although they have the same density, the density of the second sample can be neglected because of the heavy rocks.

Figure 21: Fence and Thin Riparian Zone of Zone 6

The measured water temperature in Zone 6 was 27ºC with a dissolved oxygen level of 41% O_2. The water's phosphate level was 1 ppm (part per million) and the pH level was 7.75. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is slightly higher than the other zones, but the difference is not significant. The water temperature of Zone 6 is higher than the upstream zones due to the sparse shade cover as seen in Figure 21. The overall water quality can be described as fair.

3.8 Zone 7

On the side adjacent to the aqueduct, interval -1 makes up the thirty-meter Zone 7. This zone has moderate vegetation and a good amount of undergrowth. Tall Bamboo and various trees provide good shade cover for the bank and river. Only a small amount of natural debris is present in the zone. The bank is stable enough to walk on yet it is at

Figure 22: Extreme Grade near the Aqueduct of Zone 7

a steep angle. As the zone approaches to aqueduct, the grading becomes very extreme as presented in Figure 22. This zone distinguishes itself because it has good canopy cover and the abundant presence of trees and shrubs.

Zone 7 houses five tree species, four of which are native to Puerto Rico. This zone has complete canopy cover due to the large density of trees varying in heights due to difference in aging. No significant undergrowth is present, but there is an excessive amount of tree shrubs located throughout the zone. Other than Bamboo, the other prevalent species is *Guarea guidonia*, or Muskwood. Wild coffee (*Casearia guianesis)*, Jagua Box Genip (*Genipa americana)*, and Muskwood are solely present in Zone 7. This is likely due to the aqueduct rock wall that spans thirty meters and separates the zone from other vegetation. The lone invasive species is the abundant Common Bamboo. To view the abundance and characteristics of species in Zone 7, see Appendix XI.

Figure 23: End of Zone 7 at the Aqueduct

The soil samples from Zone 7 were taken in the first and last half of the zone. Both samples consist of hard packed clay and contain few roots. These samples explain why the erosion problem is not very prevalent in this zone. The two measured soil densities are 1.244 g/cm^3 and 1.435 g/cm^3. This density is comparatively greater than the other densities along the aqueduct side of the river. This demonstrates that there is a correlation between soil densities and erosion problems.

The measured water temperature in Zone 7 was 26ºC with a dissolved oxygen level of 0% O_2. The water's phosphate level was 1 ppm (part per million) and the pH level was 8.25. The water results of the zone are of less quality than other rivers in the San Juan area. The dissolved oxygen level is very low due to the stagnant water. One positive aspect was that the water temperature was low, as the area has abundant shade cover. The overall water quality can be described as below average.

3.9 Zone 8

Interval 1 makes up the thirty-meter long Zone 8. This zone houses the rock wall which is part of the dam as shown in Figure 24. At the top of the wall at the end of the zone, there is a cluster of Bamboo, but no other noticeable vegetation. The zone has only little human debris such as bathing suits and containers. This zone is distinguished by the large rock wall and lack of vegetation.

Zone 8 houses only three invasive species. There is only a small patch of vegetation at the peak of the bank following the rock wall that makes up most of the zone. The vegetation patch in Zone 8 is comprised of mostly Bamboo, while younger tree species are also present. The small patch contains Bamboo, *Citrus sp* (tree species), and an African Tulip. The concrete and rock wall of the aqueduct prevents the growth of vegetation. Furthermore, the feature prevented the team from taking soil samples. To view the abundance and characteristics of species in Zone 8, see Appendix XII.

Figure 24: Aqueduct Concrete Wall of Zone 8

The measured water temperature in Zone 8 was 25ºC with a dissolved oxygen level of 0% O_2. The water's phosphate level was 2ppm (part per million) and the pH level was 8. The water results of the zone are of less quality than other rivers in the San Juan area. The dissolved oxygen level is very low due to the stagnant water caused by the dam. The overall water quality can be described as below average.

3.10 Zone 9

Intervals 2, 3, and 4 make up the ninety-meter Zone 9. The vegetation is moderate, and it is made up mostly of Bamboo and small amounts of grass. There is also a lot of natural debris from the

Figure 25: Erosion with Zone 9

fallen dead Bamboo. However, the Bamboo provides good shade cover for the bank. The bank ranges from stable at some points to unstable at others. The excessive Bamboo has prevented the natural growth pattern of native species and has not controlled the erosion within the zone as seen in Figure 25. This zone distinguishes itself because of the presence of Bamboo and grasses.

Zone 9 houses a twelve different species. There are five tree species, the most abundant being the Palo Pelado (*Gonzalagunia hirsute*) and the African Tulip. This is the only zone where the Palo Pelado appears. These tree species provide little shade cover for the area, as Bamboo supplies a bulk of the temperature control. There are two species of shrubs, the most common being Bamboo and the other being Castor Bean. There are two vine species, two grass species, and one fern species. Both of the vine species, *Calopogonium coerulem* and the Terciopelo (*Congea tomentosa*), are abundant and found intertwined in the trees. *Calopogonium coerulem* is native while the Terciopelo is invasive and only exists in this zone. The invasive Papiro (*Cyperus involucratus*) is moderately abundant and found on the water's edge. One section of the zone is a large patch limited to tall Elephant Grass. This patch containing the Elephant Grass has no shade cover besides at the bank peak. To view the abundance and characteristics of species in Zone 9, see Appendix XIII.

Figure 26: Bamboo Cluster and Erosion in Zone 9

The soil samples for this zone were taken at the beginning and last half of the zone. The first sample in the beginning of the zone reveals a density of 1.244 g/cm$^{3.}$ This sample is medium packed soil made of mixed dirt and clay with many large roots. The second sample, taken from the end of the zone, resulted in a density of 1.052 g/cm$^{3.}$ This soil was hard packed clay with numerous large roots. The presence of roots stabilizes the bank and helps to prevent erosion in parts of the zone. However, there are still locations where erosion is prevalent. In these areas, there is not a diverse set of species. For example, one of the clusters of Bamboo is in an area where severe erosion is visible. An example of a Bamboo cluster within the zone is presented in Figure 26.

The measured water temperature in Zone 9 was 26ºC with a dissolved oxygen level of 39% O_2. The water's phosphate level was 2 ppm and the pH level was 8.25. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is somewhat lower than the average, but the difference is not significant. The phosphate level is noteworthy, allowing for good plant growth. The overall water quality can be described as fair.

3.11 Zone 10

Interval 5 makes up the thirty-meter Zone 10. In this zone, the vegetation is limited to Bamboo, but it provides good shade cover to the bank. Erosion is present in many places, yet the bank is fairly stable to walk on. The only debris in the zone is fallen and dying Bamboo. An example of the falling, dying, and excessive Bamboo is seen in Figure 27. This zone distinguishes itself because Bamboo is the lone species within the area.

Figure 27: Falling, Dying, and Excessive Bamboo of Zone 10

The large amount of Bamboo gives a good amount of shade cover. However, the excessive Bamboo growth and lack of biodiversity in the zone lead to erosion problems. The dead Bamboo prevents further growth of other vegetation that can control the sedimentation. The fallen Bamboo also uproots and breaks up the soil, causing further erosion issues. To view the abundance and characteristics of species in Zone 10, see Appendix XIV.

The soil samples in this zone range in density and composition. The sample taken from the beginning of the zone has a density of 0.765 g/cm^{3}. This soil is medium packed with few roots. Before the drying process, the sample was extremely muddy and foul smelling. The mass was measured light because the mass of the liquid was removed during drying. The Bamboo is not near the river's edge, which is why the sample collected consists solely of mud. The sample taken at the end of the zone has a density of 1.148 g/cm^{3}. This sample is hard packed with roots and a lot of organic matter.

The measured water temperature in Zone 10 was 27ºC with a dissolved oxygen level of 41% O_2. The water's phosphate level was 2 ppm and the pH level was 7. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is at the average for the river. The phosphate level is noteworthy, allowing for good plant growth. The pH level is neutral, showing there is little pollution in the area. The overall water quality can be described as above average for the region.

3.12 Zone 11

Intervals 6 through 15 make up the three hundred-meter Zone 11. This is the largest zone on either side of the river. The vegetation consists of frequent Bamboo and scattered trees, which all combined contribute fair shade cover for the zone. Some areas have grasses and undergrowth. Throughout the zone, fallen Bamboo lies on the bank along with a small amount of human debris. A majority of the bank is steep, although there is a section where the bank's grade is suitable. In this area, the riparian zone stretches for over thirty meters away from the water's edge. This section can be seen in Figure 28. This zone distinguishes itself because it has Bamboo, scattered trees, and a wide riparian zone.

Figure 28: Large Riparian Zone of Zone 11

Zone 11 houses a large diversity of species, containing nineteen in a three hundred-meter stretch. There are seven tree species within the area. The large diversity of trees and Bamboo provide good shade cover for the bank and river. There are nine shrub species, two fern species, and one grass species. The abundant species include Bamboo, Metallic Alocasia, Blue Day Flower, Guaba (*Inga vera*), Elephant Grass, African Tulip, Indian Almond, and

Figure 29: Bamboo Debris of Zone 11

Helecho. These species are ubiquitous in the zone, creating a good biodiversity. There are also several other species in the zone that are not found in other zones. Zone 11 has nine invasive species. They include the Metalic Alocasia, Bamboo, Areca Palm, Common Dracaena, Elephant Grass, Castor Bean, *Sanchezia speciosa*, African Tulip, and Indian Almond. To view the abundance and characteristics of species in Zone 11, see Appendix XV.

Due to the length of the zone, the team took four soil samples. The first sample has a density of 1.244 g/cm^3. The sample is hard packed, with light moss cover and a few roots. The second sample has a density of 1.052 g/cm^3. The sample is hard packed clay, containing few roots. The third sample had a density of 1.148 g/cm^3. The sample is hard packed with moss and lichen. There were also good roots ranging in all sizes. The fourth and final sample has a density of 0.478 g/cm^3. This was much lower than any other sample because it was loose packed soil containing mostly organic matter. The dead Bamboo creates a compost pile of dead leaves which has poor bank integrity. The dying and dead Bamboo can be seen in Figure 30.

The measured water temperature in Zone 10 was 27ºC with a dissolved oxygen level of 42% O_2. The water's phosphate level was 1 ppm and the pH level was 8. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is at the average for the river. The overall water quality can be described as fair for the region.

3.13 Zone 12

Intervals 16, 17, and 18 make up the ninety-meter Zone 12. The vegetation is full and consists of grasses and shrubs with few scattered trees. The scattered trees provide shade cover which varies from good to poor for the bank. Compared to the previous zones, there is a lot less Bamboo present. Generally the banks are

Figure 30: Team Member within Zone 12

stable with a good grade, but in places the grading is sheer. The decent grade within Zone 12 can be seen in Figure 30. There is no human or natural debris in any part of the zone. This zone distinguishes itself because there is comparatively little Bamboo and no human debris.

Zone 12 houses five species of trees, but only one of the species is native. The most abundant species are the African Tulip and the native Guaba. There are also three species of shrubs, including Bamboo and the abundant Metallic Alocasia. The Bamboo along with the tree species supply good shade cover for the top of the zone. However, most of the shade cover at the bank is provided by the Indian Almond species. The only shrub species is the native Ortiga (*Urera baccifera*). The only vine species is the Taro vine (*Epipremnum aureum*), which is only present in Zone 12. Elephant Grass is the only grass species found in the zone, and it is moderately abundant. The grass was primarily located lower on the bank where there was no shade cover from tree species. The abundant grass on the bank is providing resistance to erosion, but larger tree root structures would benefit the bank integrity in these areas. Of the ten species within the zone, eight are invasive. The invasive species are the Tall Albizia, Metallic Alocasia, Bamboo, Taro Vine, Guineo, Elephant Grass, African Tulip, and Indian Almond. The various tree species can be seen in Figure 31. To view the abundance and characteristics of species in Zone 12, see Appendix XVI.

Figure 31: Various Trees of Zone 12

The first soil sample had a density of 1.052 g/cm^3. It was hard packed clay that contained some organic matter and roots. The second sample produced a density of 1.244 g/cm^3. This sample was medium packed clay covered in moss and contained few roots. Both of the samples contain roots, which is a good byproduct of the diverse zone. The tree, shrub, and grass species all contribute to the roots found in the sample. The area has one of the most stable banks of any of the zones located on the aqueduct side.

The measured water temperature in Zone 12 was 27ºC with a dissolved oxygen level of 41% O_2. The water's phosphate level was 1 ppm and the pH level was 7.5. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is at the average for the river. Zone 12 continues the trend that the further downstream the group traveled, the temperatures increased. The overall water quality can be described as fair for the region.

3.14 Zone 13

Intervals 19 and 20 make up the sixty-meter Zone 13. The vegetation is moderate throughout and consists mostly of Bamboo with little undergrowth. The Bamboo provides fair shade cover for the bank. There is large amount of Bamboo debris present in this zone as shown in Figure 32. The bank integrity is unstable and erosion is present. This zone distinguishes itself because of the large amount of Bamboo present.

Figure 32: Fallen Debris of Zone 13

Zone 13 houses three species of trees, two of which are native. The two native trees, the Escoba Colorada and Maga (*Thespesia grandiflora*) are both more prevalent than the invasive Triplaris. These species give good shade cover to the zone, but a large contribution is also given by Bamboo. Two other abundant species of shrubs are Metallic Alocasia and Higuillo (*Piper hispidum*). Two abundant vine species which are native and located in Zone 13 are *Calopogonium coerulem* and Puerto Rican Hemp Vine (*Mikania*). The vines are demonstrated in Figure 34 to display the abundance within the area. The only grass species found in the zone is the moderately abundant and invasive Papiro (*Cyperus involucratus*). To view the abundance and characteristics of species in Zone 13, see Appendix XVII.

Figure 33: Vines within Zone 13

The two soil samples from Zone 13 contain drastically different characteristics. The first sample had a density of 1.244 g/cm^3. It was hard packed clay, covered in moss, and it contained few roots. The second sample had a density of 2.296 g/cm^3. This sample consisted mostly of small rocks and sand. The large amount of rocks gave a high density reading. The sample was taken at this location because there was no alternative location in the second half of the zone. At the sample location, the rock and sand mixture likely comes from upstream.

The measured water temperature in Zone 13 was 27ºC with a dissolved oxygen level of 41% O_2. The water's phosphate level was 1 ppm (part per million) and the pH level was 8. The water results of the zone are quite typical of rivers in the San Juan area. The dissolved oxygen level is at the average for the river. Zone 13 continues the trend of increasing downstream temperatures resulting from less shade cover. The overall water quality can be described as fair for the region.

Chapter 4: Recommendations and Conclusions

Our team's project goal was to create a conservation management plan for the Rio Piedras in the area of the aqueduct complex. Our project group completed our objectives and analyzed the results. The following sections include a compilation of the data, our analysis, and our recommendations for the river. We believe The Trust will utilize these recommendations in order to conserve and restore the Rio Piedras.

4.1 Conservation Approach

We recommend Fideicomiso implement aspects of all three conservation approaches to successfully bring back the beauty of the Rio Piedras and its ecological surroundings. So far, the classic approach has been utilized by The Trust. The site is currently closed to the public, and little access is granted to prevent further damage to the region.

Using the classic approach, The Trust should continue to expand the buffer zone by removing urban features between the river and the urban development. Also, The Trust should monitor the premises and implement fines for dumping and trespassing violations. Funding and policies will come from The Trust and organizations funding the restoration. Utilizing the populist approach, local residents and organizations that agree with The Trust's mission should become involved in the project. These groups of people likely have the passion for restoring the beauty of the Rio Piedras and the creative ideas to support the restoration project. In addition, the people could supply knowledge on the local ecosystem. The community can contribute valuable volunteer work in the river. Finally, we recommend The Trust adopt aspects of the neo-liberal approach by offering economic incentives to those who help the project. A number of organizations, such as those bordering the river, have the ability to affect the state of its environment. The Trust can prevent their abuse of the region by getting them economically motivated. These organizations are also stakeholders because they might benefit from a future public site.

4.2 Buffer Zone Expansion

The riparian zone of the Rio Piedras has a narrow width in many areas along the aqueduct complex. The team recommends the expansion of the riparian zone in order to restore the ecological health of the river. Ideally, a buffer zone of a minimum twenty-five meters would greatly aid the recovery. In many places, this will be a very difficult task because of the buildings on the urban side and the basin walls on the aqueduct side. Some of the buildings on the urban side will make the expansion impossible unless they are demolished. If demolition of urban features is not feasible, then the team recommends talking to the owners about a possibility of moving fences back for better use of the land. By utilizing the populist approach, Fideicomiso should educate the owners about the importance of the restoration site. Furthermore, they should inform the owners that their actions are directly affecting the restoration process. This could be accomplished by organizing a meeting of the surrounding business owners and residents with The Trust to explain the project and to hear feedback. At the same time, The Trust can employ the neo-liberal approach by offering economic incentives to the building owners. Fideicomiso could offer monetary rewards to the people if they allow buffer zone expansion on their land. They could also give money to business owners for them to restore or improve the property themselves.

When expanding the buffer zone, Fideicomiso should take down the fencing and other features. Where expansion is feasible, the grading issues of the Rio Piedras should also be addressed. This will help with erosion and flooding while allowing improved growth of vegetation. "The slope of the bank and its material composition will affect the speed and form the erosion will take" (Riverbank Conservation Ltd., 2009). The grade is a key source of many negative aspects of the river, especially in the case of the Rio Piedras.

However, fixing the river-bank grade problem is a highly complex process. If done incorrectly, there could be severe effects downstream or the bank could become more damaged. This creates liability for the planners and dangers for downstream landowners and businesses (Riverbank Conservation Ltd, 2009). The process would involve an in depth investigation of the bank's current state, research on methods to fix it, contact with downstream residents and businesses, and a large amount of funding to support the plan. Some of the most important factors to consider will be the urban features surrounding the riparian zone. They both create the erosion problems and provide little room to improve bank grades without a buffer zone

At the outer extents of the zone, the team advises the implementation of a new fence system (details about the system in the Debris Recommendations). This will create a large and definitive boundary for the Rio Piedras at the aqueduct complex. Within the buffer zone, native plants and shrubs should be planted. The vegetation should be relatively thick at the outer extents, incorporating the tiered vegetation system (details in Erosion Recommendations). The buffer zone will restore filtration, sedimentation, erosion control, temperature control, and the hydrologic cycle.

4.3 Erosion Recommendations

Urban Side

Our observations reveal excessive erosion in a majority of areas in the Rio Piedras. On the urban bank side, the team suggests a removal of the urban features. Although it will be difficult, the removal of the current fences, pavement, rock walls, and other features will allow the riparian zone to expand. In areas where pavement and fences are present, the erosion is more significant. These features are preventing the water from absorbing into the ground, thus the water runs over the bank and pushes sediment into the river. Our team recommends that Fideicomiso takes steps to replace the pavement of the parking lot, nearby access roads, and driveways with water permeable surfaces such as gravel and cobblestone. An example of a water permeable parking lot is presented in Figure 34, a view of Fideicomiso's tree nursery parking lot. Fideicomiso can accomplish this by using the neo-liberal approach. The Trust can offer to pay for the demolition of the current pavement and the construction of the new surface. This recommendation will not affect the how the land is used, but will greatly improve the watershed. These actions will allow the water to seep into the ground to reduce run-off, thus preventing erosion. The water will also be filtered by the ground and rocks, decreasing the ground water pollution.

Figure 34: Water Permeable Parking Lot

In addition, our team recommends the removal of damaged and fallen Bamboo throughout the urban side. The uprooted Bamboo reveals loose sediment to the elements, which in turn erodes the bank. The removal of Bamboo will also allow other native species to be incorporated into the landscape, increasing its aesthetic appeal and natural diversity.

To slow and control erosion along the river, a tiered native vegetation system should be planted. Along the water's edge, the first layer of vegetation includes larger trees with strong roots. These species ought to be planted to hold the bank firm and help with filtration. Behind and incorporated into the layer of trees, larger bushes shrubs, and small trees should be placed into the ground. Beyond that layer, grasses, ferns, and other undergrowth will fill in the rest of the gaps until reaching the urban area border. This system will help stop erosion and bring the riparian zone back to a more controlled, natural state. The tiered vegetation system is seen in the sketch of Figure 35. For details on which species should be planted, reference the Flora Recommendations of this document.

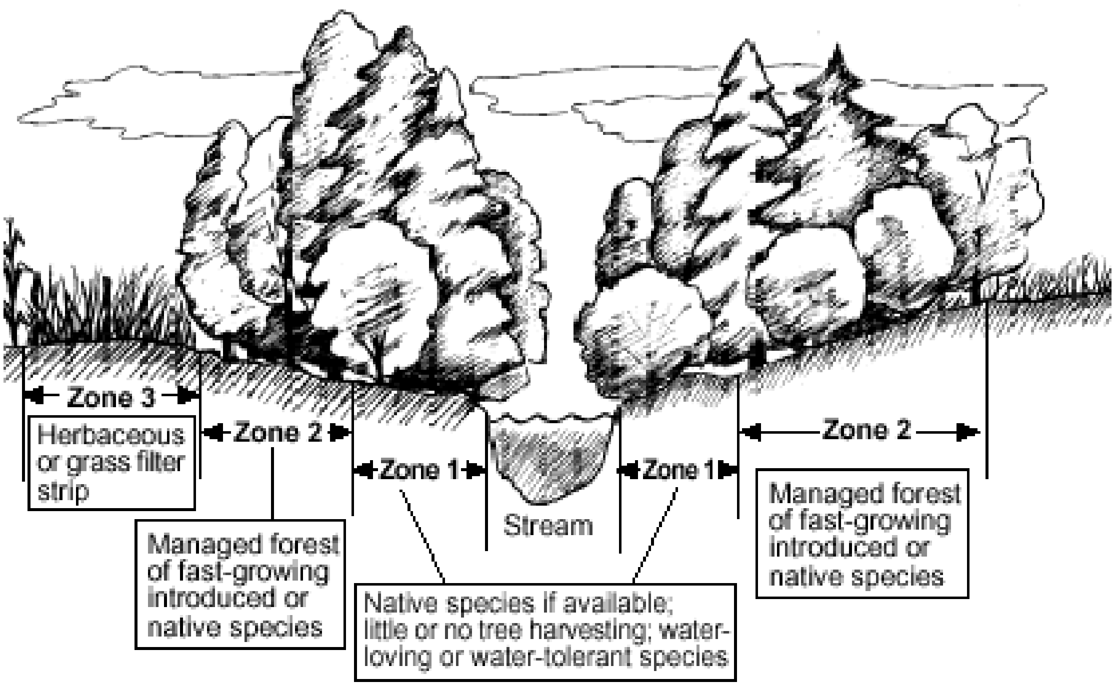


Figure 35: Tiered Vegetation System Sketch (http://cstaf.ifas.ufl.edu/ripari2.gif)

In addition to removing the urban features, our team recommends the removal of the rock embankment in Zone 5. The rocks are channeling run-off resulting in poor filtration and sparse vegetation in areas of no rocks. The removal of rocks will reveal soil that should be planted with native species. Additional soil may need to be added where the rocks have been removed. The added soil should be a rich planting mix that is able to fill in the resulting holes.

Many large trees and undergrowth will help stabilize the bank, filter the water, and slowly fix the steep grade of the bank. The root structure of the newly planted vegetation will help hold the soil together and prevent an additional loss of soil to erosion. For a temporary solution, a geo-textile net or cloth can be placed on the bare soil immediately after the new vegetation has been planted. This will stop erosion until the plants can develop a strong enough root structure to hold the bank together. The geo-textile net will be biodegradable and after a few years will be unnoticeable to any bystander.

Within Zone 6 there is an excessive growth of grasses, ferns, and other undergrowth on the eroded embankment. While this vegetation does provide erosion control, it is not maximizing the potential of the bank integrity. The poor root structure of this vegetation cannot contain sediment during floods and rains. Although they slow the process, they allow a great deal of erosion. To improve this, larger trees and shrubs should be planted along the river because of their firmer and deeper root structure. This will also help the lack of shade cover in the area, as the temperature of the water is higher than the other zones.

Aqueduct Side

A large amount of fallen Bamboo debris prevents the growth of any other species from occurring. Our team recommends the removal of Bamboo debris and the thinning of living Bamboo in the area. Once the Bamboo is cleared and thinned, we suggest that the Bamboo growth is controlled and maintained to prevent the excessive spread of the species. We also recommend that native shrubs, grasses, and trees be introduced to these regions, in the tiered method, where the fallen Bamboo has prevented such growth. The grasses and shrubs will help filter the runoff, and the trees will provide shade cover for the bank. This will help maintain the bank integrity of the river and allow a diverse set of species to thrive. Details on suggested species can be seen in the Flora Recommendations section.

4.4 Debris Recommendations

Our team discovered a large amount of dumping along the river's riparian zone. There were many large items found including a car chassis, refrigerator, engine blocks, many tires, clothing, and televisions. We recommend The Trust utilize the populist approach by getting the local community involved with a river cleanup to remove garbage and some of the natural debris. This event should be conducted annually or biannually since human and natural debris will continue to accumulate. One option is to use a company such as American Rivers, who sponsored the National River Clean Up. They can help organize the event as well as provide free trash bags and supplies. The University of Puerto Rico would also be a great source of volunteers to get involved in the cleanup project. There is great opportunity for community service for students, community members, and volunteer programs. After people become involved in the restoration, they are less likely to abuse the river in the future. Another more expensive option would be to hire a company to conduct the cleanup. This would involve less planning on The Trust's part and ensures that the job will be completed to satisfaction.

Zone 1 contains a large natural dam spanning the river. The dam was created by floating debris and garbage. The team advises Fideicomiso to remove the debris and the refrigerator (within the dam) from the water's path. The removal will allow aquatic life to once again travel downstream in an uninterrupted path. In the area of Zone 4 a car chassis can be found within the river. In order to remove this, our team recommends cutting it into smaller pieces and removing it section by section. A second option would be to have a crane come to the edge of the riparian zone and lift it out. However this would be expensive and difficult because of the overhanging Bamboo and overgrowth. In the area of Zone 12, a large tire can be found in the water. This will need to be eradicated using the same process as the car chassis. There are also many tires within the water and under the surface that need to be taken out.

In order to alleviate the trash problem, the team recommends the building of an improved fence system that is further from the river, extending the riparian zone. Ideally, a distance of twenty-five meters from the river is advised, although in places this will be very difficult. The updated fence system should address the current issues of gaps and holes that have been cut in order to prevent dumping. The team suggests building a continuous heavy-duty barbed wire chain link fence of a taller height (approximately three meters). The improved fence system should also include motion sensor lights and cameras to drive away vandals and polluters during the night hours. Our team urges Fideicomiso to incorporate signage that displays the presence of cameras and sensors while also presenting the consequences of trash dumping. Additional signage exhibiting the site restoration should also be placed on the fence to discourage pollution. These signs should be creative, displaying phrases such as "Dumping Trash Prevents Current River Restoration". Example signage can be seen in Figure 36. The next step in the proposal for the fence system is to integrate native vines and natural vegetation on the inside border of the fence and onto the fence itself. This will increase the natural aesthetic of the area in order to bring visual natural value to the land. The

Figure 36: Example Restoration Site Signage (http://www.co.clatsop.or.us/Assets/Dept_8/Images/real%20sign.jpg)

final step in the process would be to place trash barrels along the length of the fence on the side of the buildings. These efforts should help to reduce the trash and major dumping found in many zones on the urban side.

4.5 Flora

With the completion of the flora identification, our group discovered 64 different species throughout the zones. Our group commented on the abundance of the species in each zone and an overall abundance for the river. Each species was given a ranking of "+++" for widespread, "++" for localized, and "+" for sparse abundance in the riparian zone. The overall species identification spreadsheet can be found in Appendix IV and a complete list of flora with picture identification can be located in Appendix XVIII. The river contains six species that received an abundance grade of "+++", five of which are invasive species. The localized category (++) had five species while the sparsely (+) abundant category held fifty five species. The following section contains a summary of these widespread plants characteristics and our recommendations concerning them. We focused on these widespread species because they have the biggest impact in the river's ecosystem. Our group used information from the USDA Plant Database and the work done by John Francis to form our recommendations and analysis.

4.5.1 Existing Flora

Bambusa vulgaris (Common Bamboo) is an invasive species from south Asia and is found in Zone 4 and Zones 7 through 13 of the river. This is the most abundant plant on the aqueduct side, especially in Zone 10 where it is the lone species found. Bamboo is most known for its extremely fast growth rate and its cluster growth pattern. It can grow to a height of 16 meters and has an average root depth of 0.6 meters. The clusters of Bamboo create a complex matrix of roots that helps prevent erosion. Bamboo is able to grow in any soil type and in a wide range of pH values making it an adaptable plant. It has the ability to thrive in any circumstance which is why it is so widespread throughout the river. However, it disrupts and kills competing plants because it grows quickly and blocks sunlight. Although Bamboo does help with erosion, The Trust should control the spread of the species. Additionally, we recommend the removal of the dead Bamboo debris that

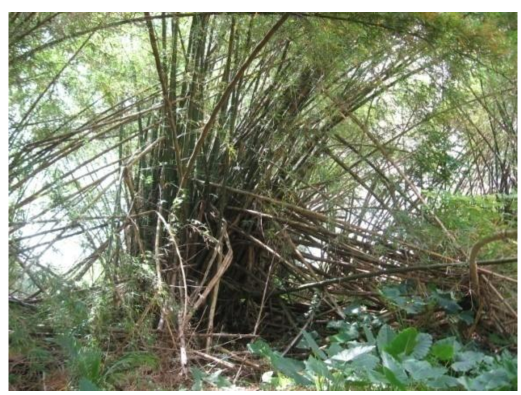


Figure 37: *Bambusa vulgaris*

is found in clusters, allowing other native species to grow. A typical Bamboo cluster is seen in Figure 37.

Calopogonium coeruleum is a native perennial legume vine, found in all six zones on the urban side. *Calopoginum coeruleum* is also found in Zones 9 and 13 on the aqueduct side. It was found growing across the ground as well as growing up surrounding trees. It will sprout roots any time it comes in contact with moist soil. *Calopogonium coeruleum* can grow in a wide variety of soil types and prefers a low pH. One of its main characteristic is the ability to smother weeds that are trying to grow. Therefore, our team suggests that Fideicomiso allow the vine to grow undisturbed because it can alter the weed growth. A typical occurrence of the species is seen in Figure 38.

Figure 38: *Calopogonium coeruleum*

Cyperus involucratus (Papiro) is an invasive grass species originating from Africa. It is found on the aqueduct and urban sides in Zones 2, 3, 5, 6, 9, and 13. It grows to a height of one meter and is found on the edges of banks or up to 400mm of water. Papiro prefers direct sun light or light shade. This plant is a persistent grass that is very difficult to eradicate yet does not have any adverse effects upon the ecology. For this reason we suggest to let the plant continue to grow and focus more of the time and effort on adding and removing other plants. A good example of a Papiro is seen in Figure 39.

Figure 39: *Cyperus involucratus*

Pennisetum purpureum (Elephant Grass) is an invasive grass species originating from the plains of Africa. It is found in Zones 1 through 6, 9, 11, and 12. The plant grows to a height of 3 meters with a root depth of 0.4 meters. It can grow in any soil type however it prefers growing in soil with a pH of 5.2 – 6.8. Elephant grass is tall, fast growing, and spreads easily. It blocks sun light from reaching the ground

Figure 40: *Pennisetum purpureum*

smothering any seedling that is trying to establish itself. We recommend the removal of the dense Elephant Grass in Zones 1 and 6. This will open up areas for the implementation of the tiered vegetation system. However in order to protect the young trees from the Elephant Grass, monthly trimmings or weeding is suggested. Typical Elephant Grass growth is seen in Figure 40.

Spathodea campanulata (African Tulip) is an invasive tree species originating from the tropics of Africa. It is found in Zones 1 through 6, 8, 9, 11 and 12. African Tulip is a fast growing tree that grows to 20 - 35 meters. The tree is also a fast spreading species that can grow in virtually any soil type. It is a main contributor to secondary forests in the moist parts of Puerto Rico. This is because its seeds germinate readily once in contact with moist soil. Although the African Tulip is an aggressive, invasive, species our group suggests letting the present African Tulips continue undisturbed. Yet, control the spread of the species by removing the seedlings and small trees. We recommend leaving the current trees because it has positive features such as shade cover and root structure that can immediately benefit the area. An African Tulip Tree found on the aqueduct side is shown in Figure 41.

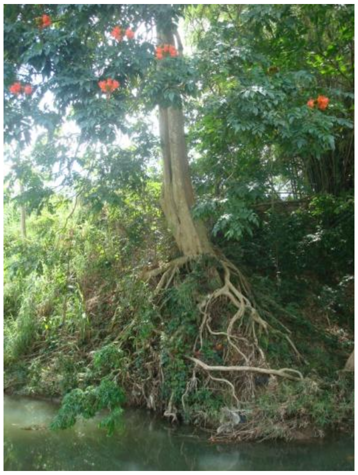


Figure 41: ***Spathodea campanulata***

Terminalia catappa (Indian Almond) is an invasive species that originates from Asia and the Indian sub-continent. It is found in Zones 2, 3, 9, 11, and 12. It can grow to a height of 14 meters and has an average root depth of 0.85 meters. It prefers coarse to medium aggregated soils with a pH level of 6.0 – 7.5. Unlike the other invasive species in the area, the Indian Almond does not have a fast spreading rate. The Indian Almond is commonly found in flood plains because it requires moist soil in order to germinate and grow. It provides strong shade cover because of the large leaves and stabilizes soil with the deep roots, which is why we suggest The Trust let the present trees continue on its natural course. Yet, control the spread by removing seedlings. The Indian Almond Tree is seen in Figure 42.

Figure 42: ***Terminalia catappa***

4.5.2 Recommended Species

We recommend that The Trust address the erosion issue by implementing a tiered vegetation system. Within this system, trees must be planted along the banks of the river. We suggest the addition of native trees that range in size and in width. The added trees will increase the shade cover, reducing the river's temperature and algae. The sturdy intricate root systems will help control the erosion by holding back the sediment. We have reviewed many different species and have identified twelve tree and shrub species that will benefit the local ecosystem. These plants were chosen based on various characteristics, including the feasibility of tree growth, accessibility for The Trust, abundance in Puerto Rico, and its contribution to the riparian zone. Although these are recommended The Trust is not limited to the twelve species on our list.

Figure 43: ***Albizia procera***

Albizia procera (Tall Albizia), although it is an invasive tree from Asia and Australia, it has positive qualities that should be utilized. Tall Albizia should be used in the first layer of the tiered vegetation system. This plant can be found in Zones 5, 6, and 12. It is a very tolerant plant as it can grow in almost any soil type and does not need nutrient rich soil. The Tall Albizia also provides adequate protection from erosion from its fast growing root structure. It can grow to heights of 20 – 25 meters which will provide the bank with good shade cover and temperature control. A Tall Albizia tree is presented in Figure 43.

Andira inermis (Angelin Tree) is a native tree that is grown in The Trust's nursery. We identified two *Andira inermis* in Zones 4 and 9. It grows to heights of 25 – 35 meters and has a root depth of one meter. Due to its height, the Angelin Tree will contribute to the canopy cover of the river and should be used in the first vegetation layer. Its deep roots will help stabilize the surrounding bank. It prefers soil ranging from coarse to medium aggregate. The Angelin Tree has a medium growth rate so the plant will need attention while it is small. If left unmonitored, faster growing weeds will smother the young plant. The species is shown in Figure 44.

Figure 44: ***Andira inermis***

Buchenava tetraphylla (Granadillo – Yellow Sanders) is a large native tree of Puerto Rico that should be planted in the first layer of the tiered vegetation. Our team identified one Granadillo in Zone 2. This tree is not grown in The Trust's nursery, but Fideicomiso could collect and germinate seeds from the Granadillo in Zone 2. The collected seedlings should be nursed until one meter tall to prevent it from being smothered by competing species. The tree grows to a maximum height of 30 meters, creating a high canopy which will provide good shade cover upon the river. The tree's most attractive feature is that is found to grow quite well on eroded banks and ridges.

Figure 45: *Byrsonima spicata*

Byrsonima spicata (Maricao) is a medium sized native tree that should be used in the second layer of the tiered vegetation. This tree was not identified in any zones of the river. The Maricao is grown in The Trust's nursery, so acquisition of the plant is easy. It can grow to a height of 20 meters contributing to the shade cover of the river. However the plant growth rate is slow, so this plant will need constant care in order to protect it from fast growing weeds that will compete for sun light. It thrives in moist to wet soils and produces fruit that is often eaten by local fauna. The flower of the Maricao is seen in Figure 45.

Calophyllum calaba (Maria) is a medium sized native tree that is found in The Trust's nursery and was identified in Zones 2 and 9. This tree should be used in the second layer of the tired vegetation. The Maria can grow to a height of 20 meters and has an average root depth of 1.1 meters. The deep roots will help stabilize the surrounding bank, while its height will provide good shade cover upon the river. It can grow in almost any soil type as long as the soil pH level is between 5.0 – 7.0. The fruits grown on the Maria are a food source for fruit bats. The Rio Piedras does have fruit bats that come out during the night hours, so this quality will increase the areas health. The leaves of the Maria Tree are presented in Figure 46.

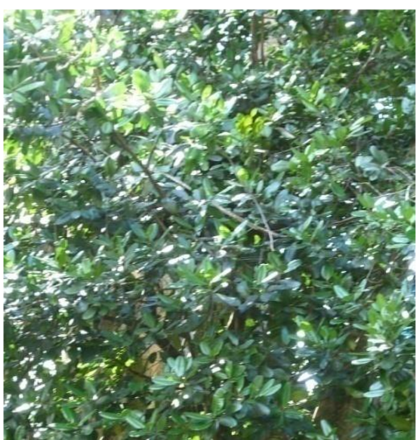


Figure 46: *Calophyllum calaba*

Citheraxylum fruticosum (Pendula) is a small native tree or shrub that is grown in The Trust's nursery. We suggest that the Pendula is planted in the second or third tiered section with other smaller trees and shrubs. The Pendula was not found anywhere in the river we assessed. It can grow to height of 5 – 8 meters. Pendula can grow in various soil types and within a wide range of pH values. The Pendula provides much needed erosion control and shade cover. It is also an ornamental tree, adding to the natural beauty of the river.

Figure 47: *Guarea guidonia*

Guarea guidonia (American Muskwood) is a native tree that is also grown in The Trust's nursery. Our team advises that American Muskwood is planted in the first layer of the tiered vegetation system. This tree was only identified in Zone 7 and grows well in moist, hilly areas. It can grow in any soil type and prefers a pH level of 6.0 – 8.0. The American Muskwood grows to a height of 27 meters and has an average root depth of .6 meters. The American Muskwood will provide good shade cover for the river while controlling the temperature of the bank and the water. The American Muskwood tree of Zone 7 is seen in Figure 47.

Hura crepitans (Sandbox) is a large native hardwood tree that should be used in the first layer of the tiered vegetation system. This tree is not grown in The Trust's nursery; however it was identified in Zone 11. It can grow to a height of 25 – 35 meters and has an average root depth of one meter. These characteristics will help the bank integrity and provide good shade cover. It grows at a rapid rate and is shade tolerant. Therefore, Fideicomiso should plant it in areas where Bamboo dominates the canopy cover. The sandbox can grow in any soil type, but prefers a soil pH range of 6.0 – 8.0. Our main reason for suggesting this plant is that it is spiny and has an irritating sap. We suggest that the sandbox be planted around the fence boarder as another way to deter people from entering the aqueduct site illegally. The Sandbox tree is portrayed in Figure 48.

Figure 48: *Hura crepitans* (wikipedia.com)

Inga vera (Guaba) is a small native tree which is not grown in The Trust's nursery. This species should be used in the second layer of the tiered vegetation system. Our team identified the Guaba in Zones 11 and 12. The Guaba can grow to 15 meters and an average root depth of one meter. It prefers deeper soils with coarse aggregate. Therefore, the tree should not be planted in areas with dry, deep sand, and shallow rocky soils. The Guaba can grow in soil with a wide range of pH levels that ranges from 6.0 – 8.5. The best quality of the Guaba is the steep bank grade that the tree can survive and grow upon. This will allow The Trust to plant the Guaba on the steep upper banks of the Rio Piedras. The Guaba's flowers attract honeybees which will help pollinate the other species in the area. It also provides fruits which are often eaten by wildlife.

Roystonea borinquena (Puerto Rico Royal Palm) is a medium sized native plant that is grown in The Trust's nursery. The Puerto Rico Royal Palm should be planted at the outer extents of the first layer of the tiered vegetation system. The Puerto Rico Royal Palm is found only in Zone 5 and grows to heights of 18 – 26 meters, while having a one meter average root depth. The Royal Palm can grow in any soil type. We recommend the planting of this tree throughout the river because of its historical significance. The trees were used for all different purposes, including thatch and food for humans and animals. An example of the Puerto Rican Royal Palm is shown in Figure 49.

Figure 49: *Roystonea borinquena*

Spondias mombin (Hogplum) is a large tree that is grown in The Trust's nursery. However, it was not identified in the river around the aqueduct. This species should be used in the first layer of the tiered vegetation. The Hogplum can grow to a height of 25 – 35 meters and has an average root depth of one meter, which will provide good shade cover and help stabilize the bank. It can grow in any soil type and especially thrives in moist forests. However, it requires a pH level between 7.4 and 8.0. The Hogplum is another species that provides fruit for wild animals. The fruit of the Hogplum tree is shown in Figure 50.

Figure 50: Fruit of *Spondias mombin* (Wikipedia.com)

Thespesia grandiflora (Maga) is a small sized native tree and is grown in The Trust's nursery. We recommend this species is planted in the section with smaller trees and shrubs of the tiered vegetation system. The Maga was identified in Zones 7 and 13. It can grow to a height of 10 – 15 meters with an average root depth of one meter.

Figure 51: *Thespesia grandiflora* (farm4.static.flickr.com)

Although the Maga is a very demanding tree, we decided that having more trees in the area would add to the aesthetic and biodiversity of the riparian zone. The Maga is prized for its beautiful flower which is recognized as the state flower. The Maga tree is shown in Figure 51.

By introducing these species, we hope to achieve solid bank integrity and good shade cover. Many of these species were chosen for their contribution to the canopy cover as well as their root structure. We also hope to provide more food for fauna with the fruits that many of the species provide. Placed in the proper location of the tiered vegetation system, we hope to repair the overall ecological health of the river and riparian zone.

4.6 Conclusions

The site of Puerto Rico's first aqueduct is one of The Conservation Trust's most unique properties because it lies within urban San Juan and the island's "Ecological Corridor". Although its location forces The Trust to overcome obstacles, it also provides an opportunity to achieve rare conservation in urban San Juan. In order to overcome the consequences of urban development, The Trust must utilize aspects of all three conservation approaches. Abusive people must be kept out, but those who want to volunteer and further conservation efforts should be utilized. The Trust could create a new set of environmental values among San Juan's people by involving them in the Rio Piedras restoration.

The Trust faces several challenges in their restoration of the river. Erosion, urban dumping, unmonitored debris accumulation, and growth of invasive species hurt the ecological health. The Trust can address these issues by expanding the buffer zone, clearing the river of debris, addressing grading problems, and introducing new species in a tiered vegetation system to benefit the biodiversity and health of the river. These recommendations are simply a start to the restoration of the river. The Trust should build upon them to recreate one of Puerto Rico's most valued pieces of land.

We feel deeply privileged to have worked with The Conservation Trust of Puerto Rico on such an important restoration project. We feel the completion of the project will trigger a change in environmental values among the local community. The current state of the Rio Piedras will be a distant memory when the public sees a gorgeous river basin surrounding the restored ancient aqueduct. We are certain that the site restoration will be completed to The Trust's high standards and form a cornerstone for conservation in the face of urban development.

References

Brown, K. (2002). Innovations for conservation and development. *The Geographical Journal, 168*(1), 6-17. Retrieved from http://www.jstor.org/stable/3451218

Francis, J. K. (1998), Tree Species for Planting in Forests, Rural, and Urban Areas of Puerto Rico. USDA Forest Service, International Institute of Tropical Forestry

Heartsill-Scalley, T., & Aide, T. M. (2003). Riparian vegetation and stream condition in a tropical agriculture-secondary forest mosaic. *Ecological Applications*, *13*(1), 225-234. Retrieved from http://www.jstor.org/stable/3099961

Natural Resources Conservation Service (2009), USDA Plant Database, USDA, Retrieved from http://plants.usda.gov/

Riverbank Conservation Limited (2009), Erosion Control and Bank Stabilization, Riverbank Conservation Limited, Retrieved from http://www.riverbankconservation.co.uk/erosion.htm

Conservation Management Plan Appendix

Appendix I: Assessment Sheet

Rio Piedras Interval Assessment Sheet			
Interval Number			Date:
Bank Side			Notes:
Shade Cover	good		
	somewhat		
	less		
	none		
Vegetation	full		
	moderate		
	less		
	none		
	excessive		
Bank Integrity	solid		
	stable		
	less stable		
	unstable		
Algae	none		
	little		
	moderate		
	abundant		
	excessive		
Debris (Human/Natural)	none		
	little		
	moderate		
	abundant		Completed By:
	excessive		
Continuity from Previous Interval	very similar		
	similar		
	not similar		

Appendix II: Water Quality Test Results

Water Quality Test Results				
Zone Number	**Temperature °C**	**Dissolved O_2 (%)**	**Phosphate (PPM)**	**pH**
1	26	39	1	8.25
2	26	39	2	8.25
3	28	0	2	8
4	26	39	2	7.5
5	28	42	1	8
6	27	41	1	7.75
7	26	0	1	8.25
8	25	0	2	8
9	26	39	2	8.25
10	27	41	2	7
11	27	42	1	8
12	27	41	1	7.5
13	27	41	1	8

Appendix III: Soil Density Test Results

Soil Density Test Results

Zone Number	Weight (g)	Density (g/cm^3)	Consistency
1	450	1.722	Loose large granules with rocks varying in size.
	325	1.244	Hard packed clay with small granules.
2	425	1.626	Lose large granules and rocks.
	300	1.148	Medium pack that crumbles easily. Has few roots and small sticks.
	275	1.052	Hard packed with moss and lichen on top. Has few rocks and few roots.
3	200	0.765	Medium pack with medium granules with few large rocks. Small amount organic matter with few roots.
	325	1.244	Hard packed clay with roots. Found white, red, and black colors in the clay.
4	275	1.052	Packed with roots that range from large to small. Moss covered. Granule is veryfine. Soil cover outside roots
	225	0.861	Medium packed sample with fine granule, packed with roots
5	375	1.435	Very hard packed clay.
	0	0.000	Unable to take a sample due to rock wall.
6	350	1.339	Sand packed with large granules and rocks.
	350	1.339	Medium packed with few roots and organic matter.
7	325	1.244	Hard packed clay with one root.
	375	1.435	Hard packed clay with a few roots.
8	0	0.000	Concrete wall from aqueduct.
	0	0.000	Concrete wall from aqueduct.
9	325	1.244	Medium packed dirt with many large roots. Clay like granule.
	275	1.052	Hard packed clay with a lot of large roots.
10	200	0.765	Medium packed with a few roots. The sample was muddy before drying.
	300	1.148	Hard packed sample with roots and lots of organic matter.
11	325	1.244	Hard packed with light moss cover and a few roots.
	275	1.052	Hard packed clay containing few roots.
	300	1.148	Hard packed with moss and lichen. Good roots varying in size from large to small.
	125	0.478	Loose packed soil that contains mostly organic matter.
12	275	1.052	Hard packed to loose packed clay that contains some organic matter and roots.
	325	1.244	Medium to hard packed covered in moss and it contains a few roots.
13	325	1.244	Hard packed clay covered in moss and it contains a few roots.
	600	2.296	The sample consists of rocks and loose sand.

Appendix IV: Flora Classification

Rio Piedras Flora Identification Spreadsheet

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Albizia procera	Albicia Tall albizia	Mimosaceae	T	I	+	5-6, 12
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	++	2, 4, 6, 11-13
Ammannia latifolia	Crab Weed	Lythraceae	S	N	+	6
Andira inermis	Moca Angelin Tree	Fabaceae	T	N	+	4, 9
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Buchenavia tetraphylla	Granadillo - Yellow sanders	Combretaceae	T	N	+	2
Callistemon citrinus	Cepillo de Botella - Bottlebrush Tree	Myrtaceae	T	I	+	3-4, 6
Calophyllum	Santa Maria	Guttiferae	T	N	+	2, 5
Calophyllum antillanum	Maria	Guttiferae	T	N	+	3
Calophyllum calaba	Maria	Guttiferae	T	N	+	2, 9
Calopogonium coerulem		Fabaceae	V	N	+++	1-6, 9, 13
Campylocentrum phyllittidis		Orchidaceae	S	N	+	4
Casearia guianesis	Cafaeillo - Wild Coffee	Flacourtiaceae	T	N	+	7
Chrysalidocarpus lutescenes	Palma Areca - Areca Palm	Arecaceae	T	I	+	2-3, 11
Cissus verticillata	Bejuco de Agua - Pudding Vine	Vitaceae	S	N	+	13
Citrus sp		Rutacae	T	I	+	8
Cleome speciosa	Volantines preciosos	Capparaceae	S	I	+	6
Commelina diffusa	Cohitre Blue Day Flower	Commelinaceae	S	N	++	1-2, 6, 11
Congea tomentosa	Terciopelo	Verbenaceae	V	I	+	9
Cordia sulcata	Moral White Manjack	Boraginaceae	T	N	+	4, 11
Cordyline fruticosa	Bayoneta Common Dracaena	Liliaceae	S	I	+	11
Costus spicatus	Caña amarga - Spiked Spiralflag	Costaceae	S	N	+	11
Cuphea strigulosa	Stiffhair Waxweed	Lythraceae	S	N	+	13
Cyathea sp		Cyatheacea	F	N	+	9
Cyperus imbricatus	Papiro	Cyperaceae	G	N	+	1, 4
Cyperus involucratus	Papiro	Cyperaceae	G	I	+++	2-3, 5-6, 9, 13
Dieffenbachia seguine	Rábano cimarrón - Dumbcane	Araceae	S	N	+	2
Eleocharys sp		Cyperaceae	G	N	+	4
Epipremnum aureum	Amapalo amarillo - Taro vine	Araceae	V	I	+	12
Genipa americana	Jagua Box Genip	Rubiaceae	T	N	+	7

Rio Piedras Flora Identification Spreadsheet

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Gonzalagunia hirsuta	Palo Pelado	Rubiaceae	T	N	+	9
Gonzalagunia hirsuta	Mata de Mariposa	Rubiaceae	T	N	+	11
Guarea guidonia	Guaragua Muskwood	Meliaceae	T	N	+	7
Hippobroma longiflora	Tibey blanco - Star of Betheham	Campanulaceae	S	N	+	1-2, 4
Hura crepitans	Molnillo - Sandbox Tree	Euphorbiaceae	T	N	+	11
Hydromystria laevigata	Cuchara	Hydrocharitaceae	S	N	+	6
Hyptis capitata	Brotoncillo Negro - Wild Hops	Lamiaceae	S	N	+	2, 5-6
Inga vera	Guaba	Mimosaceae	T	N	+	11-12
Malachra alceifolia	Malva de Caballo	Malvaceae	S	N	+	6
Melanthera aspera	Salaillo	Asteraceae	S	N	+	6
Miconia laevigata	Camasey	Melastomataceae	S	N	+	4
Mimosa pellita		Fabaceae	S	N	+	6
Musa sp	Guineo	Musaceae	T	I	++	2-4, 6, 12
Mikania sp	Puerto Rico Hemp Vine	Asteraceae	V	N	+	13
Paullinia pinnata	Bejuco de Costilla	Sapindaceae	V	N	+	6
Pavonia futicosa	Cadillo pequene	Malvaceae	S	N	+	11
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+++	1-6, 9, 11-12
Piper hispidum	Higuillo	Piperaceae	S	N	+	6, 11, 13
Pterocarpus indicus	Pterocarpo - Indian Padauk	Fabaceae	T	I	+	3-5
Ptychosperma macarthurri	Palma McArthur McArthur Palm	Arecaceae	T	I	+	3
Ricinus cummunis	Higuereta - Castor Bean	Euphorbiaceae	S	I	++	5-6, 9, 11, 13
Rourea surinamensis	Juan Caliente	Connaraceae	S	N	+	4
Roystonea borinquena	Palma Real - Puertorican Royal Palm	Palmae	T	N	+	5
Sanchezia speciosa		Acanthaceae	S	I	+	11
Sida rhimbifolia	Escoba Colorada	Malvaceae	T	N	+	5, 13
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+++	1-6, 8-9, 11-12
Syzygium jambos	Pomarrosa Rose Apple	Myrtaceae	T	N	+	2, 4, 7
Tectaria incisa		Dryopteroidaceae	F	N	+	2, 11
Terminalia catappa	Almendro - Indian Almond	Combretaceae	T	I	+++	2-3, 9, 11-12
Thelypteris sp	Helecho	Thelypteridaceae	F	N	++	1-2, 4-5, 11

Rio Piedras Flora Identification Spreadsheet

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Thespesia grandiflora	Maga	Malvaceae	T	N	+	7, 13
Triplaris cumingiana	Triplaris	Polygonaceae	T	I	+	6, 13
Urera Baccifera	Ortiga	Urticaceae	S	N	+	12
Vernonia cinerea	Rabo de Buey	Asteraceae	S	I	+	6

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix V: Flora of Zone 1

Rio Piedras Flora Identification Spreadsheet						
Zone 1						
Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Calopogonium coerulem		Fabaceae	V	N	+++	1-6, 9, 13
Commelina diffusa	Cohitre Blue Day Flower	Commelinaceae	S	N	++	1-2, 6, 11
Cyperus imbricatus	Papiro	Cyperaceae	G	N	+	1, 4
Hippobroma longiflora	Tibey blanco - Star of Betheham	Campanulaceae	S	N	+	1-2, 4
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+++	1-6, 9, 11-12
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+	1-6, 8-9, 11-12
Thelypteris sp	Helecho	Thelypteridaceae	F	N	++	1-2, 4-5, 11

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix VI: Flora of Zone 2

Rio Piedras Flora Identification Spreadsheet

Zone 2

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	+	2, 4, 6, 11-13
Buchenavia tetraphylla	Granadillo - Yellow sanders	Combretaceae	T	N	+	2
Calophyllum	Santa Maria	Guttiferae	T	N	+	2, 5
Calophyllum calaba	Maria	Guttiferae	T	N	+	2, 9
Calopogonium coerulem		Fabaceae	V	N	+	1-6, 9, 13
Chrysalidocarpus lutescenes	Palma Areca - Areca Palm	Arecaceae	T	I	++	2-3, 11
Commelina diffusa	Cohitre Blue Day Flower	Commelinaceae	S	N	+	1-2, 6, 11
Cyperus involucratus	Papiro	Cyperaceae	G	I	++	2-3, 5-6, 9, 13
Dieffenbachia seguine	Rábano cimarrón - Dumb cane	Araceae	S	N	+	2
Hippobroma longiflora	Tibey blanco - Star of Betheham	Campanulaceae	S	N	+	1-2, 4
Hyptis capitata	Brotoncillo Negro - Wild Hops	Lamiaceae	S	N	+	2, 5-6
Musa sp	Guineo	Musaceae	T	I	+	2-4, 6, 12
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+++	1-6, 9, 11-12
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	++	1-6, 8-9, 11-12
Syzygium jambos	Pomarrosa Rose Apple	Myrtaceae	T	N	+	2, 4, 7
Tectaria incisa		Dryopteroidaceae	F	N	+	2, 11
Terminalia catappa	Almendro - Indian Almond	Combretaceae	T	I	+	2-3, 9, 11-12
Thelypteris sp	Helecho	Thelypteridaceae	F	N	+++	1-2, 4-5, 11

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix VII: Flora of Zone 3

Rio Piedras Flora Identification Spreadsheet

Zone 3

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Callistemon citrinus	Cepillo de Botella - Bottlebrush Tree	Myrtaceae	T	I	+	3-4, 6
Calophyllum antillanum	Maria	Guttiferae	T	N	++	3
Calopogonium coerulem		Fabaceae	V	N	+	1-6, 9, 13
Chrysalidocarpus lutescenes	Palma Areca - Areca Palm	Arecaceae	T	I	++	2-3, 11
Cyperus involucratus	Papiro	Cyperaceae	G	I	+	2-3, 5-6, 9, 13
Musa sp	Guineo	Musaceae	T	I	+	2-4, 6, 12
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+	1-6, 9, 11-12
Pterocarpus indicus	Pterocarpo - Indian Padauk	Fabaceae	T	I	+	3-5
Ptychosperma macarthurri	Palma McArthur McArthur Palm	Arecaceae	T	I	+	3
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+	1-6, 8-9, 11-12
Terminalia catappa	Almendro - Indian Almond	Combretaceae	T	I	+	2-3, 9, 11-12

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix VIII: Flora of Zone 4

Rio Piedras Flora Identification Spreadsheet

Zone 4

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	+	2, 4, 6, 11-13
Andira inermis	Moca Angelin Tree	Fabaceae	T	N	++	4, 9
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Callistemon citrinus	Cepillo de Botella - Bottlebrush Tree	Myrtaceae	T	I	+	3-4, 6
Calopogonium coerulem		Fabaceae	V	N	++	1-6, 9, 13
Campylocentrum phyllittidis		Orchidaceae	S	N	+	4
Cordia sulcata	Moral White Manjack	Boraginaceae	T	N	+	4, 11
Cyperus imbricatus	Papiro	Cyperaceae	G	N	+	1, 4
Eleocharys sp		Cyperaceae	G	N	+	4
Hippobroma longiflora	Tibey blanco - Star of Betheham	Campanulaceae	S	N	+	1-2, 4
Miconia laevigata	Camasey	Melastomataceae	S	N	+	4
Musa sp	Guineo	Musaceae	T	I	++	2-4, 6, 12
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+	1-6, 9, 11-12
Pterocarpus indicus	Pterocarpo - Indian Padauk	Fabaceae	T	I	+	3-5
Rourea surinamensis	Juan Caliente	Connaraceae	S	N	+	4
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	++	1-6, 8-9, 11-12
Syzygium jambos	Pomarrosa Rose Apple	Myrtaceae	T	N	+	2, 4, 7
Thelypteris sp	Helecho	Thelypteridaceae	F	N	+++	1-2, 4-5, 11

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix IX: Flora of Zone 5

Rio Piedras Flora Identification Spreadsheet

Zone 5

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Albizia procera	Albicia Tall albizia	Mimosaceae	T	I	+	5-6, 12
Calophyllum	Santa Maria	Guttiferae	T	N	+	2, 5
Calopogonium coerulem		Fabaceae	V	N	++	1-6, 9, 13
Cyperus involucratus	Papiro	Cyperaceae	G	I	+	2-3, 5-6, 9, 13
Hyptis capitata	Brotoncillo Negro - Wild Hops	Lamiaceae	S	N	+	2, 5-6
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	++	1-6, 9, 11-12
Pterocarpus indicus	Pterocarpo - Indian Padauk	Fabaceae	T	I	+	3-5
Ricinus cummunis	Higuereta - Castor Bean	Euphorbiaceae	S	I	+	5-6, 9, 11, 13
Roystonea borinquena	Palma Real - Puertorican Royal Palm	Palmae	T	N	+	5
Sida rhimbifolia	Escoba Colorada	Malvaceae	T	N	+	5, 13
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+++	1-6, 8-9, 11-12
Thelypteris sp	Helecho	Thelypteridaceae	F	N	++	1-2, 4-5, 11

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix X: Flora of Zone 6

Rio Piedras Flora Identification Spreadsheet						
Zone 6						
Genus and Species	**Common Name**	**Family**	**Life Form**	**Origin**	**Abundance**	**Zone**
Albizia procera	Albicia Tall albizia	Mimosaceae	T	I	+	5-6, 12
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	++	2, 4, 6, 11-13
Ammannia latifolia	Crab Weed	Lythraceae	S	N	+	6
Callistemon citrinus	Cepillo de Botella - Bottlebrush Tree	Myrtaceae	T	I	+	3-4, 6
Calopogonium coerulem		Fabaceae	V	N	++	1-6, 9, 13
Cleome speciosa	Volantines Preciosos	Capparaceae	S	I	+	6
Commelina diffusa	Cohitre Blue Day Flower	Commelinaceae	S	N	++	1-2, 6, 11
Cyperus involucratus	Papiro	Cyperaceae	G	I	+++	2-3, 5-6, 9, 13
Hydromystria laevigata	Cuchara	Hydrocharitaceae	S	N	+	6
Hyptis capitata	Brotoncillo Negro - Wild Hops	Lamiaceae	S	N	++	2, 5-6
Malachra alceifolia	Malva de Caballo	Malvaceae	S	N	+	6
Melanthera aspera	Salaillo	Asteraceae	S	N	+	6
Mimosa pellita		Fabaceae	S	N	+	6
Musa sp	Guineo	Musaceae	T	I	+++	2-4, 6, 12
Paullinia pinnata	Bejuco de Costilla	Sapindaceae	V	N	++	6
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+++	1-6, 9, 11-12
Piper hispidum	Higuillo	Piperaceae	S	N	+	6, 11, 13
Ricinus cummunis	Higuereta - Castor Bean	Euphorbiaceae	S	I	++	5-6, 9, 11, 13
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+	1-6, 8-9, 11-12
Triplaris cumingiana	Triplaris	Polygonaceae	T	I	+	6, 13
Vernonia cinerea	Rabo de Buey	Asteraceae	S	I	+	6

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XI: Flora of Zone 7

Rio Piedras Flora Identification Spreadsheet

Zone 7

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Casearia guianesis	Cafaeillo - Wild Coffee	Flacourtiaceae	T	N	+	7
Genipa americana	Jagua Box Genip	Rubiaceae	T	N	+	7
Guarea guidonia	Guaragua Muskwood	Meliaceae	T	N	++	7
Syzygium jambos	Pomarrosa Rose Apple	Myrtaceae	T	N	+	2, 4, 7
Thespesia grandiflora	Maga	Malvaceae	T	N	+	7, 13

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XII: Flora of Zone 8

Rio Piedras Flora Identification Spreadsheet

Zone 8

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Citrus sp		Rutacae	T	I	+	8
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+	1-6, 8-9, 11-12

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XIII: Flora of Zone 9

Rio Piedras Flora Identification Spreadsheet						
Zone 9						
Genus and Species	**Common Name**	**Family**	**Life Form**	**Origin**	**Abundance**	**Zone**
Andira inermis	Moca Angelin Tree	Fabaceae	T	N	+	4, 9
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Calophyllum calaba	Maria	Guttiferae	T	N	+	2, 9
Calopogonium coerulem		Fabaceae	V	N	++	1-6, 9, 13
Congea tomentosa	Terciopelo	Verbenaceae	V	I	++	9
Cyathea sp		Cyatheacea	F	N	+	9
Cyperus involucratus	Papiro	Cyperaceae	G	I	++	2-3, 5-6, 9, 13
Gonzalagunia hirsuta	Palo Pelado	Rubiaceae	T	N	++	9
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	+++	1-6, 9, 11-12
Ricinus cummunis	Higuereta - Castor Bean	Euphorbiaceae	S	I	+	5-6, 9, 11, 13
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	++	1-6, 8-9, 11-12
Terminalia catappa	Almendro - Indian Almond	Combretaceae	T	I	+	2-3, 9, 11-12

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XIV: Flora of Zone 10

Rio Piedras Flora Identification Spreadsheet						
Zone 10						
Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA= Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XV: Flora of Zone 11

Rio Piedras Flora Identification Spreadsheet						
Zone 11						
Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	++	2, 4, 6, 11-13
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Chrysalidocarpus lutescenes	Palma Areca - Areca Palm	Arecaceae	T	I	+	2-3, 11
Commelina diffusa	Cohitre Blue Day Flower	Commelinaceae	S	N	++	1-2, 6, 11
Cordia sulcata	Moral White Manjack	Boraginaceae	T	N	+	4, 11
Cordyline fruticosa	Bayoneta Common Dracaena	Liliaceae	S	I	+	11
Costus spicatus	Caña amarga - Spiked Spiralflag	Costaceae	S	N	+	11
Gonzalagunia hirsuta	Mata de Mariposa	Rubiaceae	T	N	+	11
Hura crepitans	Molnillo - Sandbox Tree	Euphorbiaceae	T	N	+	11
Inga vera	Guaba	Mimosaceae	T	N	++	11-12
Pavonia futicosa	Cadillo pequene	Malvaceae	S	N	+	11
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	++	1-6, 9, 11-12
Piper hispidum	Higuillo	Piperaceae	S	N	+	6, 11, 13
Ricinus cummunis	Higuereta - Castor Bean	Euphorbiaceae	S	I	+	5-6, 9, 11, 13
Sanchezia speciosa		Acanthaceae	S	I	+	11
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	++	1-6, 8-9, 11-12
Tectaria incisa		Dryopteroidaceae	F	N	+	2, 11
Terminalia catappa	Almendro - Indian Almond	Combretaceae	T	I	++	2-3, 9, 11-12
Thelypteris sp	Helecho	Thelypteridaceae	F	N	++	1-2, 4-5, 11

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XVI: Flora of Zone 12

Rio Piedras Flora Identification Spreadsheet						
Zone 12						
Genus and Species	**Common Name**	**Family**	**Life Form**	**Origin**	**Abundance**	**Zone**
Albizia procera	Albicia Tall albizia	Mimosaceae	T	I	+	5-6, 12
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	++	2, 4, 6, 11-13
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Epipremnum aureum	Amapalo amarillo - Taro vine	Araceae	V	I	+	12
Inga vera	Guaba	Mimosaceae	T	N	++	11-12
Musa sp	Guineo	Musaceae	T	I	+	2-4, 6, 12
Pennisetum purpureum	Yerba elefante - Elephant Grass	Poaceae	G	I	++	1-6, 9, 11-12
Spathodea campanulata	African Tulip	Bignoniaceae	T	I	+++	1-6, 8-9, 11-12
Terminalia catappa	Almendro - Indian Almond	Combretaceae	T	I	+	2-3, 9, 11-12
Urera Baccifera	Ortiga	Urticaceae	S	N	+	12

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XVII: Flora of Zone 13

Rio Piedras Flora Identification Spreadsheet

Zone 13

Genus and Species	Common Name	Family	Life Form	Origin	Abundance	Zone
Alocasia plumbea	Malanga Morada - Metallic Alocasia	Araceae	S	I	++	2, 4, 6, 11-13
Bambusa vulgaris	Bamboo	Gramineae	S	I	+++	4,7-13
Calopogonium coerulem		Fabaceae	V	N	++	1-6, 9, 13
Cissus verticillata	Bejuco de Agua - Pudding Vine	Vitaceae	S	N	+	13
Cuphea strigulosa	Stiffhair Waxweed	Lythraceae	S	N	+	13
Cyperus involucratus	Papiro	Cyperaceae	G	I	++	2-3, 5-6, 9, 13
Mikania sp	Puerto Rico Hemp Vine	Asteraceae	V	N	++	13
Piper hispidum	Higuillo	Piperaceae	S	N	++	6, 11, 13
Ricinus cummunis	Higuereta - Castor Bean	Euphorbiaceae	S	I	+	5-6, 9, 11, 13
Sida rhimbifolia	Escoba Colorada	Malvaceae	T	N	++	5, 13
Thespesia grandiflora	Maga	Malvaceae	T	N	++	7, 13
Triplaris cumingiana	Triplaris	Polygonaceae	T	I	+	6, 13

Life Form	F= Fern	G= Grass or Grasslike	S = Shrub	T = Tree	V = Vine
Origin	NA=Naturalized	I = Introduced	N = Native		
Abundance	+++ = Widespread	++ = Localized	+ = Sparse		

Appendix XVIII: Flora Photographs and Identification

 Albiza procera **Albicia Tall Albiza**	 Alocasia plumbea **Metallic Alocasia**
 Ammania latifolia **Crab Weed**	 Andira inermis **Moca Angelin Tree**
 Bambusa vulgaris **Common Bamboo**	 Buchenavia tetraphylla **Granadillo Yellow Sanders**

 Callistemon citrinus **Bottlebrush Tree**	 Calophyllum **Santa Maria**
 Calophyllum antillanum **Maria**	 Calophyllum calaba **Maria**
 Calopongonium coeruleum	 Campylocentrum phyllittidis

 Casearia guianesis **Wild Coffee**	 Chrysalidocarpus lutescenes **Areca Palm**
 Cissus verticillata **Pudding Vine**	 Citrus sp
 Cleome speciosa **Volantines Preciosos**	 Commelina diffusa **Blue Day Flower**

<table>
<tr>
<td>
Congea tomentosa

Terciopelo</td>
<td>
Cordia sulcata

Moral White Manjack</td>
</tr>
<tr>
<td>
Cordyline fruticosa

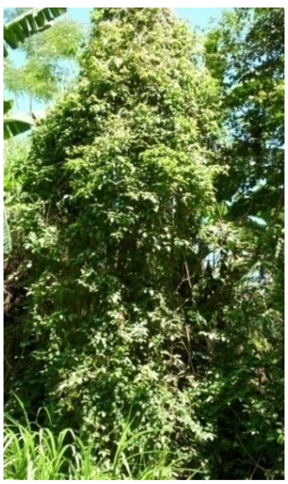
Common Dracaena</td>
<td>
Costus spicatus

Caña amarga</td>
</tr>
<tr>
<td>
Cuphea strigulosa</td>
<td>
Cyathea sp</td>
</tr>
</table>

 Cyperus imbricatus **Papiro**	 Cyperus involucratus **Papiro**
 Dieffenbachia seguine **Dumb Cane**	 Eleocharys Sp
 Epipremnum aureum **Taro Vine**	 Genipa Americana **Box Genip**

 Gonzalagunia hirusta **Palo Pelado**	 Gonzalaunia hirusta **Mata de Mariposa**
 Guarea Guidonia **Muskwood**	 Hippobroma longiflora **Star of Bethleham**
 Hura crepitans **Sandbox Tree**	 Hydromystria laevitata **Cuchara**

 Hyptis capitata **Wild Hops**	 Inga vera **Guaba**
 Malachra alceifolia **Malva de Caballo**	 Melanthera aspera **Salaillo**
 Miconia laevigata **Camasey**	 Mimosa pellita

<table>
<tr><td>
Musa Sp
Guineo</td><td>
Mykania Sp</td></tr>
<tr><td> Paullinia pinnata
Bejuco de Costilla</td><td>
Pavonia futicosa
Cadilio pequene</td></tr>
<tr><td> Pennisetum purpureum
Elephant Grass</td><td>
Piper hispidum
Higuillo</td></tr>
</table>

<table>
<tr><td></td><td>Pterocarpus indicus

Indian Padauk</td><td>
Ptychosperma macathurri

McArthur Palm</td></tr>
<tr><td colspan="2">
Ricinus cummunis
Castor Bean</td><td> Rourea surinamensis

Juan Caliente</td></tr>
<tr><td></td><td>Roystonea borinquena

Puerto Rican Royal Palm</td><td>
Sanchezia speciosa</td></tr>
</table>

Sida rhimbifolia

Escoba Colorada

Spathodea campanulata
African Tulip

Syzygium jambos

Rose Apple

Tectaria incisa

Terminalia catappa
Indian Almond

Thelypteris sp
Helecho

 Thespesia grandiflora **Maga**	 Triplaris cumingiana **Triplaris**
 Urera Baccifera **Ortiga**	 Vernonia cinerea **Rabo de Buey**

Appendix C: Water Testing Procedure

pH Testing Procedure

1. Fill up the graduated cylinder with 10ml of sample water.
2. Add one tablet of LaMotte pH Wide Range code 6459A-J to the graduated cylinder.
3. Swirl the test tube until the tablet has dissolved and observe the color.
4. Compare the color of the water to a scale to determine the pH level of the sample.

Phosphate Testing Procedure

1. Fill up the graduated cylinder with 10ml of sample water.
2. Add one tablet of LaMotte Phosphorus code 5422A-H to the graduated cylinder.
3. Cap the test tube and shake until the tablet has dissolved.
4. Let sit for 5 minutes and observe the color.
5. Compare the color of the water to a scale to determine the Phosphate level of the sample.

Nitrate Testing Procedure

1. Fill up the graduated cylinder with 5ml of sample water.
2. Add one tablet of LaMotte Nitrate Wide Range code 3703A-J to the graduated cylinder.
3. Cap the test tube and shake until the tablet has dissolved.
4. Let sit for 5 minutes and observe the color.
5. Compare the color of the water to a scale to determine the Nitrate level of the sample.

Dissolved Oxygen Testing Procedure

1. Take the temperature of the water.
2. Submerge vile until completely full, remove carefully from the water.
3. Add two tablets of LaMotte Dissolved Oxygen code 3976A-J to the graduated cylinder.
4. Cap the test tube and make sure there are no bubbles in the vile.
5. Shake the test tube back and forth for four minutes until the tablets are disintegrated.
6. Let sit for 5 minutes and observe the color.
7. Compare the color of the water to a scale to determine the dissolved Oxygen level of the sample.

Appendix D: Project Timeline

Our group completed the methods with regard to the following timeline:

Week 1 (March 16-20)
Exploration of the Area, Visiting other Trust Sites with Fideicomiso Sponsor
Week 2 (March 23-27)
Riparian Zone Interval Assessment
Week 3 (March 30-April 3)
Riparian Zone Flora Identification
Week 4 (April 6-April 10)
GPS Zone Markings, Zone Testing, Continue Flora Identification
Week 5 (April 13-April 17)
Zone Testing and Flora Identification
Week 6 (April 20-24)
Conservation Plan Creation
Week 7 (April 27-May 6)
Conservation Plan Creation
Preparation for Final Presentation, Completion of IQP Report

During the first week our group traveled to other conservation sites and learned about the values of Fideicomiso. During the second and third weeks, we divided the property into zones based on the assessment sheet and began flora identification. During weeks four and five, our team continued species documentation. We also began water quality tests along with soil density tests to describe the overall health of each zone. A botanical study was also performed during these weeks for each species and its characteristics. All testing data and specific botanical data were placed into spread sheets for future comparisons.

During weeks five, six and seven, our team finished testing and identification, while compiling the collected data to create a conservation management plan for the Rio Piedras. The plan includes assessment data for the region and then specific conservation methods for each topic that arose. The topics covered in the plan include the conservation approach, erosion control, debris control, and the addition of native flora.