April 2011

Assessing Environmental Damage at Stream Crossings in El Yunque National Forest

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Assessing Environmental Damage at Stream Crossings in El Yunque National Forest

Interactive Qualifying Project

Sponsoring Agency: United States Forest Service, El Yunque National Forest

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Executive Summary

To conserve natural resources for future generations, the United States Forest Service protects the unique ecosystem of forests, such as El Yunque National Forest in Puerto Rico. In El Yunque, the Forest Service needs to strike a balance with visitors by building inter-forest road networks that are sensitive to the flora and fauna. In order to maintain the health of El Yunque, forest rangers must be able to determine and mitigate the environmental impact of stream crossings built for vehicle traffic.

The purpose of our project was to recommend a stream crossing structure that caused little damage to the local area. To do this, we developed a methodology for assessing stream health at crossings and used it to evaluate eleven watersheds in and around El Yunque National Forest. Our chosen methodology for the study was the United States Department of Agriculture (USDA) Stream Visual Assessment Protocol (1998), which we modified for the rainforest. Using this assessment, we evaluated fifteen different stream sites and comparatively analyzed the results, using a pristine stream as the control.

We concluded that there was no connection between stream health and crossing structures because there were no differentiations between the environmental effects of bridges and culverts. Since there was no clear difference, we used comparative analysis across regional areas and individual factors in order to make recommendations. Most of the analyzed watersheds could benefit from improved livestock barriers, replanting, trash removal and a reduction in water withdrawals. Our team also developed suggestions for the three unhealthiest streams. For example, we proposed vegetated buffer strips to improve water quality in Canóvanillas. Our other proposals include a review of the water budget, which could reduce water withdrawals and improve stream health. Also, further research efforts may lead to finding environmental impact differences between structures. It is our hope that this study will contribute to the Forest Service's mission of protecting the nation's natural resources.

1. Introduction

We are four junior undergraduates from Worcester Polytechnic Institute who have accepted an eight-week project in El Yunque National Rainforest to complete our Interactive Qualifying Project. One member of our four-member team is Tom Reid. He is a varsity football player studying to become a civil engineer. Another of our members is Stacie Clark, a Biology and Biotechnology major. She is passionate about being in the outdoors and has experience working on preserving the ecosystem with the Appalachian Mountain Club. Kaitlyn Kelley, an aerospace engineer intrigued by Puerto Rico's unique ecosystem, is another team member. She also has outdoor project experience studying snow stability in Wyoming. The last member is Anika Blodgett, a double-major in Biochemistry and Theatre. Since a trip to the Amazon Rainforest, she has always harbored a fascination and appreciation for the world's rainforests. All of the members are ecstatic to be working on this project and the larger societal issues it addresses.

As many natural resources on Earth are slowly consumed, the U.S. Forest Service strives "to protect and conserve" the reserves in the nation's forests. However, the revenue generated from visitors to the forest provides the income necessary for funding the management of the forests, even though the influx of people is detrimental to the natural ecosystem. Forest managers must seek a balance that allows the public to experience the beauty of the forest while still preserving its untouched resources. It is important to maintain the integrity of the forest so that future generations may enjoy it.

In Puerto Rico, El Yunque's Forest Service division is attempting to find a balance between an infrastructure that can support the needs of Puerto Ricans, and maintain the natural environment. Due to the presence of tourists and a multitude of rivers in El Yunque, there are currently stream crossings installed in the forest. Especially important are motor-able stream crossings in and around El Yunque. Ideally, these crossings should not leave an ecological footprint nor negatively affect the surrounding environment, while still allowing for human traffic. The rangers currently know little about how the streams are being affected by the constructed crossings.

There are three key issues we need to understand to successfully assess environmental damage at stream crossings: typical stream crossing structures, factors that affect stream health and ways to evaluate these factors. In our research, we found that culverts and bridges are two major types of crossing structures found in El Yunque. Culverts are used to span smaller streams and bridges are constructed across major streams too big for culverts. We will evaluate and compare these structures during our stream health assessment.

Our research showed that certain factors are indicative of stream health. These have both physical and biological components. We determined stream crossings cause three important physical disruptions to the natural environment: flow alteration, channel condition change (Jackson 2003) and an increase in water velocity (Prof. John Bergendahl, personal communication, Feb. 11, 2011). These physical changes cause observable effects on the environment of the area. Some biological effects include reduction in plant life along the bank of the stream and the presence of macroinvertebrates, such as fish and insects. Both biological and physical factors can be visually assessed using an existing evaluation protocol.

There are many different ways to evaluate stream health. Official methods, such as the United States Department of Agriculture (USDA) Stream Visual Assessment Protocol (1998), have been used to evaluate stream health for years. After examining assessment protocols, we decided that the USDA's Stream Visual Assessment Protocol would be used to evaluate our sites, as it is simple and best suited considering the resources available. This protocol involves assessment of stream health based on observation. Fourteen different factors that affect stream health are observed and assigned a relative score. These scores are averaged to determine stream health. This is the protocol that we will use.

However, the USDA protocol has flaws. It was developed for streams in the Pacific Northwest. For example, the protocol suggested that flooding once every year or two is healthy for a stream. But El Yunque streams flood multiple times a year. An additional issue was that the USDA Protocol relates only to stream health in general and provides little information about whether or not a stream crossing may be causing poor stream health. To determine the negative impact of stream crossings, we needed to compare it to an area without crossings. This untouched area was our control, the undammed Mameyes River. By developing this modified protocol, we created an effective way to evaluate stream health at crossings in a rainforest area.

Understanding the key issues of crossing structures, stream health factors and evaluation protocols will help us determine how streams are being affected by crossings. With this knowledge, we can inform the rangers about how crossings affect stream health and recommend measures to restore the health of the area. This will help the forest rangers maintain the natural ecosystem of El Yunque while allowing for visitor traffic.

2. Background

The streams of El Yunque act as the bloodlines of the forest and serve a vital role in the health of the ecosystem. Stream crossings have been constructed and maintained throughout the forest in order to provide visitors with access to the beauty of El Yunque. Unfortunately, these stream crossings often cause environmental harm, such as decreased vegetation along the stream banks. Due to the potential damage caused by these structures, it is important to protect the ecosystem of El Yunque National Forest by recommending biological and structural improvements that can reduce ecological damage.

In this chapter, we will provide an overview of the rainforest ecosystem, watersheds and stream crossing structures. We will then describe the current methodologies used to evaluate stream health. Finally, this chapter concludes with information on specific issues concerning El Yunque National Forest. This information helped us to understand the complicated ecosystems we are evaluating as well as the potential impacts caused by the crossings.

2.1 Rainforest Ecosystem

Although rainforests only cover about seven percent of the world's land mass, their ecosystems are among the most diverse. Containing one half to two-thirds of the planet's plants and animal species, rainforests have very complex ecosystems (Bierregaard, et al., 1992). These unique ecosystems are a reason that many tropical rainforests are studied and observed closely. One area in particular, the ecosystem surrounding streams, is vital to our study because it is most directly affected by stream crossing structures.

2.1.1 The Riparian Zone

The riparian zone, the land on either side of a river or stream (Freitag, 2010) is the area we will be evaluating in our assessment. According to Freitag, when undisturbed, riparian zones generally have high and steep stream banks, with a fairly consistent stream flow. The water flowing through the riparian zone (when healthy) is clear and contains natural nutrients from leaves, branches, and fallen trees. If the habitat is disturbed, the banks will be undercut, there may be flooding, and the water will no longer be clear.

Overall, a healthy riparian zone provides benefits to the ecosystem. It supplies sediment filtering, bank stabilization, water storage and release, and an important habitat for wildlife (Freitag, 2010). Pusey (2003) states that this zone regulates the transfer of energy and/or material to the other habitats, with which it is connected. He further suggests that the absence of a riparian zone may result in the disruption of the reproduction of animal species and may also have a direct effect on animal mortality rates. In addition, the riparian zone helps maintain the structure of the surrounding habitat, water clarity, and the food-web structure.

According to Lowrance (1984), the riparian zone is an efficient “nutrient sink” and buffers the nutrients that result from the plants and animals living in the surrounding area. The riparian vegetation helps control the movement of sediments and chemicals into river channels, and it serves as a nutrient filter to ensure the uptake of nutrients, but not harmful chemicals. Therefore, avoiding the disturbance of this habitat is very important to stream health and the health of the rainforest as a whole.

2.1.2 Indicator Species in El Yunque National Forest

Indicator species are animals that are sensitive to habitat changes, particularly to pollution (NRCS, 1998). In El Yunque National Forest, forest rangers have developed a list of such species (Table 1) to gauge how well the forest is managed. If we are able to find stable populations of these indicator species, it will indicate that the stream and riparian zones are healthy.

Table 1: Management Indicator Species (Ortega 2010)

Common Name	Scientific Name	Forest Range
Yellow-bearded Anole	Anolis gundlachi	Forest wide
Goby	Sicydium plumieri	All Forest rivers
Mountain Mullet	Agonostomus monticola	Two major Forest rivers
River Shrimp	Macrobrachium carcinus	All Forest rivers

Certain plants may also serve as indicators of stream health. Macrophytes are aquatic plants, growing in or near water (EPA, 2011). A moderate presence of macrophytes indicates good stream health because the plants provide oxygen for aquatic wildlife, as well as food and shelter for these species. An overabundance of macrophytes, however, indicates poor stream health because plant respiration and decaying plant matter consume oxygen from the river. This creates stress for the oxygen-dependent organisms. Great quantities of these plants may also clog the stream and pose a threat to natural organisms (USDA, 1998). Monitoring the presence of these plants will help determine the health of a stream.

2.2 Watersheds

A watershed is an area of land that collects rainfall and other precipitation and then funnels it into a marsh, stream, river, lake or groundwater (USDA, 2007). Watersheds offer a wide array of benefits, including the absorption of snow melt, the slowing of storm runoff, the recharging of aquifers, the filtering of pollutants from the air, as well as providing habitats for wildlife (UDSA, 2007). Since watersheds regulate many vital processes, it is important for our team to understand these processes and the impact stream crossings may have upon them.

2.2.1 Watersheds in Puerto Rico

Ten main rivers and their tributaries form the twelve watersheds in El Yunque. The majority of the streams flow either north or south. In the south, Quebrada Grande runs into the Río Santiago watershed. Río Blanco also flows south of the forest, supplied by tributaries including Río Cubuy, Quebrada Maizales and Río Sabana. Río Gurabo is the final southern river. The northern rivers include the Río Espíritu Santo, which flows northwest of the forest. Additionally Río Mamayes, Río Sabana and Río Pitahaya run north of the forest. Finally, Río Fajardo streams east of the forest with tributaries Quebrada Grande and Quebrada Sonadora. Río Juan Martín also flows eastwardly. Río Canóvanillas runs to the west near the other western river, Río Canóvanas (Weaver, 2011). Although Figure 1 illustrates many of these rivers, the watershed areas have been re-defined since 2007 to include streams in the surrounding area, such as the Río Herrera and Río Juan Martín.

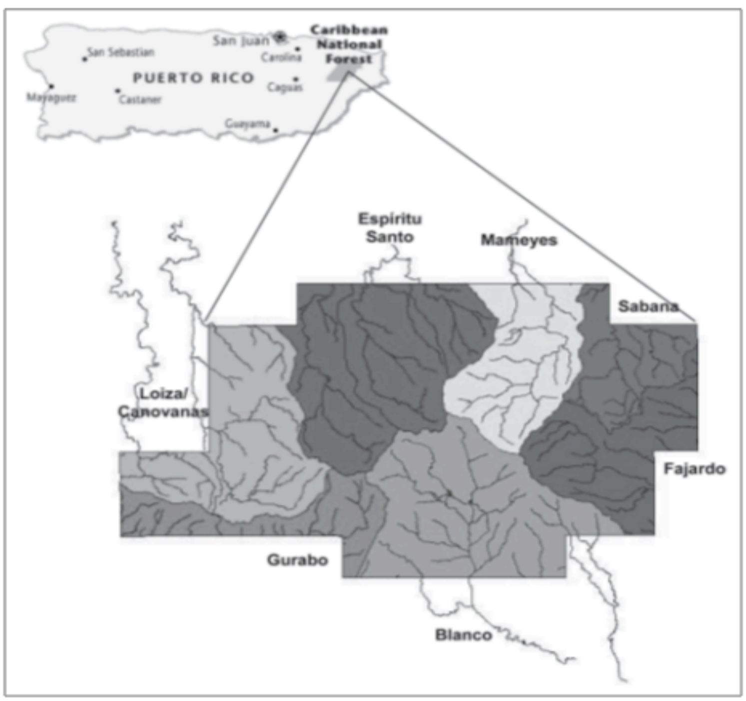

Figure 1: Watersheds of El Yunque (Crook et al., 2007)

2.2.2 Stream Modifications

Stream crossings are not the only human modification that can negatively impact streams. Almost all of the twelve watersheds are dammed in multiple places. The only exception is Río Mameyes, which is not dammed anywhere along its length (Pedro Rios, personal communication March 15, 2011). However, most rivers have an extraction or withdrawal where water is piped for public use. Withdrawals come in various sizes, ranging from small to large enough to power a hydroelectric plant (Benjamin Fuentes, personal communication, March 24, 2011). Withdrawals alter the flow of the stream and often negatively affect the ecosystem. The locations of extractions (Crook et al. 2007) operating in 2002 and assumed to operate now were plotted using the Google Earth application in Figure 2. Knowing the locations of these extractions aids in determining how much the flow of the river is altered, with a potentially negative impact on the surrounding environment.

Figure 2: Extraction Sites

2.3 Crossing Structures

In order to recommend an effective type of crossing at the end of our project, our team needs to compare the different structures used in El Yunque. These structures could pose specific problems, such as sedimentation or barring migration of fish.

2.3.1 Stream Crossing Classifications

According to the Transportation Structures Handbook (1994) the three main types of crossings include bridges, major culverts, and minor culverts. The handbook defines a bridge as, "a road or trail structure, including supports, erected over a depression or an obstruction, such as water, road, trail, or railway, and having a deck for carrying traffic or other loads" (US Forest Service, 1994). It defines a major culvert as one that has an opening or multiple openings greater than thirty-five square feet including a single round pipe, an arched pipe, box culverts, and arched culverts. Minor culverts are any culverts not classified as a major culvert. These culverts can be placed next to each other or they can be placed continuously when necessary. According to the handbook (1994), culverts and bridges are also classified as short-term or long term. Short-term structures are implemented for only a short time, five to fifteen years depending on the area and the materials used in construction. Contrastingly, long-term structures are intended to be permanent, forty to fifty years or longer of service depending on the materials used.

When stream crossings are part of trails, more specific classifications can be used such as those defined in the Forest Service Trail Bridge Matrix (2007). The matrix states that trail bridges are classified under three divisions for the purpose of inspection and include: complex trail bridges, major trail bridges, and minor trail bridges (US Forest Service, 2007). Complex trail bridges and major trail bridges are greater than twenty feet in span and have a height from the stream channel or ground of at least five feet. The matrix (2007) also explains that complex trail bridges include all truss, suspension, multiple-span, and non-timber/log bridges. However, major trail bridges with major defects and complicated minor trail bridges are also considered complex. Major trail bridges include all single-span timber/log trail bridges but may also include minor bridges that have increased complexity or user safety concerns, such as short bridge over a deep gorge. Minor trail bridges are classified as being all trail bridges that do not meet the standards of a complex trail bridge or major trail bridge. Minor trail bridges also do not include boardwalks and other similar structures (US Forest Service, 2007).

Identifying these structures is vital to our project. Comparing different types of structures is how we will determine which structure is least harmful to the environment.

2.3.2 Environmental Impacts of Bridges and Culverts

There are two major types of crossings used to traverse rivers and their tributaries, bridges and culverts. Like most man-made structures, these crossings tend to interfere with the local environment in various ways.

One common problem of crossings is sedimentation, where soil builds up before or after the crossing. This can be detrimental to the environment since the sediment deposits change the natural flow of the stream, such as when they block a culvert pipe or build up at bridge banks. In 2000, a study by Wellman (2000) in Tennessee compared the relative sedimentation deposits of bridges and culverts. He concluded that culverts had greater sediment deposits. However, this sediment depth was not problematic enough to impact fish communities.

Fish and other macroinvertebrates can be impacted by stream crossings, however. If sediment builds up, the fish will no longer be able to pass under a bridge. Other structures, such as a dam or a drop structure also inhibit fish movement (NRCS, 1998). If fish or other animals cannot pass under a crossing, it can negatively impact the local ecosystem.

The most common problems associated with stream crossings are sedimentation and barriers to fish movement. Anything that changes the natural flow of the stream tends to have a negative impact. Therefore culverts and bridges need to be designed so that they alter the flow as minimally as possible. In the case of El Yunque, we hope to recommend stream crossings that have small effect on the alteration of flow.

2.3.3 Stream Crossing Regulations

In certain places, specific regulations are put into place regarding stream crossings. The state of New York follows very specific guidelines set forth by the Department of Environmental Conservation with the aim of limiting the environmental impact of stream crossings. These standards establish that bridges and bottomless arches are the best type of crossings to use. If box and pipe culverts are used, they must be embedded into the streambed to at least 20 percent of the culvert height at the downstream culvert. The must be used only on “flat” streambeds with slopes no steeper than 3 percent, and they must be installed level as seen in Figure 3.

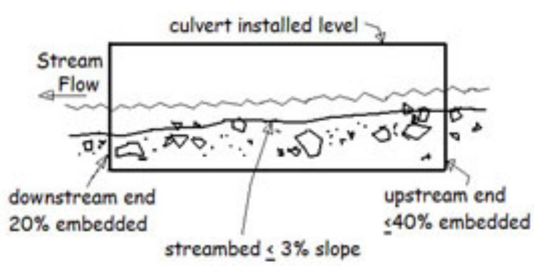

Figure 3: Proper Placement of a Culvert According to the DEC (DEC, 2011)

Additionally, the NY state regulations also require that the crossing opening should be at least 1.25 times the width of the stream channel bed as seen in Figure 4.

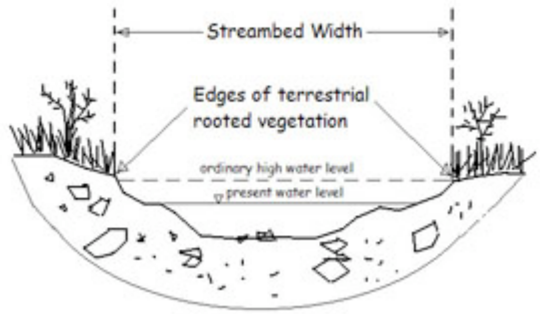

Figure 4: Proper Width of a Stream Crossing According to the DEP (DEP, 2011)

In terms of stream depth and velocity, the NY state regulations require that these factors in streams affected by crossings should remain the same as those of natural areas upstream and downstream of the crossing. It requires that the substrate used within the crossing should match substrate up- and downstream of the crossing (DEC, 2011). Although these standards apply particularly to New York, the general ideas can also be applied to Puerto Rico. During our assessments we can observe whether or not the crossings follow these standards. If they do not, we can recommend that similar standards be introduced to Puerto Rico.

2.4 Evaluation Protocols

In order to understand the impact of stream crossings, we must assess the health of the stream. Although many studies have been done on the topic of stream health, there is little consensus about which variables to test. Some complex studies look at the micro-bacterial make-up of the region. For example, Bunn, Davies, and Mosisch (1999) determined stream health based on measurements of gross primary production and respiration. Other simpler studies visually assess larger scale variables. For example, De Jesus Crespo and Ramirez (2010) determined stream health based on the variety of species of macroinvertebrates that were observed. The complications lie in the fact that there are many variables that can be tested, but little agreement as to which are the most important. Each team of researchers has to evaluate the variables for themselves.

2.4.1 Stream Health Factors

One highly technical way that stream health can be determined is the "benthic metabolism" of the river ecosystem (Bunn, et al., 1999). This metabolism is related to the production, Gross Primary Productivity (GPP), and consumption, R^{24}, of carbon. There is a baseline ratio of production to consumption that is considered healthy according to Bunn and his colleagues (p. 341). When the ratio fluctuates due to overgrowth or elimination of certain microorganisms, scientists can determine if the stream is unhealthy by comparing it to world standards.

A less complex evaluation of stream health is a mixture of both chemical and visual assessment. De Jesus Crespo and Ramirez (2010) conducted such a study in Puerto Rico. They used the Hawaiian Stream Visual Assessment Protocol along with the Biotic Index, Simpson's Diversity Values and a water quality test. Both the Biotic Index and Simpson's Diversity values are an analysis of the mammals and insects found in the area. In this evaluation, a stream is also considered healthy if there is at least one intolerant species dominant in the environment (USDA, 1998). This idea is also used in the official USDA Stream Visual Assessment Protocol, the foundation for the Hawaiian Stream Visual Assessment Protocol.

The USDA Stream Visual Assessment Protocol (1998) was developed in the Pacific Northwest for landowners to evaluate stream health on their property. It is quite basic, but it covers a multitude of factors. The backbone of the assessment is a scoring sheet that ranks different factors on a scale from one to ten, where a score of ten is a healthy stream, and a score of one is an unhealthy stream. The scores are easy to evaluate because there is a definite visual cue for each given score. The major drawback to this assessment is that it is very general and must be modified for each stream assessed. For example, flooding patterns are different in Puerto Rico, so we cannot use flooding patterns to determine health. Instead we have to focus on other factors. Also, there is not a widely accepted value for a healthy stream. A stream is considered healthy if its average score is in the top ten percent.

Boulton (1999) states that there is no consensus on which factors should be evaluated to determine stream health. Each stream is unique, and evaluation factors should be chosen for the specific site and technological capabilities of each assessing team. Our team needs to account for differences between Puerto Rico and the Pacific Northwest, such as dissimilar flood patterns.

2.4.2 Evaluation at Stream Crossings

Although each stream should be evaluated as a unique entity, stream crossings cause similar problems at many sites. In addition to sedimentation and barrier issues mentioned before, other problems include coverage of the streambed by unnatural materials, constriction of flow and water runoff (Jackson, 2003). However, none of the assessments researched revealed a way to evaluate these factors. Instead, our assessments look for deterioration of other stream health factors, such as channel condition or flow alteration. To properly assess El Yunque National Forest's watersheds, we will need to focus upon the health factors that reveal this ecosystem's decline.

2.5 El Yunque

Puerto Rico is home to the only tropical rainforest in the US National Forest System, El Yunque National Rainforest (USDA, 2011). This 28,000 acre forest includes the Luquillo Mountains, which rise to 3,533 feet above sea level and sometimes receive over 200 inches of rain annually. El Yunque's average temperature of 73° F and extraordinarily slight seasonal changes make it the perfect habitat for 150 fern species and 240 tree species. El Yunque is divided into four forests: Tabonuco Forest, Palo Colorado

Forest, Palma Sierra Forest and En Las Nubes Forest. Understanding the forest we're helping to preserve will help us to evaluate streams more accurately.

2.5.1 Tourism in El Yunque National Forest

Many tourists each year travel to El Yunque National Forest. To accommodate for this influx of people, stream crossings had to be built to allow the visitors to explore the rainforest. Without tourism, stream crossings would not be as necessary.

According to the US Forest Service website (2011), the El Yunque National Rainforest has about 1,250,000 visitors a year who enjoy the marvels of the rainforest. El Yunque boasts many hiking trails including the hike to the Mount Britton Observation Tower, El Toro Trail and the Trade Winds National Recreational Trail, all of which offer magnificent panoramic views of the surrounding forest as well as the Caribbean and Atlantic Oceans. The forest also has many streams, rivers and waterfalls including La Coca Falls and Juan Diego Creek. The rainforest also offers four picnic areas: Sierra Palm Recreation Site, Palo Colorado Recreation Site, Camitillo Recreation Site, and Quebrada Grande. These many attractions often require stream crossings to be built. Knowing the roads and their amount of use can help us determine the impact of stream crossings.

2.5.2 Current Challenges in El Yunque

The health and ultimate survival of Puerto Rico's El Yunque National Rainforest is under constant threat from many areas. One of the most prevalent problems in El Yunque, as well as for rainforests in general, is the problem of habitat loss and destruction due to deforestation for commercial purposes. According to Ecoscenarios (2011), each hour about 9,000 acres of rainforest are cleared somewhere in the world (p. 7). This constant deforestation also creates runoff, which results in pollution of the rainforest's watersheds and streams.

The installation of stream crossings for the benefit of tourists and vehicles is also posing a threat to El Yunque's ecosystems. Stream crossings may negatively affect a stream environment via flow alteration, channel condition change, increase in water velocity, etc (Prof. John Bergendahl, personal communication, Feb. 11, 2011). Various regulations have been put into place to limit the effect of stream crossings on the rainforest stream environments.

2.6 Summary

Stream crossings are a potential challenge to any forest environment. In the rainforest, they can heavily impact the riparian zone and stream ecosystem. However, each watershed is distinctive and reacts differently to stream crossings. It is important that our team become familiar with each watershed and the modifications made to it. With this knowledge, we can choose and adjust an assessment to suit the unique conditions in El Yunque National Forest.

3. Methodology

The major objective of our project was to assess the damage due to stream crossings in each of the twelve watersheds in El Yunque and provide recommendations for structures that have the least environmental impact on their streams. This evaluation also achieved our second objective of gathering ecological information for the El Yunque National Forest database because we will also be documenting stream health and crossing location throughout our assessment. For our project, we observed fifteen stream sites in and surrounding El Yunque National Forest. The assessment used documents and photographs as evidence. Using these tools and an evaluation protocol, our group hoped to discover the impact of stream crossings on the local ecosystem and add to the park's ecological database.

3.1 Stream Evaluation

To determine the most effective stream crossing, our group evaluated the amount of damage done to the environment at each stream crossing. Due to time and technology constraints, our methods were simple. Sites with stream crossings (impacted sites) were evaluated according to the USDA Visual Stream Assessment Protocol (Appendix A) with some minor modifications. These impacted sites were compared to a control river (in this case, the Río Mameyes) that had been less affected by crossings and damming. This method of comparative analysis was crucial to our project because comparing the data from our stream sites to the control has helped us to gauge the overall impact of stream crossings on their environments. Also, comparing parts of stream health to other factors such as crossing location, stream orientation, and stream size has made several trends and patterns visible in terms of stream health. This has helped us to infer conclusions not only about our assessment protocol, but also about how various qualities of different stream crossings affect the health of their streams.

3.1.1 Site Mapping

Due to time restraints, our team had to carefully choose the sites assessed. Our objective was sampling each of the twelve watersheds in El Yunque at three different elevations, both in and out of the forest area. We also had to choose multiple control sites, so that we had an assessment of the control river, Río Mameyes, at each elevation range. The elevations were chosen based upon which areas were accessible. The elevation ranges chosen are shown in Figure 5, where low elevation sites are shown in green, mid elevation are shown in yellow and high elevation sites are shown in red.

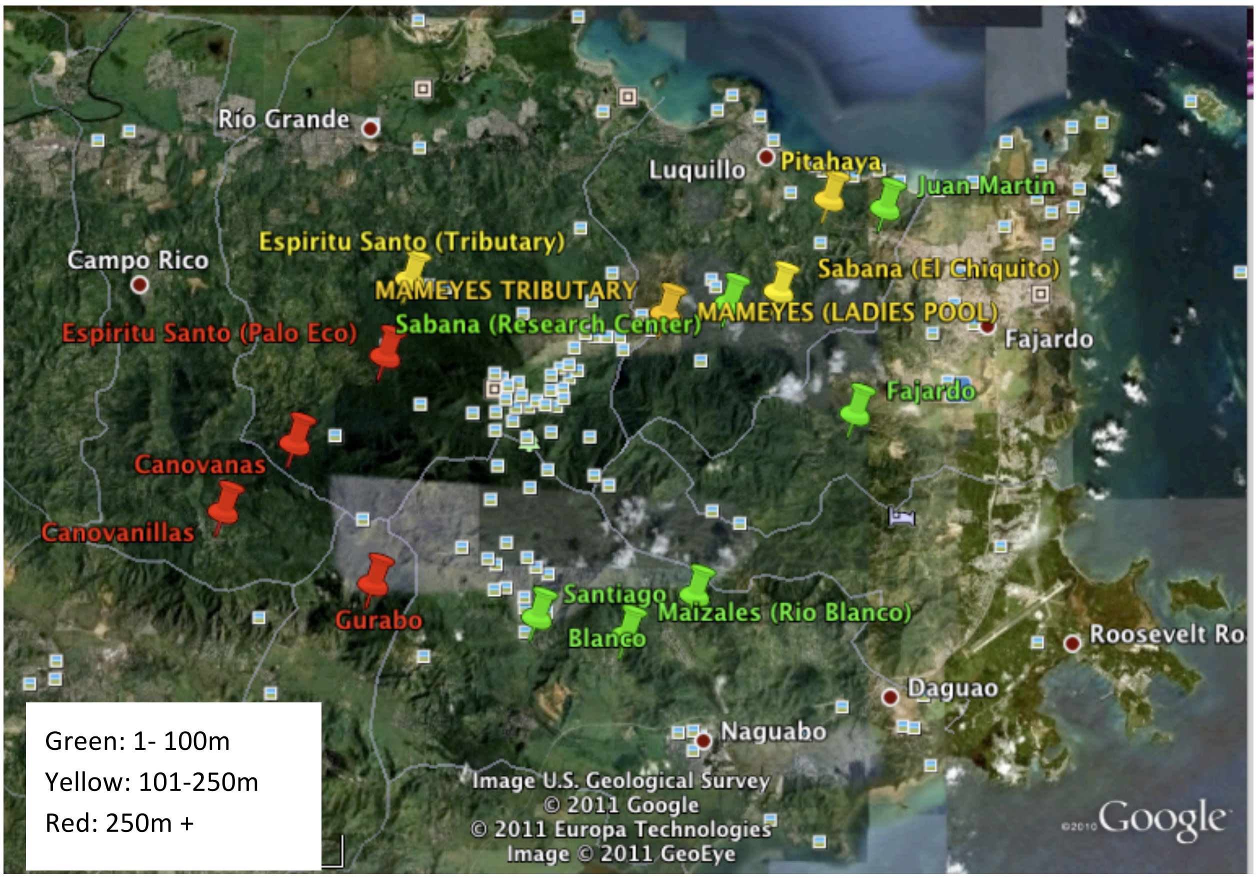

Figure 5: Stream Assessment Sites Elevation

3.1.2 Evaluation Protocol

The basis for our evaluation was the USDA Visual Stream Assessment Protocol (1998), which was chosen for its simplicity and the minimal technology required. The protocol gave instructions for assessing the health of a stream through observation. Users of this method can evaluate fourteen different factors that impact stream health by visually scoring them from one to ten (NRSC, 1998). The scores are then compiled and averaged as shown in the USDA Visual Stream Assessment Protocol (1998). This method has been developed for use anywhere in the United States.

Since the United States covers a great variety of ecological regions, some modifications needed to be made to develop this generalized protocol for El Yunque National Rainforest and stream health at crossings. A WPI environmental civil engineering professor, John Bergendahl (personal communication, February 10, 2011), pointed out that water runoff was an important aspect to evaluate at stream crossings. Water runoff that changes the speed of the river needs to be evaluated because a large amount of runoff would negatively impact the stream environment. Since the USDA Protocol does not account for this factor, we developed our own evaluation standard (Table 2). Due to lack of tools that measure water velocity, the El Yunque transportation engineer, Manuel Cruz (personal communication, March 17, 2011) suggested that we measure the amount of debris present in drainage structures. More debris implies greater water velocity. This observed data is reflected in our evaluations standard shown below.

Table 2: Runoff

Score: 10	Score: 7	Score: 3	Score: 1
No debris	Little to no debris	Some debris	A lot of debris

Other modifications were made to USDA Protocol factors. For the macroinvertebrates observed, freshwater shrimp and freshwater mullets were used as intolerant species indicators instead of caddis flies and mayflies. This modification was made because different species are present in the rainforest under study. Additionally, hydrologic alteration was limited to the presence of withdrawals instead of the amount of flooding. The protocol was not made for streams that flood multiple times a year due to heavy rainfall. Besides these few factors, we were able to use the USDA Protocol in its original form.

3.1.3 Interviews

To obtain the information required to make the modifications to the USDA Stream Visual Assessment Protocol, our team conducted both formal and informal interviews with several specialists working within the Forest Service and at WPI.

Professor Bergendahl of WPI explained general stream crossing structure and its effect on the surrounding environment. Also, within the Forest Service, engineer Manuel Ortiz provided us with information on the specific stream crossing structures we would find in El Yunque as well as the associated environmental issues that the forest faces.

Felipe Cano and Luis Rivera, the Forest Service Biologist and Tropical Vegetation Specialist respectively, informed us of the organisms and plant species that we should expect to find in El Yunque's stream environments. They provided us with information on the specific species that serve as indicators of both good and poor stream health. This helped a great deal in the modification of several biotic factors in the assessment protocol.

El Yunque's Archaeologist, Jeff Walker, informed us that many of the stream crossings within the forest had been built by the Civilian Conservation Corps (CCC) in the early 1900's, and that this organization paid particular attention to the environmental impacts of the crossings they installed. He also cautioned that these crossings couldn't be structurally modified because they have historical significance.

Our sponsor, Pedro Rios, Ecosystem Management and Planning Team Leader of the Forest Service, discussed with us the breakdown of the watersheds in El Yunque and the best way to execute our research.

In a less formal setting, Forest Rangers Benjamin Fuentes and Anastacio Gomez brought us on tours of the forest trails and stream crossing sites, providing crucial hands-on experience and information regarding the rainforest environment that has proven helpful in the accurate assessment of the streams.

Selected interview protocols and full interviews can be found in Appendices C and D.

3.1.4 Geographic Information System (GIS)

After we identified our sites and carried out our assessments, we delivered our data to the Forest Service for inclusion into existing GIS files. Geographic Information System (GIS) is a useful tool that allows the user to create a layered map of any and all types of geographic information and to later view and analyze as well as update this data. The Forest Service located in El Yunque recently completed a compilation of information on the watersheds in and around El Yunque. Our results will add to this database and be available for the Forest Service to input into their GIS database. El Yunque's Forest Service division should be able to access our information and assessment data on all of the stream crossings we evaluated. They will be able to use this data to monitor each crossing as well as to make recommendations on future stream crossing replacements.

3.2 Summary

Determining the effects of stream crossings on their environments and how much damage has been caused by them was a difficult task to perform. We began by choosing sites to examine from all twelve watersheds and multiple elevations and then assessed these sites in accordance with the USDA Visual Stream Assessment Protocol (1998). We gave this information to the Forest Service to be added to existing GIS files previously assembled. We supplemented the information we collected on stream crossings with observational data gathered in the field. After extensive data analysis, we made recommendations on which stream crossings in and around the El Yunque National Forest had the least detrimental effect on the surrounding environment.

The recommendations that we have made focused on the assessment protocol itself, the types of crossings that had the least detrimental effect on their streams, and restoration methods for the worst crossings. We have surmised that the protocol used worked best for medium-sized streams. We have also suggested that streams built by the Civilian Conservation Corps mostly within protected areas can be used as models of efficient stream crossings. Finally, we have provided recommendations on the specific factors that should be focused on when restoring unhealthy streams in general, as well as the three unhealthiest streams specifically.

We hope that these recommendations can be used to improve the quality of existing and future crossed streams in El Yunque.

4. Results

At the end of our data collection, we had the scores for fifteen evaluation factors at fifteen different sites, which included eleven of the twelve watersheds (Río Herrera was not assessed because of time constraints). Due to the nature of the USDA Protocol, one or two factor scores did not give an accurate estimate of the stream health. For example, salinity is one of the factors used in the protocol; but throughout our interviews we have gathered that excess salt is not an issue in El Yunque and it was not scored. Additionally, our added factor of runoff was difficult to score at streams. To get an idea of stream health as a whole, the scores were averaged. The results were then broken down into categories based on the differences in elevation, stream size and crossing type. Groups of factors were also used to compare biological versus geomorphic characteristics, where the biological factors were a measure of the health of the organisms and environment of the streams and the geomorphic factors were a measure of the physical health of the stream.

4.1 Stream Health Averages

Before looking at specific areas and factors, our team analyzed stream health as a whole. According to the USDA protocol (NRCS, 1998), the total health (Figure 6) is the average score.

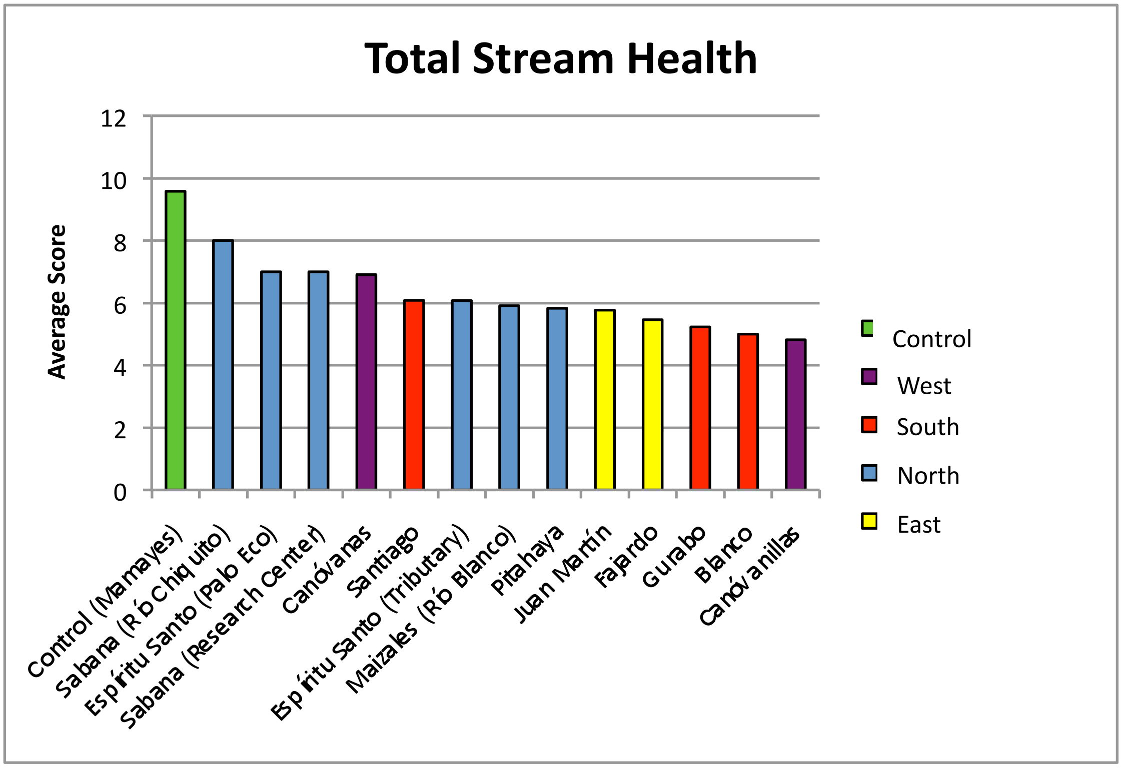

Figure 6: Total Stream Health Graph

This graph displays the average stream health scores for fourteen assessment sites. The control's health was assessed at two locations and averaged into the final score shown in green. The streams are shown in order of decreasing health, where the control is the healthiest and Río Canóvanillas is the least healthy. The stream scores are further broken down according to the direction of flow; see the legend on the right. As whole, the northern streams were the least impacted by human activity. The southern and eastern streams were more heavily impacted on the whole than the northern streams. There was no correlation between the two western streams; one was healthy and the other was the unhealthiest of all of the streams.

4.1.1 Comparisons in Size and Elevation

In order to recommend what stream areas need improvement, stream health was compared across various sizes and elevations (Figures 7 and 8). The comparison was also used to determine if the USDA protocol analysis favored a particular size of stream. For example, we were concerned that some of the factors were biased toward larger streams because we had a difficult time finding macroinvertebrates in smaller streams.

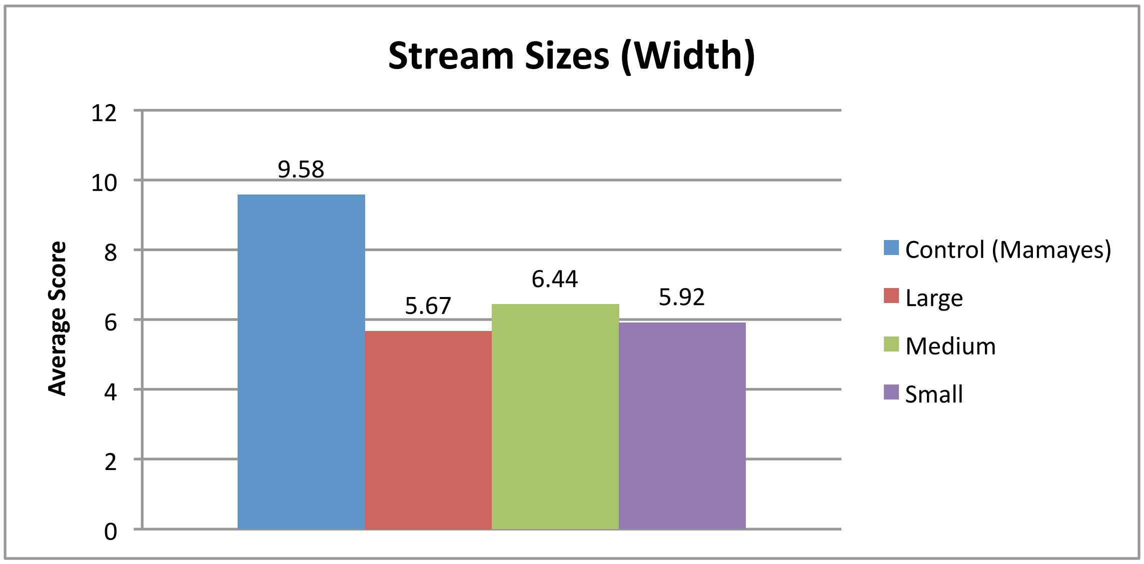

Figure 7: Stream Size Comparison Graph

The above figure was determined by averaging the scores of the streams in each category of large (greater than 20 ft. across), medium (5ft – 20ft across) and small (less than 5 ft. across). The averages were found for four large rivers, six medium rivers and three small rivers. The medium streams had the highest average, but not by a large amount. The average scores of the large and small streams were quite comparable. However, of the three unhealthiest streams, two were large rivers (Río Blanco and Río Gurabo). Two medium-sized streams, the two Sabana locations, were among the top three healthiest streams.

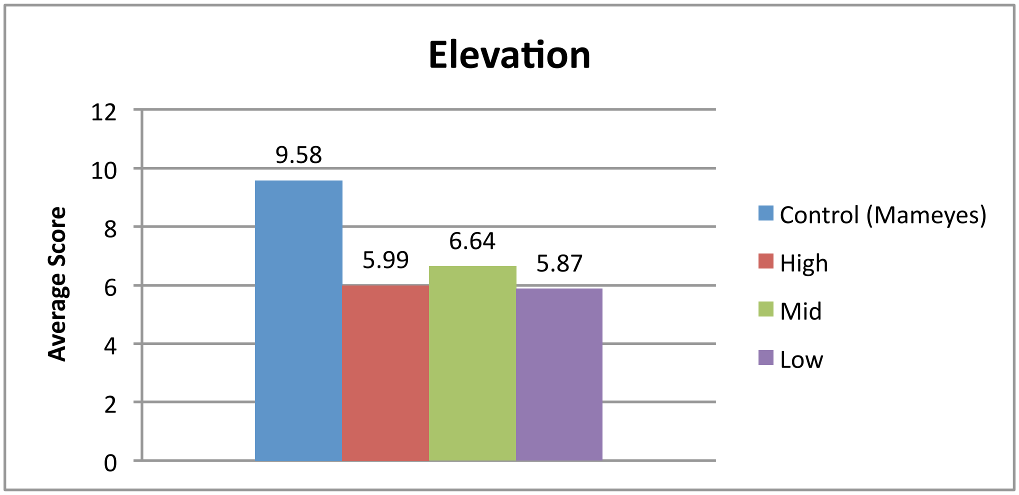

Figure 8: Elevation Comparison Graph

The average scores across three elevations are shown in Figure 8. The elevation ranges were broken down as follows: low (1-100m), medium (101-250m) and high (251m +). Six low rivers, three mid-elevation rivers and four high rivers were used in this analysis. The average scores are similar across all three elevation ranges. Additionally, the three healthiest streams and the three unhealthiest streams all contain one river at each elevation. All the elevations have the similar distributions of healthy and unhealthy streams.

When stream health is compared across stream size and elevation, few patterns emerge. Large streams did tend to score lower on the whole. There were also two large streams in the three unhealthiest streams. However, there were no discernable patterns across elevation (12m-575m). Each elevation range had a similar number of health and unhealthy streams, though the mid-elevation streams did have the highest average. The medium-streams and mid-elevation streams had the highest averages.

4.1.2 Comparisons across each Regional Area

One objective of this project was to look at stream crossings in all three regional areas: protected rainforest, unprotected rainforest, and coastal land to see which areas have the healthiest stream crossings. The coastal area is the outermost land type and it is located outside of the rainforest. This zone is more settled than the others. The next regional area is part of the rainforest; however, it is not protected by the government so it has private human settlements. The unprotected forest lies in rural area. Finally, the innermost zone is El Yunque National Forest itself, which is protected by the government.

We assessed three stream crossings in the protected area, five in the unprotected area, and five in the coastal area. The average score of each is shown below in Figure 9.

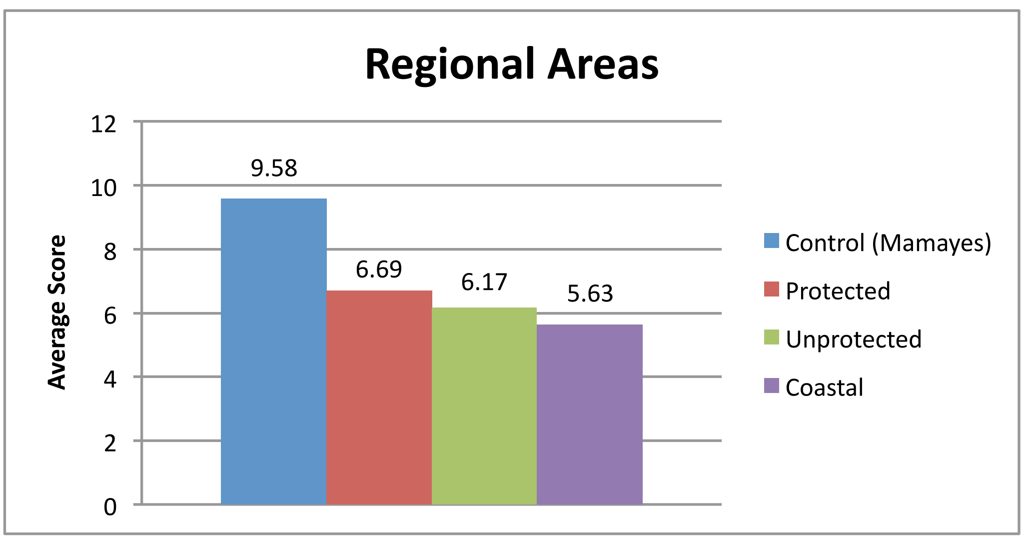

Figure 9: Trends across Regional Areas Graph

Our data revealed the trend that we expected; the stream crossings in the protected rainforest zone had the highest average, followed by the stream crossings in the unprotected forest, and then by the stream crossings in the coastal zone. The average scores of stream crossings in the protected forest had a range of 0.92, showing that the stream crossings affect stream health similarly in El Yunque.

However, the stream crossings in the unprotected forest have the largest range; they had both the highest and the lowest score with a range of 3.18 (refer to Appendix E, Figure 24). This shows that the crossings in the unprotected region of the rainforest are not consistent. Finally, the stream crossings in the coastal region have a range of 1.08. These stream crossings have consistent low scores.

Although there was a great diversity of river health, some regions proved to have consistently higher or lower scores. Breaking down the rivers by different regions displays clear patterns of health, and shows that our team needs to concentrate restoration recommendations for the stream crossings in the coastal regional area.

4.1.3 Comparisons across Structural Types

The major purpose of our project is to determine if a particular structural type is less detrimental to the environment. We encountered two basic structure types, bridges and culverts. However, the culverts presented themselves in a variety of types: split culverts, one-pipe culverts and drop culverts. The bridges varied in size, but usually not in design. We assessed four culverts and nine bridges. The average scores for each structural type are shown in Figure 10 (next page).

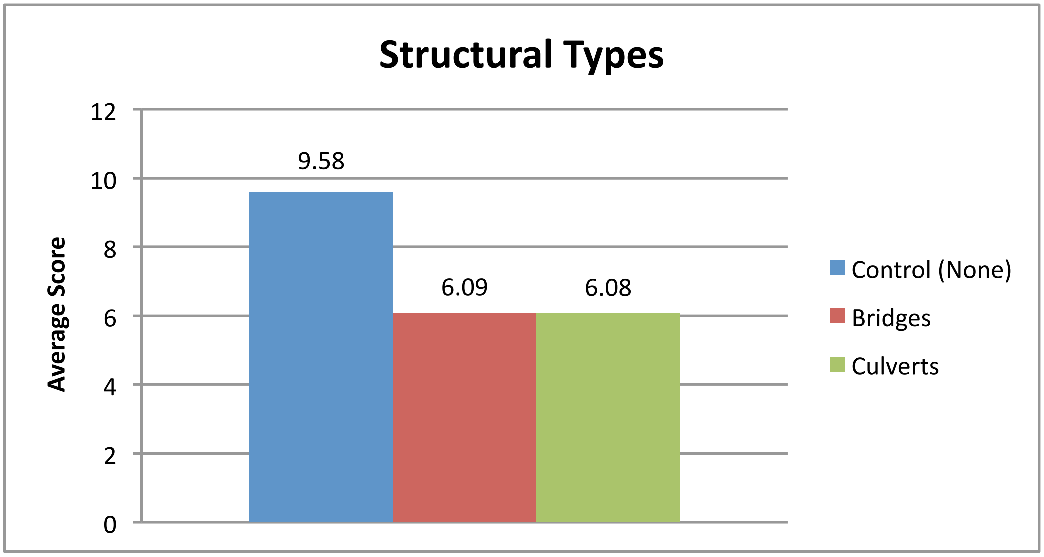

Figure 10: Structural Type Comparison Graph

Bridges and culverts had almost the same average score. The difference was much less than one percent. However, all of the culverts had similar scores. The lowest score was 5.23 and highest was 6.91, a range of 1.68. By contrast, bridges had both the highest and lowest scores of the streams with a range of 3.82. Culverts were not present in the three healthiest streams and only one of the three unhealthiest streams was a culvert. Although the averages are nearly the same, bridges have a greater diversity of stream health than the culverts. There was no correlation between stream health and crossing structure for our team to base our recommendations upon.

4.2 Stream Health Factor Groups

Although average scores most accurately define the streams' health, our team also analyzed individual factors. Sometimes, one or two factors caused an average score to be extremely low or high. In this section, our project team averaged each factor and grouped them into geomorphic and biological sub groups (see Figure 11). These breakdowns reveal what factors in particular need to be improved at stream crossings.

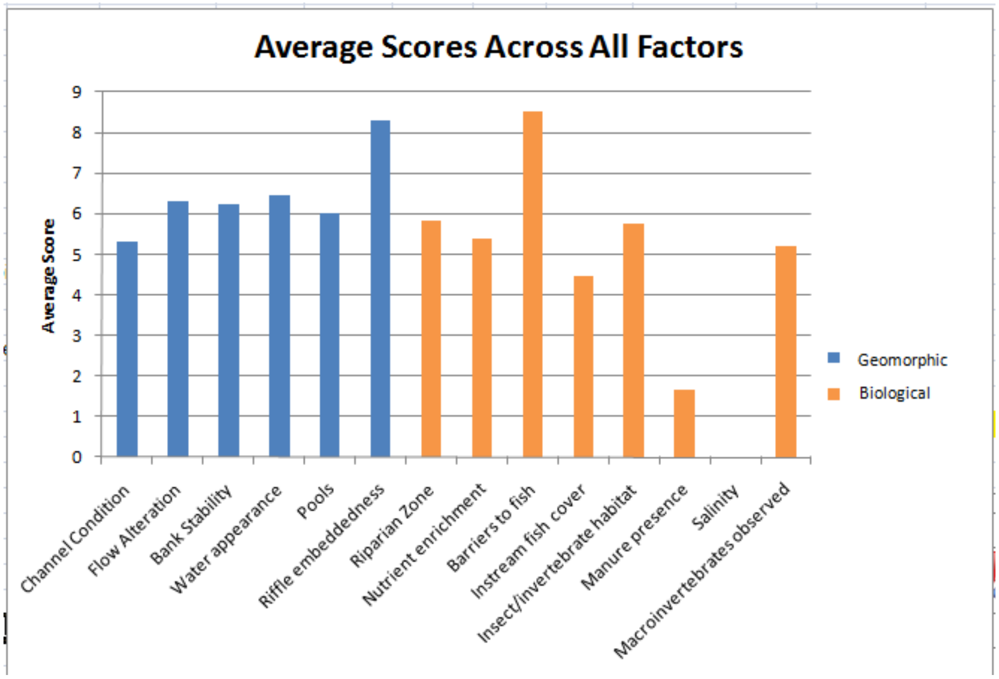

Figure 11: Average Scores of All Factors Graph

The purpose of this graph was to analyze patterns across all the evaluation factors because factors with low scores could point to unhealthy trends across all the rivers. However, the factor with the lowest score was manure presence, which is a skewed factor. It was only scored if there was possible manure presence and not scored if there was no manure, so it was only graded at unhealthy sites. Other low scores included in-stream fish cover, macroinvertebrates and channel condition. However, even the control recorded lower scores for in-stream fish cover as well as nutrient enrichment. The highest scores belonged to barriers to fish and riffle embeddedness. These averages display how each factor scored across all the evaluated rivers.

As shown above, the highest and lowest factors are a mix of geomorphic and biological factors. The geomorphic factors are all a measure of the physical health of the stream and the biological factors are all a measure of the organism and environmental health of the stream. The factors were broken down in to these two factors and graphed to visualize correlations (Appendix E, Figure 25). In about half the assessments, the two data series had a difference of one or less between them. However, Río

Gurabo had a difference of over 4.5. In this case, even though the river was geomorphically healthy, the biological health of the area was in poor condition. Although this was most pronounced at Río Gurabo, nine of the fourteen assessment sites (64%) had higher geomorphic scores than biological. This correlation points to the need to focus on biological improvements, since a healthy geomorphic score doesn't necessarily mean a healthy river.

4.3 Individual Site Analysis

In addition to analyzing all the streams, our team closely analyzed the least healthy rivers for common factors, such as flow alteration and in-stream fish cover. Again, the factors were averaged, but only across three rivers this time (Río Gurabo, Blanco and Canóvanillas). The results are displayed in Figure 12.

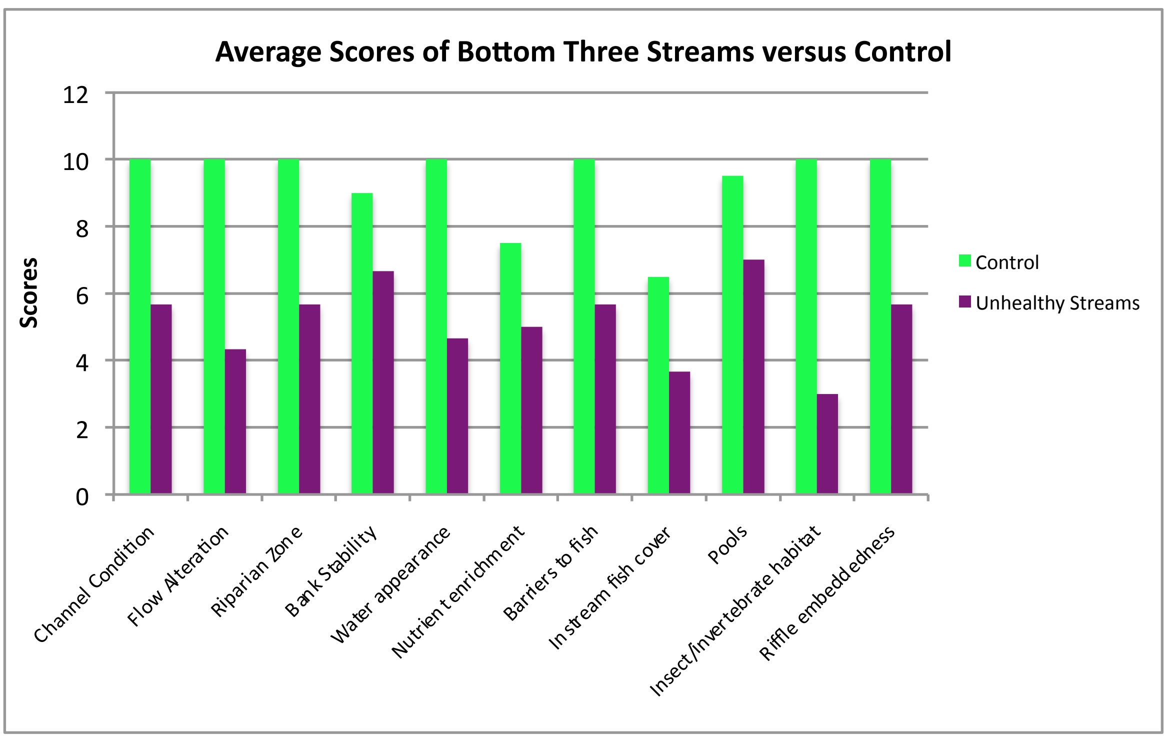

Figure 12: Graph of Average Factor Score of Worst Streams versus Control

This graph shows the average scores for the unhealthy rivers as well as how the scores compare to the control. The lowest scores for the worst streams are registered in insect and invertebrate habitat, in-stream fish cover and areas of flow alteration. The smallest differences between the two data sets were bank stability, pools and nutrient enrichment. The biggest dissimilarity was in insect and invertebrate habitats, where the averages were seven points apart. Other large deviations included flow alteration and water appearance. The factors with large differences display the most notable discrepancies between healthy and unhealthy streams, which helped determine what factors need to be improved. However, it must be noted that these are averages. Sometimes one river in poor health scored lower or higher than another. For example, although the water appearance average is low for unhealthy streams, Río Gurabo scored an eight, which is a high score. This led us to evaluate the three worst rivers separately, concluding that they have unique problems that cause poor health.

Each of the three unhealthiest rivers had one factor in which they all scored a one, the lowest score possible. For Río Canóvanillas, it was water appearance. Río Blanco scored extremely low in riparian vegetation and Río Gurabo had a barrier to fish movement (a drop culvert). The visual difference between these low scores and the perfect scores of the control (10) are shown in Figure 13.

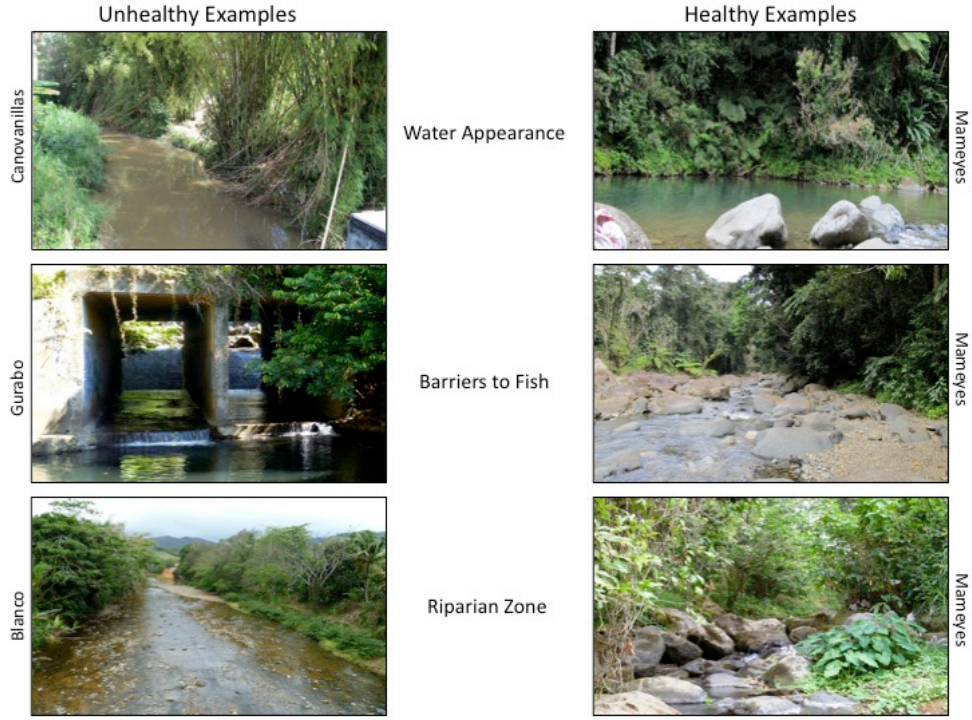

Figure 13: Visual Differences between Healthy and Unhealthy Streams

Although the river is evaluated as a whole, sometimes one or two factors can change the overall average of the score. Even in the almost perfect controls, low scores were obtained for in-stream fish cover and nutrient enrichment. For our worst streams, all three of them were given a lower average due in major part to one score. Knowing these correlations helped us to develop better recommendations for individual streams as well as for the watersheds as a whole.

4.4 Conclusion

Although we analyzed the streams through many different perspectives (elevation, regional area, size etc.), only a few patterns emerged. Some were expected, such as the healthier stream sites were located in the protected area of El Yunque. However, there was no particular area or stream size that dictated restoration recommendations. Instead, as our research confirmed, each stream has unique problems and needs to be evaluated individually. These analyses will help us develop recommendations, which are discussed in the next section, for the twelve watersheds that will improve the health of the streams that were impacted by the stream crossings.

5. Discussion

The results discussed in the previous section will help us recommend the best restoration techniques. It will also help the US Forest Service pinpoint which areas and particular rivers need the most attention. In this section, we discuss the trends and provide an analysis of them. We have also analyzed the three unhealthiest streams and provided recommendations for restoration techniques.

5.1 Patterns in Stream Health Averages

After observing several stream crossing features (such as stream size, stream orientation, stream elevation, and crossing type) and their relation to overall stream health, we found that medium-sized streams, streams that flow northward, and streams in a protected area tend to have the best overall stream health. No correlation was found in terms of stream elevation or crossing structure type.

One of the purposes of this project was to assess the environmental damage of stream crossings on overall stream health. It was necessary, therefore, to measure a control area to prove that this negative impact does in fact exist. Our control, Río Mameyes, is undammed and considered pristine. Thus, we expected this site to have the best stream health when compared to the affected sites. The average of the scores for two sites along the Mameyes amounted to a higher score than that of the affected sites, as can be seen in Figure 6. This correlation suggests that the stream crossings in El Yunque are having a negative impact on stream health.

Medium-sized streams not only generated the highest average score (Figure 7), but also showed a positive correlation with overall stream health. This may be associated not with the impact of the crossings found across medium-sized streams, but with the fact that the USDA Stream Visual Assessment Protocol may be more suited to the evaluation of streams of this size. Streams that were small proved difficult in terms of macroinvertebrate observation, an important factor, because the water in these streams is shallow. This affected the observation of other factors as well. The protocol may also be unsuitable for large rivers because accessibility to the water is limited when the stream or river reaches a certain width. We recommend that if this protocol is used in the future, that it be used mostly for medium-sized streams where there is access for observation along the entire stream environment.

When comparing the directional flow of each stream to its overall health, steams that flow northward tend to be less affected by their crossings (Figure 6). This may be because crossings over northern-flowing rivers are located mainly inside the protected forest. Many of the crossings along these rivers were built by the Civilian Conservation Corps (CCC). This is an organization that engaged in extensive research before it built crossings, deciding upon the ones that would be most environmentally efficient, according to El Yunque's Archaeologist (personal communication, Apr. 8, 2011). For further research into the best type of stream crossing, it is our recommendation to observe these specific crossings in terms of structure, width, depth, placement, etc., as they have shown through our data set to have a less detrimental effect on the stream environment. Crossings in the south and east tended to have lower scores because they are located in either coastal or unprotected areas, which tend to be more populated.

When observing stream health in relation to the type of area in which the stream is located, we have found that the crossings that are located in protected areas have less of an impact on the ecosystems compared to those in unprotected or coastal areas. This may be because protected areas contain stream crossings built by the forest service, which are monitored, restored, and maintained when necessary. Crossings built in rural unprotected areas are occasionally constructed by individual landowners or government agencies and may not be as efficient (Pedro Ríos, personal communication, March 15, 2011). Stream crossings in these areas in particular should be observed in the future, as their structures may be having an especially negative impact on stream environment.

5.2 Stream Health Factor Group Analysis

Each factor was evaluated individually after the assessments were completed. In some cases one or two factors skewed the average score for the stream health. After grouping the factors into geomorphic and biological sub groups, the factors that need to be improved were identified.

As stated earlier, nine of the fourteen assessment sites had higher geomorphic scores than biological. This shows that biological improvements should be the focus at each site rather than geomorphic improvements. The biological factors are the riparian zone, nutrient enrichment, barriers to fish, in stream fish cover, insect/vertebrate habitat, macroinvertebrates observed, manure presence, and salinity. Additionally, this finding displays that a physically healthy stream does not necessarily mean that local organisms are healthy.

Even though it is the biological factors that should be improved, there are not many ways to improve them without altering the natural state of the stream or changing the stream crossing itself. On average, the riparian zone did not have a very low score. However, some streams had very poor riparian zones, such as the site at the Juan Martín. To restore the riparian zone after damage from a stream crossing, more riparian vegetation should be planted (Luis Rivera, personal communication, Apr. 8, 2011). Another factor that can be improved is manure presence. We noticed that many stream crossings, in the coastal regional area in particular, had barbed wire around the stream so that the livestock could not have access to the stream. The crossings that had livestock in the area with no barbed wire almost always had manure present in the area. To improve this factor, barbed wire should be installed around the stream if there is livestock in the area to prevent access to the stream.

Nutrient enrichment, in stream fish cover, insect/vertebrate habitat, macroinvertebrates, and barriers to fish are the factors that cannot be improved directly. Barriers to fish had the highest score on average. Most of the barriers that were found at the sites were natural, and not caused by stream crossings. Another factor, macroinvertebrates observed, couldn't easily be restored without altering the structure of the crossing. Native fish could be reintroduced to the area, if needed. The other factors can be improved indirectly by repairing the riparian zone. In general, nutrient enrichment slightly correlated with the riparian zone. After planting riparian vegetation, the nutrients should eventually be restored in the area. Furthermore, the restoration of the riparian zone may also improve the condition of in-stream fish cover and insect/ vertebrate habitats. With the new plants, eventually logs and leaves will fall back into the stream, providing a new habitat for the insects and invertebrates.

As a whole, it is more beneficial to restore the biological factors, such as the riparian zone and manure presence, of the stream instead of improving the geomorphic factors of the stream, such as flow alteration and channel condition. Starting these restoration techniques will help forest rangers improve the health of the stream.

5.3 Individual Site Analysis

Since our project is about improving conditions at current stream crossings, we closely examined the three least healthy rivers: Canóvanillas, Gurabo and Blanco. As shown in the results, these rivers did have some common features and low average scores.

One major factor that each river had in common was a low score in flow alteration due to water withdrawals. This is an important human impact on the streams. Because it changes the velocity of the stream and could potentially impact flooding, flow alteration is often considered more harmful than the construction of stream crossings. At stream crossings, flow alteration can be avoided by accurately sizing the bridge or culvert. In other areas, the effects of withdrawals can be mitigated by doing a water budget (last completed in 2007) to assess the effects of withdrawals and minimize the water extractions.

The other two low-scoring factors, insect habitat and in-stream fish cover, are related. They both evaluate the type of debris found in a stream. One reason for these low scores could be the chosen methodology. Developed in the Pacific Northwest, it may not be suitable for rivers that flood as often as those in Puerto Rico. Flooding could seriously affect the amount of debris in the river. This could be an issue because even control did not score well on the in-stream fish cover factor, but it got a perfect score for insect and invertebrate habitat. Therefore, insect and invertebrate habitat could be improved in the low-scoring streams because the control demonstrated that protocol worked well for this factor.

Natural flooding patterns could benefit the insect and invertebrate habitat. A stream with too much or too little flooding would have an unhealthy amount of debris. The easiest way to resolve flooding problems is to eliminate the water withdrawals. However, since water extraction is necessary, our recommendation would still be to do a water budget assessment.

By re-evaluating water use and potentially reducing withdrawals, the three lowest scoring factors could be improved. Additionally, the removal of some of the trash in the area would be beneficial. Although these changes would positively affect all low scoring streams, each of the three unhealthiest streams also had individual problems that need to be addressed. Río Gurabo, Río Blanco and Río Canóvanillas all had one particular score that brought the average down.

5.3.1 Río Gurabo

Río Gurabo, the third unhealthiest stream, had one major issue, barriers to fish. As shown in Figure 13, there is a drop of nearly half a meter in the culvert. Although Benstead and his colleagues (1999) discovered that shrimp can pass over a 1.2 meter dam, the same does not appear to be true for fish. Río Gurabo, despite being geomorphically healthy, has no visible fish population. This is an issue that eliminating withdrawals will probably not improve, so a new solution needs to be found.

Although making structural changes in Puerto Rico is difficult because government approval is needed, there is no other way to improve fish movement. There are two structural changes that could decrease the barrier. First, the incline of the drop could be decreased. Currently, it appears to be forty-five degrees. This steep angle can increase water velocity and prevent fish passage (NRCS, 1998). Decreasing the angle would lower the water velocity and allow for passage of fish. The second solution is to decrease the drop. Any drop over a third of a meter is considered unhealthy. However, if the drop could be reduced to less than a third of a meter, the stream would be given a average score of five, which is a great improvement from a score of one (NRCS, 1998). Any way to reduce the height of the drop or the slope of the drop would be beneficial to the passage of fish.

5.3.2. Río Blanco

Although Río Blanco scored better than Río Gurabo on fish passage, the two rivers had similarly low scores. For the Río Blanco, this was due to the lack of riparian vegetation. Riparian zone vegetation needs to extend at least half of the stream width to be considered healthy (NRCS, 1998). By our estimation, the Río Blanco riparian zone extended less than a third of the stream width on either side. The most common way to repair this area is to replant it with native woody species (Kauffman et al, 1997).

However, Río Blanco's condition could also be helped by a reassessment of the water budget. The river also received a low score in flow alteration because there is a large withdrawal at a hydroelectric plant. This modification can result in less flooding and lower stream velocity. Since the stream and surrounding area are connected, this could also be reason for the impairment of the riparian zone. The riparian zone and river health as a whole would benefit from a water budget assessment and replanting efforts.

5.3.3. Río Canóvanillas

This stream had the lowest score due to its muddy water appearance. Nothing was visible even a few inches deep. The water also had a mild but unpleasant smell. If the murkiness was due to sedimentation, the solution would be to remove the crossing structure. But the murkiness was pronounced both upstream and downstream of the river and the river was quite deep. These observations suggest that sedimentation isn't the major cause of the cloudiness. Other solutions are required.

One way to improve water quality is to make artificial nutrient sinks through vegetated buffer strips (Osborne et al, 1993). When Osborne and Kovacic (1993) tested these buffers strips, they found that both the nitrate and phosphorous concentrations of a stream could be decreased. Later, the chemicals would be released. For Río Canóvanillas, a water quality test would need to be done in order to see what chemicals are out-of-balance. If nitrate concentrations were high, forested buffer strips would work better than grass buffer strips according to Osborne (1993). However, if the phosphorus concentration were high, grass buffer strips would be our recommendation as well as Osborne's. These buffer strips might help clarify the water quality at Río Canóvanillas.

5.4 Methodology Improvements

In order for our research to be continued, our methodology needs to be altered and further adapted to better suit the unique ecosystem of El Yunque. Our factors and how we grade stream health according to those factors should be modified and more streams crossings should be evaluated in order to provide a better overall scope of the affects that have occurred as a result of these crossings.

5.4.1 Protocol Adaption Suggestions

Although we improved our methodology to suit El Yunque, we encountered some elements of our protocol that need to be improved to better assess stream health in the future. We recommend that both bank stability and salinity be eliminated. Our protocol assesses bank stability based mainly on the height of the stream bank with the assumptions that higher banks (typically made of soil) would be less stable. At the evaluated sites, we found that streams in El Yunque have high banks and therefore should receive lower scores. However the banks were made up mostly of rock and were in fact stable. Due to these findings, every site received similar scores; therefore this score provides no addition to a comparative analysis and should be eliminated. El Yunque experiences high annual rainfall and frequent flooding and yet still overall the stream banks remain relatively intact, which further supports our theory. During our assessments, we found no evidence of salinity and therefore we believe that there is no need to include it as a factor in future protocols. In place of these factors we recommend that pollution be added to future protocols. While carrying out our evaluations, we noticed that pollution was a common theme and may be directly deposited in the river at heavily populated stream crossings such as our site at Río Canóvanillas. Pollution may also occur indirectly due to runoff where trash is pulled into streams at stream crossings rather than directly deposited. Adding pollution to the protocol and eliminating salinity and bank stability will be more suitable for EL Yunque.

We also recommend the following alterations to existing factors:

Riparian Zone:

- Problem: Roads interfere with measuring the width of riparian vegetation
- Solution: Vegetation extending one third of the active channel with should be considered average as opposed to poor and therefore receive a score of a 5 as opposed to a 1

Barriers to Fish:

- Problem: Small streams tend to be shallower and dry out more easily therefore the barriers to fish appear more dramatic.
- Solution: The score of an 8 should take the place of what constitutes a 10 when evaluating small streams. The rest of the scale should be adjusted accordingly.

Flow Alteration (Hydrological Alteration):

- Problem: Flooding characteristics noted in our original protocol did not match what represents healthy flooding in El Yunque.
- Solution: USGS maps should be utilized to develop a scale that shows what a healthy flooding pattern is for streams in El Yunque, using Río Mameyes as a model for health flooding.

Runoff:

- Problem: Runoff was difficult to evaluate especially during our study because it was dry.
- Solution: If runoff is evaluated in the future, it should be conducted while raining in order to view the amount of water and debris that enters the stream.

We also encountered some issues that need further study in order design an improved stream assessment protocol. One of the issues we had with the USDA protocol was that it was subjective when describing water appearance and nutrient enrichment. We recommend that more research into what constitutes healthy color for streams by looking at streams of known health as models and comparing sites to them in order to determine a scale and assign grades. Additionally the requirements for pools need to be changed since small and medium rivers often did not have areas greater than three feet deep. This limited them from receiving a high score because the protocol requires deep pools for a healthy score. Another issue we faced was finding insect habitats and grading riffle embeddedness in large streams. We recommend that the assessment be adjusted to account for the different types of habitats in large streams. Riffle embeddedness should not be part of a protocol for the assessment of large streams or that some other means of evaluation be determined.

These adjustments to our modified protocol will be an improvement upon the original assessment. Hopefully, the Forest Service will continue to improve these methods until they are well-suited to El Yunque National Forest.

5.5 Conclusion

The results of our assessments provided us with information used to determine multiple patterns from our data. Weighing these individual factors, while keeping in mind aspects including stream size, location, elevation, and flow direction provided different angles for analysis. We found a trend of healthier average scores among streams flowing north, medium-sized streams, and streams flowing through protected areas. Additionally, flow alteration, insect habitat, as well as in-stream fish cover were the three factors identified as having the most influence on stream health. In order to improve the health of the Río Gurabo, Río Blanco, and Río Canóvanillas as well as of the other rivers, we made detailed recommendations to the National Forest Service. As a whole, the rivers would benefit from a new water budget with reduced withdrawals, replanting in the riparian zone and trash removal. Vegetated buffer strips could also improve streams with poor water quality like Río Gurabo. We hope that forest rangers can construct some of these modifications in order to improve stream health.

6. Conclusion

Maintaining our planet's resources is becoming urgent for society today. National forests have become beacons of hope for protecting these natural resources. Perhaps their most important function is to find and maintain a balance that allows visitors to see much of these forests while at the same time does not jeopardize the forest's integrity. In El Yunque National Forest, there are streams throughout the rainforest and, in order to allow visitors to explore them and the surrounding area, stream crossings have been constructed. These stream crossings have proved to have a negative impact on the health of the streams.

To understand these effects, our team evaluated stream health at a crossing in eleven watersheds. In order to carry out these assessments we used the United States Department of Agriculture (USDA) Stream Visual Assessment Protocol (1998). This proved to be somewhat difficult to apply to the unique ecosystem of El Yunque, but we were able to adapt it to the unique environment of the rainforest. We also chose to use the undammed Río Mameyes as our control so that we could compare it to the sites we evaluated.

By choosing and evaluating sites in and around the forest, we were able to come up with comprehensive data that showed different patterns that we could analyze and use to make recommendations. By analyzing individual factors, as well as such features including stream size, location, elevation, and flow direction, we were able to discover correlations in our data. From these, we provided the following recommendations, summarized in Table 3.

Table 3: Summary of Recommendations

	All	Canovanillas	Gurabo	Blanco
Improved livestock barriers	✔		✔	
Riparian replanting	✔			✔
Trash removal	✔		✔	✔
Water extraction reduction	✔	✔	✔	✔
Structural changes			✔	
Vegetated buffer strips		✔		

Table 3 summarizes recommendations that can have a direct impact upon an observed problem at most of the watersheds or the three worst. However, some of the recommendations could have an indirect impact upon a stream site. For example, even though we didn't see a problem with riparian vegetation at Río Gurabo, riparian replanting could be beneficial to other issues, such nutrient enrichment, insect habitat, and bank stability. But, since such interrelations are so complex, they were not included in this table.

From the table, we can determine that reducing water extractions would be the most beneficial recommendation. It would improve every stream site that was affected by water withdrawals. We came to this conclusion after observing wide and shallow rivers, such as the Río Blanco and Río Fajardo. Additionally, flow alteration, which was determined by the amount of water extraction, was a lower scoring factor. Another recommendation would be trash removal. Although this factor was not included in our study, the majority of the streams were affected by trash. The unprotected and coastal areas were particularly polluted, which could have led to their low average scores. Our final general recommendations are riparian replanting and improved livestock barriers. The riparian replanting is important because the riparian zone provides sediment filtering, bank stabilization, water storage and release, and a habitat for wildlife. Improvement of this area could have drastic effects on a wide range of factors. Finally, manure presence is unhealthy for streams and improved livestock barriers would eliminate that pollution.

Also in our table, we had two specific recommendations that applied only to Río Gurabo and Río Canóvanillas. Río Gurabo's main issue was a large barrier to fish movement, a one-meter sloped drop within the culvert. This can be only be improved by structural changes, such as decreasing the height of the drop or the angle of the slope. The issue with Río Canóvanillas was water clarity. We suggest completing a water quality test to determine the chemical imbalances in the water and then use the appropriate vegetated buffer strip to counteract these imbalances. Although these solutions are helpful to Río Gurabo and Río Canóvanillas, they might not necessarily help any other river.

It is our hope that the research we have conducted and the recommendations we have formulated will help to improve stream health in El Yunque National Rainforest, as well as to preserve this natural resource so it may continue to benefit tourists and locals. To continue improvements in El Yunque, we recommend continuing our project over wider areas and in Río Herrera, the watershed that we omitted. Another helpful project would be re-evaluating the water budget in hopes of reducing water withdrawals. We hope this project will be the beginning of a larger attempt to preserve the natural world.

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Appendix A: Watershed Data

Watershed	**Pitahaya**	Large supported bridge
Location	N18°21.293’ W065°42.041’	
Elevation	131 Meters	**Mid**
Size	18'	**Medium**

Factor	**Score**	**Notes**
Channel Condition	4	
Flow Alteration	8	
Riparian Zone	10	
Bank Stability	3	
Water appearance	7	
Nutrient enrichment	5	
Barriers to fish	10	
Instream fish cover	5	
Pools	5	
Insect/invertebrate habitat	8	
Manure presence		
Salinity		
Riffle embeddedness	3	
Macroinvertebrates observed	2	
Total	5.833333333	

Watershed	**Juan Martín**	Large Bridge
Location	N18°21.065’ W065°41.109’	
Elevation	23 meters	**Low**
Size	4'	**Small**

Factor	**Score**	**Notes**
Channel Condition	3	
Flow Alteration	7	
Riparian Zone	1	
Bank Stability	3	
Water appearance	9	
Nutrient enrichment	6	
Barriers to fish	10	
Instream fish cover	5	
Pools	3	
Insect/invertebrate habitat	5	
Manure presence	3	
Salinity		

Riffle embeddedness	10	
Macroinvertebrates observed	10	
Total	5.76923077	

Watershed	**Gurabo**	Small Culvert with drop
Location	N18°14.869’	
	W065°49.796’	
Elevation	347 meters	**High**
Size	30'	**Large**

Factor	**Score**	**Notes**
Channel Condition	6	
Flow Alteration	6	
Riparian Zone	8	
Bank Stability	7	
Water appearance	8	
Nutrient enrichment	7	
Barriers to fish	1	
Instream fish cover	5	
Pools	9	
Insect/invertebrate habitat	3	
Manure presence	1	
Salinity		
Riffle embeddedness	10	
Macroinvertebrates observed	-3	
Total	5.23076923	

Watershed	**Santiago**	Smaller Split Culvert
Location	N18°14.578’	
	W065°44.377’	
Elevation	93 meters	**Low**
Size	7'	**Medium**

Factor	**Score**	**Notes**
Channel Condition	5	
Flow Alteration	8	
Riparian Zone	5	
Bank Stability	6	
Water appearance	6	
Nutrient enrichment	4	
Barriers to fish	10	
Instream fish cover	5	
Pools	3	
Insect/invertebrate habitat	7	
Manure presence		

Salinity		
Riffle embeddedness	10	
Macroinvertebrates observed	4	
Total	6.08333333	

Watershed	**Maizales (Río Blanco)**	Smaller Bridge
Location	N18°14.104’	
	W065°45.514’	
Elevation	12 meters	**Low**
Size	5'	**Small**
Factor	**Score**	**Notes**
Channel Condition	6	
Flow Alteration	5	2 withdrawals (paper)
Riparian Zone	2	
Bank Stability	6	
Water appearance	10	
Nutrient enrichment	7	
Barriers to fish	10	
Instream fish cover	5	
Pools	5	
Insect/invertebrate habitat	7	
Manure presence		
Salinity		
Riffle embeddedness	10	
Macroinvertebrates observed	-2	
Total	5.916666667	

Watershed	**Blanco**	Wide Bridge
Location	N18°14.343’	
	W065°47.082’	
Elevation	45 meters	**Low**
Size	25'	**Large**
Factor	**Score**	**Notes**
Channel Condition	6	
Flow Alteration	2	hydroelectric plant
Riparian Zone	1	
Bank Stability	9	
Water appearance	5	
Nutrient enrichment	4	
Barriers to fish	8	
Instream fish cover	3	
Pools	6	
Insect/invertebrate habitat	3	

Manure presence		
Salinity		
Riffle embeddedness	8	
Macroinvertebrates observed		no access to stream
Total	5	

Watershed	**Fajardo**	Large Bridge
Location	N18°17.805’	
	W065°41.607’	
Elevation	47 meters	**Low**
Size	30'	**Large**
Factor	**Score**	**Notes**
Channel Condition	5	
Flow Alteration	6	1 withdrawal (paper)
Riparian Zone	1	
Bank Stability	9	
Water appearance	7	
Nutrient enrichment	8	
Barriers to fish	10	
Instream fish cover	3	
Pools	4	
Insect/invertebrate habitat	4	
Manure presence	1	
Salinity		
Riffle embeddedness	7	
Macroinvertebrates observed	6	
Total	5.46153846	

Watershed	**Espíritu Santo (Tributary)**	Two Shallow Split Culverts
Location	N18°19.913’	
	W065°49.294’	
Elevation	241 meters	**Mid**
Size	5'	**Small**
Factor	**Score**	**Notes**
Channel Condition	3	
Flow Alteration	6	1 withdrawal
Riparian Zone	10	
Bank Stability	8	
Water appearance	4	
Nutrient enrichment	4	
Barriers to fish	5	
Instream fish cover	3	
Pools	3	

Insect/invertebrate habitat	7	
Manure presence		
Salinity		
Riffle embeddedness	10	
Macroinvertebrates observed	10	
Total	6.083333333	

Watershed	**Espíritu Santo (Palo Eco)**	Large Bridge
Location	N18°18.751’ W065°49.327’	
Elevation	525 meters	**High**
Size	25'	**Large**
Factor	**Score**	**Notes**
Channel Condition	7	
Flow Alteration	7	
Riparian Zone	8	
Bank Stability	7	
Water appearance	7	
Nutrient enrichment	4	
Barriers to fish	9	
Instream fish cover	8	
Pools	9	
Insect/invertebrate habitat	6	
Manure presence		
Salinity		
Riffle embeddedness	8	
Macroinvertebrates observed	4	
Total	7	

Watershed	**Canóvanas**	Small Culvert
Location	N18°17.602’ W065°51.021’	
Elevation	575 meters	**High**
Size	8'	**Medium**
Factor	**Score**	**Notes**
Channel Condition	6	
Flow Alteration	9	
Riparian Zone	10	
Bank Stability	6	
Water appearance	4	
Nutrient enrichment	2	
Barriers to fish	10	
Instream fish cover	5	

Pools	8	
Insect/invertebrate habitat	8	
Manure presence		
Salinity		
Riffle embeddedness	8	
Macroinvertebrates observed		too cloudy
Total	6.90909091	

Watershed	**Canóvanillas**	Small Bridge
Location	N18°16.033’	
	W065°52.501’	
Elevation	407 meters	**High**
Size	20'	**Medium**

Factor	**Score**	**Notes**
Channel Condition	5	
Flow Alteration	5	
Riparian Zone	8	
Bank Stability	4	
Water appearance	1	
Nutrient enrichment	4	
Barriers to fish	8	
Instream fish cover	3	
Pools	6	Hard to identify due to water appearance
Insect/invertebrate habitat	3	
Manure presence		
Salinity		
Riffle embeddedness	6	
Macroinvertebrates observed		too cloudy
Total	4.818181818	

Watershed	**Mameyes (Tributary)**	control/no crossing
Location	N18°19.025’	
	W065°45.149’	
Elevation	191 meters	**Mid**
Size	4'	**Small**

Factor	**Score**	**Notes**
Channel Condition	10	
Flow Alteration	10	
Riparian Zone	10	
Bank Stability	9	
Water appearance	10	
Nutrient enrichment	7	
Barriers to fish	10	

Instream fish cover	8
Pools	9
Insect/invertebrate habitat	10
Manure presence	
Salinity	
Riffle embeddedness	10
Macroinvertebrates observed	10
Total	9.416666667

Watershed	**Sabana (Research Center)**	Large Bridge
Location	N18°19.508’	
	W065°43.783’	
Elevation	100 meters	**Low**
Size	10'	**Medium**
Factor	**Score**	**Notes**
Channel Condition	6	
Flow Alteration	6	2 small withdrawals (Benjamin)
Riparian Zone	2	
Bank Stability	8	
Water appearance	8	
Nutrient enrichment	7	
Barriers to fish	10	
Instream fish cover	3	
Pools	9	
Insect/invertebrate habitat	7	
Manure presence		
Salinity		
Riffle embeddedness	8	
Macroinvertebrates observed	10	
Total	7	

Watershed	**Sabana (Río Chiquito)**	Large Bridge
Location	N18°19.705’	
	W065°42.879’	
Elevation	143 meters	**Mid**
Size	9'	**Medium**
Factor	**Score**	**Notes**
Channel Condition	7	
Flow Alteration	7	
Riparian Zone	10	
Bank Stability	5	
Water appearance	8	
Nutrient enrichment	8	

Barriers to fish	10
Instream fish cover	5
Pools	8
Insect/invertebrate habitat	7
Manure presence	
Salinity	
Riffle embeddedness	10
Macroinvertebrates observed	11
Total	8

Watershed	**Mameyes (Ladies Pool)**	control/no crossing
Location	N18°19.387’	
	W065°45.068’	
Elevation	131 meters	**Mid**
Size	30'	**Large**

Factor	**Score**	**Notes**
Channel Condition	10	
Flow Alteration	10	
Riparian Zone	10	
Bank Stability	9	
Water appearance	10	
Nutrient enrichment	8	
Barriers to fish	10	
Instream fish cover	5	
Pools	10	
Insect/invertebrate habitat	10	
Manure presence		
Salinity		
Riffle embeddedness	10	
Macroinvertebrates observed	15	
Total	9.75	

Appendix B: Sponsor Description

US Forest Service in El Yunque National Forest

The El Yunque National Rainforest Stream Crossings Project is sponsored by Pedro Ríos, the Natural Resources Staff Officer and Ecosystem Management & Planning Team Leader of the USDA Forest Service for El Yunque National Rainforest in Puerto Rico.

The United States Forest Service (2009) is a non-profit, government agency that is a part of the United States Department of Agriculture. The mission of the Forest Service is, "to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations" (US Forest Service, About Us- Mission, 2009). Its motto is "caring for the land and serving people" (US Forest Service, About Us- Mission, 2009). The Agency aims to preserve and enhance the nation's forests and to restore biodiversity and forest health for both economic and recreational purposes.

According to the US Forest Service (2009) website, the organization receives $5 billion per year, which is used for many purposes. The majority of the money went to the National Forest System ($1.5 million) and the Wildland Fire Management Program ($2.1 million), according to the US Forest Service Budget Overview (2010). The funding for these myriad purposes comes from the Subcommittee on Appropriations---InteRíor, Environment, and Related Agencies.

This money is distributed through nine different regions, which have a total of 34,250 employees (USDA, 2011). In each of the nine regions, there is a regional forester who reports to the Chief. The Chief is in charge of the entire National Forest Agency and reports to the Under Secretary for Natural Resources and Environment in the USDA. The Chief is assisted by five deputy chiefs who specialize in the following departments: The National Forest System, State and Private Forestry, Research and Development, Business Operations and Finance. El Yunque National Forest Service itself has a forest supervisor, Pablo Cruz, who is in charge of the Ecosystem Management team, Property

Management and Customer Service team, Forest Planning and Administration team, and the Law Enforcement team (US Forest Service, 2009). Each of those teams has a leader that controls all of the executive decisions.

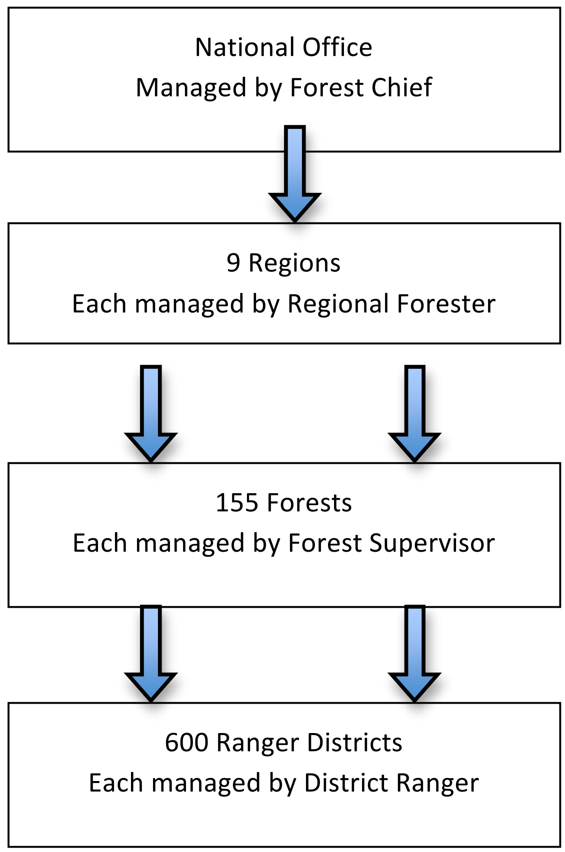

Figure 14: The Organizational Hierarchy of the US Forest Service

The Chief determines which portion of the Agency's $5 billion dollar budget goes toward El Yunque rain forest (Pabon et al., 2008). Additional elements, such as site-specific funding and volunteers, are also vital to this area. Some alternative funding comes from donations from visitors. To keep expenses low, El Yunque forest also relies on its large contingent of volunteers, nearly 730 people strong in 2007.With generous donations, the support of the National Forest Agency and an impressive number of volunteers, the El Yunque rainforest has great resources.

Another government – funded organization that encounters similar problems with respect to the responsibility of appropriate land management and generating sustainable solutions is the Environmental Protection Agency (EPA). The mission of the EPA (2011) is to protect both the health of the public and the environment. Through creation and enforcement of regulations, providing grants, as well as studying and publishing information, they are able to inform the public and protect the environment. As fellow government agencies, the EPA and USDA Forest Service share information with each other and yet still have their own individual responsibilities.

Appendix C: IQP Qualifications

The Interactive Qualifying Project is one of the academic requirements necessary for graduation from Worcester Polytechnic Institute. This intensive project challenges WPI's students to understand the intersection of science and technology with social and human issues and needs. Additionally, students may choose to complete this project off-campus; this allows the student not only to gain experience with the unique junction between science and society, but to gain new perspectives on different cultures and real-world situations.

The IQP is meant to introduce students to the fact that the prospective careers to which they aspire will eventually have a great impact on the society in which they practice it, both on the individual and community level. The project is meant to teach the student that in addition to gaining all of the technical skills of their particular technological fields, they must also learn how to apply those skills to society in a positive and beneficial way. Upon the completion of the IQP, the student will have gained insight into human interaction, humanities, technological applications, and the concept of using scientific skill for the greater good of society.

This Interactive Qualifying Project in particular, regarding the potential remedy of the environmental impacts of stream crossings in Puerto Rico's El Yunque National Rainforest, will accomplish all of these goals. Our group will utilize many forms of technology to accomplish our goals. These include vaRíous assessment protocols and crossing regulations, advanced GIS software, as well as the technique of the scientific method. These technologies will be used to potentially remedy the environmental impacts of stream crossings in a popular tourist location. This will benefit the tourist system, which not only brings revenue to the forest, but allows the people of Puerto Rico and visitors to Puerto Ricoto admire and use this amazing natural habitat without worry or negative consequence.

While we are completing this project, we will be living in San Juan, Puerto Rico. Here we will experience a culture that is different from our own. We will interact with people of another native tongue, different native traditions, and diverse experiences and perspectives on the world. This is an experience that could never be achieved from the confines of a campus.

When we have finished our project and travel home, we will have gained skills and concepts that could not have been found through any other method. We will have gained an understanding of the fact that the skills we learn within the classrooms of WPI can have a major positive impact on the world around us. We will have experienced, inexorably and undeniably, the very motto that defines WPI: *Lehr und Kunst*; Theory and Practice.

Appendix D: Interviews

<u>Professor Bergendahl</u>

February 11, 2011

1. What types of stream crossing structures are built and what types of materials are used to build them (roads for vehicles vs. walking trails)?
    - There is a lot of breadth when considering stream crossings: a highway crossing is different from a regular stream crossing. One of your biggest concerns will be to minimize the loss of soil. Soil can only bear so much weight, so you may need to choose a design with a foundation with more surface area to avoid pushing down soil.
    - Reduction suspended solids with certain types of swales (sp?) may be appropriate.
2. How might a stream crossing divert or block a stream? What are the most common ecosystem damages related to stream crossings in areas with high rainfall?
    - It is smart to design crossings so that the impact to wildlife is minimized. Some crossings consist of a big round pipe which is elevated. The discharge is above the stream, and fish and other wildlife can't get through that. Techniques have been developed that sink the pipe into the stream bottom, so that fish can go through it. Some pipes were more half-pipes that would rest on the edges of the stream and not affect wildlife movement.
3. How does sedimentation occur and what affects does it have? How much runoff is there in general from a stream crossing into the surrounding area?
    - There will be two major issues regarding sedimentation: that which occurs during construction (excavation) and that which occurs after the crossing is built.
    - One can stop the effects of during-construction sedimentation by minimizing the contact of the crossing with the steam. One may do this by either making a longer crossing span, or installing a design that stops sedimentation.
    - Once the crossing is built, you change the hydrology of the landscape. When it rains, the water has to go somewhere, and a badly designed crossing may increase the velocity of the stream and cause the rainwater to carry anything right into the stream. There are vaRíous practices to avoid this. Massachusetts has some guidance as to how to address this type of runoff. But the main emphasis is to avoid changing the hydrology of the site after construction has taken place. One should make sure that the water that hits the ground contributes to the groundwater as much after as it did before the construction.
4. How do you test to determine if a stream has become polluted due to the construction of a nearby stream crossing?
    - There is generally no testing of the waters around stream crossings for toxicity. VaRíous streams and rivers are tested for different purposes anyway, in terms of pH, turbidity, average strength. In general, footbridges and cars are not going to toxify a stream. I don't know of any specific tests for crossings.
5. Do you have any sources that you feel might be useful to us?
    - There is an MQP done by a CE major and an ME major regarding a sustainable trail system in Costa Rica. It doesn't necessarily deal with stream crossings, but it contains information about erosion, so it might be of interest to you.
    - The engineering department at the University of New Hampshire has some storm water reports that might be useful. They would need to be adapted to a rainforest environment.

- There may be some governmental guidelines for stream crossings. Look at the Federal Highway and Safety Commission.
- The Department of Agriculture and Forestry Service may have sections on minimizing erosion when building roads.

Pedro Ríos

March 15, 2011 (Paraphrased)

1. Where should we evaluate sites?
    - I would like you to evaluate both stream crossings on major highways and stream crossings on smaller roads or trails. If you find that your chosen evaluation sites are tending to be major highways, venture from your chosen site a bit and find a more rural crossing.
2. Would you prefer if we evaluated more sites less carefully or just a few sites in detail?
    - I would like representation in each of the ru. There are quite a few, so you may want to think about a less time-consuming assessment to use at a large number of sites.
3. Because we need to evaluate more sites, it will be difficult for us to have a control upstream of each one. Can we use an undisturbed stream as a control as long as we evaluate it at different elevations?
    - Yes. The Río Mameyes is an undammed stream that is considered very pristine. This river would be a suitable one to use as a control for ideal stream health.

March 17, 2011

4. One of the issues we need to look at is channel condition, which requires knowledge of how often the area floods. Where can we find flood information?
    - You would have to do research to find the flood information for specific streams. I can give you some documents that will help you to obtain this information.
5. In our assessment, it says that flooding every one to two years is healthy. However there is more rainfall here. How much flooding would be considered healthy?
    - I suggest that you consult flooding maps developed by the USGS for the past fifty years.
6. A factor we need to evaluate is riffle embedding. Do the streams contain riffle?
    - Yes, all of the streams in the area contain riffle.
7. Manure presence is another factor we might need to evaluate. Would it be applicable to any our sites?
    - Yes. You'll find that some sites will be near sites of livestock grazing. It is very possible that you may find manure near a stream, and you should consider this factor in your stream assessment.
8. In evaluating channel condition, we have to identify down cutting and aggredation. How can we identify these processes?
    - If you take pictures, I might be able to help you identify these processes.

<u>Luis Rivera (Botanist)</u>

March 17, 2011

We would like your input on some of the factors we need to evaluate. The flora and fauna of El Yunque mean that some of our factors need to be modified and we'd appreciate your help.

1. What types of intolerant species are present in the El Yunque streams?
    - Shrimp, mollusks, mountain mullet

Presence of algae is important to our evaluation, so

2. Does algae grow in the rivers of El Yunque?
    - Definitely. If the stream is rich in nutrients, macrophytes and algal blooms will be present. An overabundance of these species, and thus of stream nutrients, however, is actually bad for the stream health.

We also need to evaluate fish cover. Our assessment names 7 different types of fish cover.

3. Are these types of fish cover still valid in a rainforest ecosystem?
    - Yes. You will see all of these cover types in the rainforest.

Thank you for all your help.

<u>Manuel Ortíz</u>

March 22, 2011

1. What are the qualitative ways to measure run off?
    - Drainage. Structures are usually not big enough. Steepness is another way too so you can look at water that comes from the watershed verses water that comes from the road. Is there a lot? If there is intense rain in a steep area the run off will be at high intensity.
    - Leaves are important to look at. If the culvert is clumped with leaves it can show that the water is moving at a high velocity which could be a result from run off.
2. How do you grade run off on a scale?
    - Well, it is good to go out while it is raining so you can see for sure if there is run off or not. Most structures function at capacity and some are not sized properly so run off is more likely to occur. Even if they are sized properly, rocky beds can still clog them. At I91 and I96 you can see that the waterway is constricted and there are a lot of boulders/ small rocks blocking the waterway.
3. Does elevation have an effect on run off?
    - I guess, because water velocity decreases as you go down in elevation.
    - At the Río Mamayes, two inches of rain/ two hours will get the river over the bank so there will be run off. You can look at the USDS Flood Plains to look at the flooding.

4. How do you classify the stream crossings in terms of bridges vs. culverts vs. pipes?
    - There is a large variety of culverts but there are a lot of box culverts. We only have inventory of the forest system roads. On the trails there is a variety; fewer bridges and mostly rock/concrete culverts.
    - The Forest Service has a handbook that classifies the stream crossings, so I can send that you.
5. Can you tell us more about bank stability? Are most of the banks stable here?
    - Most of the channels are very stable. Very few crossings alter stream channels. A flood doesn't even take a chunk out of the bank often. Once the banks are established, they are stable.
6. How do the crossings affect the fish?
    - Most streams have fish, so there is not much that you can do about it. Little to no streams that have fish migration will have a culvert because culverts are the number one enemy to fish migration.

Appendix E: Graphs

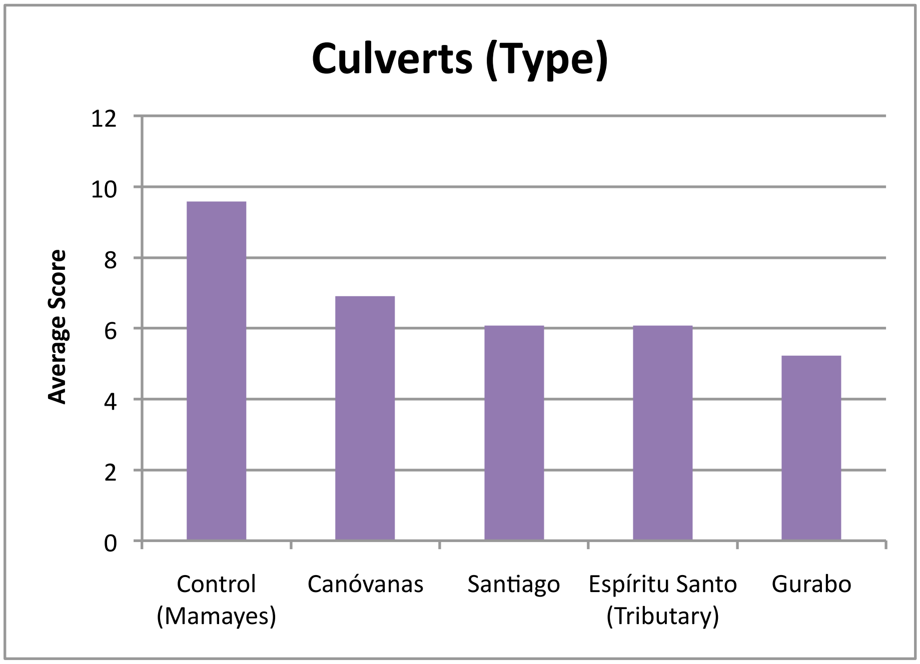

Figure 15: Scores of Streams Crossed by Culverts

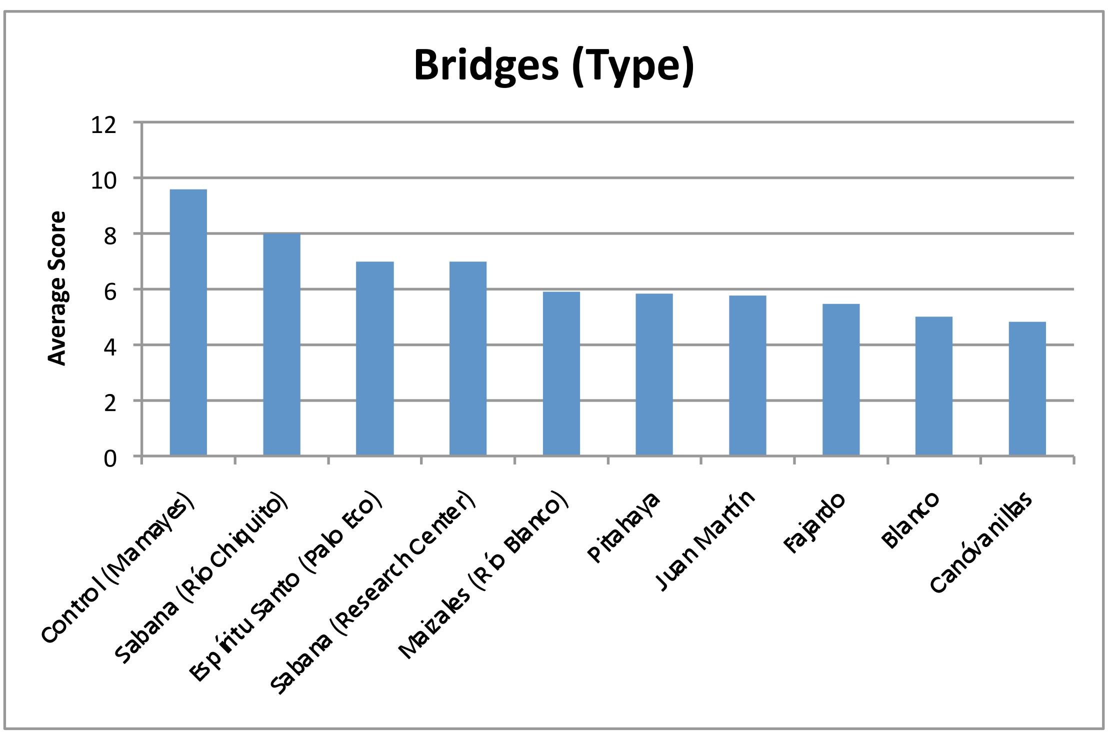

Figure 16: Scores of Streams Crossed by Bridges

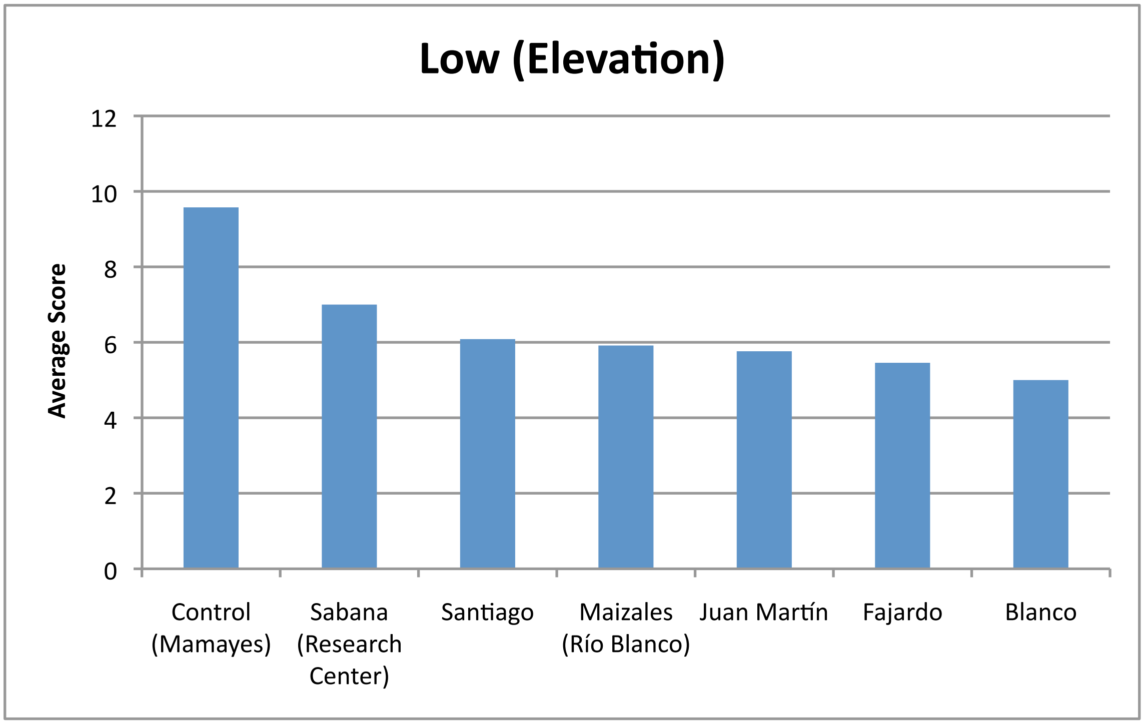

Figure 17: Stream Scores at Low Elevation

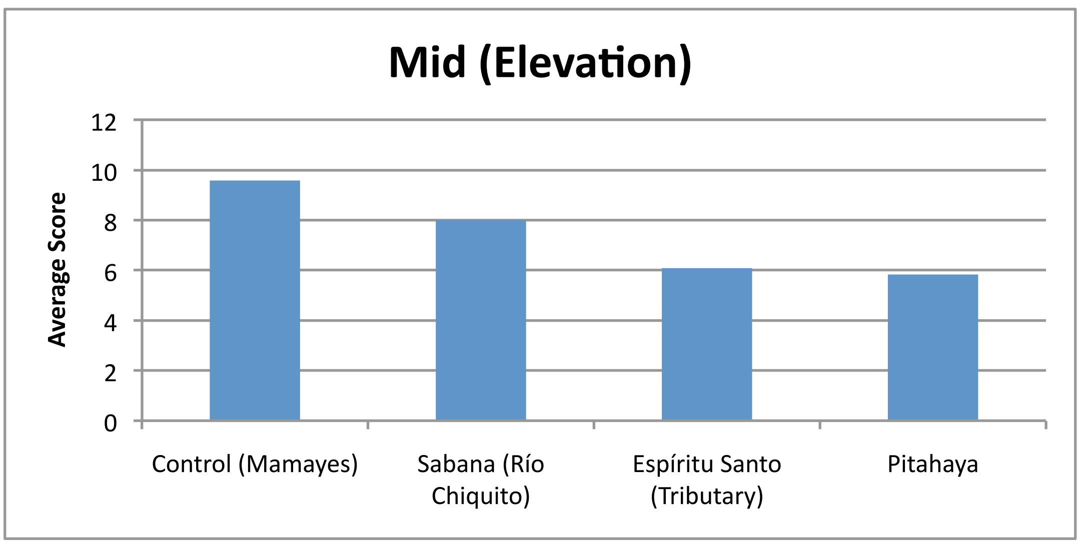

Figure 18: Stream Scores at Mid Elevation

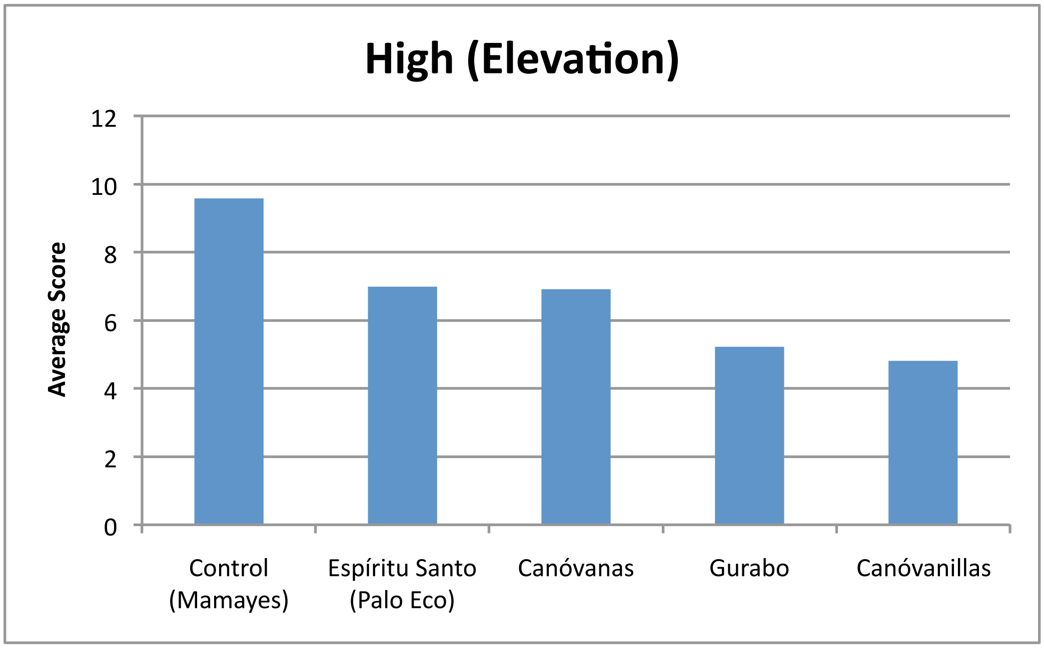

Figure 19: Stream Scores at High Elevation

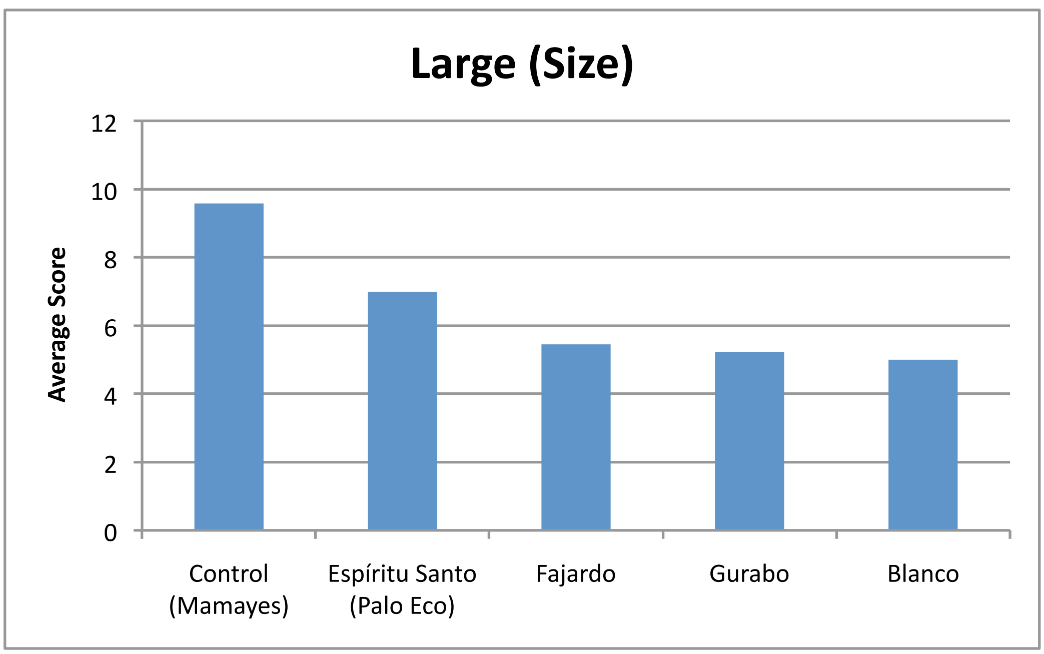

Figure 20: Scores of Large Streams

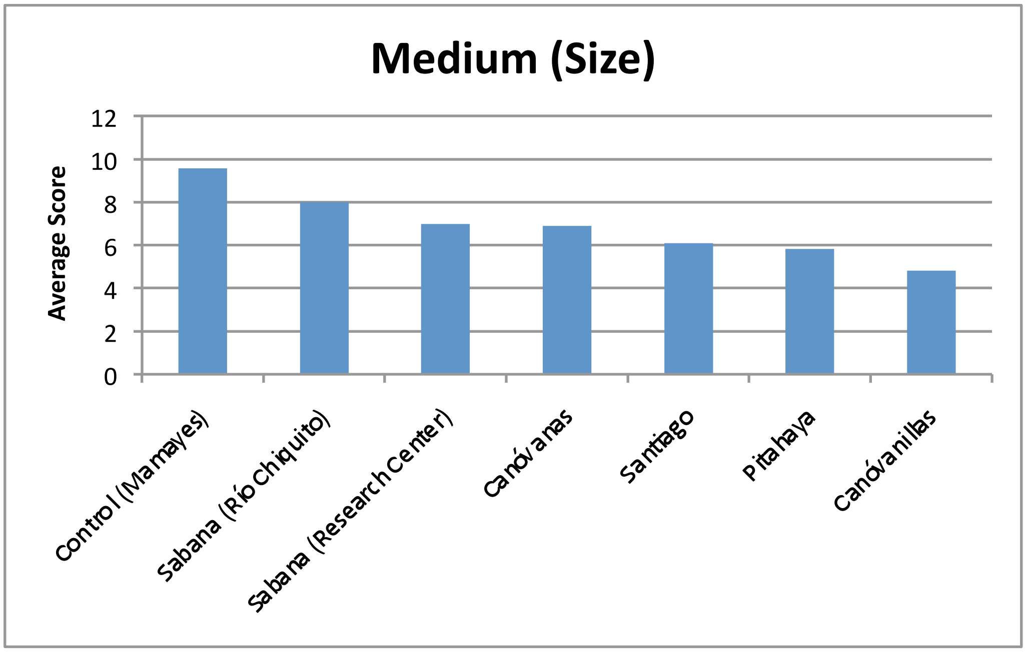

Figure 21: Scores of Medium Streams

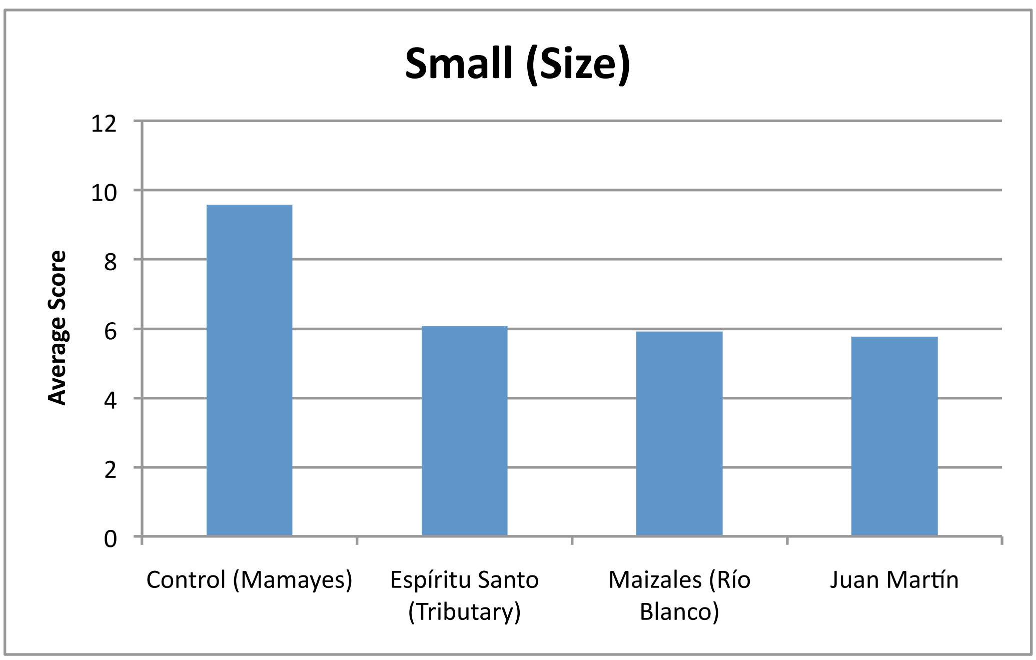

Figure 22: Scores of Small Streams

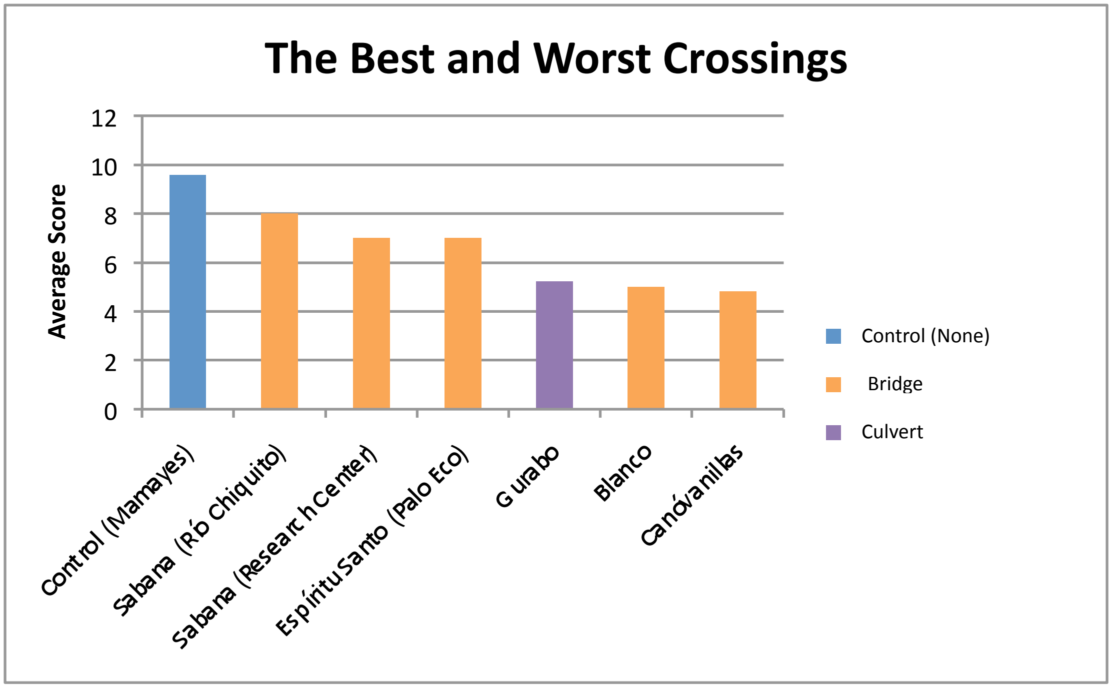

Figure 23: Scores of the Best and Worst Crossings

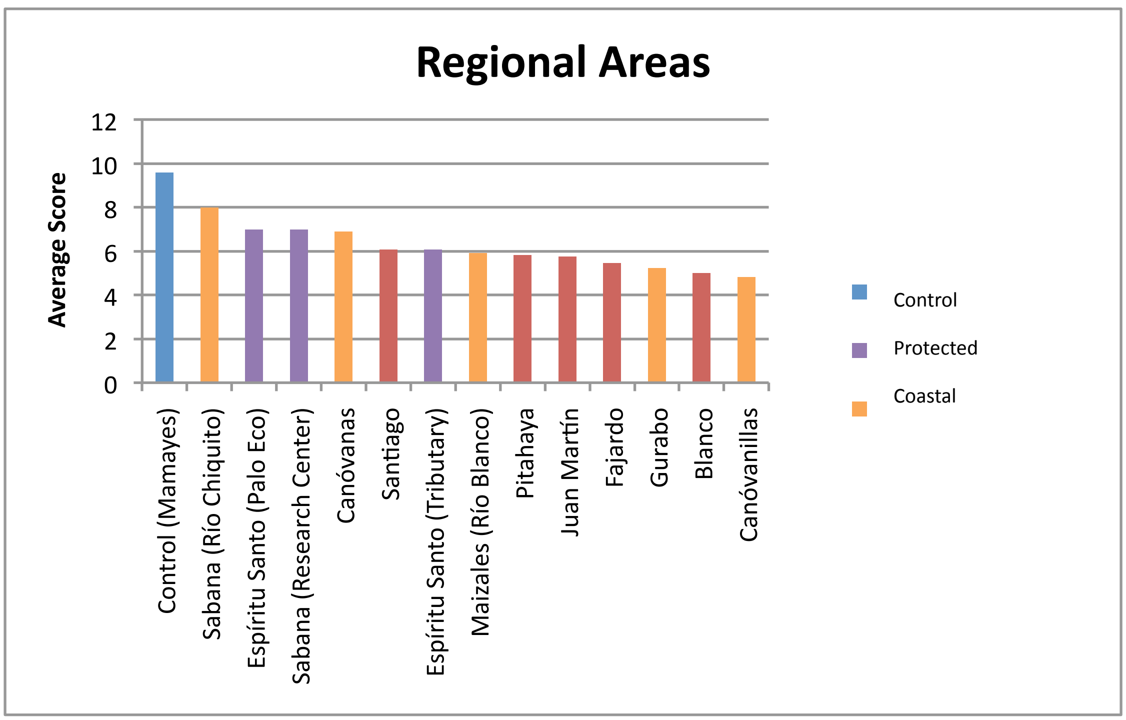

Figure 24: Scores of Streams in Each Regional Area

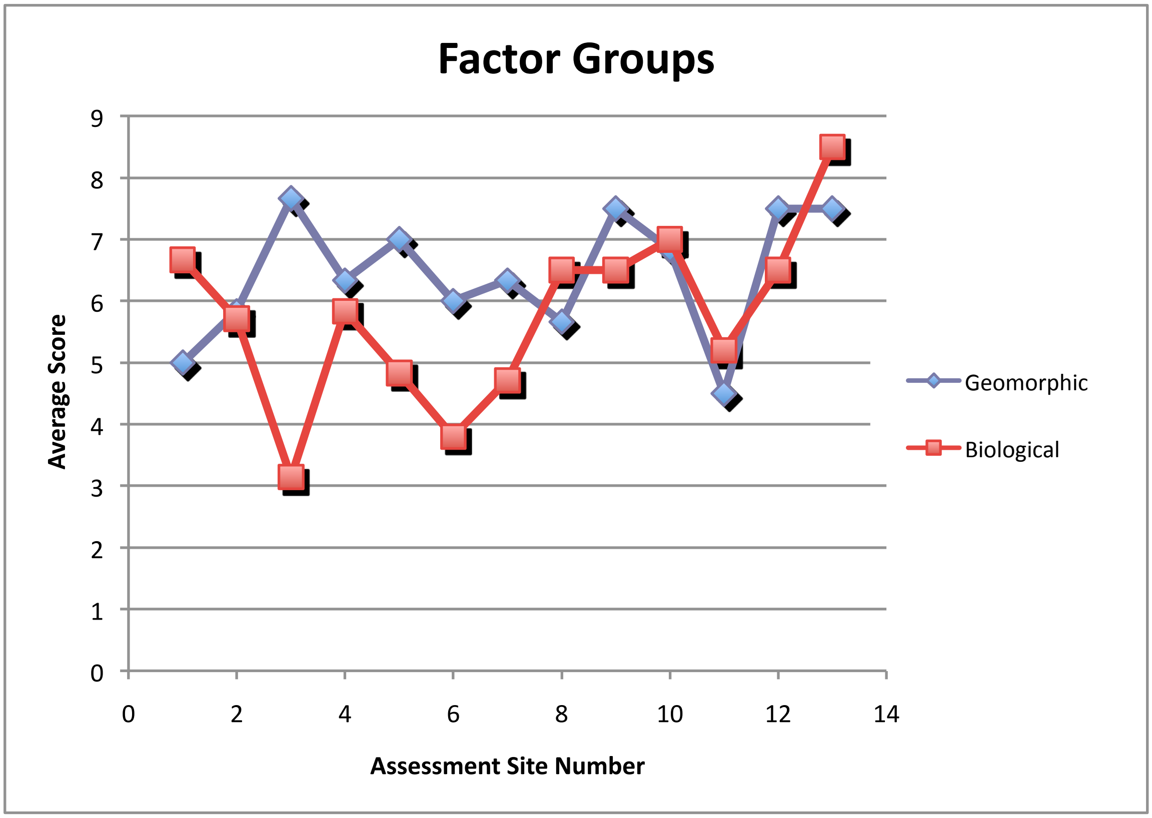

Figure 25: Factor Groups

Appendix F:

USDA Protocol Example

Stream Visual Assessment Protocol

Owners name ______________________ Evaluator's name______________________ Date ____________

Stream name ______________________________ Waterbody ID number ______________________

Reach location ____

____

Ecoregion ______________________ Drainage area ______________ Gradient________________

Applicable reference site ____

Land use within drainage (%): row crop ______ hayland ______ grazing/pasture _______ forest ______ residential _______

confined animal feeding operations ______ Cons. Reserve ________ industrial _______ Other: ________________

Weather conditions-today ________________________ Past 2-5 days ____________________________

Active channel width ______________ Dominant substrate: boulder ______ gravel ______ sand ______ silt ______ mud ______

Site Diagram

Assessment Scores

Channel condition	
Hydrologic alteration	
Riparian zone	
Bank stability	
Water appearance	
Nutrient enrichment	
Barriers to fish movement	
Instream fish cover	
Pools	
Invertebrate habitat	

Score only if applicable

Canopy cover	
Manure presence	
Salinity	
Riffle embeddedness	
Marcroinvertebrates Observed (optional)	

Overall score		<6.0	**Poor**
(Total divided by number scored)		6.1-7.4	**Fair**
	________	7.5-8.9	**Good**
		>9.0	**Excellent**

Suspected causes of observed problems____

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Recommendations____

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