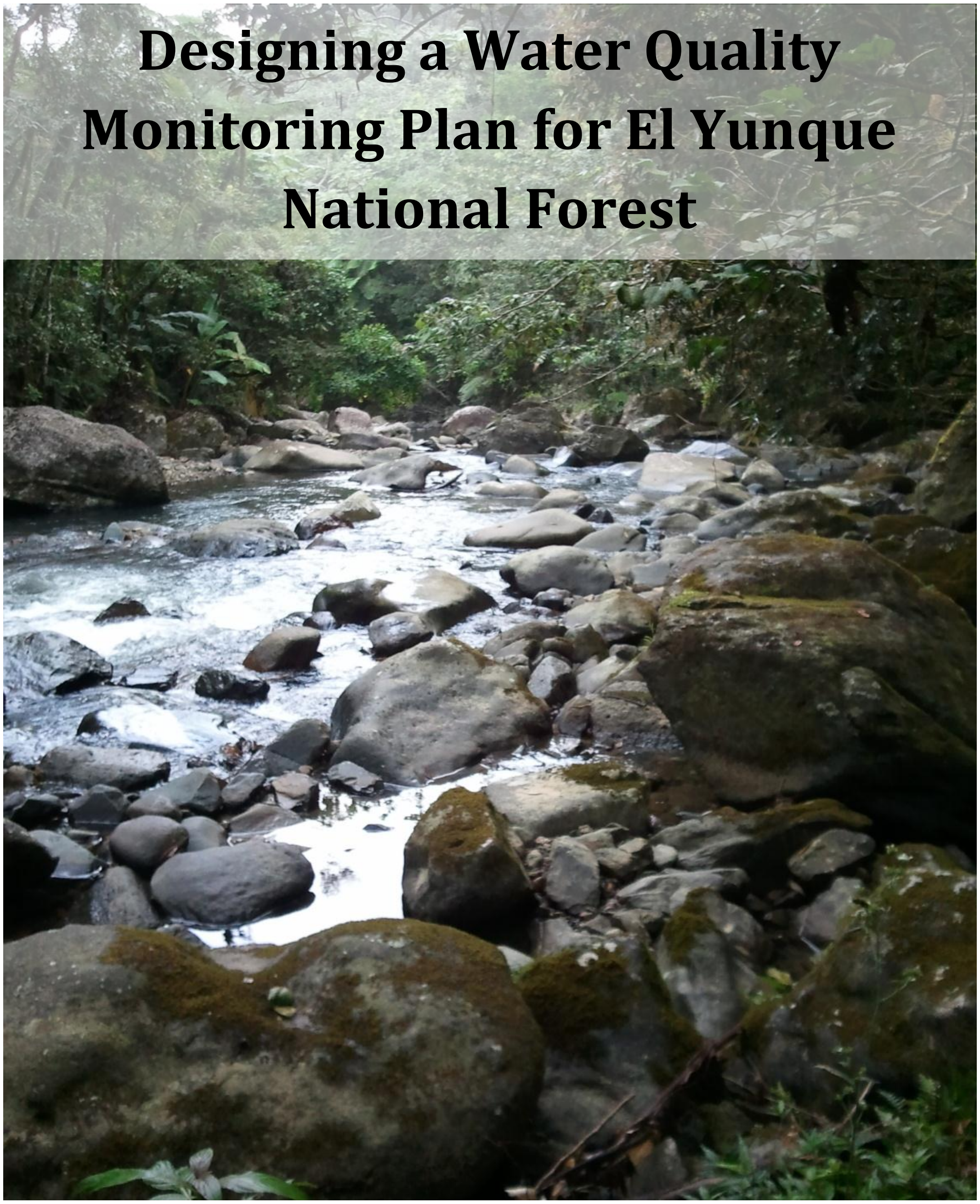
Designing a Water Quality Monitoring Plan for El Yunque National Forest



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Designing a Water Quality Monitoring Plan for El Yunque National Forest

An Interactive Qualifying Project Report
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Degree of Bachelor of Science

Sponsoring Agency: El Yunque National Forest

Submitted to:

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Abstract

The US Forest Services needs a sustainable method of measuring the water quality of El Yunque National Forest's wild and scenic rivers. Our project developed a monitoring plan for these rivers that is both accurate and cost efficient. Based upon the opinions of water quality experts and our own on-site analysis, our final plan includes seven sampling sites on three rivers. We recommend the use of a multi-parameter probe to reliably collect water measurements and calculated one year of monitoring will cost approximately $4,000.

Acknowledgements

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We also received valuable help and guidance during our research and interview stage from the United States Geological Survey, Professor Bill McDowell of the University of New Hampshire and Professor Paul Mathisen of WPI. These interactions ultimately helped us finalize almost every aspect of our monitoring plan.

Lastly, we would like to thank our advisors, Professors Aarti Madan and R. Creighton Peet, for their guidance and helpful comments throughout the last two terms. This report would not be as succinct and well composed if it were not for their feedback on our weekly drafts.

Authorship Table

Abstract .... Valdes

Acknowledgements .... Miller

Authorship Table .... All

Table of Contents .... Hickey

Table of Figures and Tables .... Hickey

Executive Summary .... **Error! Bookmark not defined.** All

1.0 Introduction .... All

2.0 Background .... All

2.1 Freshwater Ecosystems .... Hickey, Miller

2.1.1 Importance of Water Quality .... Hickey, Miller

2.1.2 Societal threats to freshwater ecosystems .... Hickey, Miller

2.2 Monitoring River and Stream Water Quality .... Miller, Valdes

2.2.1 Designing a Water Quality Plan .... Miller, Valdes

2.2.2 Monitoring Standards .... Miller

2.2.3 Current Technologies and Equipment .... Miller

2.2.4 Interpreting Results .... Miller

2.3 Non-formal Education .... Hickey, Bruton

2.3.1 Instructional Guides .... Hickey, Bruton

2.3.2 Professional and Vocational Training .... Bruton

2.4 El Yunque National Forest .... Hickey

2.4.1 El Yunque's Wild and Scenic Rivers .... Hickey

2.5 Summary .... **Error! Bookmark not defined.** All

3.0 Methods .... All

3.1 Identify Current Methodologies and Technologies .... Miller, Valdes

3.1.1 Correspondence with Local Experts .... Miller, Valdes

3.1.2 Interviews with USFS Staff .... **Error! Bookmark not defined.**

3.2 Design and Testing of a Water Quality Monitoring Plan **Error! Bookmark not defined.** Bruton, Miller

3.2.1 Variable Selection .... Bruton, Miller

3.2.2 Sampling Locations .... Bruton, Miller

3.2.3 Interpretation of Results .... Bruton, Miller

3.3 Training Program Development .... Hickey

3.4 Summary .... Hickey
4.0 Results & Analysis ....All
4.1 Analysis of Sampling Locations .... Valdes
4.1.1 Finalized Sampling Locations .... Valdes
4.1.2 Locations' Accessibility and Frequency of Future Testing .... Valdes
4.2 Analysis of Water Quality Results ....Hickey, Miller
4.2.1 Visual Observations.. Miller
4.2.2 Instrument Readings ....Hickey, Miller
4.2.3 Comparison to Puerto Rico EPA Water Quality Standards **Error! Bookmark not defined.**Hickey, Miller
4.3 Cost Analysis ....Hickey, **Error! Bookmark not defined.**
4.3.1 Cost of Implementation .... **Error! Bookmark not defined.**
4.3.2 Benefit of a Water Quality Plan .... **Error! Bookmark not defined.**
4.4 Training Program.. **Error! Bookmark not defined.**Bruton
5.0 Conclusions & Recommendations ....**Error! Bookmark not defined.**Bruton, Valdes
5.1 Conclusion.. Valdes
5.2 Recommendations for the water quality monitoring plan .... **Error! Bookmark not defined.**
5.3 Recommendations for future training ....**Error! Bookmark not defined.**Valdes
References .... **Error! Bookmark not defined.**All
Appendix A: Sponsor Description – US Forest Service.........................**Error! Bookmark not defined.**Miller
Appendix B: Professor Mathisen Interview .... Bruton, Valdes
Appendix C: Professor McDowell Interview ....**Error! Bookmark not defined.**Miller
Appendix D: USGS Interview... **Error! Bookmark not defined.**All
Appendix E: USFS Interview .... **Error! Bookmark not defined.**All
Appendix F: Stream Quality Data...**Error! Bookmark not defined.**Hickey
Appendix G: Time To Sampling Locations & Sampling Schedule .... **Error! Bookmark not defined.**All
Appendix H: Wild and Scenic River Map.. **Error! Bookmark not defined.**All
Appendix I: Cost Analysis Calculations..**Error! Bookmark not defined.**Miller
Appendix J: Monitoring Plan Training Pamphlet...All

Table of Contents

Abstract ii
Acknowledgements iii
Authorship Table iv
Table of Contents vi
Table of Figures and Tables viii
Executive Summary ix
1.0 Introduction 1
2.0 Background 3
2.1 Freshwater Ecosystems 3
2.1.1 Importance of Water Quality 3
2.1.2 Societal threats to freshwater ecosystems 4
2.2 Monitoring River and Stream Water Quality 5
2.2.1 Designing a Water Quality Plan 5
2.2.2 Monitoring Standards 6
2.2.3 Current Technologies and Equipment 7
2.2.4 Interpreting Results 9
2.3 Non-formal Education 10
2.3.1 Instructional Guides 10
2.3.2 Professional and Vocational Training 11
2.4 El Yunque National Forest 11
2.4.1 El Yunque's Wild and Scenic Rivers 12
2.5 Summary 14
3.0 Methods 15
3.1 Identify Current Methodologies and Technologies 15
3.1.1 Correspondence with Local Experts 15
3.1.2 Interviews with USFS Staff 16
3.2 Design and Testing of a Water Quality Monitoring Plan 16
3.2.1 Variable Selection 16
3.2.2 Sampling Locations 18
3.2.3 Interpretation of Results 19
3.3 Training Program Development 19

3.4 Summary 19
4.0 Results & Analysis 20
4.1 Analysis of Sampling Locations 20
4.1.1 Finalized Sampling Locations 20
4.1.2 Locations' Accessibility and Frequency of Future Testing 22
4.2 Analysis of Water Quality Results 23
4.2.1 Visual Observations 23
4.2.2 Instrument Readings 24
4.2.3 Comparison to Puerto Rico EPA Water Quality Standards 25
4.3 Cost Analysis 26
4.3.1 Cost of Implementation 26
4.3.2 Benefit of a Water Quality Plan 27
4.4 Training Program 27
5.0 Conclusions & Recommendations 29
5.1 Conclusion 29
5.2 Recommendations for the Water Quality Monitoring Plan 30
5.3 Recommendations for Future Training 30
References 31
Appendix A: Sponsor Description – US Forest Service 34
Appendix B: Professor Mathisen Interview 36
Appendix C: Professor McDowell Interview 37
Appendix D: USGS Interview 39
Appendix E: USFS Interview Results 40
Appendix F: Stream Quality Data 41
Appendix G: Time to Sampling Locations & Sampling Schedule 44
Appendix H: Wild and Scenic River Map 46
Appendix I: Cost Analysis Calculations 47
Appendix J: Monitoring Plan Training Pamphlet 49

Table of Figures and Tables

Figures

Figure 1: A Typical Water Quality Monitoring Station 8
Figure 2: The HANNA HI 9828 multi-parameter probe 17
Figure 3: Eliminated Sampling Site - Mameyes Estuary 21
Figure 4: Eliminated Sampling Site - La Mina Falls 21
Figure 5: Locations of Finalized Sampling Locations 22
Figure 6: The US Forest Service Organizational Structure 34
Figure 7: The Management Team at El Yunque National Forest 35

Tables

Table 1: Times to Each Sampling Point and Suggested Sampling Frequencies 23
Table 2: Water Quality Readings at Each Site 24
Table 3: EPA Standards and El Yunque's Rivers Statuses 25
Table 4: Acquired USFS Cost Information 26

Executive Summary

Freshwater ecosystems are sensitive to change and can suffer from physical disturbances as well as pollutants (Dodds, 2002). These aquatic ecosystems have significant benefits in that they provide potable water, have significant monetary value, and allow for the production of crops. Freshwater environments also provide a habitat for many species of animals and plants. These are just a few of the benefits that can be obtained from healthy freshwater ecosystems.

Tropical forests are home to the greatest biological diversity in the world, mostly due to their structural complexity (Terborgh, 1992). El Yunque National Forest (2008), the only tropical forest in the U.S. National Forest System, is similarly diverse in that it has 500 native plants and animals. In an attempt to protect this unique tropical environment, the United States Department of Agriculture (2008) designated three of El Yunque's rivers as being "wild and scenic". These pristine rivers—the Río Mameyes, Río de la Mina, and Río Icacos—are home to endangered plants and animals that rely on the delicate ecosystem in which they live. Given these unique flora and fauna, the purity of the Forest's streams and rivers is of the utmost importance. El Yunque National Forest has made it clear that establishing an effective monitoring program is necessary to ensure that the aforementioned aquatic environments remain at a high quality.

The goal of this project was to identify and recommend a sustainable method of monitoring the water quality of El Yunque National Forest's wild and scenic rivers. In order to successfully and effectively accomplish this task we created three objectives:

- To determine an up-to-date, feasible method of monitoring the water quality;
- To determine the best training methods for USFS field personnel so water quality monitoring can be correctly carried out in the future;
- To develop and recommend a plan for making water testing a sustainable practice.

Through a literature review and several interviews with local experts, we determined how best to design and execute a water-sampling plan for the wild and scenic rivers in El Yunque. Specifically, these interviews helped us decide which equipment to use and which types of variables would be best to monitor. When deciding on these details, we had to ensure the proposed plans were economically sustainable and efficient for El Yunque National Forest. Ultimately we decided to use a multi-parameter sampling probe in our water quality monitoring plan due to the equipment's relatively low price, high

accuracy and speed of sampling. The particular equipment we used, a HANNA HI 9828 probe, allowed us to sample several important quality variables such as pH, dissolved oxygen, salinity, and dissolved solids.

We conducted one week of field testing in the forest to identify the most desirable sampling points on each stream. We selected the seven sampling points by taking into account various factors such as possible disruptions to tourist activities, distance and time spent to reach each location; we also considered whether the testing results would be representative of the entire stream. One location, the Bisley sampling point, ought to be sampled less frequently due to the travel challenges and time demands required to reach this wild portion of the Rio Mameyes. We recommend monitoring the other six sampling points four to six times per year due to their accessibility and potential to be sampled over the course of a single day.

After finalizing the water quality monitoring plan we conducted a training session to inform the staff of El Yunque National Forest on how to properly conduct water quality tests. We decided to give an interactive presentation, emphasizing common sampling mistakes and points of caution to ensure El Yunque's water quality results are reliable. This training also incorporated a hands-on portion with the equipment, allowing the trainees to navigate the menus, explore the various features and ask any questions they had. We also developed a pamphlet for the equipment explains the proper usage of the multi-parameter probe. The use of both a training session and the development of a short easy-to-read brochure will help ensure that reliable and accurate water quality results are achieved in the future.

Once all of the field data had been collected, we were able to conduct a preliminary analysis of the water quality results. In the five stream sites sampled there was a high volatility in several important parameters; however, *there were no clear trends of diminishing water quality when comparing scenic and recreational areas on the rivers*. Additional testing over the course of a year will need to be conducted to assess whether there is any trend or causal relationship visible amongst the sampling sites. Most importantly, all of the sites sampled passed Puerto Rico Class SD water quality standards, meaning that both Rio Mameyes and Rio Icacos are acceptable for use as public water supplies and for recreational purposes.

By making use of the information collected in our site visits we were able to calculate how much it would cost for the forest to implement our program. We determined that a water quality monitoring plan, inclusive of equipment, labor and vehicle costs, could be implemented for one year for under $8,000. A large portion of this cost is attributed to the equipment that must be purchased in order to conduct the testing. Fortunately this is a one-time cost, so each future year of testing would only be between $2,800 and $3,800 depending upon the frequency of testing undertaken.

Recommendations

The result of our project is a solid framework for future water sampling that can be used to assess El Yunque's wild and scenic streams and rivers. Assuming sufficient funds are available, we recommend El Yunque National Forest do the following to ensure the forest's wild and scenic rivers remain pristine:

- Implement a water quality monitoring plan using the recommended sampling points and frequency;
- Purchase a multi-parameter water quality probe that includes a probe able to measure nitrates in addition to common key variables (pH, dissolved oxygen, etc.);
- Establish an annual one-day session for managers and field personnel to discuss water quality results and consider necessary steps to correct any problems encountered.

The key elements of a water quality monitoring plan are not highly variable and may only need slight adjustments over time to ensure they continually achieve the desired purpose. With training materials already developed and such a relatively small implementation cost, we believe that our water quality monitoring system could be easily implemented in other National Forests that wish to assess whether tourism and other influences are impacting the health of their aquatic ecosystems

1.0 Introduction

Improper management of water can severely harm the flora and fauna that rely on the water to survive (Scenic Rivers, 2002). Unfortunately, overuse of freshwater has caused several cities in the United States to consider constructing desalination plants to remedy their freshwater shortfall (Yuhas & Daniels, 2007). Animals, unlike humans, must rely on the quality of water supplied from local aquatic ecosystems – whether clean or not. This clean water dilemma is an even greater problem in the world's tropical rainforests, where the presence of sensitive and endangered species demands that water quality be of the highest purity.

Freshwater quality is not simply a problem confined to urban areas. Water quality issues are beginning to impact El Yunque National Forest, a landlocked tropical rainforest in the northeastern corner of Puerto Rico (USFS, 2008). The Caribbean National Forest Wild and Scenic Rivers Act (2002) designated portions of three of El Yunque's rivers as wild and scenic for future generations to enjoy. While this increased publicity is good for increasing the number of tourists, the increased amount of human activities and automobile traffic in the National Forest threatens the possibility of maintaining the water systems in their current pristine state. The rise in tourists, to over 1.2 million visitors in 2010, has highlighted the need to develop ways to test the forest's wild and scenic rivers, to ensure that the delicate ecosystems are left undamaged. The vast amount of wildlife and biological diversity within the rainforest that could be affected by any change in the ecosystem is substantial (Dodds, 2002; Harker, 1993; Head & Heinzman, 1990).

The designation of El Yunque's rivers as wild and scenic means they must be protected for their inherent value to the environment and for the people living around them. With the increasing popularity of the rainforest, maintaining these rivers in their near untouched state is extremely difficult. Negative influences by tourists can be seen at a recreational site called Puente Roto, in the approximate center of El Yunque, which has recorded above average fecal coliform levels (El Yunque, 2008). Additionally, the same study states that there is also significant pollution coming from neighboring ranches and farms in the form of fertilizer runoff. This runoff can trigger unhealthy, elevated levels of bacteria and hormones in local streams. Outside El Yunque National Forest, there is extensive research that focuses on varying water quality assessment methods that range in simplicity from a visual evaluation (USDA, 1998), which examines factors such as clarity and fish populations, to a bioassay method (Moiseenko, 2004), which tests the concentrations of lethal chemicals in the water using laboratory analyses. There has also been research conducted on the evaluation of water quality in other tropical ecosystems, such as in Kenya (Mokaya, Mathooko, & Leichtfried, 2004).

In El Yunque National forest there is, however, a lack in knowledge concerning water quality assessment systems. Conducting water quality assessments is not as simple as merely using a generic assessment system; each area is unique, and there is a risk of inaccurate water health evaluations if a protocol specific to El Yunque is not created (Boulton, 1999). Therefore it is essential to identify the unique factors that play a role in determining water quality levels in El Yunque's streams and rivers. A detailed plan to examine stream health to ensure that the water will remain clean enough to preserve this natural ecosystem has yet to be developed for El Yunque.

The goal of our project was to identify an up-to-date, economically sustainable method of monitoring the water quality of El Yunque National Forest's wild and scenic rivers that can be used for many years. We reviewed the various techniques and equipment available for testing water quality and determined which was most appropriate for El Yunque National Forest's personnel and budget. After finalizing a plan to monitor the rivers, we developed a series of training materials to educate field personnel on how to properly use the equipment. Specifically, we conducted a training session, directed a hands-on field training demonstration and created an information guide so the forest service personnel could become knowledgeable on the intricacies of water sampling. Our successful completion of these steps has provided El Yunque National Forest with a time- and resource-efficient method to ensure that their rivers can be maintained at the forest's high standards.

2.0 Background

The environmental importance of rainforest ecosystems requires that they be adequately monitored for their long-term preservation. Tropical rainforests exist between the Tropics of Cancer and Capricorn, flourishing only in climates where the average temperature is eighty degrees Fahrenheit (Perry, 1990). Rainforests receive ample amounts of rain, ranging from three to six meters annually. The unusual combination of sun, rain, and humidity allow for these regions to be extremely biologically diverse. These ecosystems are home to millions of different species, which can range from trees and bushes all the way to exotic birds, flowers and aquatic organisms. This diversity is a key factor behind the importance of monitoring a tropical rain forest ecosystem." It has often been said that tropical rain forests are the richest ecosystems on Earth, but just how rich is only beginning to be appreciated" (p. 29). Scenic rivers in rainforests have many desirable assets that should be preserved. In order to keep these diverse ecosystems safe, the water quality of these freshwater ecosystems must be kept very high and ideally monitored for any changes.

2.1 Freshwater Ecosystems

Freshwater ecosystems are defined as any body of water that has a total dissolved solids level that is less than 10,000 mg/L (Younger, 2007). These systems can be extremely varied in appearance, ranging from standing water in wetlands and lakes to running water in streams and rivers. They are increasingly facing attack by human influences in the form of habitat destruction, fishing and various forms of pollution (Baskin, 2003).

2.1.1 Importance of Water Quality

The Ecological Society of America has identified five "environmental factors" that constitute a healthy freshwater ecosystem (Baskin, 2003; Younger, 2007).

1. Flow patterns: This looks at the flow rate of water, which can be used to assess the retention time of nutrients and toxins. It is essential in assessing the amount of time needed for new water to replace old.
2. Chemical and nutrient conditions: These can serve as a regulator for the pH of the aquatic system, which influences the plants and animals that can be sustained in the habitat.
3. Temperature and light penetration: Levels of sunlight are known to influence the levels of algal and other plant growth. This growth can indirectly impact the types of organisms found

in the environment. The temperature of the water has a significant impact on the rate of metabolic processes and consequently the productivity of aquatic fauna.

4. Sediment and organic matter: These components are critical for the storage of nutrients. Certain environmental structures can also serve as spawning locations for aquatic organisms.
5. Plant and animal assemblage: The flora and fauna relying on the freshwater can give an approximate indication of the ecosystem's health.

While these variables are all important individually, it is the dynamic interaction of all these factors that determines the stability of an aquatic environment (Baskin, 2003). Environmental influences can cause significant seasonal changes in each of these factors, which animals and plants must adapt to in order to be successful and reproduce. Extreme natural hydrological events such as floods and droughts can occasionally occur, providing a natural method for the increasing species diversity and richness. These natural events, particularly flooding, can cause the spread of seeds and spores to areas where they might not have been previously. The increased diversity in fauna is typically due to a migration after their previous habitat is destroyed or damaged. Despite being able to readily adapt to hydrological events, freshwater ecosystems struggle to combat the effects of human impacts (Revanga et al., 2006).

2.1.2 Societal threats to freshwater ecosystems

Revenga et al. (2006), illustrate the dire situation of many freshwater ecosystems resulting from human impacts. They estimate that the threats faced by freshwater ecosystems are far greater than those of any other ecosystem. For example, in North America the extinction rate of freshwater fauna is projected to be five times higher than that of terrestrial fauna. The growing human population and a greater need for freshwater resources will place an increased burden on these already stressed aquatic ecosystems.

The human disturbance of freshwater ecosystems is becoming common in both developed and less developed countries. An example of the endangerment of a clean and pristine system can be seen in the suspected contamination of the Metolius River in Deschutes National Forest, a relatively isolated National Forest in central Oregon (Wild and Scenic, 2003). This contamination was presumably caused by mismanagement of upstream cabin septic systems, over logging surrounding areas, and improper use of recreational and camping activities. To prevent further contamination and ensure this river remained a valuable asset to the surrounding ecosystem, the United States Forest Service implemented a water quality monitoring system to monitor levels of various parameters such as pH, ammonia, nitrates, and bacteria. These were then used to arrive at recommendations and to educate the public on how to best preserve the Metolius River.

2.2 Monitoring River and Stream Water Quality

The importance of freshwater ecosystems and the rapid rate at which they can be contaminated creates a need to monitor their quality closely. This is difficult as water ecosystems are ever-changing, making them a challenge to monitor (Andrew & Mapstone, 1987; Sokal & Rohlf, 1995). As a result, it is critical to properly design a monitoring plan that can account for a river's dynamic nature. Since there is no perfect monitoring system, a number of testing variables must be examined to ensure the testing strategy is practical and sustainable.

2.2.1 Designing a Water Quality Plan

A proper sampling plan must be determined to avoid wasting resources (Downes et al., 2002). The optimal results for a water monitoring program would have the researcher taking numerous samples from various depths and at a copious number of locations throughout the stream's entire length. While this is statistically desirable, it is not feasible to conduct such an intensive method of testing for an extended period of time. Water quality researchers must be aware of this to ensure their sampling method is practical.

Downes et al. (2002) stipulate that when conducting causal testing, the first step necessary to cut down the number of sampling locations is to understand that there are two or three critical testing points needed: a control location, an impact location and an optional reference location. The impact location is the "location of concern", or where there is thought to be an undesired impact that is adversely affecting overall aquatic health. This location is then compared to a control, which is almost identical in terrain and water characteristics (depth, width, turbidity, etc.) but not likely to have any impacts. If any contamination is suspected to be at the control location, a third location called the reference location is desirable. The reference location, typically quite different in terrain and appearance, is used due to its known "pristine" nature. Using this technique, the reference and control locations can then be evaluated in comparison to the impact location.

The second way of limiting the number of samples and ensuring the results are reliable is by conducting random samples. There are many methods of conducting a random sample, with varying degrees of complexity. Water quality researchers frequently use simple random samples and stratified random samples due to their simplicity (Wymer, 2008). In many cases, when conducting a simple random sample the researcher randomly generates a number, which corresponds to a certain location on the body of water. The sample of water is then drawn from that randomly chosen location.

Lastly, duration of the monitoring is an important factor in achieving a successful water quality study (Wymer, 2008). If you are assessing the impact of a negative stressor on the ecosystem, you must allow it to complete several natural impact cycles. While this may be time consuming, if the study is conducted in this manner a causal relationship will be easy to identify.

2.2.2 Monitoring Standards

Not only are lentic and lotic ecosystems ever-changing, but their conditions also vary widely from region to region (Boulton, 1999; Downes et al., 2002). Nonetheless, there is a set of water quality measurement standards that holds true no matter what flowing water system is being examined.

There are several different types of water quality monitoring systems depending on the variables the researcher wishes to assess (Downes et al., 2002). Each varies in the level of complexity and in the results that are produced. The most basic assessment is an *environmental monitoring* plan. This assessment examines the overall state of the ecosystem by taking a visual examination of the area surrounding the local water source. Since the area immediately adjacent to the stream or river is not likely to drastically change in health, this technique works best for infrequent or periodic evaluations. This technique cannot adequately pinpoint a specific source of pollution as specific variables are not being measured. Essentially the overall well-being of the local ecosystem is all that can be gleaned from this monitoring strategy.

Compliance monitoring is slightly more complex in that samples must be taken from a specific discharge site to assess the chemical make-up of the water that was withdrawn (Downes et al., 2002). This assessment is frequently used by industries to ensure the composition of their effluent has pollutant levels below those stipulated by government standards and health regulations. This evaluation method does not take into account the water quality far downstream, as the composition at discharge is generally the only thing that matters.

Long-term monitoring and *impact monitoring* are the most complex strategies insofar as they must be well planned in order to be successful (Wagner, 2000). Both of these monitoring techniques are used to find causal explanations, since they look for the impacts caused by outside interference on a flowing water system (Downes et al., 2002). These impacts are typically due to some form of human intervention. However, it is not uncommon for large-scale catastrophes, such as a volcanic eruption or flooding, to cause drastic changes in measurement readings.

While the choice of monitoring program is important, the difference between a successful and unsuccessful monitoring program hinges upon the variables the researcher wishes to monitor (Downes et al., 2002). An open mind is required when selecting the monitoring variables as there are advantages and disadvantages associated with every taxa. For example, measuring the amount of plankton in a sample can be extremely beneficial due to the plethora of information regarding their behavior in response to toxins (Ruse & Hutchings, 1996). However, there are some glaring disadvantages. There can be extremely high variability among samples, and it requires a high level of scientific expertise. In sum, the choice of taxonomic groups to monitor should not be taken lightly.

The variables chosen are largely dependent upon the questions the researcher wishes to answer. For example, in 1973 the United States National Forest Service began noticing unusual fluctuations in the water level of Redwood Creek, an essential water source for some of the largest redwoods in the world (Smelser, & Schmidt, 1998). Alarmed by this discovery, the U.S. Geological Survey established a water monitoring program that assessed sediment transport and deposition in Redwood Creek. Ultimately, by assessing these variables they were able to surmise that the fluctuations were caused by timber harvesting upstream. These variables were selected after extensive background review of climate records, past stream data and dendrochronology.

2.2.3 Current Technologies and Equipment

The current research conducted by Wagner (2000) reveals that water quality monitoring stations are typically used to ease the difficulty of obtaining water samples. These monitoring stations can have a range of testing apparatuses, which are housed in a water sealed location that can assess a range of variables (i.e. temperature, pH, turbidity, and the amount of dissolved oxygen in the sample). *Figure 1* shows a detailed schematic of a water quality monitoring station. The most important feature of the monitoring station is the sonde, which functions as a data logger, gathering all of the outputs from the aforementioned instruments and recording their values at specified time intervals. The recorded data on the sonde can then be retrieved by researchers when it is most convenient for them.

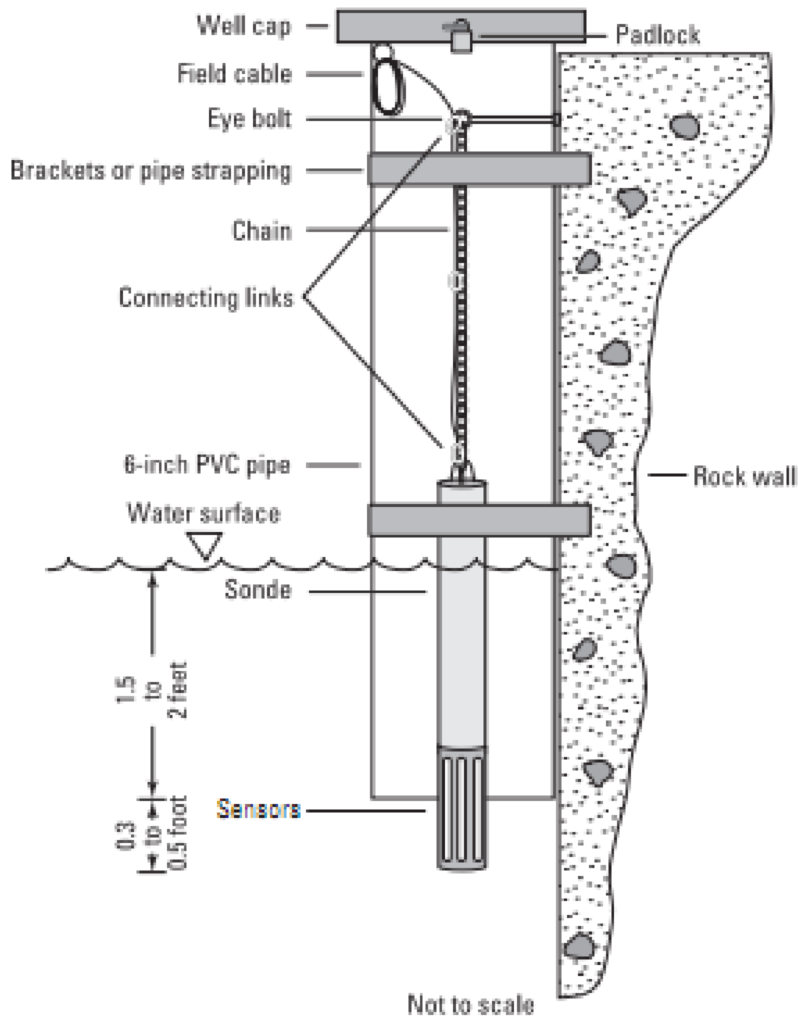

Figure 1: A Typical Water Quality Monitoring Station (Wagner, 2000, p.7)

Temperature of a water sample is a very important measure as it can directly impact the solubility of gaseous components (Wagner, 2000). A simple thermoresistor is the typical means of measuring the temperature of a sample due to its low cost and high accuracy. Salinity and the number of ions in the water can be found by assessing the specific conductance between two electrodes. While these two measurements are simple, more advanced water analyses such as measurements of dissolved oxygen and pH cannot be explained without advanced chemical knowledge. There are some additional tests, such as levels of phytoplankton and bacteria, that require advanced laboratory work. If the equipment needed to test these variables is not on hand, the samples must be sent to a laboratory, slowing down the speed that data can be analyzed and interpreted.

2.2.4 Interpreting Results

The proper design and execution of a plan to monitor water quality will produce a wealth of data that can be used to infer conclusions and generate recommendations (Underwood, 1997). Incorrect use of statistical outputs can lead to an inaccurate diagnosis, which could result in monitoring being disrupted prematurely or prolonged unnecessarily.

In any organization the staff must weigh the cost of acquiring information with its respective benefits (Underwood, 1997). Cost-benefit analyses are frequently used in water quality assessments due to the limited amount of funds available for multiple projects. For corporations deciding whether to change a procedure often hinges on seeing whether the change is financially advantageous. This is far easier than the tradeoffs one would experience in an environmental situation. The collection of monthly stream data over a span of several years can be tough to justify to the public when government funds are low and taxes are soaring. There can also be serious moral dilemmas when organizations and agencies are forced to put a price on an important issue such as the survival of an endangered species.

Underwood (1997) discusses the difficult position many ecological organizations face when they rely upon funding from government appropriations and public donations. The nature of these donations requires that the recipient of the funding publish their accomplishments on an annual basis. This means that funding must be used in a way that effectively produces tangible and significant results. The sampling of water for quality measurements is far from an inexpensive task as it is very labor intensive. Therefore, a cost-benefit analysis when applied to water quality monitoring will seek to minimize the number of samples needed to produce equivalent, or near equivalent statistical results. Sokal and Rohlf (1995) discuss how the number of samples can be minimized by calculating the variation in water quality readings. This is important because results and data will not be sacrificed, but instead the optimal number of samples will be withdrawn.

According to studies conducted by Armour (1983), the end goal of most water monitoring studies is to ensure the waterway achieves or maintains a desired level of ecological diversity. Since remediation is typically hard to accomplish, it is a common error in sampling to almost entirely stop once the end goal is obtained. This is a critical error as an ecosystem is not completely stable until all previously endangered species in the population are capable of self-replacement. Connell and Sousa (1983) argue that the aforementioned criteria are not even sufficient, and that *all species* must complete one population cycle and maintain healthy levels before the system has recovered. There is consensus among researchers that the best way to judge the stability of a system is by comparing it to a similar or benchmark ecosystem.

Restoration of rainforests has been a popular research topic recently due to the demolition of much of Costa Rica's natural rainforest habitats in the 1970s and 1980s (Colchester, & Lohmann, 1993; Harker, 1993; Place, 1993). Despite this extensive research, there is no known research done on restoring the quality of rainforest aquatic habitats, as all of the research is focused upon repopulation of tree and terrestrial species (Nicolas et al., 2001; Piotto et al. 2002; Carpenter et al., 2004).

When the objectives and criteria for a given stream have been met, it is essential for the testing to continue, although less frequently (Middleton, 1999). This allows past data to be relevant and usable in the event that another environmental problem occurs in the stream or river at a later time.

2.3 Non-formal Education

Staff chosen to conduct water quality monitoring may have limited experience in water sampling so they must be trained on proper methods and procedures (Bartrom & Balance, 1996). Non-formal education is popular for this purpose because the educational component is outside an established educational system, which is much more conducive to learning for many adults (Infed, 2001, ¶8). Despite not being as structured as a formal educational approach, non-formal education is typically seen as the ideal learning style for adults as it is more interactive and dynamic. There is a limited amount of research regarding educating field personnel using non-formal techniques, but we will nevertheless discuss the benefits and disadvantages of two important methods: instructional guides and professional and vocational training.

2.3.1 Instructional Guides

Instructional guides are the most pertinent to what our project entails, as it can be used by many people and remains valid over many years. These guides can easily illustrate the needed steps one should take to solve a problem or to accomplish a task. Frequently the tasks are numbered with a short description telling the user how it should be accomplished. There are many ecological instruction guides published by state and federal agencies for the use of local landowners. Recently the United States Forest Service (2004) released an instructional guide with how to identify if any trees on one's property are being inhabited by the Asian Longhorned Beetle (ALB). The guide outlines a series of five steps or modules that walk the landowners through the steps needed to eradicate the pest from their property and prevent further infestations.

2.3.2 Professional and Vocational Training

According to Bartram and Balance (1996), professional and vocational training is a most favored type of non-formal education technique for educating staff who will conduct water quality tests because it pairs a general educating session with field work. Being able to actually learn the methods with mentors nearby means the correct procedures will naturally be incorporated into future water tests. Numerous studies (Greenwood, 1982; Karem, 2010) state that for small class sizes, non-formal education approaches produce the best results. In Karem's study, Saudi Arabian students were split into two groups, classroom only and classroom/non-classroom exposure, where they were taught about current environmental issues. The findings revealed that the students who had the classroom/non-classroom exposure had made significantly more strides in regards to being environmentally conscious than the classroom-only group. However, this educational approach can be time consuming, with a well-organized training session taking as long as one to two weeks.

There are a plethora of other professional educational opportunities. Workshops are also commonly used for adults because they are intensive and typically last no longer than one or two days. Workshops also allow attendees to converse and form a rapport that can be used to broaden their professional network. Ultimately, the instructional method we suggest will likely depend upon what the staff at El Yunque National Forest have liked and disliked from past educational sessions.

2.4 El Yunque National Forest

According to the United States Department of Agriculture (2011), El Yunque National Forest is the only tropical rainforest in the United States National Forest System. Every year, El Yunque draws more than one million visitors to observe its biodiversity. Despite being one of the smallest national forests in the system, it is one of the most ecologically diverse. Within the 28,000 acres of the forest, several ecological zones and niches are present, which would be separated many miles apart in other rainforests. El Yunque contains 150 fern species and 240 tree species, 23 of which are only found in El Yunque.

El Yunque is divided into four major forest types (USDA, 2011). The Tabonuco, with vegetation characteristic of a rainforest, makes up over fifty percent of the forest and contains the foothills and slopes of El Yunque. The next largest forest type, the Palo Colorado, occupies the mountain slopes approximately 2000 feet above sea level. The Palo Colorado differs from the Tabonuco in that the trees do not grow as high and canopy layers are less evident. At approximately the same elevation but on the very steep slopes is the Sierra Palm forest. Lastly, the Cloud forest type makes up the remaining part of El Yunque, comprised of the steepest slopes and high peaks. El Yunque includes ten major rivers that form twelve watersheds throughout the forest (Blodgett et al., 2011). These rivers need to be monitored carefully as they play a vital role in the stability of the rainforest ecosystem. The water in a rainforest's streams can provide data on its overall health by analyzing the amount of bacteria and aquatic organisms and many other characteristics. Within El Yunque, wild and scenic rivers have been designated in order to preserve and protect certain parts of the forest.

2.4.1 El Yunque's Wild and Scenic Rivers

A wild and scenic river is considered to be especially scenic and recreationally valuable (USDA, 2011). The designation of wild and scenic rivers requires approval by Congress. The desired effect of this classification is that these river segments will be protected ensuring the surrounding ecosystem remains unharmed and intact for many decades into the future. For the most part, these rivers are only accessible by hiking trails and are free of structures and modifications such as channelization. Congress has also placed several constraints on these areas in order to aid in their preservation. Some of these limitations include no road construction, no mechanized vehicle use such as bicycles, no manipulative research, and high standards for trail construction. The United States government has bestowed this classification on three of El Yunque's rivers due the uniqueness of being the only tropical rivers in the National Forest System.

One of the designated wild and scenic rivers is the Río Mameyes, spanning a length of four-and one-half miles (Perry, 1990). The Río Mameyes has scenic value because of its remote and isolated location. In this region are masses of boulders, several small pools and waterfalls, and a narrow gorge about one mile in length. The Río Mameyes also has recreational value such that it is the most popular area for water recreation. Historically, the scenic portion of the river contained homestead sites dating to the 1930's and earlier. The Mameyes watershed covers nearly seven square miles of the forest, playing a significant role in water discharge. The most important feature of the Mameyes region is its biological value. It provides a habitat for the Puerto Rican Parrot and Puerto Rican Boa, both of which are endangered species. The threatened Broad-Winged and Sharp-shinned hawks are also present in the area, among other sensitive species. Three sensitive plant species also thrive in the region. Significantly, the Mameyes is the only river that is un-interrupted from origin to sea. This explains why the Mameyes has the highest level of aquatic diversity of all the watersheds. In its waters are five species of fish, nine species of freshwater shrimp, and its only freshwater crab.

Río de la Mina, another designated scenic river, has a total length of 2.1 miles and has the most visitors (Perry, 1990). La Mina has small segments with unique views of the Palo Colorado and Sierra Palm forests. In terms of recreation, the Palo Colorado and Sierra Palm picnic sites are located along the river and experience lots of visitors. One of the most valuable falls in the forest, La Mina Falls, is located along La Mina trail and connects with La Coca trail. La Coca trail contains a view of an old mine tunnel where gold was once extracted, providing much recreational value. Water quality is said to be good in the area but is known to be affected by the picnic areas. Biologically, La Mina is also an important habitat to several endangered species including the Puerto Rican Parrot.

The third and most southerly of the wild and scenic rivers is Río Icacos (Perry, 1990). The scenic value of the Río Icacos can be attributed to the varied terrain along its length and the many rare plant species that grow nearby. It contains a sandy bed upstream and a rapids-filled downstream, more common to many other rivers in the forest. Although there are a limited number of trails in the area, hiking is a significant recreational activity. In contrast to many other streams and rivers in El Yunque National Forest, the upper region of Río Icacos has a flat bottom and slight gradient. Many Civilian Conservation Corps projects and sites dating back to the 1930s exist along the river, including work camps and a hydroelectric dam, adding historical value. Pre-Columbian Taino petroglyphs are located along the river in addition to one rock shelter containing Spanish colonial ceramics. Geologically, the river contains an intrusion of quartz diorite. There are clay flood plains and frequent landslides within the region. These landslides contribute to the majority of the sediment in the river. Although the Puerto Rican Parrot does not live in the area, it is considered to be a necessary location for species recovery. However, the endangered boa and hawks do use the Icacos area as a habitat. The sensitive Burrow Coqui lives in the area along with four endangered and fifteen sensitive plant species. The topography within the Río Icacos valley makes it unique among the forest rivers, having one of two slow moving streams within El Yunque National Forest.

2.5 Summary

Freshwater ecosystems have an extremely high biological value. Unfortunately, societal mistreatment of these freshwater ecosystems has made monitoring the water quality of streams and rivers a necessity. When designing and executing water quality monitoring plans it is crucial that they are practical and sustainable for long-term testing. The wild streams and rivers of El Yunque National Forest have been deemed by US Congress as a valuable asset and thus must remain at their current pristine state. As a result, an efficient water quality monitoring plan needs to be established.

3.0 Methods

The goal of this project was to design an up-to-date water quality monitoring system for El Yunque National Forest's wild streams and rivers. In addition to this, we designed a training program to educate forest rangers how to adequately and quickly assess the quality of the water regardless of their professional/educational background. To help us achieve these objectives we developed a variety of research methods. This chapter details the process and reasoning behind why each method was selected.

3.1 Identify Current Methodologies and Technologies

In the first phase of our project, we determined what current methodologies and technologies are being used in Puerto Rico to measure stream and river water quality. The information that we obtained formed the foundation of our proposed water quality testing plan for El Yunque National Forest. This stage was important in filling any gaps in knowledge with regard to conducting water quality testing in a tropical environment.

3.1.1 Correspondence with Local Experts

Our group interviewed various local water quality experts in order to develop a plan to monitor stream health. We discussed our project with Bill McDowell, a professor who specializes in environmental and water resources, at the University of New Hampshire. Professor McDowell works in the field of environmental science and is the director of the New Hampshire Water Resource Research Center. This correspondence provided us with insights from a scientist who is extremely knowledgeable and has had numerous years of experience monitoring the streams of El Yunque. We contacted Professors McDowell by telephone, and he helped us to refine our water quality monitoring plan. This was done by asking various questions, provided in Appendix C, that primarily focused on water quality standards and understanding the dynamics of El Yunque National Forest's aquatic ecosystems.

To better understand El Yunque we also interviewed three members of the United States Geological Survey, or the USGS. The USGS is a government organization that monitors water quality in various public watersheds. These members of the USGS were an invaluable resource because of their experience with working in the rainforest and other areas of Puerto Rico. Our questions focused specifically on what the important water quality factors are and the equipment used to test for them. The interview transcript from our visit to the USGS can be found in Appendix D.

3.1.2 Interviews with USFS Staff

To understand the training of USFS staff and to become acquainted with the water testing equipment available to the USFS, we informally interviewed two members of the USFS Planning and Ecosystem team. We discussed any possible shortcomings and frustrations that they might have with establishing a water monitoring system. This early interaction with forest personnel was imperative, as it allowed us to form plans for developing a realistic monitoring system. It also helped us to adjust the complexity of our sampling methods to ensure that all staff members could conduct the necessary water quality testing quickly and correctly. To see the interview results from the USFS, refer to Appendix E.

We also spoke with other USFS members within El Yunque National Forest. Specifically, we talked to a member of the Property Management and Customer Service team to discuss the geographical features of the forest and inquire as to how we should structure our sampling plan to minimize disturbances to forest visitors. It was also important to discuss our monitoring plan with the Forest Planning and Administration team, as they have past water quality monitoring data. They informed us about the several locations of the rainforest that are of concern and in need of close attention when establishing a water quality monitoring plan.

3.2 Design and Testing of a Water Quality Monitoring Plan

This section outlines how we went about designing and testing a water quality monitoring plan. Having done extensive research on water quality monitoring, we utilized our knowledge of sampling designs, variable selection and statistical analyses to evaluate the water quality of El Yunque’s wild and scenic rivers.

3.2.1 Variable Selection

There are no universal standards for measuring a stream’s health; every area is unique, and the factors that are analyzed must be relevant to El Yunque National Rainforest. Therefore, our team had to carefully consider which variables a water quality system in El Yunque should measure. We communicated with our project liaison, Pedro Rios of the USFS, by phone so that we could know what their expectations were for the monitoring system before we arrived in Puerto Rico. This interview was vital to our project, as we found out that a member of the USFS team was going to be ordering equipment so it could be available before we arrived in El Yunque.

The equipment we used to conduct our testing was the HANNA HI 9828 multi-parameter water quality meter pictured below in Figure 2. These meters operate very similarly to that of the water quality stations mentioned in the background section; however, they are very different in that they are portable due to their small size (9”x4.5”x2.5”) and reasonable weight (0.75 kilograms). Encased in long cylindrical probe portion, on the right of Figure 2, are compartments that can accommodate three sensors modules. The sensor modules we were provided with allowed us to test a plethora of water quality parameters such as conductivity, dissolved oxygen, temperature, pH, temperature and turbidity. With the purchase of additional sensor modules, levels of more complex variables such as nitrates, ammonium and chlorate levels could be measured.

Figure 2: The HANNA HI 9828 multi-parameter probe

We conducted additional research that focused on determining which other variables could be important to monitor in El Yunque National Forest. This research included interviews with two local sources of expertise: the USGS and the University of New Hampshire. We asked members of these institutions questions that focused on other methods of measuring stream health. The interview protocol we used focused on variables that were not already chosen to be sampled. The results of our interviews can be found in Appendices C and D. These allowed us to assess if there would be additional equipment the USFS should consider purchasing in the future.

3.2.2 Sampling Locations

We decided on sampling locations and sampling methods through our conversations with the USGS, the USFS and WPI's Professor Paul Mathisen, both specialists in water quality management. In order to most effectively conduct water quality tests we first selected which points along each river would be practical and accessible for testing. This was done by looking at a map of El Yunque to assess the topographic and spatial surroundings. Of specific importance was proximity to roads and trails, density of forest cover and the gradient of the river.

We then visited each of these proposed sites to determine the distance traveled by vehicle and the amount of time required to reach the sampling locations. This was done by recording the amount of time in minutes and distance in miles relative to the Forest's Catalina headquarters to each planned water quality testing site. In addition, in our field observations we recorded any cautionary notes such as locations where the roads were of poor quality and where there are natural barriers to vehicle transportation. Pictures and videos of the sampling locations were also taken in the event that our field notes were not satisfactory.

We evaluated our aforementioned field notes when deciding on the final sampling locations. For Rio Mameyes and Rio de la Mina, we chose several points so that we could have a sampling point in a "wild" region, a "scenic" region and a "recreational" region of each aforementioned river. We decided to only use one sampling point along the Icacos due to the difficult river access and the minimal variability in the water throughout its entire length. We know there is very little change in river flow and expected contamination based on our interview with the USGS (Appendix D). At each location we deployed the probe into the water for one minute and had it record data at ten second intervals, due to logistics and the desire for maximum efficiency. This sampling method is the most practical, because it allowed for *several* samples to be quickly recorded in just one site visit. When sampling, it is best to have a large number of samples in order to minimize the sampling error and increase the validity of the results, but this was not feasible for the one week we spent in the forest. Therefore, we recorded water quality data with the previously mentioned parameters (one minute duration and with data recorded at a ten second interval). This provided us with enough data to see if any variables were of concern and should be monitored closely by forest staff in future water testing.

3.2.3 Interpretation of Results

Once all water samples had been collected, we decided which readings from the water quality results were the most important. We made use of Microsoft Excel to make the averaged data understandable and easily comparable by expressing the numerical results in a tabular form. We did not create a spreadsheet for the forest service as many multi-parameter equipment kits come with an in-house computer program.

3.3 Training Program Development

An important part of our project was to teach the method of testing water quality we had identified to the El Yunque National Forest staff members. This will allow them to carry on water quality measurements after we have departed. The development of a training session was the foundation of our educational approach. Some points of emphasis were proper water sampling methods, data recording techniques and how to understand the results of various tests. We also took two members of the staff out to the various rivers to demonstrate proper sampling techniques. We also created a training pamphlet to supplement our training session and shortened the learning curve needed to become familiar with these new testing technologies.

3.4 Summary

The development of a framework for future testing in a rainforest the size of El Yunque was not a simple task. Our approach of first gathering information from local experts and then pairing that with universal water monitoring techniques ensures that the system is up-to-date and appropriate for a tropical ecosystem. Close attention to details during the design and testing stage guaranteed that this sampling system will be both reliable and replicable. Most importantly, it allowed us to develop the concepts and models that we passed on to staff working at El Yunque. Overall, this will allow the streams of El Yunque to be monitored effectively for many years into the future.

4.0 Results & Analysis

Our correspondence with local experts, interviews with USFS staff and analysis of various river locations in El Yunque provided us with the information we needed to develop a comprehensive plan for monitoring El Yunque's wild and scenic rivers. In this chapter we examine the results of our research and the feasibility of the entire plan. We first discuss how we finalized our sampling locations, and then we briefly assess the water quality results we obtained in each of these locations. The final two sections of this chapter discuss a program cost assessment and an evaluation of our training program.

4.1 Analysis of Sampling Locations

We initially proposed nine different water sampling points on the rivers under study. Due to poor sampling conditions and logistical concerns we eliminated two of these locations resulting in a seven final sampling locations. These seven final recommended sampling locations were chosen by considering the importance of accessibility and for their strategic location in each of their respective watersheds.

4.1.1 Finalized Sampling Locations

We finalized our sampling sites based on their accessibility, including time and distance to each point as well as how feasible it was to collect data representative of the entire stream at each site. After assessing each point we decided to eliminate two of the original nine locations. The first location to be eliminated was the tourist viewing area at La Mina Falls and the second was the estuary outside the El Yunque National Forest formed by Rio Mameyes flowing into the Atlantic Ocean.

We found that gathering data at La Mina Falls proved to be inefficient for several different reasons. Reaching this point required walking on a long distance on a trail that would be difficult to navigate on days with high tourist volume. Additionally, there was no ideal sampling location due to the hazardous conditions that would be needed to place the sampling probe in a desired location and because the water being sampled would have temporarily elevated dissolved oxygen levels caused by the falling water. We eliminated the point since it was not critical to our overall sampling plan, as we already had two different locations that were representative of the composition of Rio de la Mina.

There were also a few complications concerning testing water quality on the Rio Mameyes site located near the ocean. Being an estuary this part of the river was very wide, which made it difficult to reach an appropriate point at which to collect data. We also determined that our data would be skewed regardless of the area we chose to test, as the saline ocean water would flow back into the estuary and mix with the contents of the freshwater river. It was for these reasons that we chose to exclude these points from our monitoring plan.

Figure 3: Eliminated Sampling Site - Mameyes Estuary

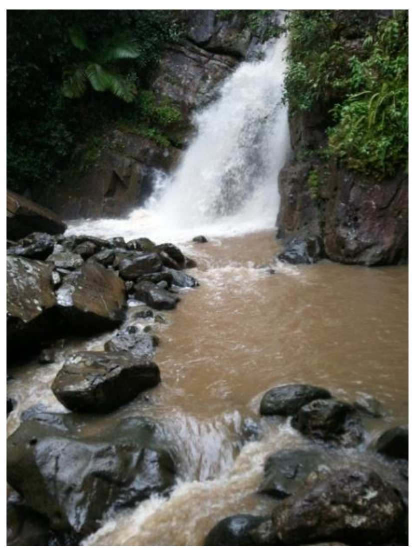

Figure 4: Eliminated Sampling Site - La Mina Falls

The finalized reccomended sampling points can be seen in Figure 5. We strategically chose these points so we had coverage in both wild, scenic and recreational portions of the rivers. An important aspect of any water quality monitoring plan is to have at least one sampling point upstream and another downstream. We have accomplished this by having three upstream locations on the Mameyes watershed and three points further downstream. If any data inconsistencies appear, the location causing the problem can be pinpointed immediately and rectified after one round of water quality tests.

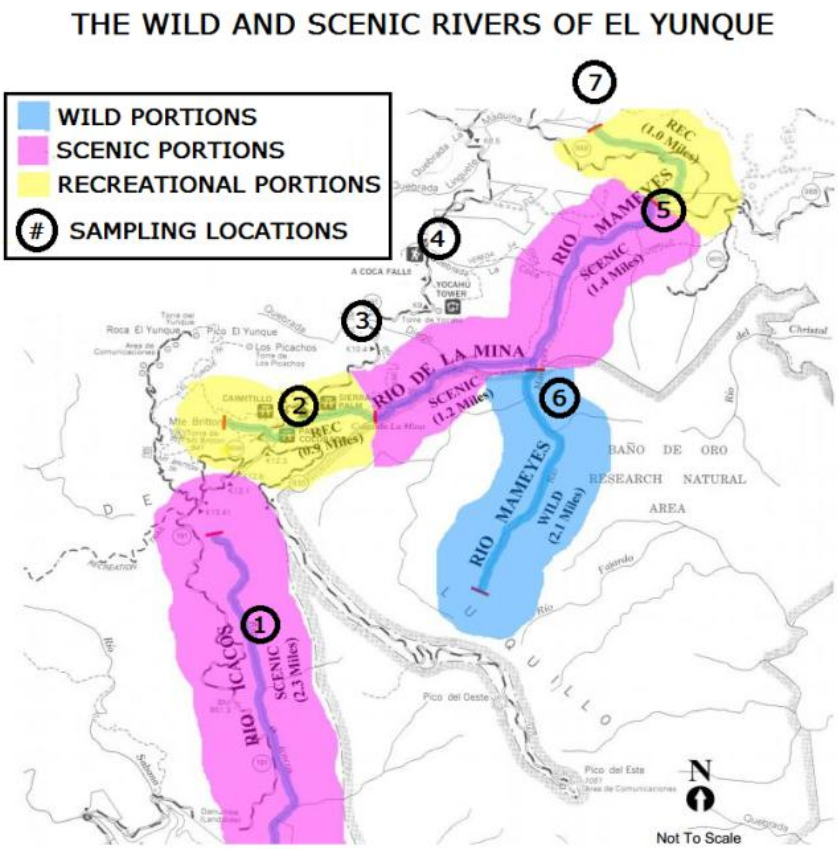

Figure 5: Locations of Finalized Sampling Locations

4.1.2 Locations' Accessibility and Frequency of Future Testing

The accessibility and recommended frequency of future testing are both very important in that they have a direct impact on the final cost off the monitoring plan. Sampling points 1, 2, 3, 4 and 7 are all located just off of the main road into El Yunque National Forest, Route 191. Sampling points 5 and 6 are reached via Route 988, which joins Route 191 right before the forest's headquarter building.

As shown in Table 1 below, most of our proposed points could be reached from the USFS headquarters in less than 20 minutes. An exception to this was the Bisley Trail, which led to a point where we could sample the wild portion of Rio Mameyes. Reaching this point required one hour and forty-five minutes, most of which had to be traveled on foot as opposed to by car. We found that testing for all points <u>except</u> for the Bisley trail point could be completed in one work day. Due to the difficulty of the hike, an entire extra day had to be allotted for testing the Bisley trail point. For this reason, we suggest that this specific point only be tested only twice per year.

Table 1: Times to Each Sampling Point and Suggested Sampling Frequencies

	From Headquarters, One Way		
Sampling Point	Time	Mileage	# of Yearly Visits
1. Icacos - USGS	40 min	13 km	4 to 6
2. La Mina - Palo Colorado	20 min	7.8 km	4 to 6
3. La Mina - Juan Diego	10 min	5.4 km	4 to 6
4. Mameyes - La Coca	10 min	3.8 km	4 to 6
5. Mameyes - Angelito	20 min	3.9 km	4 to 6
6. Mameyes - Bisley	1 hour 45 min	6.4 km	2
7. Mameyes – Off RT. 191	10 min	2.2 km	4 to 6

Due to a landslide on Route 191, the watershed of Rio Icacos only has one point that is readily accessible for testing, which is located forty minutes from the forest headquarters. At a distance of 13 kilometers, it is also the point that is furthest away. Despite the time and length of travel required to sample this point, we decided that this river could be tested with the same frequency as the other selected sampling points. This is because it was the only point that would provide data for Rio Icacos, and it is possible to combine this sampling with sampling at points 2, 3 and 4 on the return trip to the headquarters.

4.2 Analysis of Water Quality Results

Visual inspection and data collection were conducted at five sampling points along the Mameyes, Icacos and La Mina rivers. First, the data were analyzed by comparatively seeing if there were any visible trends among sampling points. We then compared the water quality values we had obtained, focusing on dissolved oxygen, temperature, pH, and dissolved solids, and compared them with the EPA water standards for Class SD in Puerto Rico.

4.2.1 Visual Observations

All of the streams and nearby vegetation appeared to be healthy and thriving in their lush rainforest environment. There was no murkiness, unusual color or foul odor being emitted by the streams and rivers we visited. Lastly, each sampling location we visited was free of any sort of trash or debris in the rivers. This was the case even in recreational and picnic locations, leading us to believe that visitors are properly disposing of any garbage they produce.

The upstream portion of Rio Icacos we visited had a flat sandy bottom with a small gradient, slow moving water and a muddy appearance from high levels of erosion. The Mameyes watershed, including both Rio de la Mina and Rio Mameyes, had a much higher clarity due to the difference in soil composition. The waterfalls in this area are known to be popular recreational spots; however we never observed any recreational swimming, but we were told by forest service employees that swimming is very common so consequently we did not modify our testing scheme.

4.2.2 Instrument Readings

Based upon our initial data collection, there was no clear trend of diminishing water quality when going from wild portions of the rivers to more recreational areas. The headwaters of Rio Mameyes (Quedabra Juan Diego, La Coca and Palo Colorado) had pH, conductivity and DO values that varied significantly. The result of these smaller streams with widely varying properties was an intermediate value produced downstream at the Rio Mameyes – Angelito Trail sampling location. It should be noted that the increase in stream and river temperature over the course of the day can likely be attributed to warming by means of solar radiation. All of these observations can be gleaned from Table 2 below. Detailed results of all measurements at each site can be found in Appendix F.

Table 2: Water Quality Readings at Each Site

Sampling Point	Dissolved Oxygen (DOmg/L)	pH	DS (ppm)	Temp (°C)	Salinity
1. Icacos - USGS	8.09	6.10	23.39	20.19	0.01
2. La Mina - Palo Colorado	9.10	6.65	32.84	20.25	0.01
3. La Mina - Juan Diego	6.97	7.16	67.16	20.58	0.02
4. Mameyes - La Coca	7.45	7.44	76.12	21.29	0.02
5. Mameyes - Angelito	7.07	7.21	71.64	22.63	0.02

The multi-parameter water quality probe appeared to be very accurate as the data logged in the sonde had very little variability over one minute of logging time; however we did have one clear outlier. This outlier value, 16.3 milligrams of oxygen per liter of water produced by the fourth dissolved oxygen reading at the Palo Colorado sampling site, was ignored as it produced a relative dissolved oxygen reading of 192.2%, which is unattainable. It is important to note that even though the data appear accurate, all of the above conclusions are being drawn on just one day of water sampling records. Ideally, the data should be collected in the same manner multiple times before coming to any conclusions and to see if any trends are apparent or if there are times of the year when some streams have been impacted negatively

4.2.3 Comparison to Puerto Rico EPA Water Quality Standards

Since some of El Yunque's rivers are used for a myriad of purposes they must meet or exceed the standards set by the United States Environmental Protection Agency (EPA). We used the Class SD levels, as these rivers act as a location of "primary or secondary contact recreation" and are "use[d] as a raw source of public water supply, propagation and preservation of desirable species, including threatened or endangered species" designating them as Class SD streams and rivers (Puerto Rico Water Quality Standards Regulation, 2010, p. 37). Listed in Table 3 are the specific standards for each variable and whether each stream met the benchmarks that are set by the EPA for Class SD rivers.

Table 3: EPA Standards and El Yunque's Rivers Statuses

Class SD EPA Standards	Icacos (Point #1)	De La Mina (Point #2&3)	Mameyes (Point #4&5)
Dissolved Oxygen (greater than 5 DOmg/L)	✔	✔	✔
pH (between 6 and 9)	✔	✔	✔
Dissolved Solids (less than 500mg/ml)	✔	✔	✔
Temperature (less than 32.2 °C)	✔	✔	✔

✔ = met EPA standards
X = failed EPA standards

Each one of El Yunque's rivers passed EPA's standards for dissolved oxygen, pH, dissolved oxygen and temperature. Rio Icacos, with a pH level of 6.1, was close to falling below the EPA's minimum pH level of 6. Further investigation into this situation should definitely be conducted as Rio Icacos is located in a relatively isolated portion of the forest and should not be impacted by visitors. All of the other parameters passed the EPA standards. In particular, the rivers of El Yunque National Forest are extremely well oxygenated, which bodes well for longevity of the river's fish and shrimp species.

4.3 Cost Analysis

In strategically selecting our sampling points we were able to minimize the cost for the implementation of a water quality monitoring program in El Yunque National Forest. The nature of our monitoring program will, however, require sporadic monitoring throughout the year. While this monitoring program may appear time consuming, the results obtained are important because they can help contribute to the understanding of the forest's watersheds and allow this forest to comply with federal requirements that mandates wild and scenic rivers must be monitored.

4.3.1 Cost of Implementation

As previously mentioned, Pedro Rios of USFS provided us with some basic cost information so that we could approximate the cost of obtaining stream quality data. These costs, listed in the Table 4 below, and the calculations behind the each respective cost can be found in Appendix G.

Table 4: Acquired USFS Cost Information

	Cost
Labor	
Field Technician	\$202.00 per day
Supervisory Technician	\$271.00 per day
Vehicle	
Daily Use Fee	\$12.00 per day
Mileage Cost	\$0.28 per mile
Equipment	
Purchase Price	\$2,000 to \$4,000
Maintenance Cost	\$50 per year

$$\boldsymbol{Start - up\ Cost} \approx Equipment\ Purchase\ Price \approx \$\mathbf{2,000}\ \boldsymbol{to}\ \$\mathbf{4,000}$$

$$Annual\ Cost \approx Labor\ Cost + Vehicle\ Cost + Equipment\ Maintenance\ Cost$$

$$\boldsymbol{Annual\ Cost} \approx \$3{,}800 + \$150 + \$50 \approx \$\mathbf{4,000}$$

The start-up cost is simply the one-time cost of purchasing the multi-parameter water quality sampling device. The $2,000 range in the start-up cost is so large because the price of the equipment depends upon the brand of probe and the respective parameters it measures. For reference, the HANNA HI 9818 probe we used for our sampling would fall in approximately the middle of our equipment price range. The annual cost approximates the amount needed to fund one year of collecting water quality data at the points we have identified. As you can see in the calculations above, the annual cost is approximately $4,000 if the USFS were to sample the main locations six times per year and the wild portion of Rio Mameyes (#6 – Bisley Trail on Figure 3) just twice per year. Sampling the main locations two times less per year would save approximately one thousand dollars in labor and vehicle expenses for an annual cost of approximately $3,000. When considering both of these costs, it would be quite achievable to purchase equipment and monitor the water quality of El Yunque's wild and scenic rivers for one year for a **total cost** of under $8,000.

4.3.2 Benefit of a Water Quality Plan

There are many benefits of adding a water quality monitoring plan to El Yunque's wild and scenic rivers. The most general reason is that many endangered species are dependent on the forest's wild and scenic rivers. With a monitoring plan, elevated levels of pollutants can be recognized before the flora and fauna are impacted by these unusually high levels. The forest service can then identify what the source is and take actions to improve the quality or eliminate the cause. In addition to protecting species, there are also financial benefits. The cost of eradicating a pollutant after it has been in the aquatic ecosystem for an extended period of time is far greater than that incurred if periodic testing caught and controlled the pollutant earlier. Lastly, the monitoring plan will have a positive effect on the community's health. The water from these rivers is used as a source of drinking water and for recreation and as such it must be of high quality. If water quality declines, the forest service will be able to identify this and inform the public if necessary. This eliminates the possibility of illness occurring within the population from waterborne pathogens.

4.4 Training Program

We conducted a training session to help the USFS employees learn how to properly use the equipment that would be used for testing the water as well as to familiarize them with our proposed wild and scenic river monitoring plan. This training, in the form of a presentation, explained the equipment's basic rules of operation and how to navigate the various functions, and identified which parameters would be measured. There were two question and answer portions of the presentation to ensure that all questions and information desired by the forest service staff were covered by the team. After the presentation, an informal hands-on training session was led by the team. The employees were shown how to use the multi-parameter probe and then could try using it themselves. This allowed for direct experience with the equipment that helped the employees learn by navigating the menus and asking questions if they had any difficulty in operating the equipment.

We decided to supplement our presentation session with a pamphlet, which can be found in Appendix J. This short directional guide provides an overview of the multi-parameter probe and its use in the water quality monitoring plan. We also provide some troubleshooting tips and a link to the detailed HANNA HI 9828 instructional guide in the event additional help is needed.

5.0 Conclusions & Recommendations

The product of this project is a carefully crafted water quality monitoring plan that can be used by El Yunque National Forest. The specific recommendations of this plan, in an abbreviated form, can be found in this conclusion section. In addition, we provide a few recommendations to maximize the value of this water quality monitoring plan and ensure future testing is successful.

5.1 Conclusion

Our team was able to reach several conclusions about the introduction of a water quality testing plan based on the data we collected while in El Yunque National Forest. The time that we spent traveling to Rio de la Mina, Rio Icacos and Rio Mameyes allowed us to finalize our monitoring plan by selecting the seven sampling sites shown in Figure 4. These points were chosen due to their accessibility and distance from the USFS headquarters, as shown in Table 1. The sites we picked allow for all testing, exclusive of the Bisley trail site, to be completed in a single day. This method will require the use of a multi-parameter water quality probe, which can efficiently and accurately collect a number of water quality parameters.

We determined that this plan could be implemented for under $8,000, including labor, equipment and travel costs. Factored into this cost is the purchase of a high-end multi-parameter tool, meaning the projected total cost could be nearly $2,000 less if a more inexpensive model is purchased. The methods we have chosen will allow for a precise assessment of El Yunque's wild and scenic rivers in the least amount of time and at the lowest possible cost.

An integral component of our project included training the forest staff employees to familiarize them with both the monitoring plan and the equipment. We opted to give a presentation explaining the basics of operating the equipment as well as the parameters we would be testing. After the presentation the staff was given a survey in order to evaluate the session. They suggested that we provide a manual for using the equipment, prompting our team to make a pamphlet that explains the proper usage of the tool. Based on the feedback we received from the survey, our group concluded that the presentation was effective in training the forest staff on the proper methods of carrying out our proposed monitoring plan.

5.2 Recommendations for the Water Quality Monitoring Plan

While our multi-parameter probe tested numerous important variables, El Yunque National Forest staff has mentioned the desire to monitor levels of nitrates and coliform in the water given the frequent human recreation in the forest's rivers. For this reason we would recommend they purchase a multi-parameter probe that has the ability to measure these additional contaminants. Due to health concerns, if unusually high levels of coliforms or nitrates are seen we would encourage USFS staff to monitor these locations at a greater frequency to pinpoint what is causing these conditions.

Having already developed training materials and having recommended basic equipment to be used, we believe that our water quality monitoring system could be easily implemented in other National Forests. This plan would give other forests the ability to assess whether tourism and other factors are influencing the health of their aquatic ecosystems.

5.3 Recommendations for Future Training

There are certain considerations that must be taken into account with regard to future training. It is possible that the equipment used in the coming years may evolve, and for this reason we recommend that the training materials we have provided are maintained and updated in response to the introduction of any new equipment. Updated equipment and training will ensure that the forest staff employees are always prepared to use the tools necessary to carry out any water quality monitoring plan. We also recommend that all field personnel and managers convene on an annual basis to discuss results and any issues encountered during field testing. Following these recommendations will allow accurate, cost effective, and proper testing of El Yunque's wild and scenic rivers for many years into the future, thereby guaranteeing the health of the forest as well as the plants and animals that call it home.

References

Allan, J. D. (1995). *Stream Ecology: Structure and Function of Running Waters*. London, UK: Chapman & Hall.

[Allan discusses the dynamic nature of flowing water streams and how that can make sampling water and conducting tests seem "overly complex". However, despite the huge differences in the appearance of streams, rivers and estuaries there is a common set processes the underlie them all. This is a good background for those wanting to learn about the basic dynamics of a stream ecosystem.]

Armour, C. L. (1983). *Field methods and statistical analyses for monitoring small salmonid streams*. Washington, DC: Fish and Wildlife Service, U.S. Department of the Interior.

[This publication outlines the use of a water quality study to assess the impact of human activities on a small salmon stream. Armour outlines the steps in a water quality measurement program and sampling methods for a small stream environment.]

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[This past WPI IQP done in El Yunque National Forest looks at the impact of using bridge crossings on stream health.]

Brouwer, R., & Pearce D. W. (2005). *Cost-benefit analysis and water resources management*. Northampton, MA: Edward Elgar.

[This book examines the relatively new application of cost benefit analysis to water monitoring. Brouwer and Pearce provide real world examples of how the CBA technique was used in in multiple European locations facing water scarcity.]

Cech, T. (2005). *Principles of water resources : History, development, management, and policy.* (2nd ed.). Hoboken, NJ: John Wiley & Sons.

[This source discusses numerous details about stream not exclusive to water quality. There is a significant amount of discussion about groundwater hydrology and how that ties in with the hydrolytic cycle. The later portion focuses on governmental regulations specifically applied to water quality.]

Cruz, Pablo. (2008). *Fiscal year 2008 monitoring and evaluation report* (ME Report). El Yunque National Forest. Retrieved 1/28/2012, from https://docs.google.com/viewer?url=http%3A%2F%2Fwww.fs.usda.gov%2FInternet%2FFSE_DOCUMENTS%2Fstelprdb5304902.pdf

[The 2008 ME Report provides a look into the budget, staff and overall operations at El Yunque National Forest. They also highlight some issues the forest is dealing with – invasive species, air quality & water quality.]

Davis, J. C. & Minshall, G. W. (2001). *Monitoring wilderness stream ecosystems*. Ogden, UT: U.S. Dept. of Agriculture, Forest Service.

[This book discusses the myriad of potential threat to wilderness steams and how these threats can be averted by careful stream monitoring. Most importantly, they discuss how sampling strategies in small wilderness streams are different than that which would be conducted in an urban stream.]

Downes, B. J., Fairweather, P. G., Keough, M. J., & Mapstone B. D. (2002). *Monitoring ecological impacts: Concepts and practice in flowing waters*. New York, NY: Cambridge University Press.

[Downes et al. provides a breakdown of how a water quality study should be executed from the planning stage all the way to interpreting the results. The explanation and discussion of each topic is brief however it serves as a good starting point for further research.]

Infed. (2011). Smith, M. E.. *Non-formal Education.* Retrieved 1/28/2012, from http://www.infed.org/biblio/b-nonfor.htm

[This source discusses what constitutes non-formal education and how it differs from formal education techniques.]

Hoppers, W. (2006). *Non-formal education and basic education reform: A conceptual review*. Paris, France: International Institute for Educational Planning.

[We consulted this sources for a significant amount of information regarding what constitutes non-formal education and how the methods of education have changed over time. It specifically talks about popular education, methods of personal development and various types of professional training.]

Smelser, M. G., & Schmidt, J. C.. (1998). *An assessment methodology for determining historical changes in mountain streams.* Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station.

[This contains a thorough assessment of how to statistically analyze fresh water mountain streams by utilizing USGS gage stations. Depth, velocity, width and sediment deposition are variables of greatest importance.]

Sokal R. R., & Rohlf, F. J. (1995). *Biometry* (3rd ed). New York: W.H. Freeman.

[This source deals with applying statistical analyses to aquatic systems. It specifically helps you decide what statistical tests to conduct. Their complexity ranges from a simple inear regression to a more complex ANOVA test.]

Tchobanoglous, G. (1985). *Water quality: Characteristics, modeling, modification*. Reading, MA: Addison-Wesley.

[This source deals with the characterization of water and what components constitute "pure" water. There is emphasis upon the quality of wastewater streams. In the latter portion of the text there is an emphasis on the methoods of water quality management.]

Underwood, A. J. (1997*). Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance*. New York: Cambridge University Press.

[Underwood delves into how to interpret and make water sampling methods more efficient. One specific point of emphasis is the conducting of a cost benefit analysis to determine the effectiveness of the monitoring plan.]

USDA. (2011). Wild and Scenic Rivers. *El Yunque National Forest.* Retrieved 1/28/2012, from http://www.fs.usda.gov/detailfull/elyunque/home/?cid=fsbdev3_042977&width=full#wild_scenic

[This source discusses what constitutes a "wild and scenic" river is based upon the USDA's Wild Scenic River Act. It outlines what aspects of Rio Mameyes, Rio de la Mina and Rio Icacos make them unique as compared to other freshwater habitats.]

USDA Forest Service. (2012). *Fiscal year 2012 budget overview.* USDA Forest Service. Retrieved 1/28/2012, from http://www.fs.fed.us/aboutus/budget/2012/justification/FY2012-USDA-Forest-Service-overview.pdf

[This budget overview published by the National Forest Service shows fiscal appropriations and how they have varied in comparison to previous years. It also discusses the organization's mission and areas of emphasis for the upcoming year.]

Wagner, R. J. (2000). *Guidelines and standard procedures for continuous water-quality monitors : Site selection, field operation, calibration, record computation, and reporting.* U.S. Geological Survey. Reston, VA: U.S. Dept. of the Interior.

[This book is almost entirely about equipment used to measure quality (pH, turbidity, dissolved oxygen, temperature, etc). They do not only talk about operating the monitoring station – maintenance and data processing are also discussed in good depth.]

Wymer, L. J. (2008). *Statistical framework for recreational water quality criteria and monitoring*. Hoboken, NJ: John Wiley & Sons.

[This book by Wymer talks in depth about sampling methods. It also touches upon some statistical studies such as sensitivity analyses and measuring the robustness of your result.]

Appendix A: Sponsor Description – US Forest Service

El Yunque National Forest, is a landlocked tropical rain forest in the northeastern corner of Puerto Rico, and is the sole rain forest in the US National Forest System (2008). As a federally funded, government agency all land managed by the US Forest Service is part of the public domain. The agency's commitment to both land preservation and public service is evidenced in their motto, "caring for the land and serving the people" (p. 1). The Forest Service's mission further shows an important aspect not seen in the motto, which is the desire to preserve the "Nation's forests and grasslands to meet the need of future generations" (p. 1).

The organizational structure of the United States Forest Service (2008) is quite unique as it must manage 34,250 employees and 1,755 National Forests and Grasslands. As a result, the US Forest Service has had a decentralized administration policy since its inception in 1905. This allows the Chief of the Forest Service to appropriate fiscal resources for each region, which consequently provides the nine Regional Foresters some flexibility in deciding how the funds should be best spent. Of the nine geographical regions, El Yunque National Forest is part of the southern region.

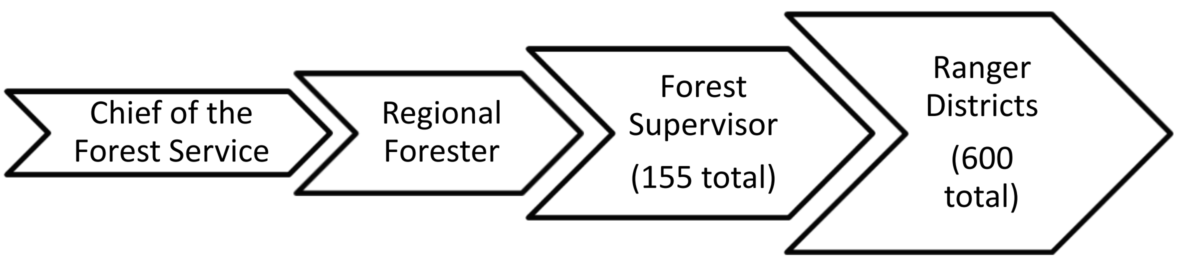


Figure 6: The US Forest Service Organizational Structure (USFS, 2008, p.1)

The USFS's organizational structure is greatly simplified at the local level. According to the 2008 Monitoring and Evaluation Report, Pablo Cruz, the Forest Supervisor, is tasked with managing a 4.3 million dollar budget and thirty-three full time employees (El Yunque ME Report, 2008). There are four Team Managers, who are essential to achieving smooth daily forest operations. The liaison for this project, Pedro Rios, is the leader of the Ecosystem Management Team at El Yunque National Forest. His team's primary duties are to "implement the forest Natural Resources agenda and provide high-level technical skills in support of Conservation and Land Management projects" (El Yunque, 2012, p. 1).

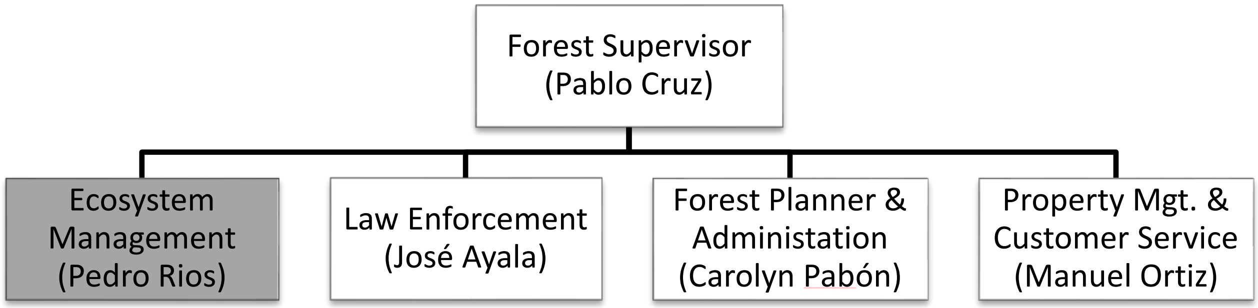


Figure 7: The Management Team at El Yunque National Forest (El Yunque, 2012, p. 1)

The department of El Yunque's management system we will be working with is the Ecosystem Management team. They specialize in "Geographic Information Systems (GIS) services, Vegetation Management, Geological and Soil Resources Management, Air Quality Resources Management, Heritage Resources Management (Archaeology), Hydrology Management, Wildlife Management (wildlife and fisheries), Fire and Incident Plan Implementation and Management, and Search and Rescue support for local emergency medical teams and law enforcement agencies" (US Forest Sevice, 2012, p. 1). They use these areas of expertise to aid in Conservation and Land Management projects.

Recent economic hardships have decreased the amount of funding the US Forest Service receives (USDA, 2012). For the 2012 Fiscal Year the budget request is approximately $5.1 billion dollars, a 3.5% decrease as compared to the 2011 budget. This significant budget reduction should not be felt drastically by those at El Yunque, as the largest cut was to the Wildland Fire Management program. However, this does indicate that the funding available for the execution and completion of projects is likely very limited.

There are several organizations that support the mission of El Yunque National Forest (El Yunque, 2007). The US Geological Survey Caribbean Water Science Center has done some extensive work in the past to help issue recommendations as to how minimize the effects of human caused pollution on the streams and rivers. The forest also maintains close contact with the International Institute of Tropical Forestry (IITF), a scientific organization which specializes in the research and managing the various difficulties of managing a tropical forest. Despite its relatively small size IITF has conducted research in virtually all of the Caribbean Islands, Mexico, South America and Central America. El Yunque is inherently closely tied to IITF as they are both funded by the USDA and based out of nearby University of Puerto Rico, which is rather close to El Yunque National Forest.

Appendix B: Professor Mathisen Interview

DATE: 02/10/2012

INTERVIEWER: Frank Bruton and Richard Valdes

Richard Valdes (RV): How can water quality be assessed in rural streams and rivers?

Professor Paul Mathisen (PM): First it is important to get a sense of the overall area, and what drains into the rivers. Then obtain the flow rate and any other indicators you are looking for. Some important aspects to test are for chemical characteristics, such as pH levels, dissolved oxygen, temperature, and dissolved solids. I would also recommend looking at the water to assess the turbidity.

RV: What specific strategies have you used in the past when conducting tests for water quality? How frequently should these tests be conducted?

PM: It is important to test downstream and an area upstream that seems like a good representation of overall quality. Doing this helps narrow down where changes occur. If possible you should also try to find the stream's flow rate.

RV: What factors are important when assessing water health especially in "wild and scenic" rivers?

PM: It is critical that the sample comes from water that is well mixed. Frequently major concerns are waste, sediments from erosion, bacteria. Nutrients can be a good waste water indicator. You should also ensure that there are no major day to day changes.

RV: In a place with high rainfall like El Yunque, what kind of natural processes may influence water quality?

PM: There are a variety of aspects that can influence water quality following rainfalls. Some of these are: the gradient of the surrounding land (run off), nature of the ground water, characteristics of the vegetation and land (hydraulic condition) and types of soil. The amount of sediments in the water can have a significant impact of plant and aquatic life.

RV: Are there any specific books or articles that you feel may be useful to our project?

PM: The USGS and EPA websites might have a manual on water quality and watershed associations (i.e. Charles River) might have field guides.

Appendix C: Professor McDowell Interview

DATE: 03/22/2012

INTERVIEWER: Xavier Miller

Xavier Miller (XM): What are some important visual aspects of stream health that can be monitored?

Professor Bill McDowell (BM): Some important things to take note of at each site are: the overall color or the stream, any debris in the water, the turbidity, health of nearby vegetation and any unusual surface slicks. I would advise you take pictures to help supplement your notes.

Xavier Miller (XM): In addition to pH, dissolved oxygen, dissolved solids, temperature and salinity what are other variables would you consider monitoring?

Professor Bill McDowell (BM): It really depends on your budget and equipment. If you are using a sampling kit I would only sample the variable you mentioned. With a water quality meter I would recommend testing nitrate and ammonium levels.

XM: Since Puerto Rico has extreme variations in the rate of rainfall, how can we be sure our measurements are consistent on a day-to-day or month-to-month basis?

BM: You should do your best to make sure the measurements are taken on days when the weather and streams are comparable to when previous samples were withdrawn. I would recommend you structure your sampling plan to avoid Puerto Rico's rainy season. For example, if you are going to sample six times per year you should start in February and sample every other month. This would avoid the rainiest month of May.

XM: We are supposed to develop a water quality monitoring plan for Rio Mameyes, Rio de la Mina and Rio Icacos - our hope is to test the wild, scenic and recreation portions. What specific sites you would recommend testing?

BM: On Rio Icacos the only access point I know of is the USGS sampling station, however that isn't a problem as the water quality is relatively consistent throughout its entire length. On Rio Mameyes there is also another USGS testing site at the bridge (just before you get to the Angelito trail).

XM: What equipment do you use or recommend that scientists use to monitor water quality in rivers and streams.

BM: In my monitoring plan in New Hampshire we have about several permanent water quality monitoring stations. These are typically very expensive ($20-30K), so you will likely not be able to utilize these. Despite their extremely low price, I would encourage you to stay away from sampling kits as they will not give you accurate readings.

XM: Having completed a large amount of research in El Yunque National Forest, do you have any specific tips?

BM: The trails leading to the headwaters of the Rio Mamayes are far less traveled than you would expect. That said, very little is known about the water quality of that portion of the river so any data you can collect there would be very helpful.

Appendix D: USGS Interview

DATE: 03/23/2012

INTERVIEWER: Frank Bruton, Kassy Hickey, Xavier Miller & Richard Valdes

WPI: What do you think is the most effective way of testing the water quality at various locations in El Yunque?

USGS: We would recommend a multi-parameter water quality meter. This equipment can provide you immediate results and most importantly you can record the data and later upload it to your computer. Our organization has found YSI brand meters to be the most reliable.

WPI: What variables do these have the ability to measure?

USGS: Almost all of the meters will measure pH, temperature, dissolved oxygen and dissolved solids. You can purchase more expensive models to add additional variables or swap out sensor modules.

WPI: How long do these meters last and is there a significant upkeep cost?

USGS: The probes are very durable and reliable. Most all of them will be water resistant and impact resistant, so barring an unforeseen problem you can usually be assured they will last more than ten years.

WPI: What is the cost of these multi-parameter meters?

USGS: It really depends on the brand you purchase. The end cost for most with several additional features will be around $4,000. If you are not going to be conducting extensive testing you might want to consider renting a unit from us.

WPI: Currently we only have one tentative sampling site for Rio Icacos due to the difficulty in accessing other portions of the river. Is that sufficient and why?

USGS: That should be sufficient because you will likely only be able to test the river at the USGS station due to the landslide that occurred on Route 191. This should not be a problem as the river is slow moving and we have found it to be almost the same in composition for its entire length.

Appendix E: USFS Interview Results

DATE: 3/26/2012 – 3/30/2012

INTERVIEWERS: Frank Bruton, Kassy Hickey, Xavier Miller & Richard Valdes

WPI: Are any portions of the forest (both aquatic and terrestrial) known to be unhealthy? Do you know why?

USFS: The Puerto Rican Parrot, a bird currently on the endangered list, has been dwindling in number despite aggressive restoration attempts. Currently, however, there is no known cause for their disappearance.

WPI: Are there any data from past water quality studies? If so, how can they help us complete our project?

USFS: There is a published thesis report on the study of recreational activities at Puente Roto. The report looks into whether there are fecal coliform levels are above an acceptable level due to human waste discharge in streams.

> *Interviewer's note:* This report found that there are above average fecal coliform levels, however they are not significantly high enough to pose a risk to any recreational swimmers.

WPI: What water quality monitoring equipment does the USFS have?

USFS: We currently have a sampling kit that is able to test a range of variables, however the age of this kit is not known. Several years ago we also purchased a water quality monitoring probe but it is no longer operational. The Tropical Institute of Forestry (TIF) has a HANNA HI 9828 probe that is available to use.

> *Interviewer's note:* The chemical contents of the sampling kit were likely expired as the kit was purchased in 1997, so we elected to borrow the multi-parameter water quality probe from the TIF.

WPI: What types of trainings have you participated in the past that you liked?

USFS: We prefer learning things out in the field as opposed to the in the office.

Appendix F: Stream Quality Data

Juan Diego Sampling Site

	Sample Numbers						
Variable (Units)	1	2	3	4	5	6	AVG
Dissolved Oxygen (mg DO/L)	7.19	7.53	6.96	6.81	6.7	6.61	6.66
pH	7.16	7.16	7.16	7.16	7.16	7.16	7.16
pHmV	-31.2	-31.6	-31.6	-31.6	-31.5	-31.3	-31.46
Temperature (°C)	20.58	20.58	20.58	20.58	20.59	20.59	20.58
Pressure (mm Hg)	725.9	725.9	725.8	725.8	725.9	725.9	725.87
Dissolved Solids (mS/cm)	49	49	49	49	49	49	49
Dissolved Solids (mS/cm3)	45	45	45	45	45	45	45
Dissolved Solids (tdsppm)	24	24	24	24	24	24	24
Salinity	0.02	0.02	0.02	0.02	0.02	0.02	0.02
ORP	214.4	214.7	214.9	215.1	215.4	215.7	215.03
DO %	83.8	87.9	81.2	79.4	78.2	77.2	81.28

Angelito Sampling Site

	Sample Numbers						
Variable (Units)	1	2	3	4	5	6	AVG
Dissolved Oxygen (mg DO/L)	7.24	7.18	7.09	7.03	6.99	6.91	7.07
pH	7.21	7.21	7.22	7.21	7.21	7.2	7.21
pHmV	-34	-34	-34.6	-34.2	-34.2	-33.9	-34.15
Temperature (°C)	22.57	22.97	22.57	22.57	22.57	22.57	22.64
Pressure (mm Hg)	758.6	758.6	758.6	758.6	758.6	758.6	758.6
Dissolved Solids (mS/cm)	51	51	51	51	51	51	51
Dissolved Solids (mS/cm3)	48	48	48	48	48	48	48
Dissolved Solids (tdsppm)	25	25	25	25	25	25	25
Salinity	0.02	0.02	0.02	0.02	0.02	0.02	0.02
ORP	246.5	246.6	246.3	247.1	247.2	247.7	246.9
DO %	83.9	83.2	82.1	81.5	81	80.1	81.97

Palo Colorado Sampling Site

	Sample Numbers						
Variable (Units)	1	2	3	4	5	6	AVG
Dissolved Oxygen (mg DO/L)	13.01	9.91	8.98	8.5	16.31	9.01	10.95
pH	6.65	6.65	6.65	6.65	6.65	6.65	6.65
pHmV	-2.5	-2.4	-2.3	-2.3	-2.4	-2.2	-2.35
Temperature (°C)	20.26	20.25	20.25	20.25	20.25	20.25	20.25
Pressure (mm Hg)	713.9	713.9	714	714	713.9	713.9	713.93
Dissolved Solids (mS/cm)	24	24	24	24	24	25	24.17
Dissolved Solids (mS/cm3)	22	22	22	22	22	22	22
Dissolved Solids (tdsppm)	12	12	12	12	12	12	12
Salinity	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ORP	214	213.9	213.8	213.8	213.8	213.8	213.85
DO %	153.3	116.7	105.8	100.2	192.2	106.2	129.07

La Coca Falls Sampling Site

	Sample Numbers						
Variable (Units)	1	2	3	4	5	6	AVG
Dissolved Oxygen (mg DO/L)	7.94	7.67	7.48	7.33	7.2	7.08	7.45
pH	7.42	7.44	7.44	7.45	7.45	7.45	7.44
pHmV	-46.2	-47	-47.5	-47.7	-47.9	-48.1	-47.4
Temperature (°C)	21.3	21.29	21.29	21.29	21.29	21.29	21.29
Pressure (mm Hg)	729	729	729	729	729	728.9	728.98
Dissolved Solids (mS/cm)	55	55	55	51	55	55	54.33
Dissolved Solids (mS/cm3)	51	51	51	51	51	51	51
Dissolved Solids (tdsppm)	27	27	27	27	27	27	27
Salinity	0.02	0.02	0.02	0.02	0.02	0.02	0.02
ORP	221	220.5	220.3	220.2	220.1	220.1	220.7
DO %	93.6	90.4	88.1	86.3	84.8	83.4	87.77

Icacos Sampling Site

	Sample Numbers						
Variable (Units)	1	2	3	4	5	6	AVG
Dissolved Oxygen (mg DO/L)	8.22	8.19	8.15	8.11	8.06	8	8.10
pH	6.12	6.11	6.1	6.09	6.08	6.08	6.10
pHmV	-	-	-	-	-	-	-
Temperature (°C)	20.2	20.19	20.19	20.19	20.19	20.19	20.19
Pressure (mm Hg)	727.5	727.5	727.6	727.6	727.5	727.5	727.7
Dissolved Solids (mS/cm)	16	16	16	16	16	16	16
Dissolved Solids (mS/cm3)	15	15	15	15	15	15	15
Dissolved Solids (tdsppm)	8	8	8	8	8	8	8
Salinity	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ORP	131.1	130	131.1	130.8	131.2	131.1	130.9
DO %	96.7	96.3	95.9	95.4	94.8	95.1	95.69

Appendix G: Time to Sampling Locations & Sampling Schedule

	From Headquarters, One Way		
Sampling Point	Time	Mileage	# of Yearly Visits
1. Icacos - USGS	40 min	13 km	4 to 6
2. La Mina - Palo Colorado	20 min	7.8 km	4 to 6
3. La Mina - Juan Diego	10 min	5.4 km	4 to 6
4. Mameyes - La Coca	10 min	3.8 km	4 to 6
5. Mameyes - Angelito	20 min	3.9 km	4 to 6
6. Mameyes - Bisley	1 hour 45 min	6.4 km	2
7. Mameyes – Off RT. 191	10 min	2.2 km	4 to 6

DAY 1 SCHEDULE

8:00 Depart Catalina Headquarters

9:00 Arrive at Rio Icacos

9:30 Arrive at Palo Colorado

10:00 Arrive at Quedabra Juan Diego

10:15 Arrive at Coca Falls

11:00-12:00 LUNCH

12:30 Arrive at Rio Mameyes (via Angelito Trail)

1:30 Arrive at Rio Mamayes outside El Yunque Forest

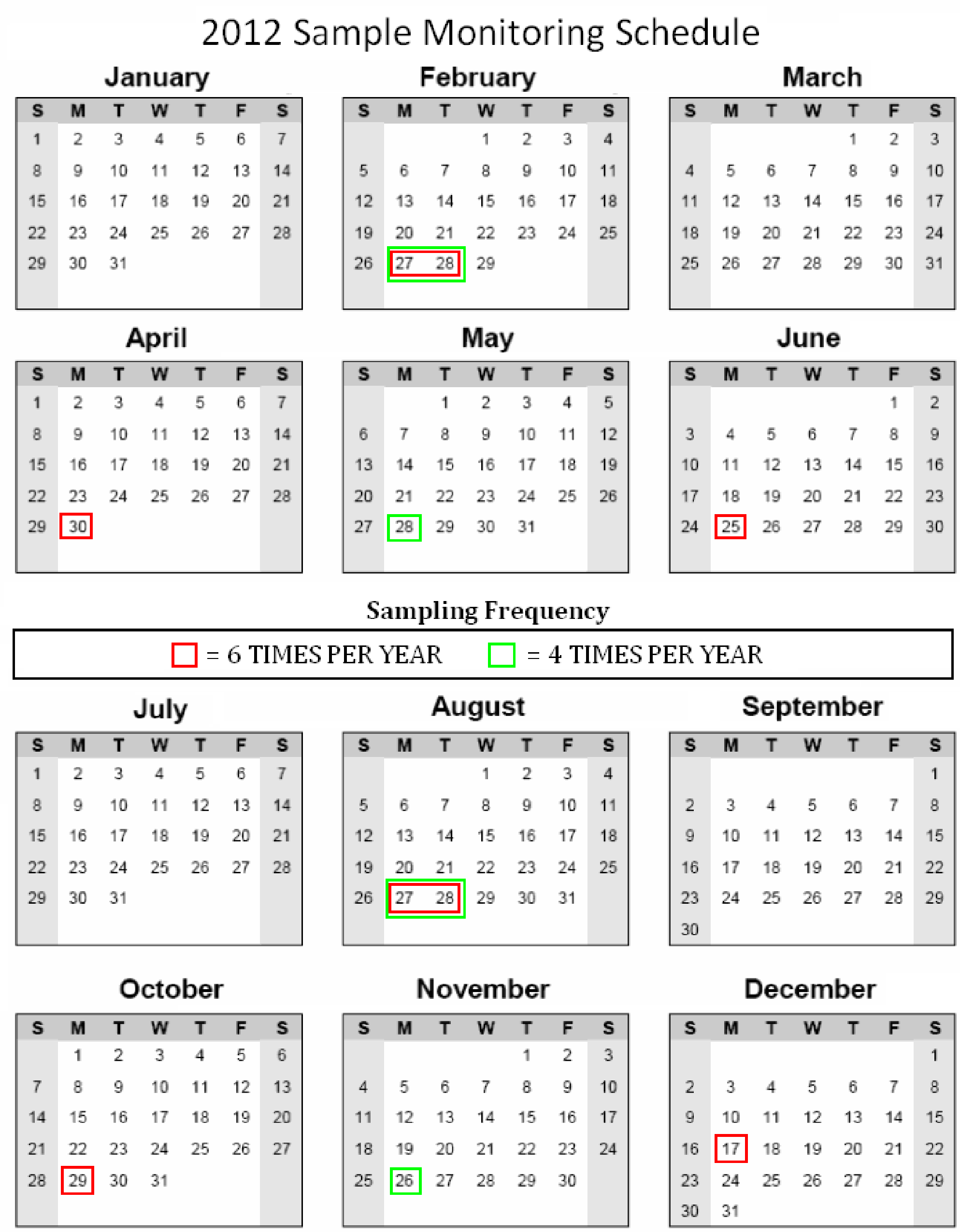
2:00 Return to Catalina Headquarters

DAY 2 SCHEDULE

8:00 AM: Depart Catalina Headquarters

10:00 AM: Rio Mameyes - Bisley Trail

12:00 PM: Return to Catalina Headquarters



This is an example of how the sampling dates should be approximately evenly spaced throughout the span of one year. When selecting sampling months you should try to avoid Puerto Rico's rainiest month, May.

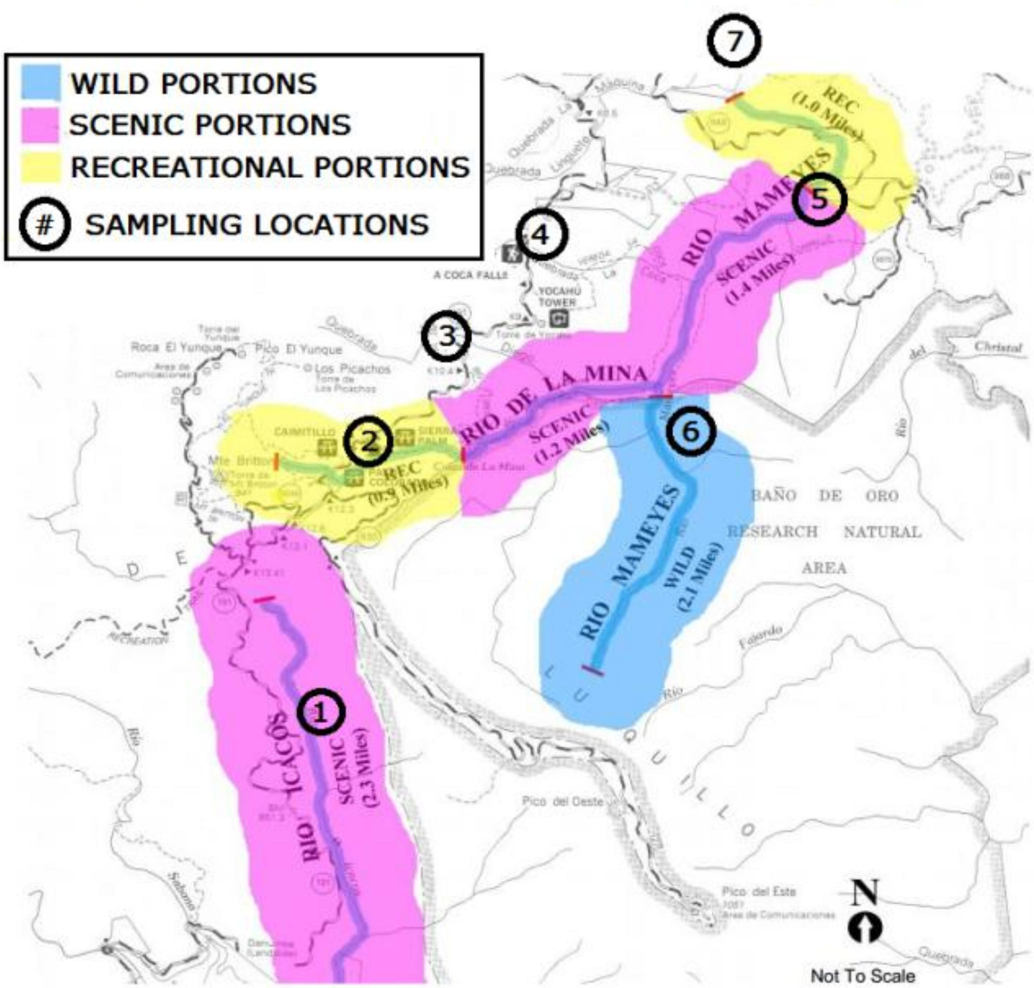
Note: In each frequency plan there are two times in the year where there are two consecutive sampling days. The second day is added in each instance to accommodate sampling the wild portion of Rio Mameyes (via Bisley trail).

Appendix H: Wild and Scenic River Map

Sampling Points
1. Icacos - USGS
2. La Mina - Palo Colorado
3. La Mina - Juan Diego
4. Mameyes - La Coca
5. Mameyes - Angelito
6. Mameyes - Bisley
7. Mameyes – Off Route 191

All of the sampling points except for the wild portion of the Rio Mameyes are readily accessible off the main roads, Routes 191 and 988. The strategic location of these points allows El Yunque National Forest to observe any negative impacts that may result from recreational activities at the Palo Colorado picnic facilities and Puente Roto.

THE WILD AND SCENIC RIVERS OF EL YUNQUE



Appendix I: Cost Analysis Calculations

	Cost
Labor	
Field Technician	$202.00 per day
Supervisory Technician	$271.00 per day
Natural Resource Specialist	$330.00 per day
Vehicle	
Daily Use Fee	$12.00 per day
Mileage Cost	$0.28 per mile
Equipment	
Purchase Price	$2,000 to $4,000
Maintenance Cost	$50 per year

$$\boldsymbol{Start - up\ Cost} \approx Equipment\ Purchase\ Price \approx \$\mathbf{2,000}\ \boldsymbol{to}\ \$\mathbf{4,000}$$

$$Annual\ Cost \approx Labor\ Cost + Vehicle\ Cost + Equipment\ Maintenance\ Cost$$

$$\boldsymbol{Annual\ Cost} \approx \$3{,}800 + \$150 + \$50 \approx \$\mathbf{4,000}$$

The wide range for the equipment cost is largely due to the variability in features available for multi-parameter probes. Some customizations that can increase the price include increasing the length of the probe cable, internal memory and adding GPS tagging ability. The additional probe modules, priced at approximately $400 apiece, provide the ability to measure nitrates, ammonium, and chloride levels which are not included in a standard equipment package. As mentioned in the recommendation section, we would highly encourage you to buy a nitrate probe module with your multi-parameter purchase.

The annual labor and vehicle cost calculations below are based on a sampling frequency of six times per year. To avoid being repetitive, the calculations for a sampling frequency of four times per year were done exactly the same but were omitted. The total cost of each component, bolded below, gives a range for the price that would be spent depending on whether a four and six times per year sampling frequency is chosen. For example, sampling only four times per year would result in a labor cost of approximately $2,850, nearly $1,000 less than the $3,800 cost to sample six times per year.

$$Annual\ Labor\ Cost \approx (Field\ Tech\ \ Pay + Supervisory\ Tech\ Pay) * Sampling\ Days\ per\ Year$$

$$Annual\ Labor\ Cost \approx (\$202/day\ \ + \$271/day) * 8\ days/year$$

$$\boldsymbol{Labor\ Cost} \approx \$\mathbf{2850}/\boldsymbol{year}\ \text{ to }\ \$\mathbf{3800}/\boldsymbol{year}$$

$$Annual\ Vehicle\ Cost \approx Mileage\ Cost * Miles\ Traveled + Daily\ Fee * Days\ Used$$

$$Annual\ Vehicle\ Cost \approx \$0.28/mi * 6(23.9\ miles) + 2(8.0\ miles) + \$12/day * 8\ days$$

$$\boldsymbol{Vehicle\ Cost} \approx \$\mathbf{105}/\boldsymbol{year}\ to\ \$\mathbf{150}/\boldsymbol{year}$$

Appendix J: Monitoring Plan Training Pamphlet

Connecting and Uploading to Excel

1. The logged data can be transferred to PC by means of the USB connector HI7698281 and the HI 92000 Windows® compatible application software.
2. Insert the CD into the corresponding PC drive. The software menu window should start automatically; (If it does not, go to the folder "software" in the CD and double-click "setup.exe"); click "Install software" and follow the instructions.
3. With the meter OFF, disconnect the probe. Connect the USB cable to the meter and to the USB port on PC. Turn ON the meter; the message "PC connection" appears.
4. Run the HI 92000 application software, select the number COM port within the "Settings window" and then press CONNECT HI 92000 downloads the logged data and on the PC monitor a window with the GLP data and a window with the logged lot will appear. On the meter display, during download, the percentage of transferred data is visualized.

For full instructions and manual, please see:

http://www.hannainst.com/manuals/manhi_9828.pdf

Common Problems

1. Placing the device under heavy flow. Never take measurements while the device is under falls. This will lead to an inaccurate measurement with high levels of dissolved oxygen.

2. Placing the device in standing water. In order to get accurate measurements, the device should be placed within a flowing environment. Standing water will not adequately represent the river as a whole.

Water Quality Monitoring Plan for El Yunque's Wild and Scenic Rivers

United States Forest Service

Water Quality Plan

Congress designated portions of the Icacos, La Mina, and Mameyes rivers as wild and scenic. As wild and scenic rivers, they are required by law to be sustained in quality. To ensure the quality of these rivers remains pristine, it is necessary to monitor them effectively.

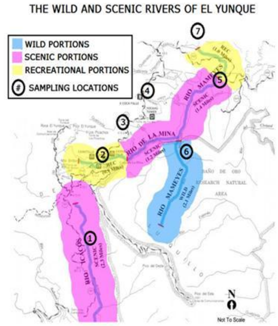
A monitoring plan was created for the three rivers in order to aid the United States Forest Service. As part of the plan, this guide was created to ensure access to training. This guide is a brief overview of the wild and scenic river water quality monitoring plan.

Areas of Sampling

In order to adequately monitor the Icacos, La Mina, and Mameyes rivers, sampling must be done. The table below shows the sampling locations for these rivers, the amount of testing to be done per year, and the approximate time of travel from headquarters to each point.

	From Headquarters, One Way		
Sampling Point	Time	Mileage	# of Yearly Visits
1. Icacos - USGS	40 min	13 km	4 to 6
2. La Mina - Palo Colorado	20 min	7.8 km	4 to 6
3. La Mina - Juan Diego	10 min	5.4 km	4 to 6
4. Mameyes - La Coca	10 min	3.8 km	4 to 6
5. Mameyes - Angelito	20 min	3.9 km	4 to 6
6. Mameyes - Bisley	1 hour 45 min	6.4 km	1 to 2
7. Mameyes – Off RT. 191	10 min	2.2 km	4 to 6

THE WILD AND SCENIC RIVERS OF EL YUNQUE



Logging Data and Uploading to Excel

The data retrieved from the rivers must be logged into the multi-perimeter device and transferred to a computer. In order to do this, you can follow these easy steps:

1. When in measurement mode, press LOG to memorize the enabled readings
2. The meter asks where to store the readings. Press OK to accept the proposed lot
3. To insert other information related to the logged value or to select the continuous logging mode press OPTIONS and a sequence of questions appears:
4. Logging type, ONE SAMPLE or CONTINUOUS: press one of these soft keys to select the desired option.
5. Where to save the readings: scroll with the arrow keys to select an existing lot and press OK to accept or press NEW LOT to create a new lot; a textbox appears for inserting the desired code. Use the keyboard to insert the code and then press OK.
6. Add a remark: press YES or NO. If YES is pressed and a remark list already exists, it is possible to select the desired annotation or press NEW to insert a new remark; a textbox appears for inserting a note for the logged sample.
7. Press SKIP if no tags are available.
8. To set lots, insert remarks, review logged or plotted data and also to delete lots, from the main menu select LOG DATA with the arrow keys.

For PC connection, see next page.