Restoration in El Yunque National Forest: Riparian Corridor Assessment and Prioritization

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Submitted to: Pedro Rios (USFS) & Dr. Nicholas Williams (WPI)

WPI

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Riparian Corridor Assessment and Prioritization

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Abstract

Hurricanes Irma and Maria caused lasting damage to Puerto Rico's natural ecosystems, especially El Yunque National Rainforest. Intervention is required to expedite recovery and maintain crucial areas such as riparian corridors. The current protocols used by the USFS to assess these areas do not explicitly outline a procedure for involving local communities. We generated a guide containing methods to supplement existing assessment protocols with community input and implemented it within El Yunque National Forest to carry out a restoration project.

Acknowledgements

This project was greatly influenced by the contributions of several individuals whom we wish to acknowledge. We would like to begin by thanking our sponsor, the United States Forest Service and Pedro Rios for the opportunity to work on such a project and the support that that was provided along the way. Without the tools, materials, and personnel provided to us, this project would never have been possible.

We would also like to thank Ms. Lizandra Nieves-Rivera, USFS soil scientist for all of her help along the way. Entering this project, none of our group members had any experience in ecology or life sciences and this project dealt with complex interactions between soil, water, and plants. As such, Ms. Nieves-Rivera took it upon herself to teach us what we need to know along the way and guide our understanding as our project grew and changed.

We also have to thank Dr. Ricardo Santiago, USFS ecologist for his help with gathering ecological data in the field and understanding the limitations placed upon possible restoration projects. His expertise proved vital in data collection and saved us hours of confusion in attempting to carry out riparian assessments.

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Finally, we would like to thank our advisor, Dr. Nicholas Williams for his guidance throughout the project and his suggestions on the structure of this paper. His comments challenged our perceptions and improved the paper and the project overall.

Executive Summary

As the rate of climate change continues to accelerate, one of the many resulting effects is the increase in the frequency and intensity of tropical cyclones, including hurricanes. Hurricanes cause widespread destruction in both the communities and ecosystems they pass over. In recent years, Puerto Rico has had to deal with the effects of two devastating hurricanes, Irma and Maria, which both struck the island within two weeks of each other. An area of the island that suffered significant damage was El Yunque National Forest, which is controlled by the United States Forest Service (USFS). When looking to restore the forest, it is important for the USFS to look at areas of particular ecological significance, such as riparian areas. Riparian areas, or terrestrial areas near the edge of a river or stream, are not only essential to natural ecosystems, but for the nearby communities that rely on rivers or streams for their water supply.

While the USFS has already formulated guidelines for assessing riparian areas, previous assessment protocols have lacked explicit instructions on gathering and incorporating community input, which can be an invaluable resource for gathering data, as locals may have information on their surrounding ecosystems that is not readily available to a larger agency. The goal of our project is to create a guide that allows for any agency attempting to restore riparian areas in a tropical rainforest to supplement their existing riparian assessment protocols with methods to gather, analyze, and integrate community feedback. In order to create and test the validity of our guide, our project was split into five main objectives:

1. Select a watershed
2. Select drainage basins within the chosen watershed
3. Select riparian areas to assess and restore
4. Carry out a restoration effort in the selected riparian area
5. Evaluate community input on involvement

Due to only having seven weeks to work on this project, several limitations were met when executing our objectives and we were unable to conduct as thorough of an investigation as we originally planned. Despite this, our methods and results are listed below.

Methods and Results

In order to select a watershed to target, our team first spoke with stakeholders to obtain community opinions on watershed needs and compiled ecological data in the form of GIS maps of four watersheds within El Yunque. After analysis of these factors, we elected to focus on significant drainage basins in the Rio Espiritu Santo watershed. We then conducted participatory mapping exercises and interviews with community members to generate GIS layers which were used to identify drainage basins of importance. We ecologically assessed three sites after generating an assessment protocol. We chose the riparian area near the Eliza Colberg Girl Scout Camp for restoration due to its proximity to local communities and feasibility for a passive restoration effort. Once the restoration project was completed by our team, we sent out a briefing to the individuals that we interviewed. These briefings include a questionnaire asking how satisfied they were with the selection of areas to repair, and if they felt they had an adequate say in the selection process.

Conclusions and Recommendations

To preface future restoration projects, we encourage the involvement of community leaders to inform the community of the team’s efforts and outline their overall goals. This also gives the leaders an outlet to voice any questions or concerns they may have.

When selecting the watershed, we found it beneficial to couple input from community leaders with ecological GIS data to determine how badly damaged areas are and how prone they are to future damages. GIS layers that include community information such as water intake points and points of interest can be integrated as well. Another conclusion we drew was that there was a strong interest in parts of the watershed outside of USFS jurisdiction. In future projects such as this, the original gathering of GIS data should be applied to the entire watershed.

When selecting a drainage basin, our project found it best to almost exclusively use community input. Due to project limitations, we were unable to interview people from outside the watershed, however interviews should be spread across the watershed to reduce area biases and to provide information on areas outside forest boundaries. A combination of interview questions and participatory mapping exercises work well together, allowing interviewees the chance to indicate and explain the importance of different areas. The participatory maps can then be weighted and put into GIS layers for further inspection.

To assess the riparian areas we used ecological data collected from the field. It is better for the ecological health of the drainage basin to be assessed professionally with an established protocol. We found that it works to assess these areas in teams, using a professionally customized protocol and short surveys to gauge the health of the area.

During the restoration project, it was both beneficial and detrimental to have volunteers from the community nearby to help, as was our original intent. Training these volunteers took longer and required more instruction, however, simpler tasks were executed easily by the volunteers while trained personnel tackled the more skilled tasks. Additionally, it lends a sense of connection and accomplishment to the people in that community. Thus we encourage future iterations to include the community in the actual restoration effort when feasible. It is also important to maintain contact with the community members who helped by keeping them up to date on information relevant to the project.

Future projects should consider including more organizations in efforts such as these. Other organizations can add legitimacy to the project, and possibly establish friendlier relations with communities nearby. These communities may know the other organizations better, and could be more likely to respond positively to the effort if it was backed by a recognizable name outside of just the USFS. However, adding more organizations does require more communication and creates the possibility for a conflict of interest and therefore should be considered thoroughly.

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1.0 Introduction

Climate change is causing global weather patterns to shift, which is in turn bringing about the increased frequency of extreme climatic events, such as tropical storms (Harris, Hobbs, Higgs & Aronson, 2006). Future projections show that these storms, along with becoming more frequent, are increasing in intensity (Knutson, 2010). Hurricanes are tropical cyclones that bring about powerful winds, floods and landslides. With stronger and more common hurricanes on the horizon, it is necessary to understand their repercussions. These events are so intense and catastrophic that they cause lasting and dramatic devastation to the communities and ecosystems in their path by depositing litterfall (dead plant material), damaging root systems, and defoliating trees (Liu et al, 2018) (Lodge & McDowell, 1991).

One area of particular concern in terms of hurricane damage and ecosystem value is the riparian corridor. Riparian corridors are defined as areas near bodies of water, which are especially moist as well as rich in nutrients from nearby waterways (Anderson, 1987). These areas are intrinsically linked to watersheds, which are areas of land that channel rainfall into streams, creeks, and eventually outflow points such as reservoirs or oceans (NOAA, 2018). Healthy riparian zones adjacent to said watersheds are quintessential to the overall wellbeing of their environment (Ranalli, 2010). The riparian areas, and in particular the vegetation found there, contribute greatly to erosion control and improved water quality (Schultz & Isenhart, 1995). Improving water quality is crucial to communities in close proximity to such waterways, as much of their potable water can be traced back to streams served by riparian corridors (Ferre-Sadurni, 2017). Due to this close relationship with nearby water, riparian corridors are specifically susceptible to the impacts of tropical storms. Extreme precipitation from hurricanes cause flooding, which redirects river paths and boundaries of riparian corridors (Friedman & Lee, 2002). Additionally, the high wind speeds threaten the nearby vegetation and can cause debris and sediments to clutter up essential waterways (United States Forest Service, 2018a). Damage to waterways can impact the quality of drinking water garnered out of impacted streams, making it harder for local communities to access clean water.

After large natural disturbances, restoration efforts are typically undertaken in order to mitigate the damage that has occurred to riparian areas, thereby restoring access to potable water (Eubanks, 2004). Since riparian areas are quite environmentally diverse, proper assessment protocols are necessary in order to determine which areas to target in any restoration effort. These protocols are used to determine the extent and type of damage sustained in an area, as well as other factors relevant to a particular project. Some parameters that these protocols include are channel stability, including the measurement of bank angle, width, depth, and estimated incision height and distribution of wood within the stream reach (Somerville, 2010). The specific factors and how they are assessed vary based on location and environment. A study of three such protocols in 2003 found that despite their technical differences, information captured by each method proved effective in assessing riparian health (Ward et al, 2003).

Although these existing assessment protocols factor in many variables, one common issue is that they do not take into account opinions of local communities near the riparian areas. Of the 32 riparian assessment protocols reviewed by the Environmental Protection Agency, none included community input as an assessment parameter (Somerville, 2010). By not interacting with the nearby communities, these protocols can fail to account for information that only locals may know (Lienert, 2018). In addition, locals often hold a large deal of responsibility in carrying out restoration efforts. Thus, it is important that initial area assessments factor in the communities' input and proximity to restoration sites.

One such area that exemplifies this hurricane damage is El Yunque National Forest in Puerto Rico. When hurricanes Irma and Maria made landfall in Puerto Rico in September 2017, they caused widespread damage across the island, destroying 23-31 million trees (Clinton Foundation, 2018). Specifically in El Yunque, massive amounts of debris and sediments were introduced into the waterways, requiring extensive attention (United States Forest Service, 2018a). Restoration efforts within El Yunque, which is managed by the United States Forest Service (USFS), have in the past met resistance in the absence of community input. The 1986 Land Management Plan faced harsh criticism from Puerto Rican locals, including protest marches and court challenges, leading to numerous revisions of the plan's structure (McGinley, 2017). Although recent efforts within the forest have been slightly more community oriented, it is imperative not to lose sight of how important the forest and its management is to the local population. With the recent damage caused by the hurricanes, local communities have experienced reduced water quality, introducing a dual need for restoration, both in terms of ecological and human needs. To encompass and weigh both concerns, an assessment protocol needs to be applied to assess ecological damage, but the community also needs to be engaged to determine how to best restore water quality.

This project generated a guide that supplements the technical aspects of an existing assessment protocol with community input to prioritize riparian zones for restoration. To achieve this goal, we worked alongside USFS to gather scientific data and engage communities near El Yunque National Forest through interviews and participatory maps. Using both the social and technical data, we narrowed the scope of our restoration project to one riparian zone that was both ecologically damaged and important to the community. After selecting this area for restoration, we updated the community on how their input affected our decision and invited feedback on our community involvement process. We then refined our guide for future projects to follow. As climate change brings more powerful and frequent hurricanes, the guide generated from this project can be applied globally to involve local communities in the restoration of riparian areas in tropical environments.

2.0 Background

Hurricanes have inflicted significant harm to waterways and adjacent riparian areas. These areas are critical to the overall health of the environment and the well-being of the surrounding communities, especially as they apply to water quality. With the amount of damage that these areas have sustained, it is unreasonable and infeasible to restore them all. As such a list of priorities must be established in order to address the needs of the damaged ecosystems. Despite the importance of riparian areas to local communities, damage assessment protocols prior to restoration are solely focused on environmental factors, largely ignoring the needs of the local population.

In this chapter, we will provide an overview of climate change and its effect on hurricanes and the resulting impact on tropical ecosystems. We will then explain what a riparian area is and what such an ecosystem provides to the environment and people living nearby. This will lead into a discussion of restoration efforts and prioritization methods, ending with issues specific to El Yunque National Forest. This information will help to guide our understanding of these complex ecosystems as well as the best strategy to assess damage that they have sustained.

2.1 Hurricanes and Ecosystem Impact

Hurricanes cause widespread destruction in both the communities and ecosystems they pass over. Despite being natural occurrences, the intensity and scale of these tropical cyclones alter ecosystem-level processes essential to animal and plant populations. Hurricanes do so by depositing litterfall (dead plant material), damaging root systems, and defoliating trees (Liu et al, 2018) (Lodge & McDowell, 1991). These storms have been growing in scale and frequency, leading to a greater concern around their impact.

Tropical storms are only becoming more of a threat. Confirming trends based strictly on past data proves difficult due to limited historical data on tropical cyclones; however, future projections show a probable shift in global intensity of these storms to be stronger (Knutson, 2010). Additionally, due to climate change global weather patterns are likely to shift over the next century, bringing several drastic changes such as increases in average temperatures, sea level, and frequency of extreme climatic events (Harris, Hobbs, Higgs & Aronson, 2006).

One ecosystem that is particularly susceptible to these more powerful storms is the tropical forest ecosystem. Tropical rainforests are vital to the survival of nearby communities. Many local communities depend on these forests for access to water (United States Forest Service, n.d. [b]). Tropical rainforests are important for the world around them as well; these forests are crucial in absorbing carbon dioxide and stabilizing the Earth’s climate (Rainforest Alliance, 2017). These forests are heavily reliant on the health of the trees that define them. Besides being a habitat for many animals in the forest, these trees can provide stability to the river banks that provide water for local people (Attanasio et al, 2012). With more powerful storms, more trees can be uprooted or defoliated. On the Caribbean Windward Islands, 93 percent of tree stems were found defoliated, 84 percent of which lost primary and secondary branches and 36 percent sustained severe structural stem damage (Eppinga & Pucko, 2018). A wet forest in Nicaragua had 80 percent of its tree stems and roots uprooted or broken by

Hurricane Joan (Tanner, Kapos & Healey, 1991). Hurricane winds not only physically destroy trees, but also deposits dead organic material into waterways (Elmore, 1987). This too can impact nearby communities as these blocked waterways can decrease the quantity and quality of water that flows through a stream, or even totally divert the path of the stream away from where people gather their water

A hurricane's impact is not solely measured in tree mortality; there also are negative long-term effects on forest ecosystems. One study in South Carolina found that previously damaged trees are more likely to be damaged by a subsequent hurricane (Putz & Sharitz, 1991). Another study found that while many tree stems sprouted in the wake of a hurricane, few sprouts actually established themselves and survived long-term (Edmund et al 2016). The production of flowers and fruits by sierra palms were found to be dramatically affected by hurricane disturbance. It took ten months for sierra palm production to return to normal levels after Hurricane Georges in the Luquillo Mountains (Zimmerman & Covich, 2007). Many of these effects take a particular toll on watersheds and riparian areas; crucial aspects of many ecosystems across the world.

2.2 Riparian Areas

The term riparian as used in this report comes from a combined definition proposed from the different scholarly opinions on the word, "riparian areas are any areas which, by intervention of any body of water nearby, have soil that is wetter than other nearby soils, resulting in a specific 'soil-vegetation complex'" (Anderson, 1987). In this paper, the USFS definition will also be relevant: "Riparian management zones are defined as a 100-foot zone inland from each edge of a river or stream (defined as bank full), unless a site-specific analysis is conducted to identify and delineate the riparian management zone" (United States Forest Service, 2018a). Both definitions are essential in understanding why these zones are important.

2.2.1 Watersheds and Catchments

In order to visualize where riparian areas fall into place geographically, a familiarity with watersheds and catchment areas are vital. Essentially, a riparian corridor is located inside of a catchment area, which is a subsection of a watershed. A watershed is an area of land that channels all groundwater in a particular area into larger bodies of water, which eventually lead to a large outflow point downstream (NOAA, 2018). A catchment area is a particular tract of land inside of a watershed through which water flows to reach a stream or river (Oxford, 2019).. These catchments may differ greatly from one another even within one watershed based on their slope and the quantity of water that they contribute to the watershed as a whole.

2.2.2 Importance

Riparian corridors are immensely important to the surrounding communities as well as the surrounding environment. This importance comes from the relationship that they hold with their watersheds as well as the water inside them. This relationship is important because the water health is entirely dependent on the health of the watersheds and their riparian corridors. Any drinking water that comes from surface sources pass through watersheds to get to the mouth of those drinking the water (EPA, 2018). In order for these watersheds to be healthy, so too must the riparian zones within them.

Riparian corridors are healthiest when they have vegetation and trees growing in them. The plant-life in these areas are one of the main things that buff the sustainability and durability of nearby watersheds, as the plant-life itself is what keeps the soil together and prevents it from eroding as easily from water flowing through it (Attanasio et al, 2012). By protecting the soil from the passing water such as rain, or flooding, the trees themselves also help the bank stability of watersheds, with the roots of the trees helping to bind soil together on sloped lands (Gregg, 2008). Should the vegetation in these areas suffer at all, it will lead to increased concentration of ammonium and sediment in the water as well. Even a 10 meter riparian buffer zone has been shown to decrease the dissolved ammonium concentration by 73% (Souza et al, 2013). All of these different benefits come from the combined health of riparian corridors and watersheds, and they lead to pure and clean water that is easier to filter for those drinking it. Any water retrieved from land passes through watersheds. This makes watersheds and riparian corridors vitally important for the sake of water quality and safety. Healthier water means less processing and less risk of contamination from its consumption (EPA, 2018).

2.2.3 Health and Hurricane Impact

Due to the importance of riparian corridors, it's crucial to understand what factors make one healthy. This allows for specific targeting of areas that have the greatest impact on riparian health. These factors include high vegetation density, sturdy trees, soil durability, and path consistency (Friedman & Lee, 2002). The impact of hurricanes in areas can be especially devastating, since the effects that the hurricanes bring tend to exploit weaknesses in these essential riparian qualities. Extreme precipitation and flooding can cause rivers and other bodies of water to redirect, shifting the boundaries of the riparian corridors. This terminates the consistency of the riparian paths, and upsets the relationship the old path had with the environment it was in (Friedman & Lee, 2002). The high wind speeds can also damage and uproot the nearby trees and vegetation, forcing debris and runoff into essential waterways (USFS, 2018a). Since the riparian bank stability is positively affected by these trees and vegetation, removal of said plantlife deteriorates stability and leads to erosion of these banks (Krzeminska, et al, 2019). With all these factors working together, many foreign objects and dead organic material are introduced into the riparian systems and the bodies of water, yet again weakening their biological integrity and threatening the health of the water that riparian corridors serve to protect (Elmore, 1987).

2.3 Restoration Efforts

When sustained damage from hurricane winds or flooding occurs to riparian areas, restoration efforts are planned and executed to mitigate damage and restore the ecosystem to its previous state (Eubanks, 2004). These restorative projects will become more prevalent as larger storms become increasingly common due to climate change (Harris, Hobbs, Higgs, & Aronson, 2006). One critical step for any riparian restoration effort is the establishment of a riparian buffer strip (Kauffman et al. 1997). Buffer strips are vegetated areas that filter sediments, reduce erosion, and reduce nutrient loads of streams. Restoring the natural vegetative structure through the planting of local species ensures the effectiveness of these important functions (The Federal Interagency Stream Restoration Working Group, 1998). Another important step is stabilizing the bank of a riparian corridor to restore its original structure (Holmes et al, 2004). There are a number of different stabilization techniques; all include plant establishment through seeding or container-grown plants but differ in supplemental strategies (The Federal Interagency Stream Restoration Working Group, 1998). These riparian restoration techniques are often the most cost-effective means for restoring water quality in streams (U.S. EPA, 1996). In general, restoration efforts in riparian areas have been proven an economically feasible investment with significant positive impact, even when only partially restored (Holmes et al, 2004). However, their success largely depends on an assessment of the riparian areas prior to restoration.

2.3.1 Assessment protocols

The Environmental Protection Agency defines riparian assessment protocols as the procedures used to assess primary stream and riparian functions in a particular riparian area by evaluating the extent of sustained damage (U.S. EPA, 1996). Dependent on the damage and geomorphology of a particular site, the use of a protocol on a specific site can take 1-2 days to gather a sufficient amount of data. As a result, site selection generally occurs before applying the assessment protocol in the field (Environmental Protection Agency, 2010). The site selection process begins with compiling and reviewing existing data, such as topographic maps, GIS layers, watershed assessment documents, management records, land survey notes, and aerial images (Bureau of Land Management, 2013). Geographic Information Systems (GIS) data in particular can be helpful when gathering preliminary data for an assessment. GIS data is geographical information presented as layers overlaid on a map. This can show ecological information such as canopy loss and erosion history as well as non-ecological data such as the locations of roads or the location of nearby communities.

This information can be analyzed to choose a watershed, and then specific catchment areas within a watershed, to further evaluate for restoration. Once catchment areas have been selected, the assessment team goes through a delineation process to break the catchments into specific riparian areas to be assessed. (Bureau of Land Management, 2013) The chosen assessment protocol is then applied to each area along the stream in order to obtain both qualitative and quantitative data through a variety of methods. Each protocol contains different assessment parameters when combined can estimate the health of a riparian area. These parameters generally fall into either channel morphology, physical habitat, water quantity and quality, or biology. The methods by which to collect data on these parameters differ, and can either use tools to collect data, or professional analysis to observe different conditions (United States Forest Service, 2012a). For example, the Groundwater Dependent Ecosystems Field Guide presents several ways to collect flow rate measurements including the use of a Portable Wier Plate and mathematical calculations to determine how much water passes through a section of a stream per unit time (United States Forest Service, 2012a). Likewise, methods to assess the stability of a stream are presented in the Proper Functioning Condition Assessment for Lotic Areas. These methods include measures of stream slope, sinuosity, and width/depth ratio and qualitative parameters to determine if the evaluated stream falls has stable characteristics (Bureau of Land Management, 2013).

Due to the environmental diversity of riparian corridors, unique assessment protocols have been generated for different restoration scenarios. These protocols differ in several areas: parameters measured, assessment results obtained, intensity of effort and training needed to execute, source of reference condition information, and geographic applicability (Somerville, 2010).

2.3.2 Community Input

One aspect existing assessment protocols fail to include in preparing for restoration is community input. Of the 32 riparian assessment protocols reviewed by the Environmental Protection Agency in the Stream Assessment and Mitigation Protocols report, not one established a process by which to engage nearby communities during assessment (Somerville, 2010). Involving communities in restoration efforts has proven beneficial; utilizing strategies such as participatory mapping can provide local information not possible to gather through technical analysis, such as areas of particular cultural, religious, or recreational value (Plieninger et al, 2013). Often, locals are privy to information that a larger agency may not be aware of. An example is a project carried out in Denmark that was able to increase the length of stream proposed for restoration by 135% without changing budget constraints simply by incorporating practical local knowledge (Amigos, 2018). Another study reviewed 147 ecological projects from the United States; seven of the eight projects that scored highest in ecological success were distinct from the other projects in that they integrated significant community input (Bernhardt 2007). Additionally, the process of gathering local information ensures the local community feels that their opinions are valued (Lienert, 2018). It also keeps public work projects accountable to the community. Events such as public meetings can be a useful checkpoint to ensure that the project stays relevant to the issues facing the local people (Bernhardt 2007). Engaging the community both before and during a restoration process can lead to greater support; for example, the restoration of an Australian forest found immense success due to high levels of collaboration between scientific researchers and the broader community (Catterall & Harrison, 2006). An effort to restore a tropical dry forest in Costa Rica engaged not only community members, but politicians, landowners, and philanthropic organizations as well, and was extremely successful (Clemwell, 2006).

However, failure to correctly engage the community has led to conflict. In Arizona, there was public outcry against a ponderosa pine forest restoration effort, due to fear of endangered species being lost in the process (Ghioto, 2003). Restoration projects in Morocco often fail to hold any public meetings during planning phases, and have met public resistance after utilizing an unpopular forest species for the restoration effort (Swart, 2018). In an effort to reduce overgrazing in China, local governments spoke with community leaders about possible solutions. However, local herders were not informed of the reasoning behind their choice of solution, and indicated that this resulted in feelings of distrust (Swart, 2018). These restoration efforts will become increasingly relevant with climate change’s encroachment into the lives of people in affected areas. Keeping in mind the needs and concerns of local populations while restoring ecosystems impacted by these more intense storms will be critical in ensuring the health of the natural environment and the people that rely on these areas to survive.

2.4 El Yunque National Forest

In the wake of recent hurricane damage, our project site, El Yunque National Forest, provides a prime example of an area in need of riparian restoration. The forest is situated in the northwest corner of Puerto Rico and is the only tropical rainforest within the United States National Forest system. El Yunque National Forest has a total of 2,113.83 acres of riparian areas and is home to over 830 plant species and 180 animal species (United States Forest Service, 2018a). Of these, eight plants and five animal species are listed by the United States Federal Government as 'endangered' or 'critically endangered' with an additional 39 plants listed as species of 'special concern' (United States Forest Service, 2018b). Different management styles applied in the forest over time have had different degree of success due to differing amounts of community support (United States Forest Service, n.d.[c]).

2.4.1 Hurricanes Irma and Maria

Puerto Rico, being a Caribbean island, is victim to these hurricanes and their effects with increasing frequency. It has experienced more than 50 tropical storms in recorded history (Munroe, Harris & Heartsill-Scalley, 2018). The Saffir-Simpson scale rates hurricanes based on their sustained wind speed severity and the impact those storms can have. Hurricane Maria, Puerto Rico's most recent, was classified as category 5 storm with winds in excess of 155 mph (Karl, 2005). Hurricanes Irma and Maria took a heavy toll on Puerto Rico, especially due to the short time frame in which they both hit the island. It is estimated that Puerto Rico suffered around 90 billion dollars in damages as a result of Hurricane Maria (Munroe, Harris & Heartsill-Scalley, 2018). The island also lost between 23-31 million trees during Hurricanes Irma and Maria and in the resulting flooding and landslides (Clinton Foundation, 2018). Some officials believe that the damage caused by Maria may take up to a century to fully recover (Ferre-Sadurni, 2017).

The damage to El Yunque National Forest, is important to the surrounding communities. About 20% of drinkable water in Puerto Rico comes from watersheds in El Yunque (Ferre-Sadurni, 2017). These watersheds have experienced the introduction of tons of sediment and debris, harming both the water supply and the riparian ecosystems surrounding these streams (United States Forest Service, 2018a). These diminished conditions, if not repaired could result in a negative effect on not just the ecosystem present in the stream itself, but also propagate negative impacts on the shore environment and fisheries where these watershed drain to the sea (Heartsill-Scalley & Lopez-Marrero, 2014). The devastation present in the forest also impacts El Yunque's 3.5-million-dollar tourism industry (United States Forest Service, 2018b).

2.4.2 Watersheds in El Yunque

El Yunque forest is divided into eight watersheds; Rio Blanco, Rio Mameyes, Rio Espiritu Santo, Rio Fajardo, Rio Santiago, Tio Pitahaya, Rio Sabana, and Rio Grande de Loiza (Nieves-Rivera, 2018). Specifically the focus of this project will be on the Rio Blanco, the Rio Mameyes, the Rio Espiritu Santo, and Rio Fajardo watersheds. Although Rio Fajardo is currently functioning properly, the other three are currently "functioning at-risk" (United States Forest Service, 2011). All four watersheds play an important role in providing water to nearby communities. It is important to note that for all four of these watersheds, only part of the actual watershed under the control and ownership of the United States Forest Service, with Rio Mameyes having the highest percent in El Yunque (55%) and Rio Fajardo having the smallest percent in El Yunque (17%) (Nieves-Rivera, 2019).

2.4.3 United States Forest Service

Our project sponsor, the United States Forest Service (USFS), is an agency of the United States Department of Agriculture (USDA) that was formed in order to protect and manage national forests in 43 states as well as Puerto Rico (United States Forest Service, n.d. [a]). The agency has four main purposes: protection and management of natural resources on National Forest Lands, research on forestry, working with all levels of government to protect and manage non-federal lands, and international assistance in building policies to protect forests around the world (United States Department of Agriculture, 2005).

The United States Forest Service has created a general outline for repairing and restoring riparian areas, specifically noting the importance of properly researching the historical records of the affected area, soils, hydrology, vegetation, and wildlife (United States Department of Agriculture, 2004). Despite these guidelines, not all management strategies pursued in the context of El Yunque have had success. Management schemes that have ignored the needs of the community have sometimes faced resistance and failure, such as the 1986 land and resource management plan. The proposal was based on a rigid adherence to scientific approaches, largely discounting the needs of the surrounding communities. This led to a protest of the plan and twelve court filings which resulted in the Forest Service providing copies of public releases in Spanish and a revision of the plan to incorporate more community input (McGinley, 2017).

The most recent Revised Land Management Plan contrasts many of the earlier methods in its commitment to community engagement and flexible decision making (McGinley, 2017), (United States Forest Service, 2018b). In addition to a commitment to working closely with local populations, the plan also cites an increased focus on maintaining and restoring riparian areas. Unfortunately, the plan stops short of prescribing a method with which the riparian areas of El Yunque National Forest should be restored or a guide to which specific areas should be targeted (United States Forest Service, 2018b).

In recent years, the USFS has developed the “all-lands approach” for restoring ecological areas. This has been an important shift in USFS policy as the all-lands approach emphasizes restoring all lands in an ecosystem, even those not directly owned by the forest service (Tidwell, 2010). This approach requires the USFS to partner with other agencies such as Para La Naturaleza (PLN), a non-profit organization whose primary focus is to increase the amount of protected lands in Puerto Rico to 33 percent by 203. They also work with local communities in order to fulfill their long-term restoration goals.

3.0 Methodology

The goal of this project was to prioritize riparian areas within El Yunque National Forest for restoration by the United States Forest Service. Through this process, we generated a guide that supplements the technical components of an existing assessment protocol through inclusion of community input, and can be used globally in restoration of riparian areas in tropical environments. This guide was developed through the achievement of the following five objectives:

Objective 1: Select Watershed

Objective 2: Select Drainage Basins

Objective 3: Select Riparian Area

Objective 4: Carry out Restoration in Selected Area

Objective 5: Evaluate community opinion of involvement

This project took place over the span of seven and a half weeks, from March 11, 2019 to April 30, 2019. Now established, this guide can be used as a basis for other restoration efforts in tropical rainforests outside of El Yunque.

3.1 Select Watershed

Our team met with our USFS sponsor to obtain the initial scope of our project. This included the general extent of damage caused by Hurricanes Irma and Maria, the physical resources available to us, and the temporal restrictions our project was expected to adhere to. Additionally, we were introduced to a number of USFS staff members who would work directly or indirectly with us on different components of our project. These staff members included Ricardo Santiago, an ecologist, Lizandra Nieves-Rivera, a soil scientist, and several others.

The first task we undertook was to choose which major watershed to focus on from three possible options; the Rio Blanco, Rio Espiritu Santo, and the Rio Mameyes. These three watersheds were identified as "Functioning at Risk" by the Forest Service in their *Watershed Program 2019 Briefing Paper* using the Watershed Condition Framework (Nieves-Rivera, 2019). However, after consulting with contacts at Para la Naturaleza, we expanded our scope to include a fourth watershed, Rio Fajardo. According to PLN's regional superintendent, Antares Ramos Álvarez, this watershed is critical to the health of their reserve at Las Cabezas de San Juan (Personal Communication, 2019).

To make this selection, we used an analysis of topographical maps of the forest consisting of several data layers compiled by the Forest Service in Geographic Information Systems (GIS), including QGIS and Google Earth. After receiving and gathering all available data, we evaluated each layer and determined which would be most relevant and helpful for us to make our selection (Rahman & Chongfa, 2014). These GIS files contained both ecological and community data concerning El Yunque National Forest. To pair down the layers we would focus on, we looked to see if the layer was the most current available, had relevant information, and made visual sense. Some layers were outdated, irrelevant, or disorganized and confusing. We were able to collect enough data that such layers could be excluded without detriment to the quality of information used in our project. We compiled these data layers and performed GIS analysis to determine which watershed to focus on based on ecological health, importance to communities, and likelihood that restoration efforts would take hold and yield positive long term results. This determination was made by grouping like layers together and looking on the map to see what watersheds had clusters of a certain type of data (Rahman & Chongfa, 2014). We grouped ecological data into one map and social data into another. This way, we could understand what we were looking at without becoming overwhelmed by extraneous data. Clusters of data such as landslides in the ecological dataset, or water intake points in the social dataset would indicate that a location was in need of restoration, but areas with steep slopes would indicate that restoration would be difficult, and might not yield positive results.

Another component of the watershed selection was input from a group of stakeholders that attend a monthly community leader meeting with the Forest Service in order to voice concerns and get updates on the status of projects within the forests. From this meeting we contacted participants, the most significant contact being Marcella Cañon of the Souls of Bahia foundation, which is a non-profit organization focused on maintaining the ecological health of the island. The input from these stakeholders was taken into account both in terms of the importance of each individual watershed, as well as how communities should be engaged in the restoration process.

The final step in selecting a watershed was to combine the two components of information we gathered, scientific data and community input. We generated a watershed comparison chart highlighting the pros and cons of each watershed in terms of applicability to our project. Through analysis of this chart and discussion with Forest Service personnel, we were able to select the watershed that best fits the needs of our project. We examined this chart, looking for a watershed with a large amount of water intake points, which indicate the level of water usage from a watershed. We also looked for landslide concentration, points of interest, the acreage, and percentage of a watershed that falls inside of a particular watershed. Greater values for all of these values factored positively into our analysis. Combined with gathering information and establishing contacts, this process took approximately four weeks to complete.

3.2 Select Drainage Basins

After narrowing our focus to one watershed, we reached out to contacts in local communities and set up interviews with the help of USFS Ecosystem Manager Pedro Rios to gauge what areas of the forest they found most important. These interviews provided us with the opportunity to conduct participatory mapping exercises, giving us different perspectives on how to evaluate the importance of areas within the selected watershed. Participatory mapping is an activity in which community members are asked to identify locations that correspond to different prompts and mark them on a map so that the interviewer can better understand the spatial relationship between responses (Lienart, 2018). We used these interviews to probe for information on areas of importance in four categories: water use, ecological health, recreation, and cultural significance.

Due to time and logistical constraints, we were able to conduct five interviews with people that live or work within communities located in our selected watershed. These interviews were held within a one week span and were conducted through a translator, either Ricardo Santiago or Lizandra Nieves-Rivera. One group member took notes, and three group members asked questions during these interviews. Each interview typically lasted between 45 minutes and an hour, depending on the detail that the individual participant wanted to put into the participatory map.

The interviewees were Juan Guadalupe, the head of maintenance at the Eliza Colberg Girls Scout Camp, Noelia Rivera, who was also maintenance staff at the Girl Scout Camp, Jeanette Cruz Beltrán, Government and Community Relations Chair for the Girl Scout Camp, Roberto Calderon, a restaurant owner, and Nancy Santiago, a member of the non-profit Amigos del Yunque. This gave us the opportunity to synthesize the opinions of people from several different areas and integrate their opinions into our assessment of the riparian areas.

A list of the questions used to guide these interviews can be found in Appendix B, these questions were divided into the four groups listed above: water usage, ecological health, recreation, and cultural significance. While answering these questions, participants indicated areas of significance on participatory map templates that we generated from GIS data. Answers to these questions were colored coded on the maps according to their category. These questions allowed us to be better informed about the local area. The map only focused on the watershed that we had already selected so that the scale could stay reasonable; people can lose connection to the map if the scale is too large (Mwanundu, 2009). Additionally, the participants were asked to rank each of the four categories on a 1-4 scale based on importance. The weights of perceived importance were averaged over all interview. A final question was asked to determine if there are any areas the community does not want us to restore or interact with at all, for any reason they might have specified.

The resulting information was then synthesized into a series of GIS layers for ecological health, water use, recreation, and cultural significance as indicated by the community. By combining the information ascertained from the interview questions with the specific locations that were pointed out on the map, we were able to prioritize areas related to the two conditions that were consistently ranked higher in our interviews (Lopez-Marrero & Hermansen-Baez, 2011). This is not to say that areas corresponding to the other two criteria were neglected, just that they became less important in our selection. It also allowed us to gain a more in depth understanding of why each area was important to the specific person being interviewed. Through cross-referencing our maps of ecological health, water use, recreation, and cultural significance, we were able to identify areas with multi-faceted importance to the local community. Areas that had a high degree of overlap were prioritized higher, while areas with less overlap received less priority. When selecting basins, categories that received a higher average weight were emphasized more and regarded as more important. With this map, we prioritized specific basins to further evaluate on feasibility of restoration.

3.3 Select Riparian Area

Once the community identified two basins for our team to focus on, we selected three locations with the assistance of Forest Service personnel based on the content of the interviews and participatory maps. These areas were chosen to assess on the ground to further evaluate on the conditions of ecological health, level of damage, and feasibility for restoration. We employed a protocol that was synthesized from three options provided by the United States Forest Service with the help of USFS soil scientist Lizandra Nieves-Rivera. These three existing protocols were the *Proper Functioning Condition Assessment for Lotic Areas*, *The National Riparian Core Protocol*, and the *Groundwater-Dependent Ecosystems: Level II Field Guide* (Dickard, 2015; Merritt, Manning & Hough-Snee, 2017; United States Forest Service, 2012a). Not one of these individual protocols encompassed all the information that we needed in order to properly assess the unique riparian environments within El Yunque National Forest and Ms. Nieves-Rivera lent her expertise in crafting such a protocol to fit our specific needs.

The protocol establishes methods for assessing channel stability, including the measurement of bank dimensions, type of vegetation and soil present, and water quality. For bank dimensions, we measured bank and bankfull width, length, and depth as well as the slope of the bank and slope of the stream. For vegetation, we assessed the percentage of land cover occupied by each trees, shrubs, and grasses. Soil was examined for the amount and size of rocks present, as well as for signs of erosion and bank collapse. Water quality measurements were limited to an estimate of turbidity, or suspended sediments in the water, due to the time and expense that would be required for a more extensive measurement. Pictures of significant features were also taken at each site. The protocol containing these parameters was integrated into an existing field survey application called Survey123. Screenshots of the survey can be found in Appendix C. Our team executed our assessment protocol on the three riparian zones identified in our GIS map over the course of one week. Based on the estimate of time to complete given in the component protocols and Ms. Nieves-Rivera’s own estimate, each assessment was to take about 1.5 to 3.5 hours in field to complete. This estimate ended up being on the high end, as the longest assessment took less than two hours and the shortest took about an hour. The protocol was carried out on the ground with the help and advisement of USFS ecologist Ricardo Santiago, volunteer technician Roberto, and soil scientist Lizandra Nieves-Rivera.

Several logistical constraints were considered to determine feasibility. The main logistical concern was time. Due to our limited stay in Puerto Rico, we had to select a location that could benefit from a passive restoration that could be completed within the span of one to two days. Other concerns that were brought to our attention by the United States Forest Service ecologist, Ricardo Santiago, included the distance of a site from a particular community, distance from an access road, and grade of the trail to access a site (Personal Communication, 2019). Dr. Santiago noted that many areas of the forest are difficult to access, with around 24% of the forest having a 60% grade or higher and that we would have to consider ease of access when selecting an area to use as a proof of concept. According to both Dr. Santiago and Ms. Nieves-Rivera, these factors required a case-by-case analysis using information gathered as personal experiences while conducting our field analysis during the damage assessment phase of the project (Personal Communication, 2019).

Using the data gathered by the assessment protocol, our team presented a preliminary selection of one of the three riparian areas to soil scientist Lizandra Nieves-Rivera. She confirmed our choice of a site for restoration.This decision was made with care, knowing that the way in which this area was selected will serve as a benchmark for other future efforts.

3.4 Carrying out Restoration in Selected Area

Once we selected our priority riparian area, soil scientist Lizandra Nieves-Rivera was able to generate a restoration plan for this particular site. Our team executed this restoration plan, which consisted several restoration strategies, with the assistance of about 15 USFS staff and several volunteers. Originally, the plan was to have local communities involved in the effort, but due to time constraints, no community members were able to attend the planting activity. This activity helped to assess the feasibility of restoration in the area which we selected. The planting activity took about five hours to complete and was conducted in accordance with USFS best practices (United States Forest Service, 2012b).

3.5 Evaluating Community Opinion of Restoration Efforts

Once the restoration project was completed, we sent out a briefing to the individuals that we interviewed, to the Forest Service staff, and stakeholders that we interacted with. These briefings discussed what our project accomplished, focusing on what impact the community had on our decision making. Additionally, we included a description of the restoration activity itself and what was accomplished. Finally, this briefing included a request for feedback in the form of a set of questions that we would like each individual to respond to. It has been found that the input of those involved in communal efforts are the most important people to contact regarding the success of the project (Boulmetis & Dutwin, 2011). Due to this, participants were asked how satisfied they were with the selection of areas to repair, and if they felt they had a say in the selection process. They were also asked to critique what they saw in the selection process, and suggest any sort of improvements they would like to see in the future recovery efforts. This gave the participants an outlet for their opinions a second time, and opened the door to the community as a whole again, allowing community members to have more of a say in the recovery efforts, and more control over their environment (Hall et al, 2003). The briefing and questions for this post-participation assessment are included in Appendix B. The responses that we received from these briefings were used to make improvements in our guide, so that it can best involve the community in restoration efforts in other tropical rainforests in the future.

4.0 Results

Through GIS data mapping and layer analysis, collaboration with community leaders and forest scientists, interviews of local community members, generation of technical procedures to supplement with our guide, field research on the selected drainage basins, and execution and analysis of a small-scale restoration project including the nearby community, we developed a guide to involve the community in future prioritization efforts in tropical rainforests. Using the methods outlined in the previous section and in accordance with our guide, our team was able to select a watershed, drainage basins within that watershed, and a riparian site for restoration. Our guide can be found in Appendix A.

4.1 GIS Mapping

We utilized a Geographic Information System (GIS) approach to select the watershed within El Yunque National Forest our team would work with further. Below are a series of GIS maps that we used to help our team to both understand the layout of the forest and select a watershed to focus our further assessment efforts within.

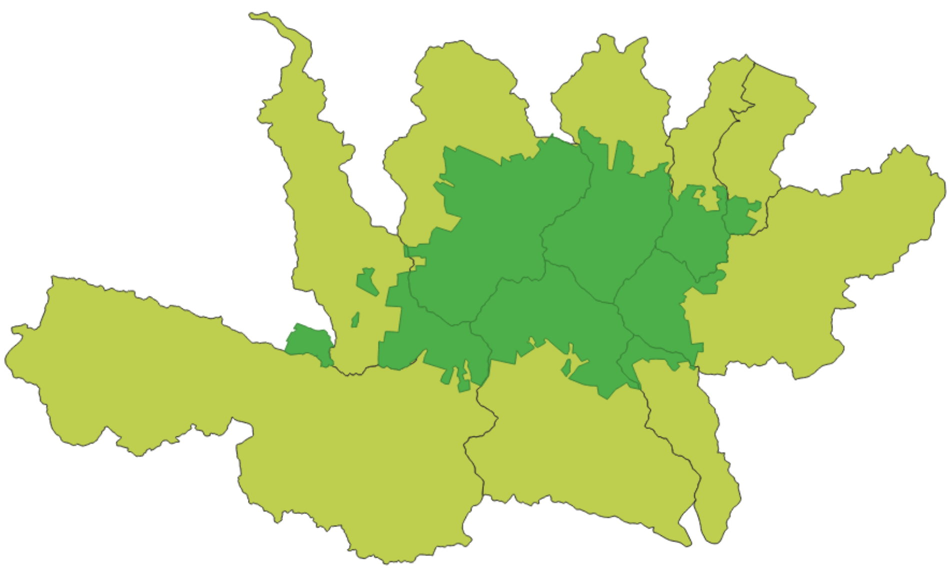


Figure 1: Watersheds with land in El Yunque National Forest boundaries

Figure 1 displays a map of the nine watersheds in Puerto Rico that have land within the Forest Service's jurisdiction. The light green regions show the boundaries of the watershed areas defined in the National Hydrology Dataset, and the dark green regions how much of these watersheds are part of designated National Forest, in which the Forest Service operates. This map gave our team context on the scale of watersheds in relation to El Yunque, and gave a general sense of which areas the riparian corridors within the forest flow to.

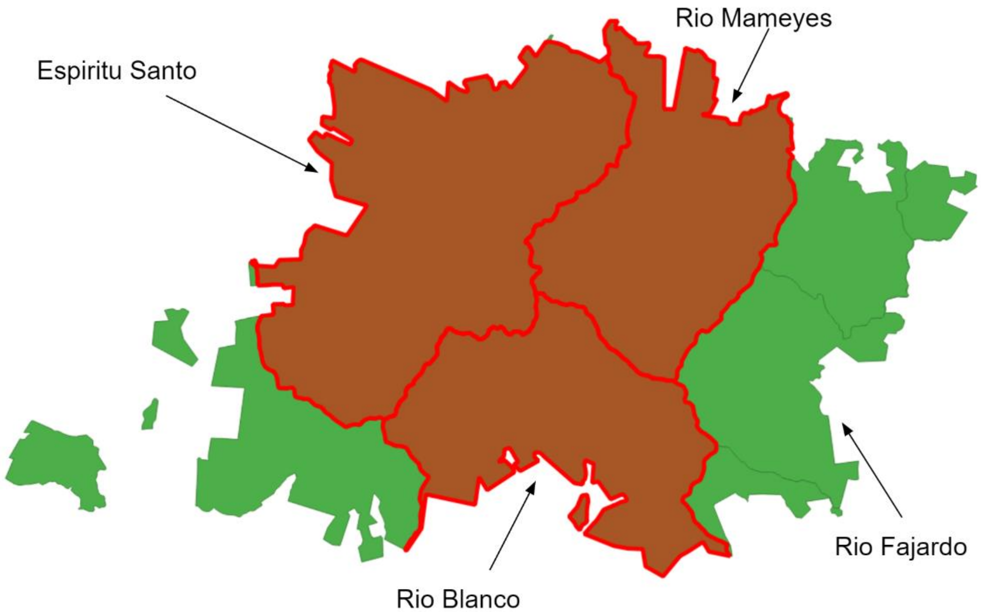


Figure 2: Watersheds "Functioning at Risk" within El Yunque National Forest

Figure 2 displays a map of the boundary of El Yunque National Forest. In red were the three watersheds that were indicated as "Functioning at Risk" under the guidelines of the Watershed Condition Framework, which was used to evaluate the forest in 2018 after Hurricanes Irma and Maria. Initially our sponsor wanted us to consider those three watersheds, Espiritu Santo, Rio Mameyes, and Rio Blanco, for restoration. At the suggestion of Para la Naturaleza, we also evaluated a fourth watershed, Rio Fajardo. This watershed is located on the eastern side of the forest, and has less land area within the designated National Forest than the other watersheds. This map gave us valuable basic information for each of the four watersheds, including area in acres, ecological condition, and location within the forest. It serves as the base layer for the majority of the following GIS maps.

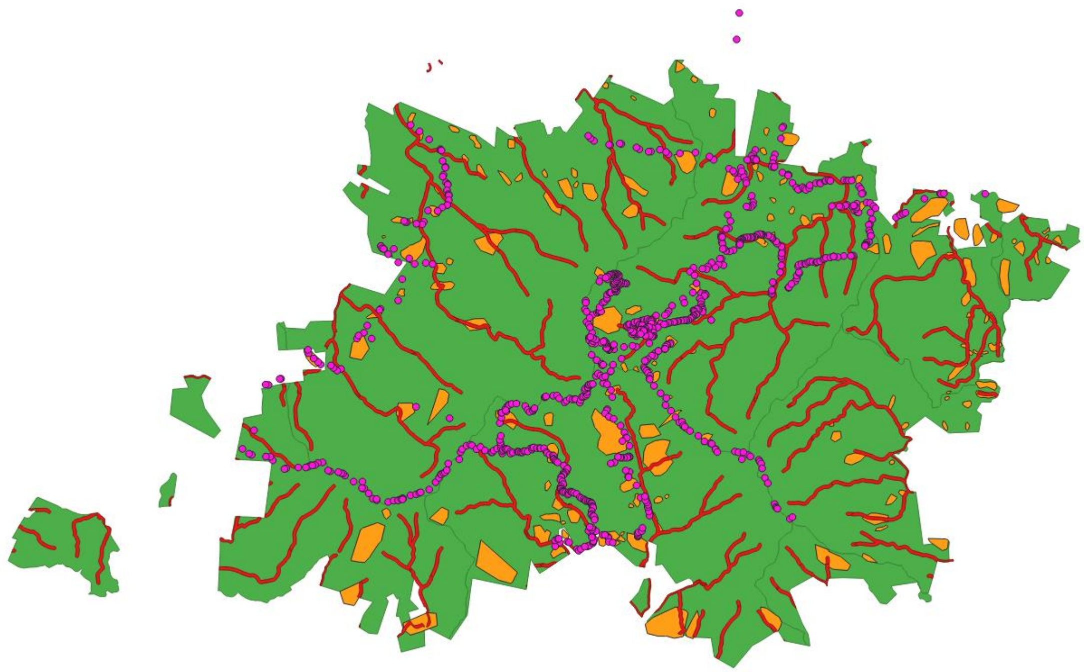


Figure 3: Historical and recorded landslides in El Yunque National Forest

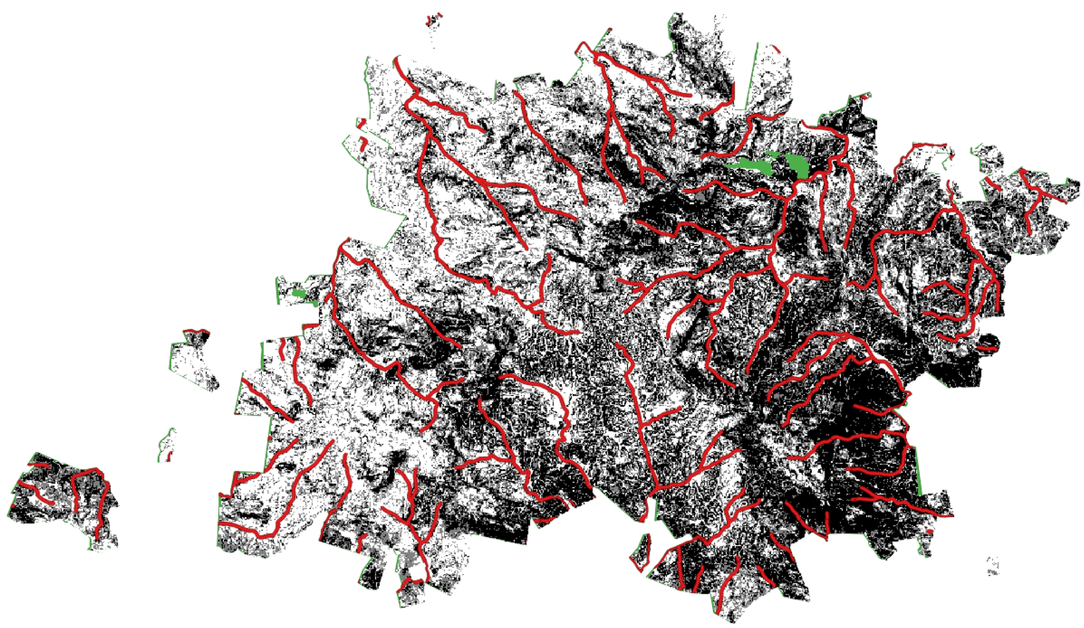


Figure 4: Slope in El Yunque National Forest

Figures 3 and 4 display ecological data gathered by USFS in El Yunque. Figure 3 displays landslide data alongside major riparian corridors, outlined in red. Orange regions indicate areas of historic landslide prevalence; pink markers indicate specific landslide events recorded by the USFS along trails and roads in the forest. From this map we were able to determine Rio Blanco is historically the most vulnerable to landslides, and Rio Mameyes has the most documented landslides, likely due to the large number of trails in that watershed.

Figure 4 displays the slope of the forest alongside major riparian corridors, outlined in red. Slope percentage is a white to black gradient with values ranging from 1-3. White indicates a slope of less than thirty percent, grey indicates a slope of between thirty percent and forty-five percent, and black indicates a slope of greater than forty-five percent. This map allowed us to identify areas with consistently high slopes, which in turn makes restoration efforts harder to execute correctly. These areas were Mt. Britton in Rio Mameyes, and a large portion of Rio Fajardo.

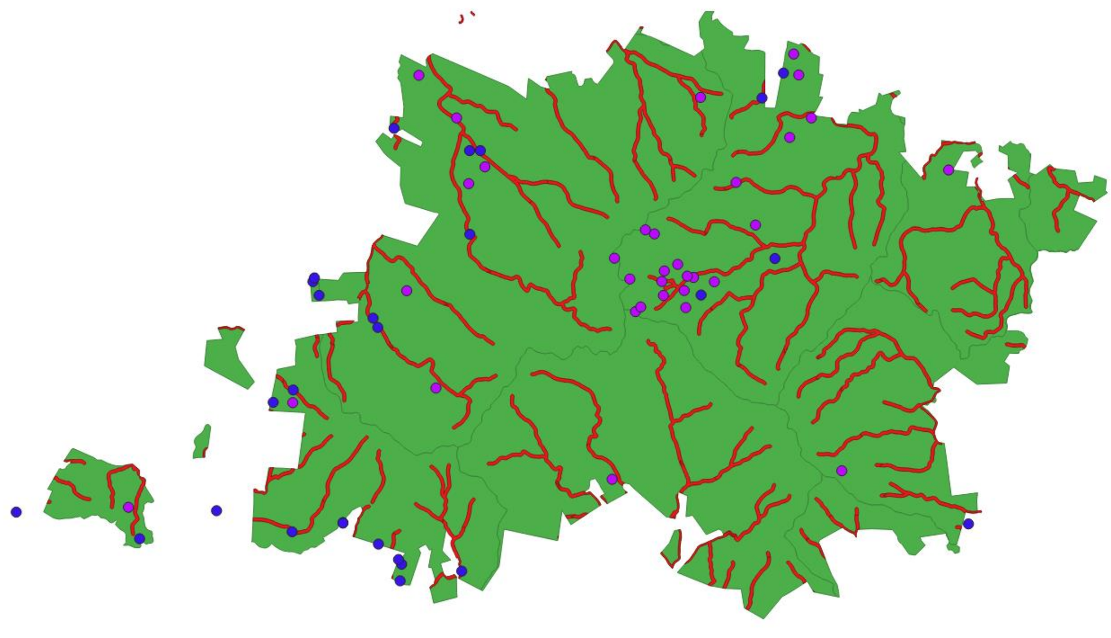


Figure 5: Water intake points and points of interest in El Yunque National Forest

Figure 5 displays water intake points (blue markers) and points of interest (purple markers), both defined by the Forest Service, alongside major riparian corridors. This non-ecological data allowed the team to evaluate the watersheds on basis of what would be important to communities as well. Rio Mameyes had the most points of interest, which indicates high tourism and trail use. Espiritu Santo had the most water intake locations, leading us to conclude its high importance to nearby communities in the form of water access.

4.2 Watershed Selection

After conducting the GIS exercise, we compiled the GIS data with information that we had gathered from conversations with USFS staff and community stakeholders, along with printed material. From this information, we generated the following comparison chart of the parameters to consider when choosing a watershed.

Watershed	Functioning at Risk	Landslide Prevalence	Road Access	# Water Intakes	% Owned by USFS	Acreage Owned by USFS	In NEPA	Places of Interest
Rio Espiritu Santo	Yes	High	Yes	9	52	8708	No	8
Rio Mameyes	Yes	High	Yes	4	55	5500	Yes	20
Rio Blanco	Yes	High	No	0	29	5185	Yes	1
Rio Fajardo	No	Medium	No	1	17	2806	Yes	1

Table 1: Watershed Comparison Chart

Rio Espiritu Santo, the watershed in which we chose to focus our work, has the most water intakes, as well as the most land area owned by the USFS. Marcella Cañon, a member of the Souls of Bahia foundation, stated that for a restoration involving community, Espiritu Santo would be an optimal choice due to its communities relying on water access and being close to the rainforest (Personal Communication, 2019). According to soil scientist Lizandra Nieves-Rivera, Espiritu Santo has many small communities that directly border the forest and rely on water taken directly from streams fed by the headwaters within El Yunque (Personal Communication, 2019). Further downstream and in the northern section of the watershed, there are multiple formalized communities, including Rio Grande, La Dolores, Bartolo, Las Tres T, and Samuel Davila. All of these communities belong to the Metro region of Puerto Rico Aqueduct and Sewer Authority's (PRASA) management, which receives water from treatment plants within the forest (Lázaro & Acosta, 2012). Additionally, in our review of applicable literature, the "Water Withdrawn from the Luquillo Experimental Forest, 2004" report gave that Rio Espiritu Santo had the most water use both in terms of absolute quantity and in percentage of total outflow (Crook, Scatena & Pringle, 2007). Another consideration that was important to this selection was PR 186 which passes directly through this watershed. This roadway is important to be able to get volunteers and equipment to any selected area without excessive hiking. The only factor against the selection of this watershed is the fact that it is the only one of the four watershed examined that was not part of the Northeast Partners Alliance (NEPA). This means that work in this watershed will not be able to garner interagency support as easily as work in another watershed would. For an effort as small as ours, and with such strict time constraints, this factor was not as crucial as it could be for a more extensive or long-term project.

Rio Mameyes would have been the second choice of watershed if Rio Espiritu Santo became infeasible to work with. It is "Functioning at Risk," has multiple water intake points, high trail use, and easy road access for restoration. However, the main tourist access road into the forest, PR 191, goes right through the heart of the watershed, with numerous recreational sites all along its reach. Research Scientist Tamara Heartsill-Scalley informed our team that Mameyes also is home to the only wild and scenic river in El Yunque (Personal Communication, 2019). Much of the Forest Service's current efforts, including riparian restoration, will continue to be focused around these areas due to their inherent tourism value. Additionally, the Forest Service Public Affairs Officer Carolyn Krupp informed us that the Forest Service is already largely involved in the communities surrounding Rio Mameyes and wants to increase its presence in other watersheds (Personal Communication, 2019). As a result, the team decided another less prioritized watershed would be more valuable to restore for this project.

Rio Blanco was the most damaged watershed and it quickly seemed to present the most difficulties. This watershed has been designated "Functioning at Risk" since the Watershed Condition Framework was developed in 2011 and has been having issues for years before then (Nieves-Rivera, 2019). This watershed is built on a base layer of quartz diorite, which according to the Forest Service Ecologist Ricardo Santiago, presents a host of issues when designing a restoration (Personal Communication, 2019). Adding to the restoration difficulty is the fact that the access road, PR 191 has been blocked by landslides and remains impassible. Finding community members interested in engaging in a restoration effort here may have also presented a challenge, as both the Forest Service and Para la Naturaleza have very few contacts in the municipality of Naguabo, or any of the three smaller communities that border this watershed.

Rio Fajardo was considered at the request of Para la Naturaleza, who were primarily concerned about the water flowing out of this watershed through their site, Las Cabezas de San Juan. This watershed was not listed as "Functioning at Risk" when assessed in 2018 by the USFS and the landslide GIS data in Figure 3 reflects this assessment (Nieves-Rivera, 2019). Additionally, the slope of this watershed is a concern, as Figure 4 shows it to be one of the steeper areas of the forest, especially if equipment had to be carried in and out. Most importantly, this watershed has the lowest percentage of total area contained within the El Yunque forest boundaries. Though the Forest Service does acknowledge the "all lands approach" written into their new Land Management Plan, the process the Forest Service would need to go through in order to work with lands outside of their ownership would take much too long.

4.3 Basin Selection

We conducted interviews and participatory mapping exercises to select the drainage basins within the Espiritu Santo watershed our team would look into further. Five community members were interviewed. Maintenance employees Juan Guadalupe and Noelia Rivera, along with Government and Community Relations Chair Janette Cruz Beltrán, work for the Eliza Colberg Girl scout camp. Robert Calderón is a business owner with a restaurant located along PR-186. Nancy Santiago is member of the Amigos Del Yunque organization. We created a participatory map template to utilize in these interviews; layers used are listed in the Legend in Figure 6. The completed participatory maps from these interviews can found here in the Appendix I.

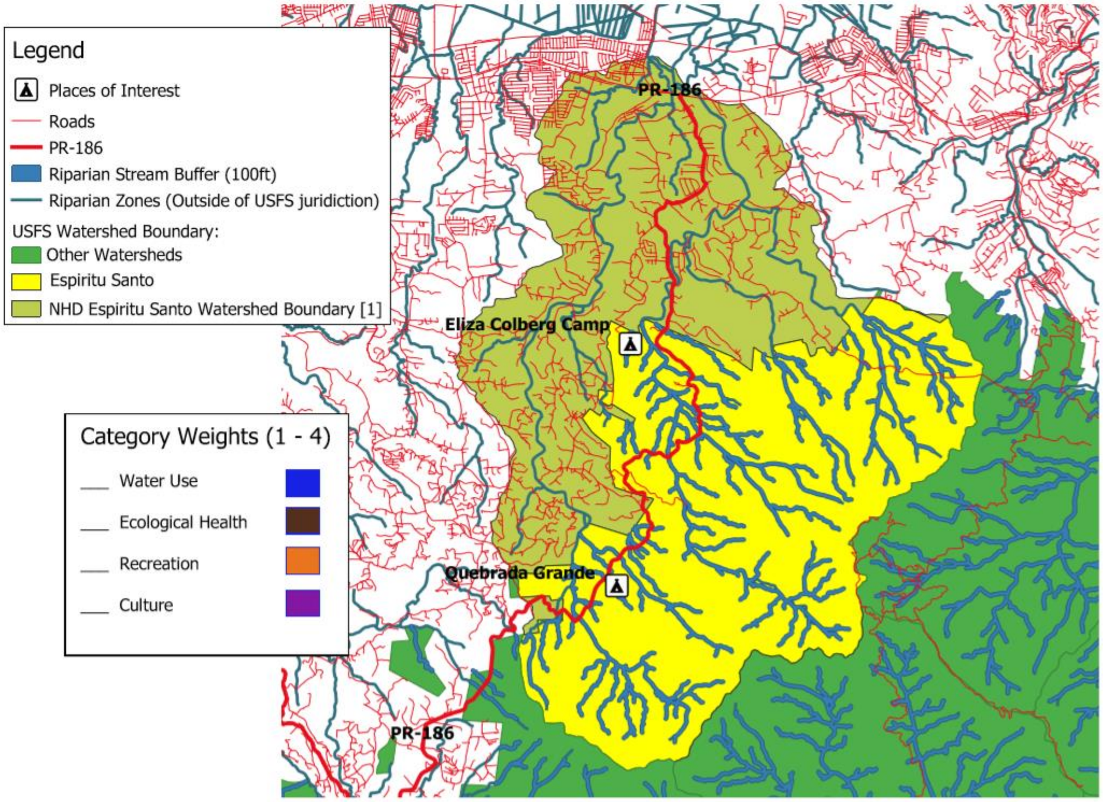


Figure 6: Participatory Mapping Template

After all interviews were completed, GIS layers were generated from the participatory maps and interview responses. A GIS layer was generated for each of the four categories of data: ecological health, water use, recreation, and culture.

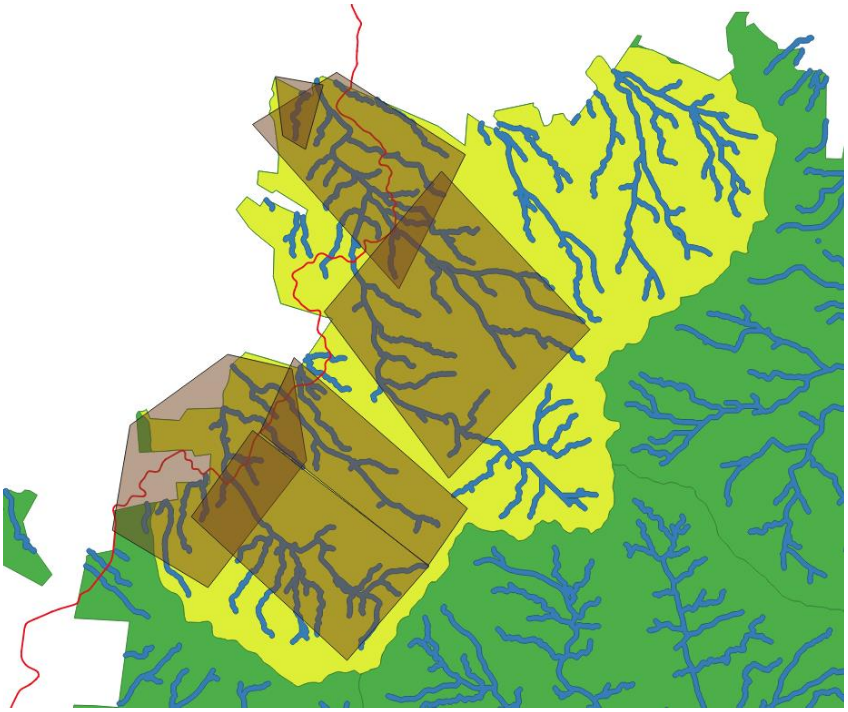


Figure 7: Ecological Health

Figure 7 displays the areas indicated by interviewees to have importance to the forest's ecological health. Juan Guadalupe explained the Girl Scout Camp's issues with from the hurricanes; it has been shut down for a year and a half due to ecological damage to the facilities and surrounding areas. Hurricane Maria caused up to four feet of flooding around the camp and deposited mass amounts of sediment near the riverbanks. He also highlighted trash and rotting animal carcasses as a big ecological concern for the community, as both get into drainage pipes. Roberto Calderón noted a severe loss of diversity in a variety of plants further up basin since the hurricanes. Additionally, he stated that canopy loss has reduced the natural air purification in the area. Janette Beltrán and Noelia Rivera stated that while the hurricanes did reduce plant life, it appeared that those plants quickly regrew.

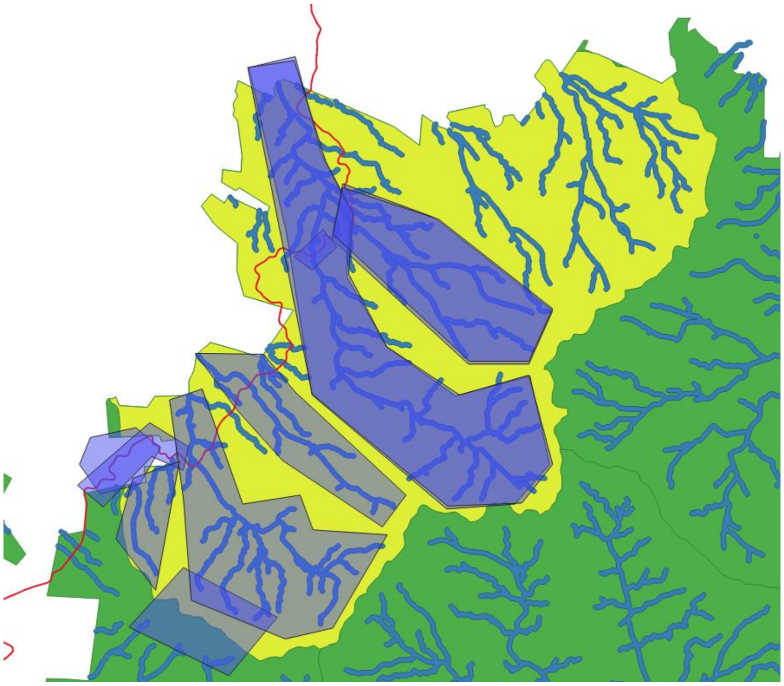


Figure 8: Water Use

Figure 8 displays the areas indicated by interviewees to have importance in community water use. Roberto identified water use as the most important category, as having clean accessible water is a prerequisite to caring about ecological, recreational, and cultural needs. He says there are five water plants along PR-186, and without this system the Rio Grande community cannot get water. According to Juan Guadalupe, the Morovis community gets its water from Rio Espiritu Santo's headwaters. Janette Beltrán and Noelia Rivera stated that while the Girl Scout Camp has an improved water system, they still have issues with pressure and broken pipes, especially since the hurricane. A lot of nearby communities rely on this, and without locals have to resort to stored and bottled water. Nancy Santiago noted the importance of the PRASA aqueducts in the watershed.

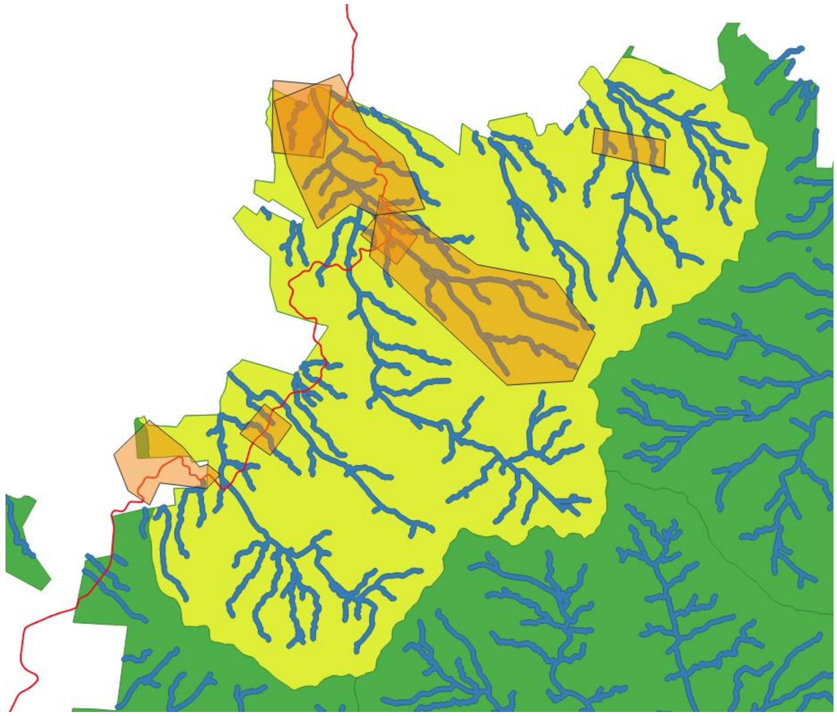


Figure 9: Recreation

Figure 9 displays the areas indicated by interviewees to have importance in recreation. All Girl Scout asserts the girl scout camp as an important recreation site. They called it a "magical place" for children to use, with visitors coming from all over the island and even the mainland. Scouts use the trails near El Verde Field Station and the Rio Espiritu Santo for recreational purposes. Nancy Santiago asserted that all quebradas in the watershed are important recreationally, as families can use them for recreation due to their accessibility along PR-186. Roberto specifically mentioned Quebrada Grande as being quite important recreationally, but has seen less activity since PR-186 sustained damage from the hurricanes. He also mentioned was trail leading to El Toro peak was an important attraction. Roberto also stated that the watershed sees the most recreation activity in the summer months.

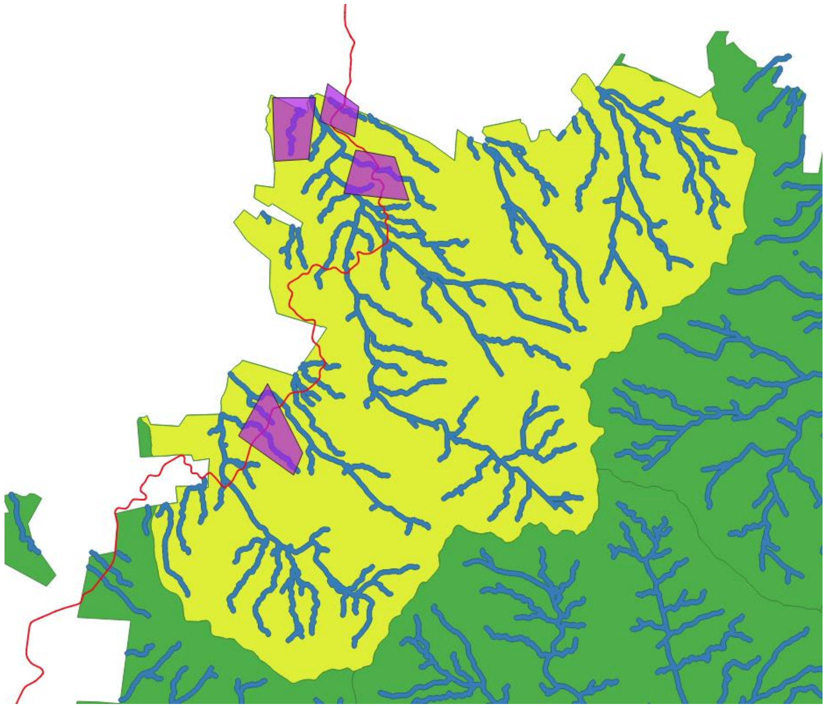


Figure 10: Culture

Figure 10 displays the areas indicated by interviewees to have cultural importance. According to Juan Guadalupe, the Girl Scout Camp was established in 1952, and thus the it has been ingrained in the community for a long time. Nancy Santiago mentioned that locals will make cultural offerings of fruit and candles at all quebradas in the forest, specifically Quebrada Sonadora and Quebrada Grande. Nancy also noted a specific local would sit on the bridge at the top of PR-186 and perform a small cultural activity near the river. All interviewees stressed the fact that the entire forest is culturally important; however, no interviewees indicated any area they would not want to see restored by the Forest Service.

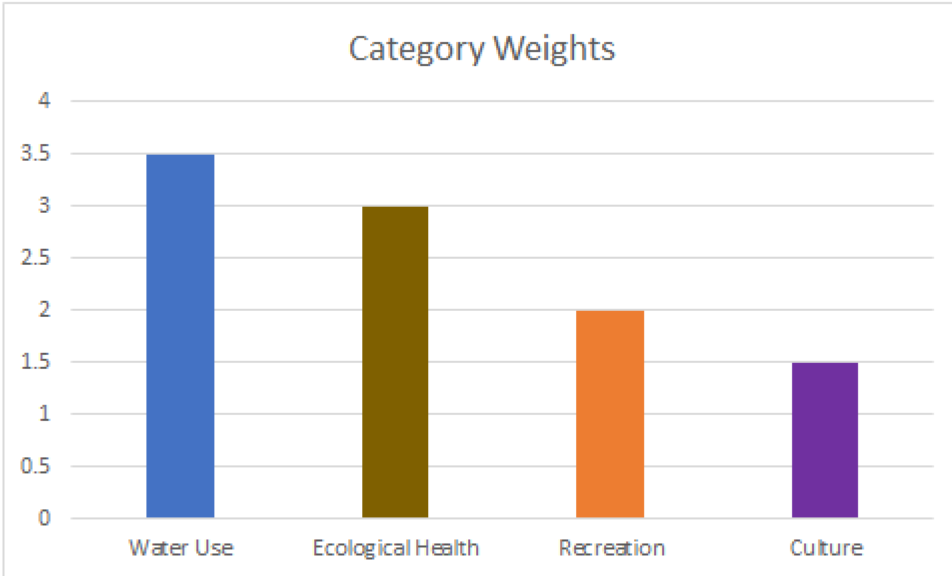


Figure 11: Average Category Weights Graph

During the participatory mapping exercise, the interviewees each ranked the four categories from 1-4, with 4 being the most important. We averaged the weights for each category and generated the graph in Figure 11. Water Use had the highest weight of 3.5, and Ecological Health was a close second with a weight of 3. Four out of the five interviewees said that water use was most important, as they felt sufficient clean water takes precedence over the other three categories until they have access to it.

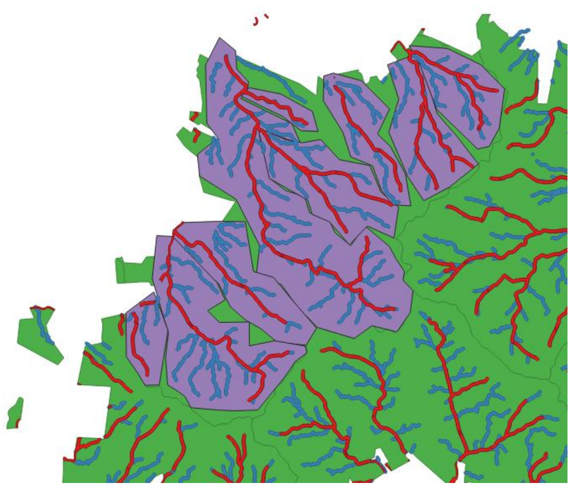


Figure 12: Drainage basins in Rio Espiritu Santo

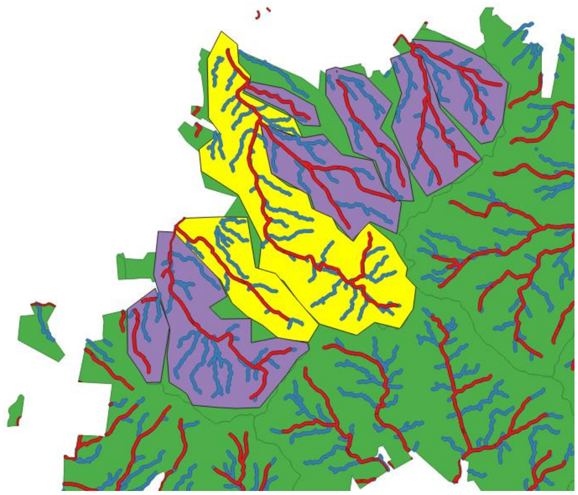


Figure 13: Selected drainage basins in Rio Espiritu Santo

With the help of Soil Scientist Ms. Nieves-Rivera, we divided the Espiritu Santo watershed into nine different drainage basins, corresponding to riparian corridors and buffer zones as displayed in Figure 12 on the left. After analysis and discussion with Forest Service personnel, the two basins shown in yellow in Figure 12 on the right were selected for assessment in the field. Water Use and Ecological Health were prioritized when selecting these basins due to the category weight averages in Figure 11. The upper basin contains Rio Espiritu Santo, which leads in the Eliza Colberg Girl Scout Camp. It was selected for the following reasons:

- Water Use - Four out of five of those interviewed identified Rio Espiritu Santo as an important headwater for community water use, as it flows to PRASA water treatment plants.
- Ecological Health - Nancy Santiago identified canopy cover as a major ecological issue around this area. Juan described the damage that flooding from the hurricane caused to river channels, which could clearly be restored.
- Culture - All members of the Girl Scout Camp asserted that the community highly values the camp due to how long it has been established, and are in the process of making the camp more available to all locals rather than just organized camp groups.
- Recreation - All members of the Girl Scout Camp stated that community members and Girl Scouts use trails all along Rio Espiritu Santo for hiking purposes. They also said that river itself is also used for swimming purposes. Juan Guadalupe said Girl Scout camp itself is also a very important recreation site for the community.

The lower basins contains the Quebrada Grande site, an area used by locals for recreation by locals. It was selected for the following reasons:

- Water use - Roberto Calderón identified Rio Grande important headwater for community water use, as it flows directly into the Rio Grande community.
- Ecological health - Roberto Calderón highlighted a severe loss of natural air purification and diversity in a variety of plant life since the hurricane damage to the canopy.
- Culture - Nancy Santiago stated that Quebrada Grande holds a huge cultural importance to locals, as community members can be seen making fruit and candle offerings at this location.

- Recreation - Roberto Calderón stated that Quebrada Grande is the most important recreation site to locals in this watershed. He has seen less use since the hurricanes, likely due to trail and road damage.

4.4 Riparian Assessment

To choose a site for restoration within the selected basin, we created a protocol to assess the ecological condition of riparian areas along this basin. This protocol consists of a combination of factors taken from the *Proper Functioning Condition Assessment for Lotic Areas*, *Groundwater Dependent Ecosystems Field Guide*, and the *National Riparian Core Protocol*. This protocol was input into an application called Survey123 in order to be filled out in the field. The full protocol can be found in Appendix C.

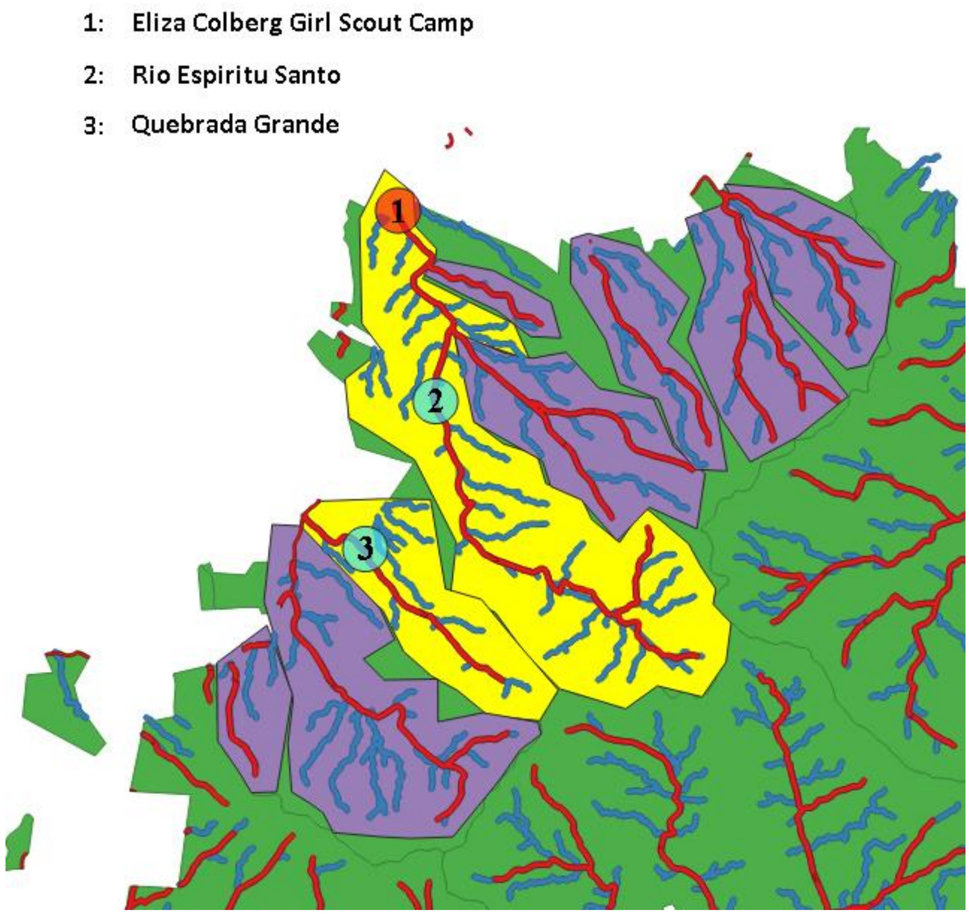


Figure 14: Selected riparian areas for assessment

Our team applied the protocol on the ground at the three separate locations within the previously selected drainage basins, as numbered in Figure 14. These locations were selected for reasons covered in the Section 4.3, in addition to discussion with Forest Service personnel. Each assessment provided us with ecological information about the site in the form of a spreadsheet that can be found in full here in the Appendix G.

The first location that we assessed was the riparian area behind the Eliza Colberg Girl scout camp, shown at "1" in Figure 14. The area had easy access via PR-186 and the nearby camp provided easy parking and available facilities for any possible volunteers. The region clearly suffered damage from the hurricanes; canopy cover was not as dense as was expected, and the banks had suffered erosion. The area was suffering encroachment, meaning that non-riparian vegetation was found in the zone. In addition, the Girl Scout camp was the only area affected by invasive species including a vine known as kudzu, which covered much of the vegetation surrounding the stream and the pomarosa tree. After assessing the area alongside Dr. Santiago and Ms. Nieves-Rivera, Ms. Nieves-Rivera deemed that the area would be feasible for a passive restoration project if chosen. We decided to select the Eliza Colberg Girl Scout Camp site for restoration due to its ease of access and applicability for a passive restoration project.

The second area that we assessed was Quebrada Grande, shown at “2” in Figure 14. Through this assessment we learned that the area is accessible and feasible for restoration. Its distance to nearby communities/groups is a moderate distance, and since PR-186 remains open to the public, it could be reached by anyone involved. The actual area itself had sustained a good deal of damage. The most striking issues that it had were the soil erosion and the stability of the vegetation in the area. The soil had been eroded in several places along the bank of the river, leading to precariously positioned trees and root systems that were definitely vulnerable to another strong storm. The vegetation along the banks, within the lower elevations of the riparian areas was loosely held in place in many spots, and much of the runoff from higher elevations had slipped through the plant systems, leading to more debris in the river than we would have liked to see. Unfortunately, to restore an area such as this, it would require a more active restoration process that the USFS team was not prepared to take on at that time, and that made it less likely to get restored during our tenure with them. With these factors all taken into account, we could not select Quebrada Grande for our restoration effort.

The last area that we assessed was a portion of Rio Espiritu Santo, shown at “3” in Figure 14. This proved to be a difficult area to assess for a number of reasons. The main access points to the riparian corridors along this area are either direct climbs up 90 degree inclines, or steep and rocky terrain that was difficult to traverse even with sure-footed personnel. As a result, it made it impossible to include any younger or elderly participants, and excluded many people because of the inability to access the actual riparian areas themselves. This also leads to many difficulties in repairing the area, since it would be difficult to do anything with lasting effect to an area that was mostly just large boulderous rocks sitting on top of one another. In terms of damage, it also seemed to be in better condition than other areas that we saw, since the trees were beginning to grow anew and the plants were finding ways to solidify their roots within the rock system. Because of these factors together, and the inability to access this area, we could not focus our restoration on Rio Espiritu Santo either.

4.5 Restoration Project

Ms. Nieves-Rivera generated a restoration plan for the selected riparian area near the Eliza Colberg Girl Scout Camp using the results of the assessment protocol. The plan, which contains several specific methods to restore the riverbank, can be found in its entirety in the Appendix C.

Figure 15: Restoration Plan

Figure 16: Restoration result

The selected riparian proved to be feasible for restoration. The first step in the restoration process was to set aside any woody debris on the way to the river channel. Next, invasive species of plants, specifically the vine kudzu, were removed by hand, as they interfere with the proper growth of native species. The next step was sheet flow reduction activity, in which the team covered the surface of the buffer with the aspen fiber erosion blankets shown in orange in Figure 15. Next, a check dam was created with rocks to provide erosion control in area shown in the white circle in Figures 14 and 15. Next, a side ditch, shown by the red line in Figure 15, was dug to facilitate drainage into the river. Finally, eight tree saplings were planted along the bank of the river to provide stability and reduce encroachment. Our team spent a half day performing this restoration alongside Forest Service personnel and several volunteers. More pictures of the results of these restoration activities can be found in Appendices E, F, and G.

After the restoration, we sent out a short briefing, including the goals of our project and what we accomplished to each individual that we interacted with throughout the course of this project. In this briefing, we asked community members for their opinions on how they felt they were engaged in the restoration process and how they would recommend the process be improved in the future. We will include any responses we receive here, a link to the briefing in the Appendix H, and how the responses affected our guide.

5.0 Conclusions & Recommendations

The goal of this project was to generate a guide that supplements the technical aspects of an existing assessment protocol with community input to prioritize riparian zones for restoration. Analysis of results gathered throughout the project has allowed us to create a set of conclusions, and recommendations the USFS should follow to properly engage the community in future restoration efforts. We learned that, as predicted, there are many benefits of involving the community in efforts such as these. Our experts confirmed that without this guide and the involvement of the community, the USFS would not have selected the site we restored, and might not have even considered the areas we narrowed down to in their own vision of restoration. The following will outline what our guide did well or poorly, and suggest edits so that future implementations around the world can effectively involve their own communities.

5.1 Summary of Key Findings

From this project, our team concluded that prioritization efforts in rainforest restoration should involve the community. There are several ways to include them in such an effort, and our conclusions can help to guide future endeavors into similar projects. A simple breakdown of the factors which go into assessment protocols can be broken into two components, the first being scientific information and the second being social/community information. In execution of this project, the main selection broke down into three specific stages: choosing a watershed, choosing a drainage basin, and choosing a riparian area. Each of these stages of the selection process had differing amounts of interaction with the community; this strategy allowed us to appropriately factor in local opinions in the steps of the process where applicable.

5.1.1 Conclusions from Guide Implementation

Involving the community in prioritization and restoration efforts requires a large amount of additional planning and work. The organization performing the restoration must consider whether the extra work of engaging nearby communities makes enough of a difference to justify it. Through the implementation of our guide, we learned that the changes we made to the assessment process provided several social benefits, and resulted in a much more inclusive selection than the USFS would have made without them.

In the first step of the process, we modified how the USFS selects watersheds. We factored in the same ecological data that are normally used in the GIS layers they supplied us with, but we also gathered or created other data that was relevant to the community, such as water intake points, community proximity, water consumption, and community leader opinions. Due to this community inclusion, we selected the watershed that was most relevant and useful to communities rather than that with the most damage or that with the highest tourism value.

According to Lizandra Nieves-Rivera, at this point in the process, the USFS will normally move on to the headwaters of the selected watershed to focus on since these are the most important sites ecologically (Personal Communication, 2019). In our guide, we instead chose the drainage basin component of the process to be where the community gets to play the largest role in the selection process. Here we selected a drainage basin to focus on based solely off of local input, through interviews and participatory mapping. By conducting these interviews and relying on the information gathered, it narrows the selection to areas that are more important to the community, rather than just ecologically to the forest.

The final step of the assessment process was the same as before; several riparian sites were evaluated within drainage basins already selected from community input. Since this is too small a scope for the community to know which areas to target, it makes more sense for the USFS to assess the most damaged areas and prioritize accordingly. It would be more beneficial to have the only community factor in this selection be overall feasibility of community participation in the restoration effort. The areas would then be analyzed exclusively on a scientific basis via on-site evaluations by Forest Service personnel.

These three steps together result in a much different selection than would normally be made by the Forest Service's existing process. This is better for the community since the area selected is that which they deemed most useful and important to them. Both processes lead to ecological benefits, however the main difference is that by implementing this guide, the process also leads to social benefits. The involvement of the community does not detract from helping the ecological health of the forest; rather, it enhances the community's impact in their environment. By hearing the community and factoring in their input, our methodology leads to many benefits to both the USFS and the communities around the forest.

5.1.2 Social Benefits

The implementation of our guide provided many social benefits to both the USFS and the communities involved. Since the Forest Service's new management plan intends to involve the community in future efforts, this project serves as a crucial pilot in such efforts (United States Forest Service, 2018b). Said pilot can open the door for many restorations down the road and is a great sign of effort for the community to see.

There currently exists a trust gap in the relationship between local community members and the USFS and other government agencies, as we learned from both the experts in the USFS office as well as from the community members interviewed (Personal Communications, 2019). By following this guide, the USFS can begin bridging this gap between them and the community. Doing so positively impacts both parties involved. By making themselves more reliable and open to input, the Forest Service demonstrates to the community their intent to modify how they currently work on the forest; which promotes future collaborative effort. This process is cyclical and will compound with each iteration. The community will have an established outlet for their opinions to be heard, leading to more members being willing to reach out and help. This means easier large-scale restoration projects, and more willing participants in the interviewing and participatory mapping portion of the protocol.

The idea of mutual benefit is a constant theme throughout this project. One such example is that the community gets to see a successful attempt of this process with their input factored in. In order to foster the relationship between both parties, it is vital to include small-scale efforts that demonstrate success. These small efforts instill faith in the community of the actual feasibility of larger scale projects, and they prove to both parties that the relationship between the two of them is possible and healthy (Metcalf et al, 2015). This project acts as such a pilot project, since it is a small-scale example of the capabilities of both parties.

Throughout the final stages and wrap-up of this project, we had several experts from the USFS reflect on their experience. USFS personnel indicated that without this project they would never have learned the things the community values the most, nor would they know of the additional concerns that the community has (Personal Communications, 2019). Some examples of this information, for the Espiritu Santo watershed, are that the quantity of water is a large concern in the community, and litter across the watershed seems to be compounding as people are more removed from their relationship with the forest. We gathered this information from doing the individual interviews with community members, and Lizandra Nieves-Rivera said that this will surely impact future efforts made by the USFS (Personal Communications, 2019).. These same interviewees were also willing to maintain connection with the USFS and act as a resource for future similar information.

5.1.3 Global Application

The methods within our guide are not exclusively for use in Puerto Rico; they outline a standard, universally applicable procedure for engaging the community, a component of restoration projects that organizations continue to face issues with. Too often restoration projects only consider ecological data in their decision-making processes. Conversely, when they do attempt to involve social data, they do not always correctly engage their communities. While these projects still positively impact ecosystem health, not involving the community breeds mistrust and can make future restoration efforts more difficult (Metcalf et al, 2015). We believe that the social benefits that resulted from implementing our guide within the context of El Yunque National Forest will be mirrored when applying our guide to other restoration projects.

A study of such projects in Morocco showed that they met public resistance due to the use of unpopular forest species. Had a public meeting been held during the planning phase, as suggested in our guide, locals could have had the opportunity to share their concerns and clarify which species they would prefer to have planted (Swart et al, 2018).

In China, a restoration project set out to reduce overgrazing by implementing grazing bans. The government discussed this approach beforehand with community stakeholders, however local herders were not informed of the reasoning behind the bans, sewing distrust. Allowing the community to understand the broader context of the project through better communication could have promoted trust and even voluntary participation (Swart et al, 2018).

A ponderosa pine forest restoration effort in Arizona also met public outcry, as locals feared the loss of endangered species in the burning process (Ghioto, 2003). Had the organization decided to interview locals, they could have learned the importance of said species to the community and modified their restoration plans accordingly. It is also possible for their experience to mirror our specialists', where they learned useful information about the forest that they did not know going into the project.

In the southwestern USA, stakeholder meetings similar to ours were held to discuss riparian management of a National Forest. However, the participants were frustrated, feeling that "there was limited time to discuss their concerns" and "people did not want to hear what they had to say." In addition to being more willing to listen during the meeting, the facilitators could have updated stakeholders on how their concerns were taken into account throughout the project; this would ensure stakeholders felt their opinions were valued (Arnold et al, 2012). They also could have allowed more time for each stakeholder to speak, so they did not feel rushed when asked for their input.

5.2 Deliverables

Throughout our project, our goals were separated into several deliverables. The first of these was the watershed rationale table found in the results Section 4.2. This table compiles all of the information we gathered from different GIS maps, combined with printed information that we received from forest specialists. This table allowed us to select our watershed and justify that selection.

The second deliverable we produced was our specific assessment protocol. This protocol was not a direct goal of our project and is thus not explained in detail in this paper. We owe a large thanks to Ms. Lizandra Nieves-Rivera for help with the creation of this protocol, as well as with its application. This document combines elements from three of the standard protocols used by the Forest Service to assess riparian areas for the purpose of restoration. It allowed us to scientifically evaluate several areas and ultimately pick an area to restore that was both in need of restoration and within our capabilities.

The third deliverable was the actual restoration effort. We executed this with the help of USFS personnel who have worked on restoration before, and knew how to carry out efforts such as these. This team helped to train us and other volunteers who did not have experience doing any sort of restorations in the past. It also allowed for us to get a close up understanding of the effectiveness of our selection process.

The final deliverable is our "Involving the Community in Riparian Restoration Efforts in Tropical Rainforests: A Comprehensive Guide," which is designed to give a breakdown of our methodology, updated with recommendations for future efforts. This guide is a concise document, set in a broad context, which should allow both the Forest Service, or any other organization conduct a similar prioritization and restoration. Hopefully the USFS will utilize our guide and improve upon it in the future. This guide can be found in Appendix A.

5.3 Limitations

While we consider this project a success, there were several limiting factors that prevented us from fully implementing all strategies that we recommend in both our guide and this report. First, it is important to understand that most efforts similar to ours take upwards of a year to complete; however, we executed ours inside seven weeks. Organizing focus groups proved a difficult task, and we ended up performing interviews with specific community members instead. Additionally, the selection of our watershed made working with PLN and their established community contacts less feasible. It is also important to note that none of the members of our group are life science or civil/environmental engineering majors or have any experience with ecological assessment. As a result, a great deal of information had to be learned while we were conducting our project. Finally, due to time constraints, our interviewees were not able to provide feedback in time for us to incorporate it into our guide accordingly.

Though many different variables turned into limiting factors, it should not reflect poorly on the USFS or on the feasibility of our prioritization model. The major limiting factor in this effort was the time constraint, as the project had to be completed before our departure. The guide we created, however, can be executed over a longer period of time with teams other than ours.

5.4 Recommendations

To start the community engagement process at the beginning of a restoration project, we recommend holding a series of meetings with community leaders from all around the forest. These meetings should explain the watershed selection process and outline the specific effort in the broader context of all the work currently being undertaken in the forest . They should also allow local communities to understand where they fit into conservation and restoration efforts and how their needs are being addressed (Khalil, 2017). This is an opportunity for any questions or concerns to be taken into consideration for later steps of the selection process.

The United States Department of Agriculture has found that when restoring ecological functions, data should be gathered "across ownerships and land uses" (USDA, 2004). Thus, we recommend compiling ecological and social information that covers the entirety of each watershed, not only the parts that lie inside USFS jurisdiction. When narrowing scope, this information would allow the USFS to consider areas outside of forest boundaries that may be in need of restoration in accordance with the Forest Service's "all lands approach" introduced in the 2018 Revised Land Management Plan. Through interviewing the community, we learned that they agree with the "all lands approach," and specifically asked that steps be taken to gather information in the entirety of each watershed, not just inside the forest boundaries (Personal Communication, 2019). Inclusion of these areas within the scope of a restoration process opens up more possibilities and allows a greater capability to address specific needs of the community. Focusing efforts only within forest boundaries, while convenient and ecologically important, does not get the community as engaged as an effort that they can see directly and experience immediately. Such efforts let the people see that their government is working for them and in their interests, in turn providing an increased likelihood of positive interactions in the future.

An effort should also be made to partner with outside organizations, such as other federal agencies, state or local government, or private non-profit organizations in order to expand the available resources. Since the community will see more legitimate organizations as part of the restoration effort, this partnership can also bolster its importance in the minds of community members. Other benefits include more contacts in nearby communities and more resources to complete restoration projects in the future. Past works, such as *Understanding Community-Based Forest Ecosystem Management* have displayed that cross functional and cross jurisdictional groups can be a benefit to forest management. The benefits to such cooperative approaches often outweigh the risks and should be pursued in most cases (Gray, Enzer & Kusel, 2008).

When gathering community input through interviews and focus groups, we recommend the use of participatory mapping. This technique has proven to be essential in our project when selecting a location for further assessment, as it allows community members to give specific information about local concerns and locations important to them while being able to pinpoint exactly where those locations are. For a guide to how to conduct this activity, see Appendix A.

As the project wraps up, we suggest involving the community in the concluding steps and allowing their voices to be heard farther down the road. While performing the interviews, and speaking with community leaders, all participants asked to be involved in future projects. Participants asked to be updated on how their input was used and what the final results of the project were (Personal Communication, 2019). The restoration team should gather feedback from all volunteers and participants and let them voice their opinions on anything that went well and anything that they would like to change in future iterations of these projects. Additionally, there should be an open forum, which the involved communities can access, where they recieve updates on how the project went, how their input was used, and what steps were taken after interviewing them.

This project aimed to combine two points of emphasis within the most recent 2018 Revised Land Management Plan. By improving riparian areas while involving the community more, it promotes the “shared stewardship of the forest” (USFS, 2018 [b]). Employing the methods outlined in this report, as well as the guide developed in Appendix A, allows the Forest Service and other organizations to better engage their surrounding communities and make forests more accessible. We hope this project will help the USFS to further a positive relationship with the nearby communities in addition to addressing the needs of the forest.

Bibliography

Amigos Bravos. (2018). *Step-by-step guide to integrating community input into green infrastructure projects*. Retrieved from https://www.eli.org/sites/default/files/eli-pubs/step-step-guide-integrating-community-input-green-infrastructure-projects.pdf

Anderson, E. W. (1987). Riparian area definition: A viewpoint. *Rangelands, 9*(2), 70. Retrieved from https://www.jstor.org/stable/3901071?seq=1#metadata_info_tab_contents

Arnold, J. S., Koro-Ljungberg, M., & Bartels, W. (2012). Power and conflict in adaptive management analyzing the discourse of riparian management on public lands. *Ecology and Society, 17*(1) doi:10.5751/ES-04636-170119

Attanasio, C. M., Gandolfi, S., Zakia, M., Veniziani, J., & Lima, W. (2012). The importance of the riparian areas for hydrologic sustainability of the land use in watersheds. *Bragantia; Bragantia, 71*(4), 493-501. doi:10.1590/S0006-87052013005000001

Benhandt, E. S., Suddoth, E. B., Palmer, M. A., Allen, J. A., Meyer, J. L., Alexander, G., . . . Pagano, L. (2007). Restoring rivers one reach at a time: Results from a survey of U.S. river restoration practitioners. *Restoration Ecology, 15*(3), 482-493. Retrieved from https://onlinelibrary-wiley-com.ezproxy.wpi.edu/doi/full/10.1111/j.1526-100X.2007.00244.x

Boulmetis, J. & Dutwin, P . (2011). *ABCs of evaluation: Timeless techniques for program and project managers*. https://ebookcentral-proquest-com.ezproxy.wpi.edu: John Wiley & Sons, Incorporated.

Catchment. Retrieved from https://en.oxforddictionaries.com/definition/catchment

Catterall, C., & Harrison, D. A. (2006). *Rainforest restoration activities in Australia's tropics and subtropics* Rainforest CRC.

Clinton Foundation. (2018). Commitment to action: Habitat. Retrieved from https://www.clintonfoundation.org/clinton-global-initiative/commitment/habitat

Dickard, M., M. Gonzalez, W. Elmore, S. Leonard, D. Smith, S. Smith, J. Staats, P. Summers, D. Weixelman, S. Wyman. 2015. Riparian area management: Proper functioning condition assessment for lotic areas. Technical Reference 1737-15. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

Edmund, V. J. T., Francisco Rodriguez-Sanchez, Healey, J. R., Holdaway, R. J., & Bellingham, P. J. (2016). *Long-term hurricane damage effects on tropical forest tree growth and mortality* Figshare. doi:10.6084/M9.FIGSHARE.C.3307170.V1

Elmore, W., & Beschta, R. L. (1987). Riparian areas: Perceptions in management. *Rangelands Archives, 9*(6), 260-265.

EPA. (2018). Healthy watersheds protection. Retrieved from https://www.epa.gov/hwp/basic-information-and-answers-frequent-questions

Eppinga, M. B., & Pucko, C. A. (2018). The impact of hurricanes irma and maria on the forest ecosystems of saba and st. eustatius, northern caribbean. *Biotropica, 50*(5), 723-728. doi:10.1111/btp.12600

Eubanks, E. (2004). In Technology & Development Program (U.S.), Technology & Development Center (San Dimas, Calif.) and United States (Eds.), *Riparian restoration* San Dimas, Calif: U.S. Dept. of Agriculture, Forest Service, Technology & Development Program. Retrieved from http://purl.access.gpo.gov/GPO/LPS111848

Ferre-Sadurni, L. (2017, October 12,). Lush refuge in puerto rico left shredded by hurricane. *New York Times* Retrieved from http://go.galegroup.com.ezproxy.wpi.edu/ps/i.do?&id=GALE|A509148281&v=2.1&u=mlin_c_worpoly&it=r&p=BIC&sw=w

Friedman, J. M., & Lee, V. J. (2002). *Extreme floods, channel change, and riparian forests along ephemeral streams*. Durham, N.C., U.S.A. : Duke University Press. doi:EFCCAR]2.0.CO;2

Ghioto, G. (2003, May 26,). Covington, GC trust take off gloves. *Arizona Daily Sun* Retrieved from https://www.researchgate.net/publication/265075745_Covington_GC_Trust_take_off_gloves

Gray, G. J., Enzer, M. J., & Kusel, J. (2001). Understanding community-based forest ecosystem management. *Journal of Sustainable Forestry, 12*(3-4), 1-23. doi:10.1300/J091v12n03_01

Gregg, P. (2008). Story: Soil erosion and conservation. Retrieved from https://teara.govt.nz/en/soil-erosion-and-conservation/page-7

Hall, Michael H., Phillips, Susan D., Meillat, Claudia, & Pickering, Donna. (2003). *Assessing performance: Evaluation practices & perspectives in canada's voluntary sector.* (). Montreal, Canada: Canadian Centre for Philanthropy. Retrieved from http://sectorsource.ca/sites/default/files/resources/files/vserp_report.pdf

Harris, J. A., Hobbs, R. J., Higgs, E., & Aronson, J. (2006). Ecological restoration and global climate change. *Restoration Ecology, 14*(2), 170-176. doi:10.1111/j.1526-100X.2006.00136.x

Heartsill-Scalley, T., & Lopez-Marrero, T. (2014). *Land-cover composition, water resources and land management in the watersheds of the luquillo mountains, northeastern puerto rico*

Holmes, T. P., Bergstrom, J. C., Huszar, E., Kask, S. B., & Orr, F. (2004). Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. *Ecological Economics, 49*(1), 19-30. doi:10.1016/j.ecolecon.2003.10.015

Kandil, S. (2017). Public participation guide: Public meetings. Retrieved from https://www.epa.gov/international-cooperation/public-participation-guide-public-meetings

Karl, T. R. (2005). The saffir-simpson scale.(hurricane categories). *Storm Data, 47*(3), 241.

Kauffman, J. Boone Beschta, Robert L. Otting, Nick Lytjen, Danna. (1997). An ecological perspective of riparian and stream restoration in the western united states.*22*, 12-24.

Knutson, Thomas R., McBride, John L., Chan, Johnny, Emanuel, Kerry, Holland, Greg, Landsea, Chris, Held, Isaac, Kossin, James P., Srivastava, A. K.& Sugi, Masato. (2010). Tropical cyclones and climate change. *Nature Geoscience, 3* Retrieved from https://www.nature.com/articles/ngeo779

Krzeminska, D., Kerkhof, T., Skaalsveen, K., & Stolte, J. (2019). Effect of riparian vegetation on stream bank stability in small agricultural catchments. *Catena; Catena, 172*, 87-96. doi:10.1016/j.catena.2018.08.014

Lienert, J. (2018). Participatory mapping for decision making. Retrieved from https://sswm.info/planning-and-programming/decision-making/deciding-community/participatory-mapping-for-decision-making

Liu, X., Zeng, X., Zou, X., González, G., Wang, C., & Yang, S. (2018). Litterfall production prior to and during hurricanes irma and maria in four puerto rican forests. *Forests, 9*(6), . doi:10.3390/f9060367

Lodge, D. J., & Mcdowell, W. H. (1991). Summary of ecosystem-level effects of caribbean hurricanes. *Biotropica*, *23*(4), 373-378. doi:10.2307/2388254

López-Marrero, T.; Hermansen-Báez, L.A. 2011. El Yunque Ecosystem Services: A Participatory Research Approach. [Fact sheet]. Gainesville, FL: USDA Forest Service, Southern Research Station. 4 p.

McGinley, K. (2017). Adapting tropical forest policy and practice in the context of the anthropocene: Opportunities and challenges for the El Yunque national forest in Puerto Rico. *Forests, 8*(7), 259. doi:10.3390/f8070259

Merritt, D. M., Manning, M., & Hough-Snee, N. (2017). The national riparian core protocol: A riparian vegetation monitoring protocol for wadeable streams of the conterminous united states. (). doi:10.13140/RG.2.2.21621.68325 Retrieved from https://search.datacite.org/works/10.13140/RG.2.2.21621.68325

Metcalf, E. C., Mohr, J. J., Yung, L., Metcalf, P., & Craig, D. (2015). The role of trust in restoration success: Public engagement and temporal and spatial scale in a complex social-ecological system. *Restoration Ecology, 23*(3), 315-324. doi:10.1111/rec.12188

Munroe, T., Harris, N. & Heartsill-Scalley, T. (2018). While Puerto Rico's people still suffer the effects of hurricane maria, its forests are faring much better. Retrieved from https://www.wri.org/blog/2018/07/while-puerto-ricos-people-still-suffer-effects-hurricane-maria-its-forests-are-faring-much-better

Mwanundu, S. (2013). *Good practices in participatory mapping* (1st ed. ed.). US: Wiley-Iste. Retrieved from https://www.ifad.org/documents/38714170/39144386/PM_web.pdf/7c1eda69-8205-4c31-8912-3c25d6f90055

Nieves-Rivera, L. (2019). *USFS - El Yunque National Forest - Watershed Program 2019 Briefing Paper*

NOAA. (2018). What is a watershed? Retrieved from https://oceanservice.noaa.gov/facts/watershed.html

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land use Policy, 33*, 118-129. doi:10.1016/j.landusepol.2012.12.013

Putz, F. E. and R. R. Sharitz. (1991). Hurricane damage to old-growth forest in congaree swamp national monument. *U.S.A. Canadian Journal of Forest Research, 21*, 1765-1770.

Rahman, M., Shi, Z., & Chongfa, C. (2014). Assessing regional environmental quality by integrated use of remote sensing, GIS, and spatial multi-criteria evaluation for prioritization of environmental restoration. Environmental Monitoring and Assessment, 186(11), 6993-7009. doi:10.1007/s10661-014-3905-4

Ranalli, A. J., & Macalady, D. L. (2010). The importance of the riparian zone and in-stream processes in nitrate attenuation in undisturbed and agricultural watersheds – A review of the scientific literature. *Journal of Hydrology, 389*(3), 406-415. doi:10.1016/j.jhydrol.2010.05.045

Rood, S. B., Gourley, C. R., Ammon, E. M., Heki, L. G., Klotz, J. R., Morrison, M. L., . . . Wagner, P. L. (2003). Flows for floodplain forests: A successful riparian restoration. *BioScience, 53*(7), 647-656. doi:FFFFAS]2.0.CO;

Ruiz-Jaén, M. C., & Aide, T. M. (2005). Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. *Forest Ecology and Management, 218*(1), 159-173. doi:10.1016/j.foreco.2005.07.008

Schultz, R. C., Isenhart, T. M. (1995). Riparian management to protect water quality. *Forest Sciences Commons,Hydrology Commons, and the Natural ResourcesManagement and Policy Commons*

Somerville, D. E. (2010). *Stream assessment and mitigation protocols: A review of commonalities and differences.* (). Retrieved from https://www.epa.gov/sites/production/files/2015-07/documents/stream_protocols_2010.pdf

Souza, A. L. T. d., Fonseca, D. G., Libório, R. A., & Tanaka, M. O. (2013). Influence of riparian vegetation and forest structure on the water quality of rural low-order streams in SE brazil. *Forest Ecology and Management, 298*, 12-18. doi:10.1016/j.foreco.2013.02.022

Swart, J. A. A., Zevenberg, J., Ho, P., Cortina, J., Reed, M., Derak, M., . . . van der Windt, Henry J. (2018). Involving society in restoration and conservation. *Special Issue: Involving Society in Restoration and Conservation, 26*(S1), S6. Retrieved from https://onlinelibrary.wiley.com/doi/full/10.1111/rec.12709

Tanner, E. V. J., Kapos, V., & Healey, J. R. (1991). Hurricane effects on forest ecosystems in the caribbean. *Biotropica, 23*(4), 513-521. doi:10.2307/2388274

The Federal Interagency Stream Restoration Working Group. (1998). *Stream corridor restoration principles, processes, and practices.*(). Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf

Tidwell, T. (2010). An all-lands approach to conservation. Retrieved from https://www.fs.fed.us/speeches/all-lands-approach-conservation

Tropical forests in our daily lives. (2017). Retrieved from https://www.rainforest-alliance.org/articles/tropical-forests-in-our-daily-lives

USDA. (2004). *Conservation corridor planning at the landscape level—Managing for wildlife habitat* Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/nrcs143_009912.pdf

U.S. EPA. (1996). *Ecological restoration: A tool to manage stream quality. environmental protection agency.* ().

United States Department of Agriculture. Riparian restoration. Retrieved from http://www.remarkableriparian.org/pdfs/pubs/TR_1737-22.pdf

United States Forest Service. (a). About the forest. Retrieved from https://www.fs.usda.gov/main/elyunque/about-forest

United States Forest Service,. (b). El Yunque National Forest history & culture. Retrieved from https://www.fs.usda.gov/main/elyunque/learning/history-culture

United States Forest Service. (c). From the desk of the forest supervisor: Progress update on el yunque and summer plans. Retrieved from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd579215.pdf

United States Forest Service. (d). Water Facts; Retrieved from https://www.fs.fed.us/managing-land/national-forests-grasslands/water-facts

United States Forest Service. (2005). Caring for the land and serving the people. *Forestry & British Timber,* , 14. Retrieved from https://search.proquest.com/docview/223780379

United States Forest Service. (2012a). *Groundwater dependent ecosystems: Level II inventory field guide* ().United States Forest Service.

United States Forest Service. (2012b). *National best management practices for water quality management on national forest system lands.* ().United States Forest Service.

United States Forest Service. (2018a). *Impact statement.* ().United States Department of Agriculture. Retrieved from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd592246.pdf

United States Forest Service. (2018b). *Revised land management plan.* ().United States Department of Agriculture. Retrieved from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd592253.pdf

Ward, T. A., Tate, K. W., Atwill, E. R., Lile, D. F., Lancaster, D. L., McDougald, N.,. . . Larson, S. (2003). A comparison of three visual assessments for riparian and stream health.

Journal of Soil and Water Conservation, 58(2), 83. Retrieved from http://www.jswconline.org/content/58/2/83.abstract

Zimmerman, J. K. H., & Covich, A. P. (2007). Damage and recovery of riparian sierra palms after hurricane georges: Influence of topography and biotic characteristics. *Biotropica, 39*(1), 43-49. doi:10.1111/j.1744-7429.2006.00237.x

Appendix A: Our Guide

Involving the Community in Riparian Restoration Efforts in Tropical Rainforests:

A Comprehensive Guide

Introduction

In previous iterations of riparian assessment protocols (specifically with those of the USFS), there has been a lack of emphasis on community involvement. This not only leads to distrust of the local and federal government in communities, but can also be detrimental to the longevity of restoration projects in said forests. By only including ecological or scientific factors in the selection of riparian corridors to restore, organizations can overlook features of the forest that inspire communities to maintain these areas beyond official restoration efforts. These communities have vital information in regards to the cultural and historical importance of areas they live in and around. This could manifest itself in knowledge of anything from what waterways are most commonly used, to religious or cultural importance of different areas.

This guide serves as a tool to supplement traditional prioritization protocols with community input, involving them in the decision of which areas to focus on. It identifies four steps in involving the community in the prioritization of riparian areas for restoration which can be seen below. The amount of community involvement varies for each level. By following this guide, an organization can better respect and utilize the communities around the areas of concern, while hopefully encouraging a connection between local communities and the forest near them.

It is important to note that this guide was developed in the context of El Yunque National Forest with assistance from the United States Forest Service. Many of the suggestions found in this guide were implemented in a riparian area prioritization project in El Yunque.

Watershed Selection	Drainage Basin Selection	Riparian Area Selection	Restoration
Community Involvement: Medium - Identifying communities - GIS - Interviews with community stakeholders - Select a watershed that has communities you can work with	**Community Involvement: High** - Establish broader context with community - Focus groups - Participatory Mapping	**Community Involvement: Low** - Assume an ecologist can make the protocol on their own - Communities will not need to have input on restoration site selection	**Community Involvement: High** - Carry out restoration project with community

Watershed Selection

In order to begin selecting a riparian area for restoration, it is important to begin by narrowing the scope of possible areas. Thus, it is important to first select a watershed to target for restoration. When selecting a watershed, geographic information system (GIS) data is an essential tool. By obtaining layers of information and overlaying them on a map of the whole forest, it's possible to identify the boundaries of different watersheds, where communities are situated in and around these watersheds, where specific riparian corridors lie, and what areas have experienced damage (such as canopy loss or landslide) among other valuable pieces of information that may be available. In conjunction with the GIS data, interviews with various community stakeholders can give insight into what the local community finds important from the forest. These stakeholders can include business owners, media figures, representatives from volunteer organizations, or any other leaders with a stake in the health of the forest. In addition to considering overall goals and information from GIS data and stakeholder meetings when selecting the watershed, one should consider which communities would be willing to work on a restoration effort. If there is already established connections with certain communities, or if some communities have reached out to offer help before, these communities may prove to be easier to work with when actually executing a restoration project. The way an organization interprets this data and the final selection of a watershed should be focused around the specific goals of a restoration effort whether that is increasing tourism, aiding local communities, repairing long-term damage, or any other overarching goal the organization has.

Drainage Basin Selection

Once a watershed has been selected, the project must be narrowed down to two or three specific drainage basins. This is the point where community involvement takes a more prominent role. At the beginning of any level of community involvement, it is important to establish the broader context for the community that is being worked with. Explain to members of the community what the bigger picture of your project is, where their specific restoration effort would fit in, and why the community members are needed for the project to work. This creates trust with the community and allows them to voice any concerns or questions that they have in regards to possible restoration efforts. An effective method for obtaining community feedback for drainage basins is through focus groups. These groups should consist of between 5-10 members of local communities and be held close to possible restoration sites. At these groups the use of participatory mapping allows group members to specifically mark points of importance for future reference. The questions asked at these focus groups should primarily be broken into five different categories: primers, ecological health, water use, recreation, and culture/other. Below, examples of these types of questions are given. The interviewees should be asked to rank these categories from 1-4 based on importance in order to gauge what the specific community finds important in regards to drainage basins. Once these questions have been asked and the answers have been recorded, analysis of the answers can begin. The interviewers should look for areas of the map where many areas of importance are located, giving extra weight to categories deemed more important by the community. Once these focus groups have been concluded, make sure to thank the focus group for their input and be sure to keep the community updated on what the results of the focus groups were. Once a drainage basin has been selected, revisit the people interviewed in the focus groups and gather feedback on the choice. Be sure to ask whether they feel like their opinions were heard and accurately represented by the final choice and if there are any changes they would make to future projects.

Primer	Ecological Health	Water Use	Recreation	Culture/Other
- Would you like to receive more updates on the status of the forest? - Do you feel you have ample representation in restorative efforts in general?	- Have you noticed any patterns in the forest that are relevant to ecological health - Which areas do you think have suffered the most damage? - What type of damage have these areas sustained?	- Can you identify which areas your community gets clean water from? - Are all water intake points marked or do you know other places people retrieve water from? - Has your community had any issues getting clean water from these locations in the past?	- In what ways do your community interact with the trails in these areas? - Do families from your community come to these areas for recreational purposes?	- How does the forest impact the way of life in your community? - Are any of the sites of particular personal importance?

Riparian Area Selection

This guide will not go into any detail about how to select factors to evaluate a particular riparian area. It is assumed that the agency utilizing this guide will have the ability to create their own assessment protocols. It is also assumed that the agency will have the access to proper experts and supplies needed to properly evaluate selected riparian areas in a chosen drainage basin. At this point in the process, a more scientific approach is required in order to determine how to solve the problems identified by the communities within the drainage basin. The selection of a riparian area should be focused on solving the issues identified by the interviews conducting during the drainage basin selection.

Restoration and Future Recommendations

Once the particular area(s) have been selected for a restoration project, it is important that all parties are informed of what area(s) have been selected and why. This step ensures transparency in this process and allows groups to know exactly where restoration priorities lay. To carry out the restoration, it is recommended that volunteers be pulled from the community in order to perform some of the manual labor. This restoration activity with the community should be relatively short and be tailored such that it falls within the physical capabilities of the community group that is being engaged with.

With the rest of the guide in mind, there are some suggestions for future projects that were unable to be implemented in the El Yunque study. First, if possible, the selection of a watershed and riparian area should expand beyond the organization's boundaries. Often, people are not allowed in government forests to gather resources, so areas outside the forest boundaries may be more important for restoration for some groups. Additionally, since watersheds often fall partially outside an organization's jurisdiction, ecologically important areas may be missed if the whole watershed is not taken into account. For this to work, it is important to gather information on important variables in these areas. Many organizations will have access to GIS files of their own land, but finding or recording data from outside their boundaries will take extra time. Finally, before the restoration begins, reach out to communities all over the watershed. This can give an initial idea of what communities would be receptive to working on a restoration effort and where their priorities lay in regards to the forest. This can help with the stakeholders meeting in determining who to invite and what questions they should be asked.

Appendix B: Interview Questions/Participatory Map Prompts

Four factor categories: Ecological Health, Water Use, Recreation, Cultural

Interviews will weigh these factors on their importance to their community. We will assess each basin based on the answers given and locations indicated on the participatory maps. The weights given by interviewees will be considered in this assessment. The first section of questions will serve as primers to start the interview and gain contextual information about USFS interactions with community members.

- Primers
    - Would you like to receive more updates on the status of the forest?
    - Do you feel you have ample representation in restorative efforts in general?
    - Are there any changes you would make to restoration efforts or how areas are prioritized at present?

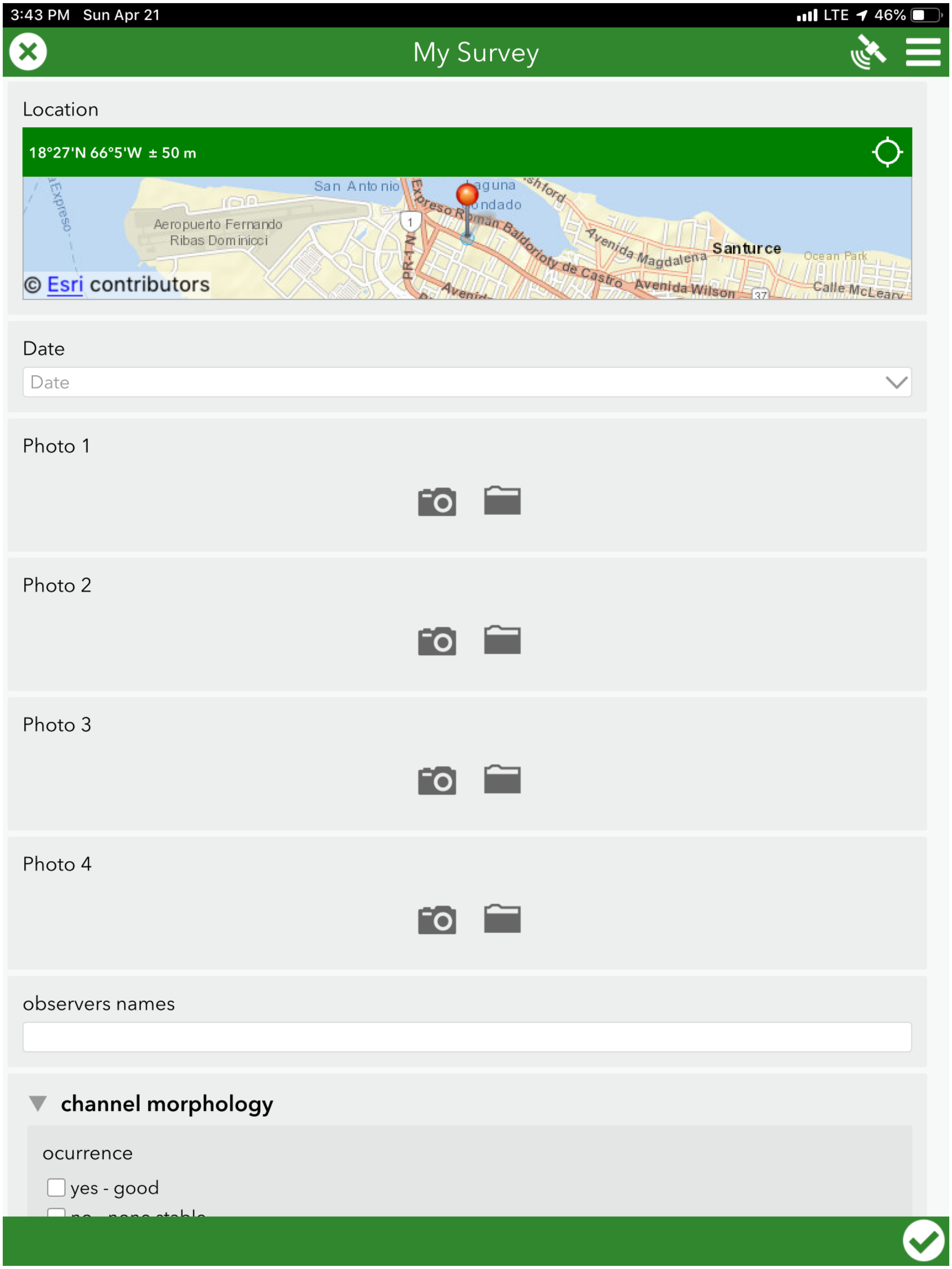
- Ecological Health
    - How has damage to the forest after the hurricanes impacted your community?
    - Have you noticed any patterns or have you experienced any conditions in the forest that are relevant to ecological or watershed health (i.e landslides, flash flood areas, collapsing banks, etc.)?
    - Which areas do you think have suffered the most damage?
        - What type of damage have these areas sustained?

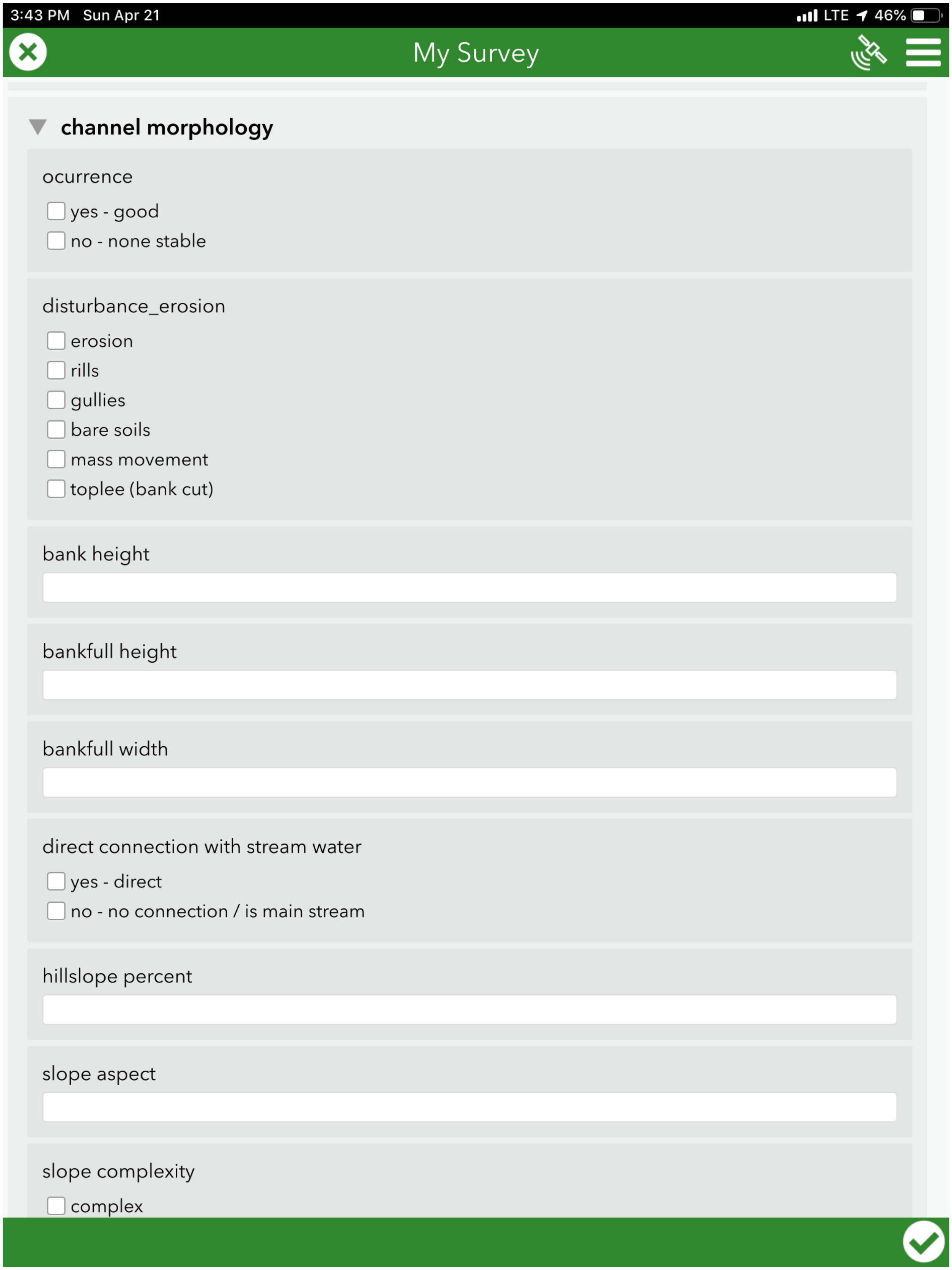
- Water Use
    - Can you identify which areas your community gets clean water from?
        - Are all water intake points marked or do you know other places people retrieve water from?
        - Has your community had any issues getting clean water from these locations in the past?
    - Which waterways does your community visit/interact with most often other than getting clean water?
        - Does anyone from your community use these rivers for fishing purposes?

- Recreation
    - In what ways do your community interact with the trails in these areas?
    - Do families from your community come to these areas for recreational purposes?
        - What kind of activities?
    - Are there any recreational sites that generate significant revenue for nearby communities?

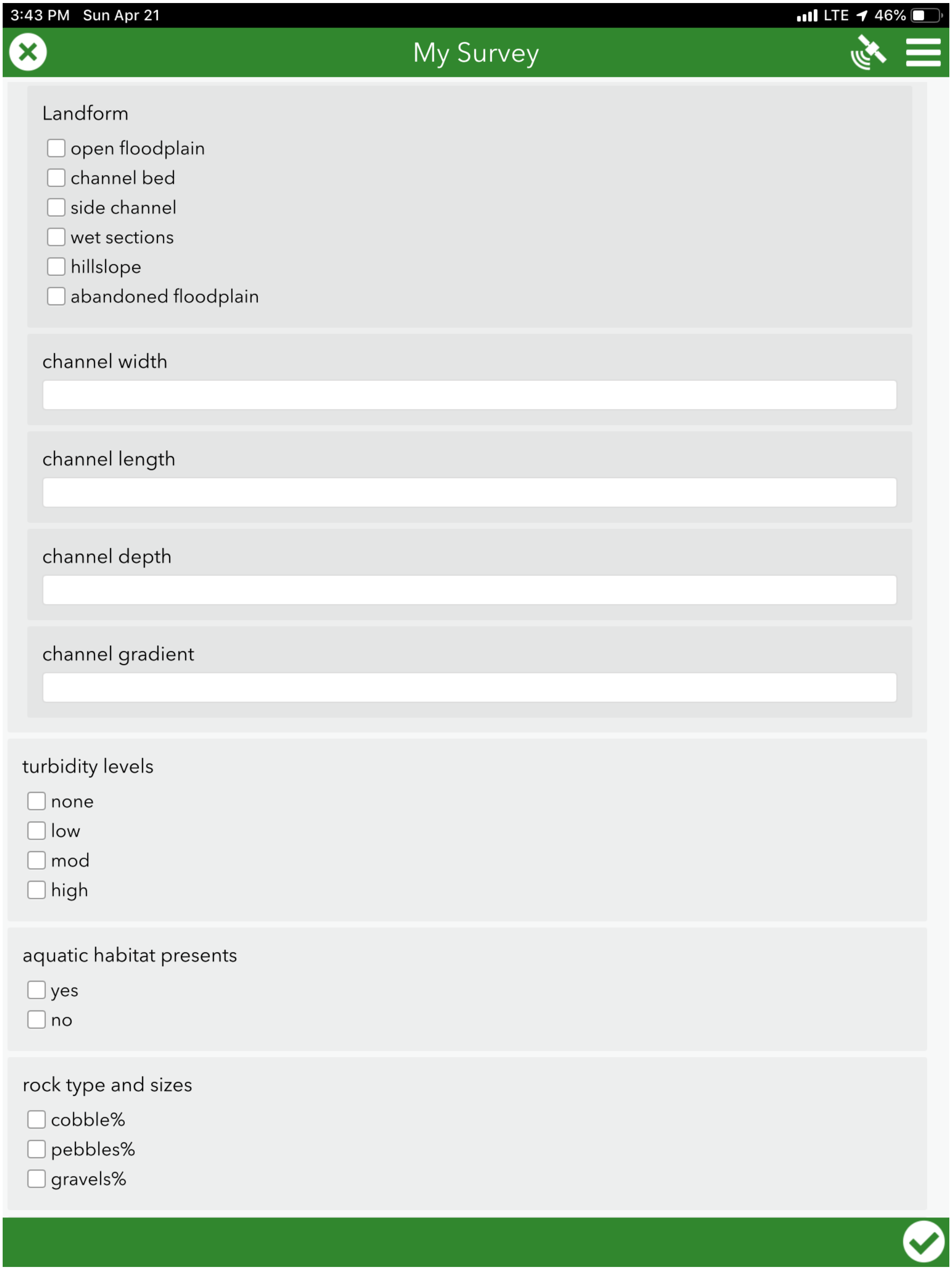
- Culture/Other
    - How does the forest impact the way of life in your community?
    - Are any of the sites of particular personal importance?
    - What has been the extent of your interactions with USFS and other previous restoration efforts?
    - Are there are any areas that you would not want us to restore?
        - Ex. any important cultural/religious sites
    - Where are important cultural/religious sites in the forest?

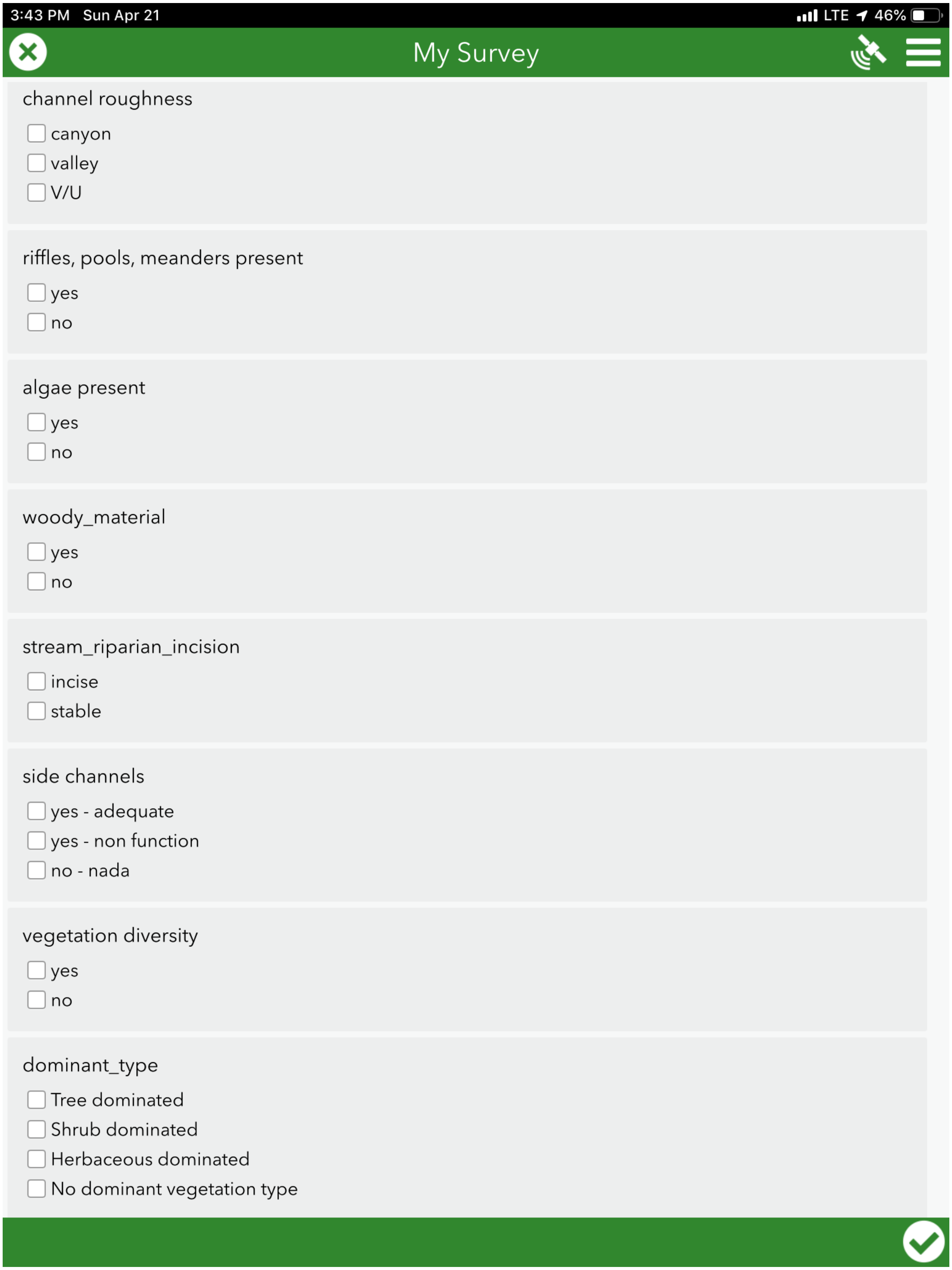
Appendix C: Riparian Assessment Protocol




3:43 PM Sun Apr 21
LTE 46%
My Survey
channel morphology
ocurrence
yes - good
no - none stable
disturbance_erosion
erosion
rills
gullies
bare soils
mass movement
toplee (bank cut)
bank height
bankfull height
bankfull width
direct connection with stream water
yes - direct
no - no connection / is main stream
hillslope percent
slope aspect
slope complexity
complex


3:43 PM Sun Apr 21
LTE 46%
My Survey
slope complexity
complex
linear
concave
convex
channel type
ephemeral
intermittent
perennial
floodplain inundation
yes-overflow
none
some areas
disturbance evidence floodplain
yes
no
Lithology - 0-12
sandy loam
clay loam
silty loam
loam
high gravel
low gravel
fine particles
rock percent /type
Landform
open floodplain
channel bed
side channel
wet sections


3:43 PM Sun Apr 21
LTE 46%
My Survey
Landform
open floodplain
channel bed
side channel
wet sections
hillslope
abandoned floodplain
channel width
channel length
channel depth
channel gradient
turbidity levels
none
low
mod
high
aquatic habitat presents
yes
no
rock type and sizes
cobble%
pebbles%
gravels%


3:43 PM Sun Apr 21
LTE 46%
My Survey
channel roughness
canyon
valley
V/U
riffles, pools, meanders present
yes
no
algae present
yes
no
woody_material
yes
no
stream_riparian_incision
incise
stable
side channels
yes - adequate
yes - non function
no - nada
vegetation diversity
yes
no
dominant_type
Tree dominated
Shrub dominated
Herbaceous dominated
No dominant vegetation type


3:43 PM Sun Apr 21 LTE 45%

My Survey

% shrubs

%_forbs

%_grasses

%_trees

% canopy cover

canopy cover levels dominant

- [ ] <3 ft
- [ ] 3-5 ft
- [ ] >5 ft

canopy_condition

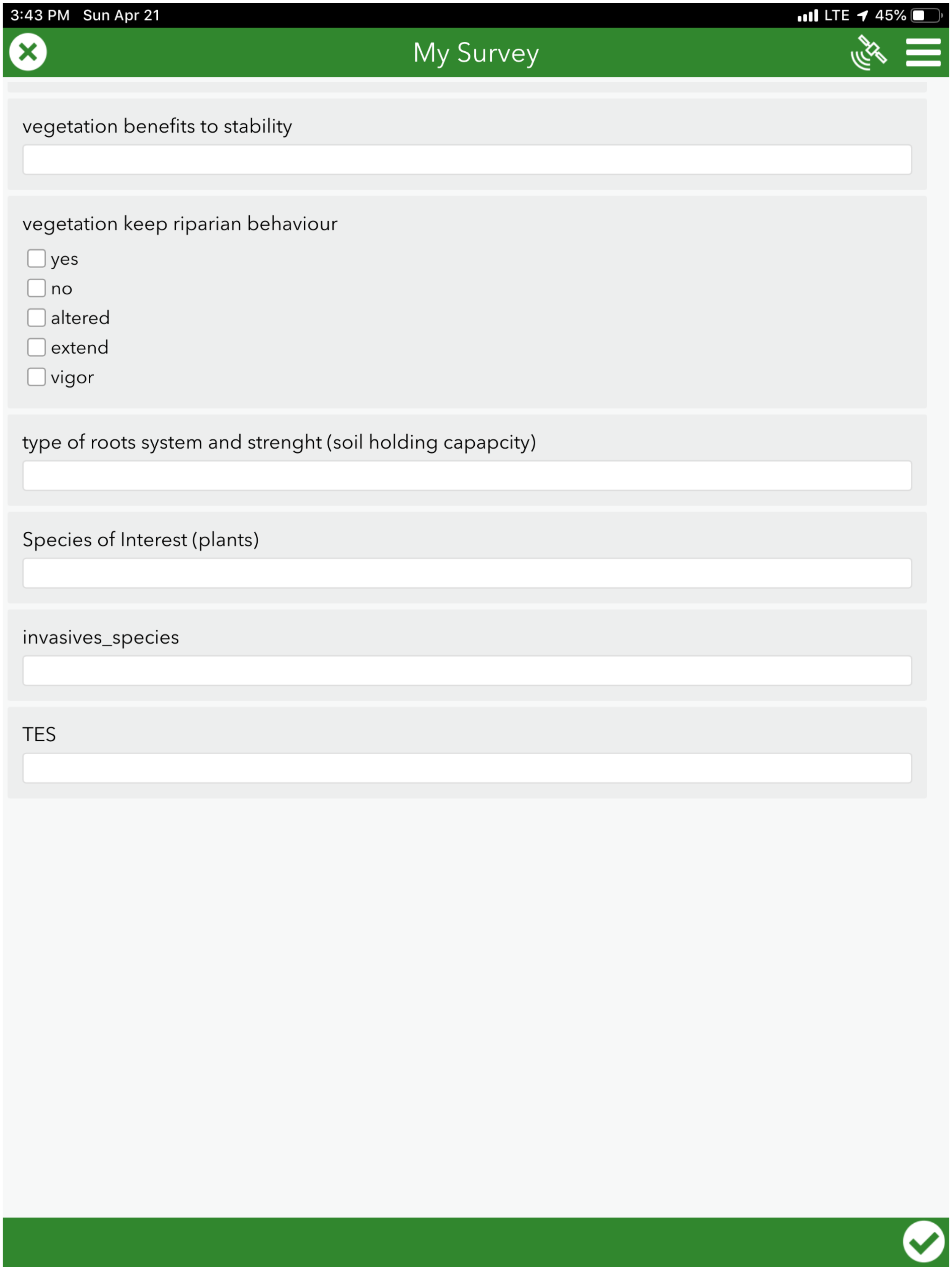
- [ ] stressed
- [ ] vigor

revegetation signs

deposition within vegetation

encroachment

vegetation benefits to stability



3:43 PM Sun Apr 21 LTE 45%

My Survey

vegetation benefits to stability

vegetation keep riparian behaviour

- [ ] yes
- [ ] no
- [ ] altered
- [ ] extend
- [ ] vigor

type of roots system and strenght (soil holding capapcity)

Species of Interest (plants)

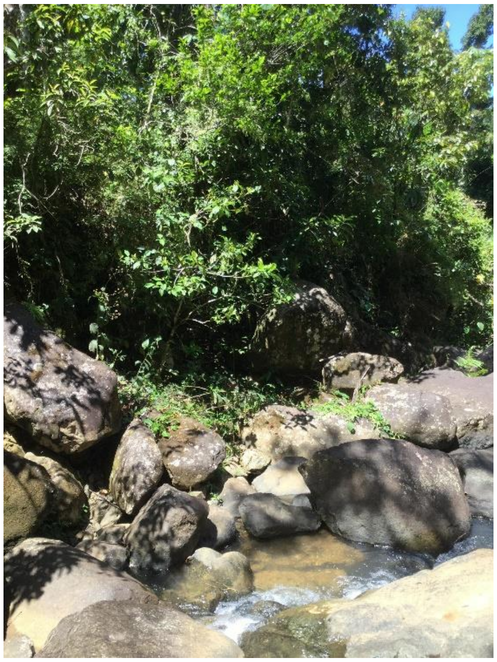
invasives_species

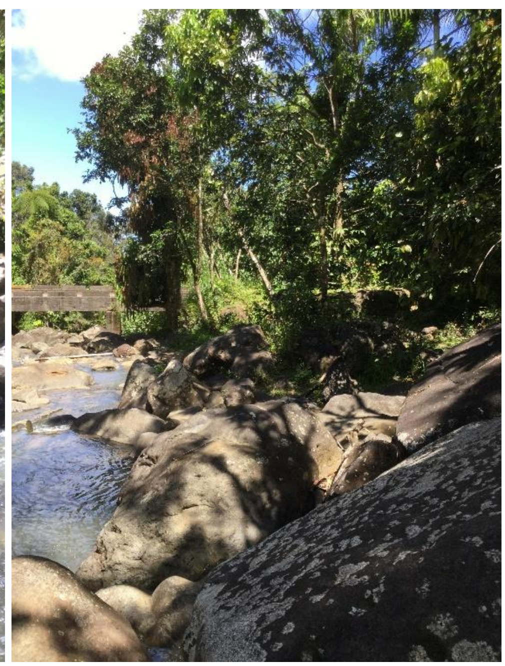
TES

Appendix D: Girl Scout Camp Assessment Images

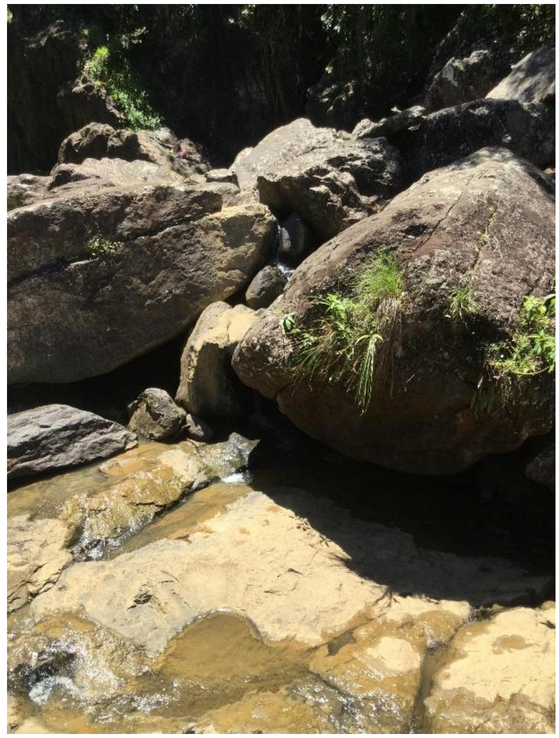
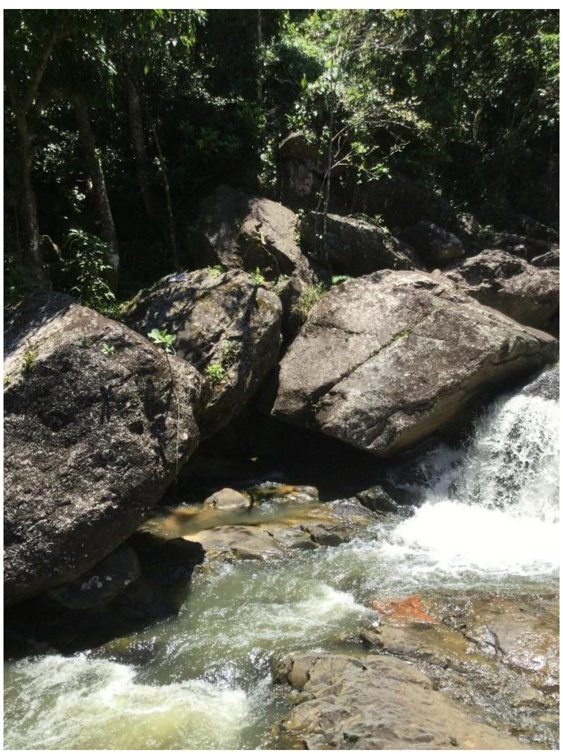
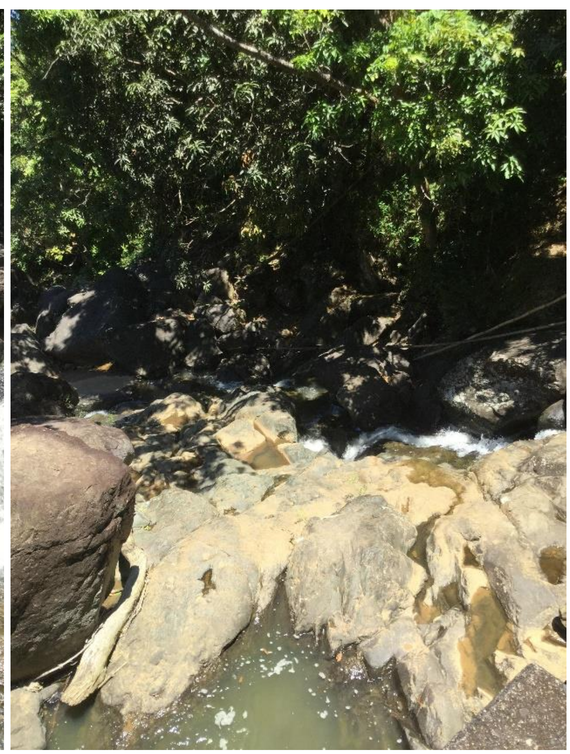



Appendix E: Quebrada Grande Assessment Images



Appendix F: Rio Espiritu Santo Assessment Images

Appendix G: Raw Area Assessment Data

Riparian Site	Rio Espiritu Santo	Quebrada Grande	Girl Scout Camp
Date	4/16/2019 4:00	4/16/2019 4:00	4/11/2019 4:00
ocurrence	yes - good	yes - good	yes - good
disturbance_erosion	erosion	erosion	erosion
bank height	7	19	64
bankfull height		30	4
bankfull width		17.5	39
direct connection with stream water	yes-direct	yes-direct	yes-direct
slope aspect	210	30	62
slope complexity	complex	complex	complex
channel type	perennial	perennial	perennial
floodplain inundation	yes-overflow	yes-overflow	yes-overflow
disturbance evidence floodplain	yes	yes	yes
Lithology	sandy loam	sandy loam	sandy loam
Landform	channel bed /open floodplain	channel bed /open floodplain	open to abandoned floodplain
channel width	56	17.5	61.9
channel length	no data	21	40
channel depth	8	6	1.6
turbidity levels	none	none	none
aquatic habitat presents	yes	yes	yes
rock type and sizes	boulders_cobbles - channel / cobble to gravel upland	boulders_cobbles - channel / cobble to gravel upland	boulders_cobbles - channel / cobble to gravel upland
channel roughness	bouldery canyon to V shape	bouldery canyon to V shape	bouldery canyon to valley (semi U shape)
riffles, pools, meanders present	yes	yes	yes
algae present	algae	algae	algae
woody_material	yes	yes	yes
side channels	no data	yes_adequate	no data
vegetation diversity	yes	yes	yes
dominant_type	tree_dominated	tree_dominated	tree_dominated
% shrubs	10	10	50
%_grasses		70	40

%_trees	90	20	10
% canopy cover	40	20	35
canopy cover levels dominant	<3ft	<3ft	<3ft
canopy_condition	stressed	stressed	stressed
revegetation signs	Yes	Not much regeneration, mostly shrubs in understory	New vegetation growth is sporadic
deposition within vegetation	Yes	No	Some
encroachment	Some	No	Yes
vegetation benefits to stability	Not much since it is mostly rock	Yes, they are stabilizing but more vegetation is needed to hold more of the erosion	Yes, helping with stability, but more vegetation is needed
vegetation keep riparian behaviour	no data	yes	yes
type of roots system and strenght (soil holding capapcity)	Deep roots from trees	Trees holding soil but some of them don't go deep and are exposed	Superficial roots from the grasses and shrubs plus deep roots from trees
Species of Interest (plants)	Many	Bamboo, mango, pomarrosa, yagrumo	Mango, pomarrosa
invasives_species	No	No	Kudzu, pomarrosa
TES	No	No	No
x	-65.8249116	-65.83261003	-65.82900238
y	18.31972443	18.30426937	18.33953845

Appendix H: Post Restoration Briefing and Questionare

To whom it may concern,

Thank you for your participation in our interview process and community mapping exercise. The insight and information you provided was essential in our selection of a riparian area to begin restoration efforts on. Our team's ultimate selection was the river behind the Eliza Colberg Girls Scout Camp, and the restoration effort was successfully carried out April 18th. Our efforts included planting several trees, laying down erosion blankets, digging trenches and creating a riff-raff to help slow down and prevent the erosion of the rivers banks. We were also able to remove a considerable amount of kudzu, an invasive vine that was covering much of the other vegetation in the area.

To provide some context on this project, we are a group of four students from Worcester Polytechnic Institute in Massachusetts. We were tasked with creating a guide which would supplement current riparian assessment protocols with methods to gather, analyze, and integrate community feedback. The goal of this guide was to not only get a more complete perspective on the forest, but to help foster a line of communication between the USFS and the people they are aiming to serve.

To ensure further growth of the relationship between USFS and the nearby communities, we have several questions listed below that we would appreciate your answers to. The answers to these questions can help us know what we did well in our process, as well as what we can improve upon in future endeavors.

Again, thank you for your help,

WPI Team

Jason King, Steve Wood, Jared DeMaio, Matt Schmitt

Questions:

On a scale of 1-5 (with 5 being the most satisfied), how satisfied are you with the final selection of riparian area for restoration?

1 2 3 4 5

On a scale from 1-5 (with 5 being the most effective), how effective was the community mapping exercise in gathering information that you deem important?

1 2 3 4 5

Would you like for the USFS to continue conducting interviews such as this to ensure that community opinions are fully taken into account?

Yes/ No

If there are any other comments or concerns that you would like to voice, please leave them below.

A quien le interese,

Gracias por su participación en nuestro proceso de entrevista y ejercicio de mapeo comunitario. La información y la información que proporcionó fue esencial en nuestra selección de un área ribereña para comenzar los esfuerzos de restauración. La selección final de nuestro equipo fue el río detrás del Campamento de Niñas Exploradoras de Eliza Colberg, y el esfuerzo de restauración se llevó a cabo con éxito el 18 de abril. Nuestros esfuerzos incluyeron la plantación de varios árboles, la colocación de mantas de erosión, la excavación de trincheras y la creación de un riff-raff para ayudar a frenar y evitar la erosión de las orillas de los ríos. También pudimos eliminar una cantidad considerable de kudzu, una enredadera invasora que cubría gran parte de la vegetación de la zona.

Para proporcionar algo de contexto sobre este proyecto, somos un grupo de cuatro estudiantes del Instituto Politécnico de Worcester en Massachusetts. Se nos asignó la tarea de crear una guía que complementará los protocolos actuales de evaluación riparia con métodos para recopilar, analizar e integrar los comentarios de la comunidad. El objetivo de esta guía era no solo obtener una perspectiva más completa sobre el bosque, sino también ayudar a fomentar una línea de comunicación entre el USFS y las personas a las que quieren servir.

Para asegurar un mayor crecimiento de la relación entre el USFS y las comunidades cercanas, tenemos varias preguntas a continuación que agradeceríamos sus respuestas. Las respuestas a estas preguntas pueden ayudarnos a saber qué hicimos bien en nuestro proceso, así como qué podemos mejorar en futuros esfuerzos.

De nuevo, gracias por tu ayuda,

Equipo de WPI.

Jason King, Steve Wood, Jared DeMaio, Matt Schmitt

Preguntas:

En una escala de 1 a 5 (siendo 5 el más satisfecho), ¿qué tan satisfecho está con la selección final del área ribereña para restauración?

1 2 3 4 5

En una escala del 1 al 5 (siendo 5 el más efectivo), ¿qué tan efectivo fue el ejercicio de mapeo de la comunidad en la recopilación de información que usted considera importante?

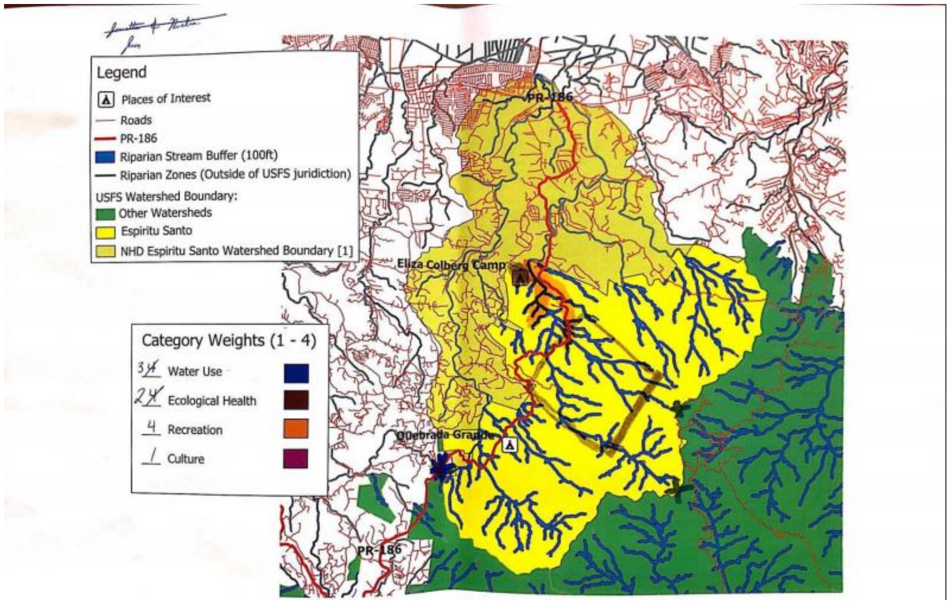
1 2 3 4 5

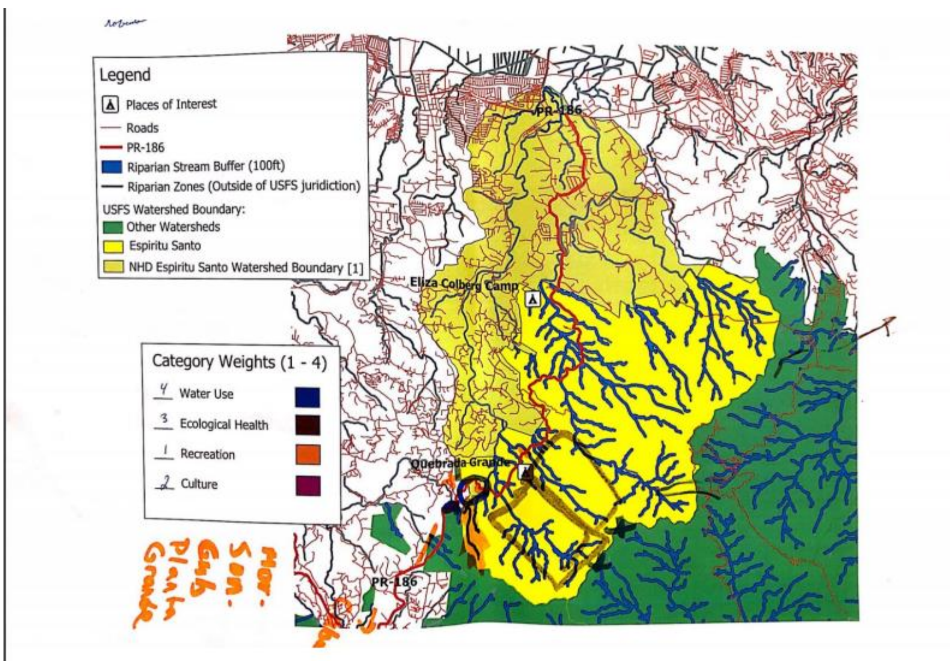
¿Le gustaría que el USFS continúe llevando a cabo entrevistas como esta para asegurar que las opiniones de la comunidad se tengan plenamente en cuenta?

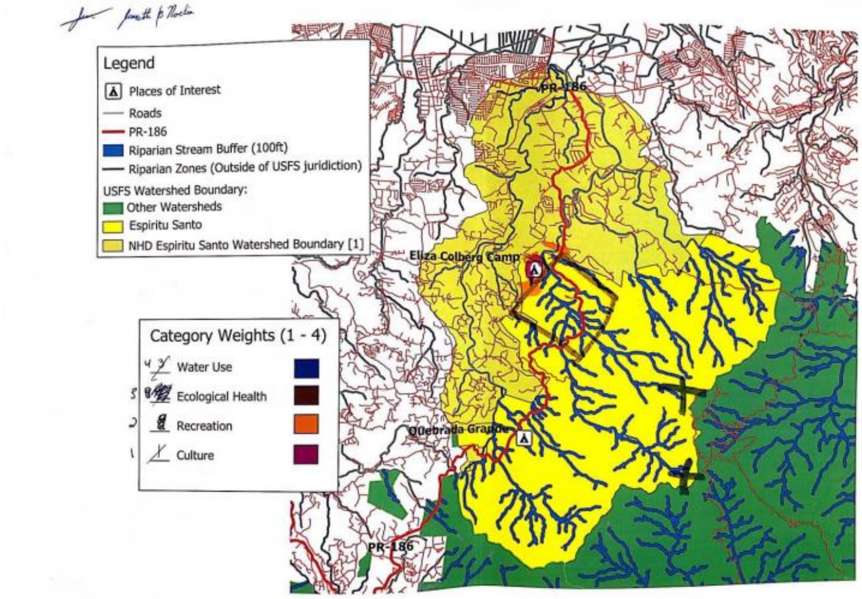
Si No

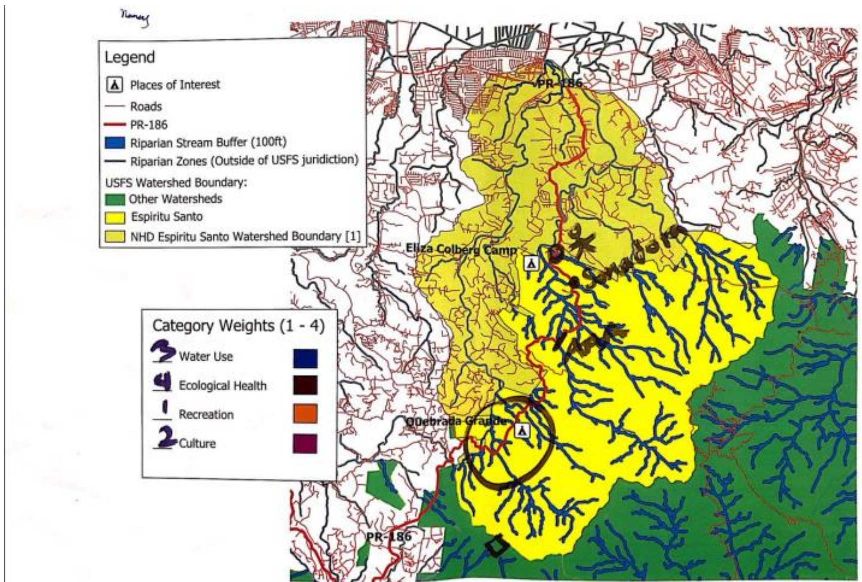
Si hay otros comentarios o inquietudes que le gustaría expresar, por favor déjelos a continuación.

Appendix I: Participatory Maps





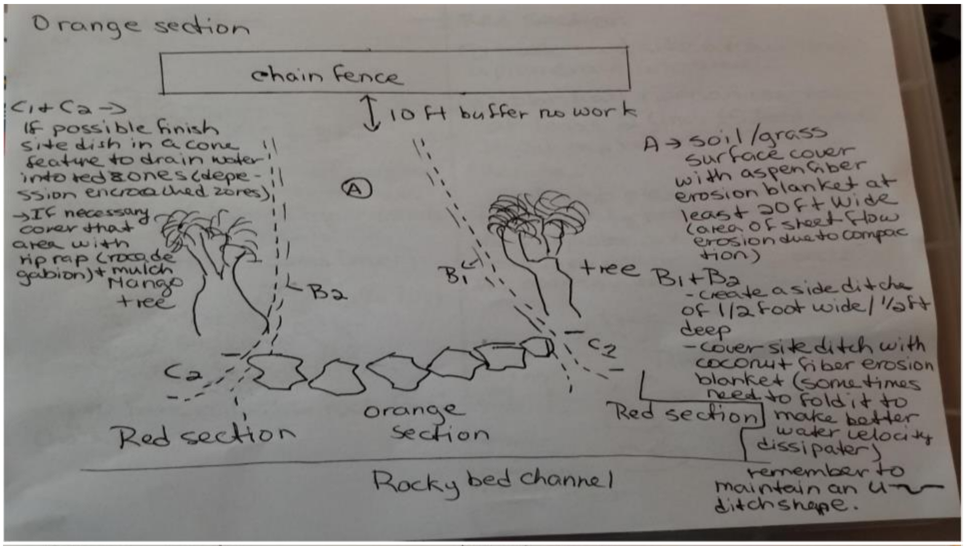

Legend
Places of Interest
Roads
PR-186
Riparian Stream Buffer (100ft)
Riparian Zones (Outside of USFS juridiction)
USFS Watershed Boundary:
Other Watersheds
Espiritu Santo
NHD Espiritu Santo Watershed Boundary [1]
Category Weights (1 - 4)
Water Use
Ecological Health
Recreation
Culture
Eliza Colberg Camp
Quebrada Grande
PR-186
PR-186

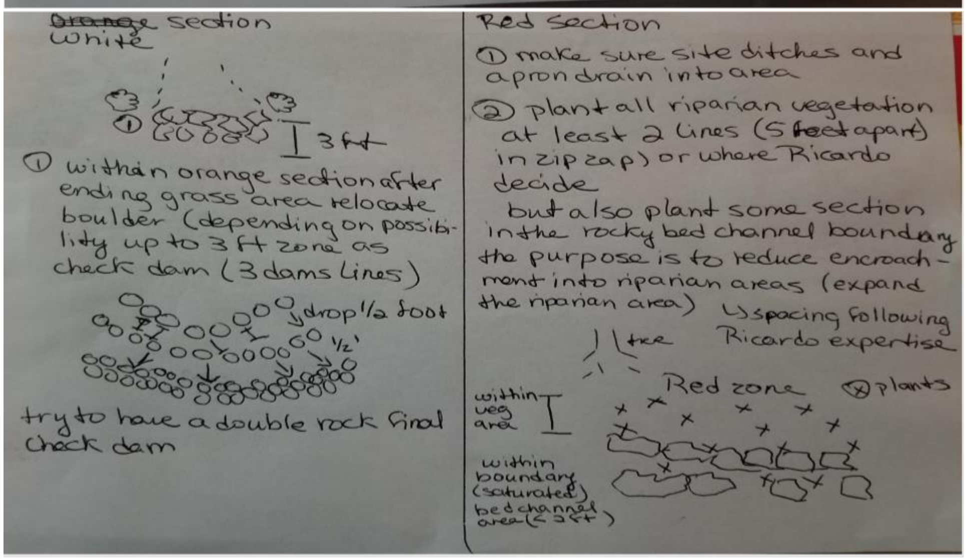

Legend
Places of Interest
Roads
PR-186
Riparian Stream Buffer (100ft)
Riparian Zones (Outside of USFS juridiction)
USFS Watershed Boundary:
Other Watersheds
Espiritu Santo
NHD Espiritu Santo Watershed Boundary [1]
Category Weights (1 - 4)
3 Water Use
4 Ecological Health
1 Recreation
2 Culture
Eliza Colberg Camp
Quebrada Grande
PR-186
PR-186

Appendix J: Restoration Plan

First Restoration Steps:

1. Pick up any woody debris material such as limbs branches all the way to the river channel and set aside in a pile.
2. Hand remove any invasive species in all the project area. Follow El Yunque National Forest Ecologist input for areas. Try removal if necessary at least 2 feet inside the rocky bed channel.
3. Follow the page design on page 3. Each color square represent a restoration activity.
   a) Orange – sheet flow (erosion) reduction task
   b) White - Small check dams and water flow
   c) Red sections – area of water deposition/saturation and riparian planting reforestation.


Orange section
chain fence
10 ft buffer no work
C1 + C2 →
If possible finish site dish in a cone feature to drain water into red zones (depression encroached zones)
→ If necessary cover that area with rip rap (roca de gabion) + mulch
Mango tree
A
B2
B1
tree
C2
C2
A → soil/grass surface cover with aspen fiber erosion blanket at least 20 ft wide (area of sheet flow erosion due to compaction)
B1 + B2
- create a side ditch of 1/2 foot wide / 1/2 ft deep
- cover site ditch with coconut fiber erosion blanket (sometimes need to fold it to make better water velocity dissipater)
remember to maintain an U ditch shape.
Red section
orange section
Red section
Rocky bed channel


White section
1
3 ft
1 within orange section after ending grass area relocate boulder (depending on possibility up to 3 ft zone as check dam (3 dams lines)
drop 1/2 foot
1/2'
try to have a double rock final check dam
Red Section
1 make sure site ditches and apron drain into area
2 plant all riparian vegetation at least 2 lines (5 apart) in zip zap) or where Ricardo decide
but also plant some section in the rocky bed channel boundary the purpose is to reduce encroachment into riparian areas (expand the riparian area)
spacing following Ricardo expertise
tree
Red zone
plants
within veg area
within boundary (saturated) bed channel area (< 3 ft)