Creating a Process for the Reforestation and Protection of Watersheds in Puerto Rico

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

Table of Contents

Abstract

This report, prepared for the Department of Natural and Environmental Resources in Puerto Rico, presents an analysis of the watershed reforestation practices that exist on the Island. The analysis is based heavily on interviews with experts in watershed management and on existing watershed reforestation plans. The report assesses the physical and social problems with existing plans, and presents recommendations for a unified watershed process between different environmental organizations and private landowners involved in watershed management efforts. This unified watershed process is demonstrated in a case study of two sub-basins in the Rio Grande de Loíza Watershed in eastern Puerto Rico. The recommendations proposed to the DNER will ensure the improvement of the water quality of the Island by decreasing sedimentation and pollution throughout the watersheds.

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List of Tables

List of Figures

1.0 Introduction

Puerto Rico is an island located on the eastern end of the Greater Antilles archipelago, which is located in the Caribbean Sea. It is part of a tropical climate that experiences easterly trade winds and hurricanes. Due to the topography of Puerto Rico, the climate varies considerably, from its mountain ranges, coastal plains, and interior karst. For example, the mean annual precipitation for the mountain regions is approximately 2500 mm, 1500 mm on the north and east coasts, 1800 mm on the west coast, and 800-1000 mm of rainfall on the south coast.

1.1 Water Resource Problems

With a population of an estimated four million people and a density of 440 people per km^2, water is an important natural resource for Puerto Rico (Department of Natural and Environmental Resources, 1998). Water resources are especially important to manage on the Island because of sustained droughts during the dry season. In an average year, 7.5 times the amount of water needed to support the population flows through the rivers of Puerto Rico, but only one-third of the demand for water can be held in the reservoirs (Hunt, 1976). This creates a problem because there is not a sufficient water storage area to provide water to the general population during prolonged seasons or under drought conditions. Storage problems are also exacerbated as sedimentation reduces the storage capacity of the reservoirs on the Island.

Sedimentation occurs when soils erode directly into a water source. The soil flows with the current and then accumulates in the bottom of the reservoirs. Sediment

also carries many forms of pollution, which decrease the quality of the water. For example, water pollutants carried by sediment are often caused by different types of land use causing it to be a major issue to consider when examining water quality. The two major types of land use in Puerto Rico are agriculture and urban development. Agricultural pollution takes the form of nutrients, pesticides, and fecal coliform. Construction to increase urban development leads to the disposal of wastes that accumulate and lower water quality. The pollution that is caused by these different types of land uses needs to be controlled and managed to effectively improve the health and water quality of the Island.

1.2 Effective Management of Water Resources

Since sedimentation and pollution are major problems affecting water quality on the Island, there are many agencies working to try to manage the watersheds of Puerto Rico. Unfortunately, there appears to be limited cooperation between the agencies as groups at the federal, commonwealth, and municipal levels work towards similar goals. Federal agencies included in watershed management consist of the following:

- Environmental Protection Agency (EPA)
- United States Department of Agriculture (USDA)
    - International Institute of Tropical Forestry (IITF)
    - Forestry Division
    - Natural Resource Conservation Service (NRCS)
- National Estuary Program (NEP)
    - San Juan Bay Estuary Program (SJBEP)

- United States Geological Survey (USGS)

Commonwealth agencies include the Department of Natural and Environmental Resources (DNER), the Puerto Rico Coastal Non-Point Source Committee (PRCNPSC), and Environmental Quality Board (EQB). Every autonomous municipality also has their own planning board, which leads to individual watershed management plans.

Reforestation, the most common watershed management technique, is used to improve water quality. By renewing forest cover and replacing vegetation the process of reforestation reduces sedimentation and non-point source pollution by limiting erosion. Therefore, reforestation is an effective way to manage and improve water resources on Puerto Rico.

1.3 Project Statement

The purpose of our project was to develop a process to identify and reforest critical areas of land within a watershed. This process will focus on selecting critical areas for reforestation in watersheds to help protect the water quality by reducing sedimentation and pollution. To create this process, we assessed federal, commonwealth, and municipality management and conservation plans and utilized the successful factors from each. The final recommendations will include a template for agencies to use to evaluate sites and plan for future reforestation efforts.

1.4 Case Study

For a case study, we will be examining two sub-watersheds in the Loíza Watershed. The Loíza Watershed is the largest in Puerto Rico, with an area of approximately 797 km^2. The watershed's largest municipality is the city of Caguas, the 5^{th} largest in Puerto Rico, with a population of 574,391 inhabitants. The Lago Loíza, a reservoir north of Caguas, provides San Juan with over half of its water supply. This watershed demonstrates the problems with water quality faced throughout the Island. Sedimentation has drastically reduced the storage capacity of the Lago Loíza, creating water shortages in San Juan and other municipalities that rely on the Loíza as their primary water supply. In addition, water quality is poor throughout the watershed due to sedimentation and non-point source pollution. The area is highly developed both in urban and agricultural areas, which makes effective management techniques difficult to apply.

1.5 Summary

This project relates science and technology with social and economic issues. Using scientific methods and evaluations, the project will help solve the problems that currently affect water management systems. The ultimate goal of this project is to help restore the ecological habitats of the Island, and provide the population of Puerto Rico with a healthier and more effective water system.

In the remainder of this report, we will present background information on the importance of reforestation and watershed management. We will then describe the methods that we used in collecting data and analyzing the physical and institutional factors that influence the effectiveness of existing management plans. Conclusion and

recommendations have been proposed to enhance and improve ongoing reforestation efforts on the Island. By creating a watershed management process we hope to provide a template for future reforestation projects.

2.0 Background/Literature Review

The purpose of our project was to develop a process for identifying and reforesting critical areas of land within a watershed. The plan focused on working at the watershed and sub-watershed level, combining existing programs at the municipality, commonwealth, and federal levels.

The focus of our research was the Loíza Watershed. The Loíza Watershed is the drainage basin that empties into the Rio Grande de Loíza, a river in the eastern side of the Island. This river flows through the city of Caguas, which is the 5th most populated municipality in Puerto Rico. Our study of the Loíza Watershed will focus on this municipality because the Turabo and Caguitas rivers, the two main tributaries of the Loíza, join the river in Caguas. This drainage basin collects water for the Lago Loíza (also called the Lago Carraizo) Reservoir, which provides water for San Juan.

Information on erosion, water sedimentation, pollution, land development, deforestation, and watershed management are critical to understanding watersheds. These topics, which are discussed below, will provide an awareness of the current environmental problems of Puerto Rico. Background information will also provide an understanding of the purpose and magnitude of our project.

2.1 Watersheds

A watershed is defined as a unit of land on which all the water that falls or originates from springs collects by gravity and fails to evaporate, runs via a common outlet (Black, 1991). A typical watershed can cover tens to hundreds of square miles. Figure 1 depicts a

common watershed layout. Sources of water, primarily rainfall and snow, run downhill and carry sediment and other materials into a river system or a group of river systems. Each individual watershed is composed of smaller units called sub-watersheds. Sub-watersheds are a fraction of the original watershed and they generate runoff from rainfall and other forms of precipitation (Holland & Schueler, 2000). Watersheds and their sub-watershed units often comprise many different ecosystems, such as forests, glaciers, deserts, and grasslands. Mountains, hills, and ridges that are located within the area create boundaries between two different watersheds. Numbers of watersheds can combine to form a larger watershed, which is referred to as a basin. The basin ends up draining to a major body of water, such as a large river, estuary or lake.

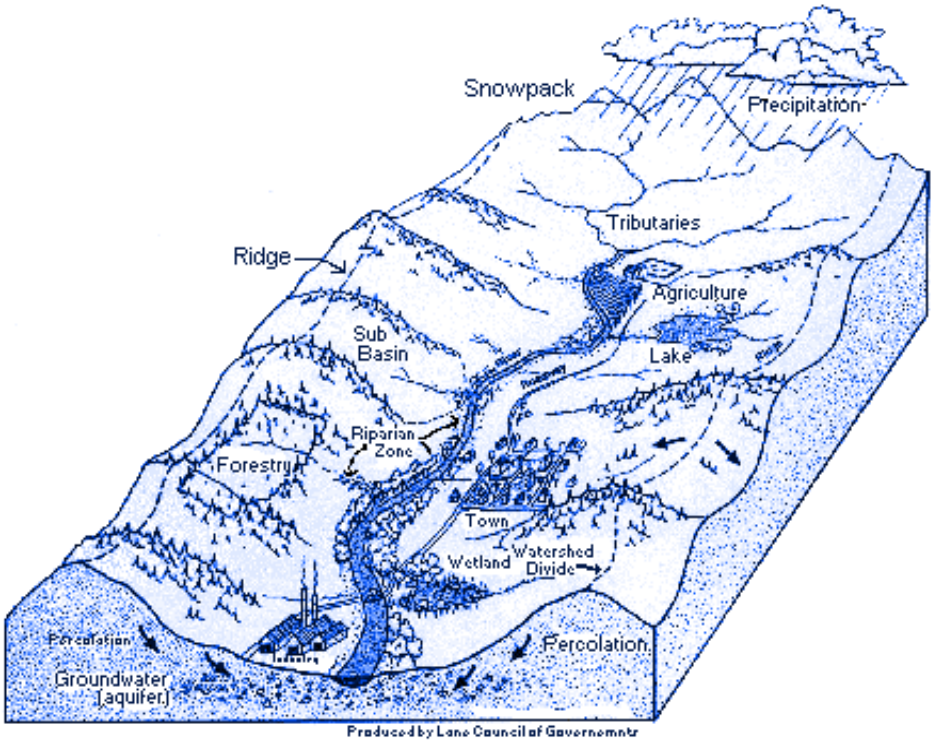

Figure 1: Example of watershed layout

Adapted from: http://www.epa.gov/win/what.html

Construction of a successful reforestation management process requires research of the area and development of successful methods to manage the water and other natural resources. Scientists have found that in order to effectively accomplish this goal it is important to understand and manage the area on a watershed basis (Hoban, 2000).

On the Island of Puerto Rico there exists the Eastern Puerto Rico Watershed. Within this watershed, there flows a smaller watershed named the Rio Grande de Loíza (See Figure 2 for a visual depiction of the area). It is a very developed watershed located in the Luquillo Mountains and drains into the Atlantic at the village of Loíza forty miles from its origin. The river's primary feature is Lago (Lake) Loíza. The lake is in the municipalities of Trujillo Alto, Caguas, and Gurabo. This reservoir is of importance because it provides a large portion of the water for the metropolitan area of San Juan.

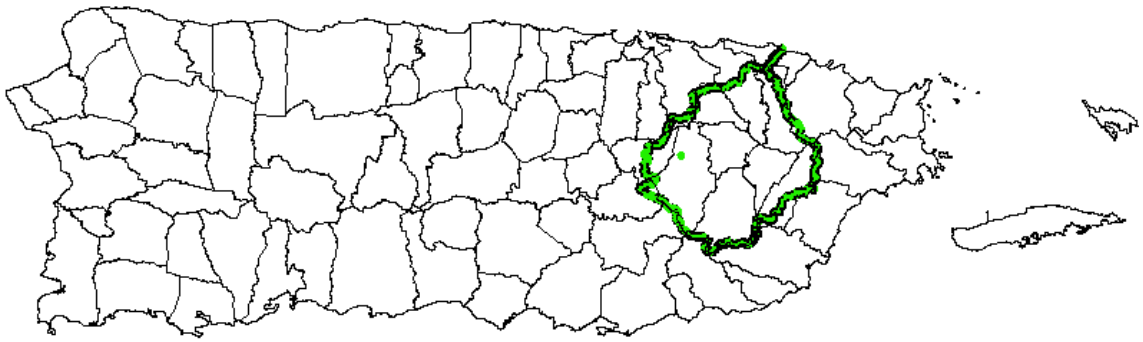

Figure 2: The Loíza Watershed

Created using GIS layers provided by the EPA and the DNER

The watershed is surrounded by dense residential and agricultural development, which has led to problems concerning sedimentation and water storage in the lake.

Problems with slope and high levels of erosion have forced this watershed to become a priority area for reforestation.

2.1.1 Watershed Importance

Watersheds play an important role in ecosystem health and human existence. They provide natural services and are one of the main sources of drinking water for urban areas (Holland & Schueler, 2000). The soils that are imbedded within the grounds of the watershed act as a giant filter to purify the water and dispose of wastes that are applied to the land or directly to the streams.

In addition, watersheds are essential because they serve as a wildlife habitat. The streams create a biological corridor that connects the up and down-stream wildlife. Biological corridors are crucial to the environment because they increase and maintain biodiversity by sustaining the diversity of species in each ecosystem, as we plan human activities that affect the use of the land and natural resources.

There are many factors that affect the health of a watershed. These factors are erosion, water sedimentation, pollution, land development and use, and deforestation. Understanding these problems is necessary in order to help prevent them and reverse the economic and environmental problems that they cause.

2.1.2 Erosion

Brooks et al. (1991) defines erosion as the "process of dislodgement and transport of soil particles from the surface by water and wind." In layman's terms, this is when rain or wind causes some of the topsoil to be washed or blown from its current location,

and transports it some distance. This is a worldwide issue in all types of areas, but becomes a significant problem in areas that have been deforested.

There are several factors that determine the severity of erosion. These factors include climate, soil character, topography and soil cover (Brooks *et al.*, 1991).

Climate

Climate can be divided into several elements. The first is rainfall runoff, which is when rain causes erosion directly. There are two forms of rainfall runoff. Splash erosion occurs where a raindrop hits the ground, and the soil is displaced by the splash of water hitting the ground. This breaks down the surface and dislodges soil, which causes slight erosion, and makes the next type of rainfall runoff cause greater damage, leading to flow erosion. Flow erosion is when the force of running water breaks up soil and carries it to a new location. These are the most common types of erosion, and can be seen at the extremes of tiny channels in a fresh pile of dirt to places as large as the Grand Canyon (Brooks *et al.*, 1991).

Temperature is another factor in erosion. Freezing and thawing cause the soil to expand and contract, which loosens the soil and makes it more susceptible to other elements. Another way in which temperature affects erosion is in the amount of vegetation that is able to grow in a specific climate. The effect of vegetation on erosion will be discussed in more detail below (Goldman, 1986).

Wind patterns vary due to the climate and are a direct effect on erosion. Wind blows loose sand that has been dislodged or is not firmly attached to the ground. It also increases the intensity of rainstorms.

Puerto Rico has a varying climate, differing from rain forests to mountains, to semi-arid plains. The Loíza River flows through many of these types of areas, leading to several different climate patterns throughout the course of its watershed. The area in which the project will focus is located in the semi-arid region. Since we are focusing on this region, it should be noted that many types of fauna would be able to thrive there. This leads to increasing runoff potential, but the actual rainfall would be lower, decreasing runoff.

Soil Character

Goldman et al. suggest that the properties of the soil constituents are important indicators of erosion (1986). There are many types of soil characteristics that can be examined, but the four important soil characteristics in determining erodibility are texture, organic matter content, structure and permeability. Size and proportions of the particles are different in each soil type.

The three main soil types are sand, silt and clay. Each of these has different textures. Sands have a course texture, which allows water to sink into the soil quickly and limits runoff. Clay and silt, on the other hand, have a finer texture that does not allow water to seep in and increases runoff. These two soil types are the most critical for assessing problems in watershed areas because they are difficult to remove from flowing water and will settle to the bottom of non-flowing water.

Another factor that must be examined in determining erodibility is organic matter, defined as decomposing plant and animal matter. Organic matters cause the soil to be

more permeable, fertile, and structurally sound. This combination of characteristics decreases erosion and runoff.

If the soil is densely compacted, water flows off of it instead of being absorbed, which increases runoff. Conversely, if the soil is very granulated, it will have a greater absorption rate, which decreases runoff. Permeability is the ability of the soil to allow water and air to move through it. The higher the permeability, the more water can be absorbed into the soil, which leads to less runoff. The combination of these four factors is used to determine the characteristic of the soil (Goldman *et al.*, 1986).

Topography

Slope is a critical factor in soil erosion. As the slope becomes steeper, the energy of running water increases. This increased energy leads to increased erosion. The length of the slope also affects erosion. If the slope of the hill is long, it allows the runoff to build momentum, increasing erosion. Finally, the orientation of the slope, combined with existing climate conditions such as the predominant wind direction, can increase or decrease erosion by either diminishing or increasing the effectiveness of the climatic forces (Brooks *et al.*, 1991).

Soil Cover

The final intervening variable in erosion is soil cover. Soil cover is any vegetation that covers the soil from being directly hit by rain or wind. Vegetation of any kind gives protection to the surface of the land through several factors. The first factor is canopy. Canopy lessens the force of rain hitting the ground. By lowering this force, it decreases splash erosion and limits the amount of soil broken up. Soil cover also

increases the water holding capability. This occurs by increasing the permeability of the soil and because the vegetation absorbs a portion of the water that is stored in the soil. Finally, vegetation holds soil in place with its roots. Trees, and other plants with large, thick roots, hold the soil together at a deep level, while smaller vegetation holds the topsoil in place (Brooks *et al.*, 1991).

2.1.3 Types of Erosion

Goldman identifies five different forms of erosion: splash erosion, sheet erosion, rill erosion, gully erosion, and channel erosion. Splash through gulley erosion is usually a process completed by rainfall. The process begins with splash erosion, which has little displacement, and ends with gulley erosion, where large quantities of soil have been displaced. Channel erosion is not a part of this process and occurs solely in watershed areas. All of these types of erosion relate to our project and are occurring not only throughout Puerto Rico, but also throughout the world. By understanding each type, it will be possible to understand the severity of the erosion in a particular area, as well as costs and strategies to repair the damage caused.

Splash Erosion

Splash erosion occurs when raindrops directly impact on the soil surface, which displaces the soil. A very heavy rainstorm can cause up to 100 tons of soil per acre to be displaced (Goldman *et al.,* 1986). The actual affect of splash erosion depends mainly on the size of the raindrops. Larger rain drops hit with more force, which leads to a greater impact and creates more erosion. Though the actual movement of the soil is minimal,

splash erosion is important because it makes it easier for other types of erosion to take place. The reason for this is that the aggregates of the soil are broken up, which reduces the soils overall structure, and makes it more susceptible to running water. The dirt that is moved by splash erosion can also harden, making the soil less permeable.

Sheet Erosion

Sheet erosion is caused by water, flowing in shallow sheets over soil (Goldman *et al.*, 1986). This sheet of water is too weak to dislodge soil because it is very shallow and slow moving, but when soil has already been dislodged by splash erosion, it picks up the soil that was displaced and carries it away. Due to the fact that the ground is rarely flat, these sheets of water flow into lower surface areas and lead to the formation of rills.

Rill Erosion

Rill erosion is the next type of erosion to occur. The sediment carrying flowing water from the sheet erosion enters into the slight depressions in the ground, and begins to run along it. These slight depressions are usually areas of breaks in vegetation or the bottoms of valleys (Brooks *et al.,* 1991). This allows the water to deepen and gain velocity, and it soon begins to displace more soil. These slight depressions become rills. "Rills are small but well-defined channels that are at most only a few inches deep (Goldman *et al.,* 1986)." As these rills become more defined, a storm can quickly increase the water flowing down them and turn them into gullies.

Gully Erosion

A gully is "a relatively deep, recently formed channel on valley sides and floors where no well-defined channel previously existed (Brooks *et al.,* 1998)." These gullies are caused when a heavy rain hits an area where there are many rills. These rills are deepened and widened into gullies that continue to grow until they are repaired. The one unique aspect of gully erosion is that it can erode both upstream and down. This is caused when water flowing into the gully causes turbulence that swirls the water and undercuts the wall of the gully. The wall can eventually collapse, expanding the gully (Goldman *et al.,* 1986).

Figure 3: Example of gully erosion along the banks of the Caguitas River

Channel Erosion

Channel erosion is not caused by any of the processes discussed to this point. Though gulley erosion can lead to channel erosion when a gully reaches the edge of a stream, this is not the usual cause. Specifically, channel erosion occurs when the watershed is altered through human interaction, such as vegetation removal, storm drains or bridges narrowing the flow of water. Alterations of the watershed change the natural flow of a stream. Over time, a natural stream adjusts to the normal amounts of water entering it through runoff, and the vegetation and rocks at the streams edge protect the streambed from excess runoff. However, when this vegetation is removed, or the water flow entering the stream at a certain area is increased (through a storm drain, or the formation of a gully flowing into the stream), the sides of the stream begin to erode. This causes the stream bed to widen at some points, or even to change course. When this occurs, the extra sediment that is washed into the stream is then carried to slower moving water where it settles, creating sedimentation issues that were mentioned earlier.

2.1.4 Problems Caused by Erosion

Now that we know what erosion is, what problems does it pose? It poses many problems both environmentally and economically. Environmentally, most of the problems are caused in watershed areas. Economically, erosion can have many negative affects on society. At our project site, problems we encountered were primarily environmental, which have led to an economic problem as well.

Environmental Problems

Erosion can seriously affect the environment in several ways. The first type of impact deals primarily with the issue of water pollution. Eroded soil contains many nutrients, and when it is washed into streams and rivers the nutrients can cause algae to grow. The oxygen in the water is then depleted, which can lead to killing marine life in the lake. From a more recreational point of view, it decreases water clarity and creates odors, two things nobody wants to happen to their old swimming hole or pond.

The next issue is that erosion can kill streamside vegetation. The destruction of this vegetation can lead to many problems in the aquatic and wildlife ecosystems of a body of water. The eroded soil can coat the bottom of streams and lakes, making them shallower and killing underwater vegetation. Another environmental damage is the removal of topsoil which leaves only the sandy, rocky subsoil. This soil is far less fertile, and makes it very difficult to promote the growth of vegetation in that area (Goldman *et al.*, 1986).

Economic Problems

Erosion affects the economic level of society, but it is difficult to measure the extent to which this occurs. The first economic issue is that lakes and reservoirs are slowly filled with sediment. One example is in the Cull Canyon Reservoir in Alameda County, California. In less then eleven years after construction, over 400,000 yards of sediment were removed at a cost of over 1 million dollars (Goldman *et al.*, 1986). Another example is the La Plata Reservoir, used for thirty-six percent of the water supply for San Juan, Puerto Rico. Since built in 1974, it has lost thirty percent of its water

holding capacity, which has led to increased water shortages in times of drought (Del Mar Lopez, 1998). Though an exact economic figure cannot be determined for this example, the human suffering from lack of water confirms how large the problem of erosion is during times of drought.

Another economic problem created is that land can be made less fertile to plant growth as a result of erosion. Less fertile land costs farmers money because they cannot grow crops productively, and can increase the price of food for the rest of society if it happens on a large enough scale. It can also result in non-point source pollution if a farmer is forced to resort to the use of fertilizers to restore the land.

Finally, landslides are caused by a weakened slope due to erosion. In 1974, more than 49 million dollars was spent in the United States repairing highways that were damaged by landslides (Gray, 1982). However, more importantly, human lives are sometimes lost. In a study by the Canadian Geological Survey, approximately 570 people have died since 1840, when they first started recording landslide deaths. In most cases, these landslides were created by a natural disaster (such as an earthquake, hurricane, or other large storm) that caused an eroded hill to collapse (Evans, 1997).

The problems created by erosion have always affected the environment to some extent, but these problems have increased due to human activities. A major cause of increased erosion is deforestation. Deforestation removes vegetation, which is one of the main ways to prevent erosion.

2.1.5 Deforestation

The rate at which humans have been depleting natural resources has risen significantly in the past 200 years. Resources are being used faster then the rate in which they are able to regenerate. Wood is one of the most abundant natural resources, but is the most exploited. Tropical forests have been depleted at a most alarming rate. Tropical forests cover only six percent of the earth's land area, but they are home to the majority of plant and animal species (Mastrantonio & Francis, 1997). There are a variety of causes of deforestation including cutting for fuel, wood, lumber, clearing for agriculture or cattle grazing, and other resources.

Deforestation can completely destroy wildlife habitats and in some cases entire ecosystems. Many species of plants and animals, especially in the tropical forests, are endangered and close to extinction due to forest destruction. Various natural cycles are disturbed and the effects are often negative for humans. For example, plants are essential to human survival because they remove carbon dioxide from the air and release oxygen that humans breathe. Roots help hold soil so water can be absorbed into the ground instead of washing it away. Thus, a serious consequence of deforestation is that the land becomes more susceptible to flooding and drought, and fluctuating water levels in rivers and lakes, which also affects the surrounding ecosystems (United Nations Development Program *et al.*, 2000).

Deforestation and Land Use in Puerto Rico

Puerto Rico was not heavily populated for over 200 years, so its natural resources, with the exception of precious metals, remained intact. During the early nineteenth century Spain lost control of other islands in the Caribbean, so many people immigrated to Puerto Rico. The Caribbean economy was predominately focused on agriculture at the time, so with the increase in population, the Puerto Rican economy surged toward agriculture. To make room for the crops, largely coffee and sugar plantations, many forested regions were cleared out (Harley, 2003). At the beginning of the century seventy-two percent of the Island was forested, but by the end of the century it had been reduced to twenty-five percent (Research Plan, 2002). Agriculture prospered into the twentieth century, but sugar cane became the primary crop because it was of greater value to the United States. A sugar based economy worked for a few decades, but it ended up failing when low wages and poverty spread, and fields became increasingly less fertile.

Between 1950 and 1970 the economy shifted toward industry and urban expansion, and many agricultural lands were abandoned. At the dawn of the 21st century, Puerto Rico was still industry based and thirty-four percent of the Island was forested. However, today eighty-two percent of the forested land is privately owned and only six percent are protected (Harley, 2003). Puerto Rico's fight against industrial and urban development in forested areas is not their only concern. The need to reforest much of the land is to help protect the Island from Mother Nature. Intense downpours and periods of drought cause problems in many parts of the island because the land cannot absorb and

hold the water. The island is also in the hurricane pattern, which has caused large amounts of forest destruction in the form of landslides. Much of the damage is still visible today, such as the landslide caused by Hurricane Hortense in 1996 in the Luquillo Experimental Forest (Troester, 2001). The deforestation of the 19th and early 20th century was quite severe, but the latter half of the 20th century saw a drastic increase in watershed management and reforestation efforts.

2.2 Watershed Management

In order to maximize the benefits that watersheds provide, the natural condition of the land must be protected. When watersheds are altered, especially if they are converted for urban uses such as roads and parking lots, the surface is transformed. This often causes the decomposition of the chemical, physical, and biological makeup of the streams. In Puerto Rico, the water quality and eventual degradation of the Rio Grande de Loíza Watershed is caused primarily by non-point source pollution. This is defined as pollution that has sources related to the use of the land by man and to natural processes occurring in the watershed. In many watersheds, non-point source pollution, such as runoff from cropland, urban storm water, and runoff from construction sites, has become a major water quality problem (Chesters, 1981). Non- point source pollution in this watershed has been caused by agricultural practices and urban development. This has led to extreme sedimentation rates and depletion of water quality. Implementation of watershed management tools is required to reverse the effects of such pollution.

2.2.1 Management Tools

The first step in the effort to protect and manage watersheds in order to conserve the resources that they provide is to become familiar with the watershed and its characteristics. Some features that should be examined are size, boundaries, and terrains. The different types of soil that are found within the watershed are also a factor because it can affect runoff and erosion. The manner in which the land is used is also important because different land uses, like farming, recreation, and forestry can significantly affect the conditions of the watershed and its natural resources.

Erosion and Sediment Control

Erosion and sediment control are tools that may also be used to protect watersheds. When the lands within or around watersheds are disturbed, due to construction and other human factors, trees and topsoil are removed, soils are exposed to erosion, and the natural topography and drainage patterns are altered (Holland & Schueler, 2000). To alleviate these problems, techniques should be implemented to reduce sediment loss and to ensure that conservation areas, buffers and forests are not cleared or disturbed as a result of construction. Control methods are directed at the establishment and maintenance of vegetative cover to reduce erosive impact of rainfall and to provide an organic soil cover permeable to moisture (Environmental Protection Agency, 1973).

Land Use Planning

Impervious cover of the land has a strong influence on the quality of the watershed, so it is important to analyze the degree and location of future development within the regions of the watershed. Land use planning techniques redirect development, preserve sensitive areas, and maintain or reduce the impervious cover. Some ways to achieve this are watershed based zoning, overlay zoning, and urban growth boundaries (Holland & Schueler, 2000).

Watershed zoning consists of identifying the existing conditions of the watershed, classifying the watershed by the amount of impervious cover that it will have in the future, and then changing the existing management plan to work with these new conditions. Overlay zoning, on the other hand, is a technique that involves applying regulations and specifying permitted uses that are otherwise regulated without changing the base zoning. When considering the technique of urban growth boundaries, it requires dividing lines between areas within the watershed, such as agricultural and rural areas in order for protection (Holland & Schueler, 2000). Creating dividing lines between the areas within the Rio Grande de Loíza Watershed in Puerto Rico could ultimately lower the amount of non-point source pollution depleting these ecosystems.

Land Conservation

Land conservation is another tool that centers on preserving or restoring the earth's natural resources. The critical habitat, aquatic corridors, hydrologic reserve areas that sustain a stream's hydrologic regime, water pollution hazards, and cultural and

recreational areas need to be conserved within the watershed to optimize its natural qualities (Holland & Schueler, 2000). To successfully conserve the resources within these areas in Puerto Rico, it is important to determine which of the above types of land must be safeguarded in order to sustain the vitality of its aquatic ecosystems.

Aquatic Buffers

In order to maintain biodiversity within watersheds, it is important to protect biological corridors. Aquatic buffers are placed along a stream or shoreline in order to physically protect these areas from future disturbance or infringement. Buffers hold many advantages because they effectively remove pollutants, sediments, and bacteria traveling in storm water and groundwater (Holland & Schueler, 2000). Some other benefits include the fact that they control floods, stabilize stream banks, and control stream temperature. This is important to the overall conditions of a watershed because buffers are a critical part in protecting the water quality.

Watershed management tools, such as the ones listed above, are important for a successful watershed process. There are many factors, such as sediment loss, erosion, land use, and wildlife habitats that need to be considered when trying to protect the natural environment within a watershed. The natural ecosystems of the Rio Grande de Loíza Watershed in Puerto Rico have been disturbed and need to have management techniques administered in order to successfully restore and maintain the health of its environment.

2.2.2 Reforestation

The most widely practiced watershed management tool is reforestation. Reforestation is the reestablishment of a forest by planting or seeding in an area from which forest vegetation was removed, and renewing forest cover by planting seeds or young trees (Merriam-Webster, 2003). It is a slow process, taking about 50 years for a secondary forest to completely blend in with undisturbed areas. There are many techniques that can be used to reforest an area of land, but the technique depends on the intended use of the land.

The two main focus points of reforestation are renew-ability and sustainability. In forests used for logging, harvest-regeneration and clear cutting methods are utilized. The older, slow growing trees are cut and small, fast growing ones are planted in their place. With a large enough area of forest, timber production can be sustained without actually depleting the amount of forested land (Mastrantonio & Francis, 1997).

However, different techniques are used when reforesting a tropical area. Plantation Forestry is when specific trees, like mahogany or eucalyptus are planted for use in the future. Agro forestry, which is when trees are planted among agricultural crops, is also popular in the tropics; however, this can only be successful in areas where there is an abundant water supply so that the trees and crops do not compete for it. Shade cropping is a technique particularly used in Puerto Rico to grow coffee. Trees with large canopies are used to provide shade for the crops and protect them from the weather. Windbreaks are trees and shrubs planted in a row to protect crops and farms from high winds. The wall of vegetation should contain 30-50% holes for wind to pass through. Without holes, the wind is deflected over the top of the breaker, creating severe eddies

over the crops, while with holes, the wind speed is reduced by half. Forest reserves, though, are the most beneficial reforestation areas for the environment. They focus on the restoration of watersheds, wildlife, and the natural habitat of the area (Mastrantonio & Francis, 1997). Forest reserves are ideal because they attempt to fully regenerate a forest, whereas the other techniques serve more of a dual purpose for the benefit of landowners. There are a variety of techniques that can be used to reforest an area, but the method used depends on the terrain of the area and its expected use (Pereira, 1989).

Reforestation in Puerto Rico

Although the people of Puerto Rico had mistreated their forests for many years, the effort and gains they have made in reforesting the Island during the last half century are far greater than that of any other area in the tropics. In the late 1940s, at the time when Puerto Rico was shifting from agriculture to industry, only seven percent of the land was forested. Urbanization around 1950 led to the abandonment of many sugar cane fields and other crops, and much of the land, although some was cleared for cattle grazing, was given back to nature.

The International Institute of Tropical Forestry (IITF) was founded in 1939, and the effort to restore the Island's forests was soon to begin. In 1963, the Luquillo Experimental Forest, an 11,000 hectare forest reserve was established. The Department of Natural and Environmental Resources (DNER) was created in 1972 to help protect Puerto Rico's environment. By 1985, the Island had reached thirty-five percent forest cover. After 30-50 years, many secondary forests were thriving and showed a high level of diversity (Zimmerman, 2001).

In the early 21st century, the IITF, DNER, and other environmental organizations began working on numerous projects to maintain and create the ecosystems and biodiversity of Puerto Rico. Through such projects, the reforestation of Puerto Rico and the conservation of the natural environment will achieve great success. However, there are a few barriers that must be overcome first. Perhaps the largest obstacle preventing success is the landowner. With 82 percent of the land privately owned, convincing landowners to allow reforestation on their lands is necessary. The solution to this problem is the development of incentive programs.

Incentive Programs

With most of the land in Puerto Rico privately owned, incentive programs are often needed to convince landowners to reforest their land and prevent them from developing it. Eighty-two percent of land in Puerto Rico is privately owned. The DNER currently offers five incentive programs to landowners, which depend upon the size of the land and the intended use. Anaisa Delgado, a technical assistant of the DNER, was very helpful in explaining them.

The first program is primarily for plots of land less than five acres. This program consists of three different methods: non-commercial timber planting, agro forestry, and enrichment planting. The timber planting provides the landowner with wood for personal uses, but not for commercial sale. Agro forestry methods, such as windbreaks, shade cropping, trees lining roads and trails, are most commonly used. Enrichment planting is when native species are planted to better ensure successful reforestation. For each program, the DNER provides technical assistance and the trees to be planted, but the

source of the funding differs. The DNER funds the first program, but does not fund the second.

The second program is the Forest Incentive Program. It uses the same timber planting method as in the first program, but has some key differences. While the planting method is the same, the plot of land must be ten acres or greater to qualify for the program, and the bulk of it is federally funded.

The third program is the Stewardship program, which consists of nine separate conservation practices. It is also federally funded by the Farm Service Agency. It is one of the most used programs because it is not very limiting and there is a good chance one or more of the conservation practices can be molded to suit the needs of the landowner.

The last two programs deal with already forested land. The fourth program is the Forest legacy program, in which the DNER attempts to buy the land from the landowner so that it can be permanent conservation land. The last program is the Auxiliary Forest Program. For this program, a tax exemption is provided to landowners with undeveloped land greater than five acres.

The only other incentive program offered on the island is through the United States Fish and Wildlife Service. They offer funds for preserving wetlands and have a mitigation banking program for them. The concept of mitigation banking is that a developer reforests and preserves one area of land, which gives him credits to develop on another area of land (Saeed & Atsushi, 2003).

The incentive plans currently available in Puerto Rico are fairly comprehensive. Research on the geography of Puerto Rico and its watersheds is required, however, to make sure these incentives will be able to fit any landowner's needs on the Island.

2.3 Watersheds of Puerto Rico

Puerto Rico has four major watersheds. They are the watersheds of the Rio Grande de Arecibo, the Rio Grande de Manatí, the Rio Grande de La Plata, and the Rio Grande de Loíza. These four watersheds provide nearly 100% of the water to the city of San Juan. This has led to them being the focus of most watershed restoration plans. In 2000, the EPA and the EQB finished a comprehensive study for the restoration of the Rio Grande de Arecibo watershed. This was because the reservoir in the watershed was near critical capacity. The plan will continue with the Rio La Plata reservoir, and is outlined in *Puerto Rico Watershed Restoration Action Strategies* (1999).

Climate in Puerto Rico is widely varied, even within watersheds. For example, in the watershed of the Rio Grande de Loíza, there are areas of precipitation of less then 2000 mm a year, and areas with more then 2500 (DNER, 1998). This varied climate affects any reforestation plan.

2.3.1 Climate

When developing a reforestation plan it is important to consider the climate. Climate and weather are two very different concepts. Weather information refers to the observations of atmospheric variables made at a particular time and place. However, climate is the synthesis of weather observations to obtain a statistical description of conditions over a large area (Wenger, 1984). Puerto Rico is located at 18^0N latitude and 66^0W longitude as part of the Greater Antilles Island chain in the Caribbean Sea. Puerto

Rico consists of a central mountain range, rain forests, deserts, and coastal plains. The topography and its location in the tropical zone are factors that contribute to its climate.

Precipitation

When considering drought and the water run-off from watersheds it is important to be familiar with the amount of rainfall in this climate. The precipitation varies remarkably from place to place. Moisture laden air from the ocean is carried by the trade winds inland and forced to ascend over the mountains where it is cooled, thus causing condensation and rainfall (Ruffner, 1985). The rainy season in Puerto Rico spans the months of May through November; however, sunshine is still abundant due to the fact that the rain showers are very brief. Also, tropical storms can develop from these easterly waves, which may cause torrential downpours resulting in floods. From November through April rainfall may be caused by a cold front from the United States. However, because of the topography of the Island some sections may receive heavy rains while other sections enjoy the sunshine.

Trade Winds

Another feature that contributes to the climate of Puerto Rico is the trade winds. The trade winds, modified somewhat by the land and sea breeze, pass inland to a formidable barrier of hills where they are lifted over the top or pushed aside through narrow passes and valleys until their basic characteristics have become quite confused (Ruffner, 1985). Due to the varied topography, wind speeds and direction are different all over the island. A northeast wind primarily affects the region near San Juan. The month of July brings the highest mean maximum wind speeds with an average peak

speed of 18 mph in San Juan. However, the location of the Island subjects it occasionally to extreme wind speeds created by tropical storms and hurricanes.

Evaporation

The high temperatures and wind drastically affect the level of evaporation. The San Juan annual average evaporation is 81.59. The problem lies with the fact that the annual evaporation exceeds the amount of precipitation. A problem that Puerto Rico faces due to this rapid amount of evaporation is drought. The months of December through April are typically the drought season. The scarce rainfall caused by this drought has a serious impact on agriculture as well as Puerto Rico's drinking water, which is why irrigation is critical for the Island's survival. Rainfall is Puerto Rico's greatest natural necessity because of the importance of drinking water and survival of plant life. The knowledge of what vegetation is successful in particular areas and how it is beneficial in managing erosion and sedimentation is important to be aware of when considering our project purpose.

2.3.2 Vegetation

There are a variety of trees and shrubs that contribute to Puerto Rico's vegetation and provide shade, ornamentation, and fruit. The differences in vegetation are based upon the topography, climate, and soils. Little and Wadsworth categorized eight types of vegetation on Puerto Rico in 1964: moist coastal forest; moist limestone forest; dry coastal forest; dry limestone forest; lower cordillera forest; upper cordillera forest; lower Luquillo forest; and upper Luquillo forest (U.S. Fish & Wildlife Service, 2003). There

are different common species of trees that have a better survival rate and will flourish for each region.

Trees

The knowledge of the different species associated with each of these regions is effective in determining what plants will have a high survival rate and strong roots to manage the problem of erosion. Each species provides different uses, strengths, and weaknesses. The knowledge of tree species will be helpful in determining what to plant in the areas chosen for reforestation. John K. Francis in conjunction with the United States Department of Agriculture (USDA) Forest Service and the International Institute of Tropical Forestry (IITF) has published a technical report entitled, *Especias Forestales para Plantar en Areas Forestales, Rurales y Urbanas de Puerto Rico*. This report provides all the documented tree species of Puerto Rico and their characteristics. The DNER and USDA Forest Service have also organized a guide for planting trees entitled, *A Tree Planting Guide for Puerto Rico and Other Caribbean Countries*. This report shows how to plant a tree, the spacing between trees, pruning, and how to take care of a tree.

Underbrush

Underbrush is an extremely important part of the vegetation of a forest. Small trees, shrubs, and ground cover are all beneficial in controlling soil erosion, holding down floods, and creating favorable soil conditions. The characteristics of the shrubs, smaller tress, and ground cover will be beneficial in the development of the reforestation plan's chief concern to manage and control erosion and sedimentation.

2.3.3 Loíza Watershed

We will focus our case study for critical areas of reforestation on the municipality of Caguas. The area of the Loíza Watershed includes six municipalities: Caguas, Juncos, San Lorenzo, Gurabo, Las Piedras, and Aguas Buenas. There are seven major tributaries located in the reservoir of the watershed: Rio Canas, Rio Gurabo, Rio Valenciano, Rio Bairoa, Rio Caguitas, Rio Turabo, and Rio Cayaguas. The watershed covers 132,480 acres of land and the Lago Loíza covers 743 acres (Hunt, 1976). The watershed is primarily mountainous except for the area of the Caguas Lowlands. Land use, slope, and soil textures vary in each basin.

Land Use

Initially the land of the Lago Loíza basin was used for agricultural purposes. When the first settlers came to this location the watershed was covered by a dense tropical forest. Recently, pasteurized land and urban development have increased. The data of the USGS study entitled, *Effects of Land Use on Upland Erosion, Sediment Transport, and Reservoir Sedimentation, Lago Loíza Basin, Puerto Rico*, show the land

use percentages for 1987 as rural 11.2%, pasture 48.5%, cropland 9.9%, forest 20.6%, urban 5.7%, disturbed ground 3.2%, and other land not categorized was 0.9%. There has been a 77% increase in population and 194% increase in housing units from 1950-1990, which has led to the elimination of forest and pasture.

Antonio Di Mambro, a city planner, has devised a plan for urban development to increase population density and restore the traditional appearance of Puerto Rican communities in the municipality of Caguas. This plan will include reforestation, protecting and preserving forested areas, creating a trolley system to increase public transportation, and creating a walkway along the rivers to increase recreational activities within the environment.

Another work in progress for the development of this area is the Caguitas River Project, *Honor the River*. There are 56 acres available at 156 State Road in Canabon Ward for developing an area of walks, gardens, picnic tables, bird observatory sites, etc. The municipality of Caguas is gaining notice in the Commonwealth for establishing a more environmentally friendly and organized community. It was important to be familiar with the current land uses and future plans when we recommended the most critical areas of reforestation in the Loíza Watershed.

Sedimentation

The Lago Loíza provides more than half of San Juan's drinking water. Water runoff from rain into the Loíza Basin is 7.5 times the demand by the city, but the effective storage space of the reservoir is only 1/3rd of the demand. This is not a problem during the rainy season, but is a serious issue during prolonged droughts.

Since 1953 this water-supply reservoir for San Juan has lost 47% of its water holding capacity. The water supply and quality is rapidly decreasing. This sedimentation problem is critical due to the fact that the Loíza Watershed is a major source of water for more than two million people in the San Juan area. The sedimentation also has monetary implications. In a US Department of Agriculture study done in 1976, the 6,135 acre-ft of sediment occupies an area of the reservoir that would be worth $4.8 million dollars in water storage space. Increased sedimentation and inflation have caused this number to skyrocket. Implementing reforestation where there is a high percentage slope will be essential in managing the amount of sediment flowing into the river.

2.3.4 Governmental Structure

There are many organizations involved in watershed conservation in Puerto Rico. They are spread over a hierarchy of governmental levels: federal, commonwealth and municipal. Each has its own role, but many of them overlap.

The federal agencies include the USGS, USDA, EQB, and EPA. The USGS and EQB are primarily involved in water monitoring. They each have stations located in watersheds throughout Puerto Rico where they collect information on water quality. The USGS provides technical assistance to anyone involved in water quality monitoring including the EQB. The EPA in Puerto Rico deals mostly with providing funding and technical assistance to the EQB and NRCS for their watershed monitoring practices. The NRCS along with the IITF are both subdivisions of the USDA. The IITF is more involved in research and testing things like soil and air samples. The NRCS plays a large

role in watershed management, as they develop conservation strategies and provide technical assistance for farmers.

At the commonwealth level, there is the DNER, PRASA, and the SJBEP. The SJBEP is running the restoration program for the San Juan Bay, but mostly divides the tasks among other organizations like the IITF and DNER and provides technical assistance because it is a non-profit organization. The DNER is heavily involved in restoration and conservation of natural land. From coastal management to forestry, they protect the environment. The DNER communicates with landowners and provides them with incentives in hopes to reforest and conserve more land. PRASA is involved with everything involving drinking water, and gives permits for construction near bodies of water in Puerto Rico.

At the municipal level, there are not individual organizations, but rather the planning boards of each individual municipality. What makes some municipalities different than others is their level of autonomy. Currently, most municipalities are non-autonomous. This means that they must get permits from PRASA and the Puerto Rico Planning Board in order to develop land. However, there are a few municipalities, with well organized planning boards, that are considered autonomous. This means that they don't need to have their development plans approved by PRASA or the PRPB. The path to autonomy is a five step process, in which more responsibilities are given to the municipality in each step. Some examples are the municipality of Caguas, which is on step three, and the most autonomous municipality, Ponce, which is on step four.

There are many environmental organizations in Puerto Rico at all levels of the government. There are even smaller ones that deal with specific aspects of the

environment, and there are also many private environmental consultants, who develop restoration and conservation plans. With so many groups working with the environment, it is another issue to see how they collaborate with one another. A governmental hierarchy flow chart showing the different organizations and their interaction with one another can be found in Appendix C. This issue has become one of interest, and is addressed in more detail in the data analysis section of this report.

3.0 Methodology

The methodology chapter explains the procedures used to complete our project. We identified what factors were most important in determining critical land areas in a watershed in need of reforestation, what watershed management plans had already been developed, and how agencies collaborate at different governmental levels. To find answers to these, and similar questions, we collected data through interviews, learned how to use Geographic Information Systems (GIS), and applied critical land use selection and verification. In order to ensure the validity of our methods, we consulted with Edgardo Gonzalez, a forestry expert for the DNER, in all of these decisions. Key areas of our methodology are described below.

3.1 Data Collection Methods

The first goal of our project was to gather information regarding existing plans for conservation, protection, and reforestation in Puerto Rico. We needed to collect data from agencies that are responsible for reforestation efforts on the Island. To obtain this information we collected data through resources at the DNER and through interviews with specialists from many of the Island's relevant organizations.

3.1.1 Archival Data

Edgardo Gonzalez, our liaison at the DNER, provided us with reports on reforestation to assist our project. Among them was the *Characterization and Management of Non-Point Pollution Sources and Wetland Areas in the Rio Grande de*

Arecibo Watershed, a report prepared by students at the University of Puerto Rico. Some of the recommendations of this report are similar to those that will be formulated from completing our project, and can be seen in Conclusions and Recommendations, § 6.0. Mr. Gonzalez also provided us with the *Guia Para la Reforestacion de Cuencas Hidrograficas en Puerto Rico*, a reforestation manual created by the DNER that contains techniques and procedures that should be followed to successfully reforest critical forest areas in Puerto Rico. It also highlighted factors, such as soil type, precipitation, and landslides on geographic maps that were used to create the techniques presented in the manual.

After obtaining information pertaining to existing reforestation plans, we collected archival data specific to the Loíza Watershed. Gathering data specifically on the Loíza Watershed allowed us to focus on our case study and provided us with knowledge about sedimentation, erosion, and water quality problems affecting it. We were given reports on the *Sedimentation of Loíza Reservoir Puerto Rico* and *Carraizo Lake Watershed Cooperative River Basin Study,* both written by the United States Department of Agriculture. Another important document written by the Natural Resources Conservation Service is the *Riparian Forest Buffer*. It described a plan for reforestation along a body of water, which separated the land into three separate buffer zones based on slope and distance from the shore (detailed in Data Analysis, § 4.3.1).

Information about the Loíza Watershed served as a basis for the formulation and recommendation of the best watershed management practices. This information was gathered by conducting several interviews and through the collection of archival data, such as management plans and published articles on reforestation.

3.1.2 Interviews

Through data we had already received, it was evident that many agencies have a role in environmental protection and watershed management. Based on documents we had read and the advice of Mr. Gonzalez, we proceeded to set up interviews with members of other organizations. Interviews assisted us in understanding the roles of organizations in the process of watershed protection, the existing management plans, and opinions of experts and professionals regarding watershed management practices. The information that we received from these interviews also assisted us in determining what factors were most important to consider when choosing critical land areas to reforest.

Interviews were conducted with professionals from organizations throughout the Island. These interviews were broken up into three levels: federal, commonwealth and municipal. The following is a list of people and agencies that we interviewed:

Ariel Iglesias	Environmental Protection Agency
Matthew Larson	United States Geological Survey
Jaime Pabon	San Juan Bay Estuary Program
Raul Santini	Department of Natural and Environmental Resources
Anaisa Delgado	Department of Natural and Environmental Resources
Angel R. Aguilar	Environmental Quality Board
Felix Latorre	Natural Resource Conservation Service
Antonio Di Mambro	Di Mambro and Associates, Inc.
Francisco Figueroa	Landowner participating in the Stewardship Program
Jorge Baez	Personal Environmental Consultant

3.2 Geographic Information Systems

It was evident that GIS map layers were one of the most important types of data collected in order to successfully complete this project. It was possible to overlap multiple GIS layers, which made it easier to observe different combinations of data at once. This feature was the primary tool for determining the most critical land in need of reforestation within the Loíza Watershed as we combined the layers for rivers and streams, sub-watershed boundaries, slope, soil, and land use. We decided that the best method to gain access to information that we needed was by obtaining it through the Scientific Inventory Office of the DNER, EPA, and the Institute of Tropical Forestry (IITF). We wanted to obtain Geographic Information System (GIS) data on Puerto Rico and specifically the Loíza Watershed. For example, a significant layer of data that we wanted to acquire was a complete and most recent land coverage shape file for Puerto Rico, which we obtained from Olga Ramos, GIS specialist for the IITF (§ 5.0). This shape file provided us with land use information which was an important asset to completion of this project.

Using the Scientific Inventory Office, the EPA, and IITF as sources of information, we were given data representing a variety of GIS mapping layers, and subsequently we were able to view them using the ArcView 3.0 software package. To establish critical areas we needed to view multiple map layers in the same view. Therefore, we had to learn about the different projection formats that the software contained. As a result, we downloaded a software extension for converting projection formats, and converted our data into the State Plane 1927 format, which was a format that a majority of our layers were already created in. The use of GIS allowed us to see visual

depictions of the different land features. By combining layers, we were able to extract the most critical land areas in the Loíza Watershed through examining hydrologic groups, slope and land use.

3.3 Critical Land Areas

After we collected data from interviews and different organizations we used this information to select critical land areas in the Loíza Watershed. By studying combinations of GIS layers, we were able to choose the most representative points to be reforested. For example, we combined and analyzed GIS layers of physical factors, like slope and soil type, to best identify critical areas.

To verify the validity of our data and critical land selection, we visited the selected areas and conducted field research. We examined different land features, such as ground cover and slope. It was also crucial to inspect the local tributaries into which run-off flows because it affects the quality of water. These observations made us better acquainted with the severity of erosion and sedimentation in the selected critical areas. For example, we examined these areas to verify the extent of erosion and damage that has occurred and compared these observations with GIS layers and archival data that we had obtained. This allowed us to confirm that we had chosen the best areas to focus on in our Loíza case study and in order to recommend the best watershed management process.

By combining the information that we received through gathering archival data, conducting interviews, and examining GIS layers we were able to select critical areas for reforestation in sub-basins of the Loíza Watershed. We were also able to gain knowledge about existing watershed management plans used throughout the Island by different

levels of government agencies. An analysis of the case study and the different plans assisted us in the formulation of our own recommendations for the most effective watershed management process for the Island.

4.0 Data Analysis

The data analysis chapter of this report is divided into three sections: physical analysis, social analysis, and existing management plans. Through conducting interviews and assessing existing management plans, we concluded that there were many physical and institutional factors that influence the success of watershed management in Puerto Rico. We analyzed the data to identify critical areas of reforestation and to provide recommendations that should help solve institutional problems and protect watersheds. We also conducted an analysis of each management plan to highlight their most important features.

4.1 Physical Analysis

The purpose of the physical analysis was to determine factors that affect water quality. Through analyzing archival data that we collected through interviews and existing management plans, we learned that many different factors, such as land use, soil type, sedimentation, and non-point source pollution affect the quality of water. We selected factors that were most significant in determining areas to be reforested and developed a method for critical land area selection. By assessing different reforestation practices, we developed a single reforestation strategy and derived a comprehensive watershed management plan from the existing plans that we obtained.

4.1.1 Critical Area Selection

There were many different variables that could be used to determine critical areas for reforestation. Through analyzing existing plans, we determined that soil, slope, and

land use were critical factors that each agency identified to be the main causes of erosion, non-point source pollution, and poor water quality. Erosion and non-point source pollution were factors used as secondary analysis tools in case of similarities between the first three factors. This was determined by creating a flow chart of the factors that affect water quality.

Figure 4 (below) shows the factors affecting water quality. From our background research, we determined that water quality is primarily affected by erosion and non-point source pollution. Also as discussed in the background review, soil, slope, and land use are the determining factors for erosion, and sandy soils and high degree percentage slopes are the two most significant factors leading to erosion. Erosion carries many forms of non-point source pollution such as fecal coliform, pesticides, nutrients, and debris from urban development. Non-point source pollution stems from different land uses as well.

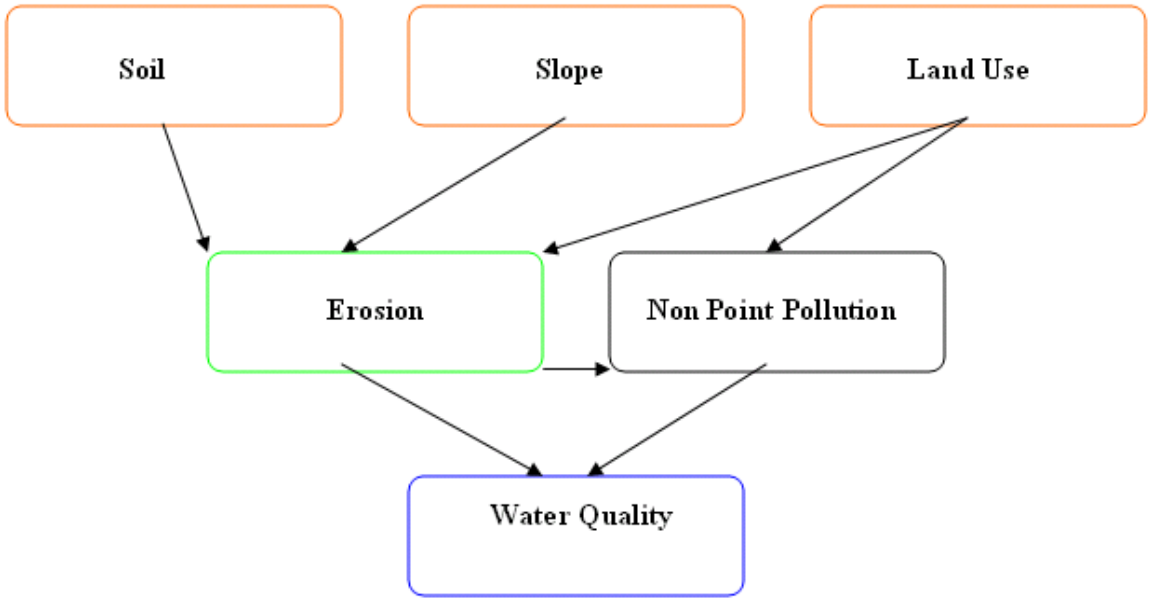

Figure 4: Connections between critical determinants of poor water quality

Land Use

The quality of water in Puerto Rico is affected by the many different types of land use. On the Island, land use predominately takes the form of pasture, forest, cropland, rural and urban development (Hunt, 1976). Table 1 illustrates the change and use of land from 1950-1987. As shown below, forest land has increased by 13% in this thirty-seven year time period. This is a positive change because it indicates that ecological areas were in the process of being preserved or reforested. There also was a 5.5% increase in urban land and a 40% decrease in cropland. These percentages indicate there was a significant decrease in the amount of agricultural land mainly due to the increase in urban development throughout the Island. The table also shows that pastureland was the major land use from 1950 to 1987.

Land Use	Percent in 1950	Percent in 1987
Rural	1.4	11.2
Pasture	40.8	48.5
Cropland	48	9.9
Forest	7.6	20.6
Urban	0.2	5.7
Other	2	4.1

Table 1 (Derived from Gellis *et al*, 1988): Land use percentage change from 1950-1987 for the Loíza Watershed

From this table we concluded that urban, pasture, and agricultural land were the most significant land uses found in Puerto Rico. A limitation of this table is that it is not recent and only calculates percentage changes until 1987. By analyzing trends represented in this table, we hypothesized that the percent of urban areas will continue to increase due to the development of residential areas throughout the Island. We also concluded that pasture land will remain a major land use and percentages will steadily

increase. This table helped us conclude that the two most prominent land uses in Puerto Rico are agricultural, which consists of pasture and cropland, and urban areas.

Effects of Land Use on Water Quality

After reading reports such as *Land Use on Upland Erosion, Sediment Transport, and Reservoir Sedimentation, Lago Loíza Basin, Puerto Ri*co, provided by the USGS, and examining land use percentage changes throughout time, it was evident that agriculture and urban land uses were major causes of pollution in watersheds. Below we discuss the effects of these two land uses on water quality.

Agricultural land can be classified as either cropland or pasture for livestock. Both of these forms of agriculture provide major sources of non-point source pollution to the rivers and streams of Puerto Rico. Raul Santini of the DNER, also chairman of the Coastal Non-Point Pollution Control Committee, told us that cropland's primary contributions to non-point source pollution are nutrients and pesticides. If agro-forestry does not exist in these areas, increased sedimentation becomes a problem. There is a need for forest buffers along rivers and streams because they have become susceptible to erosion, which has led to increased sedimentation problems. This sedimentation then carries hazardous nutrients and pesticide runoff into the water.

Analyzing the *Puerto Rico Coastal Non-point Pollution Control Plan* **(§ 4.3.2)** and speaking with Matthew Larson, hydrologist and Caribbean District Chief of the USGS, it was clear that livestock leads to the most critical form of non-point pollution in Puerto Rico, fecal coliform. High concentrations of fecal coliform are found in all regions of Puerto Rico, which creates significant water quality problems. Larson

discussed a problem with the lack of buffer zones and fencing for cattle along bodies of water. Without buffer zones and fencing, cattle are able to roam freely into rivers and streams. The main problem is caused from the deposit of fecal matter located on the hooves of the cattle, which increases fecal coliform rates in the water.

Urban land use also contributes to non-point source pollution within the watersheds of the Island. Puerto Rico's urban areas are constantly expanding due to population growth and residential development. Restoration and construction of roads and buildings are also continually taking place, which adds to non-point source pollution. Raul Santini noted that debris from construction of roads, highways, and bridges contribute to the pollution of rivers and streams. Run-off and wind can carry this debris or it can be directly deposited into the water due to construction on bridges or along coasts.

In 1972, the Environmental Protection Agency proposed a permit system to regulate sources of pollution, such as debris from construction. The National Pollutant Discharge Elimination System (NPDES) permit requires that construction companies supply a Pollution Prevention Plan when working with five or more acres of land. This year the permit has been changed to one or more acres of land. According to Ariel Iglesias, an employee at the EPA, since its introduction in 1972 the NPDES permit program is responsible for significant improvements to the Nation's water quality by controlling pollution created by urbanization.

Land Slope

The slope of the land is the main cause of sedimentation flow into rivers and streams. The steeper the slope, then the more susceptible the land is to erosion and water run-off. When determining the critical areas in need of reforestation we illustrated three ranges of slope on our GIS map: less critical (0°-15°), critical (15°-30°), and extremely critical (30° and higher). This map provided a visual depiction of what areas were most vulnerable to erosion along a sub-watershed. The Guía de Reforestación de Cuencas Hidrográficas, a report mainly generated by the DNER, also used slope as a measurement to determine critical area to be forested. Jeffrey Glogiewicz, a personal environmental consultant, informed us that the critical areas to reforest would involve a 45° slope and 80 inches of rainfall or a 20° slope and 100 inches of rainfall. We took this information into consideration, but determined that the rainfall amounts did not vary considerably within most sub-watersheds due to the similarity of geographical features. Figure 5 shows a section of a GIS map showing the ranges of slopes we used to determine critical areas.

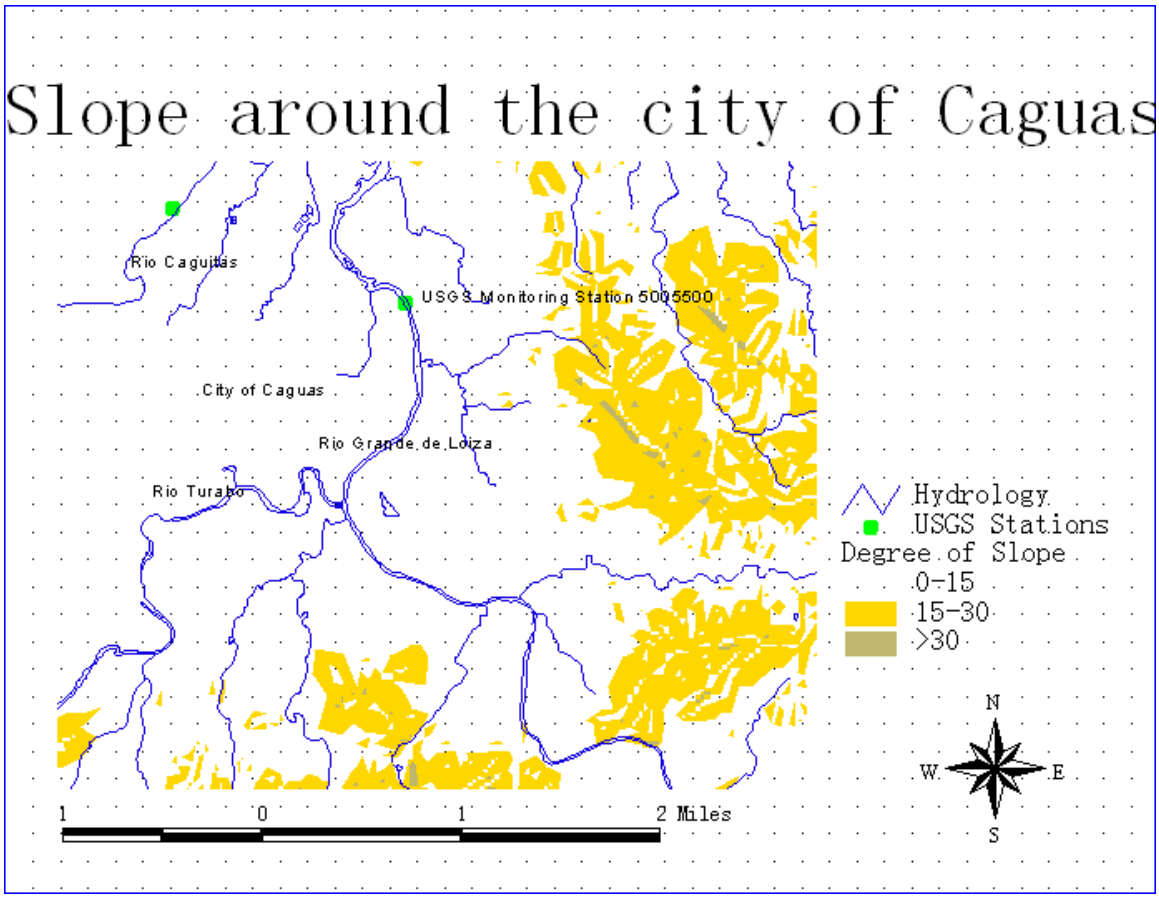

Figure 5: Slope of land around city of Caguas

Soil Type

There are over fifty different types of soil present in Puerto Rico. Our research highlighted soil as a critical factor in relation to erosion and sedimentation problems. We also discovered that the Guía de Reforestación de Cuencas Hidrográficas also used soil type in conjunction with slope as significant factors that affect water quality. Hydrologists have used a soil classification technique to create a set of criteria to identify those soil types that were more susceptible to erosion. We decided to follow that soil classification in order to make the results of our critical area selection easier to understand and identify. Figure 6 displays the four hydrologic groups, from sandy soil to

clay soil, which we used to determine critical areas. Dark brown and yellow highlight areas where the soil is either very sandy or sandy. These colors represent areas where the soil is more permeable and therefore more critical because it allows nutrients, pesticides, and other forms of pollution to flow into water runoff. Dark grey and peach represent areas where the sand is either a clay-sandy mix or clay. By examining this map, which is a section of the Loiza Watershed around the city of Caguas, we can see that a majority of the soil around the river is sandy soil. We concluded that since this soil is very permeable and allows pollution to accumulate in water runoff, then there will be high rates of non-point source pollution in those areas.

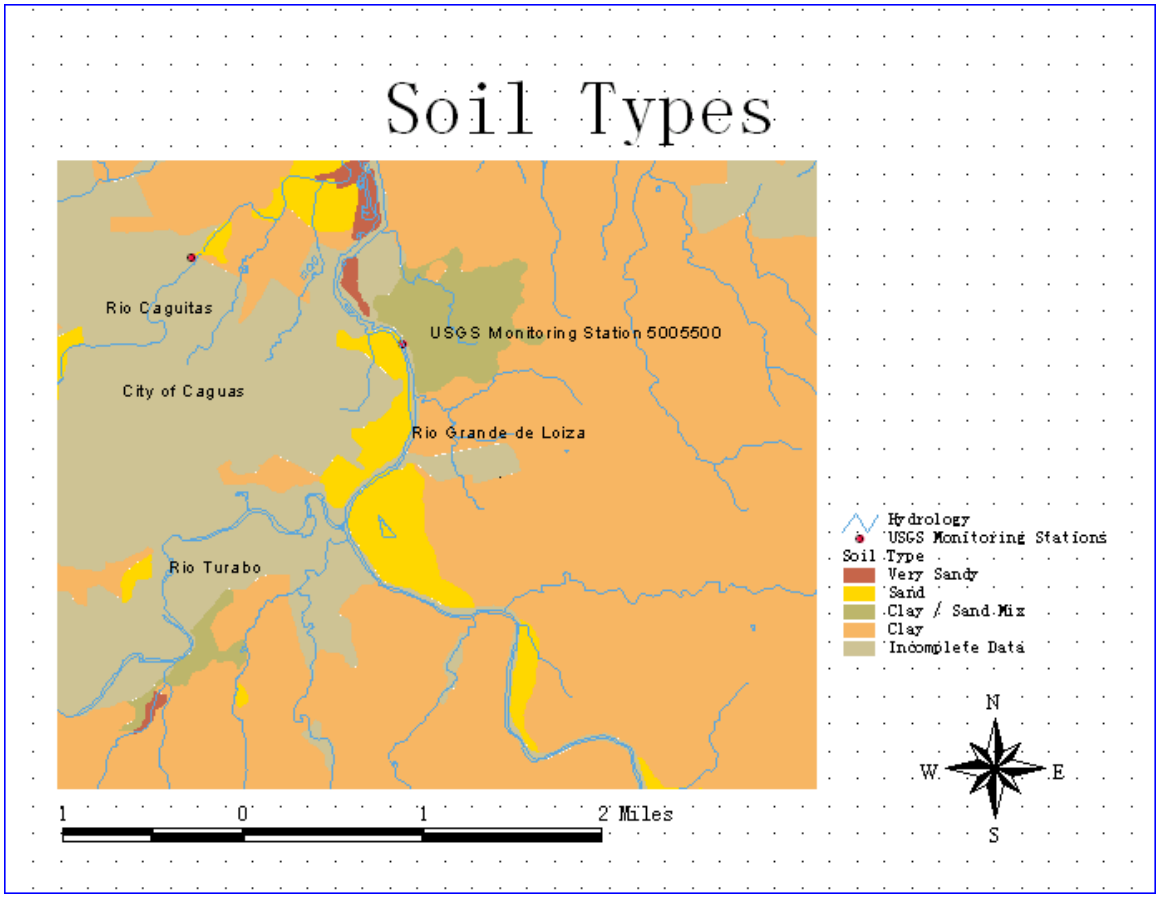

Figure 6: **Soil types around the city of Caguas**

4.1.2 Summary

In conclusion, analysis of physical factors affecting the health and conditions of watersheds assisted in the process of determining what factors should be considered when identifying critical areas of reforestation. Soil, slope, and land use were the most predominant land features that affect the amount of non-point source pollution in areas within the watershed. By completion of this analysis, we were able to set ranges for each factor that would then classify land as either a critical or suggested area for reforestation. This method of critical area selection was then tested on a case study which is detailed in § 5.0

4.2 Social Analysis

Throughout the course of our interviews, social and institutional issues appeared to be important factors influencing watershed reforestation and management practices. Collaboration between agencies, landowner assistance, public education, and enforcement of practices were the areas we encountered with significant problems. Our interviews provided us with knowledge about issues and problems that need to be rendered in order to create the most effective reforestation process.

4.2.1 Collaboration

The most important social issue we became aware of through our data collection was the lack of communication and organization between government, commonwealth, and municipal environmental agencies. Each individual agency has created or been a part

of many useful watershed management plans, but they are not implemented effectively together.

For example, from our interview with Felix Latorre, an employee at the Natural Resource Conservation Service, we learned that the NRCS holds an important role in watershed management. They have various reforestation plans such as the *Puerto Rico Watershed Restoration Action Strategies* and the *Puerto Rico Unified Watershed Assessment and Restoration Priorities,* as described in **§ 4.3.1**. Instead of enforcing these plans, Mr. Latorre informed us that the primary role of the NRCS was to contact landowners and help select the most successful conservation practice needed for their land. Once the best conservation practice was identified, the recommendation was forwarded to a field representative of the DNER, who approves the practice and starts the implementation. Latorre insisted that problems with the process do not exist, but when posed questions regarding coordination with other organizations, funding, and incentives provided to the landowner, he replied with unclear responses. We came across the fact that conservation practices recommended by the NRCS are separate from those used by the DNER. One of the main differences is that the practices used by the NRCS are not implemented with incentive programs, like the DNER. It is evident that the manner in which these two organizations operate is inefficient. Problems, such as the use of disorganized and uneconomical conservation practices, may arise and affect the success of reforestation efforts in that area. From this example, it is clear that problems such as lack of communication and cooperation plague watershed reforestation efforts and progress on the Island.

4.2.2 Landowner Assistance

After meeting with a private landowner in the Loíza Watershed, we realized that problems exist with landowner assistance. Francisco Figueroa, an active participant of the DNER's Stewardship incentive program since the mid 1980's, informed us of problems and difficulties that he has faced with his reforestation efforts. One of the main setbacks that he has experienced is the lack of cooperation from government agencies to assist him with equipment and professional support. He also stated that many landowners are at a disadvantage because of their lack of education about reforestation practices and management strategies. Mr. Figueroa also explained that he has had to deal with environmental problems, such as erosion and sedimentation buildup. He felt that if he was properly educated and given professional assistance then those problems would not have been as severe and hindered his reforestation efforts.

The importance of communication between landowners is another issue that arose during the interview with Francisco Figueroa and was repeated in an interview with Jorge Baez, a private environmental consultant. They both mentioned that increased communication between private landowners within a watershed would be beneficial because it would allow the landowners to discuss problems and suggestions with each other. Taking this into consideration, it was apparent that communication would improve collaboration and success of reforestation by private landowners. Landowners who previously worked on an individual basis could unite and work together to reforest and care for the land in their area. For example, the use of buffer zones could be continued from one landowner's property into another landowner's property.

4.2.3 Public Education and Involvement

Increasing public awareness about environmental problems is another social issue that should be examined according to our interview with Jaime Pabon, an employee of the San Juan Bay Estuary Program. The San Juan Bay Estuary Program provides us with the *Comprehensive Conservation and Management Plan for the San Juan Bay Estuary,* which proposed different technical and administrative protection tasks that should be implemented by organizations such as the DNER. He claimed that in order to increase the chance of an efficient implementation of the conservation and management plans for the estuary, emphasis should be placed on the importance of public education and involvement. By placing emphasis on these factors, the general public will be aware of the economic, environmental, and social benefits that watersheds provide. It will also increase the level of respect that communities have for the land, and in turn, may improve water quality because the public will become more cautious about polluting the environment. Another benefit of educating the public could also lead to a more active participation in reforestation.

In addition to education of the general public, landowners should also be aware of incentive programs that are offered. Jorge Baez described his approach regarding incentive programs. He conducts personal meetings with landowners to educate them about the benefits of different incentive programs. This provides the landowners with professional assistance, while also continuing education about reforestation.

4.2.4 Summary

Analysis of social and institutional factors provided us with a list of issues that needed to be considered when formulating recommendations for the most effective management process. The recommendations outlined in **§ 6.0** are based on improving problems, such as communication and collaboration between organizations, landowners, and the community. In conclusion, we were also able to examine existing management plans and determine which plans possessed the best practices based on how well they address these social factors.

4.3 Analysis of Existing Management Plans

In order to determine which management practices would contribute to the best reforestation process, we had to examine plans from various environmental agencies. By analyzing the following management plans we were able to identify and extract many useful and effective practices.

4.3.1 NRCS Watershed Management

The *Natural Resources Conservation Service Conservation Practice Standard* (2001) outlined a plan for Riparian Forest Buffers. A riparian forest buffer is "an area of trees and or shrubs located adjacent to and upgradient from water bodies (NRCS, 2001)." The purpose of this buffer is to protect water habitats and decrease non-point source pollution. This is done by increasing shade to lower water temperatures and reducing

effects of sediments and other organic materials. The plan should be applied wherever water quality is impaired or erosion is a concern. The NRCS has established three zones of forest buffer, depending on the slope percentage. The steeper the slope of the land determines the width of the spacing of the buffer zone. Table 2 shows the spacing criteria for each zone depending on the degree percentage of the slope.

Minimum Spacing Criteria for Riparian Forest Buffer Zones

Slope	Recommended Width/Zone (feet)			
%	1	2	3	Total
0-15	15	20	20	55
20	19	23	23	65
25	21	27	27	75
30	23	31	31	85
35	25	35	35	95
40	29	38	38	105
45	33	41	41	115
50	35	45	45	125
55	37	49	49	135
60+	41	52	52	145

For intermittent channels use minimum width

Table 2 (Derived from NRCS, 2001): Width of the three buffer zones and its relation to slope percentage

The NRCS has also completed studies of the grasses, shrubs, and trees that are most suitable for each zone. The Riparian Forest Buffer report contains explanations and benefits of each zone, as well as, an extensive listing of grasses, shrubs, and trees that are suitable for each zone. The NRCS is also involved in other watershed management plans.

The *Puerto Rico Watershed Restoration Action Strategies (WRAS, 1999)* is a document that was prepared for the improvement of water quality conditions in Puerto Rico to guarantee all citizens clean and safe water. The goals of the WRAS were to

restore water quality of watersheds, to manage point and non-point sources of pollution, and to establish a watershed restoration project.

The *Puerto Rico Unified Watershed Assessment and Restoration Priorities* (PRUWA, 1998) was the initial watershed document that categorized the watersheds that were priority areas for reforestation and management. The WRAS document, prepared by the EPA and USDA in conjunction with the NRCS, provided the implementation of different protection and control strategies for the restoration of the watersheds. The strategies in this report include the implementation of:

- Total Maximum Daily Loads (TMDL's)
- National Pollutant Discharge Elimination System (NPDES) Program
- Non-point source pollution Best Management Practices (BMP's)
- Puerto Rico Coastal Non-Point Sources Program and Puerto Rico Non-Point Sources Program
- Outreach programs for citizens
- Modification for current water quality monitoring stations

TMDL's are a device used to calculate the maximum daily load for point sources and identify non-point sources of pollution. Section 303(d)/305(b) of the Clean Water Act (CWA) refer to the requirements for water quality standards. CWA 303(d) provides a list of water bodies that do not meet the water quality standards. The bodies of water on this list are where TMDL's should be implemented. TMDL's are calculated on the watershed level, as water quality differs from watershed to watershed. Once the TMDL's are determined and approved by the EPA, they are enforced by the EPA or EQB depending on the source of pollution. The implementation of TMDL's and their effective enforcement will prove to be a valuable instrument in improving and documenting water quality.

The NPDES Program regulates the discharge of pollution from point sources. NPDES permits exist that limit the discharge of pollutants into bodies of water. These permits also require the EQB and EPA to supply a Monthly Discharge Monitoring Report (DMR). The monitoring network includes sampling stations for water quality, flow, and sediment. Another plan for managing the non-point sources of pollution has been created by the DNER, EQB, and Coastal Non-point Source Committee. The strategies and goals of this plan are discussed below.

4.3.2 Non-point Source Pollution Control Plan

The *Puerto Rico Coastal Non-point Pollution Control Plan* (PRCNPCP, 1999), also called "the Plan", was developed to control the problem of non-point source pollution and improve the quality of the water. A committee of sixteen Commonwealth agencies was formed to implement the Plan and adopt the 6217(g) mandatory management measures as a technical guidance for the Plan. It is a fifteen year plan divided into five year intervals. This plan focused on the implementation of management measures for the following forms of non-point pollution:

- Agriculture
- Urban
- Marinas and Recreational Boating
- Wetlands, Riparian Areas and Vegetated Treatment Systems

The DNER, EQB, and Committee developed techniques to achieve the implementation of these management measures. The techniques used to apply these measures was the use of a technical assistance plan, a process to identify critical coastal areas of pollution, continuous revisions of the management measures, and a plan to

assess the reduction of pollutants and the improvement of water quality. The technical assistance plan provides training sessions and workshops for local governments and citizens. This will increase the general public's knowledge of non-point source pollution problems and how to prevent them. Identifying critical coastal areas was done through TMDL's and coastal monitoring stations. Monitoring non-point source pollution will allow the Committee to assess the improvements of the water quality and create new measures as needed. While this plan is being implemented, the San Juan Bay Estuary has also designed a comprehensive conservation and management plan for protection of the overall health of the estuary.

4.3.3 San Juan Bay Estuary Program

The purpose of the San Juan Bay Estuary Program (SJBEP) is to protect and restore the health of the estuary while supporting economic and recreational activities. This plan focuses on technical tasks, administrative/regulatory tasks, and public involvement (Villanueva, *et al.*, 2000). The technical tasks include monitoring and research of water quality, sedimentation, and living resources. The administrative/regulatory tasks include an inventory of federal programs that apply to this plan, an analysis of federal, state, and local water quality and natural resources management, and recommendations for implementation. Finally, public involvement and education will contribute to efficient implementation of the conservation and management plans for the estuary.

The actions and strategies of this program include many of the same management techniques as the plans discussed above. These techniques include the use of NPDES

permits, monitoring stations, public involvement, and the reduction of pollution and sedimentation. These management procedures are general guidelines that should be used throughout the Island. The programs listed below are more specific municipal management plans.

4.3.4 Caguas 2020 and Caguitas Greenway

Antonio Di Mambro and Associates, Inc., a company involved with urban design and city planning, has devised a plan for the urban development of the autonomous municipality of Caguas. An urban zone study was completed to accommodate the expansion of the city's population from 140,000 people to 250,000 people over the next twenty-five years (Di Mambro, 1998). The goals of this plan include:

- Redesign and improvement of the city's transportation, circulation, and infrastructure
- Restoration and development of the city's natural environment
- Developing a denser population
- Improving the community for public involvement

There are three general projects to complete to accomplish the goals above. The Transportation Initiative will work to achieve a more public transit system. This initiative requires the expansion of the current public transit system, new designs for parking, and creation of a pedestrian friendly environment.

The River Parks Initiative is a program that will include the development of walkways and parks along the rivers of Caguas. It will increase public involvement and respect for the rivers in Caguas. The Rio Caguitas Greenway Implementation plan prepared by Wolfe Mason Associates is an example of the River Park Initiative already in progress. Also known as Honor the River, this plan will hopefully continue into other

municipalities. A path will run along the right side of the Caguitas River, shown in Figure 7. This picture demonstrates a buffer of vegetated land on both sides of the river. This specific area does not have a footpath yet, but construction will begin in the near future.

Figure 7: Caguitas River that flows through the city of Caguas

The final part of Caguas 2020 city plan is the Inner Core Initiative. The purpose of this plan is the densification of downtown and surrounding neighborhoods. The construction of these neighborhoods will also include the re-establishment of a culturally enriched and ecologically aware community.

The Caguas plan is scheduled to be completed by 2020. The plan has good intentions, but the magnitude of it will create problems. After analysis of this project, it appears as though the completion of this project will take longer than the twenty years that are planned, and will most likely run over budget. If the Caguas 2020 urban

development plan is successful, it would be beneficial to implement in other municipalities. These initiatives will improve the quality of water and establish an ecologically conscious community. Expansion and improvement of the public transport system will eventually decrease pollution and congested roadways. Creating walkways and river parks will not only improve public involvement, but it will also encourage respect for the rivers and the environment. The densification of the population will decrease urban sprawl and rural development. If the project can be completed as scheduled and on budget, the benefits mentioned above will greatly decrease the urban impact on the rivers. Decreasing the urban impact on the rivers will then lead to an increase in water quality both in the city, and throughout the watershed.

4.3.5 Summary

The management plans discussed above provide techniques and strategies that should be implemented in cooperation with each other. If there existed collaboration between agencies these management strategies for sedimentation, erosion, non-point source pollution, forest buffers, and public involvement could be used as one unified plan to implement in all of Puerto Rico's watersheds. Table 3 displays each management plan we analyzed and shows the different issues of watershed management that each plan addresses. The table shows 6 out of 7 plans focus on reforestation as a major problem to address. Non-point source pollution, sedimentation, and public education and involvement are also found in 5 out of 7 plans. It should be noted that The *Puerto Rico Watershed Restoration Action Strategies*, the *Puerto Rico Non-Point Source Pollution Control Plan*, and the *Rio Caguitas Greenway Implementation Plan* address every issue

on the table. Since some of the management plans listed do not address ever single issue, we concluded that in order to create the most effective process it is important we focus on each problem.

PLANS	PROBLEMS ADDRESSED			
	NP Source Pollution	Reforestation	Sedimentation	Public Education/Involvement
NRCS Riperian Buffer Zone	X	X	X	
WRAS	X	X	X	X
PRUWA		X		
PRCNPCP	X	X	X	X
SJBEP	X		X	X
Caguas 2020		X		X
Rio Caguitas Greenway Plan	X	X	X	X

Table 3: Issues addressed by each management plans

5.0 Case Study

We conducted a case study in several areas of the Rio Grande de Loíza Watershed. The Loíza Watershed is situated in the eastern portion of Puerto Rico, east of the capital city of San Juan, as shown in Figure 8. This case study was conducted to determine the critical areas of reforestation using the methods we formed through our data analysis (**§ 4.0**) by focusing on three physical factors that affect water quality. The factors, slope, soil type, and land use, were gathered as GIS mapping layers and compiled to display critical areas. After examining physical factors and determining critical areas of reforestation, we will then focus on institutional factors that influence the progress of watershed management in on each level.

Our study was applied on three levels, the Loíza Watershed and two of its sub-basins, the Caguitas Watershed and the Rio Grande de Loíza at Carraizo Dam. The locations of the two sub-basins in the Rio Grande de Loíza Watershed are shown in Figure 8. The Caguitas Watershed is highlighted in yellow, while the Rio Grande de Loíza at Carraizo Dam is shown in red. Each map in this section will be presented in larger versions in Appendix D.

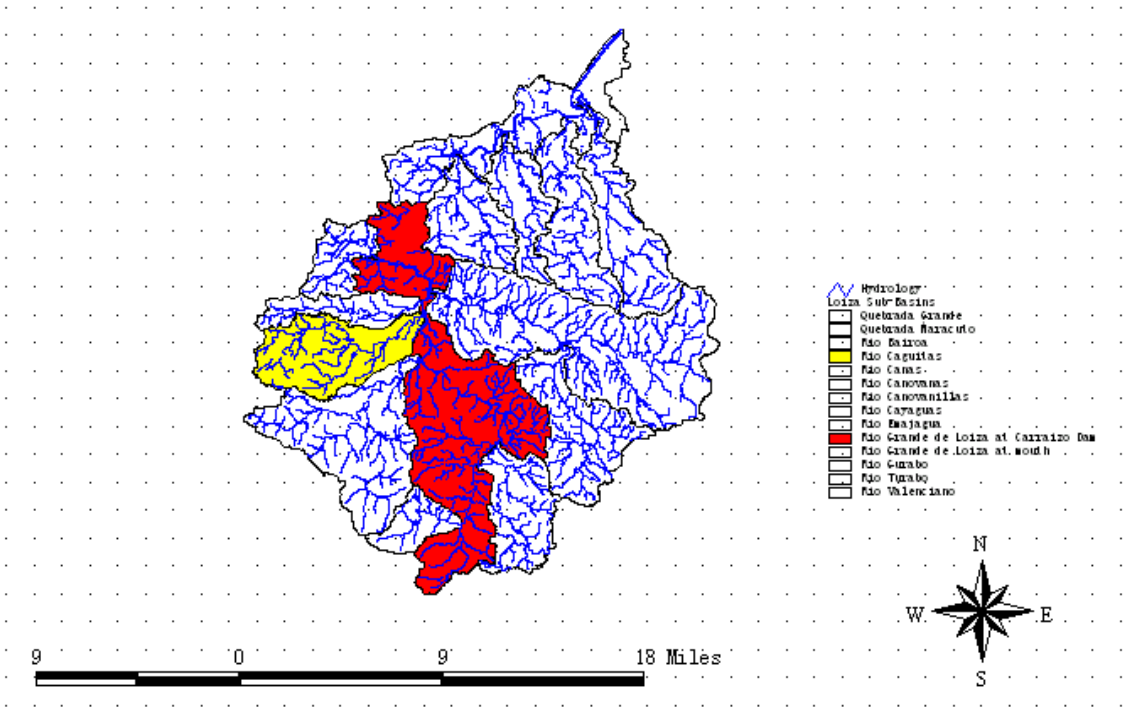

Figure 8: Locations of Rio Caguitas and Rio Grande de Loíza at Carraizo Dam Sub-Watersheds

5.1 The Rio Grande de Loíza Watershed

The Rio Grande de Loíza Watershed has a large area that is in need of reforestation. Figure 9 contains a pie chart showing the parts of the watershed that are critical areas for reforestation, where there is incomplete data, the non-critical areas, and the suggested areas for reforestation.

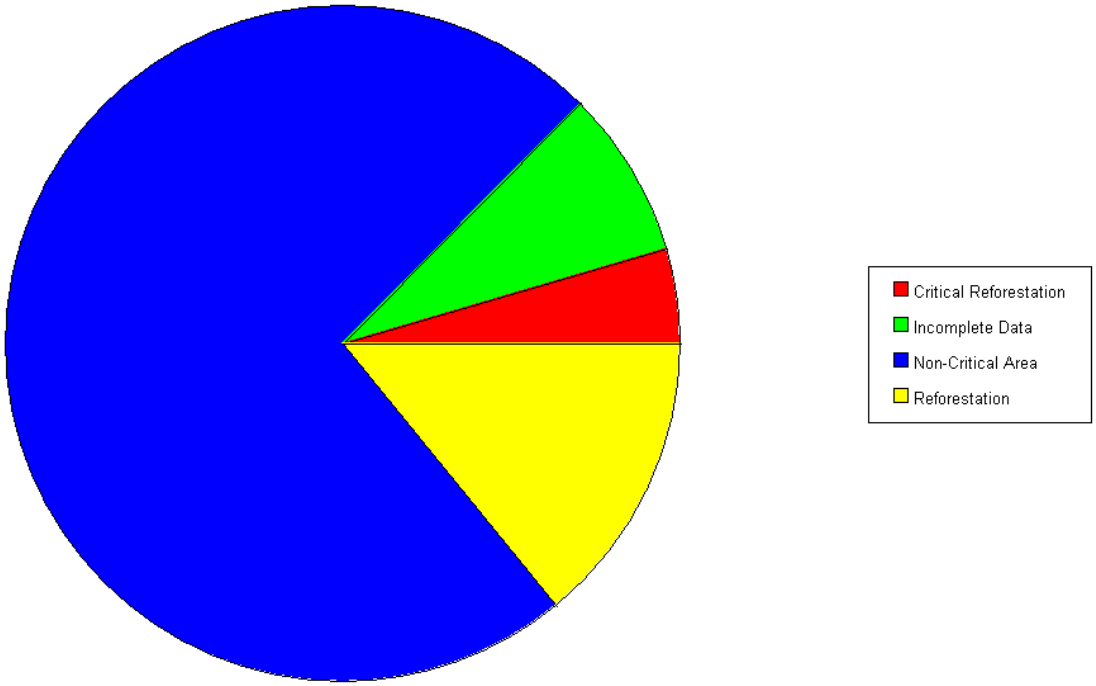

Figure 9: **Amount of area that requires reforestation in the Loíza Watershed**

As displayed above, approximately 4.46 percent of the watershed (35.5 km^2) is in need of critical reforestation. Critical areas are locations with extreme slope and permeable soil. The suggested area for reforestation was approximately 14.13 percent of the watershed (112.6 km^2).

These two types of areas do not include the area of the riparian buffer zones, which include forested land surrounding bodies of water. These areas are also critical, but are not determined using the formula of combining slope and soil type. The preliminary locations of critical areas within the Loíza Watershed are presented below in Figure 10.

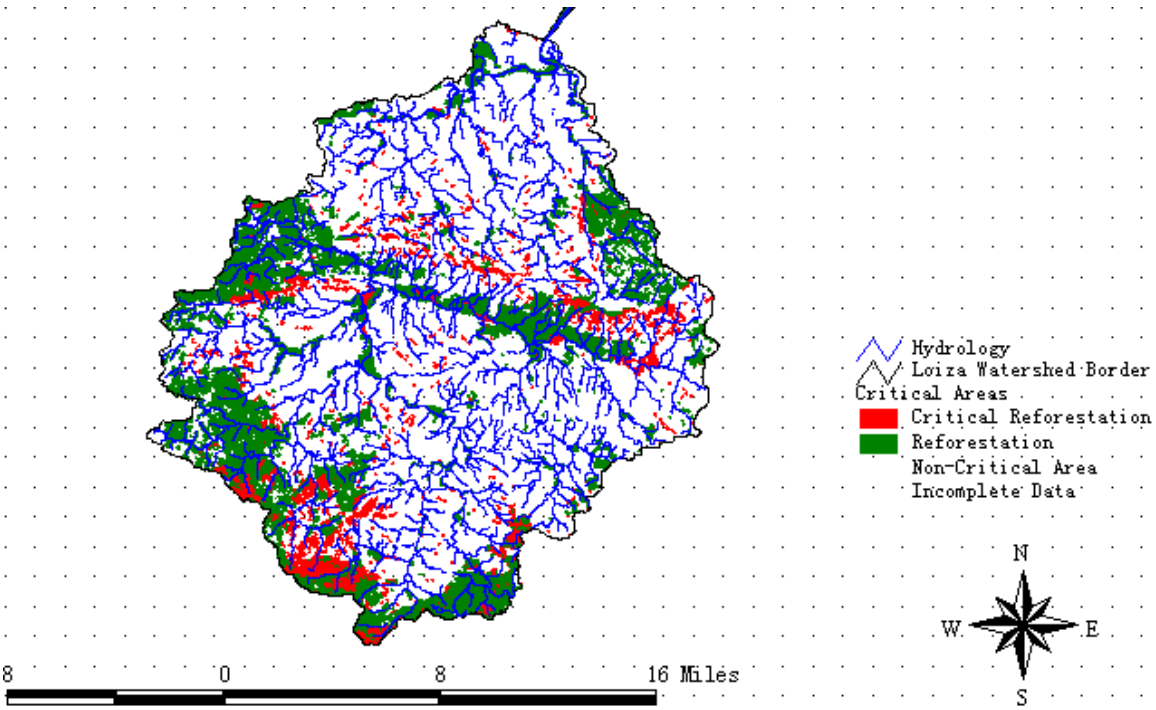

Figure 10: **Location of critical areas in the Loíza Watershed**

The map above illustrates the results of the combination of soil and slope GIS layers for the Loíza Watershed. Critical areas of reforestation are highlighted in red and consists of land with a slope of 30° and higher and any soil type or land with a slope of 15-30° and sandy soil. Suggested areas of reforestation are shown in green and consist of land with a slope of 15-30° and a mix of sandy-clay soil or land with a slope of 0-15° and sandy soil. Non-critical and incomplete areas are shown in white because they do not require reforestation. Incomplete data areas did not have complete soil/slope data or are urban areas.

The third critical selection factor examined was land use. Information that we received on land use for the watershed was very detailed. In order to clearly display the data, we created two separate land use sections. The first section contains specific land

use data, such as different forest and agricultural types. Figure 11 below shows the variety of land use and vegetation types throughout the watershed.

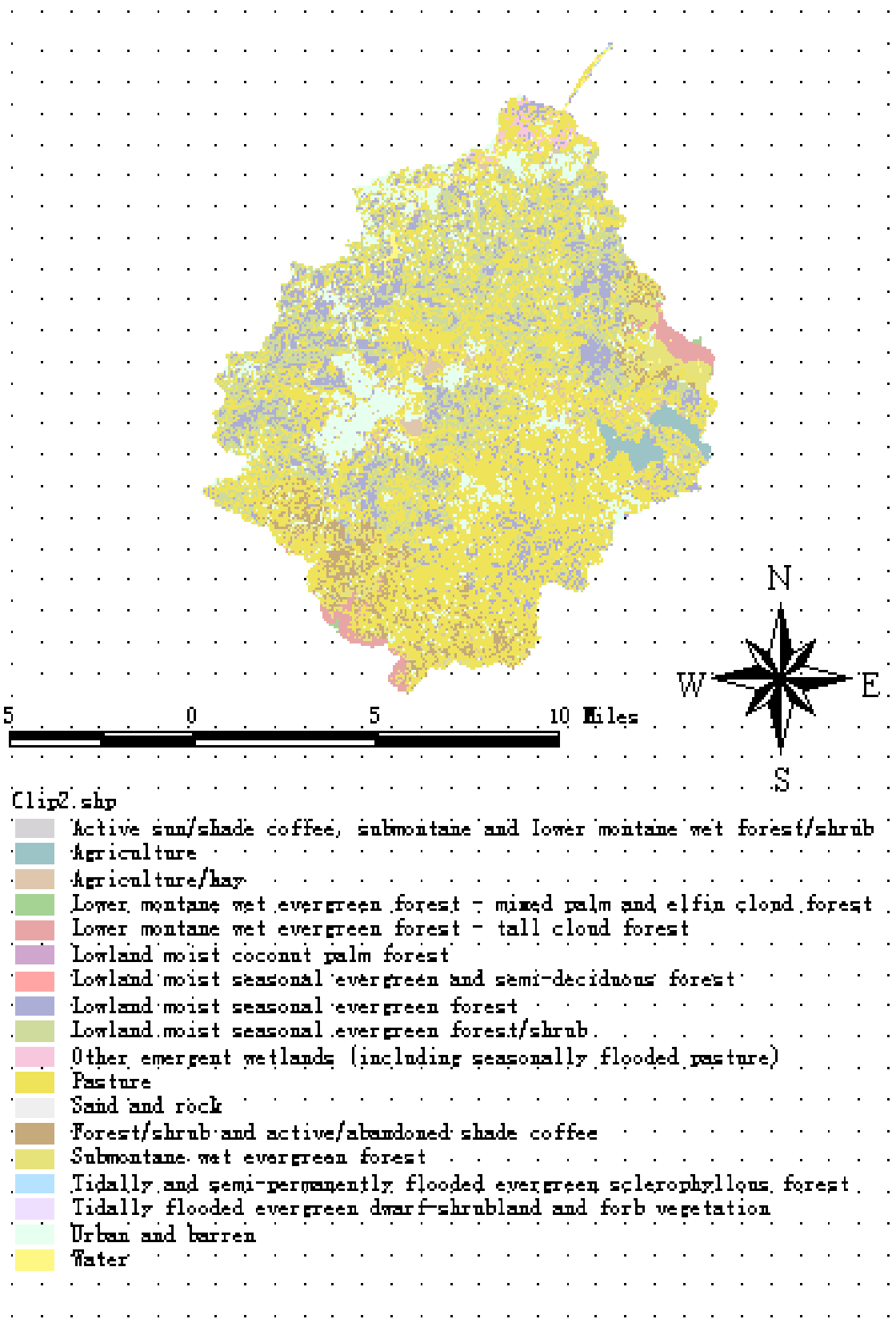

Figure 11: Specific land use map for the Loíza Watershed

As shown above, the specific land use map above is very detailed and complex. With eighteen categories of different land uses, it was decided that in order to get the best results from using this GIS layer that it would be beneficial to combine similar land use categories. By examining the map, we noticed that a majority of the land were pasture, forest, agriculture, and urban/barren. We combined the different variations of these categories to create the general land use map.

The next section contains general land use types. As described above, this map was created by generalizing similar land use types. For example, we combined sub-montane wet evergreen forests with lower montane wet evergreen forests into one category of forests. This allowed for a clear analysis of existing conditions and combinations of land use with the preliminary critical areas. The general land use map for the Loíza Watershed is shown in Figure 12. We used the general land use map when analyzing the Caguitas and the Rio Grande de Loíza at Carraizo Dam sub-basins. By using the general land use we were able to formulate detailed comparisons with critical selection areas of the sub-basins.

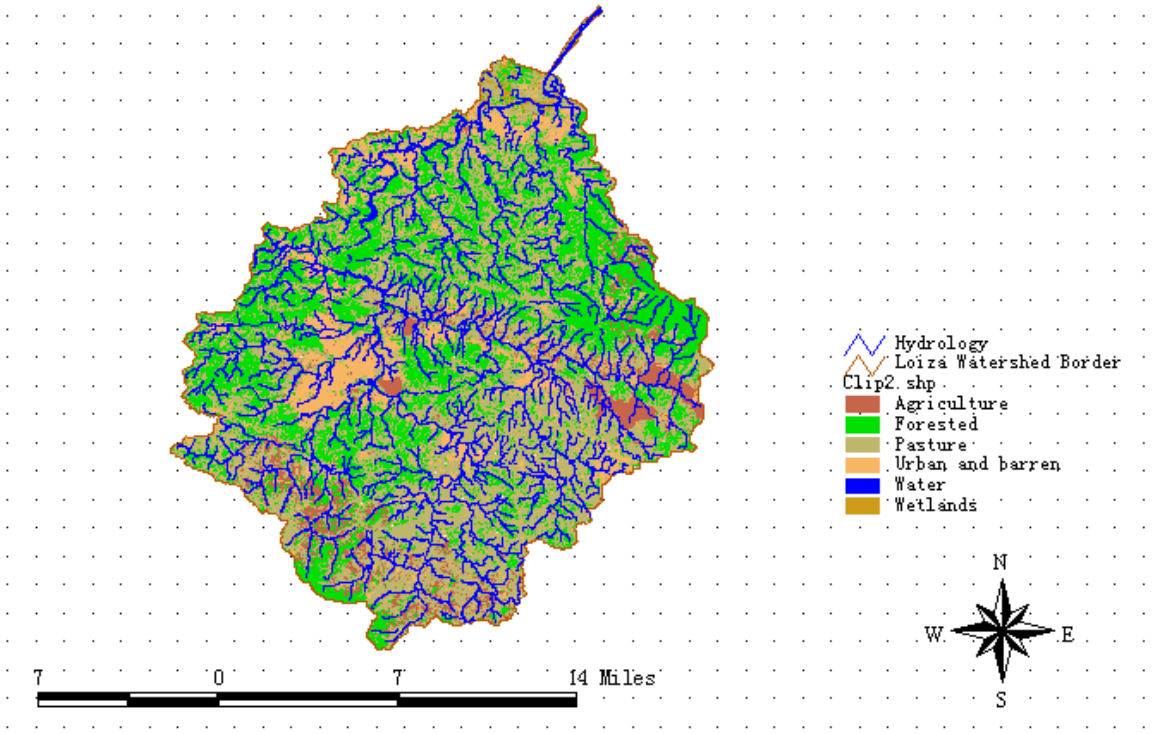

Figure 12: General land use for the Loíza Watershed

By examining Figure 12 it can be seen that a majority of land in the Loíza Watershed is forested, which is highlighted in green. There also exists pasture and agricultural land throughout the watershed, primarily in the south. Urban areas, which are highlighted in peach, are also situated throughout the watershed where a city such as Caguas is located.

The information illustrated in the critical area and land use GIS layers provided a general overview of the physical characteristics of the Loíza Watershed and the amount of land in need of reforestation. This data was specifically used when analyzing our selected sub-basins.

5.2 Caguitas River Watershed

The Caguitas River Watershed is located on the western side of the Loíza Watershed. Its location in relation to the Loíza Watershed is demonstrated in yellow in Figure 8. The main feature of the sub-basin is the Caguitas River, which is a tributary that enters the Rio Grande de Loíza in the city of Caguas. The map in Figure 13 shows the critical areas of the Caguitas Watershed. The green areas demonstrate the areas of critical reforestation, the pink is suggested area of reforestation, and the white areas show incomplete data. Incomplete data signifies a lack of information or urban areas. It is located predominately in the city of Caguas. Current reforestation plans for the city of Caguas follow the Honor the River and Caguas 2020 plans. One disadvantage of this map is that it does not show the Riparian Buffer Zones that we consider as critical areas for reforestation.

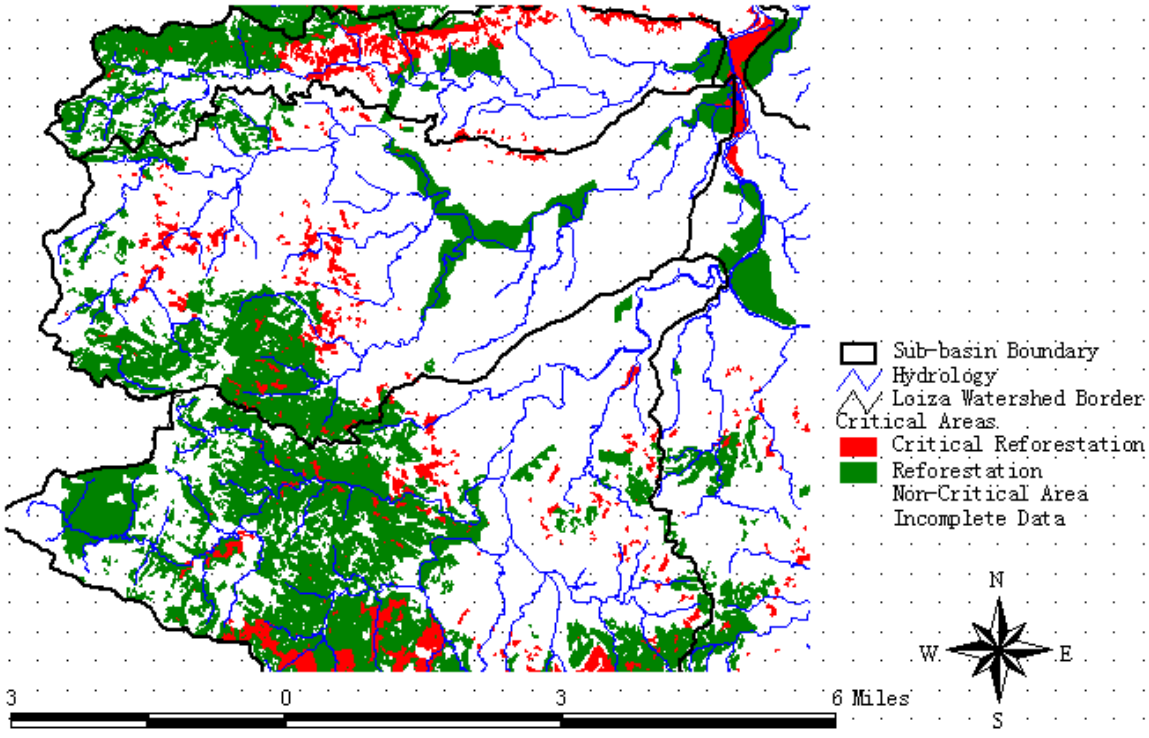

Figure 13: **Critical areas for the Caguitas River Watershed**

Land use for the Caguitas Watershed varies throughout the sub-basin. The western portion of the sub-basin consists primarily of forests and scattered pastureland, while the eastern portion consists of agriculture, urban and barren land, and pastureland. These variations are demonstrated in Figure 14.

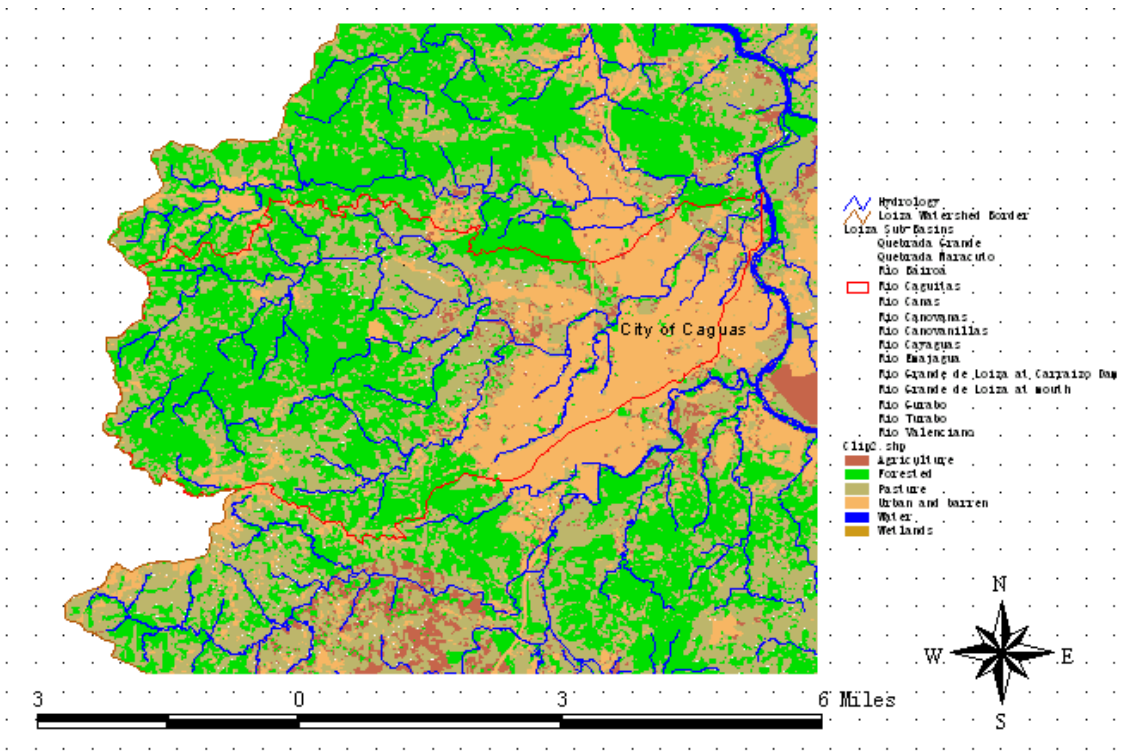

Figure 14: **Land use map for the Caguitas Watershed**

In order to create final critical areas within the sub-basins, we combined the preliminary critical areas and general land use layers. This allowed us to analyze the type of land use that is commonly found in the critical areas. Figure 15 shows the result of this combination.

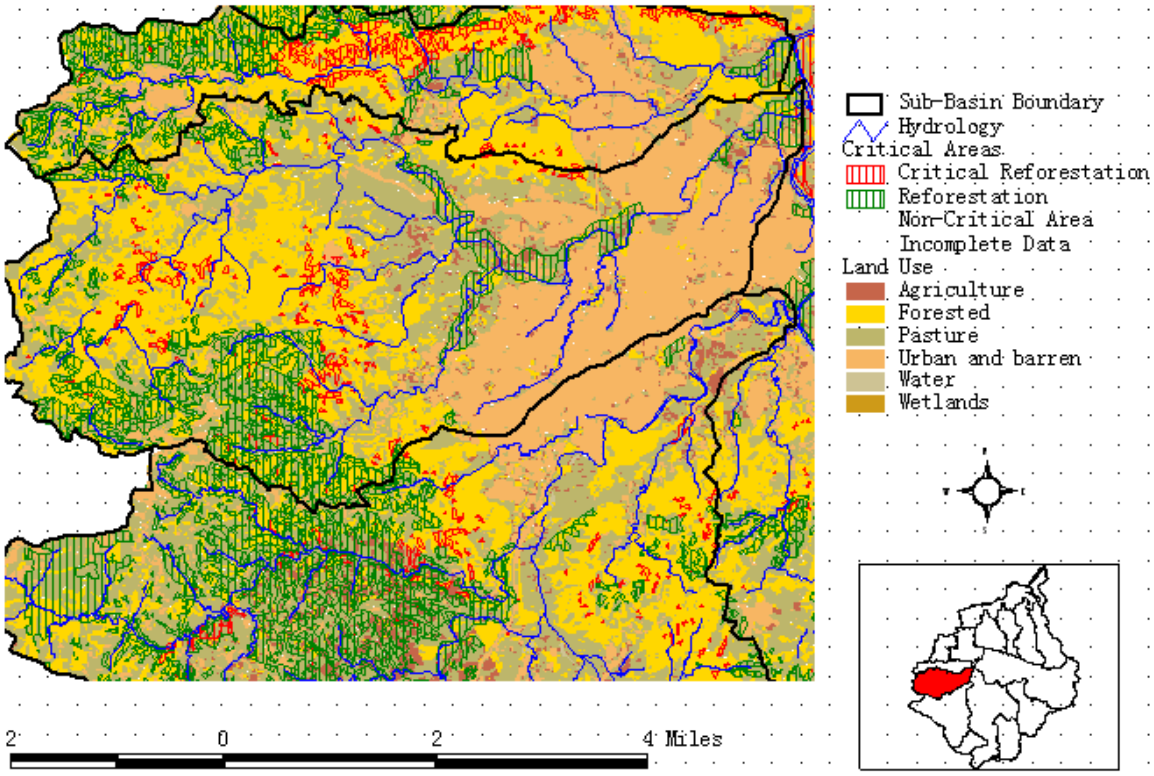

Figure 15: Combination of land use and critical areas in Caguitas Watershed

Analysis of this combination revealed several areas within the Caguitas Watershed that are in need of reforestation. From examining the map, it is evident that the largest area is located in the center of the watershed, directly west of Caguas. A large portion of land surrounding the Caguitas River, which flows through the center of the watershed, is used for pasture and agriculture. Where possible, these areas should be given direct reforestation, and agro-forestry in areas used for grazing. The southwestern portion of the watershed also contains pastureland in areas of steep slope. Some of this area falls in critical reforestation areas, which is highlighted in bright green.

5.3 The Rio Grande de Loíza at Carraizo Dam Sub-Basin

The Rio Grande de Loíza at Carraizo Dam Sub-Basin is located in the central portion of the watershed. Its location in relation to the Loíza Watershed is demonstrated in red in Figure 8. The main feature of this sub-basin is the Lago Loíza Reservoir. The farm of Francisco Figueroa, a landowner that we interviewed is also located in the eastern portion of this watershed. We focused our study on the southern portion of this sub-basin because the northern portion contains parts of the city of Caguas, which is contained in the Caguitas Watershed mentioned above. The critical areas of the sub-basin are shown in Figure 16. By looking at the map it is clear that there exist more suggested areas of reforestation then critical reforestation. Suggested areas of reforestation are primarily located along the Rio Grande de Loíza, which flows down the center of the watershed. This is an indication that land that borders the Rio Grande de Loíza are areas susceptible to erosion and sedimentation because of their slope and soil type.

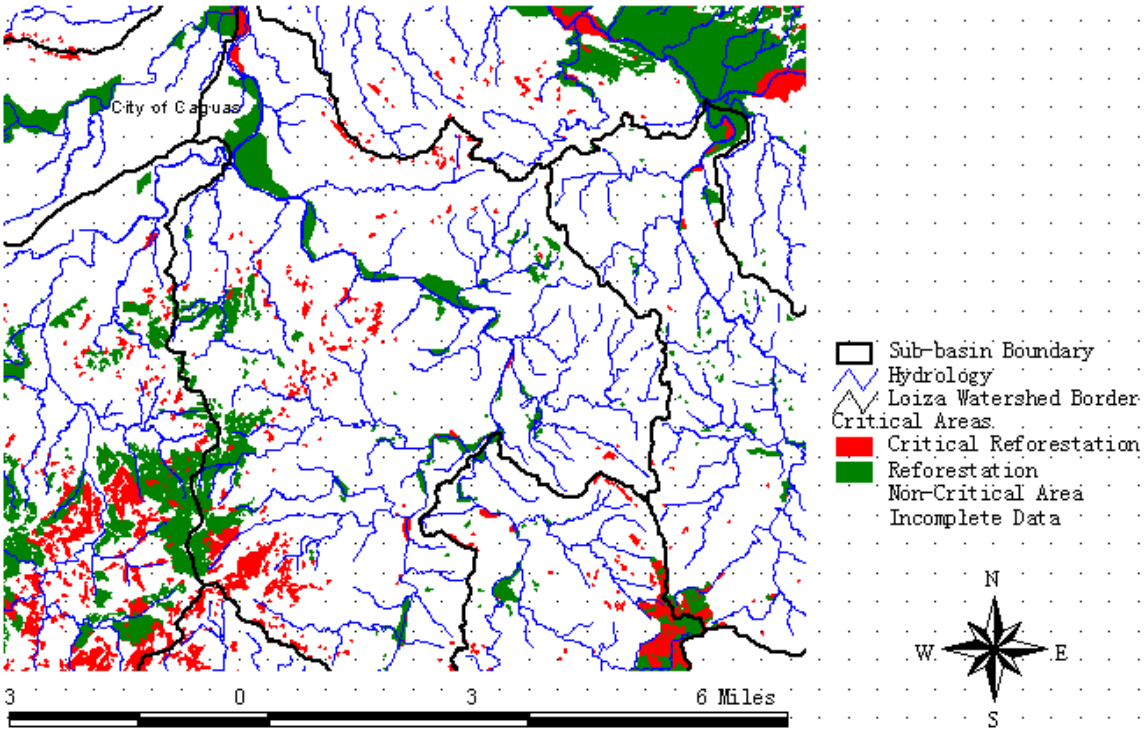

Figure 16: **Critical areas in the Rio Grande de Loíza at Carraizo Dam Sub-Basin**

The land use map of the Rio Grande de Loíza at Carraizo Dam Sub-Basin is shown below in Figure 17. This majority of land within this watershed is either forested or pasture. The Lago Loíza is bordered primarily by pastureland, which is an indication that pollutants from cattle and other animals are a prime cause of non-point source pollution in that area. Located in the top of the watershed exists a large portion of agricultural land that is close to the Lago Loíza. This land may also have an influence on the water quality and health of the area.

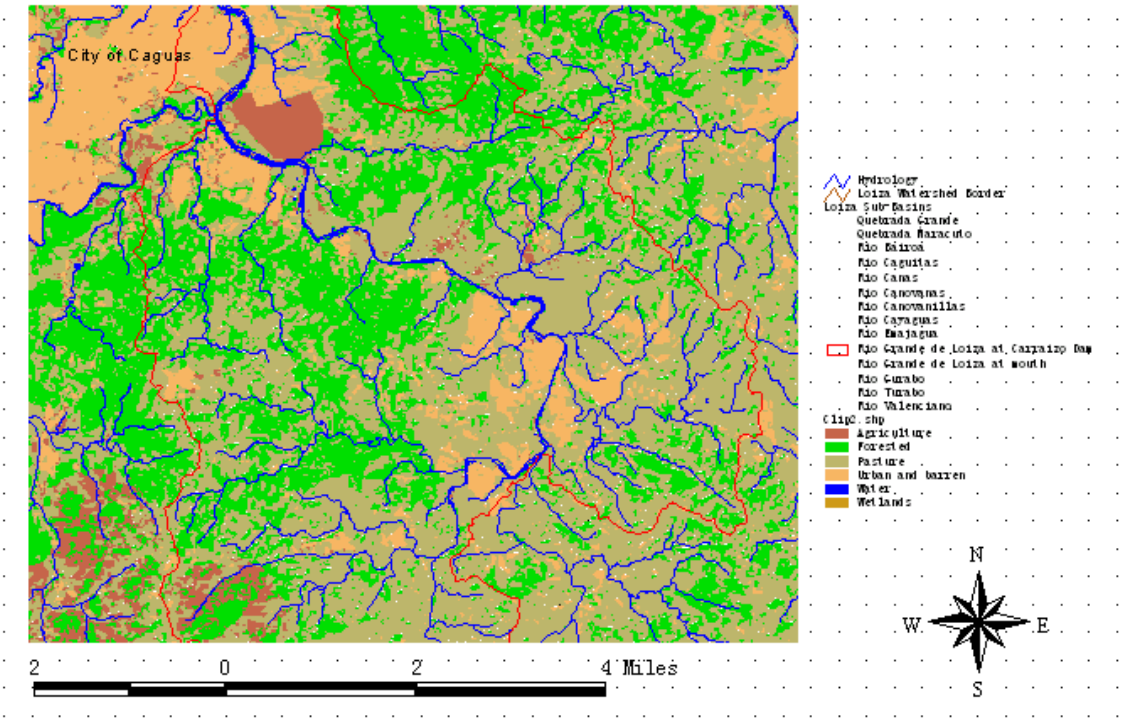

Figure 17: Land use map for the Rio Grande de Loíza at Carraizo Dam Sub-Basin

The combination of land use and critical areas in the Rio Grande de Loíza at Carraizo Dam Sub-Basin is shown in Figure 18.

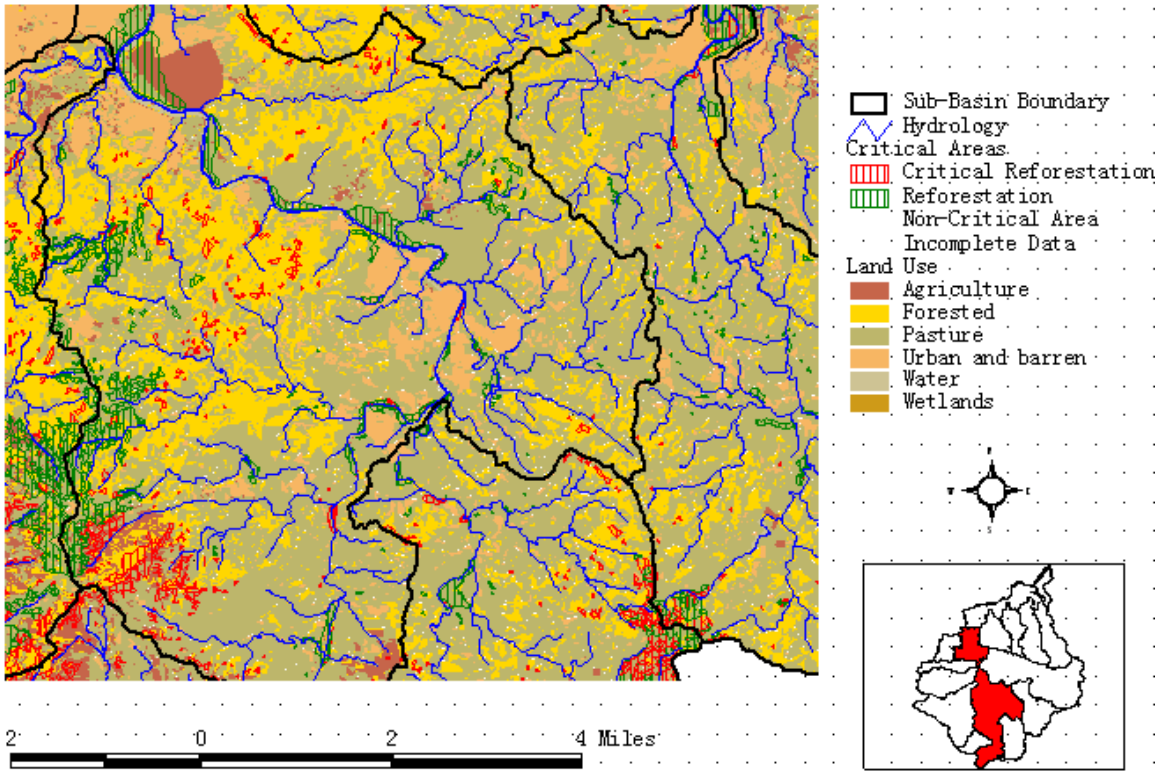

Figure 18: **Combination of land use and critical areas in Rio Grande de Loíza at Carraizo Dam Sub-Basin**

By examining Figure 18, it is evident that a majority of land in this sub-basin is pastureland. The combination map clearly shows that most of these pastures are situated in areas that require reforestation. Pink and Green areas are highlighted along local tributaries and the Lago Loíza Reservoir. The area along the Rio Grande de Loíza itself is predominately deforested. This causes many of the sedimentation problems for the Loíza. A reforestation plan in these pastures that includes fencing in cattle, reforesting along the river using the Riperian Buffer Zone strategy, and reforesting the critical areas shown in Figure 18 would help to drastically reduce the sedimentation and non-point source pollution problems of the watershed.

5.4 Case Study Conclusions

The conclusions of the case study show that pastureland is predominately found in many critical areas in need of reforestation in both watersheds. Pollution from cattle and other animals because of improper land management are factors that need to be considered when reforesting these areas. This case study used the critical selection factors from **§ 4.1.1** to provide specific areas for reforestation. Finding areas for reforestation gave an indication about where watershed management techniques should be concentrated in order to reduce non-point source pollution. This technique and information that it generates can be used by other organizations to focus future reforestation projects in specific critical locations of watersheds. Reforestation of the critical areas demonstrated in this section will help to reduce sedimentation in the Loíza Watershed.

6.0 Conclusions and Recommendations

Many management actions, strategies, and measures have been planned and implemented for protection at the watershed level. However, water quality is still one of Puerto Rico's highest priorities and there is always room for improvement of the existing management practices. Through data collection we discovered what management practices have already been implemented and organized. Through our analysis of these existing plans we determined where weaknesses were present and what we could recommend for a more effective management process of the watersheds in Puerto Rico. We have organized our recommendations into two categories, physical and social:

- Physical
  - Reforestation
  - Enforcement
  - Reforestation Progress Assessment
- Social
  - Collaboration of Agencies/Organizations
  - Landowner Assistance
  - Public Education

6.1 Reforestation

We have developed several methods to use when choosing areas for reforestation. The recommendations we made were based on our critical area analysis. Also, through interviews we established that using a community-based approach for reforestation is the most effective and efficient way to improve the status of Puerto Rico's watersheds.

6.1.1 Critical Area Selection

We recommend using our procedure for establishing critical areas of reforestation. The most significant areas that should be reforested first are those that we

discuss in our data analysis. We recommend establishing critical areas based on land use, soil, and slope of land. These are the three major factors that we discovered to lead to poor water quality. By focusing reforestation efforts on the areas determined using this effort, high erosion and non-point source pollution should be dramatically decreased. Forestry technicians should focus on reforesting these critical areas prior to reforesting anywhere else.

6.1.2 Community Approach

A method that we strongly recommend implementing is working at the sub-watershed level using a community-based approach. This would create a community and common cause between neighbors within the sub-watershed. Finding the boundaries of the private land, critical areas within those boundaries, and encouraging landowners to become involved with incentive programs would be the most efficient way to manage a watershed. This approach will allow forestry technicians to be involved directly with the landowners and establish an organized reforestation process between private landowning neighbors. The community approach will allow reforestation projects in one landowner's property to continue into another landowner's property. Landowners will then be able to communicate and work together at the sub-watershed level. This approach would be time consuming, but more effective than focusing on a larger scale or at the watershed level.

6.2 Enforcement

There exist problems with the enforcement of management practices that are crucial to protecting the watersheds. One well-organized and studied plan is the NRCS

Riparian Forest Buffer Zones. The NRCS study and development of the Riparian Buffer Zones should be implemented wherever land is used for agriculture and where there are high deposits of sediment entering a river. This report is unquestionably a very effective process for decreasing non-point source pollution.

Another practice that should be enforced is fencing for cattle, to prevent them from contributing to the fecal coliform deposits into the rivers and streams. The USGS monitoring stations have shown that fecal coliform is one of the highest forms of non-point source pollution effecting Puerto Rico's water quality. We recommend using waterholes as a water source for the cattle. This option will provide cattle with another source off drinking water instead of streams and rivers. Enforcing a law for the confinement of cattle away from water bodies should be seriously considered and put into effect.

Also the development of structures on steep hillsides should be prevented. Development of structures on steep hillsides leads to more deforestation and erosion issues. This deforestation of steep hillsides can also lead to dangerous landslides. We recommend enforcing a law to prohibit development on hillsides with a slope greater than thirty degrees. We selected this slope because the critical areas we chose for reforestation, in our data analysis, involve land slopes higher than thirty degrees. We recommend these three major issues be strongly enforced.

6.3 Reforestation Progress Assessment

We recommend measuring the effects of reforestation on water quality in these critical areas. The management practices we have analyzed and the recommendations

that we have made must be measured to identify how they have improved the quality of the watershed. Once the reforestation of a critical area has been completed it will be helpful to see how effectively the reforesting techniques contributed to improving the water quality and decreasing sedimentation. If the reforestation techniques used in one critical area have shown improvement in water quality then those techniques can be applied in other critical areas of the watershed. This will demonstrate how reforestation can effectively increase water quality and decrease sedimentation. Calculating TMDL's before, during, and after the reforestation of these critical areas should show the decrease in non-point sources of pollution. Also the amount of sediment in the river should be calculated before and after reforestation to show the improvement in that area. Overall, it will be critical to show how reforestation has improved water quality.

6.4 Collaboration of Agencies/Organizations

As we have discussed previously in this report, the communication and cooperation between agencies has slowed the process for watershed management and protection. Improving the communication between agencies at the federal, commonwealth, and municipal levels will greatly benefit and quicken the process to improve water quality and decrease erosion, sedimentation, and non-point source pollution. The following section will focus on recommendations to create an alliance between all these agencies which should improve the progress of watershed restoration in Puerto Rico.

6.4.1 Puerto Rico Watershed Control Committee (PRWCC)

We recommend creating a committee to focus on watershed control. The purpose of this committee will be to improve the communication between government, commonwealth, and municipal environmental agencies. Each agency involved in watershed management will assign a representative to be a part of this committee. The committee will focus on the sub-watershed and watershed levels rather than the municipal level. The committee will work on a sub-watershed by sub-watershed basis as a group instead of multiple unorganized projects in different watersheds. The PRWCC will also focus on the critical areas of non-point pollution, sedimentation, erosion, and water quality in the watersheds. This will be beneficial because the agencies will be able to distribute the work load evenly and efficiently. For example, the USGS and EQB could focus on the monitoring stations and TMDL's, the DNER could provide assistance with private landowners and forestry, etc. Work distribution and collaboration with one sub-basin at a time will speed up the reforestation process and make it more effective.

6.4.2 Government, Commonwealth, Municipal Website/Server

We recommend creating a website off of a centralized server that is updated regularly with all the agencies current projects, information, and GIS layers. We experienced some problems when collecting data from the different agencies. The problem of contacting and locating the proper employees from each agency left us with incomplete information and less time to complete our report. Also, major problems that we faced were that some agencies have a lack of computer storage, out of date information, and loss of data when personnel leave. This was encountered at the DNER

and EQB, where information that had previously been used was lost. Centralizing the data will allow for a greater ease of access for each agency, protect information from being lost or misplaced, and allow public access to some of the data. It would be beneficial to all agencies and municipalities if there was some source of information available for everyone.

We recommend, as the most efficient solution to this problem, organizing and creating a website off of a centralized server with all valid watershed information. The Puerto Rico Watershed Control Committee recommended above could create a department that collects and updates information. The information included on this server will include GIS mapping layers, current projects and studies, statistics of TMDL's, water quality, sedimentation, pollution, and management practices. It is also important that this information be updated yearly or bi-yearly. By doing this, individuals will be able to access efficient and up-to-date information in an expedient manner. The money that was saved by preventing repetitive studies by different agencies, and the time saved in accessing this information would help to cover the costs of this department. This recommendation will hopefully improve communication, distribution of work load between agencies, and access to information.

6.5 Landowner Assistance

We recommend providing equipment, monthly checkups, a bi-annual conference, and tax incentives for reforestation needs to landowner's involved in the incentive programs. Assisting landowner's with reforestation should make the process to protect watersheds more efficient.

6.5.1 Equipment and Assistance

We recommend more involvement and willingness to assist private landowners with equipment and assistance. Many private landowners have trouble accomplishing their reforestation projects because of the lack of equipment and man power it takes to complete large projects. The involvement of forestry technicians from federal or commonwealth agencies will not only contribute a larger work force, but also the necessary equipment and knowledge to complete high scale reforestation projects. The agencies need to work on being more helpful and responsive to the needs of the landowners. The reforestation of private land is critical to the protection of the watershed.

6.5.2 Checkups

It is important that professionals oversee the reforestation efforts of private landowners. Many landowners may be uneducated on the proper techniques used by forestry technicians and also about the management practices associated with controlling non-point source pollution, erosion, and sedimentation. We recommend the implementation of monthly visits to assess the progress and procedures of the private landowner's reforestation efforts. This will also allow the forestry technicians to make any recommendations and correct any problems that the landowner is experiencing. The progress and problems of the landowners should be recorded after each visit so that the technicians can identify the improvements from their last check-up. This will give the forest technician an indication of how the landowner is doing over periods of time. The

implementation of these checkups will increase the knowledge of the landowners and correct procedures for reforestation.

6.5.3 Bi-Annual Conferences for Landowners

In our interview with Francisco, we asked about the communication between landowners and the need for professional assistance. As mentioned above, not all landowners are well-educated with watershed management. Francisco mentioned how difficult it was to set up meetings with other landowners because of his busy schedule and the schedule of other individuals. To initiate communication between the private landowners, we recommend that forestry and hydrology professionals schedule conferences to occur bi-annually. The conference would give the landowners the opportunity to discuss their progress, problems, and suggestions with each other and to consult the professionals. The landowners that have been involved in the reforestation incentive programs for multiple years could act as mentors to the incoming participants. It would be educational and allow the landowners to work together at a watershed or sub-watershed level rather than individually.

6.6 Public Education and Involvement

Increasing public awareness of ecological issues will greatly benefit the environmental agencies efforts to restore Puerto Rico's forests. Educating the public about the current problems with water quality will hopefully get them more involved in assisting the environmental agencies. If the public is more aware of the ecological

problems that Puerto Rico is facing, then environmental laws and regulations will be easier to execute. Public education is necessary for protecting, conserving, and managing Puerto Rico's land and water bodies.

6.6.1 Communication

We recommend using newspaper, television, or radio to inform the general public about the environmental problems Puerto Rico is experiencing. These forms of communication would hopefully be available and reach out to the public across the whole Island. This would be more effective than organizing educational workshops and other outreach programs because not everyone attends these programs and they are not implemented throughout the entire Island. Using newspapers, television, or radio will provide education for all age groups and economic classes. Information that should be conveyed to the public is problems with pollution, the current status of water quality, the possibilities that may result from poor water quality, and how the public can contribute to protecting the environment.

6.6.2 Incentive Program Awareness

Another way to benefit the environmental agencies efforts for reforestation and improving water quality would be to inform private landowners about incentive programs. It is most important to find those areas where reforestation is critically needed and inform the private landowners in those areas of the benefits of the incentive programs and the importance of their participation. This task could be performed by using pamphlets or flyers that cover all aspects of the incentive programs and the problems

Puerto Rico is experiencing in its watersheds. It is extremely important that private landowners located in critical areas of non-point source pollution and sedimentation use reforestation to protect the watershed.

6.6.3 Watershed Volunteer Cleanup Program

The implementation of a fall and spring cleanup would effectively involve the public in protecting the watershed. Through field research we noticed a lot of litter polluting the rivers and land in the watershed. Organizing a voluntary cleanup would increase the public's respect for the environment and increase public involvement. This would be most effective in urban areas. Cleaning up trash and objects directly thrown into the water will help to reduce the overall pollution and restore beauty to the river. For example, in Worcester, Massachusetts, there is a fall and spring cleanup that the community and local universities participate in to sweep the streets and pick up litter in the parks and along bodies of water. This program could be easily organized and would be very beneficial in protecting against pollution.

6.7 *Summary*

The implementation of these recommendations should improve watershed management in Puerto Rico. Throughout this report, we have displayed the critical factors to consider for reforestation, the lack of communication and collaboration between agencies, some of the current major watershed management plans, and our own recommendations to improve current management strategies and to create a unified

watershed management process. Our recommendations can lead to a more effective and efficient management process for watersheds in Puerto Rico.

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Appendix A: Project Purpose

Department of Natural and Environmental Resources

P.O. Box 9066600, PTA. De Tierra Station

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Fax: 787-723-4255

The Department of Natural and Environmental Resources (DNER) needs to develop and establish a reforestation program at a watershed level. The purpose of the program is to reduce soil erosion, improve water quality, restore ecological systems, stimulate the restoration of wildlife habitat, connect fragmented ecological systems, promote biodiversity, reduce negative impacts in estuaries, and coastal habitat, diversify the recreational spectrum to the population, improve the landscape and the scenic value of the island, an stimulate citizen participation in the protection and conservation of the natural system among others. To achieve these purposes, it is necessary to identify the best reforestation areas, recognize land uses or potential uses in a sustainability framework that integrate and recognize the ecological systems of our island and to place

the most appropriate species in the most needed areas. At the same time it is necessary to evaluate and consider the economic, commercial, and urban activities that affect these watersheds.

The collection of some of the data needed for this project can be done with the assistance of the Worcester Polytechnic Institute (WPI). Students from the WPI will be in Puerto Rico collecting information needed to prepare a final report of findings and recommendations of the study done according to the selected parameters of the big picture in the watershed analyses stated above. The final report has to be presented by WPI both digitally and written in or before May 10, 2003

Appendix B: Contact List

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Raul Santini
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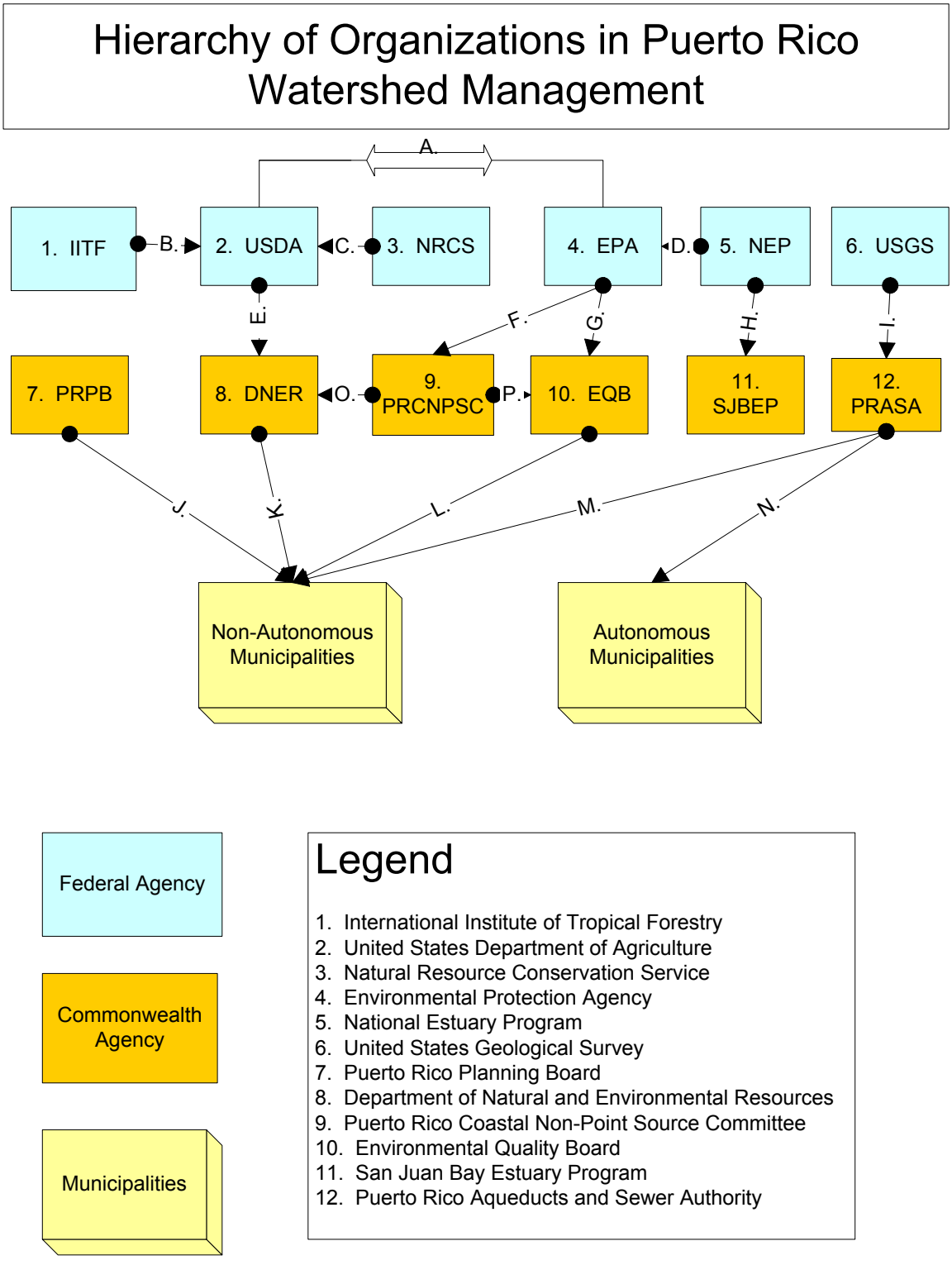
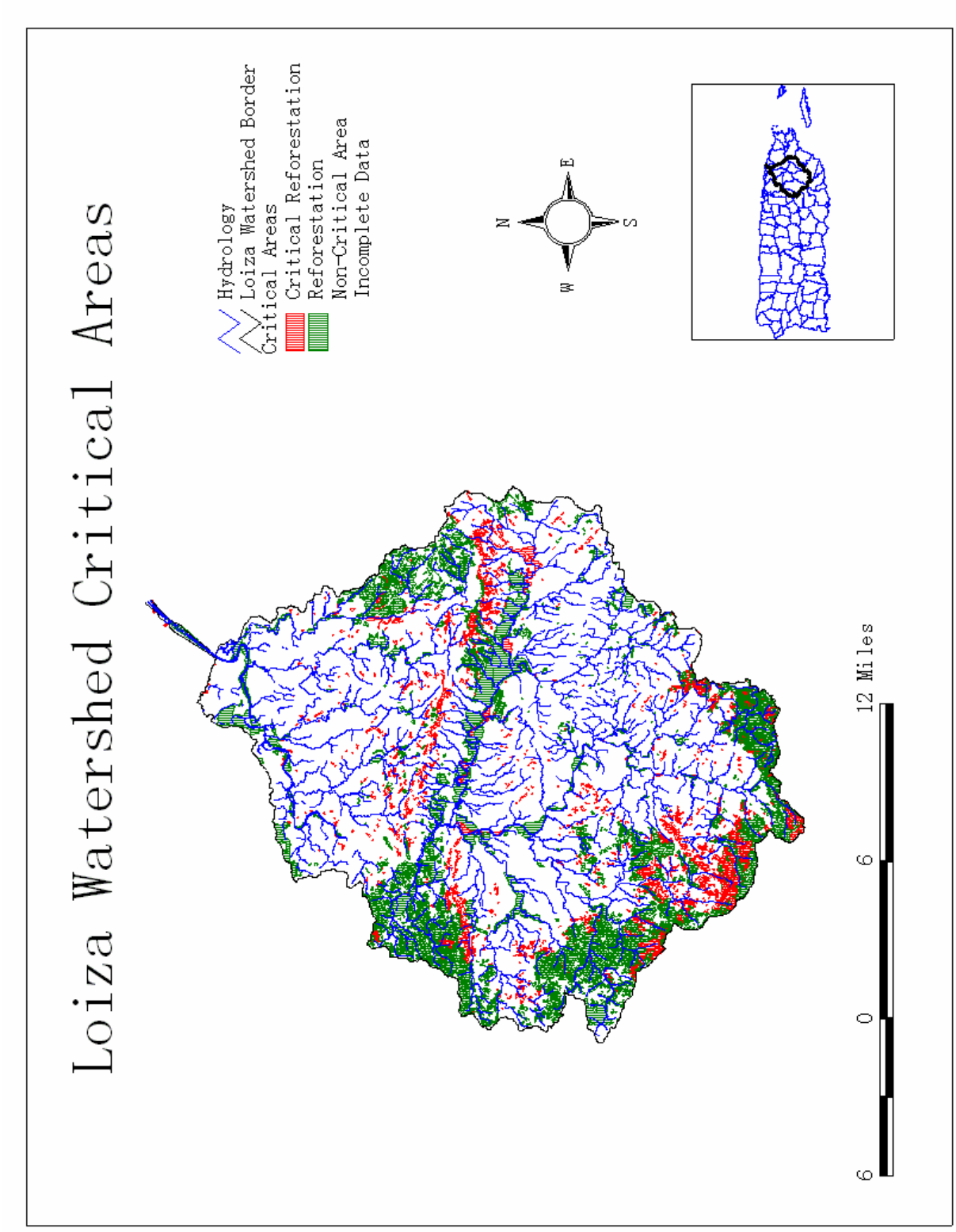
Appendix C: Government Agency Hierarchy

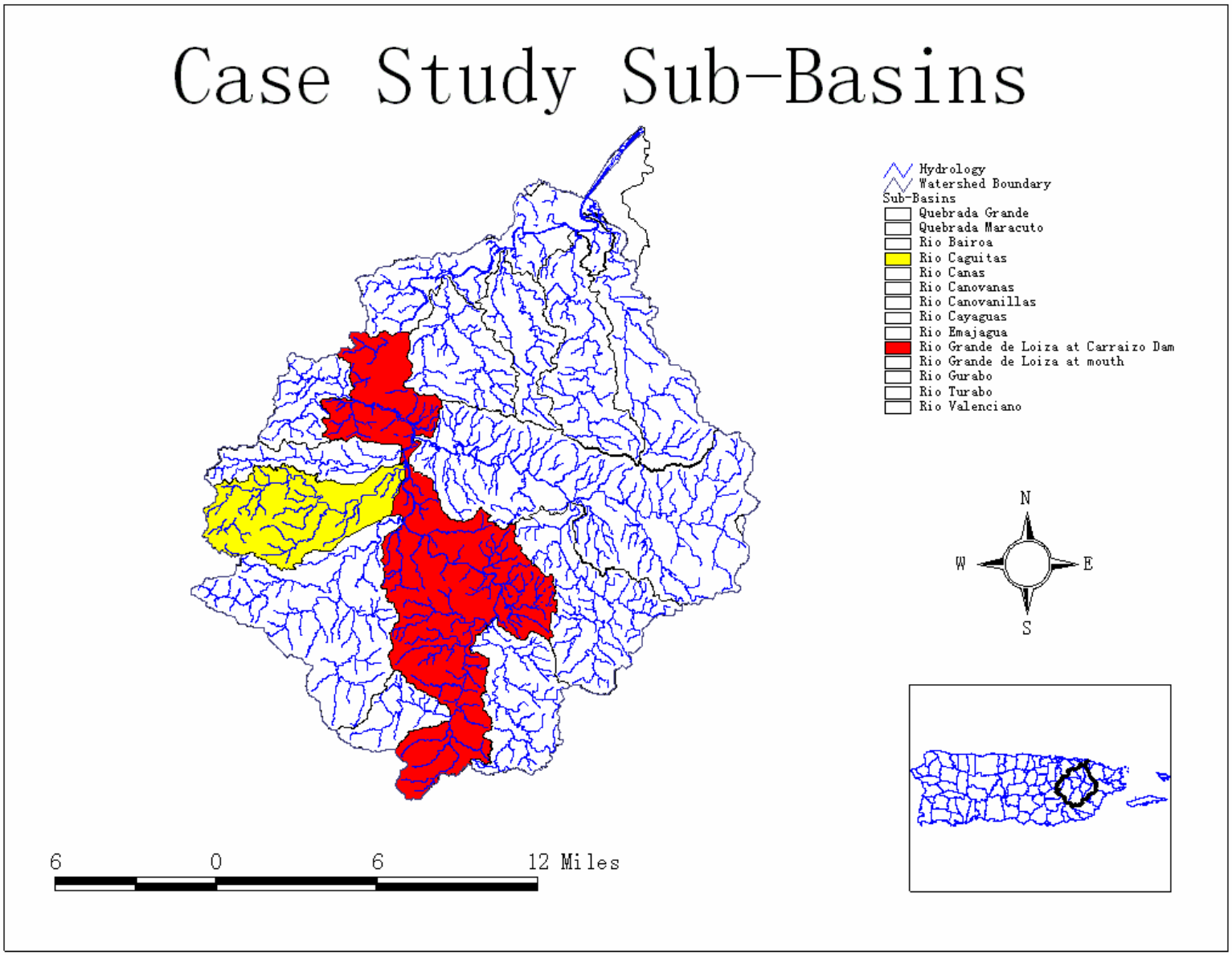


Legend B

A. Work in conjunction to enforce Federal Regulations
    a. EPA, the EQB, and subdivision of USDA (the NRCS) worked together to create the plan *Puerto Rico Watershed Restoration Action Strategies*
B. IITF is a sub division of the USDA
C. NRCS is a sub division of the USDA
D. EPA provides money and technical support for the NEP
E. USDA provides money and technical support of the DNER
    a. DNER and a subdivision of the USDA (the IITF) worked together to create the plan *Guias De Reforestacion par alas Cuencas Hidrograficas de Puerto Rico.*
F. EPA provides money and technical support to the PRCNPSC
    a. EPA, DNER, and EQB all provided information and work in the creation for the PRCNPSC's *Puerto Rico Coastal Non-Point Pollution Control Plan Update.*
G. EPA provides money and technical support to the EQB.
    a. EPA, the EQB, and subdivision of USDA (the NRCS) worked together to create the plan *Puerto Rico Watershed Restoration Action Strategies*
H. SJBEP is the San Juan Bay portion of the National Estuary Program
    a. Created a plan that called for cooperative actions between the organizations called the *Comprehensive Conservation and Management Plan for the San Juan Bay Estuary.*
I. USGS provides water quality information to PRASA
J. PRPB plans out all environmental projects in Non-Autonomous Municipalities
K. DNER completes the works of designed by the PRPB for the non autonomous municipalities.
L. The EQB inspects and carries out projects for the Commonwealth in non-autonomous municipalities.
M. PRASA maintains the sewerage and water systems for the non-autonomous municipalities.
N. PRASA maintains the sewerage and water systems for the autonomous municipalities.
O. DNER is a member of the PRCNPSC.
    a. EPA, DNER, and EQB all provided information and work in the creation of the PRCNPSC's *Puerto Rico Coastal Non-Point Pollution Control Plan Update*
P. EQB is a member of the PRCNPSC.
    a. EPA, DNER, and EQB all provided information and work in the creation of the PRCNPSC's *Puerto Rico Coastal Non-Point Pollution Control Plan Update*

Appendix D: GIS Maps




Case Study Sub-Basins
Hydrology
Watershed Boundary
Sub-Basins
Quebrada Grande
Quebrada Maracuto
Rio Bairoa
Rio Caguitas
Rio Canas
Rio Canovanas
Rio Canovanillas
Rio Cayaguas
Rio Emajagua
Rio Grande de Loiza at Carraizo Dam
Rio Grande de Loiza at mouth
Rio Gurabo
Rio Turabo
Rio Valenciano
N
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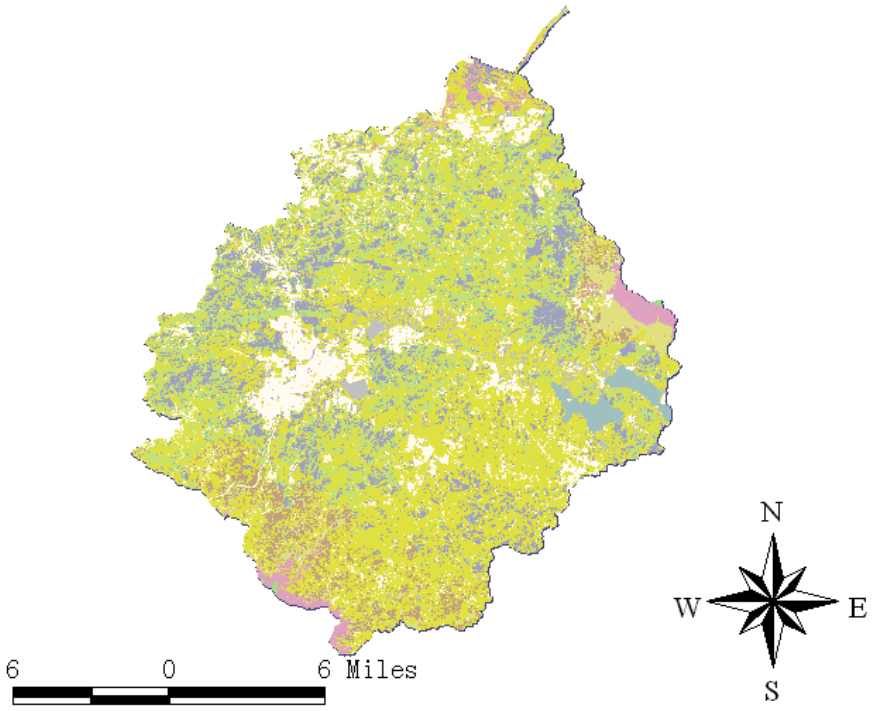
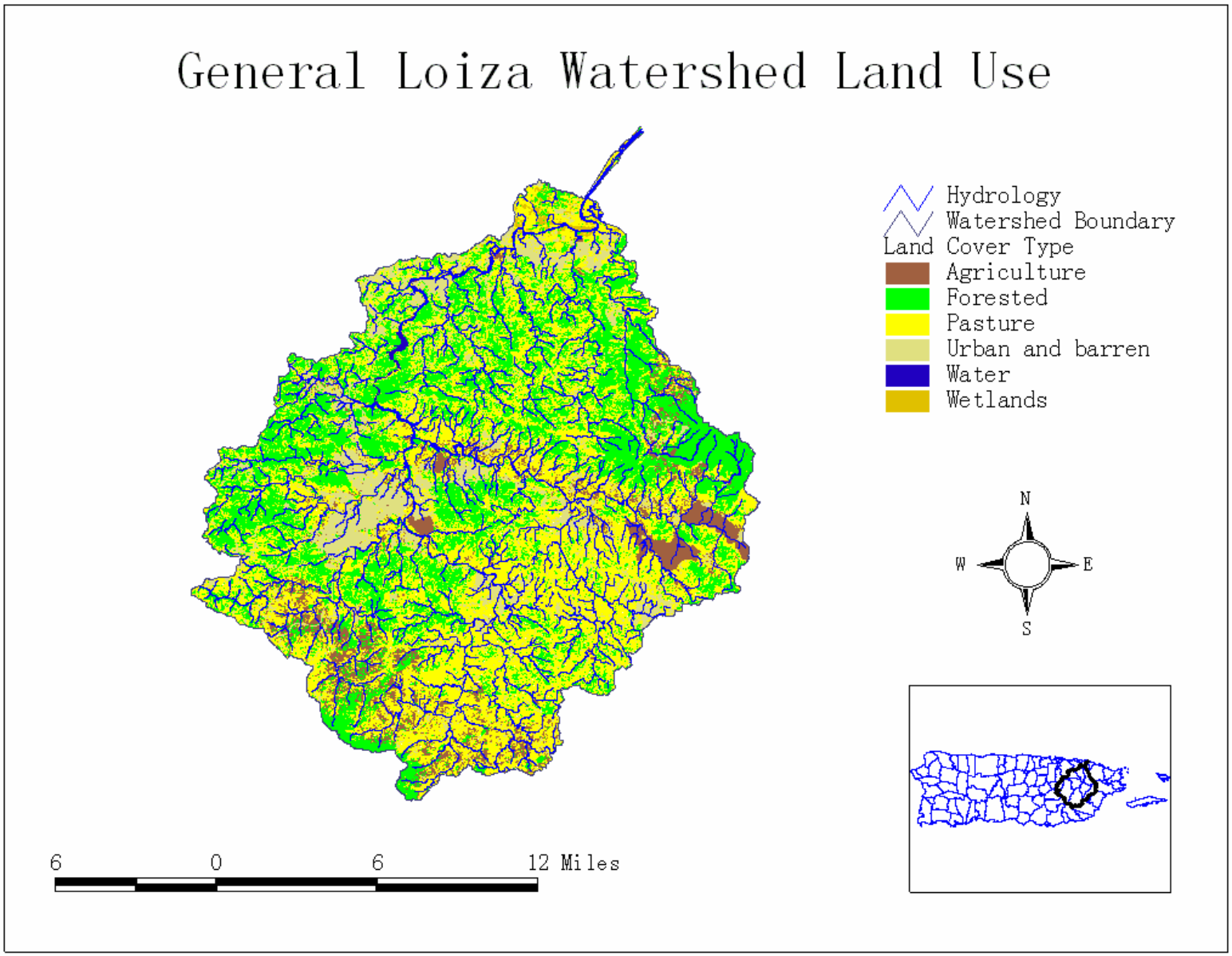
6
0
6
12 Miles

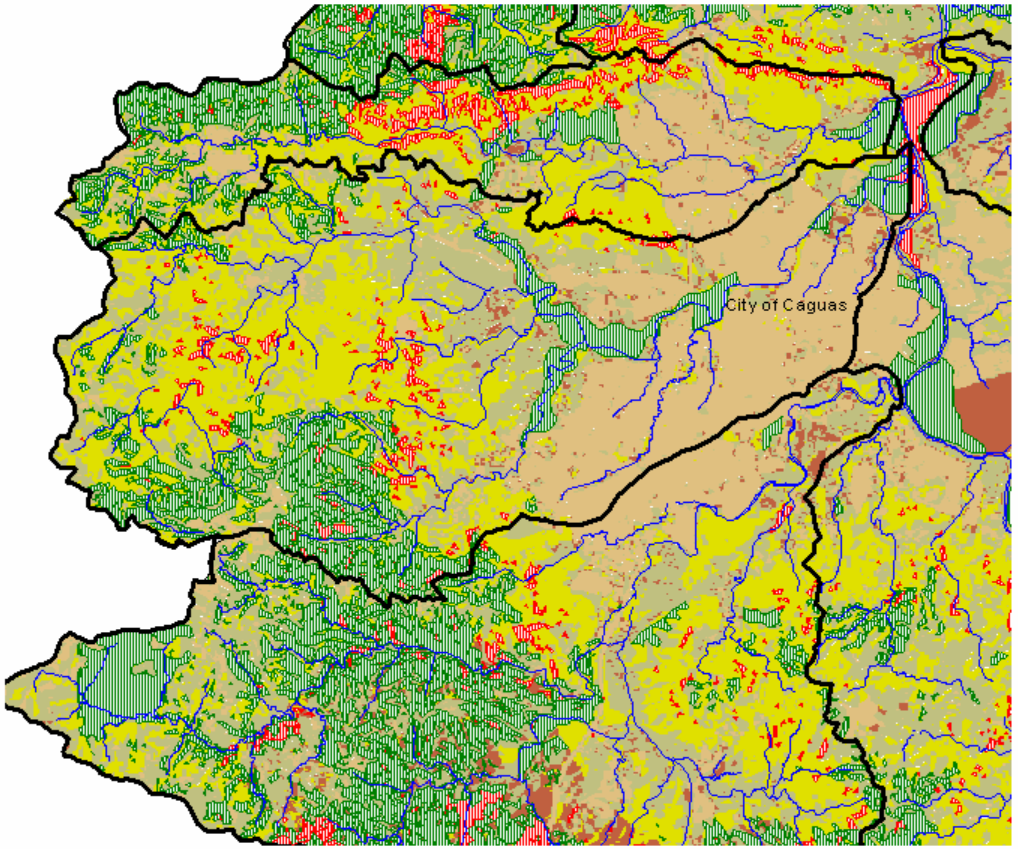
Loiza Watershed Land Use



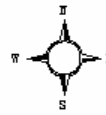
Land Cover Type
- Active sun/shade coffee, submontane and lower montane wet forest/shrub
- Agriculture
- Agriculture/hay
- Lower montane wet evergreen forest - mixed palm and elfin cloud forest
- Lower montane wet evergreen forest - tall cloud forest
- Lowland moist coconut palm forest
- Lowland moist seasonal evergreen and semi-deciduous forest
- Lowland moist seasonal evergreen forest
- Lowland moist seasonal evergreen forest/shrub
- Other emergent wetlands (including seasonally flooded pasture)
- Pasture
- Sand and rock
- Submontane and lower montane wet evergreen forest/shrub and active/abandoned shade coffee
- Submontane wet evergreen forest
- Tidally and semi-permanently flooded evergreen sclerophyllous forest
- Tidally flooded evergreen dwarf-shrubland and forb vegetation
- Urban and barren
- Water
- Watershed Boundary

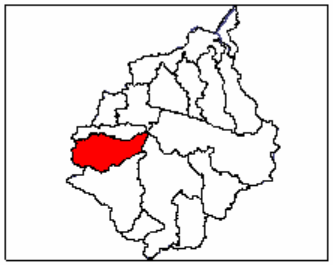

General Loiza Watershed Land Use
Hydrology
Watershed Boundary
Land Cover Type
Agriculture
Forested
Pasture
Urban and barren
Water
Wetlands
N
W
E
S
6
0
6
12 Miles

Caguitas Sub-Basin Critical Areas

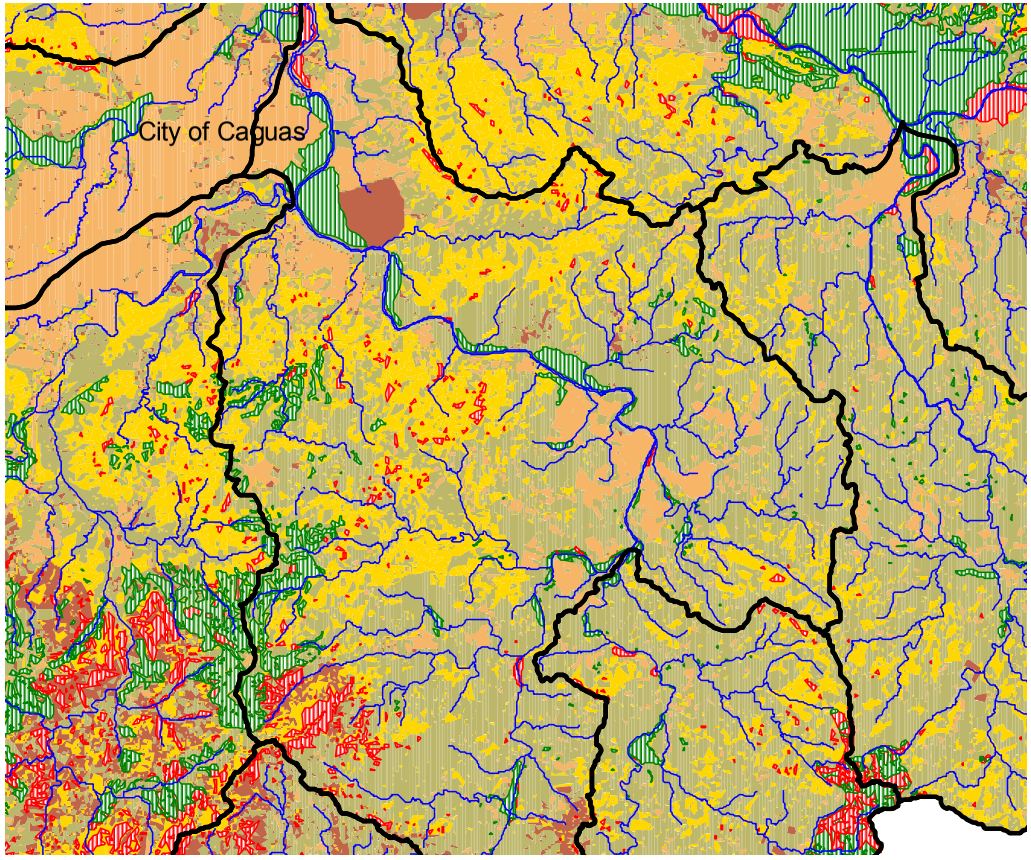


Sub-basin Boundary
Hydrology
Loiza Watershed Border
Critical Areas
Critical Reforestation
Reforestation
Non-Critical Area
Incomplete Data
Land Use
Agriculture
Forested
Pasture
Urban and barren
Water
Wetlands



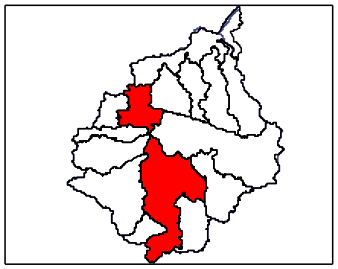


Loiza Sub-Basin Critical Areas



Sub-basin Boundary
Hydrology
Loiza Watershed Border
Critical Areas
Critical Reforestation
Reforestation
Non-Critical Area
Incomplete Data
Land Use
Agriculture
Forested
Pasture
Urban and barren
Water
Wetlands

N
W
E
S



2 0 2 4 Miles