MANAGEMENT OF THE RÍO GUAYNABO CONSERVATION EASEMENT

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Report Submitted to:

Professor Dominic Golding
Professor John Zeugner

Puerto Rico, Project Center
By

Luke Fekete

Chris Paulli

Jordan Skelly

Sabrina Zayas

In Cooperation With

Juan Rodríguez, Project Coordinator

The Conservation Trust of Puerto Rico

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

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ABSTRACT

This project, sponsored by the Conservation Trust of Puerto Rico, studied the Río Guaynabo Conservation Easement, a twenty-six acre parcel that was recently acquired by the Trust. The project group produced a separate management plan for the development of the property that includes a recommended trail map, detailed trail design strategies and techniques, and an interpretive program themed towards watershed education and conservation. The plan suggests ideas for a guided tour of the property that utilizes site specific information and interactive activities with the goal of educating the community about environmental responsibility and the importance of watershed conservation.

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EXECUTIVE SUMMARY

Puerto Rico has suffered greatly in past years from heavy deforestation caused by the need to support its ever growing population. The island has 1,100 people per square mile, ranking it one of the five most densely populated areas in the world. Fortunately, in recent years, urban living has become more prominent as well as an increase in industrial employment. This has resulted in the abandonment of agricultural fields, many of which have become reforested with secondary growth forest. It is important to the future Puerto Rico that both virgin forests and secondary forests be conserved.

The Conservation Trust of Puerto Rico (the Trust), also known as Fideicomiso, is a non-profit organization which obtains land of ecological, aesthetic, historical and cultural value in order to protect and enhance the island's natural resources. Most importantly, the Trust aims to develop interpretive and educational programs in order to provide awareness about the importance of protecting these lands.

The Trust has recently acquired a parcel of land known as the Río Guaynabo Conservation Easement, which is part the Bayamón River Watershed. The goal of the project team was to create a management plan for the property that focused on the theme of watershed conservation. The management plan includes a trail system with recommendations for trail locations and designs, and also an assessment of the site's watershed in order to provide interpretive and educational information on the importance of conserving watersheds.

The team's goal was accomplished first by developing criteria for the management plan. This included a review of relevant literature and map information. The team also visited sites owned by the Trust including La Hacienda Buena Vista and Las Cabezas de San Juan. These site visits provided the group with valuable knowledge on how Fideicomiso manages and designs their trails, and how they present their educational material. The team also established that the site will be visited by the AMIGOS program; a voluntary group of citizens and organization which help support the mission of the Trust, and groups of school children but will not be open to the general public.

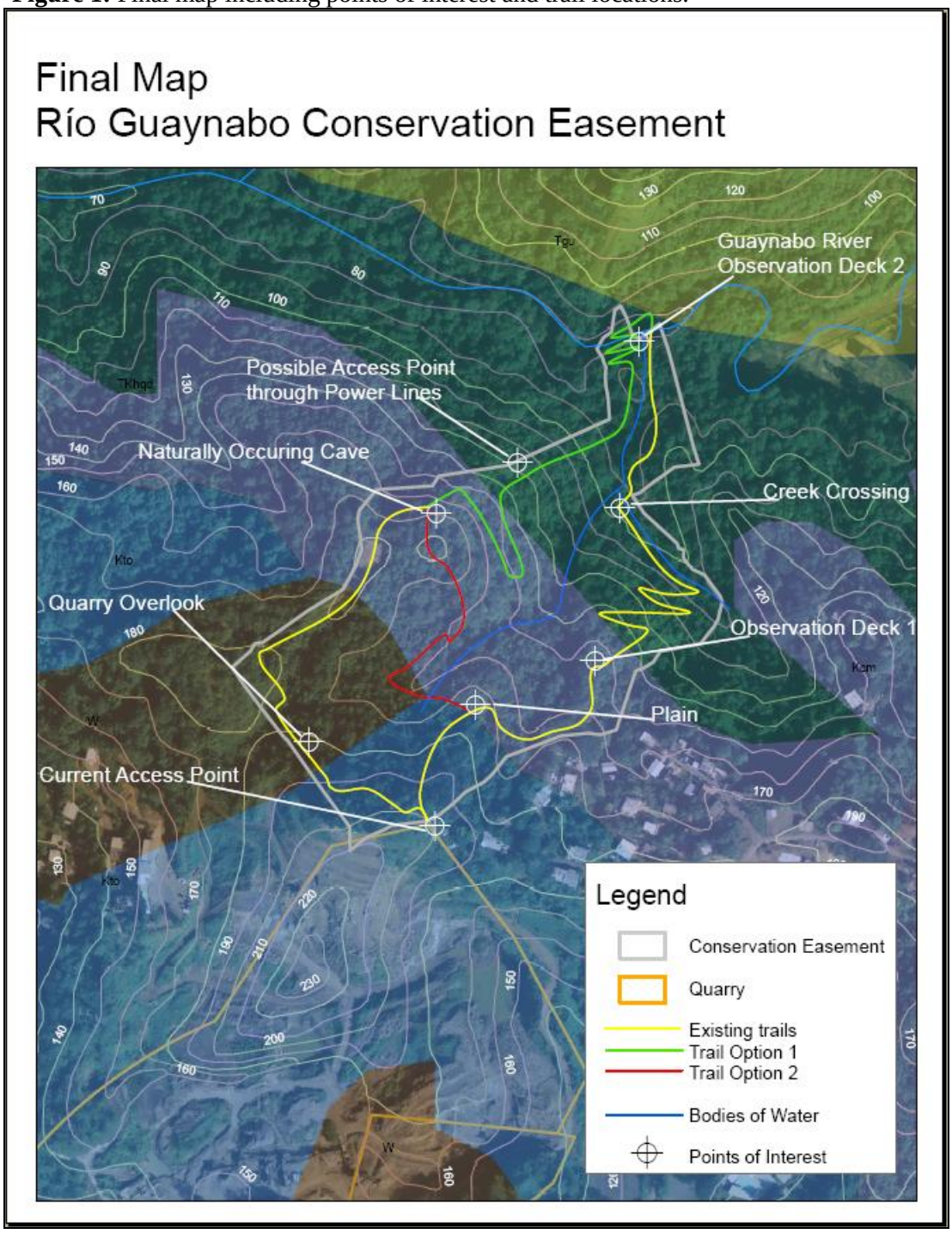
Our first objective was to create a network of trails. Points of interest were chosen for the trails not only because of their scenic interest but also because they help portray the theme of the importance of watershed. The site directly abuts a quarry which mines limestone. It is important to show the quarry as a point of interest because it shows how developments can affect a watershed. Specifically in the site, the change in elevation caused by the quarry dried one of the

creeks found in the Río Guaynabo Conservation Easement. The dried creek crosses and combines with a flowing creek. The creeks are also recommended as a point of interest because they show how water flows in a watershed. The creeks flow into the Guaynabo River which is recommended as the main point of interest for the site. Finally, the west side of the site houses a cave which is generally only found in the karst regions of Puerto Rico on the west side of the island. The cave is not only an aesthetic point of interest but can also be used as segue to explain runoff.

Through informal interviews with Fideicomiso staff, it was established that the final trail should be created primarily out of the existing trails. The team then walked the existing trails in order to determine which best displayed the points of interest and had the most accommodating level of difficulty. The team recommended two options for the trail locations. The first follows a loop of the property however requires extensive clearing of previously existing trail which have become overgrown (Figure 1). However this option is recommended first because it shows the most diverse area while including all the points of interest.

If Trail Option 1 is not feasible, the trail should follow Trail Option 2, which backtracks up to from the river until it gets to the Plain where it then cuts across the property (Figure 1). Since this option requires backtracking this trail might be repetitive to visitors however requires the least amount of impact on the environment.

Figure 1: Final map including points of interest and trail locations.



The team performed extensive background research on general trail design prior to arrival in Puerto Rico. The team was able to use the background information to give specific instructions to design an easily traversable trail. It is recommended that the Trust use the turnpike trail design for the property. Details on this technique as well as methods to get through any

obstacle are located in the results section. More specifically the team recommended that the site be surrounded by a wooden fence especially in areas where there is barbed wire fencing.

Our second objective was to develop interpretive and educational tools for the site focused on the theme of watershed conservation. This was accomplished first with an assessment of specific watershed threats in the Río Guaynabo Conservation Easement in order to use these examples to portray the general watershed education. The team has concluded that the quarry should be monitored during future use. This is because of recent land loss in the Río Guaynabo property due to explosions in the quarry. Surrounding much of the property are residential developments. The undeveloped areas should be monitored for any future growth. Also, Fideicomiso should try and acquire some of these lands to further expand the Río Guaynabo Conservation Easement. The points of interest use these threats and convey the theme of the site.

The guides will be able to show the effects that digging out the quarry caused, mainly the almost completely dried up creek bed in the center of the property that feeds into the river. At the Guaynabo River, the visitors will be able to get a better picture of what a watershed is. They will have just walked downhill from the quarry. Also at the river, the team is proposing an observation deck (Observation Deck 2) be built overlooking the river. This deck will provide a nice resting spot and scenic view for the visitor. The team is also proposing a deck (Observation Deck 1) be built at the spot shown. The deck should be built off the ridgeline so that it extends into the tree canopy. This provides a spot for the guide to talk about the local birdlife as well as a better opportunity for the visitor to view them. In addition, the naturally occurring cave will provide a good spot because it will be of general interest and provides a good talking point.

The team recommended that guides provide hands on activities for visitors, especially since groups of children will visit the site. These activities should include water tests which test for pollutants and scavenger hunt for various plants and animals. In addition to activities, the guides should provide various items which will help visitors to feel involved in the tour including a map of the site, binoculars, and hand lens.

The project team developed a separate Management Plan located in Appendix B to provide to the Trust which includes the previous recommendations. If the management plan is implemented, it will help fulfill the mission of the Conservation Trust of Puerto Rico. This site will be of value to the Trust for bringing awareness to the public about the importance watershed conservation and community involvement.

AUTHORSHIP PAGE

Chapter/ Section	Primary Author	Primary Editor
Executive Summary	Christopher Paulli	Jordan Skelly
Chapter 1: Introduction	Luke Fekete	Sabrina Zayas
Chapter 2: Literature Review	Jordan Skelly	Sabrina Zayas
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2.3.2 Watershed Pollution	Jordan Skelly	Sabrina Zayas
2.4 Trail Planning and Design	Luke Fekete	Sabrina Zayas
2.4.1 Trail Clearing	Luke Fekete	Sabrina Zayas
2.4.2 Solutions for Steep Grades	Luke Fekete	Sabrina Zayas
Chapter 3: Methodology	Jordan Skelly	Jordan Skelly
Chapter 4: Results and Analysis	Jordan Skelly	Sabrina Zayas
4.1 Criteria for Management Plan	Jordan Skelly	Sabrina Zayas
4.1.1 Site Visits	Jordan Skelly	Sabrina Zayas
4.1.1 Las Cabezas de San Juan Nature Reserve	Jordan Skelly	Sabrina Zayas
4.1.2 Discover the Nature of Old San Juan	Sabrina Zayas	Sabrina Zayas
4.1.3 Hacienda Buena Vista (Vives)	Jordan Skelly	Sabrina Zayas
4.1.2 Rapid Appraisal Report	Jordan Skelly	Sabrina Zayas
4.2 Trail System	Jordan Skelly	Sabrina Zayas
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4.4 Watershed conservation Management	Jordan Skelly	Sabrina Zayas
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CHAPTER 1: INTRODUCTION

Puerto Rico is best known for its appealing climate and its many natural features, such as beaches, coral reefs, caves, and tropical rainforests. Unfortunately, population growth and widespread urbanization have taken their toll on the island's natural resources. Puerto Rico has become one of the five most densely populated areas in the world, with approximately 1,100 people per square mile, and the island's natural environment has suffered accordingly. Heavy deforestation to accommodate the needs of urban and agricultural development has resulted in the loss of nearly fifty percent of Puerto Rico's original forest cover since the nineteenth century (Aide and Grau, 2004).

A combination of factors, including habitat destruction and modification, illegal hunting, and the introduction of invasive and destructive species has caused widespread endangerment and extinction of many of the island's endemic species of flora and fauna. Currently, seventy eight species of Puerto Rican plants are federally listed as threatened or endangered while the Puerto Rico Department of Natural and Environmental Recourses lists ninety species as being threatened or endangered and over five hundred plant species that maintain a critical status. Fortunately, a recent shift toward urban living and industrial employment has resulted in the reforestation of many now unused agricultural fields and in the past 60 years, forest cover in Puerto Rico has increased thirty percent.

Currently, only 7.2% of Puerto Rican land area is protected by law for the purpose of conservation. Despite the recent improvements regarding reforestation, the current conservation policy will not be enough to counteract the steady rise in population and increasing urbanization. The environmental well being of Puerto Rico may well be in the hands of the islands next few generations of inhabitants; it is clear that education about the necessity of conservation and instilling an appreciation for Puerto Rico's natural attributes will be crucial for success.

Today, Puerto Ricans have the opportunity to enjoy approximately 250 square miles of protected land. The Conservation Trust of Puerto Rico, or Fideicomiso, is a non- profit organization that is driven to protect and preserve sensitive and ecologically valuable lands by acquiring and developing the land in a way that enhances its natural resources while disturbing the environment as little as possible. Fideicomiso is currently proud to be in the process of

protecting and responsibly developing over 18,000 acres of land spread over twenty different locations.

While Fideicomiso has been successful in developing recreational parks and reserves throughout the island, the Trust is constantly searching for new parcels of land in need of protection. This project focuses on the development of a Management Plan for a newly acquired site, the Río Guaynabo Conservation Easement. The Management Plan provides recommendations for locations and designs for a trail system in the Conservation Easement and will provide an assessment of the site's watershed in order to educate visitors about the importance of watershed conservation. In order to accomplish the goal of the management plan the team reviewed relevant literature and developed a methodology for the project which included developing criteria for the management plan, developing a trail system including trail locations and designs, and developing educational and interpretive tools for the site through an assessment of the site's watershed. The completion of the project resulted in a final trail system map, guidelines and specific recommendations for trail designs, and educational and interpretive tools for stressing the importance of watershed conservation.

CHAPTER 2: LITERATURE REVIEW

President Theodore Roosevelt was the first to bring the subject of conservation to America's attention when he adopted this term and applied it to nation's natural resources (Black and Fisher, 2001). However since then it has become unclear what conservation encompasses. There has also been much controversy over the differences between conservation and preservation and which environmental approach is superior.

The Oxford Dictionary of Ecology defines conservation as "the maintenance of environmental quality and resources or a particular balance among the species present in a given area. It also states that conservations are managed within social and economic constraints while producing goods and services for humans without depleting the natural ecosystem diversity and then contrasts that preservation protects species or landscapes without reference to human requirement. Sarkar (1999) discusses the distinction between biodiversity conservation and wilderness preservation and concludes that it is often more feasible to achieve conservation.

Although the Conservation Trust of Puerto Rico often uses the term "conservation," its actions mostly reflect preservation (complete protection of natural resources) and therefore these terms will be used interchangeably in this report.

There are many interpretations to the definition of a conserved or protected area. According to Green and Paine (1997), a protected area is defined as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means". Green and Paine (1997) also give reasons for why an area is protected, such as scientific research, wilderness protection, preservation of species and ecosystems, maintenance of environmental services, protection of specific natural and cultural features, tourism and recreation, education, sustainable use of resources from natural ecosystems, and maintenance of cultural and traditional attributes.

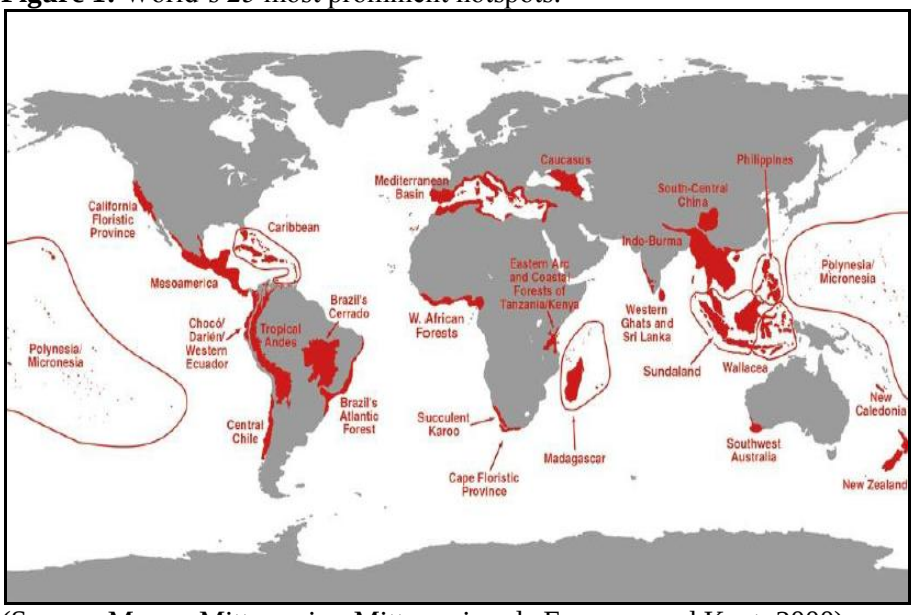
2.1 ECOLOGICAL IMPORTANCE OF CONSERVATION

The priority of the Conservation Trust of Puerto Rico is to obtain land that is of high ecological, aesthetic, historic and/or cultural value for conservation. These properties encompass several of the territory's ecological zones, including subtropical dry, moist, wet, and rain forests (Grau, Aide, Zimmerman, Thomlinson, Helmer, and Zou, 2003).

Puerto Rico has a high biodiversity with more than 2,400 species of plants, 200 species of birds, and 80 species of reptiles and amphibians (Grau *et. al.*, 2003). These lush Caribbean forests are famous for their beauty as well as their diverse collection of flora and fauna. Unfortunately, the extensive development of the island has resulted in many of Puerto Rico's endemic species being threatened with extinction. The diminishing area available for conservation resources has become a dire situation for the island. In order to maximize the protection of the most species per dollar invested, conservationists have identified biodiversity "hotspots" that feature "exceptional concentrations of endemic species and exceptional loss of habitat" (Myers, Mittermeier, Mittermeier, da Fonseca, and Kent, 2000).

The world map in Figure 1 shows the world's top 25 most prominent hotspots. The Caribbean Islands including and surrounding Puerto Rico are listed as the third most threatened hotspot in the world (Table 1).

Figure 1: World's 25 most prominent hotspots.



(Source: Meyer, Mittermeier, Mittermeier, da Fonseca, and Kent, 2000)

Table 1: Flora and fauna of hotspots

Hotspot	Original Extent of Primary Vegetation (Km^2)	Remaining Primary Vegetation (Km^2)/(% of Original)	Area Protected (Km^2) (% of Hotspot)	Plant Species	Endemic Plants	Vertebrate Species	Endemic Vertebrates
Tropical Andes	1,258,000	314,500 (25.0)	79,687 (25.3)	45,000	20,000	3,389	1,587
Mesoamerica	1,155,000	231,000 (20.0)	138,437 (59.9)	24,000	5,000	2,859	1,159
Caribbean	**263,500**	**29,840 (11.3)**	**29,840 (100.0)**	**12,000**	**7,000**	**1,518**	**779**
Brazil's Atlantic Forest	1,227,600	91,930 (7.5)	33,084 (35.9)	20,000	8,000	1,361	567
Western Equador	260,600	63,000 (24.2)	16,471 (26.1)	9,000	2,250	1,625	418
Brazil's Cerrado	1,783,200	356,630 (20.0)	22,000 (6.2)	10,000	4,400	1,268	117
Central Chile	300,000	90,000 (30.0)	9,167 (10.2)	3,429	1,605	335	61
California Foristic Province	324,000	80,000 (24.7)	31,443 (39.3)	4,426	2,125	584	71
Madagascar	594,150	59,038 (9.9)	11,548 (19.6)	12,000	9,704	987	771
Tanzania/Kenya	30,000	2,000 (6.7)	2,000 (100.0)	4,000	1,500	1,019	121
Western African Forests	1,265,000	126,500 (10.0)	20,324 (16.1)	9,000	2,250	1,320	270
Cape Floristic Province	74,000	18,000 (24.3)	14,060 (78.1)	8,200	5,682	562	53
Succulent Karoo	112,000	30,000 (26.8)	2,324 (7.8)	4,849	1,940	472	45
Mediterranean Basin	2,362,000	110,000 (4.7)	42,123 (38.3)	25,000	13,000	770	235
Caucasus	500,000	50,000 (10.0)	14,050 (28.1)	10,000	1,600	632	59

(Source: Meyer, Mittermeier, Mittermeier, da Fonseca, and Kent, 2000)

Due to their prominence as a biodiversity hotspot, Puerto Rico's forests make excellent venues for interesting, interpretive trail systems where visitors can not only enjoy the natural beauty of the island, but also be made aware of the potential threats and solutions.

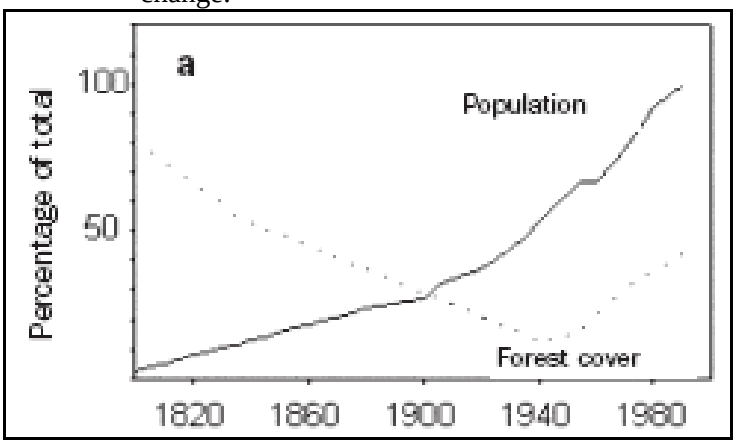
2.2 Societal Importance of Conservation

Puerto Rican population growth and change have influenced land coverage and therefore the portion of natural land available for conservation. Grau, Aide, Zimmerman, Thomlinson, Helmer, and Zou (2003) explain land-use and land-cover change (LUCC) represent a very important aspect of global environmental change. They go on to state that land-cover change is extensive in most tropical developing countries that are characterized by agricultural economies and rapidly growing populations. Much of the research on LUCC involves focuses on deforestation which is the dominant trend in most tropical areas. In contrast, while Puerto Rico suffered substantial deforestation during the nineteenth and early twentieth century, it has seen substantial reforestation over much of the main island since 1940 (Grau *et. al.* 2003).

2.2.1 Deforestation and Reforestation

According to Houghton (2003) deforestation causes over use of land, and therefore, causes a reduction in the earth's capacity to support human populations. This "over use of land" is caused by forests which are cut down and then allowed to re-grow repeatedly resulting in inferior second generation forests, soil erosion, and declining soil fertility. Deforestation in the tropics is caused by the need of lumber, fuel wood, and cropland (Copper and Griffiths, 1994). The need for these resources is caused by population growth. Puerto Rico's population density is already 1,100 people per square mile and its population has been steadily increasing since the 1800's as shown in Figure 2.

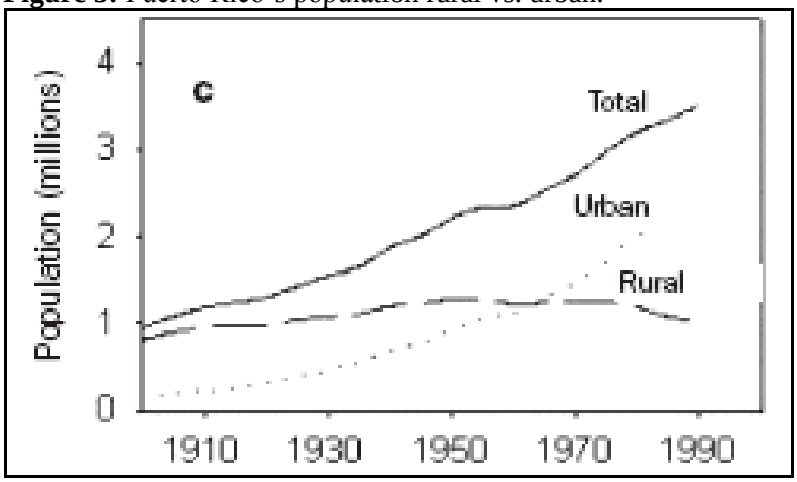
Figure 2: Puerto Rico's population growth and forest cover change.



(Source: Grau, Aide, Zimmerman, Thomlinson, Helmer, and Zou, 2003)

At the same time reforestation is occurring in Puerto Rico which is also caused by population change. In the last 40 years, rural populations living in Latin America and the Caribbean have decreased from almost half to about a quarter in size because of the decrease in agriculture (Aide and Grau, 2004). The rural and agricultural population is changing because of the increase in urbanization (See Figure 3). However, this change has allowed large areas of land, normally cultivated for crops, to reforest (Aide and Grau, 2004). In Puerto Rico forest cover increased from less than 10% to more than 40% of the territory's area in the past 60 years because of the fast recovery rate of tropical ecosystems (Aide and Grau, 2004).

Figure 3: Puerto Rico's population rural vs. urban.



(Source: Grau, Aide, Zimmerman, Thomlinson, Helmer, and Zou, 2003)

Despite this combination of deforestation and reforestation, only 7.2% of Puerto Rico's land area is protected by law for the purposes of conservation (Conservation Trust of Puerto Rico, 2007).

2.2.2 The Conservation Trust of Puerto Rico

The Conservation Trust of Puerto Rico (The Trust) is one of the most important Conservation organizations in Puerto Rico. It is a private non-profit organization that acquires and preserves parcels of land and other natural resources in Puerto Rico. The mission for the Trust is to protect and enhance the Island's natural resources. Founded in 1970 by the United States and Puerto Rico governments, the Trust was originally created to counter the adverse impacts of the aggressive modernization and industrialization in the 1960s. The Trust currently manages twenty natural reserves. Today, there are two reserves that are open to the public (Las Cabezas de San Juan Nature Reserve in Fajardo and Hacienda Buena Vista in Ponce) and one reserve that will be open to the public shortly (Hacienda la Esperanza in Manatí). Throughout all twenty natural reserves are serene lakes, vibrant wildlife and above all, many trails for users to enjoy these sites. With all of these natural resources comes added responsibility for their conservation. The Trust obtains parcels of land by donations, as well as funds generated from the rum tax returns (Conservation Trust of Puerto Rico, 2007).

The Trust can obtain parcels of land in a variety of ways. The Land Acquisition, Donations and Conservation Easement Program is the major program through which the Trust pursues its protection and conservation mission. One way the Trust receives land is through the

Conservation Easement Law of Puerto Rico (Law 183 of December 27, 2001) which encourages the private sector to participate in conservation by giving qualified participants a tax cut of 50% of the land's value (Conservation Trust of Puerto Rico, 2007). Property owners who want to protect their land in perpetuity can establish a conservation easement with a government entity, or non-governmental, non-profit organization (Conservation Trust of Puerto Rico, 2007; Starnes, n.d.).

Other ways of obtaining land and monetary donations are in effect today. Donations come from but are not limited to: current Puerto Rican residents, current USA residents, companies based in Puerto Rico, and companies based in the USA. There are certain tax benefits that come with land and monetary donations. Current Puerto Rican residents who wish to donate money to the Trust can have the contribution deducted from their adjusted gross income. The deduction will equal to the higher of two options. These options are (a) 3% of his/her adjusted gross income, or (b) 33% of contributions or donations made by said donor in that one year. If the contribution exceeds the 15% limit, the donation can then be carried over for the next 5 years (Conservation Trust of Puerto Rico, 2007). The tax benefits differ for those who live in the USA. Cash contributions from current USA residents are deductible from most state and federal tax forms up to 50% of the donor's adjusted gross income. The deduction is limited to 30% of the donor's adjusted gross income if the contribution constitutes capital assets. A similarity between cash donations for both residents is that if the donation exceeds the limit of the 50% or 30% then the donation can be carried out for 5 subsequent years (Conservation Trust of Puerto Rico, 2007).

Monetary donations from corporations differ slightly than those from residents. Corporations based in Puerto Rico are allowed to make cash donations to the Trust without exceeding 5% of their taxable net income. The 5% amount is calculated before deducting their donation. Contributions that exceed the 5% amount cannot be carried out for the next 5 years (Conservation Trust of Puerto Rico, 2007). Donations made from corporations based in the USA also differ from those made from corporations in Puerto Rico. If a corporation is subject to U.S. income tax laws, then they can deduct their cash contribution from their taxable income. The only stipulation is that the contribution cannot exceed 10% of their taxable income. If the donation exceeds the 10% limit, then the donation can be carried over for 5 subsequent years.

There are other programs besides the Land Acquisition, Donations and Conservation Easement Program implemented within Fideicomiso. One of the programs, árboles… más árboles (A+A), is a reforestation program that was begun in response to the damage caused by Hurricane Hugo in 1989. The program established four tree nurseries that were to produce thousands of trees used for reforestation in devastated areas. These trees are either distributed free of charge or for a minimal fee, depending on the area. A+A has been very successful with over a half a million trees produced and distributed in the first five years of existence (Conservation Trust of Puerto Rico, 2007).

Another program, AMIGOS, focuses on contributions to the Trust's mission. Contributions can be in a monetary donation, parcels of land, or time to help out the acquired areas. AMIGOS comprises citizens and organizations that help and support the mission of the Trust. Founded in 1970, the Trust has helped protect over 18,000 acres of land, and with the help of AMIGOS that number will continue to increase. The acres of land that are conserved via AMIGOS generally have high ecological, aesthetic, historic and/or cultural value (Conservation Trust of Puerto Rico, 2007). AMIGOS not only helps conserve the land, but has helped start up and implement educational and reforestation programs such as árboles… más árboles. The Trust promotes conservation in many of its sites with the implementation of interpretive trails for visitors. A major aspect of the interpretive nature of trails is the watershed, and management of that watershed.

2.3 Watershed Conservation and Interpretation

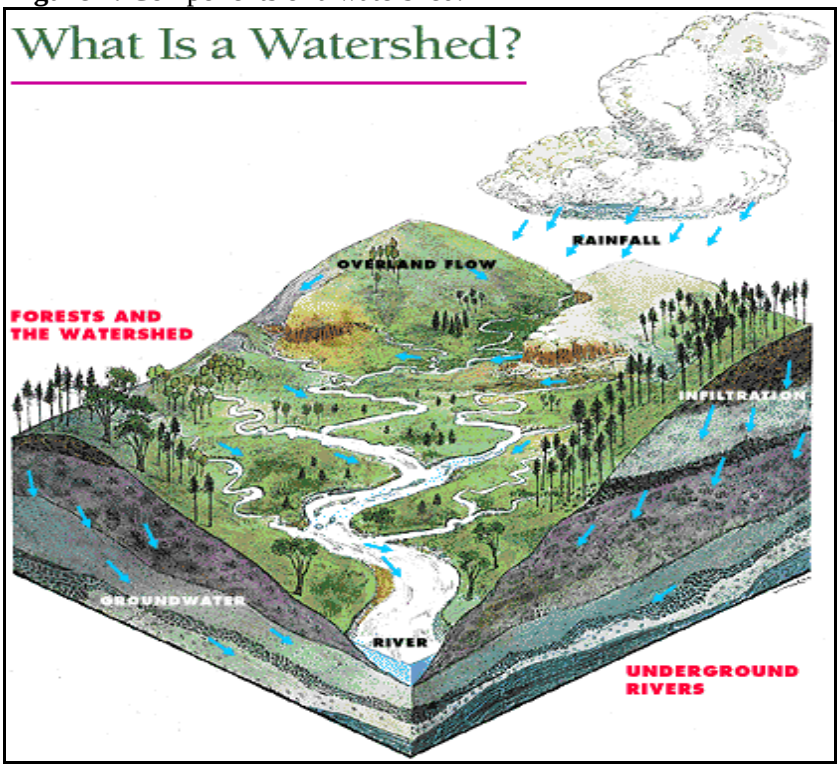
"Environmental Interpretation involves translating the technical language of a natural science or related field into terms and ideas that people who aren't scientist can readily understand" (Ham, H. S., 1992). Often, interpreters use facts and figures, but what they are really trying to express is ideas and meanings. This is what differs between interpretation and conventional instruction. Points and meanings are what a visitor will come away with and remember more so than they were told.

The main goal of interpretation is to have a theme. This is the main message is being conveyed throughout the tour. There are techniques that interpreters use to help them present a theme. These can include visual aids and activities. Aids can range from slides, overhead transparencies, props, flip charts, cloth boards, and tree cross-sections. Some of these things such

as the chalk boards and props can be used before the tour begins in order to give some background to the visitor and what they should expect to see on the tour. Also, visitors should be involved in activities carried out throughout the tour. These can include Living History Demonstrations which portray real or imaginary human figures from the past, Personification which is the portrayal of a non human object, or puppet shows. They can also include hands-on activities such as oxygen test on water supplies, scavenger hunts, or arts and crafts.

The theme of the Río Guaynabo Conservation Easement is the importance of watershed conservation. Simply put, a watershed is an area of land that catches precipitation which drains or seeps into a marsh, body of water, or groundwater. Watersheds can include houses, towns, and even cities, and most often a watershed is a part of another larger watershed. Figure 4 shows the components of a watershed.

Figure 4: Components of a watershed.

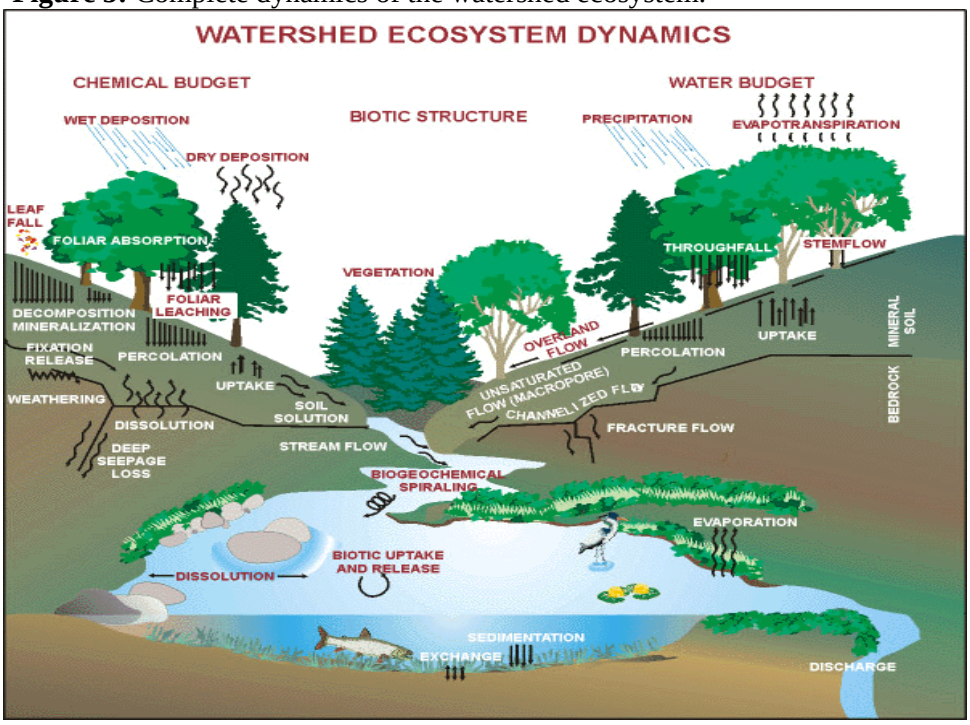


(Source: Zerbe, 2005)

Beyond these simple components of the watershed, there are many processes which take place. For example, when precipitation falls it is taken up by the trees, evaporates back into the atmosphere or seeps into the ground through percolation. The water that seeps into the ground

then makes its way into a body of water where more processes occur. As can be seen in Figure 5, even falling leaves are part of the watershed ecosystem.

Figure 5: Complete dynamics of the watershed ecosystem.



(Source: Johnson and Van Hook, 2008)

It is important to note that people's actions directly affect the watershed since any liquid that reaches the ground percolates through watersheds. In order to properly preserve a watershed a management plan must be developed, along with educational outreach programs for the community.

2.3.1 Watershed Management

Watershed management is the basis of soil and water resources (Buckhouse, 1983). Increased usability of water can have many positive effects on all aspects of site maintenance including flora and fauna health, downstream irrigation, and increased aesthetic values (Buckhouse, 1983). Increased water yield can be achieved by removing wasteful riparian vegetation and preventing sediment pollution. Water holding can be increased by manipulating soil and vegetation so that the maximum amount of water can be held (Buckhouse, 1983).

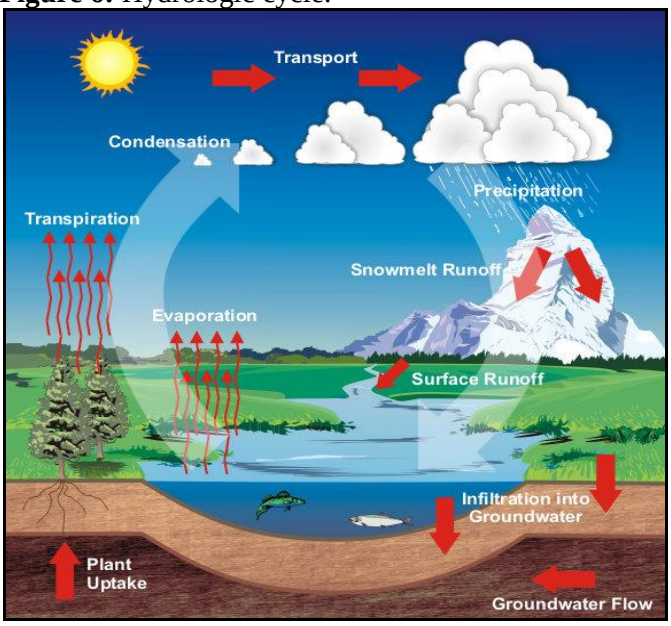
Chess and Gibson (2001) suggest that watershed management must be scientifically, socially, and motivationally feasible. They go on to state that the success of management

depends on the "trackability" and "solvability" of problems and that scientific feasibility depends on "the nature of environmental problems, the tools to track them, and the methods to improve them." Also it is important to know the source of pollution to the water and to note that because of poor land use planning a management plan may not improve things. Socially, Chess and Gibson (2001) stress that there is a need for local communities and government entities to be included in watershed management, and that there be a line of communication between all parties involved. Finally people should feel motivated to be involved in watershed management (Chess and Gibson, 2001). As mentioned previously a solid watershed management plan can increase aesthetic value of land but can also increase the monetary value of the land. These points should be stressed when motivating groups to become involved.

2.3.2 Watershed Pollution

There are two types of pollution sources: point sources and nonpoint sources. Point sources are delivered from a pipe, called a point discharge, and most often come from industrial sources such as manufacturers, power generators, or waste treatment facilities. Nonpoint sources, as their name suggests, are pollutants whose direct source is more difficult to identify. Nonpoint sources (NPS) are areas such as large agricultural fields and parking lots which carry pollutants such as sediment, pesticides, and pathogens. NPS pollutants are usually associated with rainfall runoff and vary as a function of watershed characteristics including but not limited to climate, soil type, and topography. The hydrologic processes also heavily influence NPS pollution. Figure 6 shows the hydrologic cycle.

Figure 6: Hydrologic cycle.



(Source: Roussy, 2006)

When rain falls most of it reaches the soil. This rain is then absorbed into the ground and is either taken in by the surrounding vegetation or percolates into the soil and eventually into the groundwater. Once the absorption capacity of the soil is reached, the rain either forms puddles or, if the land is sloped, become runoff. In this same way, any pollutants that reach the soil become a part of the hydrologic cycle. Furthermore, the characteristics of the rainfall also influence NPS pollution. For example, rain intensity, duration, and drop size all affect the amount of runoff that will occur.

2.4 Trail Planning and Design

The mysteries of nature and the unknown are compelling entities that inspire the imaginations of people of all ages. According to Charles E. Little, "There are some who find a trailhead or a path through the woods which curves out of sight, simply irresistible… It is a romantic idea, surely, a reaction to organized spaces of an industrial age, with all its square corners and square lives and intentionality. Sometimes we need just to set out… to see where a path takes us… But when a path and a natural scene are joined, the congruence can work powerfully on our imagination" (Gross, Zimmerman, and Buchholz, 2006).

A trail offers people the ability to escape from the stresses of their everyday lives and enjoy nature in its simplest and purest state. According to a survey done by Gross, Zimmerman, and Buchholz (2006), people claimed that they take trails in search of:

- Solitude
- Beauty
- New experiences
- Meaning/ connectedness
- Escape from daily stresses or boredom
- Self renewal
- A private place
- Peace
- Inspiration
- Novelty
- Comradeship
- Romance
- Challenge
- Memories

A well designed trail gives people the opportunity to fulfill these fundamental needs, but trail builders must understand that a good amount of planning and engineering are required to construct an effective and long-lasting trail. Unfortunately, even a well planned trail is "serendipitous and subject to the whims of nature" (Gross, Zimmerman, and Buchholz, 2006).

Concepts regarding trail design are well documented by many sources and all seem to follow the same general guidelines. British Columbia's government website contains one of the most detailed trail building guides that can be readily accessed on the internet. The site includes a free recreational manual that provides an in depth chapter that covers all the processes necessary for successful trail design. Once a parcel of land is legally acquired for development, the trail builder must survey the land and assess possible trail routes (Recreational Trail Management, 2000). The Recreation Guide carefully outlines the course of action when it becomes time to begin the actual design process as shown in Figure 7.

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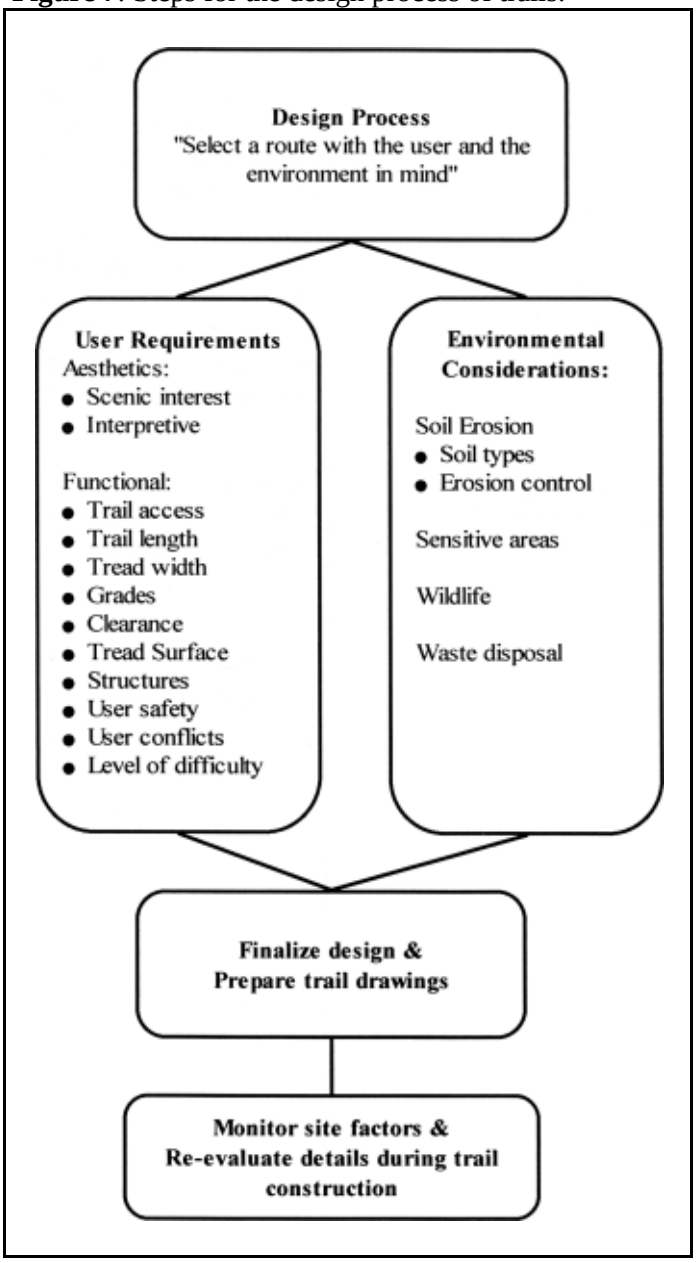
Figure 7: Steps for the design process of trails.

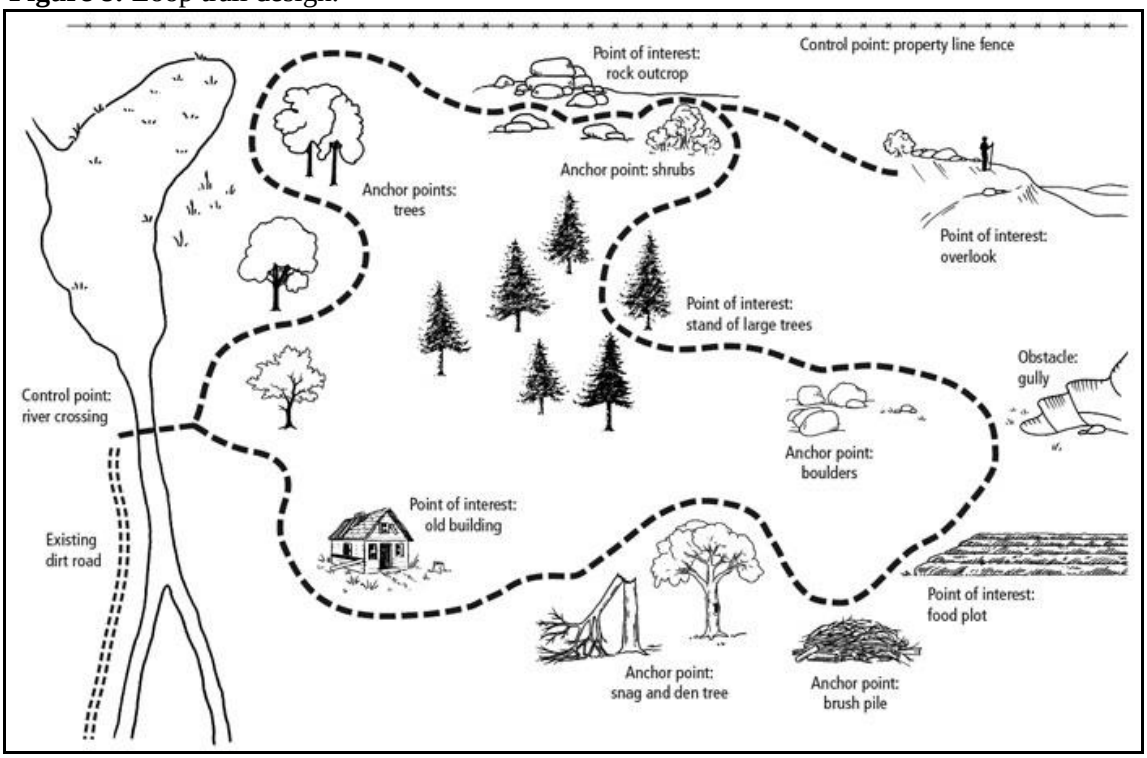


(Source: Recreational Trail Management, 2000)

In order for a series of interesting, easily maintainable trails to be developed, the land must be assessed in detail in order to minimize environmental impact while in turn maximizing user satisfaction (Recreational Trail Management, 2000). According to the recreation guide, the first step required for successful trail assessment is pre-field investigation. Aerial photos, GIS maps, and other terrain maps of the reserve must be acquired and interpreted in order to identify

surface features and soil features, hazardous terrain features and slope, potentially sensitive vegetation or habitat areas, and areas of aesthetic value before a rough trail map can be proposed (Recreational Trail Management, 2000). The trail plan should use points of interest as waypoints or landmarks in order to plot a rough route. The trail should avoid long straight-aways as often as possible and ideally adopt a loop layout so that the user never has to backtrack. Figure 8 depicts a loop trail designed in order to optimize site diversity in order to avoid trail monotony and user boredom.

Figure 8: Loop trail design.



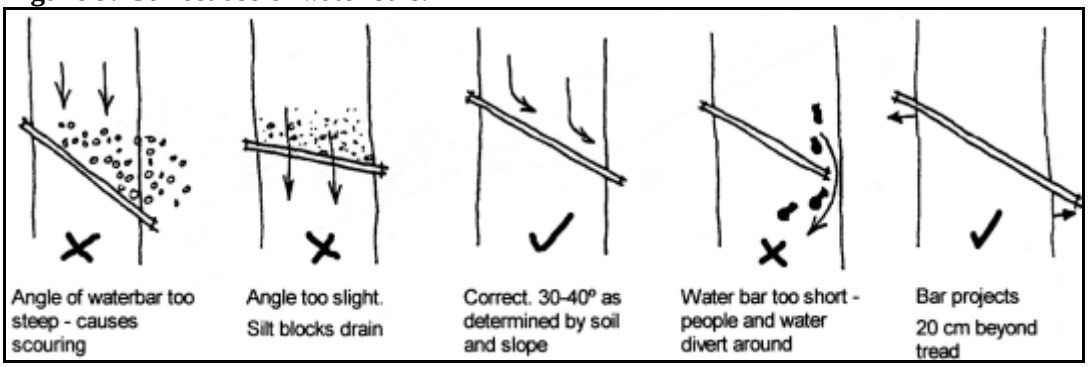
(Courtesy of: http://www.extension.umn.edu)

During the initial property survey, it is important to consider that the terrain chosen for the tread must be suitable to accommodate the standards of a "low impact, interpretive trail." According to the Recreational Trail Management (2000) manual, the purpose of an interpretive trail is "to encourage mutual understanding between the Forest Service and the public regarding forest stewardship to enable the Forest Service to act in the public's interests." The most successful interpretive trails are theme based and are designed to be enjoyable for all visitors, no matter what their hiking skill level. The success of the trail will also revolve around how well the trail is built and kept. According to Recreation Trail Management (2000), the most desirable

grades for an interpretive trail should be less than 5% while grades exceeding 10% should only span a maximum of thirty meters.

The trail surface itself should be more than a meter in width and extended to two meters near particularly scenic vistas or near plaques and trail heads. Trail surfaces that are covered with wood chips or gravel are encouraged because they are aesthetic, cheap, easy to build and maintain, environmentally friendly, and particularly useful for erosion control. According to a survey conducted by Natasha A. Lynn and Robert D. Brown at the School of Environmental Design and Rural Development in Guelph, Ontario, trail erosion plays a major role in the overall dissatisfaction of hikers due to its impact on surrounding wildlife, trail aesthetics, and the resulting pollution of nearby streams and rivers. Taking steps to prevent trail erosion is a major concern. One way to prevent erosion is the use of water bars which are depicted in Figure 9.

Figure 9: Correct use of water bars.



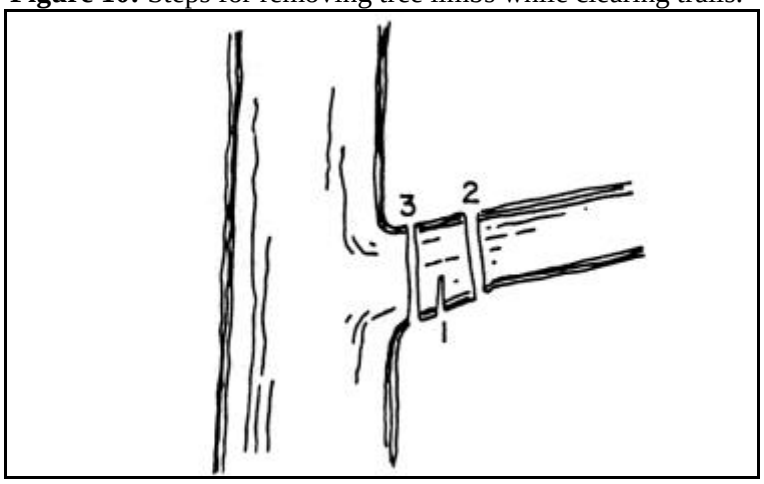
(Source: Recreation Trail Management, 2000)

In order to promote diversity and scenic interest, the trail should approach and follow rivers or any adjacent streams or ponds but, according to Rathke and Baughman (2007), it is suggested that trails near water should be placed above the normal, wet season water line and that there should be an area of vegetation, called a filter strip, between the trail and the water's edge. The roots of the plant growth will prevent any significant runoff from destroying the trail and polluting the water. Rathke and Baughman also argue that if a stream or river must be crossed, the trail builder should try to limit the number of crossings to minimize environmental disturbance.

2.4.1 Trail Clearing

Recreational Trail Management (2000) notes that all trail designs should focus on avoiding any unnecessary cutting, especially large or feature frees. If the partial removal of a tree is necessary, it is advised that only lateral branches be removed. If a treetop must be cut, it is generally better to remove the entire tree because the absence of the tree's terminal bud will result in an accelerated lateral growth into the trail way as well as leave an unsightly tree (Recreational Trail Management, 2000). To ensure a lasting effect and aesthetic quality, all branches must be cut flush with the trunk and all stumps flush with the ground. Figure 10 shows the proper procedure for removing large branches without destroying the bark on the trunk.

Figure 10: Steps for removing tree limbs while clearing trails.



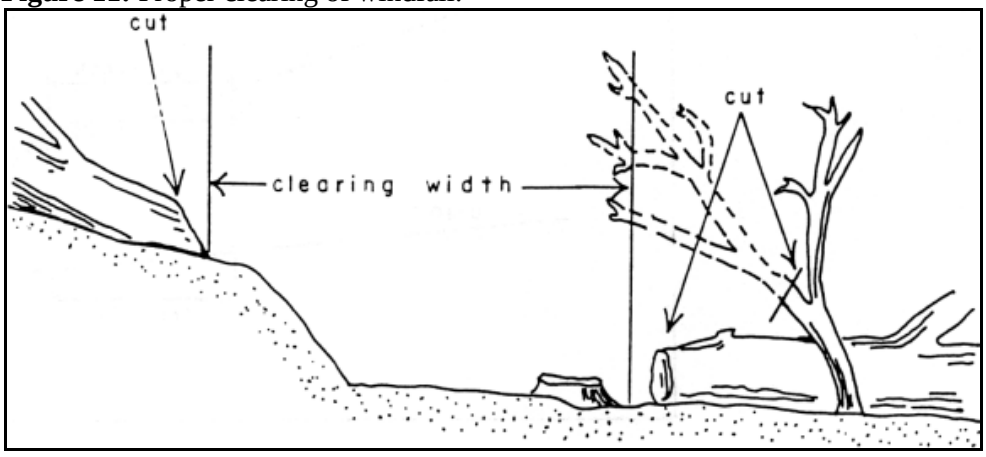
(Source: Recreational Trail Management, 2000)

Small shrubs and other undergrowth grow very quickly and should be cleared to provide safe and easy movement along the trail. Unfortunately, especially in the steep, wet forests, the removal of trailside shrubs may present other problems because their roots often hold the silt soil in place and prevent erosion. The Recreational Trail Management (2000) suggests either leaving the shrubs and periodically trimming the trailside branches or removing the shrubs and planting grass alongside the trail. Removing rocks may improve the footing for trail users, but may also encourage excessive erosion. Consequently, many trail builders leave all but the most treacherous rocks and boulders undisturbed. Accordingly, the trails must be designed to avoid any large boulders and implement a strict drainage plan when rocks must be removed.

A particular hazard for trail building is the significant amount of windfall and other debris on the forest floor. Fallen tree trunks up to a meter thick can be commonly seen fallen across existing trails in the area and dense undergrowth makes it difficult to move once cut. This

windfall and debris must be removed from the trail bed in order to meet the trail's demand for high quality. All windfall that cannot be simply dragged from the trail bed must be cut in wide sections until a foot of space separates it from the trail boundary (Recreational Trail Management, 2000). Figure 11 illustrates the proper clearing of windfall and debris hazards.

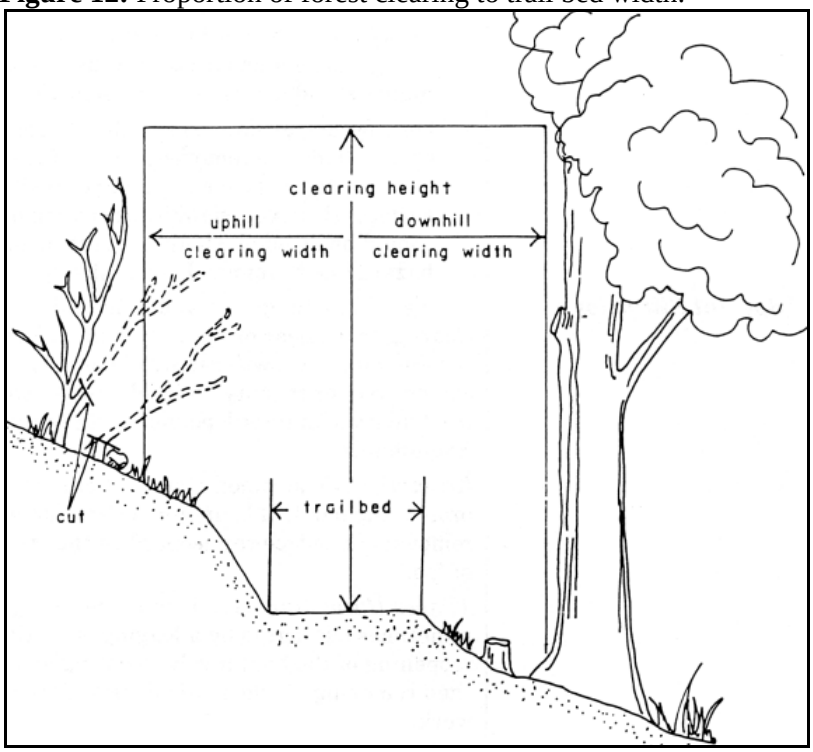
Figure 11: Proper clearing of windfall.



(Source: Recreational Trail Management, 2000)

The typical clearing dimensions for interpretive trail systems ranges between one and two meters in width and about two and a half meters in height with additional width near interpretive trail signage and sights of particular viewing interest in order to accommodate a larger viewing audience (Recreational Trail Management, 2000). Figure 12 shows the ideal proportion of forest clearing compared to the width of the trail bed.

Figure 12: Proportion of forest clearing to trail bed width.



(Source: Recreational Trail Management, 2000)

2.4.2 Solutions for Steep Grades

The standard for interpretive nature trails favor grades of less than 5% and prohibit extended grades of more than 15%, extreme measures must be taken to ease the slope induced difficulty of the trail system.

To minimize the grades of the trail, extensive use of trail grading and switchbacks is necessary. These features allow the trail to traverse steep embankments while maintaining a shallow grade. The difficulty in implementing these features comes with the threat of erosion when the trail is cut into the side of a slope. The following bulleted list lays out strict guidelines for the construction of trails cut into side slopes in order to prevent erosion and ensure the safety of the user:

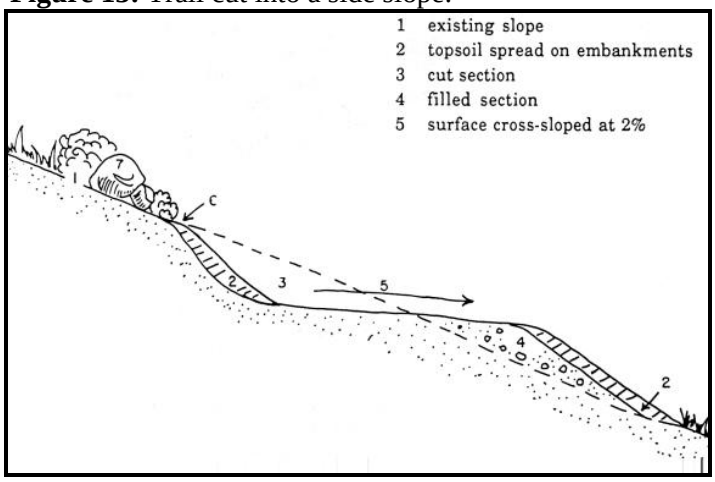
- *Leaf litter and surface soil material should be removed from the cut and fill areas, and saved for later use.*
- *The ideal angle of the cut and fill slopes should be less than a 1:1 slope.*

- *To encourage vegetation regeneration, topsoil and organic material should be spread on large embankments susceptible to erosion. On steep embankments, netting material, such as jute mesh held in place with stakes, may be required to hold the topsoil and mulch in place.*
- *Proper rounding at the top of the embankment shoulders is necessary to prevent soil from sliding onto the trail. Boulders, logs and other debris that may fall onto the trail should be removed. Exposed roots should be cleanly trimmed flush with the soil surface.*
- *The bed of the trail tread should be pitched approximately 1.5 cm per 30 cm toward the outside edge to allow for drainage off the trail.*

(Recreational Trail Management, 2000)

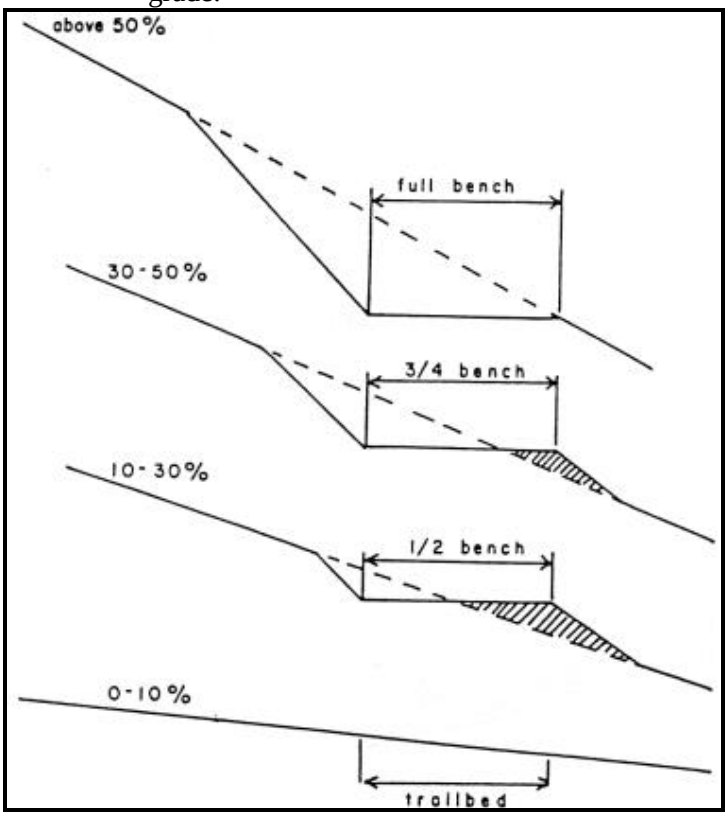
Additionally, there are guidelines for side cuts according to grade. For narrow trails with exceptionally steep grades, it is suggested that logs be wedged parallel to the down slope edge of the trail against two standing trees and leveled with small branches, rocks, and soil to achieve a durable shelf for the trail (Recreational Trail Management, 2000). Figure 13 shows properly designed trail cuts into a side slope. Figure 14 shows the length of bench needed when cutting into different slope grades and also which grades require a retaining wall.

Figure 13: Trail cut into a side slope.



(Source: Recreational Trail Management, 2000)

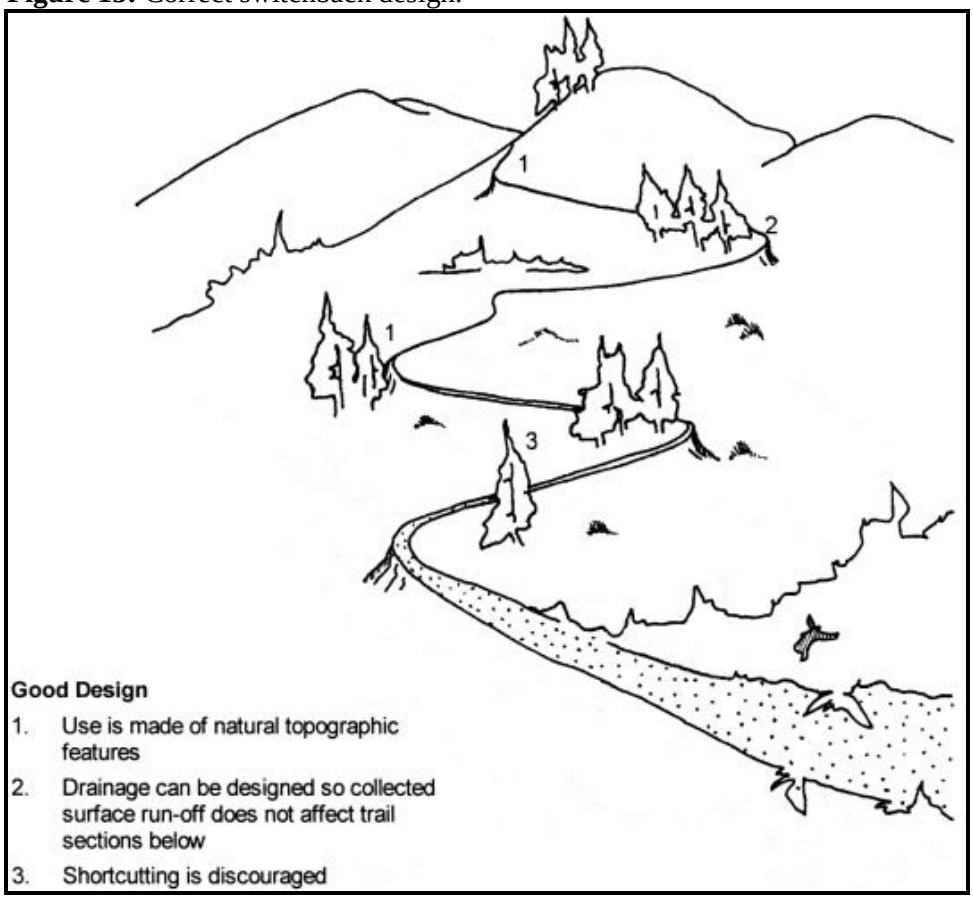
Figure 14: Bench cuts and retaining walls according to trail grade.



(Source: Recreational Trail Management, 2000)

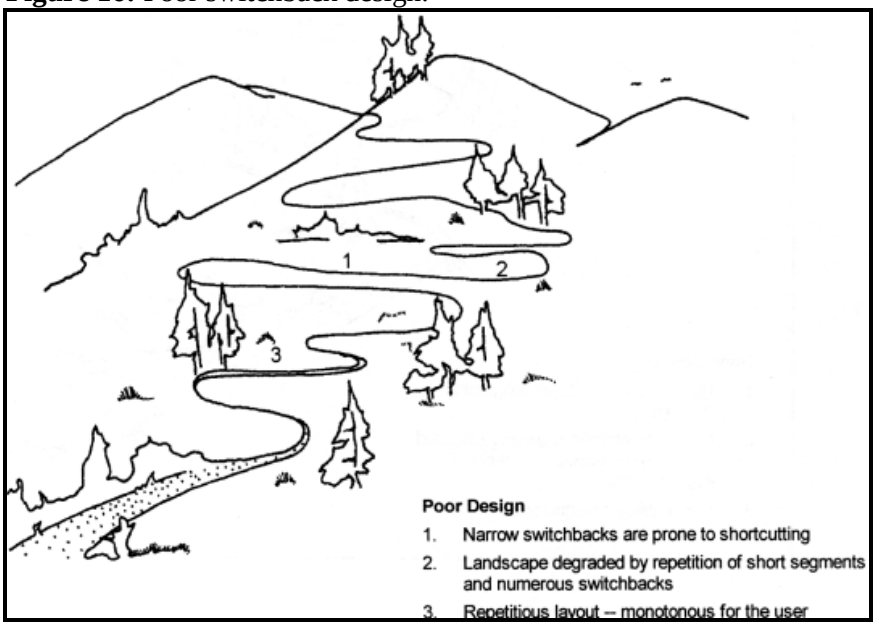
Building trails into steep slopes requires the implementation of switchbacks in order to scale the slope with a minimal grade. Trails should be designed to make the best use of topographic features, avoid repetitious short segments with numerous switchbacks, and strategically planned so that collected drainage and sediments do not affect the trails below (Recreational Trail Management, 2000). Figure 15 and Figure 16 show both ideally and poorly designed trails using switchbacks respectively.

Figure 15: Correct switchback design.



(Source: Recreational Trail Management, 2000)

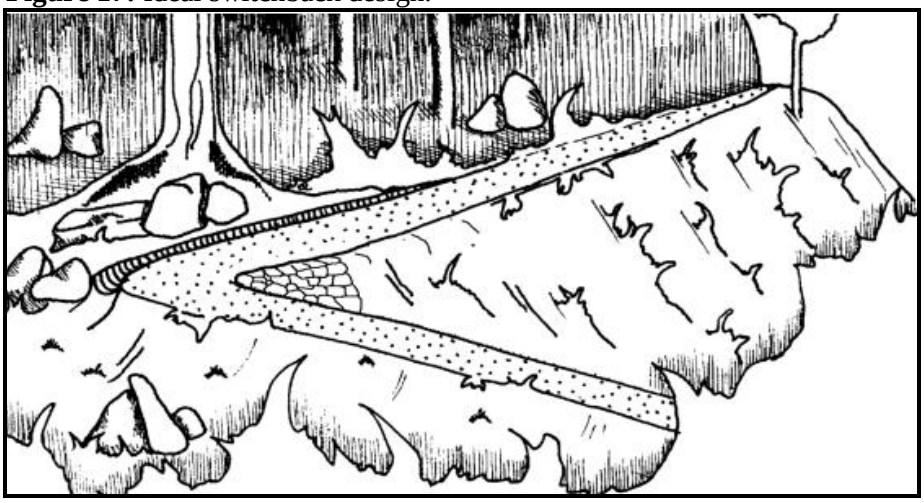
Figure 16: Poor switchback design.



(Source: Recreational Trail Management, 2000)

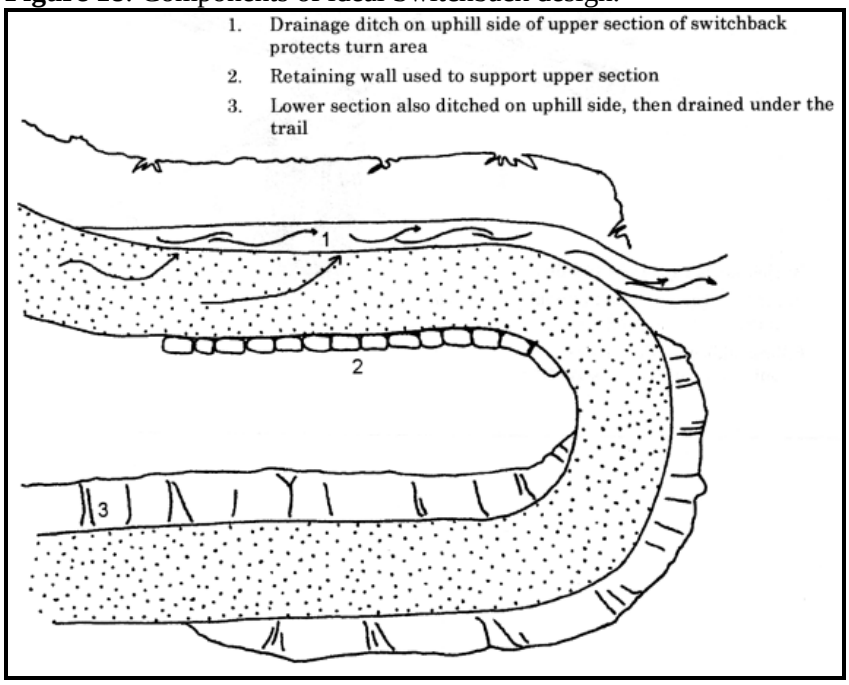
While they look simple, switchback design and implementation is actually a particularly complex process. Erosion is the single greatest threat for any trail, but it especially applies for features such as switchbacks where the trail beds are separated by a thin strip of earth on a steep slope. Figure 17 and Figure 18 outline the ideal design for trail switchbacks and their components.

Figure 17: Ideal switchback design.



(Source: Recreational Trail Management, 2000)

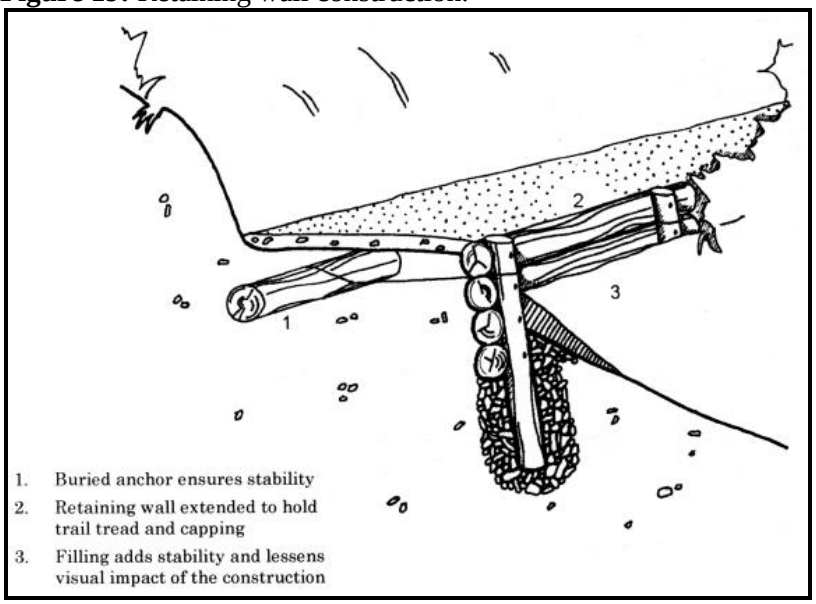
Figure 18: Components of ideal Switchback design.



(Source: Recreational Trail Management, 2000)

Figure 19 illustrates the proper way to construct an effective retaining wall. Retaining walls are used to help retain slopes, prevent erosion, and protect users from falling debris. These walls can be constructed from logs, timber, or stone and are used commonly on trails cut into side slopes and on switchbacks as shown Figure 17 and Figure 18 above.

Figure 19: Retaining wall construction.



(Source: Recreational Trail Management, 2000)

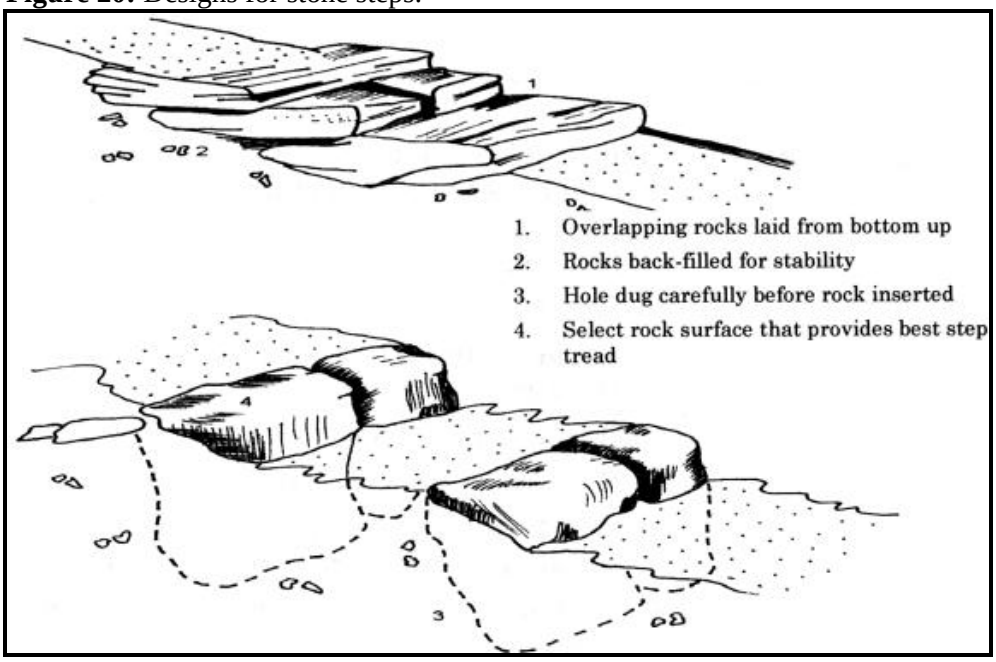
To ensure the safety of the user as well as the upkeep of the trail in these conditions, the recreational guide suggests the use of simple, low impact staircases. Stairs are a good solution for steep grades when designed correctly, but can become fatiguing and dangerous for children and the elderly if their special needs are not taken into consideration. Flights of stairs should be constructed in short series of no more than fourteen steps separated by landings, with at least one handrail on particularly long or steep flights and also establishes a rule for proportions (Recreational Trail Management, 2000):

Height (cm) X tread depth (cm) = 450

(Where the height should not exceed 20cm and the tread depth should be at least 30cm)

For more gradual sections of trail that may require stairs for traction, using stone steps for their aesthetic quality and durability. If placed carefully, stone or boulder steps will blend into the trail and retain a natural appearance (Recreational Trail Management, 2000). Figure 20 shows two designs for aesthetic and effective stone steps.

Figure 20: Designs for stone steps.



(Source: Recreational Trail Management, 2000)

For particularly steep grades or areas where loose soil or roots make it impossible to effectively set stone steps into the earth, the use of plank stairs that are connected by stringers. These staircases should be well anchored, include a rail, and must be constructed using durable, pressure treated timber.

The literature used for trail design is extensive and detailed; it gives step by step guidelines for many different types of terrain and trail applications. The team's site specific methodology will determine the specific trail building strategies that will used according to the needs of the Río Guaynabo Conservation Easement.

CHAPTER 3: METHODOLOGY

After the review of literature was complete the team developed a methodology to complete the goals of the project. The primary goal of the project is to generate a management plan for the Río Guaynabo Conservation Easement. This management plan includes a set of potential trail routes and trail designs, recommendations for watershed assessment, and suggestions for watershed conservation educational tools and programs.

The first objective for the management plan, trail planning and design, is an important way to bring in visitors in order to provide information about the importance of conservation. This objective involved several tasks, including identifying criteria for planning and designing trails, choosing trail access routes, developing preliminary trail locations and designs, and determining final trail locations and designs. These subtasks were accomplished first by reviewing relevant literature concerning trail planning and design. Next the team interviewed Fideicomiso employees and visited their conservation sites in order to gain a better understanding of their expectations and site operations. The team also reviewed mapping information and conducted multiple field surveys of the site.

The second objective was to evaluate watershed threats on the site in order to use these specific examples to convey the theme of the importance of watershed conservation. In addition the team developed an interpretive program for the site including interactive activities and watershed information that should be provided to visitors as they experience the tour. The objective was important to be accomplished because the Río Guaynabo watershed and the surrounding watersheds are at risk. The interpretive and educational aspects are important because community education is a main part of the Trust's mission.

These trail system and watershed management will provide the components of a complete management plan which will supply the Trust with the tools to begin the management of the Río Guaynabo Conservation Easement.

3.1 DEVELOPING CRITERIA FOR THE MANAGEMENT PLAN

The project team developed a set of criteria for the development of the Management Plan of the Río Guaynabo Conservation Easement reviewing the literature, conducting informal interviews with Trust employees, and visiting various conservation and parks in Puerto Rico.

3.1.1 Review of Literature

Prior to arriving in Puerto Rico basic literature was reviewed. After the project teams' arrival in Puerto Rico, more site specific materials were reviewed. The literature review included outlining the importance of conservation in Puerto Rico, the background of watersheds, and the guidelines of trail design and maintenance. The Management Plan for the Western Vieques Conservation Areas was obtained in order to review a management plan previously completed by the Trust. The team continued reviewing relevant literature throughout the entirety of the project.

3.1.2 Interviews

The project team conducted informal interviews with Fideicomiso employees in order to determine what should be included in the management plan. The project team also conducted interviews with Fideicomiso employees in order to determine the how the trails will be used, how many visitors are expected, what materials are available for the trails, and what natural resources they deem as important in the reserve. These interviews also determined how Fideicomiso generally designs, builds, and maintains its trails.

Employees from El Yunque were also contacted to determine the environmental effects of concrete trails, and the cost and maintenance of these trails but the team received no response.

3.1.3 Site Visits

The team visited sites owned by the Trust in order to have a firsthand experience of their guided tours. The team was able to gain a familiarity of the trail systems and designs used, the interpretive nature of the tours, and the information provided during the tours. Criteria that were closely studied during these sites were the environmental impact of the trails, the themes of each site, and the manner in which educational information was displayed. The sites visited were Las Cabezas de San Juan Nature Reserve (El Faro), and Hacienda Buena Vista.

3.2 Development of Trail System

One of the most important aspects of the management plan was determining a trail system for the Río Guaynabo Conservation Easement so that visitors have an opportunity to tour the area in a manner that best exemplifies the most important and interesting natural resources, flora, and fauna while developing the theme of watershed conservation. In order to accomplish

the trail system the team generated preliminary trail locations and designs for the approval of Trust employees.

3.2.1 Preliminary Trail Locations

The team identified preliminary trail locations based on points of interest in order to present trail routes to Trust employees for review. The routes were determined by a review of relevant information concerning the Río Guaynabo Conservation Easement including maps and an appraisal report, multiple field surveys of the site to determine points of interest, and finally by mapping the points of interest using GPS.

3.2.1.1 Review of Relevant Information

The first step to determining the trail routes was to review information that could be found on the site. First the team reviewed the relevant mapping information. GIS maps were obtained from Fideicomiso that showed the topography, elevation, and an overhead view of the site. These maps were used to determine potential runoff from the surrounding area and the type of land that would be found at the site.

Next the project team obtained and read the Río Guaynabo Conservation Easement Proposal Rapid Appraisal Report on Ecological Values which assessed the site. The appraisal gave information on geology, climate, flora, fauna, and management issues, as well as recommendations for the Río Guaynabo Conservation Easement.

Both the mapping information and the appraisal report were used so that the project team could have a better understanding of the site before the field survey.

3.2.1.2 Field Surveys

The team conducted multiple field surveys of the site in order to better understand the terrain, natural resources, flora and fauna, and hiking difficulty of the site. The first visit was simply a walkthrough of the existing trails in the site that led to the quarry, creeks, and the Guaynabo River to see which trails are usable, which trails need to be altered, and which trails should not be used. The first site visit was also used to view the forest type, soil type, and noticeable fauna in the area. During the second site visit, GPS was used to map points of interest and the specific existing trails that should be used during visits to the sites. Pictures of each point of interest and trail locations were taken. The points of interest were determined based on the most interpretive and low impact route to the Guaynabo River that would allow visitors to be

safe at all times. The third site visit was used to map potential routes for trails in those areas where trails do not presently exist. Once again pictures of the trails were taken.

3.2.2 Preliminary Trail Designs

Preliminary trail designs were determined based on the trail routes chosen. Design aspects included trail tread, grade, material, and clearing. Concentrating on these aspects, the group was able to determine what designs were feasible, low impact, inexpensive, and easy to maintain. For the most part guidelines for when certain trail designs should be used were outlined for the management plan. Specific designs in specific locations were only proposed where points could be taken using GPS. In order to determine the correct trail designs for the Río Guaynabo Conservation Easement, field surveys were conducted and points were mapped using GPS.

3.1.3.1 Field Survey

During the second and third field surveys of the Conservation Easement GPS points were taken at the beginning and ending of changes in the trail. For example when the trail terrain or grade changed, a point was taken. Using this method specific trail designs could be recommended designated by exact locations on a map as much as possible. The team studied the environment surrounding the trails so that the design with the least environmental impact could be chosen. Also, trail grade was considered to ensure none of the trail grades were too steep to maintain user safety and the proper level of hiking difficulty. At this point the team also decided what material the trails should be made of and how this material will be maintained. The project team also decided which sections of the routes would need railings.

3.2.3 Final Trail Locations and Designs

The preliminary trail map was presented to the staff at the Trust in order to assess the feasibility of the trails and trail designs chosen by the project team. The project team modified the trail map based on the feedback received from the Trust. Once the final trail locations, points of interest, and trail designs were chosen a final trail system map was created of the Río Guaynabo Conservation Easement using Arc GIS.

3.3 Watershed Conservation

A second major focus of the management plan was watershed conservation. The assessment of the watershed was accomplished with an evaluation of what is affecting the watershed in the area. This aspect of the management plan also included the interpretive nature and educational aspects of the site.

3.3.1 Watershed Assessment

The first task in assessing the issues of watershed management was to evaluate threats to the watershed. By providing an overview of possible threats, the Trust could further investigate how these threats are affecting the Río Guaynabo Conservation Easement and develop solutions to prevent negative effects on the watershed. This task was accomplished through background research, informal interviews with Trust employees, and field surveys of the site.

3.3.2 Watershed Conservation Interpretation and Education

Watershed conservation was chosen as the theme of the Conservation Easement by the Trust. Therefore it was necessary for the team to develop interpretive and educational tools that emphasize this theme. This aspect of the management plan was accomplished by creating guidelines for the information given during tours and recommending hands-on activities for visitors of the Conservation Easement.

CHAPTER 4: RESULTS AND ANALYSIS

The team has developed a management plan for the Río Guaynabo Conservation Easement which includes a mapped trail system and the management of the site's watershed. In order to develop the management plan, the group first determined how the site will be used. The Conservation Easement will be visited by small groups of school children and participants of the AMIGOS program and will be run with guided tours. The access point to the trails is currently undetermined; however, the trails taken should highlight points of scenic interest but most importantly develop an interpretive theme. As with most conserved and educational land areas a theme of the area must be determined. The interpretive theme of the Río Guaynabo Conservation Easement, as determined by the Trust, is the importance of the conservation of watersheds which will be conveyed with the implementation of educational tools.

4.1 CRITERIA FOR MANAGEMENT PLAN

The first step to drafting a Management Plan was to determine what it should include, and how sites of the Conservation Trust of Puerto Rico are managed. This was accomplished by visiting sites open to the public, owned by and outside of the Trust. The team also studied the Rapid Appraisal Report on Ecological Values of the Río Guaynabo Conservation Easement prepared by Envirosurvey, Inc. for the Trust in 2005.

4.1.1 SITE VISITS

The team visited various sites of the Trust open to the public in order to understand the design and environmental impact of trails, the interpretive themes and educational tools used, and in general how the guided tours are run. Figure 21 shows a map of the visited sites.

Figure 21: Sites visited by the project team.

(Courtesy of The Conservation Trust of Puerto Rico)

Each Trust site open to the public is viewed with a guided tour and has a level of difficulty as designated by the Trust. Level 1 is easy and is recommended for visitors of all ages. Level 2 is moderate and requires the visitor be in physical condition for walking through places of limited access and suggests small children be accompanied by an adult. Level 3 is extreme and requires a good physical condition for walking long distances in difficult terrains and it not recommended for children. The following site narratives explain the basic tour of the visit and are followed by aspects of the tour that can be applied to the Río Guaynabo Conservation Easement.

4.1.1.1 Las Cabezas de San Juan Nature Reserve (El Faro)

Las Cabezas de San Juan Nature Reserve was acquired by the Conservation Trust of Puerto Rico in 1975 and received its name because of the three head-like capes that can be viewed from the mainland of the site. The land obtained is a total of 316 acres which include seven different types of ecosystems: coral reefs, thalassia beds, sandy beach, rocky beach, dry forest, mangrove forest, and lagoons. Because of this array of ecological types, the site offers important opportunities for studies in marine biology, geology, and archaeology, and also allows visitors to view examples of the biodiversity of Puerto Rico. Throughout the tour there are signs which explain the flora and fauna that can be spotted along the way. Figure 22 gives an example of these signs.

Figure 22: Interpretive sign found in Las Cabezas de San Juan.

The tour of Las Cabezas de San Juan begins with a trolley ride through the forest and along the shores of the site. The path taken by the tour was left there by Spaniards who occupied the land in the 1800s and more recently was covered with asphalt. Along the way various flora and fauna can be seen, including tamarindillo, which shows that the land is a secondary forest, and many iguanas. Figure 23 shows part of the path taken by the trolley in Las Cabezas.

Figure 23: Trail in Las Cabezas.

Visitors have opportunities to walk around and observe the ecology more closely at three stops along the tour. The first is a stop at the rocky beach where one can see the coral reefs and thalassia beds through the water. The rocky beach at the site, called Los Lirios, is constantly changing. When waves hit the coast, they break coral and rocks from the cape which are left on the shore creating the rocky ground.

The next stop is at the lighthouse which was completed in 1890 and has been in continuous operation since. The Trust began restoration of the lighthouse in 1989, which including restoring the original windows, doors, surfaces, and colors. Visitors have the opportunity to enter the lighthouse which contains displays and information about fauna that cannot be viewed on the tour. The visitors are first shown tanks of fish living in and around the coral reefs and are then immediately led to the next room where a touch tank allows them to handle the creature they just observed. Visitors are also able to experience the science of the bioluminescent bays in Puerto Rico. They are led into the dark where pictures of different bioluminescent creatures light up the room and are eventually able to experience them first hand.

The tour group is then led the top of the lighthouse which holds the original copper weathervane placed there by the Spanish inhabitants. From the top the view of “Las Cabezas” can be seen along with the site’s bioluminescent lagoon. Figure 24 shows the restored light house.

Figure 24: The lighthouse (El Faro) of Las Cabezas de San Juan.

The final stop of the tour is at the wetlands of the site where the visitors walk along a boardwalk which displays the four mangle types found in the mangroves: mangle botón, mangle blanco, mangle negro, and mangle rojo. Each tree type has biological adaptations to extract excess salt water absorbed from the wetlands. The boardwalk was constructed after a hurricane which occurred in the late 80's that cleared the wetlands. The Trust used hurricane damage as an opportunity to construct the boardwalk without impacting the environment. After this stop the trolley returns the visitors to the information center. Figure 25 shows the boardwalk found in the wetlands of Las Cabezas.

Figure 25: Boardwalk in Las Cabezas.

4.1.1.1.1 APPLICATION TO THE RÍO GUAYNABO CONSERVATION EASEMENT

After speaking with the tour guide it was found that the Trust tried to minimize the environmental impact as much as possible when making trails. Existing trails were used for the trolley ride and the boardwalk was constructed when no vegetation needed to be cleared. The Trust however has added a visitor's center to the site and maintains the vegetation along the trails so that they are not overgrown. Therefore, when proposing trails for the Río Guaynabo, the team decided to choose trails that make the least environmental impact as possible. Existing trails should be used where possible and new trails should be placed where little or no vegetation needs to be cleared.

The trail designs in this site were very minimal since the difficulty level was very easy. The path the trolley took was paved with asphalt however this material is not often used in the sites of the Trust. The boardwalk was raised and wooden as can be seen in Figure 25. This material was chosen despite of the high salt content of the wetlands and repairs are made in specific areas as needed. From this visit, the team decided minimalistic designs should be proposed for the Río Guaynabo Conservation Easement. The hiking difficulty of this site was

Level 2 since places of limited access were walked through but the terrain does not at all reflect the difficulty of the Río Guaynabo.

In all aspects of the tour visitors are asked to use all their senses to interpret the land. The tours were guided by a nature interpreter who developed the theme of the site throughout the visit. The interpretive theme at Las Cabezas de San Juan was the importance of protecting the different ecologies of the site for the benefit of the community. This theme was explained mostly through the tour guide but, at areas where visitors could stop and walk around, there were signs explaining the flora and fauna of the specific ecology. As shown in Figure 22, the signs contain a sketch of the species and its name in Spanish and English. The text of the signs was in Spanish and contained a few sentences about the habitat and the food eaten by the species. The signs noting the fauna of the site all contained similar information as mentioned above. Also the Trust used the lighthouse to display the marine life of site. Activities such as a marine life touch tank and a dark room that displayed the beauty of bioluminescent creatures were available with the use of the lighthouse. In evaluating this visit, the team decided to put information on signage since it is often difficult for visitors to hear, understand, and retain the information given by the tour guide. Also the team will suggest putting the signs in both Spanish and English since areas of the Trust are often tourist attractions.

4.1.1.2 Discover the Nature of Old San Juan

The interpretive walking tour of Old San Juan starts at the Ramon Power y Giralt House located at 155 Tetuán Street in Old San Juan, which is the headquarters of the Fideicomiso Conservation Trust of Puerto Rico. Inside the house is a visitor's center along with a gift shop, the OJO Isla (Island Alert) exhibit which is the first interactive environmental exhibit in Puerto Rico, the Fideicomiso executive offices, and audio and visual rooms. The tour begins at Casa Ramon Power y Giralt with a quick presentation and video on the seven different destinations of the walk and some key facts about each site. These key facts included background information of the sites, but not too much detail. Educational tools and materials are handed out which include a Guia de Aves (bird guide), pajareando con sentido which is a bird checklist, binoculars, a wind speed gage, a thermo-hygro which is a thermometer and humidity measure, and ponchos in case of rain. The educational tools were useful in spotting different types of birds, and also helpful in teaching visitors the importance of birds in Old San Juan. Some birds are scarce and it is important for visitors to realize conservation is important, and everything they do affects nature,

for better or for worse. Also, the tools helped give an interactive aspect to the tour, and more of a hands-on learning experience. People gain a lot from interactive learning, which is why the Trust employs this type of teaching. Figure 26 shows the bird guide handed out at the beginning of the tour.

Figure 26: Bird guide for Old San Juan tour.

After the video and handing out of materials the tour leads to the second stop at Bastión de la Palmas de San José. At this stop is a pigeon park where children go to play with the pigeons. Also at this stop is a great view of the area which overlooks the water. Birds fly by frequently, and, using the binoculars, the group saw many different bird species. The third stop of this tour was at Plaza de las Monjas, which translates to Plaza of the Nuns. Plaza de las Monjas houses many ficus trees as shown in Figure 27 which are indigenous to Puerto Rico. The ficus trees grow out of the streets; this growth is not only damaging to the sidewalks but is also damaging to the health of trees since they do not have proper space to grow. The Trust runs studies on which trees work best in certain areas, such as urban vs. suburban areas.

Figure 27: Ficus tree in Old San Juan.

The fourth stop of the tour, and unfortunately the final stop on our tour due to weather, was the Puerta de San Juan, or the Gates to San Juan shown in Figure 28. Historically the entrance to San Juan, the gate was built in the 1600s and is located on Calle San Francisco and Recinto del Oeste.

Figure 28: Puerta de San Juan.

At the Puerto de San Juan hands-on activities geared toward children are offered. The tour guides engage children in experiments that test pH, oxygen, phosphate and nitrate levels. The project group conducted an oxygen test (Figure 29) to observe how these hands-on experiments are ordinarily conducted with members of the public. A water sample was taken and then a small vial was filled with the water. Two tablets were placed in the vial and the mixture was then shaken for five minutes. After the tablet and water mixture was ready a chart of different colors was used to compare the oxygen level. There were three shades of orange and pink colors. The group found that the oxygen level was at 40%, which is far below the 80% to 90% oxygen levels that are optimal for healthy aquatic ecosystems.

Figure 29: Oxygen test.

At this point the group needed to return to the office, but Omar, the tour guide, gave the group a breakdown of the other stops on the tour and explained how the Trust uses games and interpretive tools to teach the children about the environment and the effects of the city on that environment. The final stops are: Arbol de Pterocarpus, Plaza de Ballajá, and Plaza de la Benefiaéncia. The Old San Juan tour was beneficial and helped the group learn about the diverse components of the city. This tour also helped the group discover how the varied ecology impacts the city's development, and the development of areas and ecology nearby.

4.1.1.2.1 Application to the Río Guaynabo Conservation Easement

The tour of Old San Juan did not have trails so the main purpose was to view what types of interpretive tools the Trust uses. The interpretive tools were hands on and mostly geared toward children although the tour was for people of all ages. One aspect of the tour that is directly applicable to the Río Guaynabo site was the oxygen test that was performed. The oxygen test is used to show visitors that low oxygen levels are very damaging to marine life since a low oxygen level cannot sustain life. By asking people to perform the test, not just stating the oxygen levels are low, an abstract concept is made more concrete and visitors feel more involved in the tour. Also with hands-on activities the visitors are more likely to remember what was learned. The oxygen test would be a good tool for the Río Guaynabo Conservation Easement because it focuses on the health of the water in the site which is directly affected by the surrounding watershed.

4.1.1.3 Hacienda Buena Vista (Vives)

The Hacienda Buena Vista located in Ponce was the first site to be opened to the public by the Conservation Trust of Puerto Rico. The Hacienda was built by several generations of the Vives family who used the land to grow various crops. The original buildings and machinery used by the Vives family can still be found at the Hacienda including their living quarters and water powered machinery.

The tour begins in the home of the Vives family which was also used for storage. The Trust restored the building to exemplify what the home looked like in the nineteenth century while keep some original beams and flooring. Visitors are given a background of the history of the Hacienda and an opportunity to view both floors of the home. Figure 30 shows living quarters of the Vives family restored to what it could have looked like in the 19th century.

Figure 30: Living quarters of the Hacienda. Clockwise from top: Living room, bathroom, dining room, and kitchen.

The tour group is then taken through the trails of the site left by the Vives family. Next to the trails a canal system was built which manipulates the Canas River so that it fuels the water turbine. The walk through the site also highlights the areas flora and fauna. Figure 31 shows the railed trails found in the Hacienda and the canal system that runs along the side.

Figure 31: Trail in Hacienda Buena Vista.

Finally the tour group is shown the water turbine, coffee-processing machine, and corn mill which were reconstructed with original parts by the Trust and several historians and experts. Figure 32 show the restored corn mill which could process 600lbs of corn in one hour.

Figure 32: Restored corn mill in Hacienda Buena Vista.

The interpretive nature of the Hacienda highlights what life was like in the nineteenth century for the Vives family. In addition visitors are given a closer look into the development of

agricultural technology. The restorations and additions made to the site were built with the goal of causing as little environmental impact as possible as is the goal of all operations of the Trust.

4.1.1.3.1 Application to the Río Guaynabo Conservation Easement

The trails in La Hacienda Buena Vista were the existing trails used by the Vives family and built by their slaves. The hiking difficulty in this area is designated Level 2 by the Trust since children should be accompanied by an adult and some sections are not handicap accessible. However the hiking difficulty in this area still does not reflect that of the Río Guaynabo which would most likely be designated Level 3, the highest difficulty offered by the Trust.

The trail design however does reflect what might be used in the Río Guaynabo Conservation Easement. Gravel was the material used for the trails and a railing was placed along the trails since there was a large drop-off. The trails in the Río Guaynabo are also along drop-offs like this and using railings in those places would increase user safety. The interpretive nature of La Hacienda also offered insight into developing themes for sites. Themes should be a concept not only a word. For example, the theme for the Río Guaynabo Conservation Easement should not be "watersheds" but "the importance of protecting watersheds."

4.1.2 Rapid Appraisal Report on Ecological Values of the Río Guaynabo Conservation Easement

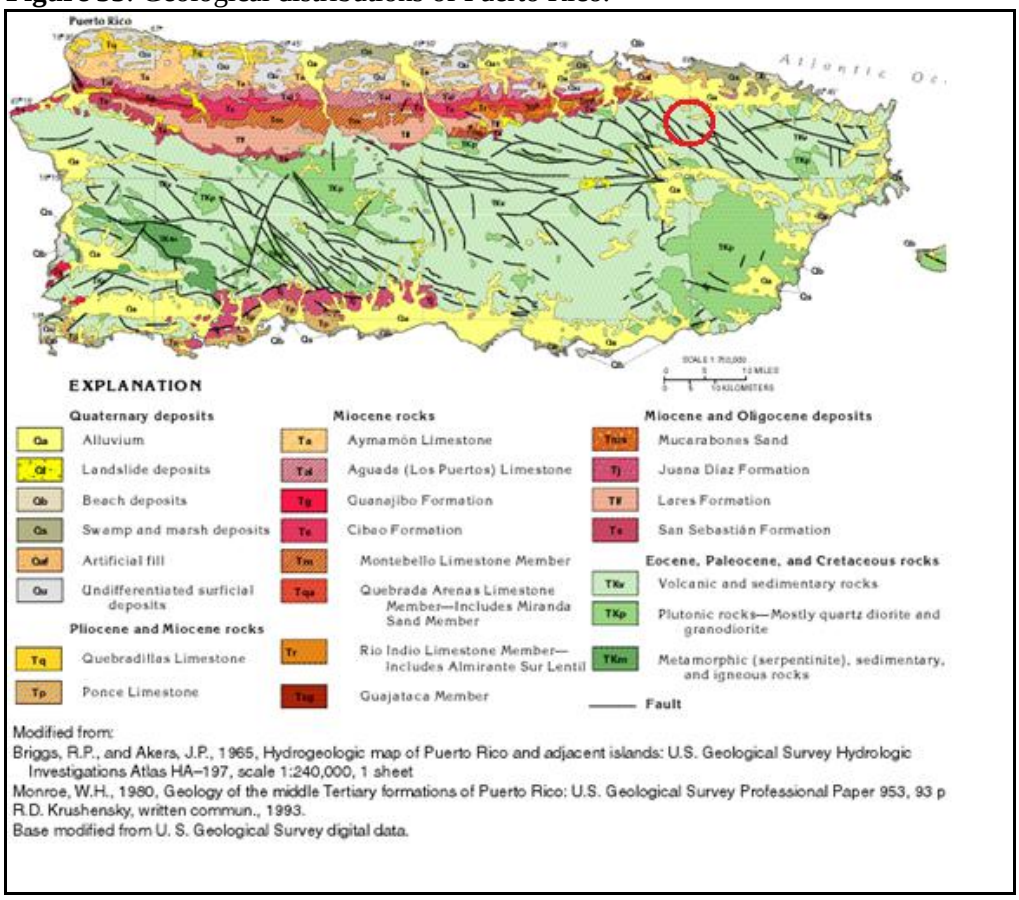
A Rapid Appraisal Report on Ecological Values of the Río Guaynabo site was conducted in order to determine if the area, now the Río Guaynabo Conservation Easement, could be of value to the Trust as a Conservation Easement and possibly as an Urban Forest for the benefit of the community. The following summarizes the finding of the Rapid Appraisal. The full report can be found in the Appendix of this Management Plan.

The site is located in the Municipality of San Juan in the north of Puerto Rico. It belongs to the Bayamón River Watershed which contains the following main water bodies: Río Bayamón, Río Guaynabo, Río Piedras, Cidra Dam, and Las Curias Dam. The land consists of early secondary subtropical forest since most of the area was deforested at one point (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005).

According to the U.S. Geological Survey and the US Environmental Protection Agency (1994), the Río Guaynabo Conservation Easement belongs to the Bayamón-Loíza region and has the geology units of the San Sebastian (Ts) and Tutu formations (Kt). The San Sebastian is derived from Miocene and Oligocene deposits and is composed of cross-bedded to massive beds

of sand, sand and gravel, and sandy clay with thin beds of sandstone and sandy limestone. The Tutu formation is for the main part a tuffaceous composite which has a few limestone beds and also includes unknown intrusive igneous rocks (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005). Figure 33 show the geological distribution of Puerto Rico. The general location of the Conservation Easement has been circled although this encompasses a much larger area than that of the site since the location was approximated. As can be seen, the major rock formations are volcanic and sedimentary rocks.

Figure 33: Geological distributions of Puerto Rico.



Based on the description of the Soil Survey of San Juan Area of Puerto Rico published by the Soil Conservation Service United States Department of Agriculture (1978), the Río Guaynabo Conservation Easement belongs to the Association of "soils formed in residuum from basic volcanic rocks" which is mainly formed in clay material from basic volcanic rocks. The only soil found in the region is Naranjito silty clay loam (NaF2), which is shown in Table 2.

Table 2: Soil Resources of Río Guaynabo Conservation Easement.

Soil Type	Slope (%)	Distribution	Texture	Runoff/ Permeability	DWT (Ft)	AWC	DS (in)	DHR (in)
NaF2	40-60	Strongly dissected uplands	Silty clay loam	Rapid/ Moderate	>6.0	Low	0-4	29-45

Legend: Depth to water table (DWT); Available water capacity (AWC); Depth from surface (DS); Depth to hard rock (DHR).
(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

The Rapid Appraisal Report (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005), contained an analysis of the ecological value of the area by making a forest inventory using the Gentry Forest-Transect method. A 1000m by 2m area was chosen and divided into 10 segments. All trees in this area with a diameter of ≥ 6cm were measured and identified by species. From this, the importance value was calucated using the following method: IV= (relative density + relative frequency + basal area). Table 3 shows the top five species and their importance value.

Table 3: Forest inventory showing top five flora species found in the Río Guaynabo conservation Easement.

No	Species	Common Name (Spanish)	Common Name (English)	Origin	Den	Fre	BA (cm^2)	Rden	Rfre	RBA	IV	RIV
1	Guarea guidonia	Guarguao	American Muskwood	N	308	9	6633.896	35.16	6.62	25.41	67.19	22.4
2	Spathodea campanulata	Tulipan Africano	African Tulip	AL	157	10	8202.289	17.92	7.35	31.42	56.69	18.9
3	Caseana guianensis	Palo Blanco	Wild Coffee	N	112	9	2017.687	12.79	6.62	7.73	27.13	9.04
4	Bucinda buceras	Ucar	Oxhorn bucida	N	45	7	1939.223	5.14	5.15	7.43	17.71	5.9
5	Ocotea leucoxylon	Laurel Geo	N/A	N	33	6	798.3212	3.77	4.41	3.06	11.24	3.75

(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

The Rapid Apprasial Report (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005) also found that the fauna distribution in the area would be predictable; the species are those typically found in that forest type. Therefore only the fauna seen during the Rapid Appraisal were recorded. Table 4 lists the species of fauna found and their common name.

Table 4: Species of fauna found in the Río Guaynabo Conservation Easement. [1]Endemic to Puerto Rico.

Group	Family	Species	Common name
Birds	Accipitridae	Buteo jamaicencis	Red-tailed hawk
Birds	Coerebidae	Coereba flaveola	Bananaquit
Birds	Columbidae	Patagioenas squamosa	Scaly-naped pigeon
Birds	Columbidae	Zenaida asiatica	White-winged dove
Birds	Cuculidae	Coccyzus minor	Mangrove Cuckoo
Birds	Embrizidae	Quiscalus niger	Greater Antillean Grackle
Birds	Fringillidae	Loxigilla portoricensis[1]	Puerto Rican bullfinch
Birds	Muscicapidae	Turdus plumbeus	Red-legged Thrush
Birds	Parulidae	Dendroica adelaidae[1]	Adelaide's warbler
Birds	Picidae	Melanerpes portoricencis[1]	Puerto Rican Woodpecker
Birds	Todidae	Todus mexicanus[1]	Puerto Rican Tody
Birds	Tyrannidae	Tyrannidae	Gray Kingbird
Birds	Tyrannidae	Myiarchus antillarum[1]	Puerto Rican flycatcher
Reptiles	Iguanidae	Anolis pulchellus	Grass anole
Reptiles	Iguanidae	Anolis evermanii	Puerto Rican Green anoli
Reptiles	Iguanidae	Anolis cristatellus	Common anole
Reptiles	Teiidae	Ameiva exsul	Puerto Rican giant ameiva
Amphibians	Leptodactylidae	Eleutherodactylus chochranae[1]	Coqui Pitito
Amphibians	Leptodactylidae	Eleutherodactylus coqui	Common coqui

(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

The Rapid Appraisal Report developed a decision matrix in order to assess the components of the report. The decision matrix was based on two main categories: the ecological values and the management issues of the site. A weighted value was given to the ecological values of the site so that its value was two thirds of the final score. A score of 1-4 was given to each criterion developed under each category. The analysis gave a final score of 7.2 out of 10 despite the small size of the site because of its relation to the green belt of San Juan, its ecological value, and large species diversity. The report strongly recommended that the site be considered as a Conservation Easement and an Urban Forest for the benefit of the community.

4.2 Trail System

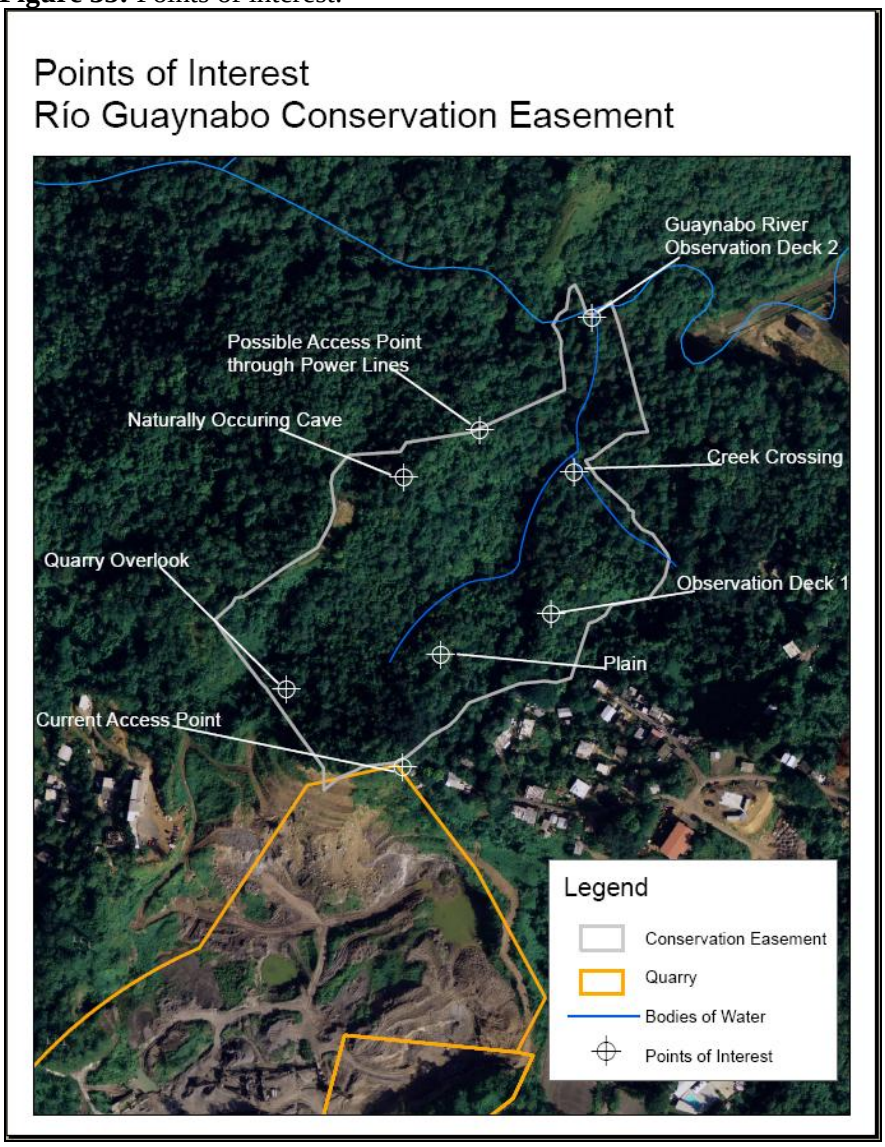
The next objective completed was to develop a trail system in the Río Guaynabo Conservation Easement to be included in the Management Plan for the Trust. The trail system consists of trail locations and designs which are summarized in a map of the site.

4.2.1 Trail Locations

Currently, Fideicomiso is attempting to gain a new entrance to Río Guaynabo that does not require access through privately-owned parcels. A gated community, Sunset Hills, is the most feasible point to gain entrance. However, there is resistance from the residents of Sunset Hills because it is a gated community. The Autoridad de Energía Eléctridad de Puerto Rico (AEE) has access to their power lines through Sunset Hills which cross part of the Conservation Easement owned by the Trust. The Trust is negotiating with AEE to use the same point of access. The AEE access route comprises a long dirt road from the south that opens up into a large clearing shown in Figure 34 where the power lines are located. This clear area could possibly be used to house a visitor center and serve as a starting point for tours. From there, the tour group would enter the forest and take the closest trail to the first point of interest. The points of interest are shown in Figure 35. In addition to the points of interest, the team also suggest two observation platforms and a resting spot aslo shown in Figure 35.

Figure 34: Land clearing at AEE entrance and possible access point.

Figure 35: Points of interest.*



The preliminary points of interest were chosen during the first field survey. The site directly abuts a quarry which mines limestone (Figure 36). It is important to show the quarry as a point of interest because it shows how developments can affect a watershed. Specifically in the site, the change in elevation caused by the quarry dried one of the creeks found in the Río Guaynabo Conservation Easement. The dried creek crosses and combines with a flowing creek (Figure 37). The creeks are also recommended as a point of interest because they show how water flows in a watershed. The creeks flow into the Guaynabo River which is recommended as the main point of interest for the site (Figure 38). Finally, the west side of the site houses a cave which is generally only found in the karst regions of Puerto Rico on the west side of the island

(Figure 39). The cave is not only an aesthetic point of interest but can also be used as segue to explain runoff. The points of interest were chosen for their scenic interest but also because they help portray the theme of the importance of watershed conservation. The reasons for choosing these points of interest in relation to the theme of watershed conservation are explained in Section 4.3.2 Watershed Education.

Figure 36: Natural cave as proposed point of interest.

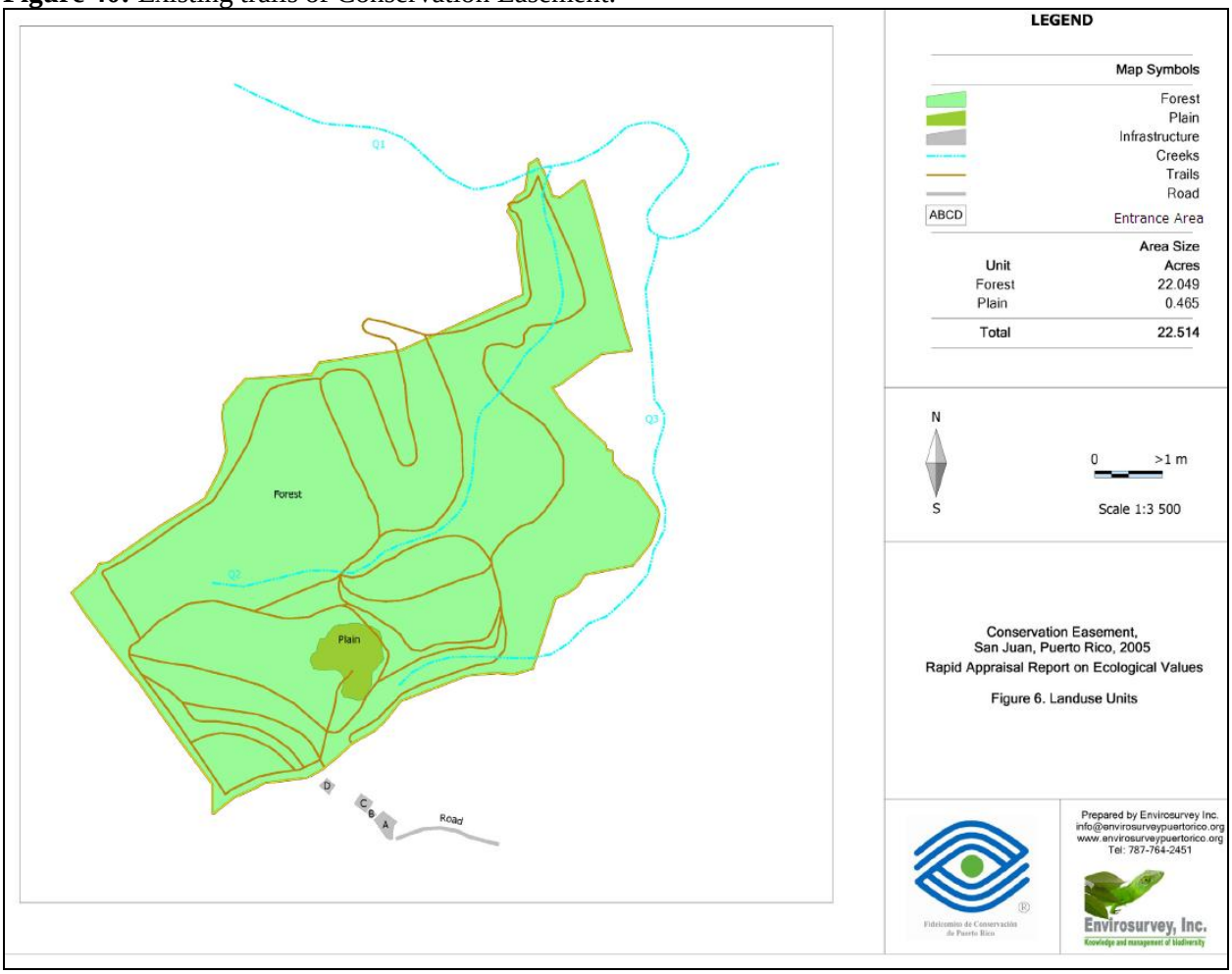
Figure 37: Quarry abutting site as proposed point of interest.

Figure 38: Creek proposed point of interest.

Figure 39: Guaynabo River proposed point of interest.

Once points of interest were chosen the team walked the existing trails in the site in order to determine the safest path which best displayed the points of interest. There are many trails that currently exist on the site since local residents have used the Conservation Easement for various purposes. Envirosurvey, Inc. prepared a map of the existing trails for the Trust in 2005, which is illustrated in Figure 40. Since the trails were mapped many of them have grown in and become unusable. The Trust would prefer that existing trails be used as much as possible when choosing trail routes so that little environmental impact is caused. Trails not used should be allowed to grow in.

Figure 40: Existing trails of Conservation Easement.

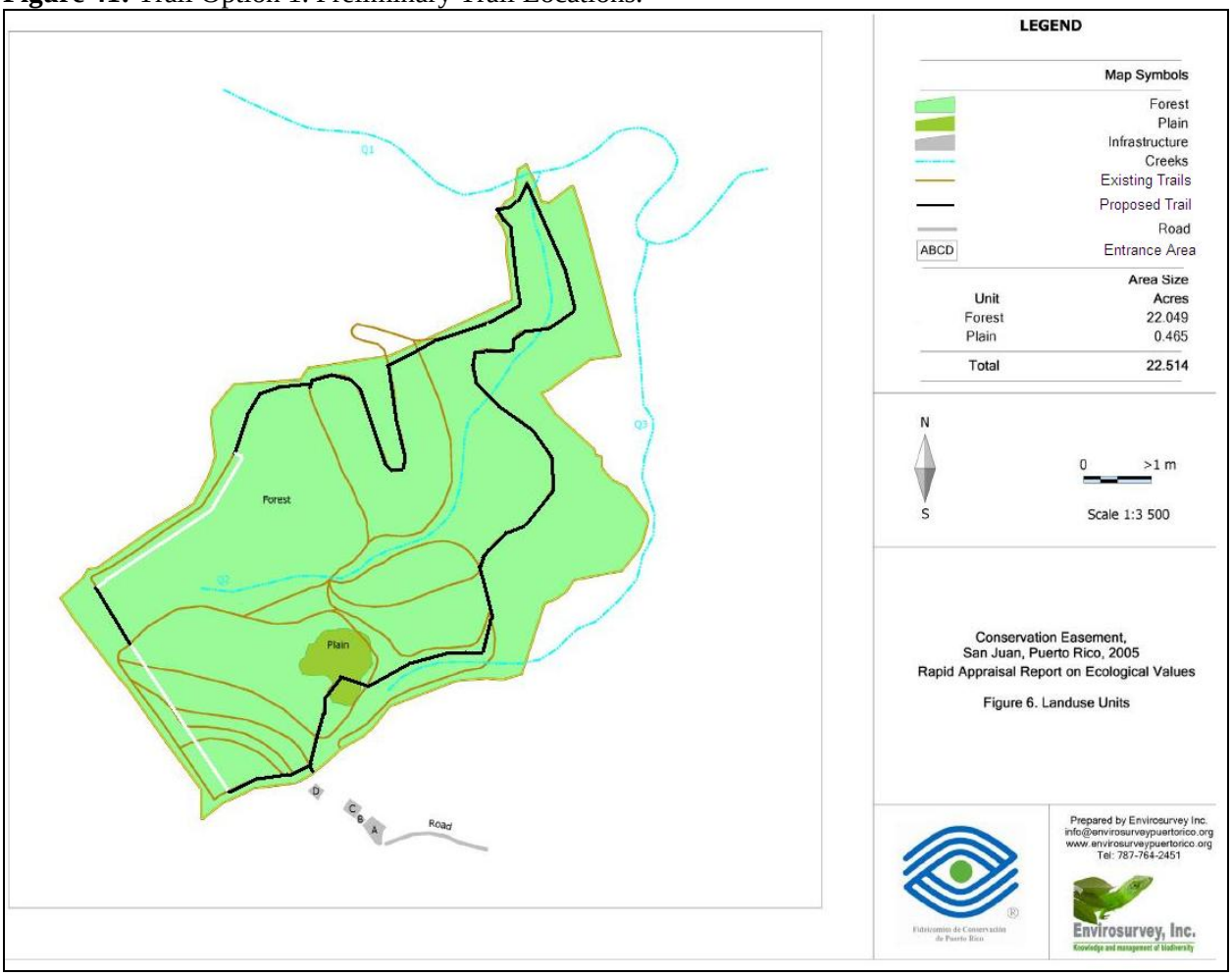


(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

The assessment of existing trails occurred during the second and third visits to the Conservation Easement. During the second field survey GPS points were taken along the trails taken by team. At this point the team developed a preliminary trail route map based on the map of the existing trails with the addition of proposed non-existing trails (Figure 41). In order to have a trail system which covers the most area of the site without backtracking, the team chose a trail system that made a loop around the perimeter of the Conservation Easement. Additionally, this type of trail system would allow much flexibility in choosing an access point since one has not yet been determined. The non-existing trails were proposed because trails close to the border of the site are fenced with barbed wire. Brining these trails back away from the fence would be safest for the visitors. During the second site visit the team visited the west side of the site not using the trails proposed in the preliminary trail locations. At this point the project team had not

explored the area in its entirety. The trail that leaves the river towards the west side of the site had not been walked and therefore it had not been confirmed that this route was feasible.

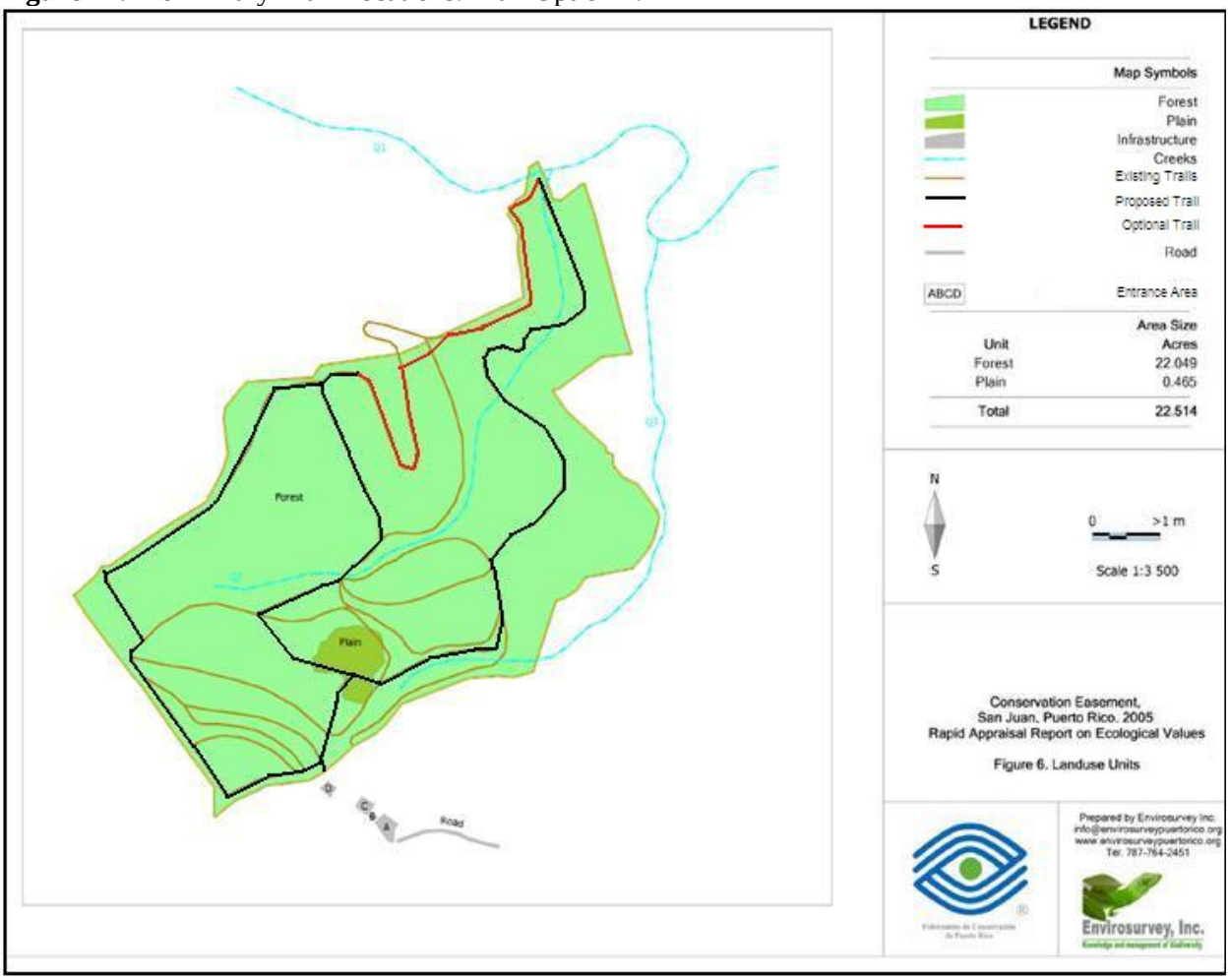
Figure 41: Trail Option 1. Preliminary Trail Locations.



(Source: Adapted from Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

During the third field survey the team was able to assess the trail that left the Guaynabo River and led to the west side of the site. A trail was found but the team was not able to reach the natural cave because the remainder of the trail was very overgrown and too difficult to hike. The Trust could still use this trail if they choose to clear it but the team decided to provide another option if clearing was not feasible. With the second trail option however, the visitors would have to back track to see the west side of the site. The team also realized that the view of the quarry would not be possible if the trails were brought back from their original location and therefore the proposed non-existing trails were eliminated. Based on these changes a new preliminary trail map was generated shown below in Figure 42.

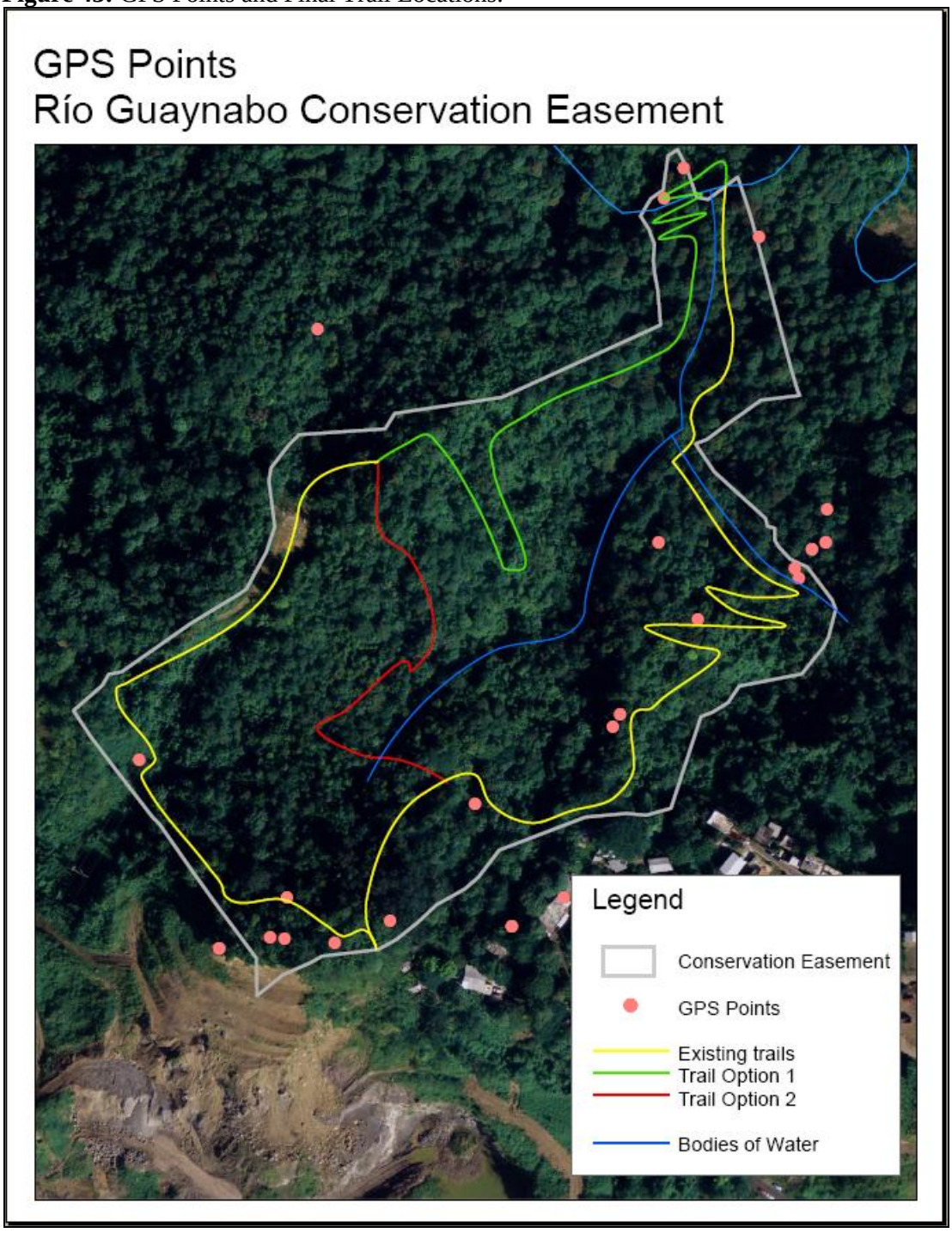
Figure 42: Preliminary Trail Locations. Trail Option 2.



(Source: Adapted from Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

After careful and extensive fieldwork of the area and trails the team designed a final trail map. The project team noticed that the previously drawn out trails were inaccurate. Once the GPS points were uploaded onto a map of the Conservation Easement it was found that previously recorded points were showing up off the site. Generally GPS points allow for around ten to fifteen feet discrepancy. During the site visit, adequate satellite strength was scarce and the GPS points were hard to acquire, thus more likely to be inaccurate. Due to these various factors the team approximated trails using a combination of GPS points, existing trails, and the teams' estimations. Figure 43 below shows the trails along with the GPS points used to mark the trails.

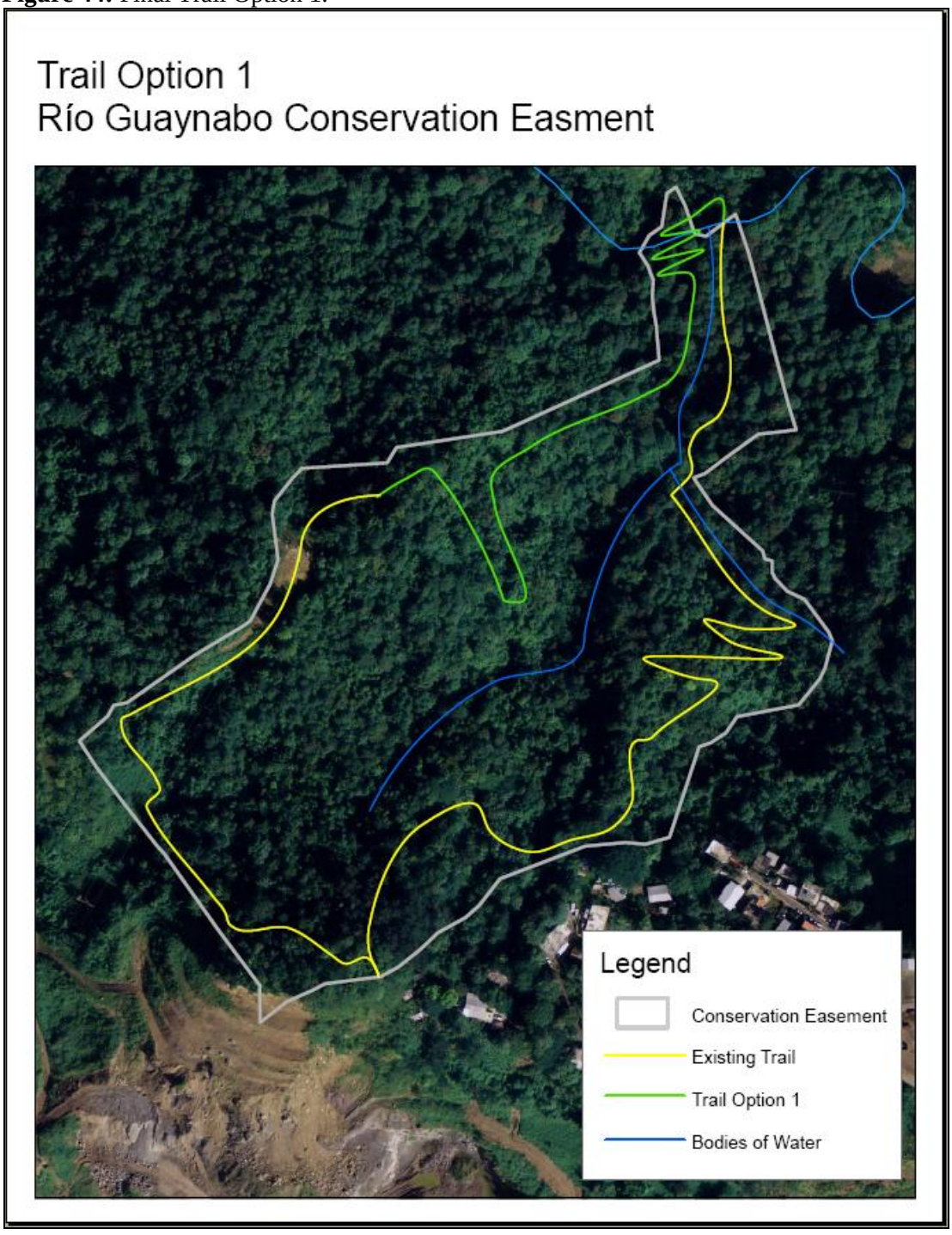
Figure 43: GPS Points and Final Trail Locations.*



The project team has designed two trail options. The first option is a loop around the general perimeter of the area. This trail allows the visitor to walk down to the river and then around the west side of the area. The pros of this trail are that the visitors get a scenic view of the river, the plain, and can also view the power lines and the cave. This trail also eliminates a back

track method giving the visitor the most diverse view of the land. Trail option 1 can be seen in Figure 44.

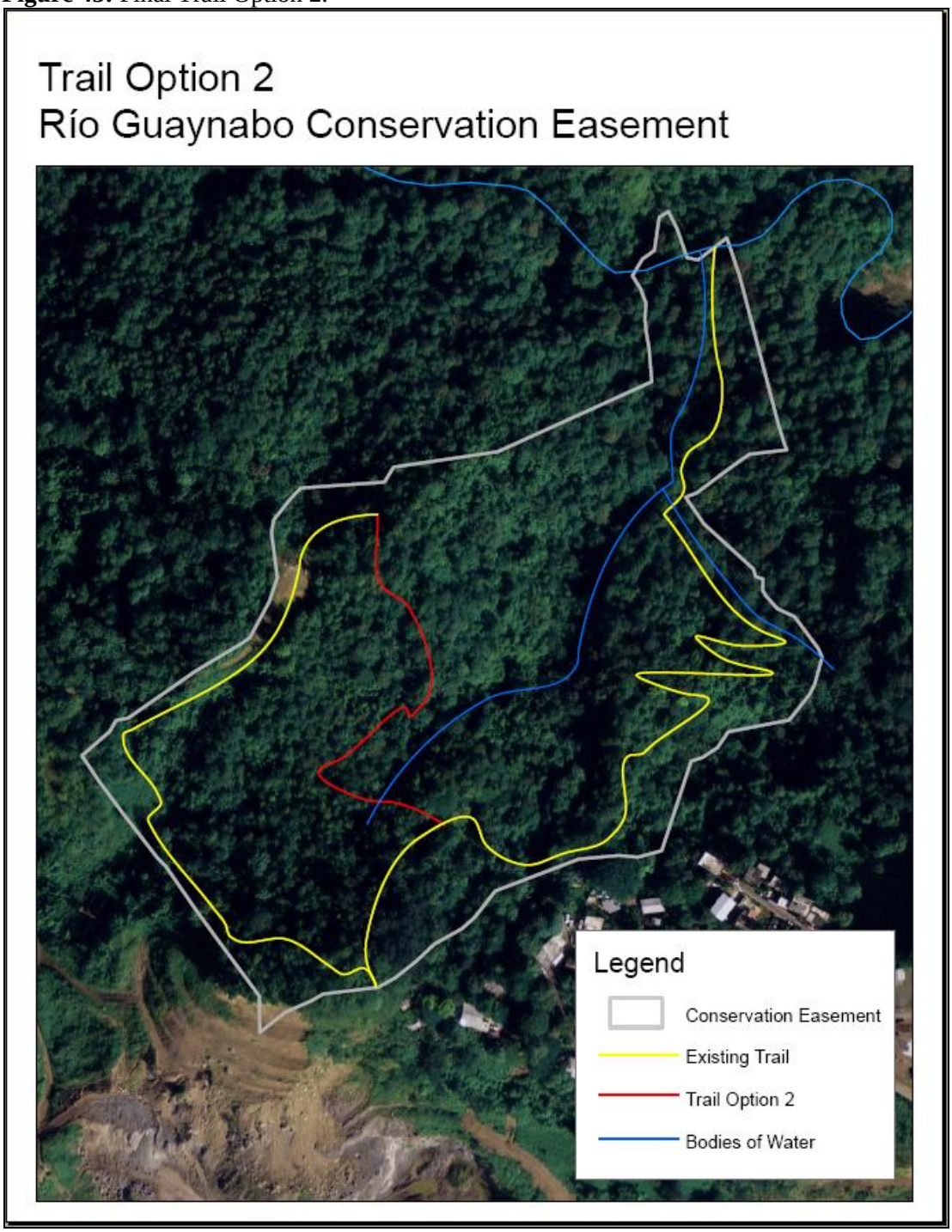
Figure 44: Final Trail Option 1.*



The second trail option, shown in Figure 45, uses the back track method avoided in trail option 1. This method does not give as diverse scenery as option 1, however, it is able to show

the river, plain, and power lines. This trail can be repetitive, but may take less time than option 1, appealing to a younger crowd and/or families.

Figure 45: Final Trail Option 2.*



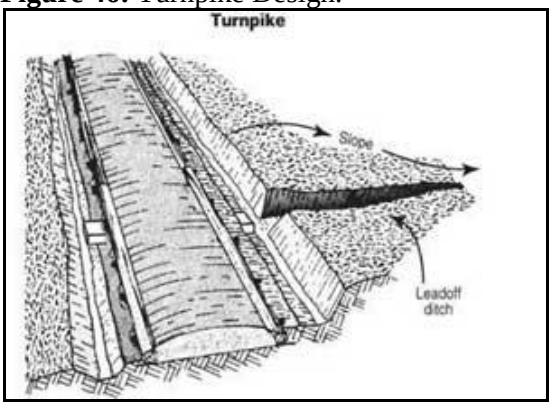
4.2.2 Trail Design

The team developed general guidelines for trail design based on the review of literature to provide to the Trust which can be found in the Management Plane in Appendix B. Including in the general guidelines were clearing methods and switchback methods. The following explains specific trail designs and graphics generated by the team and adapted from literature.

Interpretive and nature viewing trails should be designed specifically for their intended purpose. Trail features and locations should be implemented according to the central theme of the interpretive plan. For example, since the central theme of the program at the Río Guaynabo easement is watershed conservation, the trail should undoubtedly include a scenic outlook over the Guaynabo River. Many interpretive trail systems, including the Río Guaynabo Reserve, are located near heavily populated areas and heavy traffic from users of all ages and abilities can be expected. Accordingly, trail design and upkeep standards should be high in order to promote safety and ease of use. Most importantly, it is suggested that the trail builders keep in mind that a tour guide will have a hard time keeping visitors' attentions if they are forced to consistently watch their footing throughout the duration of the hike. To ease the difficulty of the trails, grades should be kept less than or equal to 5%, and extended sections of 15% should be avoided. Looped trails are most suitable, with spurs and satellite loops providing additional variety. Trail sections with curves and twists increase visitor curiosity and interest, and provide more surprises than long straight sections.

In order to build a safe trail that could be effectively implemented despite the reserve's harsh terrain and wet climate, the project team has decided to propose that the majority of trail tread be designed using the turnpike technique. Based on the literature, it was concluded that when compared to other techniques, the turnpike incorporates the best blend of features that include accessibility, drainage, aesthetics, ease of maintenance, and feasibility for the Trust. This style of trail design uses a pair of trenches coupled with a raised trail tread with a prominent crown in order to effectively direct water from the trail and prevent erosion. In addition, the design allows for drainage to be further manipulated by the implementation of strategically placed culverts and leadoff ditches. Figure 46 shows an example of the turnpike design.

Figure 46: Turnpike Design.

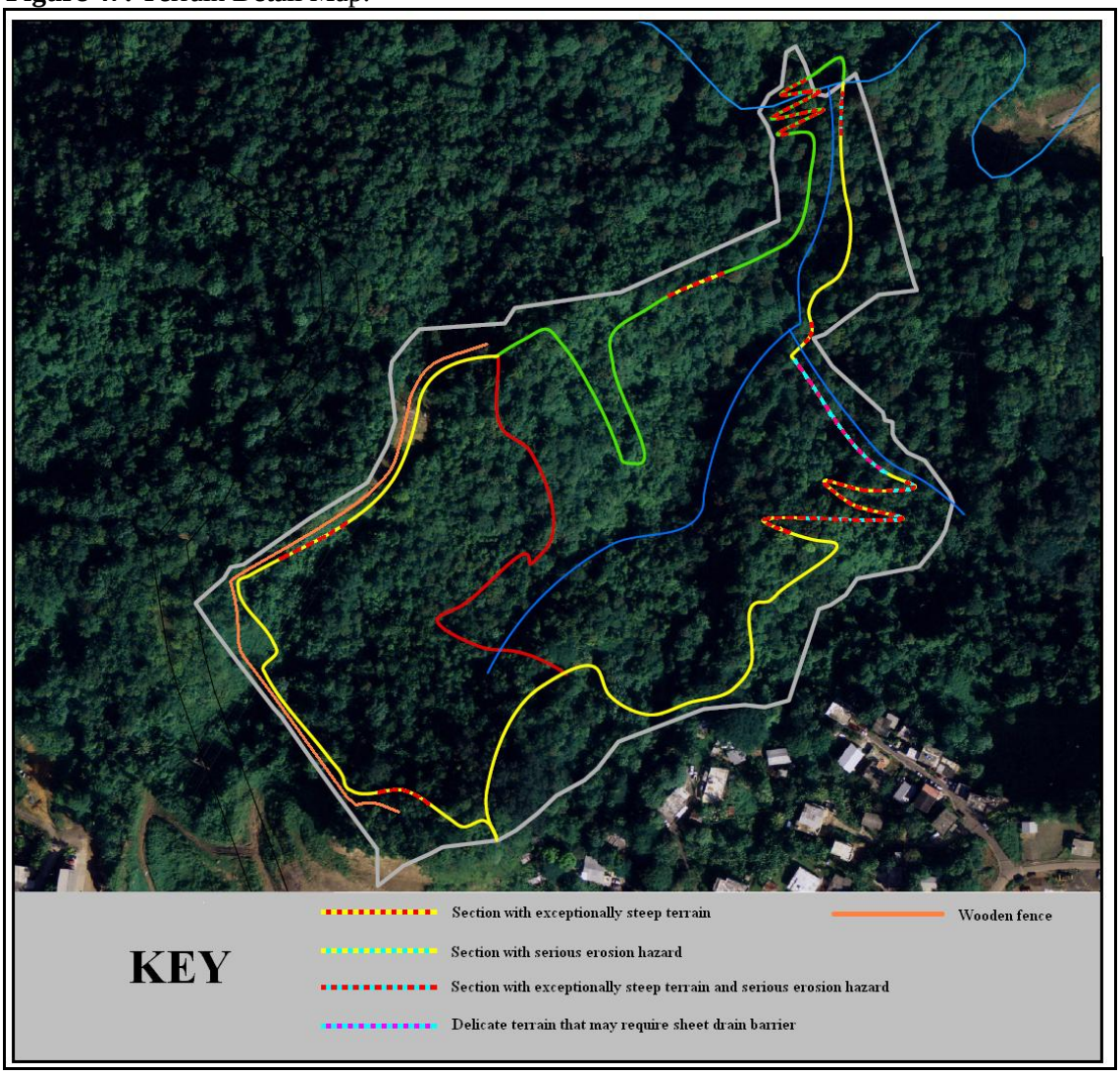


(Source: Trail Construction and Maintenance, 2004)

The downside of using the turnpike design is that its implementation is labor intensive. The route must be well cleared and graded and trees must be leveled, stripped, and pinned for use as trailside retainers. Fortunately, the finished product is a high quality, attractive, durable, low maintenance trail system that can be enjoyed by hikers of all skill levels.

The turnpike design can be used with several different tread materials including gravel, corduroy logs, concrete, asphalt, and crushed lime. After consulting with employees in the Trust, concrete tread was ruled out in favor of gravel as it is their traditional tread material at their other sites throughout Puerto Rico. Unlike concrete, the use of gravel presents several challenges due to the reserve's steep terrain. Gravel, while offering excellent drainage and good traction, is unstable and will creep downhill and off the tread line over time. In order to ease maintenance and extend trail life, the following tread solutions are proposed to slow this process. Figure 47 shows different terrains of Río Guaynabo, followed by explanations of the tread solutions. It is also recommended that wood fencing be placed in front of the barbed wire fence found at certain boundaries of the site in order to increase user safety as shown in Figure 47.

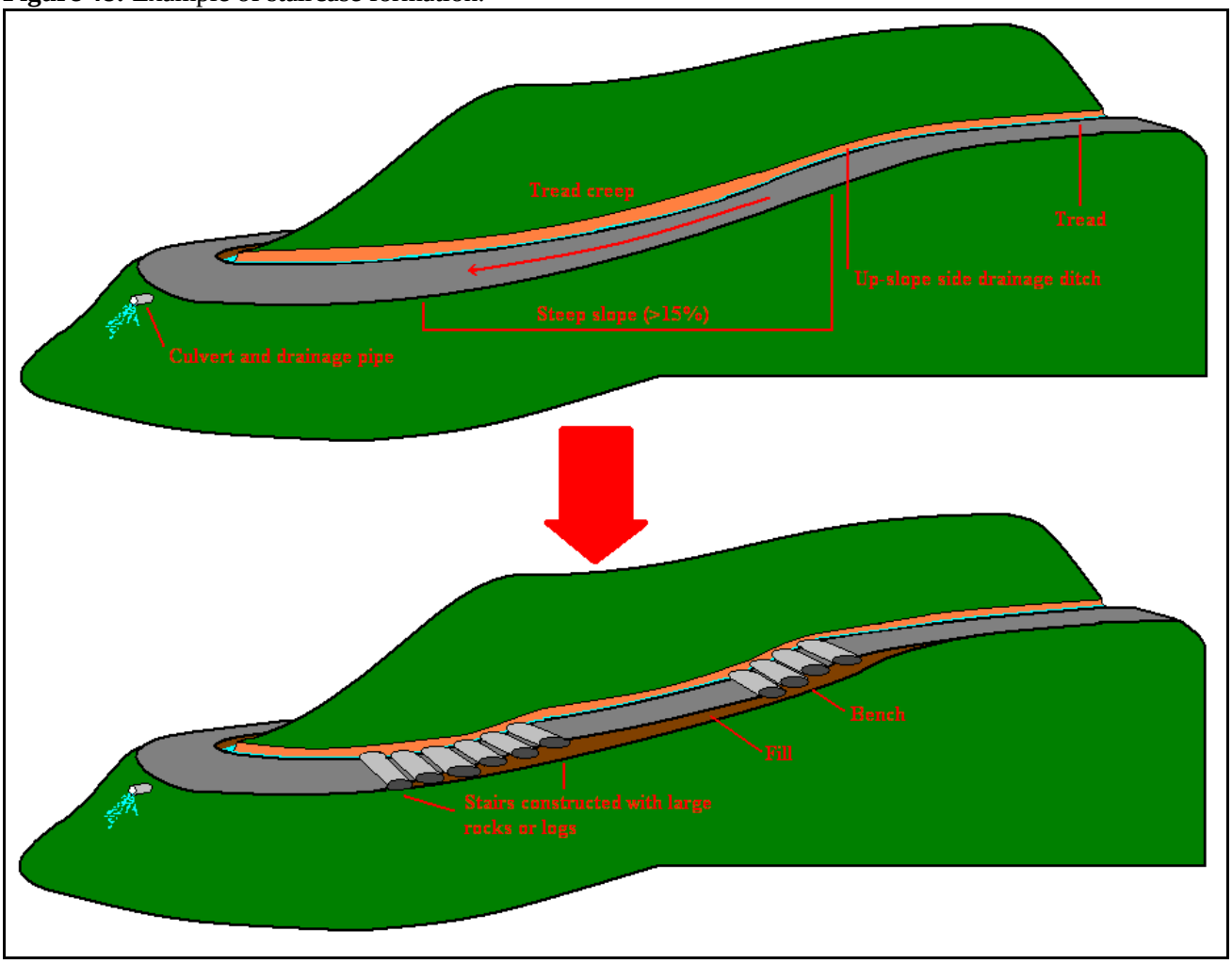
Figure 47: Terrain Detail Map.*



1. Adequately drained terrain with grade less than 15%:

In order to reduce spending, the turnpike design can be implemented on shallow grade terrain with minor erosion hazard by simply using existing excavated rocks under the tread fill for drainage and support. Windfall and other material removed from the trail during the clearing process may be pinned together and mounted lengthwise on the edges of the trail to be used as retainers where needed to reduce lateral creep and maintain the tread crown. If the grade of the path exceeds 15% and the soil remains sturdy, minor grading coupled with the use of widely spaced single or double step stairs will be adequate for the purpose of retaining a proper grade for the turnpike. This method is shown below in Figure 48.

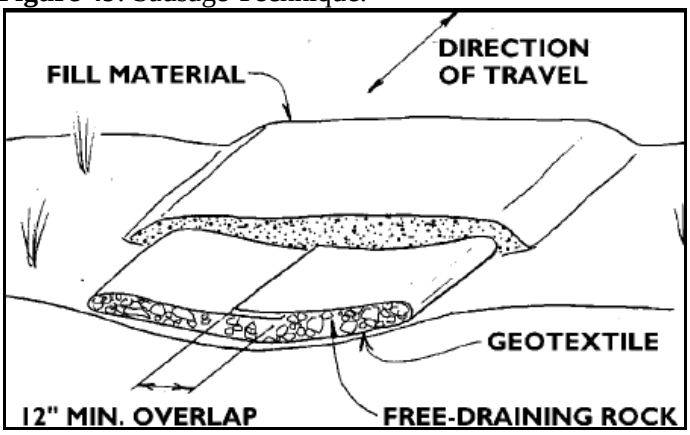
Figure 48: Example of staircase formation.



2. Wet terrain with grade less than 15%:

In areas where the ground has significant surface flow due to poor drainage, geotextile material, also known as construction fabric, will provide adequate drainage and support when using the "sausage technique" as shown in Figure 49.

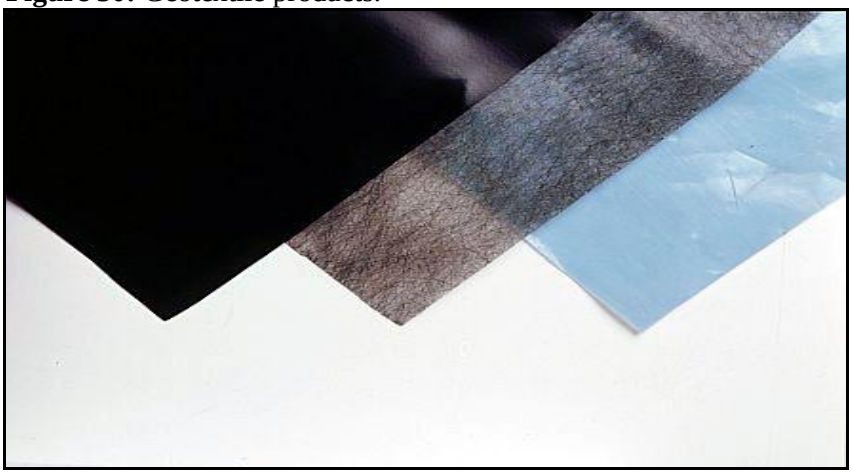
Figure 49: Sausage Technique.



(Source: Monlux, 1995)

Geotextiles are tough, porous fabrics that separate the tread from the soft, wet topsoil and the trail tread. Their high tensile strength allows the weight of the tread to be evenly distributed over the topsoil and provides excellent support. Figure 50 shows three geotextile products of different thickness and design.

Figure 50: Geotextile products.



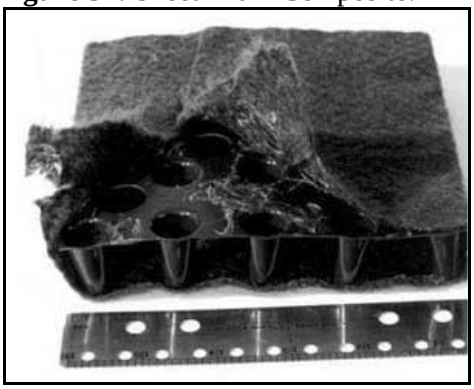
(Courtesy of: www.dkimages.com)

3. Extremely wet terrain with minor grade and poor drainage:

Some areas within the conservation easement may exhibit terrain, especially in the wet season, in which the ground is very wet and soft and/or prone to significant water accumulation. These areas are highly prone to erosion and trail degeneration and require special attention. To counter these hazards, several manufacturers produce a geotextile

composite that includes two layers of textile cloth separated by a honeycomb polymer layer called a sheet drain, shown below in Figure 51.

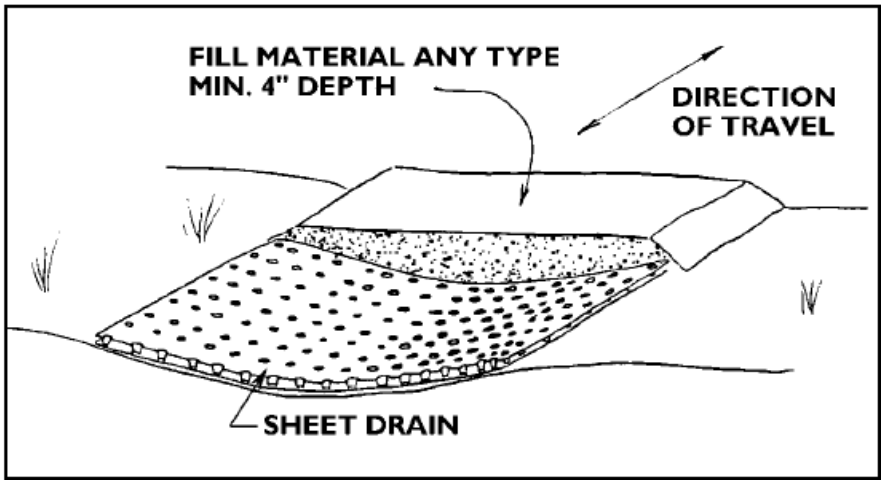
Figure 51: Sheet Drain Composite.



(Source: Trail Construction and Maintenance, 2004)

Sheet drains separate the trail tread from the muck and provide space for water to harmlessly drain under the tread into the turnpike ditches. The composites also provide excellent trail stability and support by providing a rigid foundation to evenly distribute the tread load over the wet, unstable topsoil, shown in Figure 52.

Figure 52: Sheet Drain Implementation.



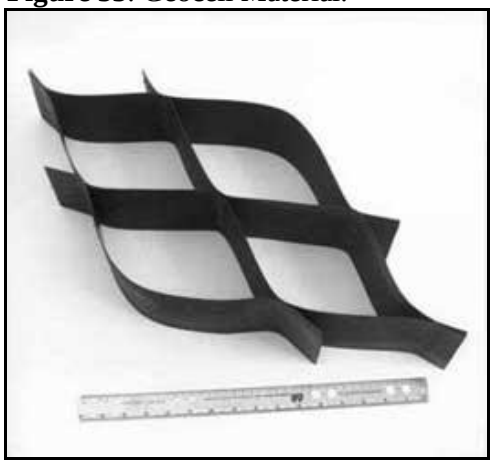
(Source: Monlux, 1995)

4. Steep terrain (>15%) with adequate drainage but unsuitable for grading/stairs:

Some areas within the easement may exhibit terrain in which the trail grade must exceed 15% for an extended section despite the use of switchbacks and cross grading as well as have

unstable or rocky soil that would discourage the use of stairs and grading. In order to prevent gravel tread from creeping, or land sliding, down steep slopes, it is proposed that the trust implement a tread reinforced by a geocell structure. Geocell, shown in Figure 53, is a simple structure that is constructed by welding polymer strips together to form a raised honeycomb network.

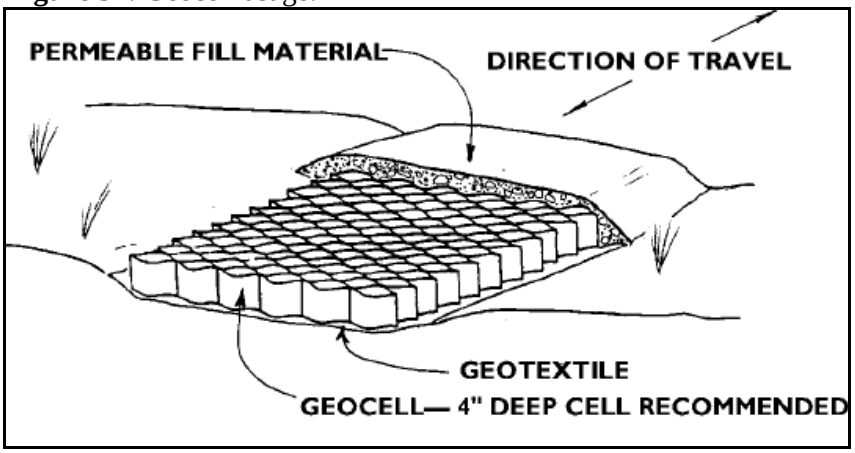
Figure 53: Geocell Material.



(Source: Trail Construction and Maintenance, 2004)

The tread is securely held in place when it is backfilled into the cells, and supported by a single layer of geotextile. Geocell offers excellent tread drainage when implemented into a turnpike design and it can also be effectively used for earthen retaining walls and other steep sections prone to erosion. The following figure, Figure 54, illustrates the proper use of geocell material.

Figure 54: Geocell usage.

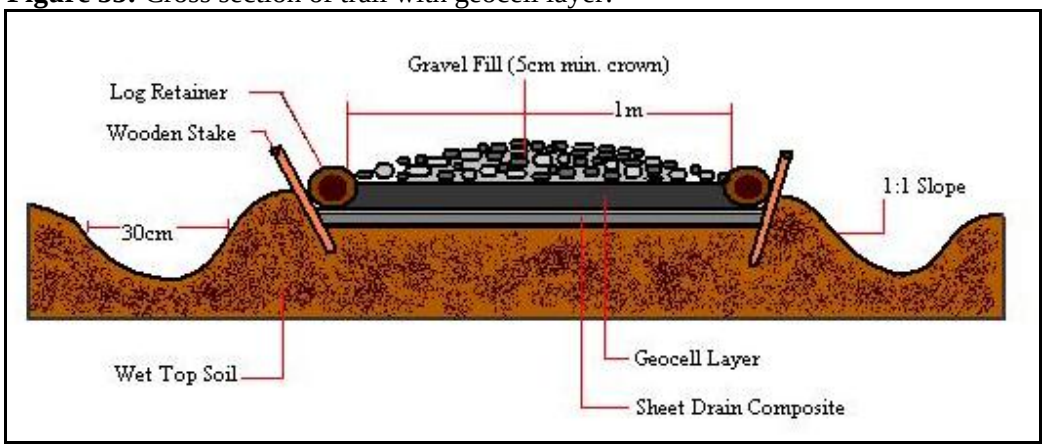


(Source: Monlux, 1995)

5. Steep terrain (>15%) on wet soil especially prone to erosion

For exclusive areas with steep grades that also present serious erosion and/or drainage problems, it is proposed that the trust use a special hybrid trail design that employs both a sheet drain and geocell structures under the tread to prevent gravel slippage, promote clean, effective drainage, and maximize user safety by ensuring consistent traction in wet conditions. Figure 55 shows a cross-sectional view of the hybrid trail layout.

Figure 55: Cross section of trail with geocell layer.

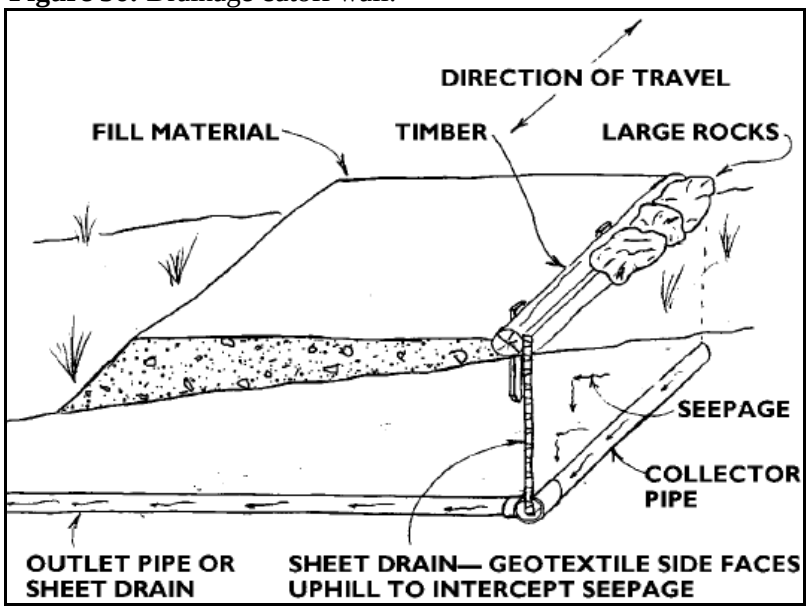


6. Delicate Terrain:

Some areas in the reserve offer interesting viewing opportunities for the user but present major trail building hazards. A good example of an especially delicate area is the bank overlooking the actively flowing creek in which the trail is eroded to the point where it is suspended on an overhang above the creek bed. This problem needs to be fixed by reinforcing the eroded areas with fill and constructing either a wooden or geocell retaining wall. Once repaired, the trail will still be prone to erosion due to the fact that it is located on a steep, wet face. If the trail erodes, the sediments will run straight into the stream and pollute the water. A possible solution for these small, fragile trail sections would use a sheet drain as a drainage cutoff wall to eliminate lateral surface flow from the trail altogether. This technique of a drainage cutoff wall can be seen in Figure 56. If the trail section is on a side slope where groundwater saturates the uphill side of the trail, a cutoff wall can be constructed

to catch surface and subsurface moisture and help drain and stabilize the trail section. The sheet drain cutoff wall is partially buried vertically along the uphill side of the trail within three feet of the trail's edge. The top edge of the drain should remain above ground to capture surface runoff moving toward the trail and covered with large rocks to protect it from deterioration from sunlight. Collector and outlet pipes can be made from PVC piping. The collector pipe can be drained into an outlet pipe or an additional sheet drain panel under the trail section.

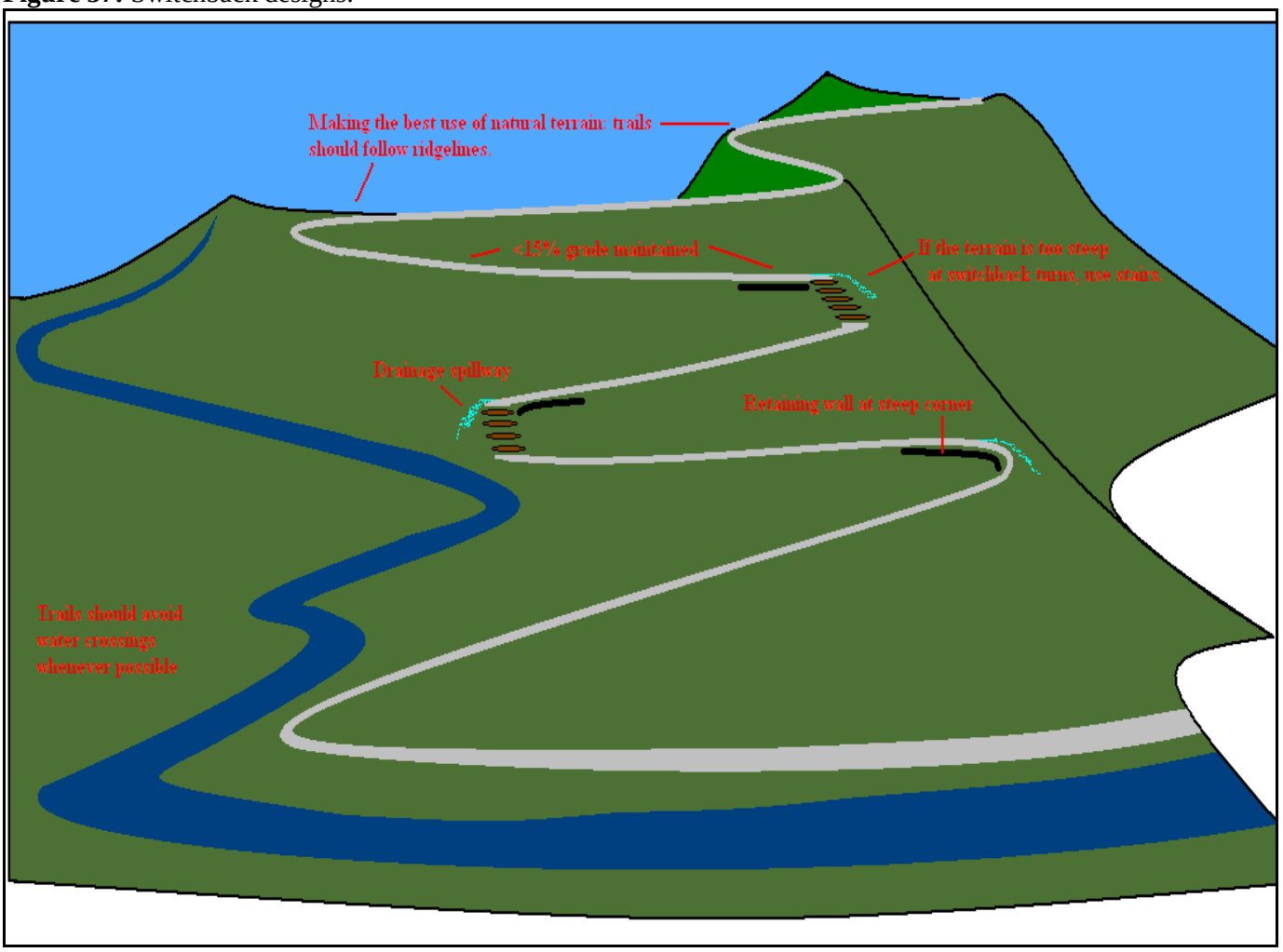
Figure 56: Drainage cutoff wall.



(Source: Monlux, 1995)

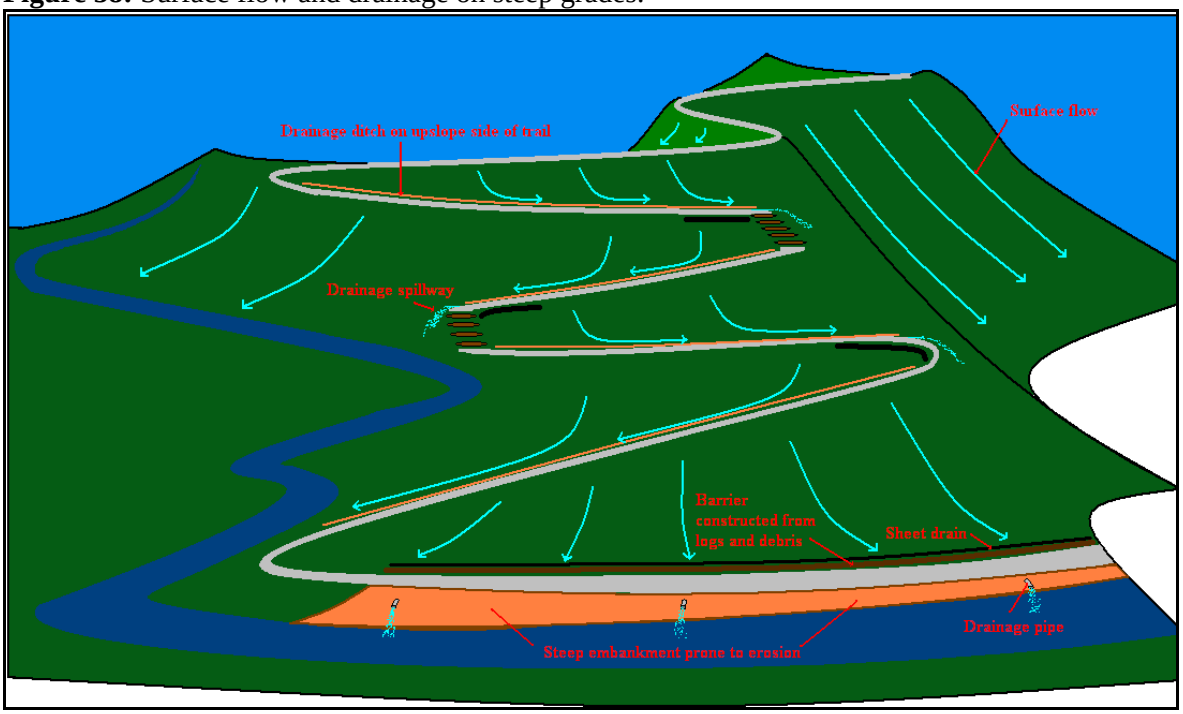
For particularly steep grades or areas where loose soil or roots make it impossible to effectively set stone steps into the earth, it is suggested that the trails use plank stairs that are connected by stringers. These staircases should be well anchored, include a rail, and must be constructed using durable, pressure treated timber. A strategic point for using these stairs is at switchback turns that may be too steep for user safety or present an otherwise unsolvable drainage hazard. Since timber stairs only break ground at the footings, drainage water can be allowed to flow around the stairs over natural foliage and terrain. For example, the section of the trail that leads down the exceptionally steep embankment toward the actively flowing creek can implement the setup shown in Figure 57.

Figure 57: Switchback designs.



When designed correctly, surface flow should make its way down steep slopes by following drainage ditches implemented into the turnpike trail design and draining away from the trails at switchback turns. Water should be drained at points where there is heavy vegetation and little or no exposed soil to prevent sediment runoff. The figure below, Figure 58**,** illustrates the correct path for surface flow on a steep slope in addition to proper application of a sheet drain cutoff wall at a delicate stream embankment as described above in Figure 57.

Figure 58: Surface flow and drainage on steep grades.



4.3 Watershed Conservation

From informal interviews and meetings with members of the Trust it has been determined that the watershed conservation focused on two main items. The first is to determine what is affecting the watershed in the Río Guaynabo Conservation Easement so that these site specific examples can be used to portray watershed education and interpretation.

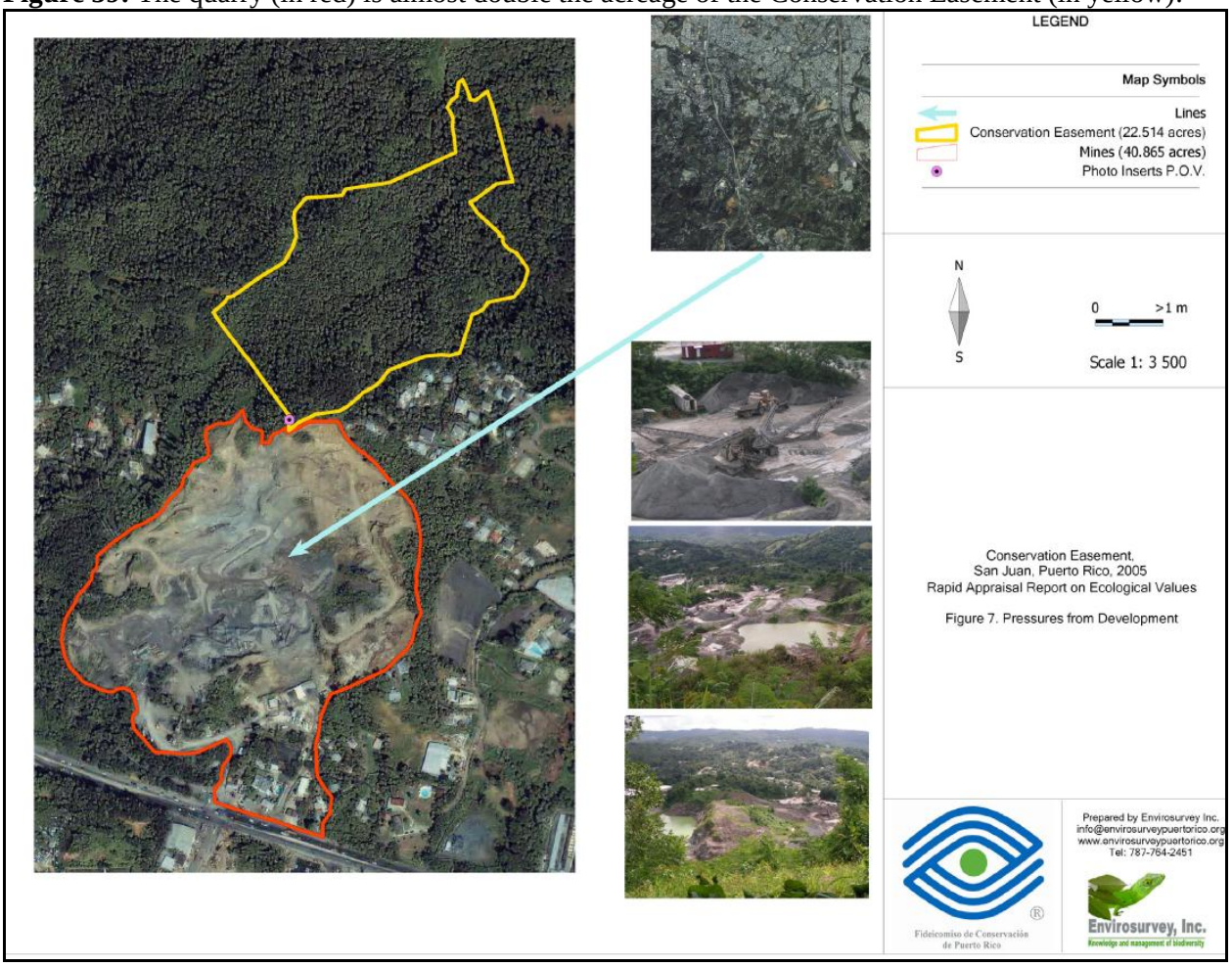
Secondly, it focused on presenting educational information to visitors so they can understand the importance of protecting watersheds. Visitors should leave with a complete understanding of what a watershed is and how it affects the rest of the ecosystem. Furthermore, visitors should receive educational information on the effects of polluting a watershed and what they can do to conserve watersheds.

4.3.1 Watershed Assessment

It appears that the quarry abutting the Río Guaynabo Conservation Easement (Figure 59) is adversely affecting the flow of water within the area. Prior to quarrying, the small stream that flowed from south to north through the site was fed by water flowing off the elevated land to the south. Quarrying has been so extensive; however, that the land to the south is now generally

lower than the Río Guaynabo Conservation Easement and the small stream is dry along much of its length.

Figure 59: The quarry (in red) is almost double the acreage of the Conservation Easement (in yellow).

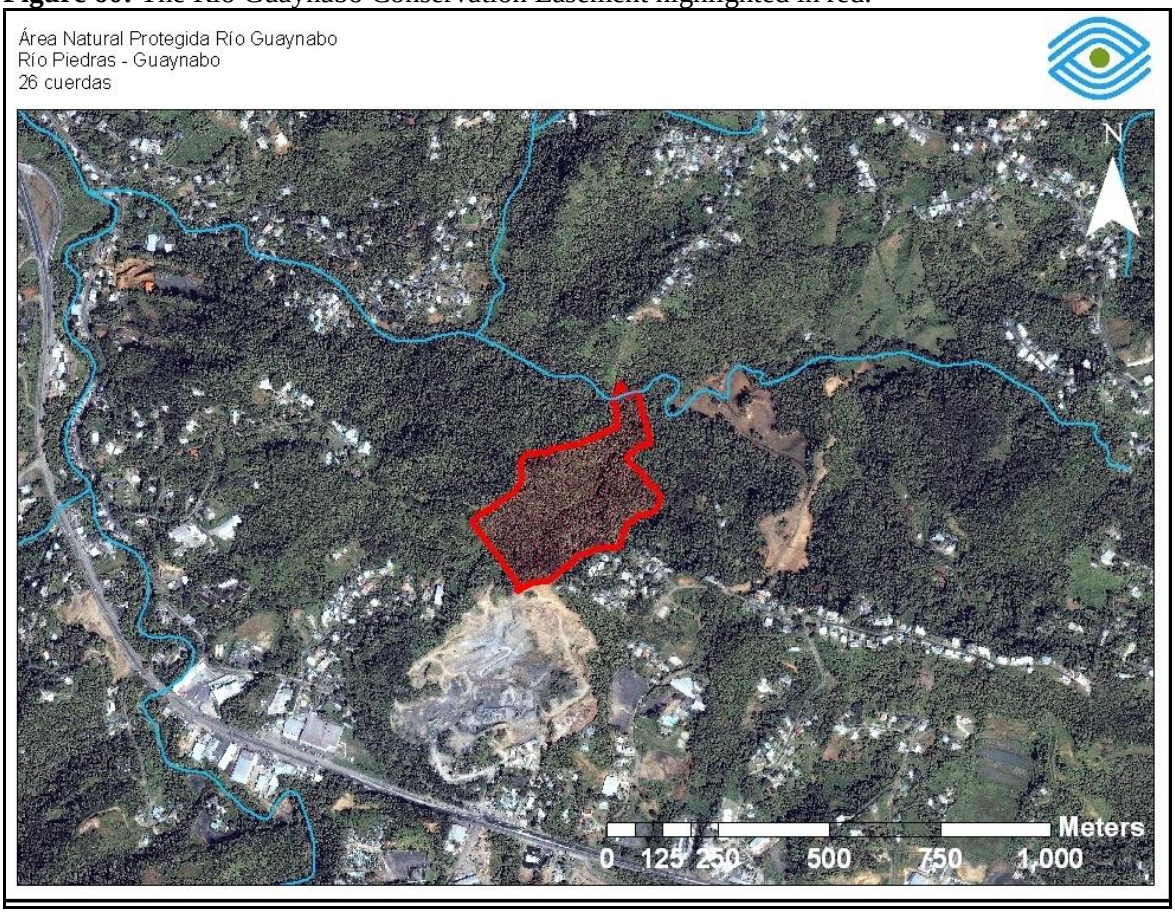


(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

Excavations continue at the quarry and part of the land on the southern boundary has already collapsed into the quarry. Also there may be pollution from the quarry seeping into the ground water and therefore entering the Conservation Easement. Because of this possible pollution the quarry should be closely monitored in the future.

Future developments in the surrounding area should also be studied closely by the Trust. Figure 60 shows the aerial view of the Río Guaynabo Conservation Easement and the surrounding land.

Figure 60: The Río Guaynabo Conservation Easement highlighted in red.

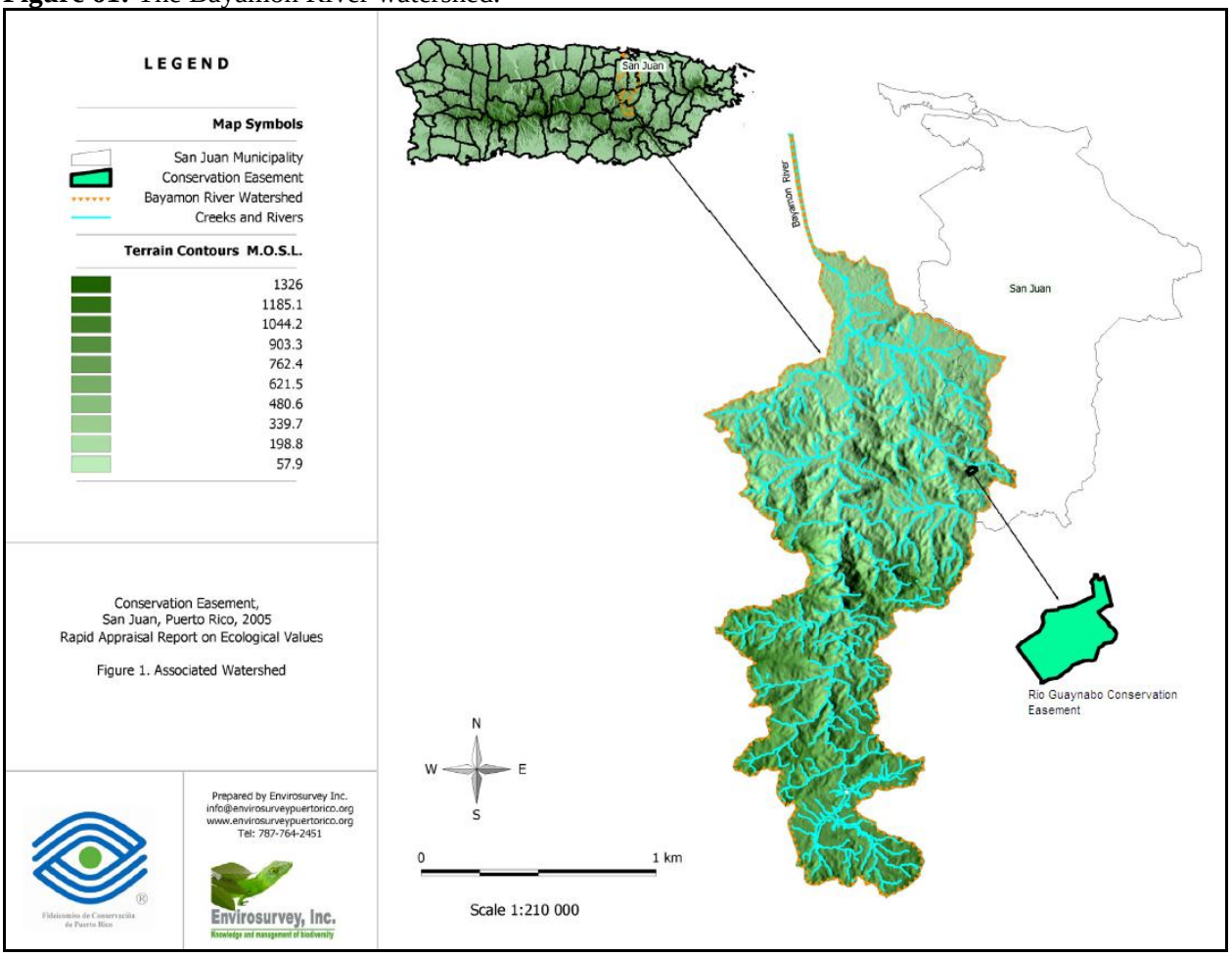


(Courtesy of the Conservation Trust of Puerto Rico)

As can be seen, there many developments surrounding the Conservation Easement. In addition, the area is surrounded by forest which is threatened by future developments. The figure also shows the part of the Guaynabo River that enters the Río Guaynabo Conservation Easement. While the Guaynabo River is relatively small, it draws runoff (and pollutants) from a wide area over its entire watershed.

However the watershed of the Guaynabo River goes beyond Figure 60. The whole of the Bayamón River watershed should be studied in order to determine where potential pollution could occur and what land is at risk for further development. Figure 61 shows the entirety of the Bayamón River watershed.

Figure 61: The Bayamón River watershed.



(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

The Conservation Easement also houses many unwanted visitors. Residents with access to the area have been using the site for riding All Terrain Vehicles (ATV) and copper burning and consequentially are leaving the area heavily littered. The team recommends that wooden fencing be placed around the perimeter of the site in order to distinguish the boundaries and potentially keep out unwanted visitors. In addition it is suggested that the litter on the site be cleaned up through the AMIGOS program. The watershed threats should be explained to visitors to help convey the necessary watershed interpretation and education throughout the tour.

4.3.2 Watershed Interpretation and Education

One of the main goals of the project is to create an interpretive program for visitors with a theme based on watershed conservation. Accordingly, the team has developed a trail system that can effectively accommodate this theme by using a series of interesting natural and man-

made features along with a series of interactive activities with the goal of providing both a fun and educational experience.

The points of interest should emphasize the importance of watershed conservation and give tour guides an opportunity to provide interpretive information. Each point of interest relates specifically to the watershed of the Conservation Easement and also to the overall theme of general watershed conservation. Many points of interest also offer opportunities to use hands-on activities that would help keep visitors engaged and reinforce their understanding of key points and concepts. Interesting trail features that can be effectively incorporated into the interpretive plan include:

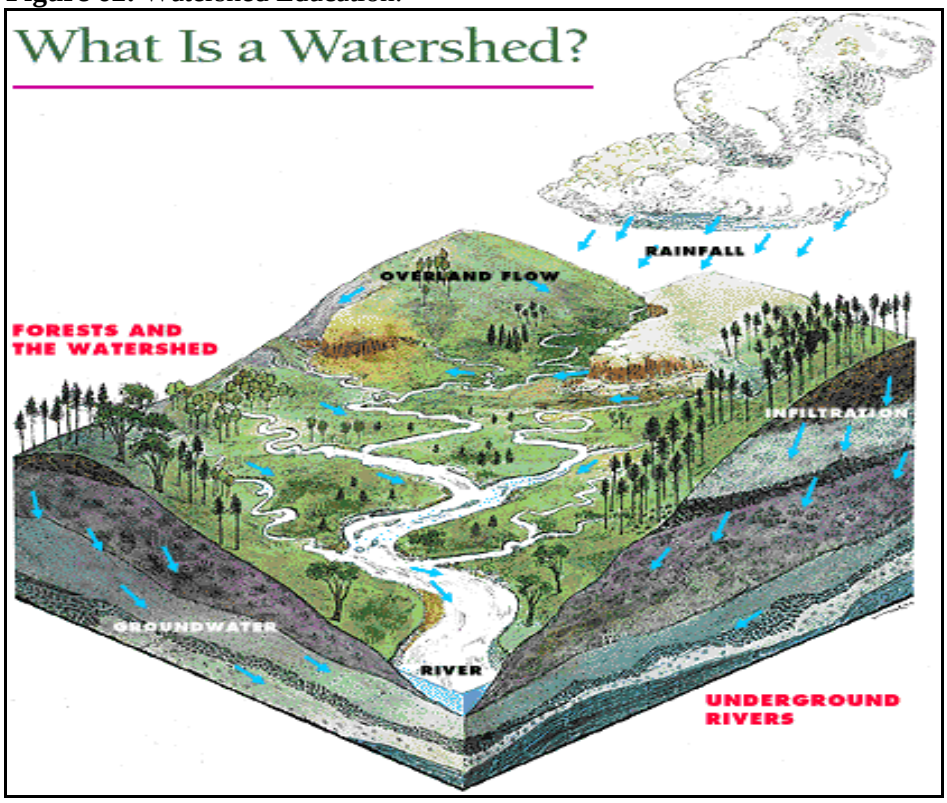
- **The cave**: The cave found near the power lines on the boundary of the property is an important point of interest because it is a typical landform found in the karst region generally found on the West coast of the island. Karst features many underground caves and cavities where pockets of limestone have eroded within the bedrock. The tour guide can emphasize that the cave in the Conservation Easement is one of only two known to be located on the East of the island and that caves such as this often provide a direct link for surface flow into underground rivers and aquifers in karst watersheds.
- **The quarry:** The quarry can be easily singled out as the largest source of non-point pollution near the property. The tour guide can use the quarry overlook to explain the dangers of sediment erosion and contamination as well as concepts involving seepage and underground flow. For example, the guide can point out the substantial section of the property that eroded and collapsed into the quarry. He or she can also point out the bowl shape of the quarry and describe how all the water that flows into the quarry can only escape by seeping into the ground. The seepage will undoubtedly carry pollutants from machinery and spills and most likely make its way into the Río Guaynabo through underground flow. The guide should also note that drastic changes in the land highly affect natural runoff and surface flow patterns, pointing out how the destruction of the hillside effectively cut the easement's central stream from its primary source and left it inactive. These specific cause and effect examples involving the quarry can be expanded upon by asking the visitors about what other

forms of human development can affect a watershed, and correcting their theories when necessary.

- **The Observation Deck:** The observation deck(s) is a possible venue that can be used to showcase the flora and fauna found in the site. Visitors can be reminded at this point that a polluted watershed directly affects the plants and animals living there. Tour guides can also engage visitors in a flora and fauna scavenger hunt. The Trust can make a key that shows pictures of the plants and animals that are likely to be found within the reserve and prompt visitors to try and spot the species as quickly as possible. Once a species has been spotted, the guides should explain general information about the plant or animal.
- **The Active Creek:** The creek crossing can be used as in interpretive point not only for its aesthetic qualities but because of its heavy content of non point pollution. The creek flows from adjacent properties and is currently filled with trash, most of which most likely is carried in with the water during the wet season. The Trust can organize volunteer trash removal activities with children or their AMIGOS program as well as show tour goers pictures of the stream in its worst state, stressing how irresponsibility and environmental neglect can lead to a major negative effect on the watershed.
- **The Río Guaynabo:** Finally the tour will lead to the Guaynabo River. Here tour guides can explain that although the Trust is taking steps conserve the watershed, they can only do so much (as exemplified in the small area of the Guaynabo River owned by the Trust). In order to make a positive change in the health of watersheds, communities must all take part in watershed conservation. Visitors can be involved in hands-on activities such as tests for oxygen and phosphate content within the water. The guide can explain how sediment contamination and other pollutants effectively lower oxygen content in water and could make underwater respiration impossible for aquatic animals. Adversely, high oxygen content might signify runoff carrying fertilizers from nearby agricultural properties that can result in the formation of invasive algae blooms that choke out other aquatic plants. The guide can also take advantage of the biodiversity found within the riparian habitat to make interesting narratives describing ecological cycles and other processes found within watershed dynamics.

The following concepts and figures are included for suggested use as educational tools regarding general watershed ecology and conservation either before or during a guided tour to the site.

Figure 62: Watershed Education.



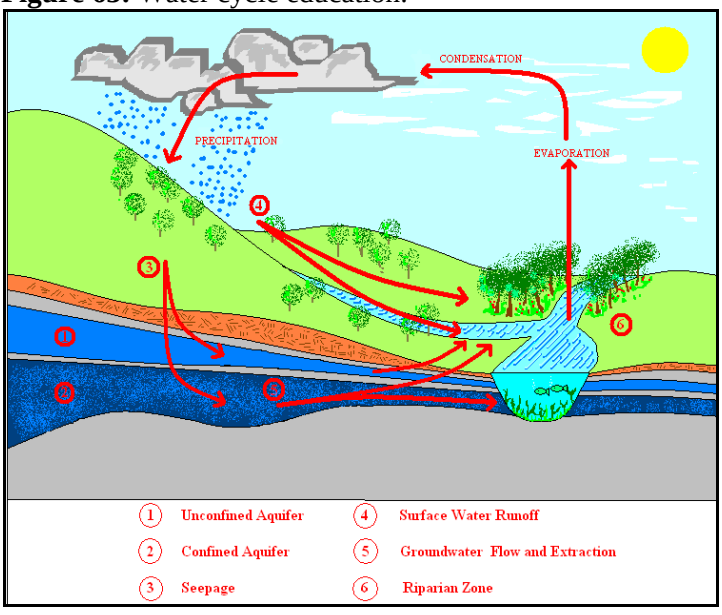
(Source: Yong, Mulligan and Fukue, 2007)

At the beginning of the interpretive tour, the guide should explain that the visitors will be given the chance to experience the natural beauty of the Río Guaynabo region with educational emphasis themed toward watershed conservation. The guide should then start the program by defining a watershed, keeping in mind that most visitors may have a cloudy perception of what watersheds really are and what they encompass. A watershed is defined as any piece of land in which all of its water sources flow into a larger body of water. Sources within a watershed could include overland flow from rainfall or snowmelt running into a stream, or bodies as large as a river flowing into the ocean. Thus, these sources can define watershed boundaries as large as, for example, the land that encompasses the Mississippi River and its tributaries in the United States,

or a piece of land as small as the area that houses the Río Guaynabo and its lesser streams such as the ones that can be found in the conservation easement.

It is important to understand that an area's natural habitats heavily depend on the condition of its water resources. Thus, a watershed not only refers to an area's streams and rivers, but its geology, sub terrain water systems, and its habitat ecosystems as well. All water within an ecosystem is recycled in a process called the water cycle. The tour guide can use examples within the reserve to illustrate the basic processes within the cycle to bring an element of interest to the visitors. For example, the guide can point out a body of water such as a stream or even a puddle, and explain how the heat from the sun evaporates the water and how the resulting vapors rise into the atmosphere. The cold air at higher altitudes causes the vapor to condense into water droplets which accumulate and form clouds. These droplets eventually become too heavy and precipitate, falling to the ground as rain. The rainwater then eventually finds its way back into a body of water by way of surface flow into streams or underground rivers, called aquifers, which flow right beneath our feet. The guide can use a graphic for additional visual reference. Figure 63 through Figure 66 show examples of graphics the guide can use.

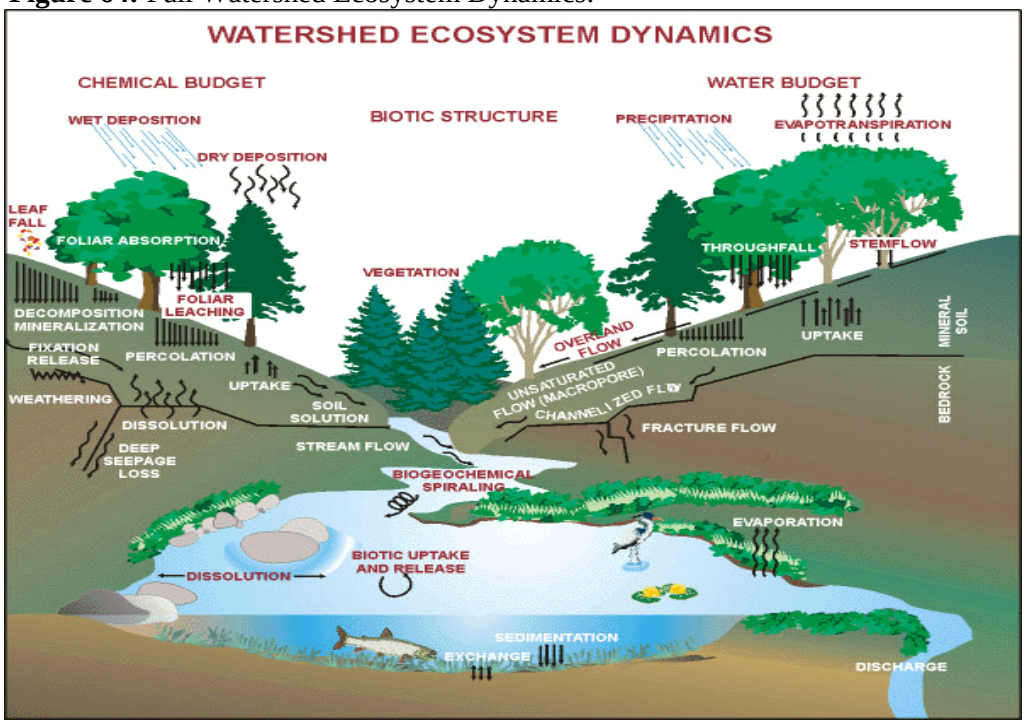
Figure 63: Water cycle education.



Rivers form unique habitats because a vast amount of flora and fauna are able to take advantage of the water resource. The riparian conditions in the conservation easement are

distincly different from other sections; the foliage is more dense and diverse, and more birds can be readily observed. The tour guide can use this visual contrast to explain watershed and river ecology as well as the dangers or water pollution.

Figure 64: Full Watershed Ecosystem Dynamics.

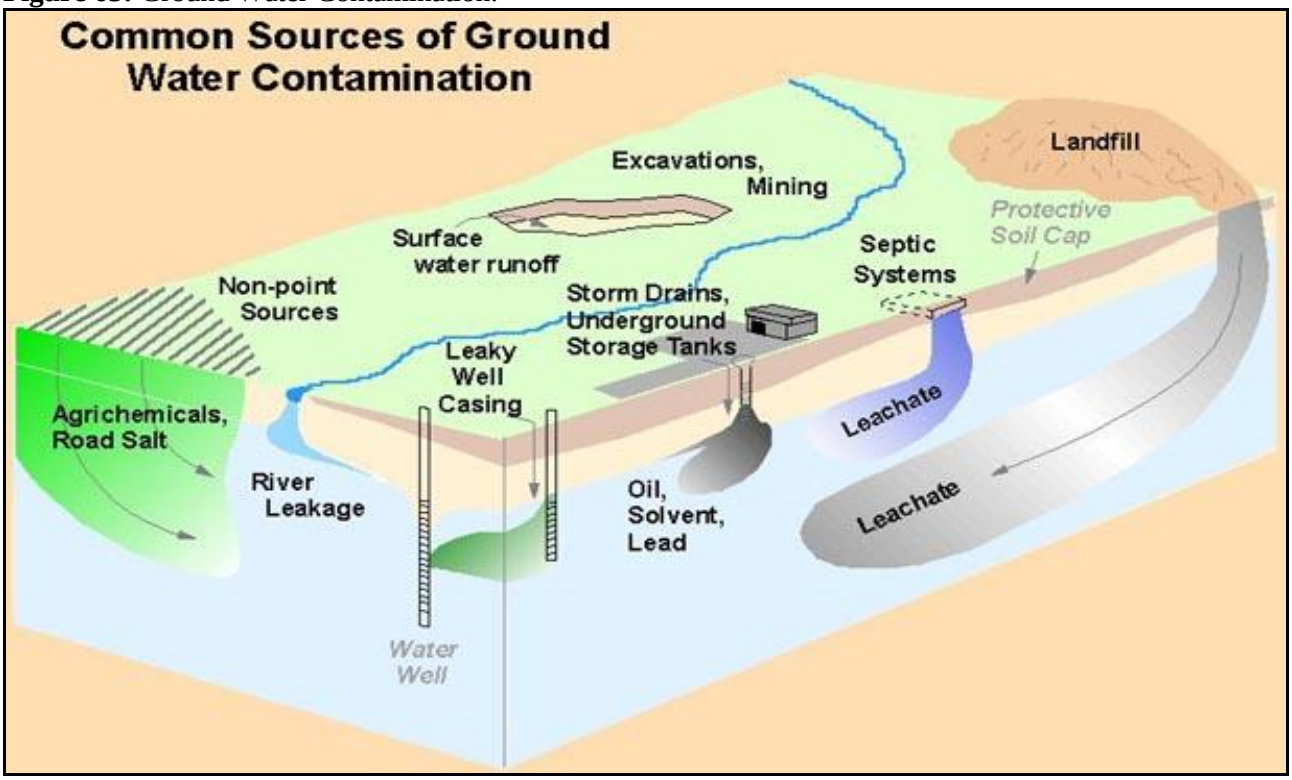


(Source: Johnson and Van Hook, 2008)

A habitat's ecosystem relies heavily on the condition of its watershed. The picture above illustrates how water is cycled within an ecosystem and how all the natural features, both geological and biological, play a specific and important role to preserve the fragile balance of the habitat. If one step of the process is disrupted by either natural occurrence or foreign contamination, the entire ecosystem will be affected. For instance, if a person thoughtlessly pours a poisonous household chemical into the soil it will eventually seep into the ground, possibly into a well, or gradually make its way into a stream. From there, it may flow into a pond where it would diffuse into the water where traces of the chemical undoubtedly be ingested by fish and other aquatic wildlife. The remaining contaminant will travel with evaporated water vapor into clouds and eventually condense and fall with the rain. The contaminated rainwater may be used by trees and other plants, some of which may then in turn be fed to livestock. Thus, in essence, the person who dumped the chemical may ingest the poison through the water he

drinks and the fish, fruit and vegetable produce, and meats he eats. The community needs to understand that while a single individual's neglect for the environment may only account for a small fraction of a watershed's contamination, every bit of pollution adds up and eventually can cause a major problem for both the environment and its natural resources which we use every day. Figure 65 displays different and common types of water contamination from the ground.

Figure 65: Ground Water Contamination.

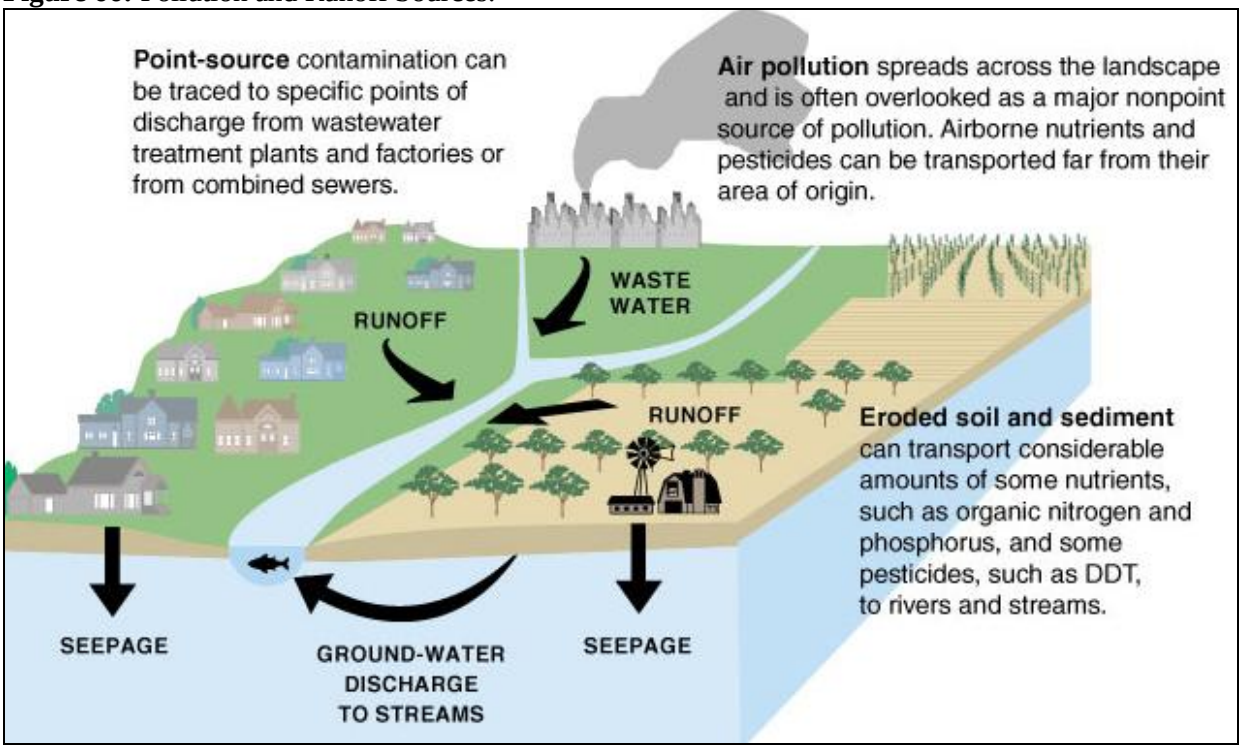


(Courtesy of: www.johnston-independent.com)

Sediment runoff is the leading contributor to watershed contamination. Construction and building development disturbs soil and makes the land prone to erosion. The eroded sediment is carried by overland flow into lakes, streams, and rivers where it dirties the water and reduces oxygen content. Surface runoff also commonly carries pollutants such as oil, fertilizer, animal waste, and pesticides that are commonly spilled or left on lawns or driveways. Once these contaminants are caught in the overland flow, they are dispersed throughout the local watershed as it flows into streams and seeps into the ground. The community can help improve the quality of their local environment and their drinking water by managing clean fill, leach fields, septic tanks, and lawn products, cleaning up solvent and petroleum spills, and properly disposing of garbage and other waste. At this point in the tour, the oxygen content of the Río Guaynabo

and/or its adjoining streams can be measured with equipment owned by Fideicomiso. The visitors can then be quizzed about the factors that can lead to low oxygen content and why it could vary between water sources. The dangers of sediment runoff can be reiterated when the tour reaches the quarry overlook.

Figure 66: Pollution and Runoff Sources.



(Courtesy of : www.johnston-independent.com)

There are two types of pollution sources: point and non-point sources. Point source pollutants are delivered from a specific location commonly known as a point discharge. Most of them are discharged via pipe from industrial sources such as manufacturers, power generators, or waste treatment facilities. Non-point sources, as their name suggests, are pollutants whose direct source is more difficult to identify. Non-point sources (NPS) are areas such as large agricultural fields and parking lots which carry pollutants such as sediment, pesticides, and pathogens. NPS pollutants are usually associated with rainfall runoff and vary as a function of watershed characteristics. The difference between point and non-point sources of pollution can be illustrated at various points in the trail. Examples of point source factors and their effects on the local watershed could include quarry sediment pollution as well its destructive effect on the water flow in the inactive streambed in addition to point source human and animal waste from

adjacent properties. The tour guide can then explain NPS pollutants by showing pictures of the garbage accumulation from indeterminate locations found in the active creek as well as additional sediment pollution from ATV use and natural erosion.

These key concepts are good examples of material that can be used on a guided tour because they use site specific points of interest to develop ideas that are relevant to all watersheds. The tour guide can give presentations about ecological processes by pointing out specific examples on site in order to visually stimulate the visitors and ensure their involvement in the tour. Most importantly, if the guide points out specific threats or point source pollutants within the site in order to convey the much broader picture regarding watershed contamination, the visitors are more likely to evaluate their own habits and attempt to be more conscientious toward the environment. The visitors should be made aware not only of the details concerning watershed dynamics, but that the community is responsible for the purity of their local watershed that is in turn essential for their own wellbeing.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The mission of the Conservation Trust of Puerto Rico is to "protect and enhance the Island's natural resources" (Conservation Trust of Puerto Rico, 2007). The Trust fulfills this mission by acquiring parcels of land for conservation and protection. In addition, it looks to educate the public about the importance of conserving the Island's resources. In order to promote conservation, the Trust offers guided tours and workshops for the public at a select few of their properties, which enables the public to get a first hand view of the benefits of conservation.

The project team was asked to develop management plan for Río Guaynabo Conservation Easement. This plan, located in Appendix B, focuses on the design of a trail system with limited environmental impact that includes an educational program designed for interpretive tours themed centrally towards watershed conservation and education.

The Río Guaynabo Conservation Easement is a parcel of land that was recently acquired by the Trust. The area is about 26 acres and is located in the Municipality of San Juan. Located within the Bayamón River Watershed, the property contains a small network of running creeks as well as dried creek beds. The easement, located within an urban forest, is surrounded and directly affected by residential development as well as a large quarry located on the boundary of the property. The Trust plans to use the property solely for exclusive guided tours for their AMIGOS program and groups of school children and will not be opened for public use.

Currently, access to the property is limited. The team recommends placing priority on acquiring a more feasible access point. The best option would be to gain access through the Sunset Hills development or joint access with Autoridad de Energía Eléctridad (AEE). A dedicated access point would allow for an attractive trailhead as well as visitor accommodations.

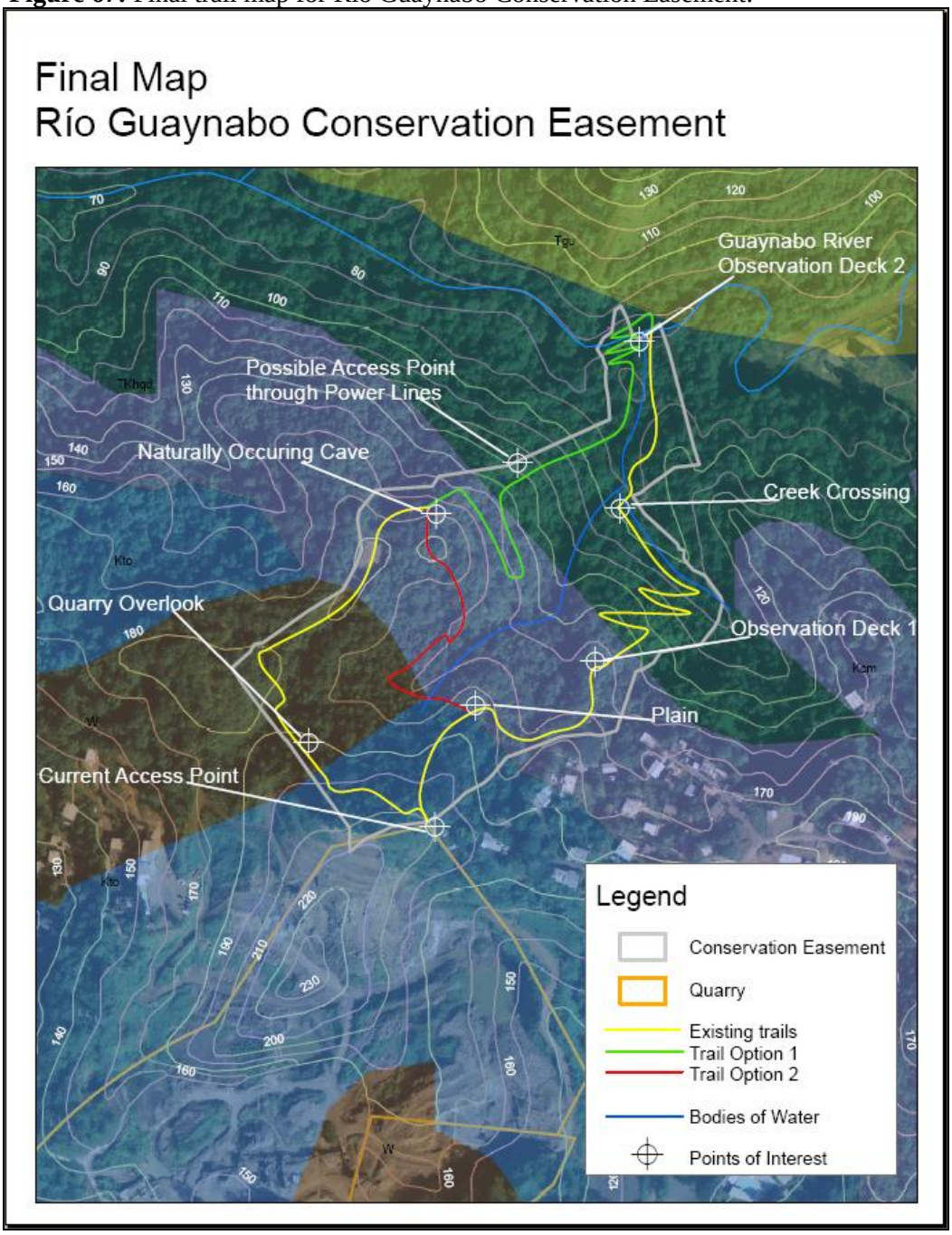
As per request of Fideicomiso, the recommended trail route is based largely on the existing trails in order to minimize environmental impact as well as labor costs. The team has come up with two trail options. The team is recommending that the Trust make a dedicated attempt to build the Trail One option. This trail completes a full loop of the area and would offer the most interesting and diverse viewing venue for the tours. The project team attempted to hike the trail shown on the map. However, the trail was very overgrown, and was eventually lost in the undergrowth. This option would require extra labor and careful trail design for Fideicomiso, but it would eliminate backtracking and present the best experience for visitors. Option 2 makes its way down to the Rio Guaynabo, but then backtracks up to the plain and makes use of an

existing trail to lead visitors to the opposite boundary of the property. The Trust's decision will be based on the choice between trail quality and interpretive value versus economic efficiency and ease of labor.

The team is recommending that the Trust uses a turnpike technique for its trails. This will provide the Trust with a rugged, aesthetic, and highly accessible trail system that emphasizes effective drainage in order to counteract the steep and wet terrain found on the property. Complete details regarding turnpike construction as well as guidelines designed to overcome any type of obstacle are available in the Management Plan in Appendix B. The management plan also outlines proper techniques recommended for clearing obtrusive foliage, safely navigating steep grades, and properly maintaining the network once it is completed.

Existing trails that will remain unused by the trust should be reforested in order to improve the natural qualities of the property and to discourage unsupervised use by visitors. Figure 67 shows the final trail map.

Figure 67: Final trail map for Río Guaynabo Conservation Easement.*



The team has compiled a list of current and potential threats to the local watershed in order for Fideicomiso to perform further investigations and implement future solutions. It is recommended that the Trust take to following measures in order to establish an effective watershed management plan:

- Closely monitor future use of the quarry

- Watch for residential development

  This not only results in deforestation, but it increases the local population. Development leads to increased potential for sediment contamination of overland flow as well as more littering and pollution in the area which will have a negative effect on the Río Guaynabo property.

- Construct a perimeter fence around area to limit access
- Investigate point and non-point sources of pollution in the Bayamón River Watershed
- The Trust should be looking to acquire more of the surrounding area to further conserve the area

It is recommended that the Trust design a guided tour that incorporates certain points of interest along the trail related to concepts concerning watershed conservation. The list below outlines several points of interest and summarizes briefly how they can be effectively used for the interpretive tour.

- Quarry

  Explain how the quarry was once at a higher elevation than the Río Guaynabo property and how this has affected the upland water sources that once fed the creeks and river. The quarry can also be used to explain groundwater contamination caused accelerated seepage of pollutants into the soil.

- Cave

  Explain how this is a naturally forming cave. It is one of two found on the east side of the island. All others are typical to the karst region located on the western side.

- Observation Decks 1 & 2

  It is recommended that an observation deck be constructed on the ridgeline overlooking the ravine and dry creek bed in order to offer the visitors a good view of the flora and fauna found within the treetop canopy of the reserve. It is advised that a second deck be constructed overlooking Rio Guaynabo in order to give visitors a good view of the riparian habitat found near the river.

- Plain

  The plain can be used as a resting spot for visitors as well as an open area in which the guide can effectively coordinate activities or demonstrations.

The team has come up with a list of interactive activities the guides can use to captivate the interests of the visitors. These activities provide a fun alternative to simply lecturing tour goers about watershed management and ecology.

- Oxygen test of the river similar to one done on tour of Old San Juan

  Low oxygen levels can result from sediment contamination as well as fertilizers and other chemicals used in everyday life. This activity can help show visitors how an action as seemingly harmless as using fertilizer on a lawn or dumping a household chemical in the woods can adversely affect the environment.
- Scavenger hunt

  School children can be equipped with an illustrated checklist of plants and animals found within the area and asked to compete to find the most species.
- Tree Finder

  This is something that the children can make out of can with the bottom cut out or paper towel roll. It can be used to focus a child's point of view in order to see specific trees or plants.

In addition to these activities, the guides should bring with them certain items that can better visitors' educational experience. The following is a list of recommended items:

- Field guides
- Binoculars
- Hand lens
- Pictures of tree cross sections
- Different maps of the area
- Mounted photos
- Tape player for bird sounds and calls

- Spray bottle with water to clearly show spider webs
- Examples of rare artifacts or hidden features of the reserve such as snake skins or soil core samples

The project team also recommends that Fideicomiso schedule programs in which volunteers are asked to help clean up litter within the site. These programs would not only improve the property but they can also be used to show how the environment can be improved through the cooperation of the community. These activities will also leave visitors with a sense of accomplishment in knowing that their effort was rewarded by helping preserve and improve the environment.

The educational information provided by the tour of the Rio Guaynabo Conservation Easement should leave visitors with an elevated understanding of how the community shares certain responsibilities in order to ensure the preservation of Puerto Rico's environment. Visitors should have an awareness of the ecological and communal importance of a clean watershed as well as realize that their actions now determine the wellbeing of their families and neighbors for generations to come.

APPENDIX A: BACKGROUND INFORMATION ON FIDEICOMISO

MISSION

The Fideicomiso Conservation Trust of Puerto Rico is a private non-profit organization dedicated to the protection of Puerto Rico's natural resources. These goals are accomplished through donations of lands that contain great ecological, aesthetic, historical, and cultural value. The Trust has developed programs, such as AMIGOS, to educate visitors to their sites about the significance of protecting these lands. Through its program Árboles…más árboles (A+A), the Trust produces and distributes native tree species in order to encourage the Island's biological diversity.

ORIGINS

At the end of the 1960's Puerto Rico's economy changed drastically. Heightened urbanization and modernization had a detrimental effect on the island's natural surroundings. This change prompted the government to create several agencies including the Department of Natural and Environmental Resources and the Puerto Rico Environmental Quality Board. In 1970 The Conservation Trust of Puerto Rico was formed by the US and Puerto Rican governments to achieve the mission stated above. During The Trusts first ten years they received funds from U.S. tariffs from petrochemical companies located on the island. Soon after, the Trust began to accumulate income through private transactions with companies operating under Section 936 of the U.S. Internal Revenue Code. When these tariffs could no longer produce any more funds for the Trust they began to invest in stocks and bonds. The stocks and bonds were used to receive a portion of the rum tax returns from the federal government. The funds generated from this tactic have enabled the Trust to acquire lands of high importance.

FUNDING

Tax refunds are only one of many ways the Trust receives funding. The Trust also receives land and cash donations from its AMIGOS program. The individuals and corporations that comprise AMIGOS are committed to the same ideals of the Trust-to the preservation and conservation of the natural resources of Puerto Rico.

HISTORY

In the first thirty-three years of its existence the Trust was led by Señor Francisco Javier Blanco. Under Sr. Blanco the Trust protected over 16,000 acres of land. The 16,000 acres include lands at Parguera in Lajas, Las Cabezas de San Juan in Fajardo, Hacienda Buena Vista in Ponce, Hacienda La Esperanza in Manatí, and many more areas all over Puerto Rico. For their exceptional preservation and restoration endeavors the Trust has received prestigious recognitions and awards. Furthermore, Sr. Blanco managed to establish mechanisms for the conservation of land in the Caribbean region, such as debt-for-nature swaps in the Dominican Republic and Jamaica. Sr. Blanco retired in December of 2002 with lawyer Fernando Lloveras San Miguel taking over as his replacement. Since his installation Sr. Lloveras has acquired over 2,000 acres of land.

Source: The information Appendix A was taken directly from the Fideicomiso website; http://www.fideicomiso.org/enter.htm

APPENDIX B: MANAGEMENT PLAN

Management Plan

For the

Río Guaynabo Conservation Easement

Guaynabo, Puerto Rico

May 2008

Management Plan
For the
Río Guaynabo Conservation Easement
Guaynabo, Puerto Rico

May 2008

Prepared by:

Luke Fekete

Christopher Paulli

Jordan Skelly

Sabrina Zayas

Prepared for:

The Conservation Trust of Puerto Rico

Advised by:

Dominic Golding

John Zeugner

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1. Introduction and Purpose

Puerto Rico is best known for its appealing climate and its many natural features, such as beaches, coral reefs, caves, and tropical rainforests. Unfortunately, population growth and widespread urbanization has taken its toll on the island's natural resources. Puerto Rico has become one of the five most densely populated areas in the world, with approximately 1,100 people per square mile, and the island's natural environment has suffered accordingly.

Heavy deforestation to accommodate the needs of urban and agricultural development has resulted in the loss of nearly fifty percent of Puerto Rico's forests since the nineteenth century. Fortunately, a recent shift toward urban living and industrial employment has resulted in the reforestation of many now unused agricultural fields and in the past 60 years, forest cover in Puerto Rico has increased thirty percent.

Currently, only 7.2% of Puerto Rican land area is protected by law for the purpose of conservation. Despite the recent improvements regarding reforestation, the current conservation policy will not be enough to counteract the steady rise in population. The environmental well being of Puerto Rico may well be in the hands of the islands next few generations of inhabitants; it is clear that education about the necessity of conservation and instilling an appreciation for Puerto Rico's natural attributes will be crucial for success.

This Management Plan was made for the Conservation Trust of Puerto Rico in order to guide the Trust in accomplishing their goals for the Río Guaynabo Conservation Easement a recently obtained property. The Conservation Trust of Puerto Rico (the Trust) is driven to protect and preserve sensitive and ecologically valuable lands by acquiring and developing the land in a way that enhances its natural resources while disturbing the environment as little as possible. This plan includes a map of the recommended trail system, guidelines and specific recommendations for trail designs, and interpretive and educational information linked to the proposed trails. The goal of the site is to make visitors aware of the integral role that watersheds have in the ecosystem and the importance of their individual conservation actions.

2. Río Guaynabo Overview

A Rapid Appraisal Report on Ecological Values of the Río Guaynabo site was conducted in order to determine if the area, now the Río Guaynabo Conservation Easement, could be of value to the Trust as a Conservation Easement and possibly as an Urban Forest for the benefit of the community. The following summarizes the finding of the Rapid Appraisal. The full report can be found in the Appendix of this Management Plan.

The site is located in the Municipality of San Juan in the north of Puerto Rico. It belongs to the Bayamón River Watershed which contains the following main water bodies: Río Bayamón, Río Guaynabo, Río Piedras, Cidra Dam, and Las Curias Dam. The land consists of early secondary subtropical forest since most of the area was deforested at one point (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005).

According to the U.S. Geological Survey and the US Environmental Protection Agency (1994), the Río Guaynabo Conservation Easement belongs to the Bayamón-Loíza region and has the geology units of the San Sebastian (Ts) and Tutu formations (Kt). The San Sebastian is derived from Miocene and Oligocene deposits and is composed of cross-bedded to massive beds of sand, sand and gravel, and sandy clay with thin beds of sandstone and sandy limestone. The Tutu formation is for the main part a tuffaceous composite which has a few limestone beds and also includes unknown intrusive igneous rocks (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005).

Based on the description of the Soil Survey of San Juan Area of Puerto Rico published by the Soil Conservation Service United States Department of Agriculture (1978), the Río Guaynabo Conservation Easement belongs to the Association of "soils formed in residuum from basic volcanic rocks" which is mainly formed in clay material from basic volcanic rocks. The only soil found in the region is Naranjito silty clay loam (NaF2).

The Eulalio Torres Conservation Easement Proposal (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005), contained an analysis of the ecological value of the area by making a forest inventory using the Gentry Forest-Transect method. A 1000m by 2m area was chosen and divided into 10 segments. All trees in this area with a diameter of $\geq$ 6cm were measured and identified by species. From this, the importance value was calucated using the following method:

IV= (relative density + relative frequency + basal area). The top four species were the Guarea guidonia (Guaraguao), the Spathodea campanulata (Tulipan Africano), the Casearia guianensis (Palo Blanco), and the Bucinda buceras (Ucar). The Rapid Apprasial Report (Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005) also found that the fauna distribution in the area would be predictable and only recorded the fauna seen during the Rapid Appraisal.

The Rapid Appraisal Report developed a decision matrix in order to assess the components of the report. The decision matrix was based on two main categories: the ecological values and the management issues of the site. A weighted value was given to the ecological values of the site so that its value was two thirds of the final score. A score of 1-4 was given to each criterion developed under each category. The analysis gave a final score of 7.2 out of 10 despite the small size of the site because of its relation to the green belt of San Juan, its ecological value, and large species diversity. The report strongly recommended that the site be considered as a Conservation Easement and an Urban Forest for the benefit of the community.

2.1 Conservation Easements

The Río Guaynabo area was donated to the Trust using the Conservation Easement program. A conservation easement is a transfer of rights of usage from the landowner to a land trust. A land trust is a non-profit organization that's mission includes conserving natural resources. The land area is generally donated for conservation, but may be donated for other varied reasons that include education and preservation. The main reason for the Río Guaynabo Conservation Easement to be a conservation easement was for the conservation of the land, and to possibly be used as an educational tool for students.

With conservation easements come some benefits and demands. First off, the owner has limited usage rights to the land, however still owns the land. As the landowner still technically owns the land, that landowner may still sell the land or pass the land on to an heir. With that said, the transfer of usage rights and restrictions placed on the land are perpetual. Some rights given up with a conservation easement include not being able to build additional structures on the land such as houses or stables. However, the landowner may still have the right to plant crops and plants on the land, as these practices are helpful with the conservation of the land. It is the job of the Trust to ensure that all the restrictions place on the land are followed in years to come after the land has been sold or passed on.

Conservation easements are generally donated land, but are sometimes the land is sold to land trusts. When the land is donated it can be evaluated to see if the land benefits the public by conserving or protecting natural resources or areas of great historical, ecological, or aesthetic purpose and value. If this is the case, and the land does offer public benefits, then the land can qualify as a tax deductible donation.

3. TRAIL SYSTEM

The following trail locations and designs were designated after several field surveys of the Río Guaynabo Conservation Easement conducted between March 20th and April 9th of 2008. A GPS unit was used to map existing and additional trails suggested for use in the site. Included in the management plan are general guidelines and specific recommendations for trail designs

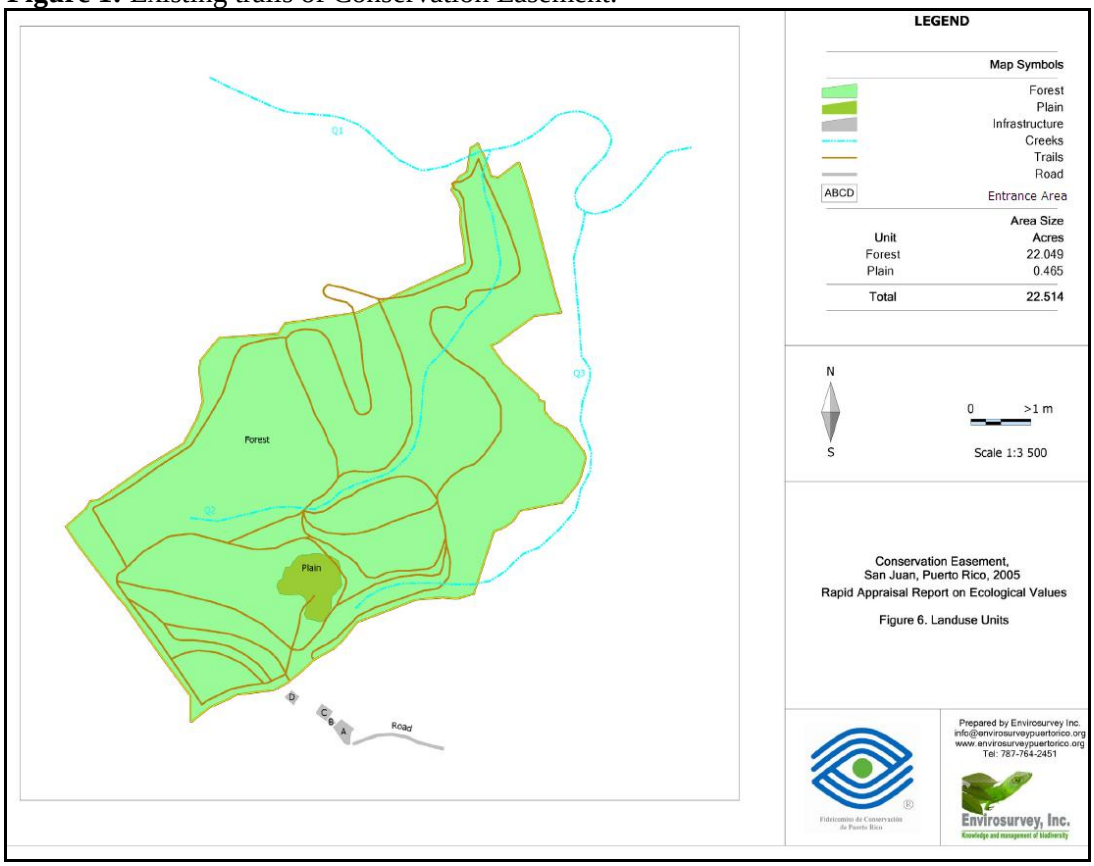
According to the Trust's hiking difficulty levels, the trails in the Río Guaynabo Conservation Easement should be marked as Level 3. The trails should be hiked by persons in good physical condition since the trails are long and mostly up and down hill.

Currently, the Trust is trying to gain a new entrance to Río Guaynabo that does not require entering the site through a privately owned property. Sunset Hills, a gated community, is the most feasible point to gain entrance. However, there is resistance from the residents. The Autoridad de Energía Eléctridad de Puerto Rico (AEE) does have access through Sunset Hills to get to their power lines. The Trust is trying to gain access to Río Guaynabo Conservation Easement through AEE since it is having such a hard time with Sunset Hills. The area itself consists of a long dirt road that opens up into a large clearing where the power lines are located. This entrance point is recommended for access to the site.

3.1 TRAIL LOCATIONS

When designating trail locations the appropriate existing trails should be used to minimize environmental impact and accommodate user requirements. Additional trails should only be used when necessary either to increase the interpretive nature of the hike or to increase user safety. Many of the trails leading to the Guaynabo River are extremely steep therefore the path with the lowest grade should be used. Figure 1 maps the existing trail in the Río Guaynabo Conservation Easement. As can be seen, there are many trail options which lead to the Guaynabo River. Additionally trails not chosen for the trail system should be allowed to grow in.

Figure 1: Existing trails of Conservation Easement.



(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

Another aspect which should be considered when designating trail locations is the points of interest which highlight the ecological value of the site and help illustrate the theme of watershed conservation (Figure 2). The site directly abuts a quarry which mines limestone (Figure 3). It is important to show the quarry as a point of interest because it shows how developments can affect a watershed. Specifically in the site, the change in elevation caused by the quarry dried one of the creeks found in the Río Guaynabo Conservation Easement. The dried creek crosses and combines with a flowing creek (Figure 4). The creeks are also recommended as a point of interest because they show how water flows in a watershed. The creeks flow into the Guaynabo River which is recommended as the main point of interest for the site (Figure 5). Finally, the west side of the site houses a cave which is generally only found in the karst regions of Puerto Rico on the west side of the island (Figure 6). The cave is not only an aesthetic point of interest but can also be used as segue to explain runoff. The points of interest were chosen for their scenic interest but also because they help portray the theme of the importance of watershed

conservation. Section 4 explains in detail how each point of interest can be used to convey the theme with site specific and also with general information. This section also recommends activities that can be implemented at certain points of interest.

Figure 2: Proposed points of interest.

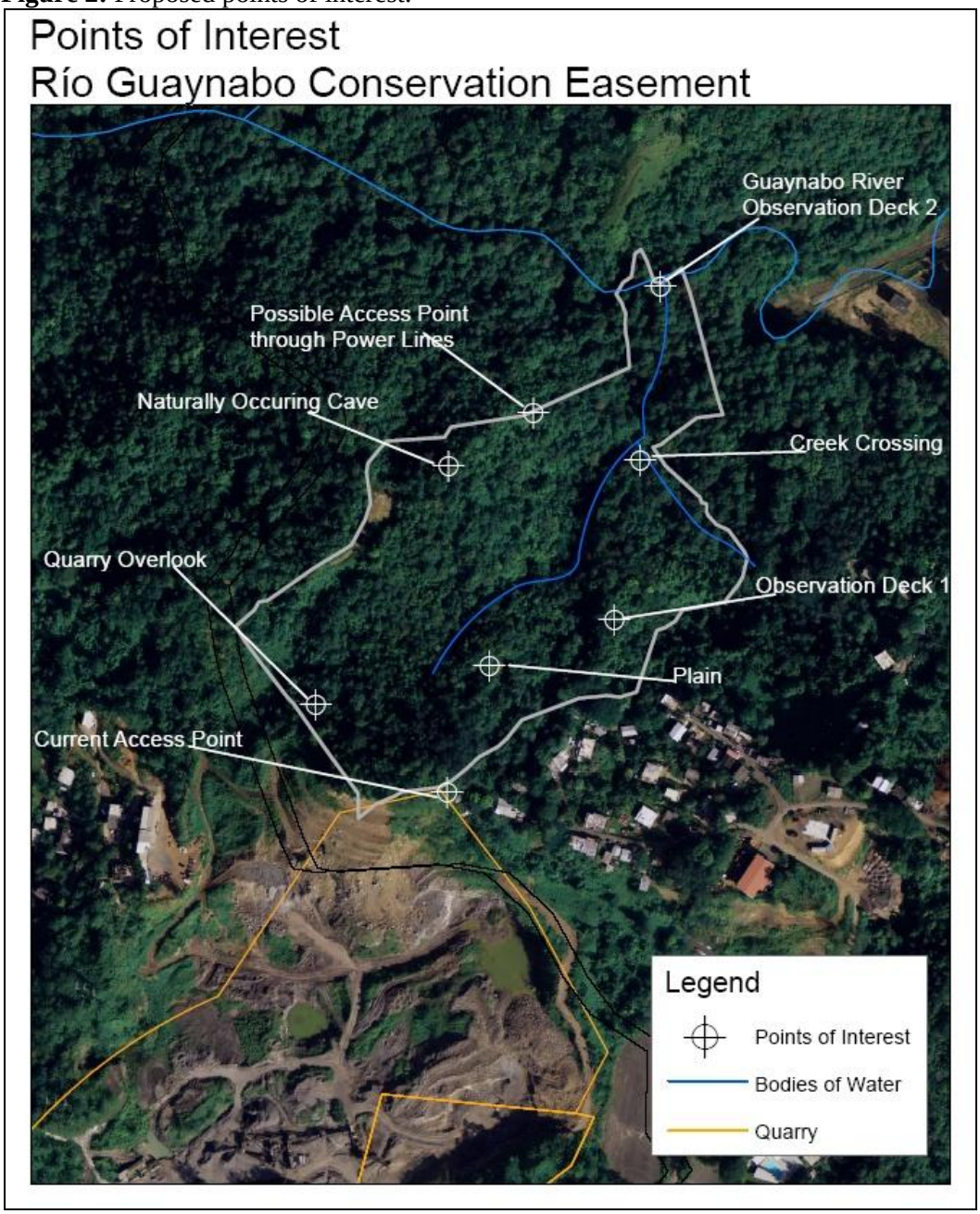


Figure 3: Quarry abutting site as proposed point of interest.

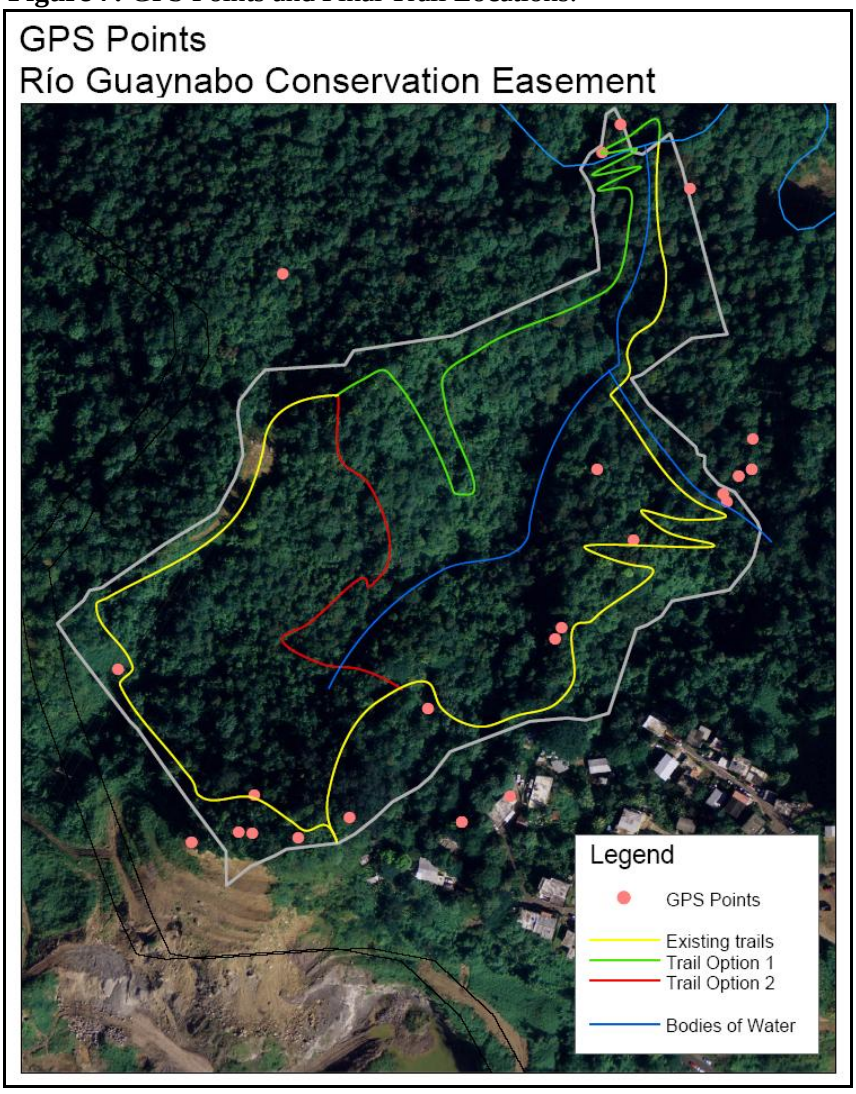
Figure 4: Creek proposed point of interest.

Figure 5: Guaynabo River proposed point of interest.

Figure 6: Natural cave as proposed point of interest.

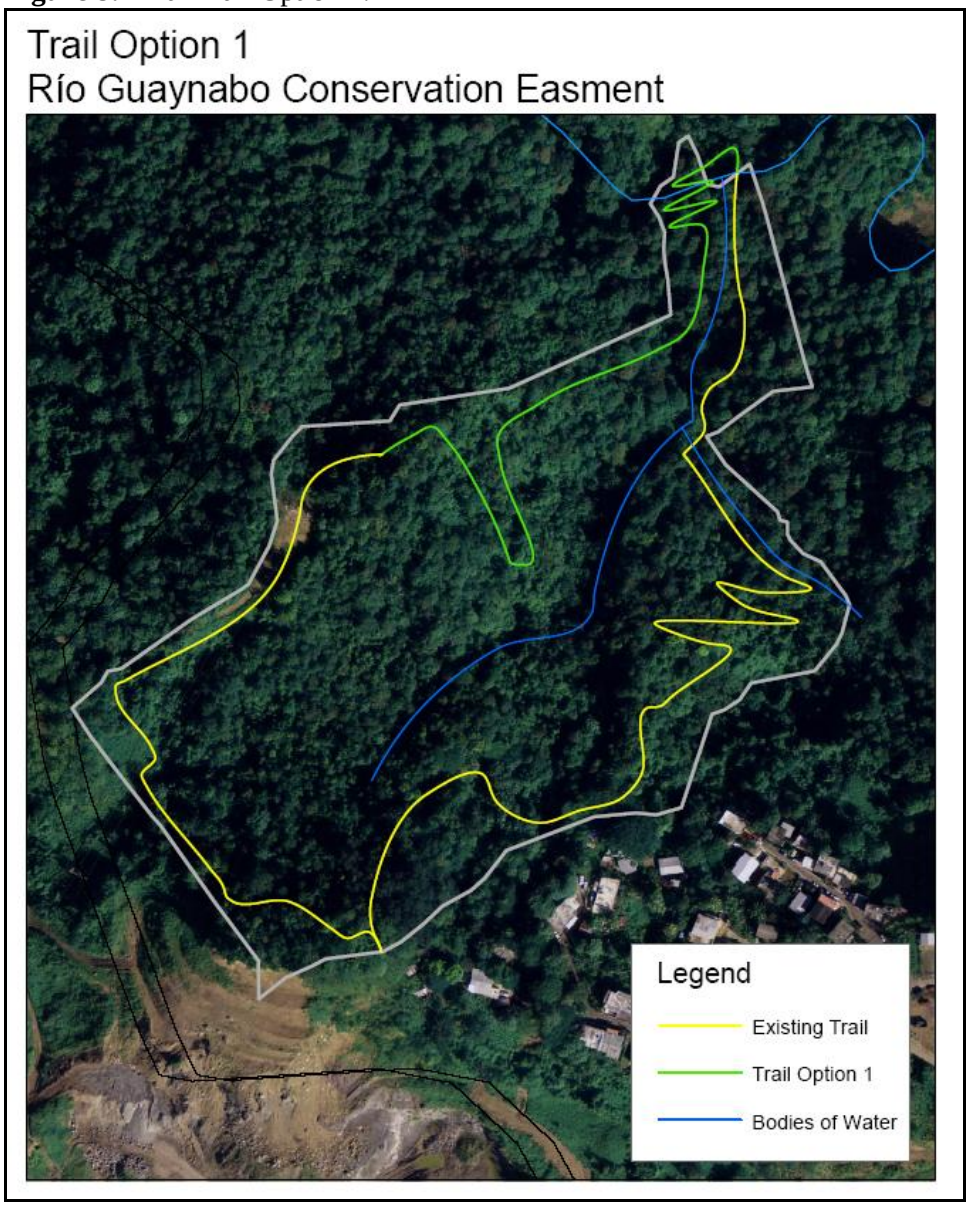
After careful and extensive fieldwork of the area and trails locations were chosen which connected the points of interest. It was found that the existing trails previously drawn (Figure 1) were inaccurate. Once the GPS points were uploaded onto a map of the Conservation Easement it was found that previously recorded points were showing up off the site. Generally GPS points allow for around ten to fifteen feet discrepancy. During the site visit, adequate satellite strength was scarce and the GPS points were hard to acquire, thus more likely to be inaccurate. Due to these various factors trails were approximated trails a combination of GPS points, existing trails, and estimations. Figure 7 below shows the trails along with the GPS points used to mark the trails.

Figure 7: GPS Points and Final Trail Locations.



Two trail options are recommended. The first option is a loop around the general perimeter of the area (Figure 8). This trail allows the visitor to walk down to the river and then around the west side of the area. This option includes all the recommended points of interest. This trail also eliminates a back track method giving the visitor the most diverse view of the land.

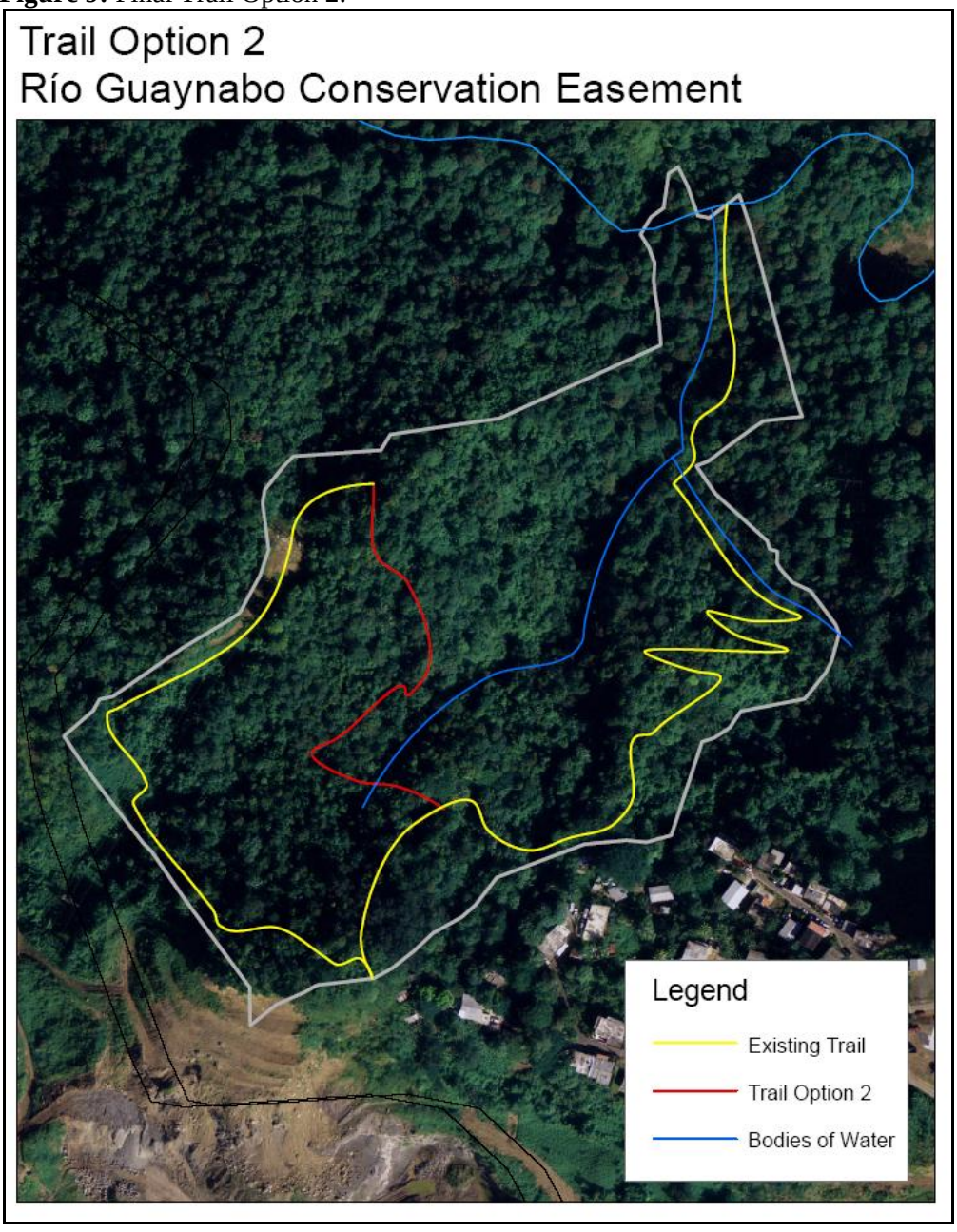
Figure 8: Final Trail Option 1.



The second trail option, shown in Figure 9, uses the back track method avoided in trail option 1. This method does not give as diverse scenery as Option 1, however, it is able to show

all recommended points of interest. This trail can be repetitive, but may take less time than Option 1, appealing to a younger crowd and/or families.

Figure 9: Final Trail Option 2.



3.2 Trail Design

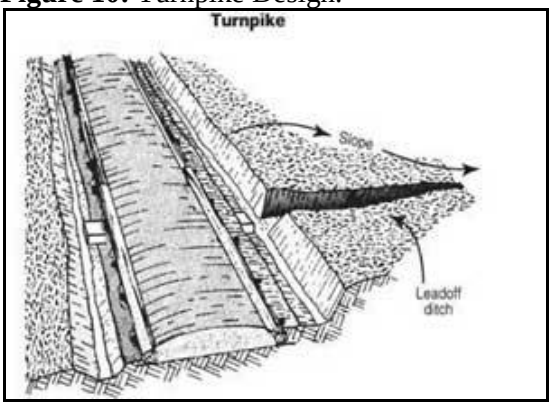
Interpretive and nature viewing trails should be designed specifically for their intended purpose. Trail features and locations should be implemented according to the central theme of the interpretive plan. For example, since the central theme of the program at the Río Guaynabo easement is watershed conservation, the trail should undoubtedly include a scenic outlook over the Guaynabo River. Many interpretive trail systems, including the Río Guaynabo Reserve, are located near heavily populated areas and heavy traffic from users of all ages and abilities can be expected. Accordingly, trail design and upkeep standards should be high in order to promote safety and ease of use. Most importantly, it is suggested that the trail builders keep in mind that a tour guide will have a hard time keeping visitors' attentions if they are forced to consistently watch their footing throughout the duration of the hike. To ease the difficulty of the trails, grades should be kept less than or equal to 5%, and extended sections of 15% should be avoided. Looped trails are most suitable, with spurs and satellite loops providing additional variety. Trail sections with curves and twists increase visitor curiosity and interest, and provide more surprises than long straight sections.

The following sections serve as a guideline for general the design and implementation of the proposed trails. More specifically sections of the trails that require special design attention are pointed out on a map and recommended solutions are explained in detail.

3.2.1 Trail Tread

In order to build a safe trail that could be effectively implemented despite the reserve's harsh terrain and wet climate, it is recommended that the majority of trail tread be designed using the turnpike technique. Based on the literature, it was concluded that when compared to other techniques, the turnpike incorporates the best blend of features that include accessibility, drainage, aesthetics, ease of maintenance, and feasibility for the Trust. This style of trail design uses a pair of trenches coupled with a raised trail tread with a prominent crown in order to effectively direct water from the trail and prevent erosion. In addition, the design allows for drainage to be further manipulated by the implementation of strategically placed culverts and leadoff ditches. Figure 10 shows an example of the turnpike design.

Figure 10: Turnpike Design.

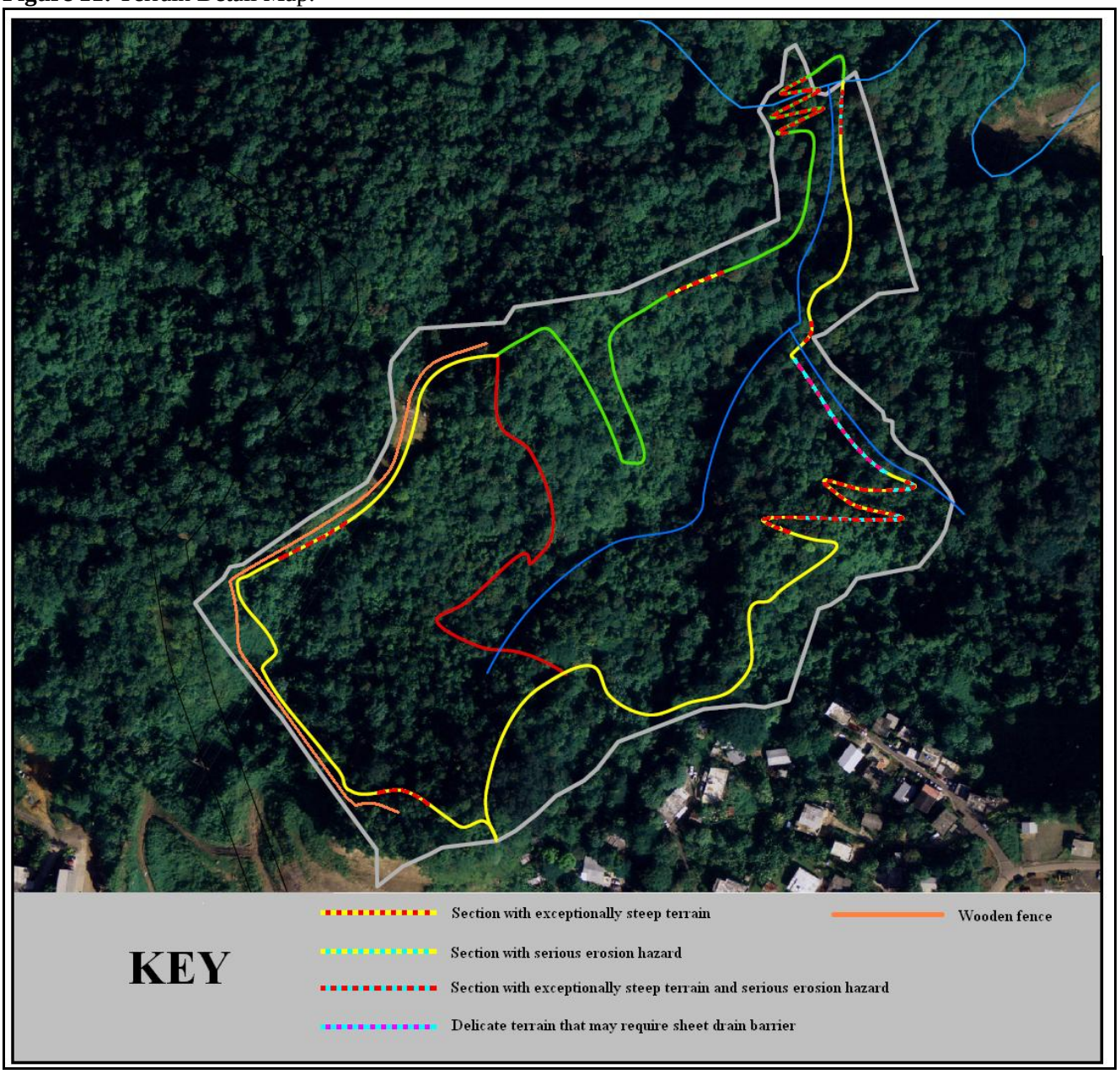


(Source: Trail Construction and Maintenance, 2004)

The downside of using the turnpike design is that its implementation is labor intensive. The route must be well cleared and graded and trees must be leveled, stripped, and pinned for use as trailside retainers. Fortunately, the finished product is a high quality, attractive, durable, low maintenance trail system that can be enjoyed by hikers of all skill levels.

The turnpike design can be used with several different tread materials including gravel, corduroy logs, concrete, asphalt, and crushed lime. After consulting with employees in the Trust, concrete tread was ruled out in favor of gravel as it is their traditional tread material at their other sites throughout Puerto Rico. Unlike concrete, the use of gravel presents several challenges due to the reserve's steep terrain. Gravel, while offering excellent drainage and good traction, is unstable and will creep downhill and off the tread line over time. In order to ease maintenance and extend trail life, the following tread solutions are proposed to slow this process. Figure 11 shows different terrains of Río Guaynabo, followed by explanations of the tread solutions. Figure 11 also suggests the implementation of a wooden fence in front of the barbed wire fence in order to create a safer, more aesthetically pleasing walk along the border of the site.

Figure 11: Terrain Detail Map.

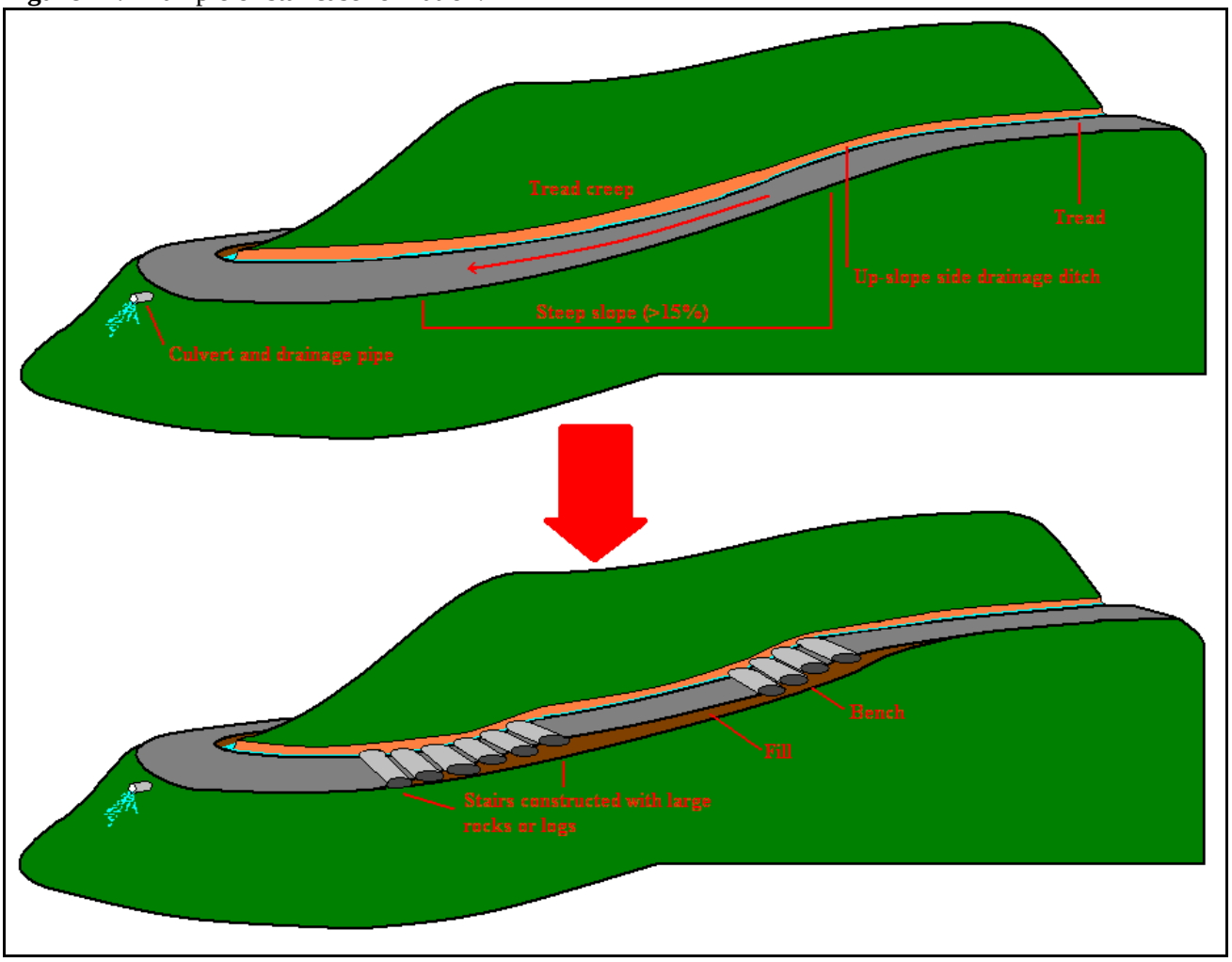


1. **Adequately drained terrain with grade less than 15%:**

In order to reduce spending, the turnpike design can be implemented on shallow grade terrain with minor erosion hazard by simply using existing excavated rocks under the tread fill for drainage and support. Windfall and other material removed from the trail during the clearing process may be pinned together and mounted lengthwise on the edges of the trail to

be used as retainers where needed to reduce lateral creep and maintain the tread crown. If the grade of the path exceeds 15% and the soil remains sturdy, minor grading coupled with the use of widely spaced single or double step stairs will be adequate for the purpose of retaining a proper grade for the turnpike. This method is shown below in Figure 12.

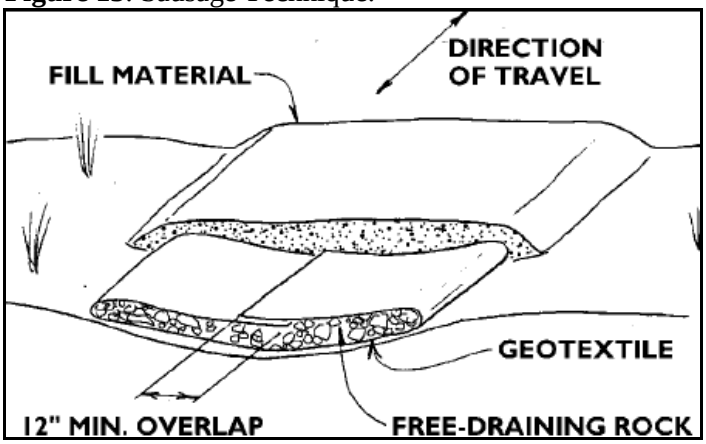
Figure 12: Example of staircase formation.



2. Wet terrain with grade less than 15%:

In areas where the ground has significant surface flow due to poor drainage, geotextile material, also known as construction fabric, will provide adequate drainage and support when using the "sausage technique" as shown in Figure 13.

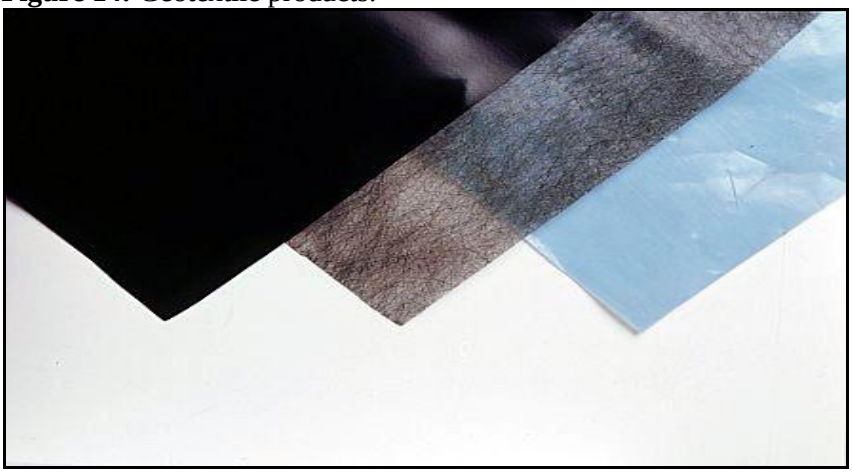
Figure 13: Sausage Technique.



(Source: Monlux, 1995)

Geotextiles are tough, porous fabrics that separate the tread from the soft, wet topsoil and the trail tread. Their high tensile strength allows the weight of the tread to be evenly distributed over the topsoil and provides excellent support. Figure 14 shows three geotextile products of different thickness and design.

Figure 14: Geotextile products.



(Courtesy of: www.dkimages.com)

GEOTEXTILES Manufacturers:

AMOCO---------- (800) 445-7732

Nicolon/Mirafi Group - (800) 234-0484

Linq Industries --------- (803) 873-5800

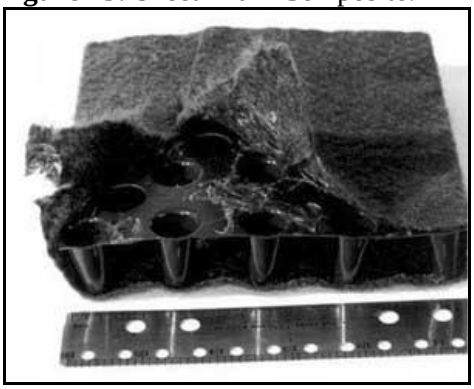
Price range: $.63 to $.72 per square meter ($.53 to $.60 per square yard)

(Most manufacturers and distributors are willing to reduce prices when the product is used in bulk)

3. Extremely wet terrain with minor grade and poor drainage:

Some areas within the conservation easement may exhibit terrain, especially in the wet season, in which the ground is very wet and soft and/or prone to significant water accumulation. These areas are highly prone to erosion and trail degeneration and require special attention. To counter these hazards, several manufacturers produce a geotextile composite that includes two layers of textile cloth separated by a honeycomb polymer layer called a sheet drain, shown below in Figure 15.

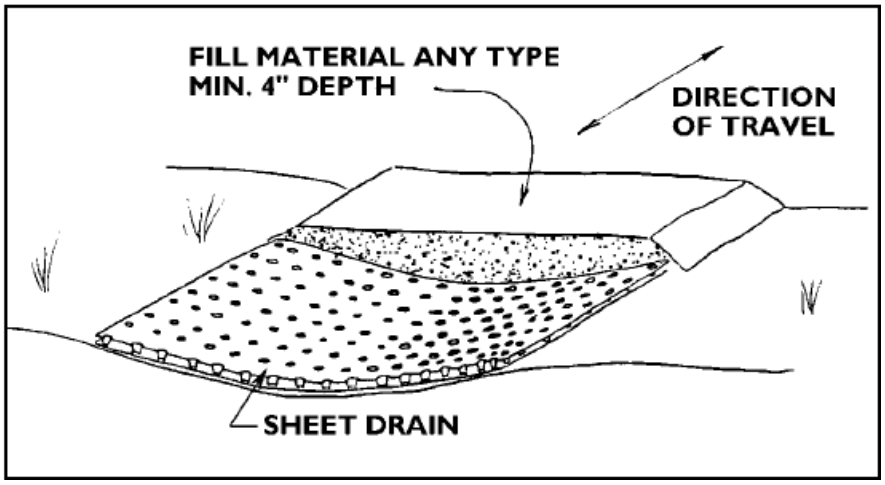
Figure 15: Sheet Drain Composite.



(Source: Trail Construction and Maintenance, 2004)

Sheet drains separate the trail tread from the muck and provide space for water to harmlessly drain under the tread into the turnpike ditches. The composites also provide excellent trail stability and support by providing a rigid foundation to evenly distribute the tread load over the wet, unstable topsoil, shown in Figure 16.

Figure 16: Sheet Drain Implementation.



(Source: Monlux, 1995)

SHEET DRAINS Manufacturers:

Mirafi--- (800) 234-0484

Contech- (513) 425-2165

Presto--- (800) 558-3525

Price range: $6.50 to $8.50 per square meter ($5.40 to $7.11 per square yard)

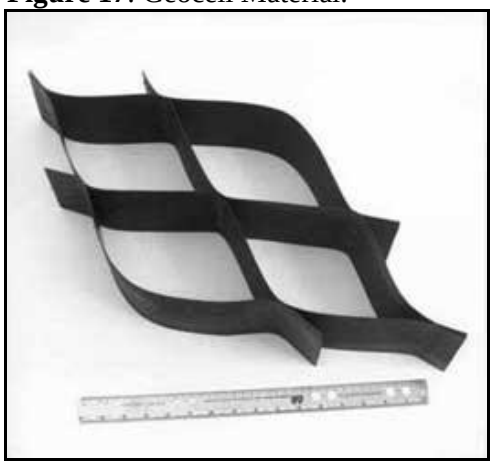
Notes: Compare desired widths with standard sheet widths and consult with manufacturers, field, or factory cutting. Various core thicknesses are available. For example, Presto makes a product called Akwadrain with a 25mm core thickness with fabric on both sides that has significantly greater bending strength which limits the settlement in soft soils, and reduces the amount of fill material required (Monlux, 1995).

4. Steep terrain (>15%) with adequate drainage but unsuitable for grading/stairs:

Some areas within the easement may exhibit terrain in which the trail grade must exceed 15% for an extended section despite the use of switchbacks and cross grading as well as have unstable or rocky soil that would discourage the use of stairs and grading. In order to prevent gravel tread from creeping, or land sliding, down steep slopes, it is proposed that the trust implement a tread reinforced by a geocell structure. Geocell, shown in Figure 17, is a simple

structure that is constructed by welding polymer strips together to form a raised honeycomb network.

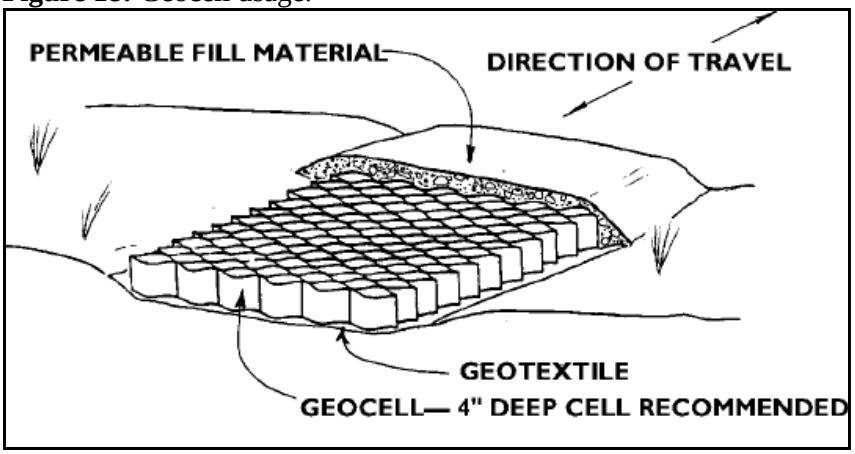
Figure 17: Geocell Material.



(Source: Trail Construction and Maintenance, 2004)

The tread is securely held in place when it is backfilled into the cells, and supported by a single layer of geotextile. Geocell offers excellent tread drainage when implemented into a turnpike design and it can also be effectively used for earthen retaining walls and other steep sections prone to erosion. The following figure illustrates the proper use of geocell material.

Figure 18: Geocell usage.



(Source: Monlux, 1995)

GEOCELL Manufacturers

Presto------- (800)-558-3525

AGH-------- (713)-552-1749

WEBTEC— (800-438-0027

Price range: $7.50 to $11.30 per square meter ($6.30 to $9.45 per square yard)

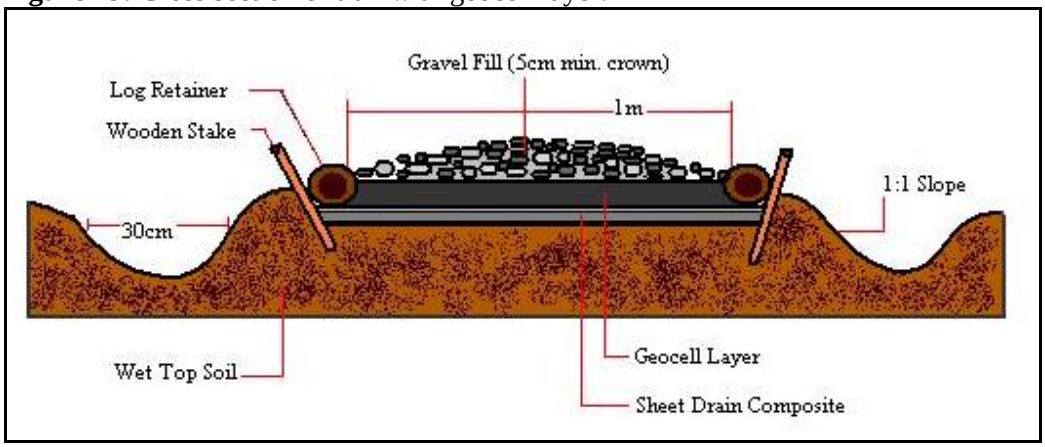
Typical product dimensions: 4" x 8" (Depth x Length) and 20ft x 8ft (Length x Width)

Notes: Specify desired product widths for the project application. The 100 mm (4 inch) cell depth should be adequate for trails - depths from 50 mm to 200 mm (2 to 8 inches) are available. Consult manufacturers for availability of different section widths and alteration of standard section widths to fit your project needs (Monlux, 1995).

5. Steep terrain (>15%) on wet soil especially prone to erosion

For exclusive areas with steep grades that also present serious erosion and/or drainage problems, it is proposed that the trust use a special hybrid trail design that employs both a sheet drain and geocell structures under the tread to prevent gravel slippage, promote clean, effective drainage, and maximize user safety by ensuring consistent traction in wet conditions. Figure 19 shows a cross-sectional view of the hybrid trail layout.

Figure 19: Cross section of trail with geocell layer.

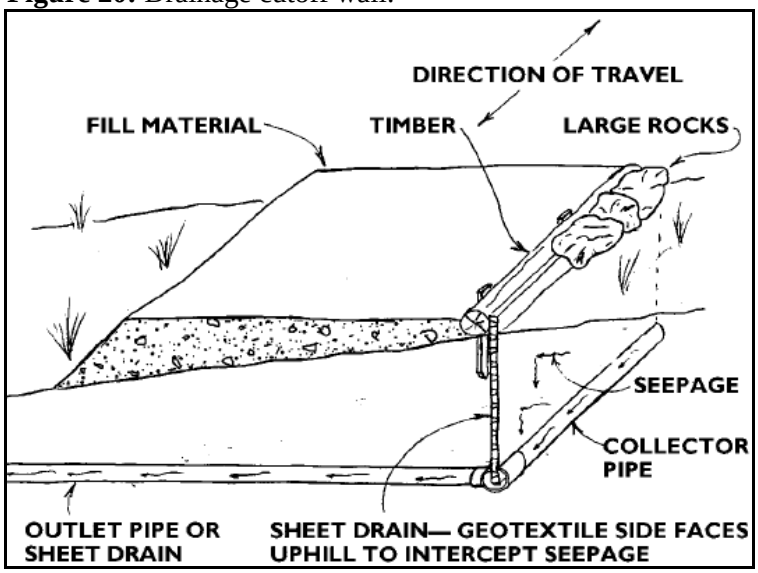


6. Delicate Terrain:

Some areas in the reserve offer interesting viewing opportunities for the user but present major trail building hazards. A good example of an especially delicate area is the bank overlooking the actively flowing creek in which the trail is eroded to the point where it is suspended on an overhang above the creek bed. This problem needs to be fixed by reinforcing the eroded areas with fill and constructing either a wooden or geocell retaining

wall. Once repaired, the trail will still be prone to erosion due to the fact that it is located on a steep, wet face. If the trail erodes, the sediments will run straight into the stream and pollute the water. A possible solution for these small, fragile trail sections would use a sheet drain as a drainage cutoff wall to eliminate lateral surface flow from the trail altogether. This technique of a drainage cutoff wall can be seen in Figure 20. If the trail section is on a side slope where groundwater saturates the uphill side of the trail, a cutoff wall can be constructed to catch surface and subsurface moisture and help drain and stabilize the trail section. The sheet drain cutoff wall is partially buried vertically along the uphill side of the trail within three feet of the trail's edge. The top edge of the drain should remain above ground to capture surface runoff moving toward the trail and covered with large rocks to protect it from deterioration from sunlight. Collector and outlet pipes can be made from PVC piping. The collector pipe can be drained into an outlet pipe or an additional sheet drain panel under the trail section.

Figure 20: Drainage cutoff wall.

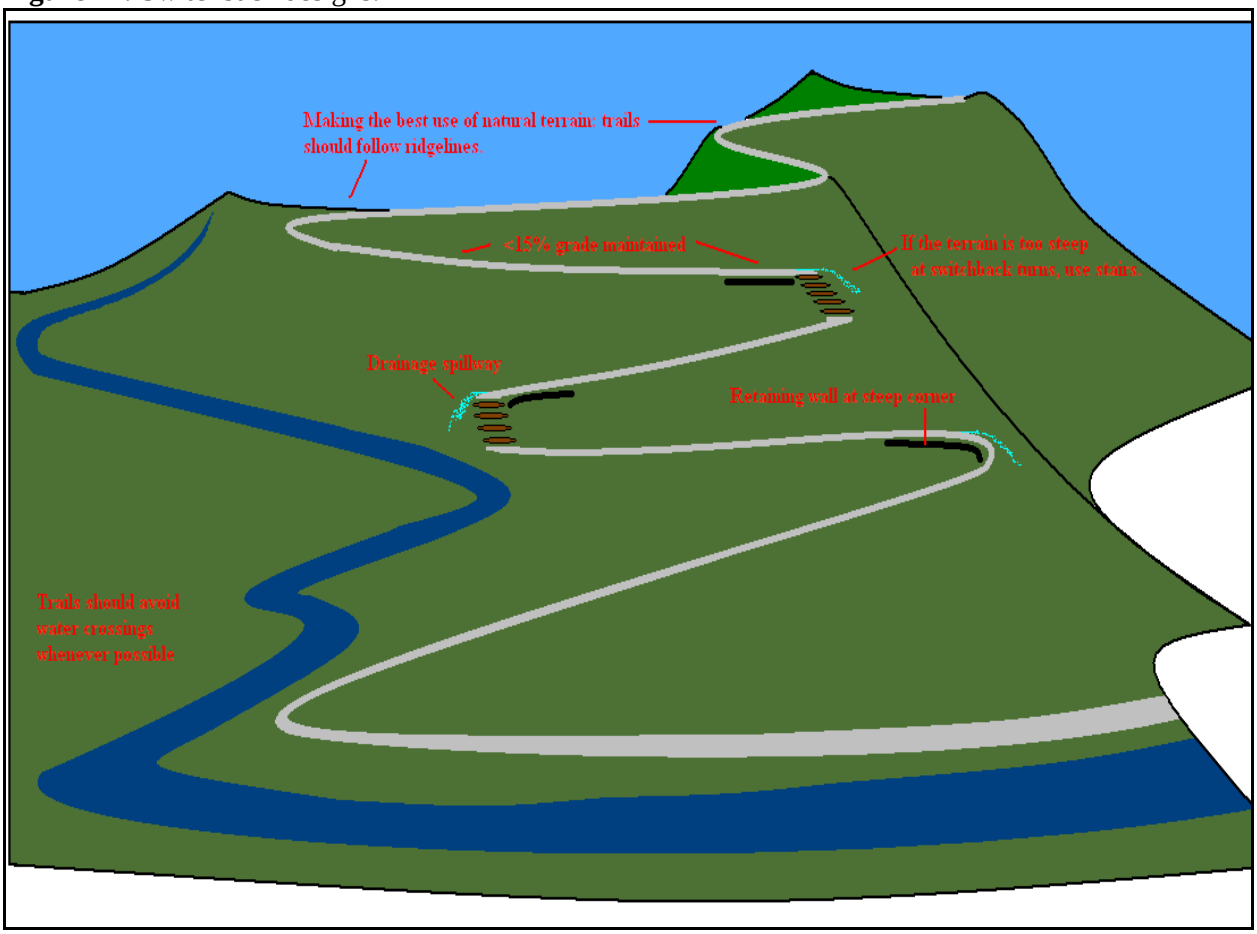


(Source: Monlux, 1995)

For particularly steep grades or areas where loose soil or roots make it impossible to effectively set stone steps into the earth, it is suggested that the trails use plank stairs that are connected by stringers. These staircases should be well anchored, include a rail, and must be constructed using durable, pressure treated timber. A strategic point for using these stairs is at switchback turns that may be too steep for user safety or present an otherwise unsolvable drainage hazard. Since timber stairs only break ground at the footings, drainage water can be

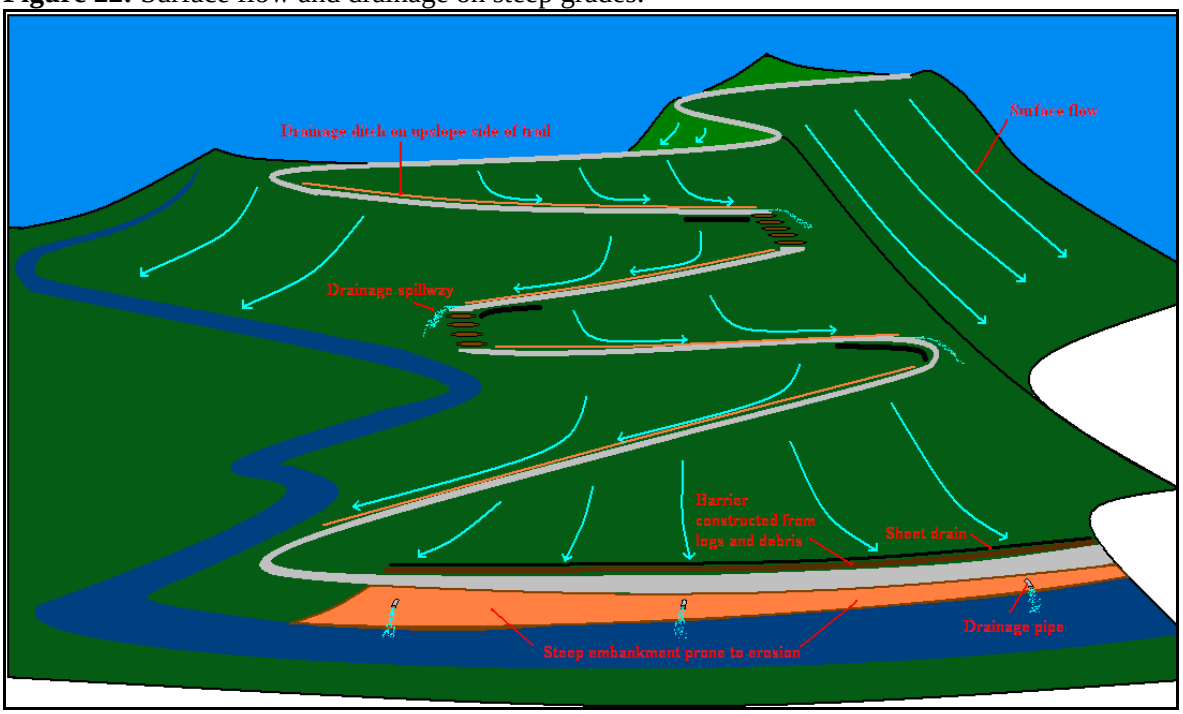
allowed to flow around the stairs over natural foliage and terrain. For example, the section of the trail that leads down the exceptionally steep embankment toward the actively flowing creek can implement the setup shown in Figure 21.

Figure 21: Switchback designs.



When designed correctly, surface flow should make its way down steep slopes by following drainage ditches implemented into the turnpike trail design and draining away from the trails at switchback turns. Water should be drained at points where there is heavy vegetation and little or no exposed soil to prevent sediment runoff. The figure below, Figure 22**,** illustrates the correct path for surface flow on a steep slope in addition to proper application of a sheet drain cutoff wall at a delicate stream embankment as described above in Figure 21.

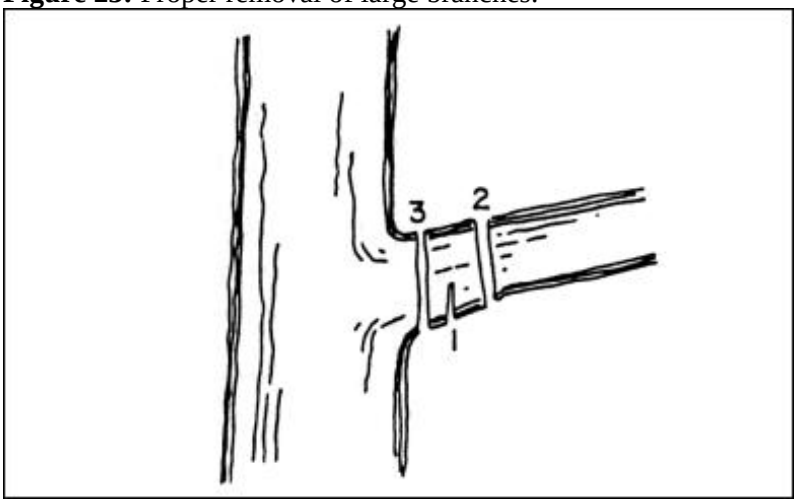
Figure 22: Surface flow and drainage on steep grades.



3.2.2 Clearing Guidelines

The forest within the boundaries of the Río Guaynabo Reserve are heavily wooded and littered with windfall. Trail builders will encounter hazards such as large, obstructive trees with heavy foliage, dense undergrowth, hanging vines, and large, wet, partially decomposed fallen tree trunks throughout the area. Accordingly, special clearing guidelines must be followed in order to ensure a safe, enjoyable hiking experience while minimizing environmental impact. According to British Columbia's trail building guide, all trail designs should focus on avoiding any unnecessary cutting, especially large or feature frees. If the partial removal of a tree is necessary, it is advised that only lateral branches be removed. If a treetop must be cut, it is generally better to remove the entire tree because the absence of the tree's terminal bud will result in an accelerated lateral growth into the trail way as well as leave an unsightly tree. To ensure a lasting effect and aesthetic quality, all branches must be cut flush with the trunk and all stumps flush with the ground. Figure 23 shows the proper procedure for removing large branches without destroying the bark on the trunk.

Figure 23: Proper removal of large branches.



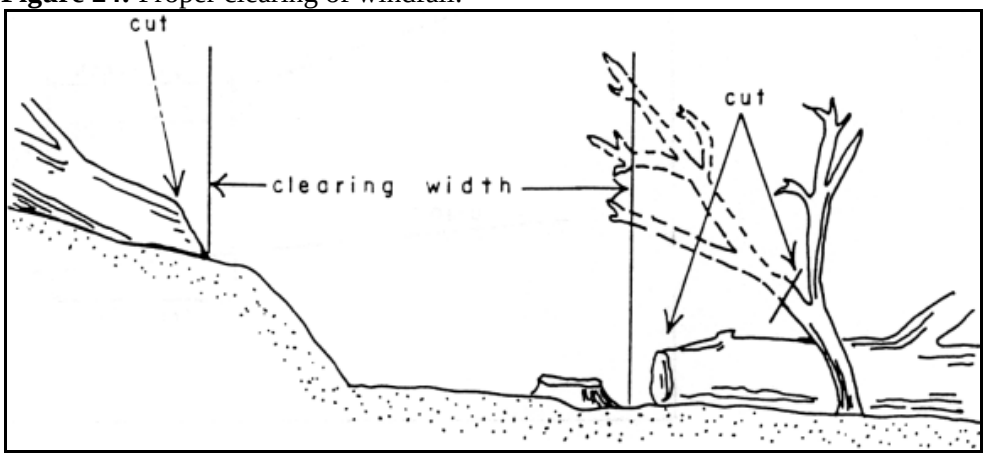
(Source: Recreational Trail Management, 2000)

Small shrubs and other undergrowth grow very quickly and should be cleared to provide safe and easy movement along the trail. Unfortunately, especially in the steep, wet forests of the Conservation Easement, the removal of trailside shrubs is an ambiguous process because their roots often hold the silt soil in place and prevent erosion. British Columbia's recreation guide suggests either leaving the shrubs and periodically trimming the trailside branches or removing the shrubs and planting grass alongside the trail. Rocks are another ambiguous hazard. Many trails leave all but the most treacherous rocks and boulders undisturbed because their almost always results in the erosion of the soft, loose soil underneath. The trails in Río Guaynabo must maintain a high standard of quality and most obstructive rocks must be removed in order to keep the users' focus directed on the interpretive nature of the trail instead of hazardous rocks on the trail itself. Accordingly, the trails must be designed to avoid any large boulders and implement a strict drainage plan when rocks must be removed.

A particular hazard for trail building in the Río Guaynabo region is the significant amount of windfall and other debris on the forest floor. Fallen tree trunks up to a meter thick can be commonly seen fallen across existing trails in the area and dense undergrowth makes it difficult to move once cut. This windfall and debris must be removed from the trail bed in order to meet the trail's demand for high quality. According to the recreational guide, all windfall that cannot be simply dragged from the trail bed must be cut in wide sections until a foot of space

separates it from the trail boundary. Figure 24 illustrates the proper clearing of windfall and debris hazards.

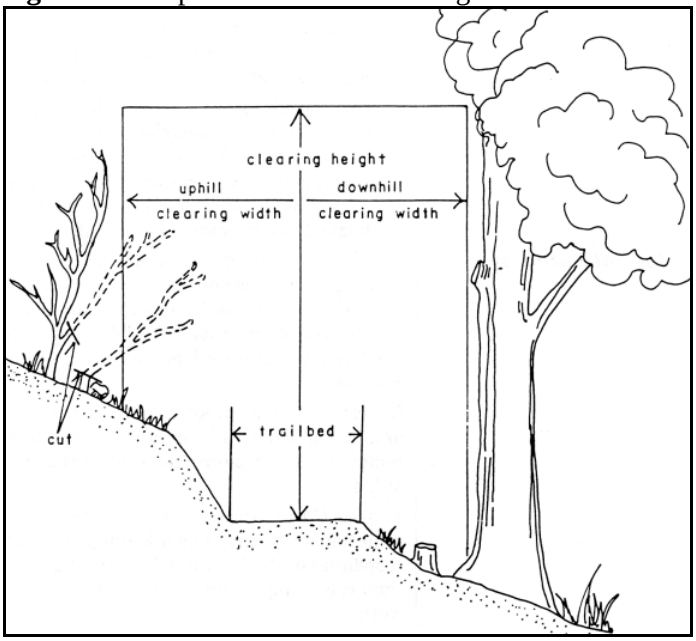
Figure 24: Proper clearing of windfall.



(Source: Recreational Trail Management, 2000)

The typical clearing dimensions for interpretive trail systems ranges between one and two meters in width and about two and a half meters in height with additional width near interpretive trail signage and sights of particular viewing interest in order to accommodate a larger viewing audience. Figure 25 shows the ideal proportion of forest clearing compared to the width of the trail bed.

Figure 25: Proportion of forest clearing to trail bed width.



(Source: Recreational Trail Management, 2000)

3.2.3 Solutions for Steep Grades

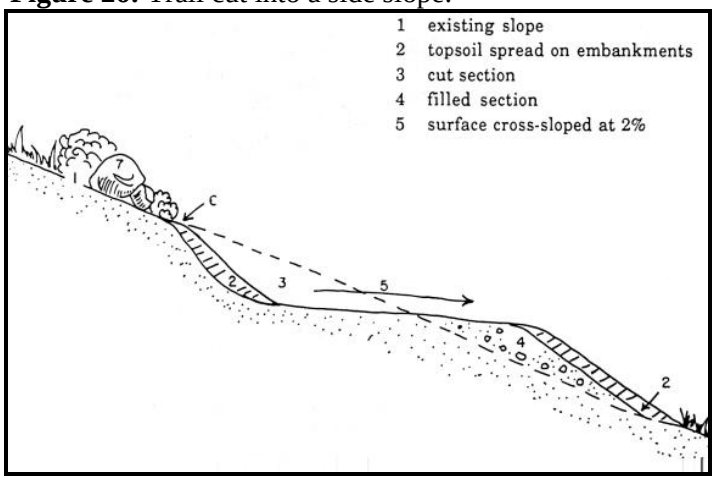
The Río Guaynabo reserve is located on a hillside that includes a vertical drop towards the Río Guaynabo of between 250 and 300 feet over a span of just over half a kilometer with a the addition of a deep central ravine that houses a dry streambed. Accordingly, the parcel includes some very steep terrain that exceeds 70 degrees in some areas. Since standard for interpretive nature trails favor grades of less than 5% and prohibit extended grades of more than 15%, extreme measures must be taken to ease the slope induced difficulty of the trail system.

To minimize the grades of the trail, extensive use of trail grading and switchbacks are recommended. These features allow the trail to traverse steep embankments while maintaining a shallow grade. The difficulty in implementing these features comes with the threat of erosion when the trail is cut into the side of a slope. British Columbia's recreational guide outlines strict guidelines for the construction of trails cut into side slopes in order to prevent erosion and ensure the safety of the user (Figure 26):

- Leaf litter and surface soil material should be removed from the cut and fill areas, and saved for later use.
- The ideal angle of the cut and fill slopes should be less than a 1:1 slope.
- To encourage vegetation regeneration, topsoil and organic material should be spread on large embankments susceptible to erosion. On steep embankments, netting material, such as jute mesh held in place with stakes, may be required to hold the topsoil and mulch in place.
- Proper rounding at the top of the embankment shoulders is necessary to prevent soil from sliding onto the trail. Boulders, logs and other debris that may fall onto the trail should be removed. Exposed roots should be cleanly trimmed flush with the soil surface.
- The bed of the trail tread should be pitched approximately 1.5 cm per 30 cm toward the outside edge to allow for drainage off the trail.

(Recreational Trail Guide, 2000)

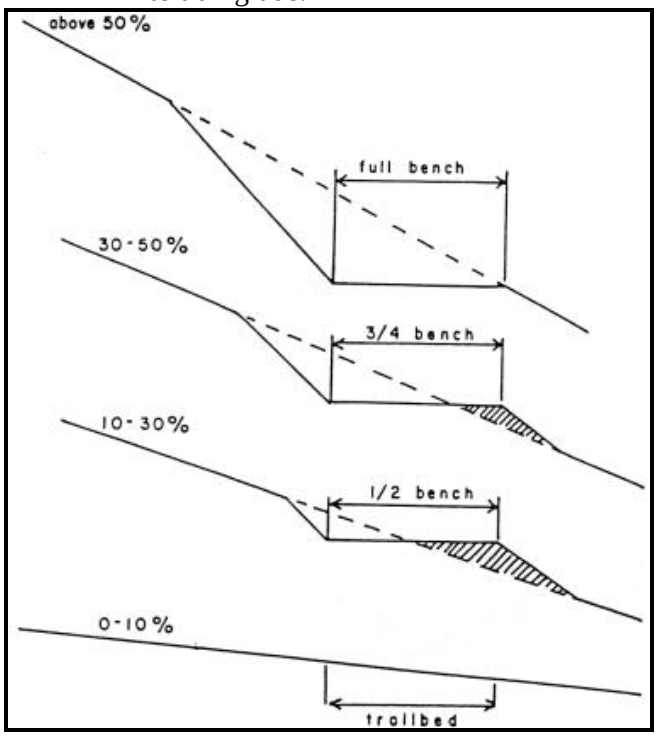
Figure 26: Trail cut into a side slope.



(Source: Recreational Trail Management, 2000)

Additionally, there are guidelines for side cuts according to grade. For narrow trails with exceptionally steep grades, it is suggested that logs be wedged parallel to the down slope edge of the trail against two standing trees and leveled with small branches, rocks, and soil to achieve a durable shelf for the trail (Figure 27).

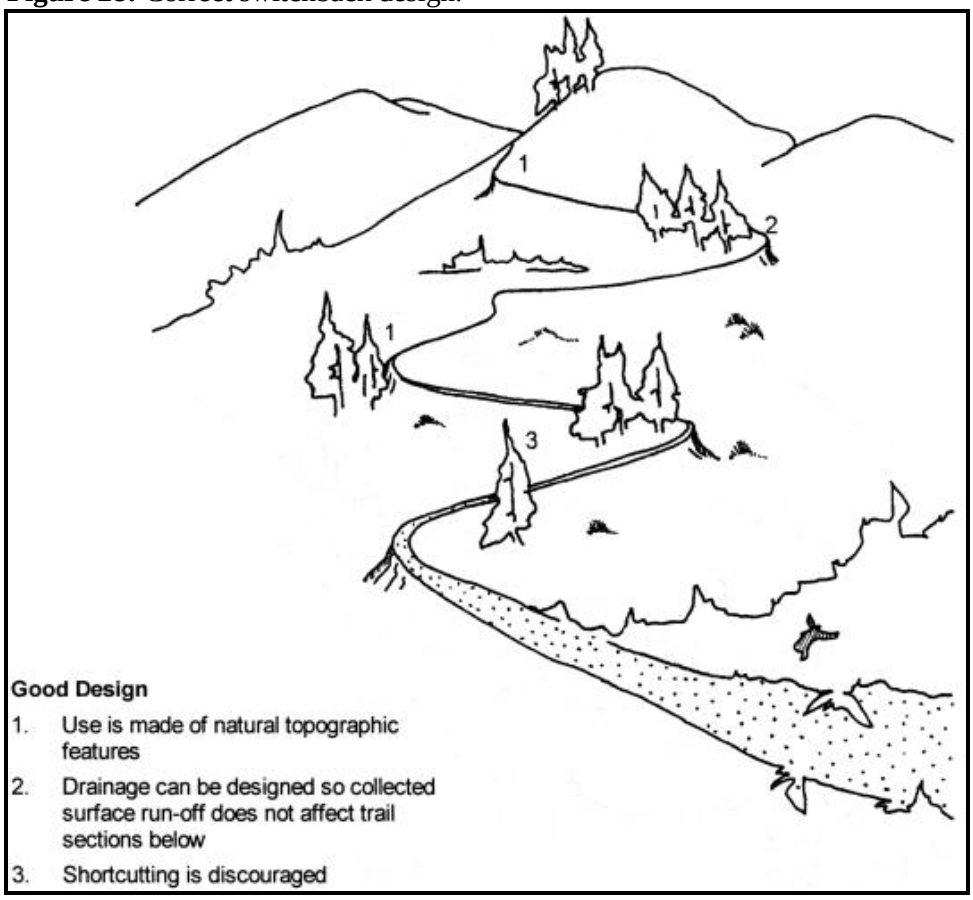
Figure 27: Bench cuts and retaining walls according to trail grade.



(Source: Recreational Trail Management, 2000)

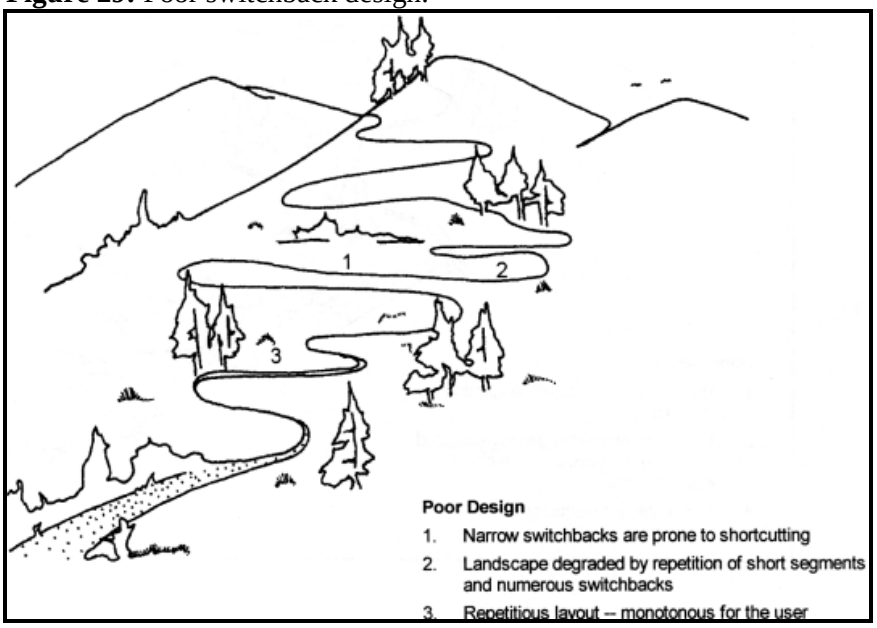
Building trails into steep slopes requires the implementation of switchbacks in order to scale the slope with a minimal grade. The recreational guide suggests that trails should be designed to make the best use of topographic features, avoid repetitious short segments with numerous switchbacks, and strategically planned so that collected drainage and sediments do not affect the trails below. Figure 28 and Figure 29 show both ideally and poorly designed trails using switchbacks.

Figure 28: Correct switchback design.



(Source: Recreational Trail Management, 2000)

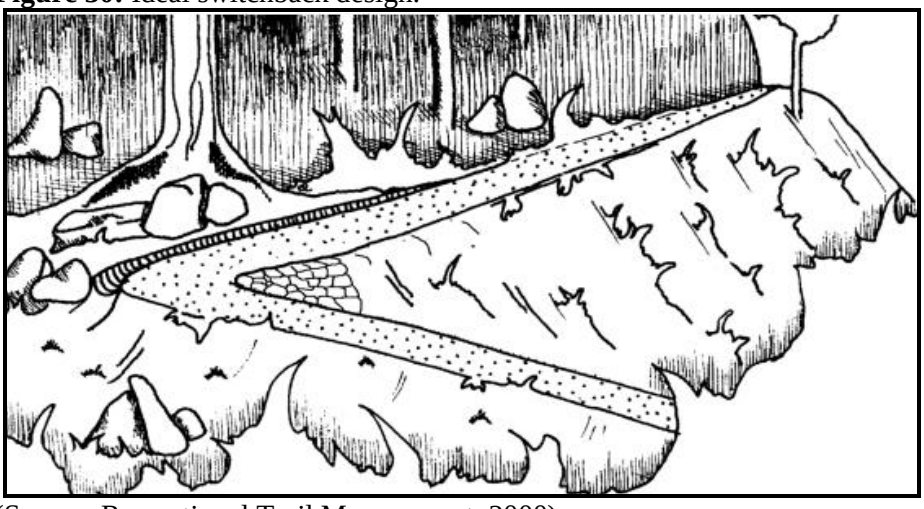
Figure 29: Poor switchback design.



(Source: Recreational Trail Management, 2000)

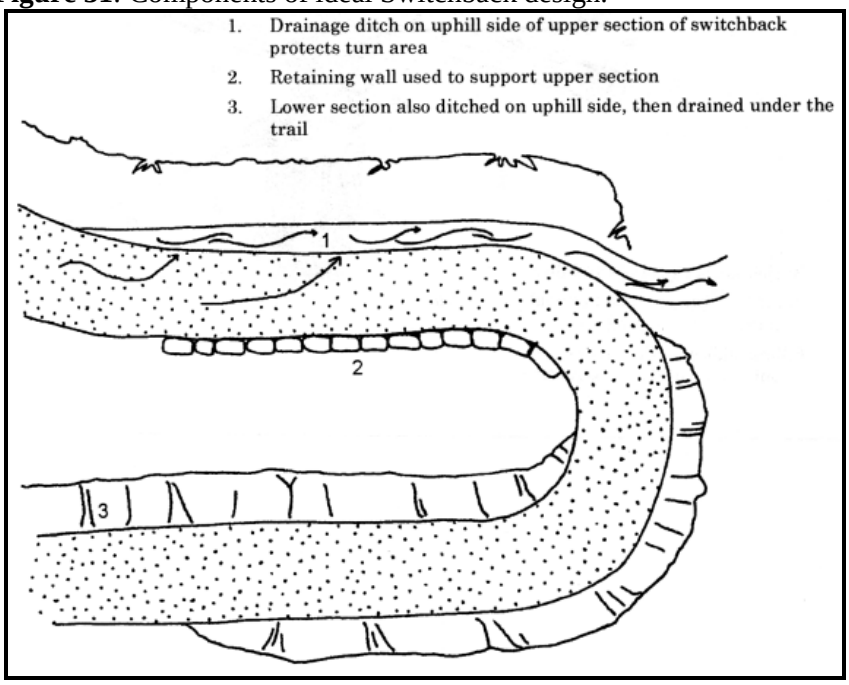
While they look simple, switchback design and implementation is actually a particularly complex process. Erosion is the single greatest threat for any trail, but it especially applies for features such as switchbacks where the trail beds are separated by a thin strip of earth on a steep slope. Figure 30 and Figure 31 show how a switchback should be properly designed.

Figure 30: Ideal switchback design.



(Source: Recreational Trail Management, 2000)

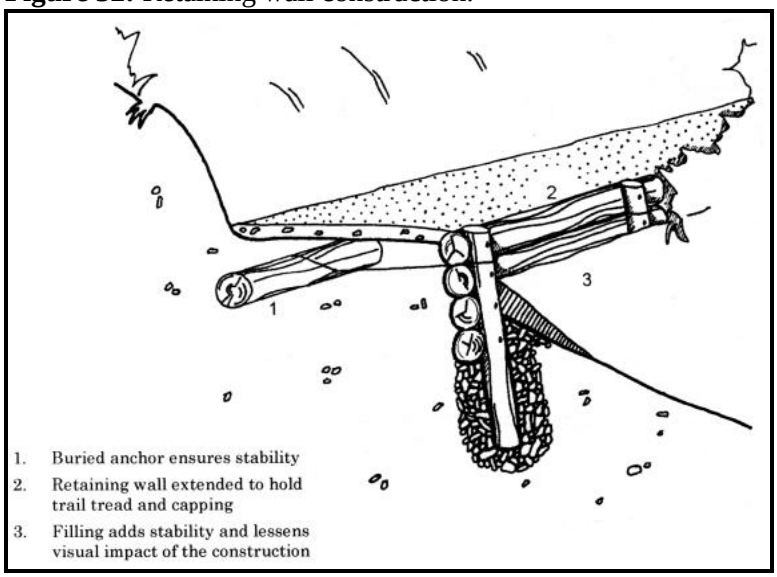
Figure 31: Components of ideal Switchback design.



(Source: Recreational Trail Management, 2000)

Figure 32 shows the proper way to construct an effective retaining wall. Retaining walls are used to help retain slopes, prevent erosion, and protect users from falling debris. They can be constructed from logs, timber, or stone and are used commonly on trails cut into side slopes and on switchbacks as shown in Figure 30 and Figure 31 above.

Figure 32: Retaining wall construction.



(Source: Recreational Trail Management, 2000)

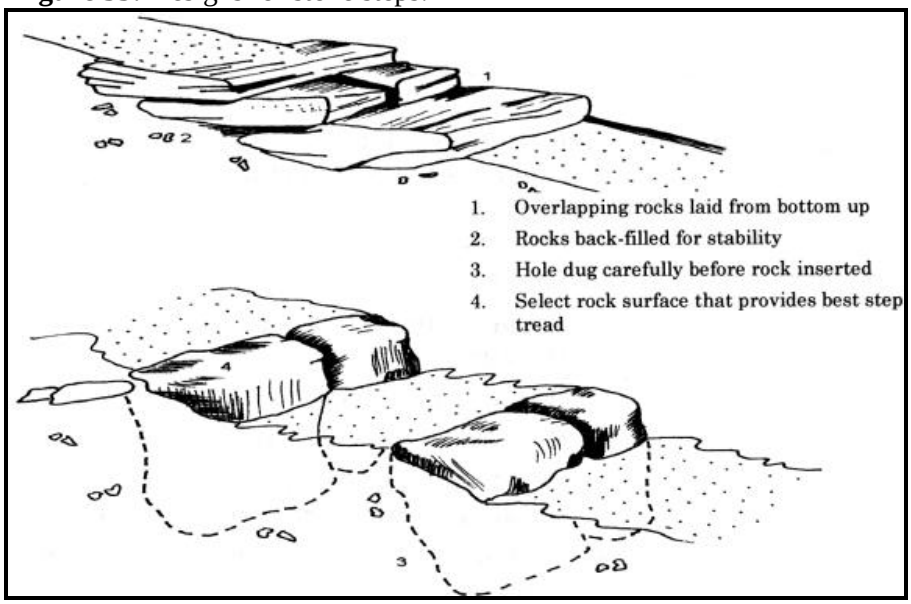
The steep and wet terrain in the Río Guaynabo may contain particularly treacherous sections in which the conditions prohibit the use of side slope grading or switchbacks. These conditions may include especially steep grades, loose soil, or obstacles that may hinder drainage. To ensure the safety of the user as well as the upkeep of the trail in these conditions, the recreational guide suggests the use of simple, low impact staircases. Stairs are a good solution for steep grades when designed correctly, but can become fatiguing and dangerous for children and the elderly if their special needs are not taken into consideration. The recreational guide suggests that flights of stairs be constructed in short series of no more than fourteen steps separated by landings, with at least one handrail on particularly long or steep flights. The guide also establishes a rule for step proportions:

Height (cm) X tread depth (cm) = 450

(Where the height should not exceed 20cm and the tread depth should be at least 30cm)

For more gradual sections of trail that may require stairs for traction, the guide suggests using stone steps for their aesthetic quality and durability. If placed carefully, stone or boulder steps will blend into the trail and retain a natural appearance. Figure 33 shows two designs for aesthetic and effective stone steps.

Figure 33: Designs for stone steps.



(Source: Recreational Trail Management, 2000)

For particularly steep grades or areas where loose soil or roots make it impossible to effectively set stone steps into the earth, the guide advises the use of plank stairs that are connected by stringers. These staircases should be well anchored, include a rail, and must be constructed using durable, pressure treated timber.

4. Watershed Conservation

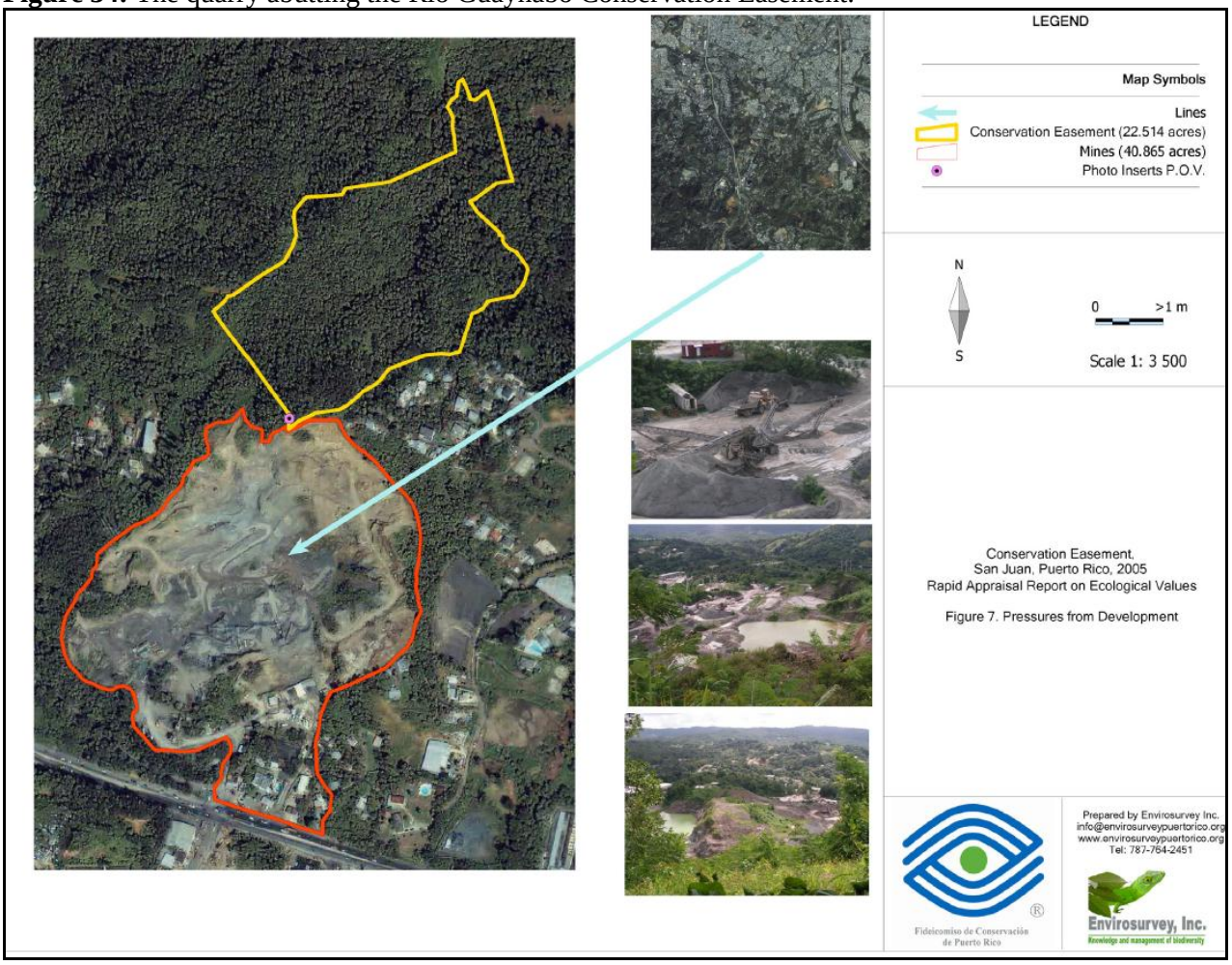
The importance of watershed conservation is the main theme of the site; therefore developing an interpretive program which illustrates this theme is necessary. This was first accomplished with the assessment of watershed threats. This assessment of threats allows for the interpretive nature of the site to use site specific examples to convey general watershed issues. With the use of a guided tour and interactive activities visitors should leave with an understanding of watersheds and be aware of the community's environmental responsibility.

4.1 Watershed Threats

It appears that the quarry abutting the Río Guaynabo Conservation Easement (Figure 34) is adversely affecting the flow of water within the area. As can be seen in the Figure the quarry (in red) is almost double the acreage of the Conservation Easement. Prior to quarrying, the small stream that flowed from south to north through the site was fed by water flowing off the elevated land to the south. Quarrying has been so extensive; however, that the land to the south is now generally lower than the Río Guaynabo Conservation Easement and the small stream is dry along much of its length.

Excavations continue at the quarry and part of the land on the southern boundary has already collapsed into the quarry. Also there may be pollution from the quarry seeping into the ground water and therefore entering the Conservation Easement. Because of this possible pollution the quarry should be closely monitored in the future.

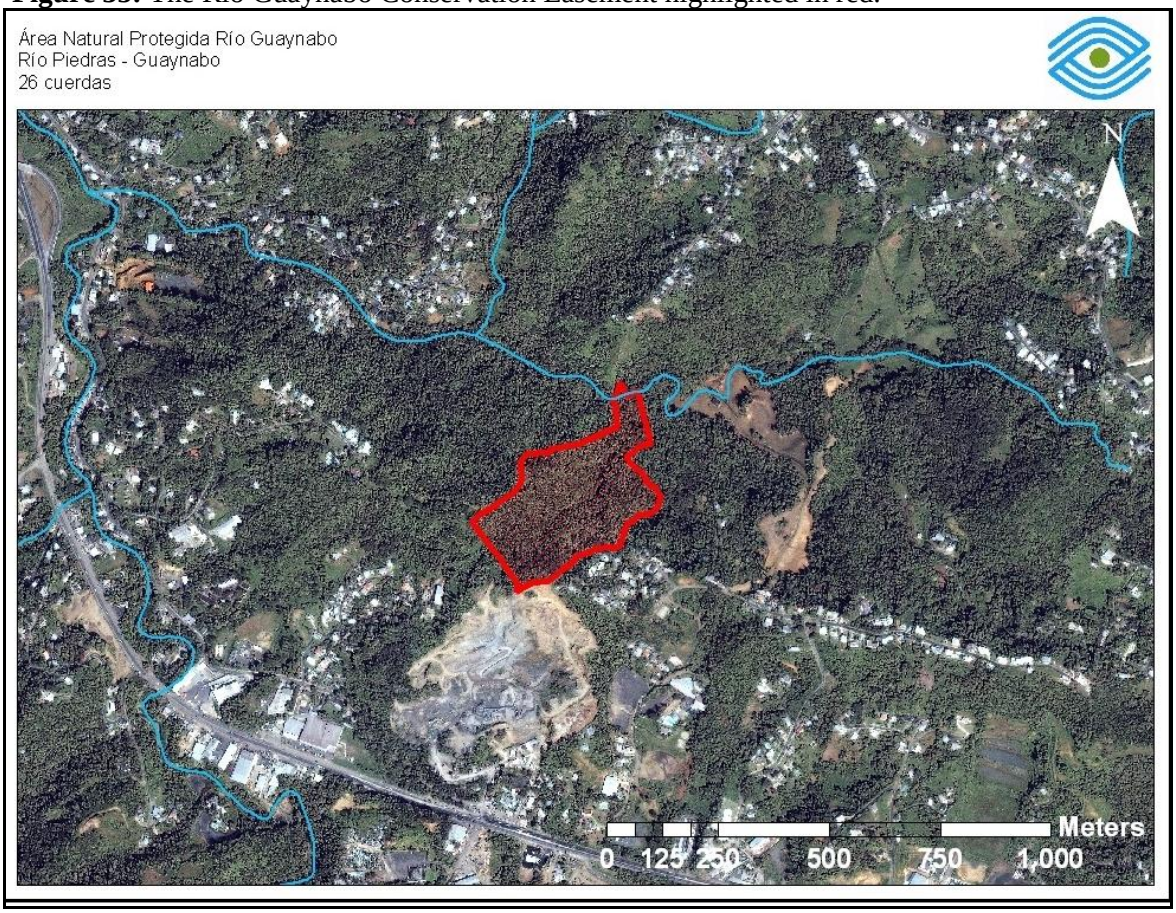
Figure 34: The quarry abutting the Río Guaynabo Conservation Easement.



(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

Future developments in the surrounding area should also be monitored by the Trust. Figure 35 shows the aerial view of the Río Guaynabo Conservation Easement and the surrounding land. As can be seen, there many developments surrounding the Conservation Easement. In addition, the area is surrounded by forest which is threatened by future developments. The figure also shows the part of the Guaynabo River that enters the Río Guaynabo Conservation Easement. While the Guaynabo River is relatively small, it draws runoff (and pollutants) from a wide area over its entire watershed. Since the area surrounding the Conservation Easement is threatened by deforestation it is recommended that the Trust attempt to acquire surrounding lands as a buffer zone or to increase the size of the site.

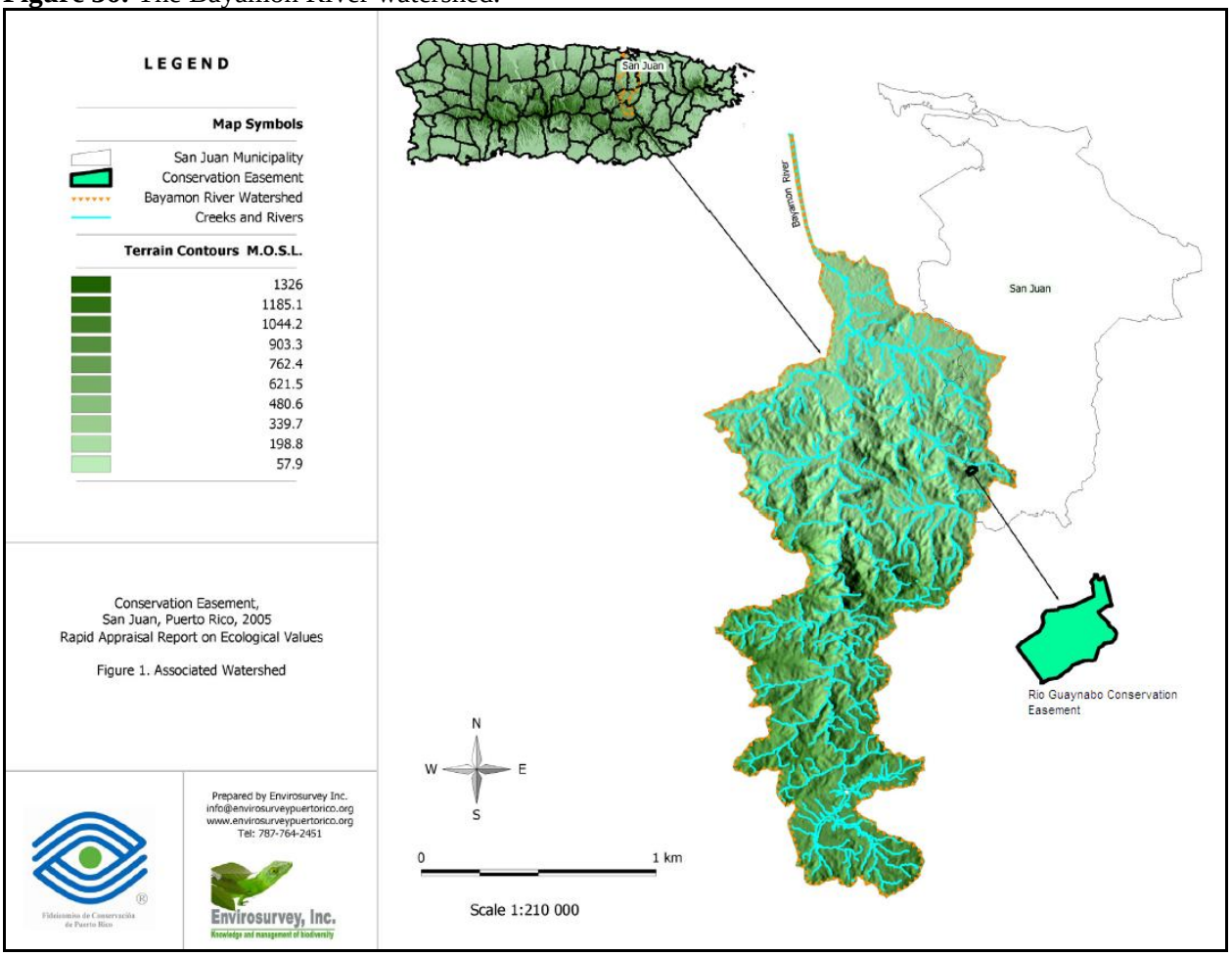
Figure 35: The Río Guaynabo Conservation Easement highlighted in red.



(Courtesy of: The Conservation Trust of Puerto Rico)

However the watershed of the Guaynabo River goes beyond Figure 35. Potential pollution can come from the whole of the Bayamón River watershed. Figure 36 shows the entirety of the Bayamón River watershed. In order to prevent pollution or simply locate the source of pollution in the Río Guaynabo Conservation Easement the Trust should identify both point source and nonpoint source pollutants in the Bayamón River Watershed. Watershed characteristics such as climate, soil type and topography highly effect runoff. The soil type in the Río Guaynabo Conservation Easement is semi-permeable and therefore is prone to runoff and erosion. The Trust should further investigate other characteristics in the site and the Bayamón River Watershed in order to determine further effects of runoff and erosion.

Figure 36: The Bayamón River watershed.



(Source: Báez-Jiménez, Trejo-Ricaño, and Quinlan, 2005)

The Conservation Easement also houses many unwanted visitors. Residents with access to the area have been using the site for riding All Terrain Vehicles (ATV) and copper burning and consequentially are leaving the area heavily littered. The team recommends that wooden fencing be placed around the perimeter of the site in order to distinguish the boundaries and potentially keep out unwanted visitors. In addition it is suggested that the litter on the site be cleaned up through the AMIGOS program. The watershed threats should be explained to visitors to help convey the necessary watershed interpretation and education throughout the tour.

4.2 Watershed Interpretation and Education

One of the main goals of the site is to convey an interpretive program for visitors with a theme based on watershed conservation. Accordingly, a trail system has been developed that can effectively accommodate this theme by using a series of interesting natural and man-made

features along with a series of interactive activities with the goal of providing both a fun and educational experience.

The points of interest should emphasize the importance of watershed conservation and give tour guides an opportunity to provide interpretive information. Each recommended point of interest relates specifically to the watershed of the Conservation Easement and also to the overall theme of general watershed conservation. Many points of interest also offer opportunities to use hands-on activities that would help keep visitors engaged and reinforce their understanding of key points and concepts. Interesting trail features that can be effectively incorporated into the interpretive plan include:

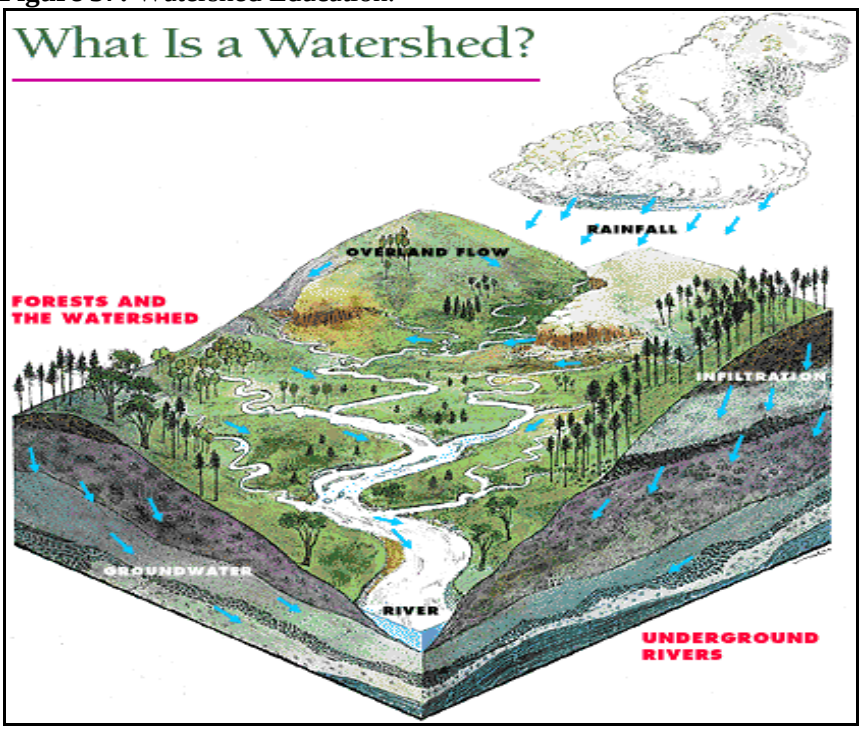
- **The cave**: The cave found near the power lines on the boundary of the property is an important point of interest because it is a typical landform found in the karst region generally found on the West coast of the island. Karst features many underground caves and cavities where pockets of limestone have eroded within the bedrock. The tour guide can emphasize that the cave in the Conservation Easement is one of only two known to be located on the East of the island and that caves such as this often provide a direct link for surface flow into underground rivers and aquifers in karst watersheds.
- **The quarry:** The quarry can be easily singled out as the largest source of point pollution near the property. The tour guide can use the quarry overlook to explain the dangers of sediment erosion and contamination as well as concepts involving seepage and underground flow. For example, the guide can point out the substantial section of the property that eroded and collapsed into the quarry. He or she can also point out the bowl shape of the quarry and describe how all the water that flows into the quarry can only escape by seeping into the ground. The seepage will undoubtedly carry pollutants from machinery and spills and most likely make its way into the Río Guaynabo through underground flow. The guide should also note that drastic changes in the land highly affect natural runoff and surface flow patterns, pointing out how the destruction of the hillside effectively cut the easement's central stream from its primary source and left it inactive. These specific cause and effect examples involving the quarry can be expanded upon by asking the visitors about what other

forms of human development can affect a watershed, and correcting their theories when necessary.

- **The Observation Deck:** The observation deck(s) is a possible venue that can be used to showcase the flora and fauna found in the site. Visitors can be reminded at this point that a polluted watershed directly affects the plants and animals living there. Tour guides can also engage visitors in a flora and fauna scavenger hunt. The Trust can make a key that shows pictures of the plants and animals that are likely to be found within the reserve and prompt visitors to try and spot the species as quickly as possible. Once a species has been spotted, the guides should explain general information about the plant or animal.
- **The Active Creek:** The creek crossing can be used as in interpretive point not only for its aesthetic qualities but because of its heavy content of non point pollution. The creek flows from adjacent properties and is currently filled with trash, most of which most likely is carried in with the water during the wet season. The Trust can organize volunteer trash removal activities with children or their AMIGOS program as well as show tour goers pictures of the stream in its worst state, stressing how irresponsibility and environmental neglect can lead to a major negative effect on the watershed.
- **The Río Guaynabo:** Finally the tour will lead to the Guaynabo River. Here tour guides can explain that although the Trust is taking steps conserve the watershed, they can only do so much (as exemplified in the small area of the Guaynabo River owned by the Trust). In order to make a positive change in the health of watersheds, communities must all take part in watershed conservation. Visitors can be involved in hands-on activities such as tests for oxygen and phosphate content within the water. The guide can explain how sediment contamination and other pollutants effectively lower oxygen content in water and could make underwater respiration impossible for aquatic animals. Adversely, high oxygen content might signify runoff carrying fertilizers from nearby agricultural properties that can result in the formation of invasive algae blooms that choke out other aquatic plants. The guide can also take advantage of the biodiversity found within the riparian habitat to make interesting narratives describing ecological cycles and other processes found within watershed dynamics.

In addition to a trail system which allows for nature interpretation guides should integrate general watershed information into the tour. This information should display the ecological value of watersheds and the positive and negative effects the community can have on watersheds. The following concepts and figures are included for suggested use as educational tools regarding general watershed ecology and conservation either before or during a guided tour to the site.

Figure 37: Watershed Education.



(Source: Yong, Mulligan and Fukue, 2007)

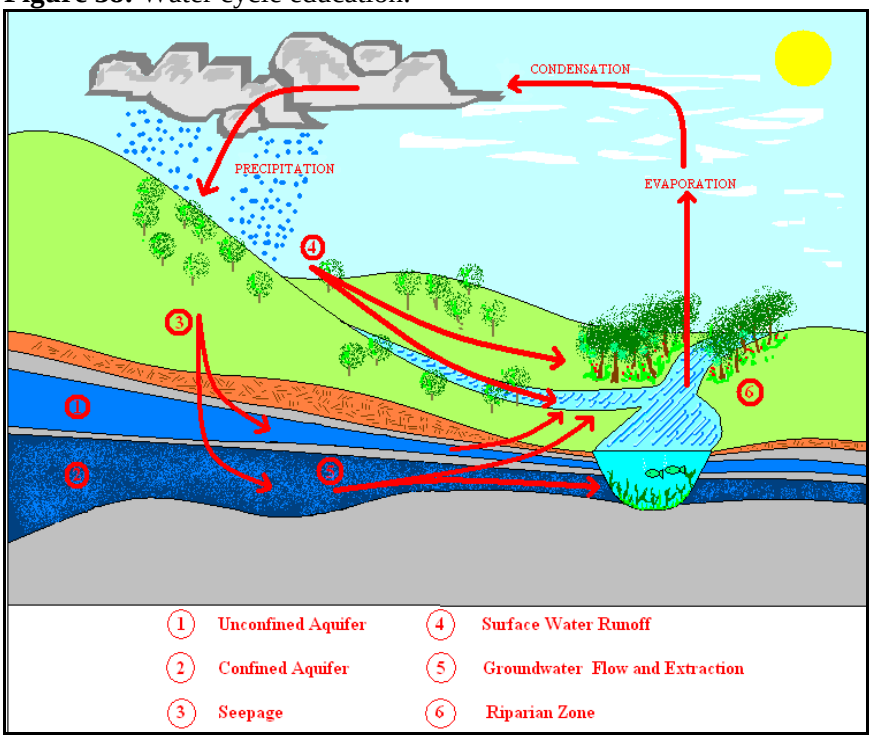
At the beginning of the interpretive tour, the guide should explain that the visitors will be given the chance to experience the natural beauty of the Río Guaynabo region with educational emphasis themed toward watershed conservation. The guide should then start the program by defining a watershed, keeping in mind that most visitors may have a cloudy perception of what watersheds really are and what they encompass. A watershed is defined as any piece of land in which all of its water sources flow into a larger body of water. Sources within a watershed could include overland flow from rainfall or snowmelt running into a stream, or bodies as large as a river flowing into the ocean. Thus, these sources can define watershed boundaries as large as, for example, the land that encompasses the Mississippi River and its tributaries in the United States,

or a piece of land as small as the area that houses the Río Guaynabo and its lesser streams such as the ones that can be found in the conservation easement.

It is important to understand that an area's natural habitats heavily depend on the condition of its water resources. Thus, a watershed not only refers to an area's streams and rivers, but its geology, sub terrain water systems, and its habitat ecosystems as well. All water within an ecosystem is recycled in a process called the water cycle. The tour guide can use examples within the reserve to illustrate the basic processes within the cycle to bring an element of interest to the visitors. For example, the guide can point out a body of water such as a stream or even a puddle, and explain how the heat from the sun evaporates the water and how the resulting vapors rise into the atmosphere.

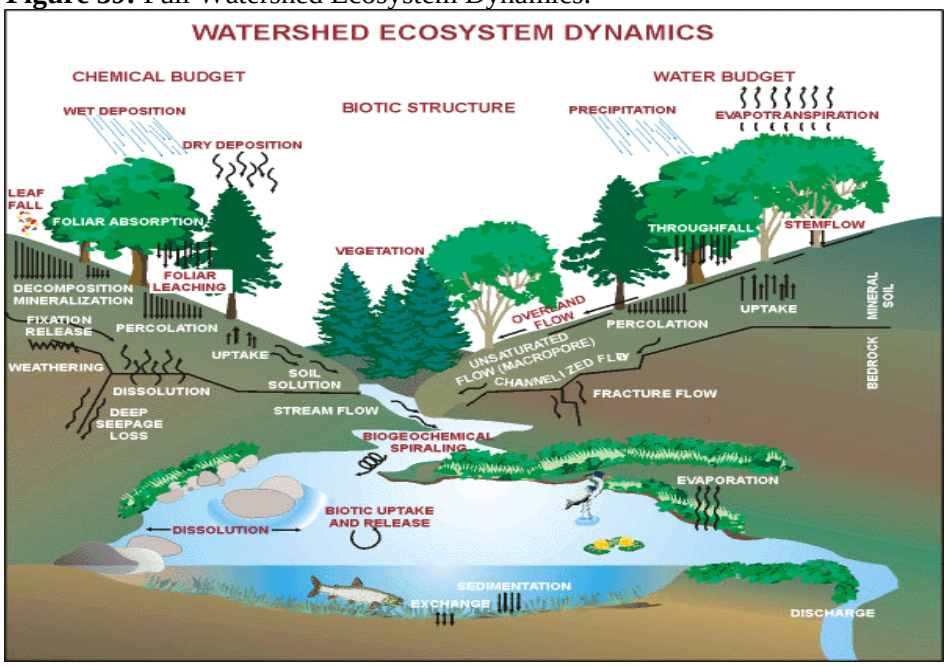
The cold air at higher altitudes causes the vapor to condense into water droplets which accumulate and form clouds. These droplets eventually become too heavy and precipitate, falling to the ground as rain. The rainwater then eventually finds its way back into a body of water by way of surface flow into streams or underground rivers, called aquifers, which flow right beneath our feet. The guide can use a graphic for additional visual reference. Figure 38 through Figure 41 show examples of graphics the guide can use.

Figure 38: Water cycle education.



Rivers form unique habitats because a vast amount of flora and fauna are able to take advantage of the water resource. The riparian conditions in the conservation easement are distincly different from other sections; the foliage is more dense and diverse, and more birds can be readily observed. The tour guide can use this visual contrast to explain watershed and river ecology as well as the dangers or water pollution.

Figure 39: Full Watershed Ecosystem Dynamics.

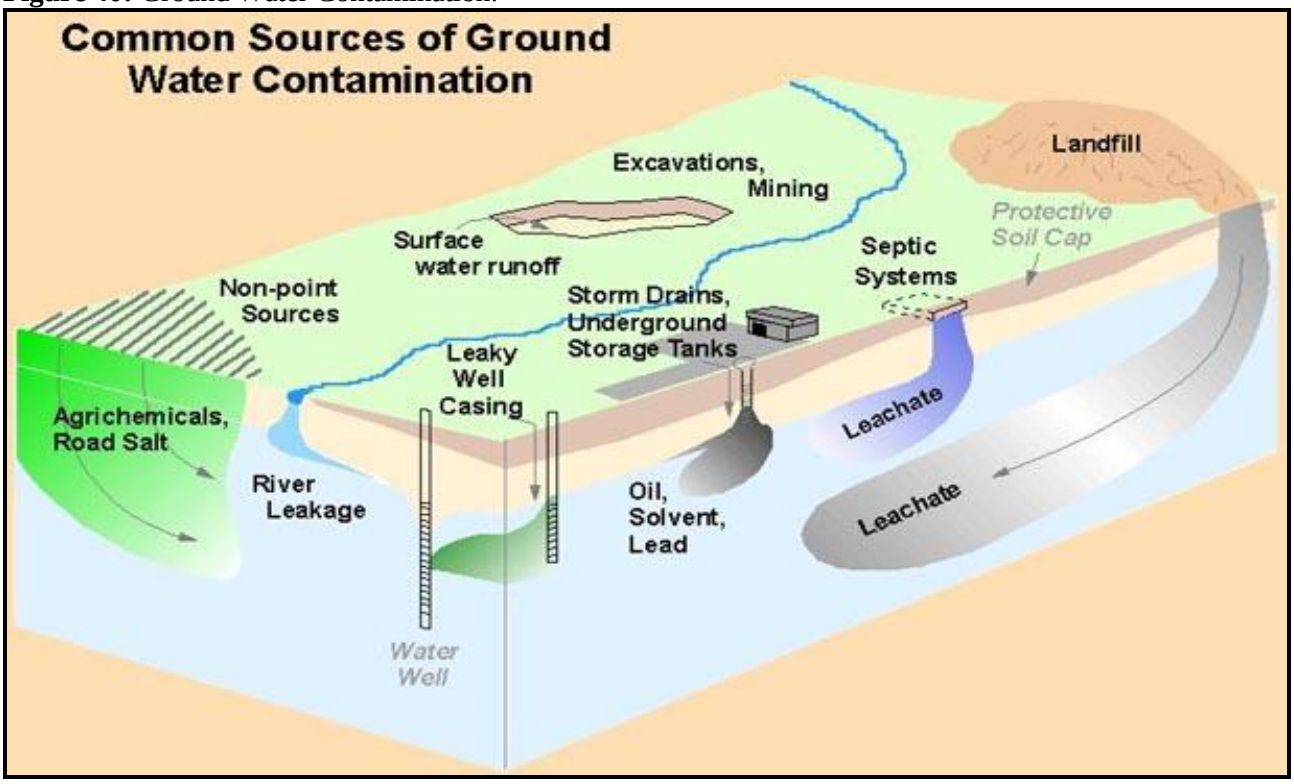


(Source: Johnson and Van Hook, 2008)

A habitat's ecosystem relies heavily on the condition of its watershed. The picture above illustrates how water is cycled within an ecosystem and how all the natural features, both geological and biological, play a specific and important role to preserve the fragile balance of the habitat. If one step of the process is disrupted by either natural occurrence or foreign contamination, the entire ecosystem will be affected. For instance, if a person thoughtlessly pours a poisonous household chemical into the soil it will eventually seep into the ground, possibly into a well, or gradually make its way into a stream. From there, it may flow into a pond where it would diffuse into the water where traces of the chemical undoubtedly be ingested by fish and other aquatic wildlife. The remaining contaminant will travel with evaporated water vapor into clouds and eventually condense and fall with the rain. The contaminated rainwater may be used by trees and other plants, some of which may then in turn be fed to livestock. Thus, in essence, the person who dumped the chemical may ingest the poison through the water he

drinks and the fish, fruit and vegetable produce, and meats he eats. The community needs to understand that while a single individual's neglect for the environment may only account for a small fraction of a watershed's contamination, every bit of pollution adds up and eventually can cause a major problem for both the environment and its natural resources which we use every day. Figure 40 displays different and common types of water contamination from the ground.

Figure 40: Ground Water Contamination.

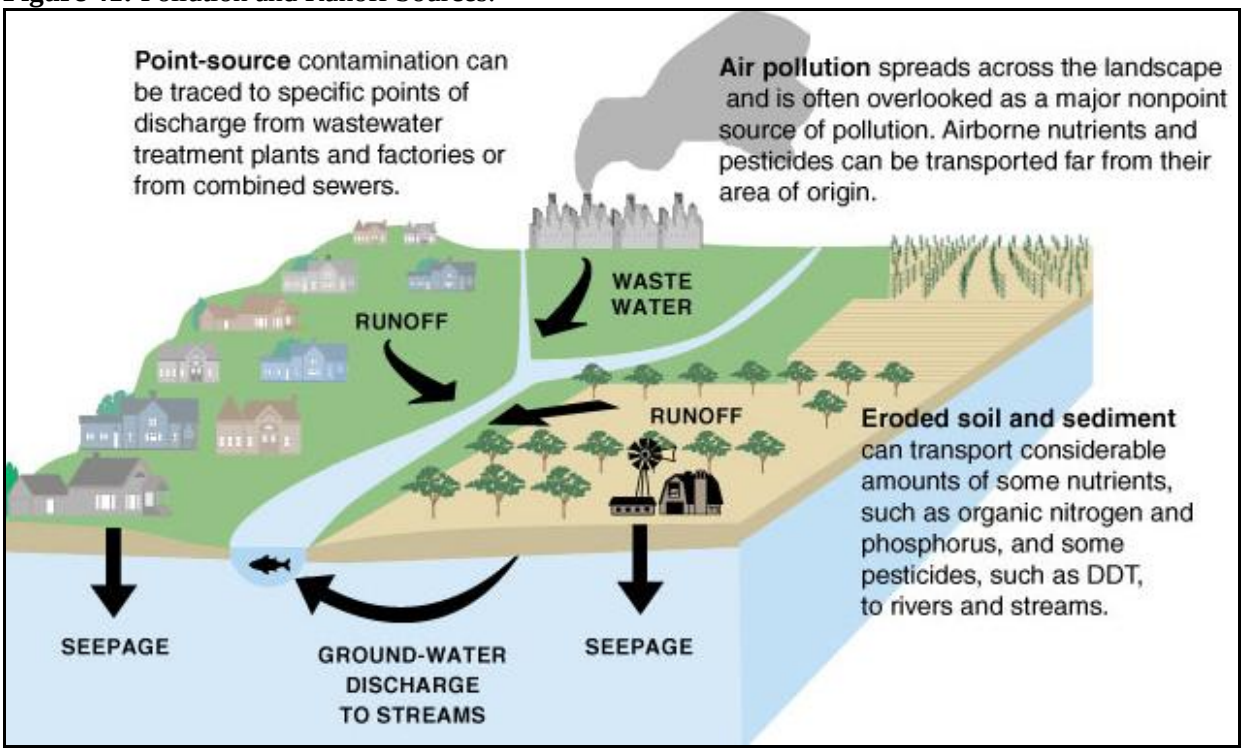


(Courtesy of : www.johnston-independent.com)

Sediment runoff is the leading contributor to watershed contamination. Construction and building development disturbs soil and makes the land prone to erosion. The eroded sediment is carried by overland flow into lakes, streams, and rivers where it dirties the water and reduces oxygen content. Surface runoff also commonly carries pollutants such as oil, fertilizer, animal waste, and pesticides that are commonly spilled or left on lawns or driveways. Once these contaminants are caught in the overland flow, they are dispersed throughout the local watershed as it flows into streams and seeps into the ground. The community can help improve the quality of their local environment and their drinking water by managing clean fill, leach fields, septic tanks, and lawn products, cleaning up solvent and petroleum spills, and properly disposing of

garbage and other waste. At this point in the tour, the oxygen content of the Río Guaynabo and/or its adjoining streams can be measured with equipment owned by Fideicomiso. The visitors can then be quizzed about the factors that can lead to low oxygen content and why it could vary between water sources. The dangers of sediment runoff can be reiterated when the tour reaches the quarry overlook.

Figure 41: Pollution and Runoff Sources.



(Courtesy of : www.johnston-independent.com)

There are two types of pollution sources: point and non-point sources. Point source pollutants are delivered from a specific location commonly known as a point discharge. Most of them are discharged via pipe from industrial sources such as manufacturers, power generators, or waste treatment facilities. Non-point sources, as their name suggests, are pollutants whose direct source is more difficult to identify. Non-point sources (NPS) are areas such as large agricultural fields and parking lots which carry pollutants such as sediment, pesticides, and pathogens. NPS pollutants are usually associated with rainfall runoff and vary as a function of watershed characteristics. The difference between point and non-point sources of pollution can be illustrated at various points in the trail. Examples of point source factors and their effects on the local watershed could include quarry sediment pollution as well its destructive effect on the

water flow in the inactive streambed in addition to point source human and animal waste from adjacent properties. The tour guide can then explain NPS pollutants by showing pictures of the garbage accumulation from indeterminate locations found in the active creek as well as additional sediment pollution from ATV use and natural erosion.

5. Conclusions and Recommendations

The Río Guaynabo Conservation Easement should be used to spread awareness about the importance of watershed conservation. The Management Plan includes a recommended trail map for the site, guidelines and specific recommendations for trail designs, and the means to implement an educational and interpretive program focused on watershed conservation.

Points of interest were recommended for the site including the quarry, the creeks, the Guaynabo River, and the cave as well as two observation decks and a resting area. Two trail options were generated although Trail Option 1 is recommended. In addition the Trust should monitor the watershed threats identified in the site.

Using this management plan, the Trust can fulfill its mission of preserving land of ecological value but most importantly, the Trust can spread awareness about the community's environmental responsibilities.

APPENDIX C: PICTURES FROM SITE VISITS

RÍO GUAYNABO

Figure 1: Tree nursery at the Botanical Garden.

Figure 2: View of quarry from the Río Guaynabo Conservation Easement.

Figure 3: Typical trail in Río Guaynabo.

Figure 4: Waterfall at Río Guaynabo.

Figure 5: Tree Snail.

Figure 6: Steep cliff on side of trail.

Figure 7: Power lines running through the Conservation Easement.

Figure 8: Entrance area from AEE. To the right is the path to the Río Guaynabo Conservation Easement.

Figure 9: Scenic view near AEE entrance.

FAJARDO

The following pictures helped with the brainstorming ideas for Río Guaynabo. Such ideas included interpretive signs, activities during tours, and scenic views for the enjoyment of the visitor.

Figure 10: Large Ceba tree to be used for educational purposes.

Figure 11: Gazebo (Observation Deck).

Figure 12: Example of interpretive sign.

Figure 13: View of bus tour.

Figure 14: Boardwalk.

Figure 15: Mangrove trees.

PONCE

The visit to Ponce helped the project team gain ideas about moveable water bridges and watershed information.

Figure 16: Interpretive sign.

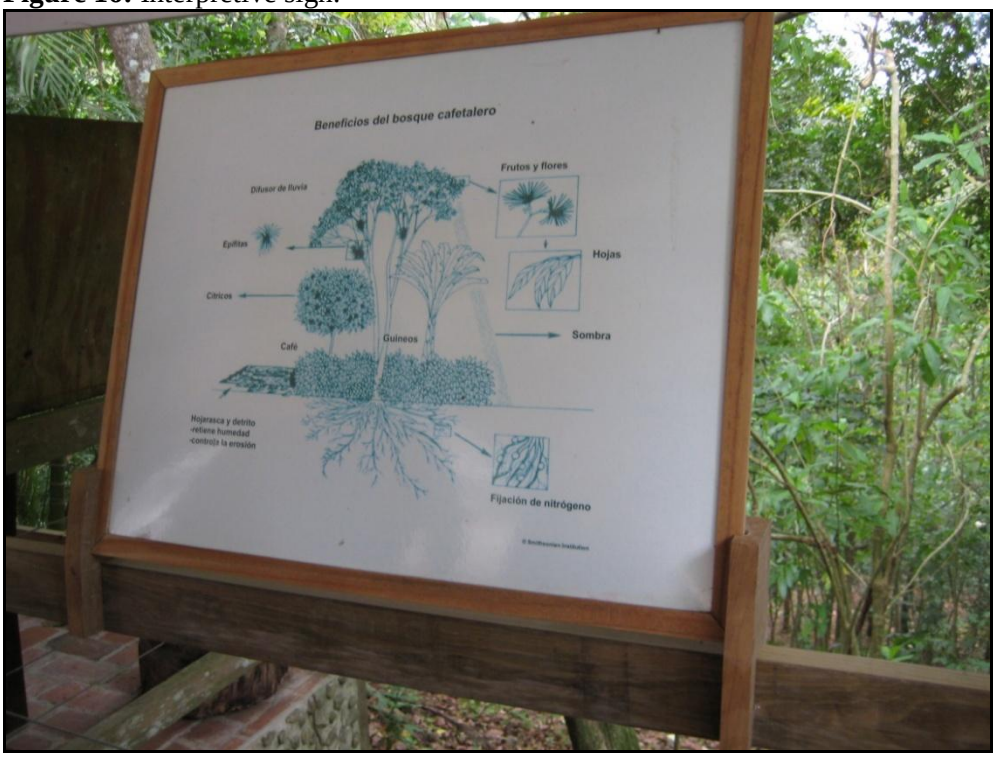
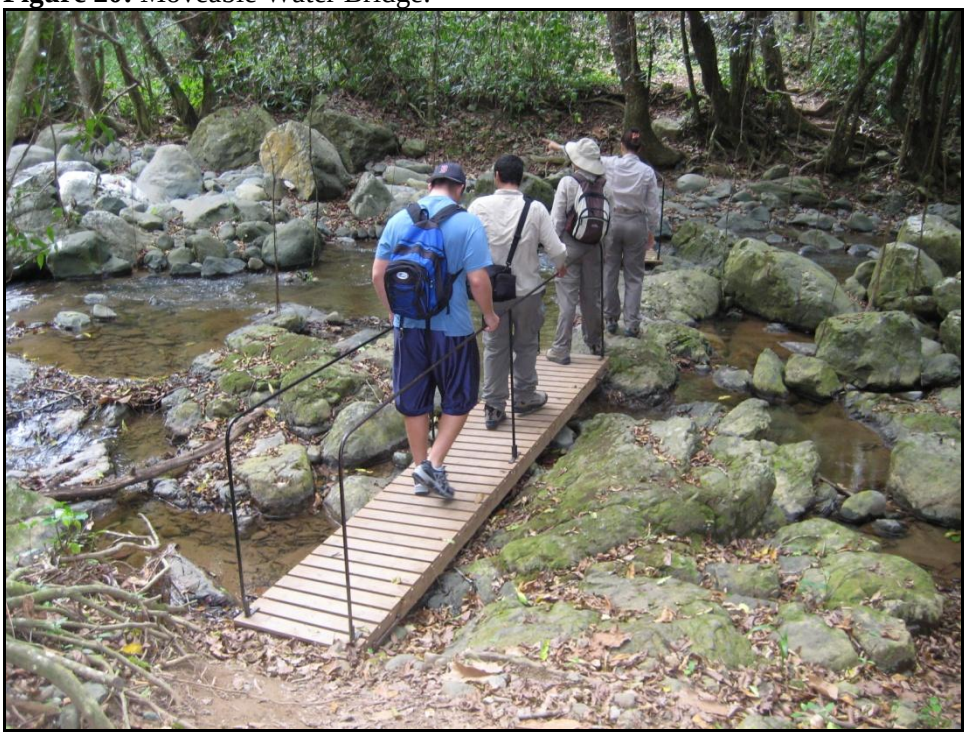


Figure 17: Manmade River.

Figure 18: Manmade waterfall.

Figure 19: Stone and dirt steps.

Figure 20: Moveable Water Bridge.



APPENDIX D: TABLES

Table 1- Flora found in the Río Guaynabo Conservation Easement

No	Species	Common Name (Spanish)	Common Name (English)	Origin	Den	Fre	BA (cm^2)	Rden	Rfre	RBA	IV	RIV
1	Guarea guidonia	Guarguao	American Muskwood	N	308	9	6633.896	35.16	6.62	25.41	67.19	22.4
2	Spathodea campanulata	Tulipan Africano	African Tulip	AL	157	10	8202.289	17.92	7.35	31.42	56.69	18.9
3	Caseana guianensis	Palo Blanco	Wild Coffee	N	112	9	2017.687	12.79	6.62	7.73	27.13	9.04
4	Bucinda buceras	Ucar	Oxhorn bucida	N	45	7	1939.223	5.14	5.15	7.43	17.71	5.9
5	Ocotea leucoxylon	Laurel Geo	N/A	N	33	6	798.3212	3.77	4.41	3.06	11.24	3.75
6	Roystonea borinquena	Palma Real	Real Palma	N	10	6	867.2353	1.14	4.41	3.32	8.87	2.96
7	Genipa americana	Jagua	N/A	N	31	5	357.462	3.54	3.68	1.37	8.58	2.86
8	Cercopia peltata	Yagrumo Hembra	Trumpet Tree	N	10	5	655.3205	1.14	3.68	2.51	7.33	2.44
9	Senna spectabilis	Casia Amarilla	N/A	AL	8	4	521.6303	0.91	2.94	2	5.85	1.95
10	Melicocca bijuga	Quenepa	Spanish Lime	AL	12	2	697.2578	1.38	1.46	2.67	5.51	1.84
11	Gmelina asiatica	N/A	Asian bruschbeech	N	18	4	124.1409	2.05	2.94	0.48	5.47	1.82
12	Eugenia jambos	Pomarrosa	Rose Apple	AL	8	5	143.3986	0.91	3.68	0.55	5.14	1.71
13	Cupania americana	Guara	Candlewood-tree	N	8	5	63.74155	0.91	3.68	0.24	4.83	1.61
14	Tabebuya heterophylla	Roble Blanco	White Cedar	N	7	5	50.92958	0.8	3.68	0.2	4.67	1.56
15	Mammea americana	Mamey	Mammee Apple	N	10	4	99.47184	1.14	2.94	0.38	4.46	1.49
16	Andira inermis	Moca	Cabbage Angelin	N	8	3	237.6183	0.91	2.21	0.91	4.03	1.34
17	Artocarpus altilis (seeded)	Pana de Pepita	Breadfruit	AL	10	2	248.1226	1.14	1.46	0.95	3.56	1.19
18	Magnifera indica	Mango	Mango	AL	6	1	550.5169	0.68	0.74	2.12	3.53	1.19
19	Zanthoxylum martinicense	Espino Rubial	White Prickle	N	5	2	370.9106	0.57	1.46	1.42	3.46	1.15
20	Artocarpus altilis (seeded)	Panapen	Breadfruit	AL	11	2	188.9965	1.26	1.46	0.72	3.45	1.15
21	Terminalia catappa	Almendro	Indian Almond	AL	2	2	458.3662	0.23	1.46	1.76	3.45	1.15
22	Piper aduncum	Higuillo	N/A	N	4	4	11.45916	0.46	2.94	0.04	3.44	1.15
23	Chrysofyllum caimito	Caimito	Star Apple	N	4	3	197.6704	0.46	2.21	0.76	3.42	1.14
24	Inga Vera	Guaba	Pois Doux	N	6	3	38.67465	0.68	2.21	0.15	3.04	1.01
25	Persea americana	Aguacate	Avocado	AL	4	3	35.96902	0.46	2.21	0.14	2.8	0.93
26	Erythina peoppigiana	Bucayo Gigante	Mountain Immortelle	AL	4	2	219.0768	0.46	1.47	0.84	2.78	0.92
27	Myrcia splendens	Hoja Menuda	Birchberry	N	4	3	27.37465	0.46	2.21	0.1	2.78	0.92
28	Manilkara zapota	Nispero	Zapodilla	AL	3	2	85.62536	0.34	1.46	0.33	2.14	0.71
29	Sloanea berteriana	Motillo	N/A	N	4	2	14.32394	0.46	1.47	0.05	1.98	0.66
30	Psychotria	Tres Cabezas	N/A	N	3	2	8.594367	0.34	1.47	0.03	1.85	0.62

	berteroana											
31	Lagerstroemia speciosa	Reina de las Flores	Queen of Flowers	AL	2	2	13.05071	0.23	1.46	0.05	1.75	0.58
32	Cordia sulcata	Moral	N/A	N	2	2	10.18592	0.23	1.46	0.04	1.74	0.58
33	Scheffiera morototoni	Yagrumo Macho	Matchwood	N	4	1	84.35212	0.46	0.74	0.32	1.51	0.5
34	Inga laurina	Guama	Spanish Oak	N	2	1	71.46057	0.23	0.74	0.27	1.24	0.41
35	Citrus reticulate	Mandarina	Tangerine	AL	2	1	13.05071	0.23	0.74	0.05	1.01	0.34
36	Cocus nucifera	Palma de Coco	Coconut	AL	2	1	10.18592	0.23	0.74	0.04	1	0.33
37	Ocotea floribunda	Laurel Espalda	N/A	N	2	1	7.957747	0.23	0.74	0.03	0.99	0.33
38	Marcgravia rectiflora	Bejuco de paloma	N/A	N	1	1	11.45916	0.11	0.74	0.04	0.9	0.3
39	Annona reticulata	Corazon	N/A	N	1	1	11.45916	0.11	0.74	0.04	0.9	0.3
40	Miconia sp	Camasey	N/A	N	1	1	3.899296	0.11	0.74	0.01	0.86	0.29
41	Eugenia jambos	Pomarrosa	Rose Apple	AL	1	1	2.864789	0.11	0.74	0.01	0.86	0.29
42	Eugenia malaccensis	Manzana Malaya	Malay apple	AL	1	1	3.899296	0.11	0.74	0.01	0.86	0.29
					876		26109.13	100	100	100	300	100

APPENDIX E: THE BIRDS OF RÍO GUAYNABO

RED TAILED HAWK

BUTEO JAMAICENCIS

Description:

The red tailed hawk is the most common and widespread hawk in North America and is a common migratory visitor in Puerto Rico. Its most distinguishing features are its broad, red tail and its harsh call. The red tailed hawk can be commonly seen soaring above the treetops or perched on tall branches in search of small mammals, reptiles, and birds.

Dimensions:

Length: 45-65 cm (18-26 in)

Wingspan: 114-133 cm (45-52 in)

Weight: 690-1460 g (24.36-51.54 ounces)

Conservation Status:

Numbers are steadily increasing throughout North America and its predation of endemic species in Puerto Rico has become a problem in recent years.

Interesting Facts:

The red tailed hawk's call is commonly used to represent all worldwide eagle and hawk calls in movies.

A mating pair of hawks can be seen performing a courtship ritual in which they lock talons and plummet thousands of feet before disengaging.

Bananaquit

Coereba flaveola

Description:

The bananaquit is a small bird characterized by its bright yellow breast, curved beak, and white eyebrow stripe. It is a common resident on Puerto Rico and can be found throughout the island, except on the highest mountaintops and driest lowlands.

Dimensions:

10-12.5cm

Conservation Status:

The bananaquit is very common throughout all of the West Indies.

Interesting Facts:

The bananaquit uses its pointed beak to pierce small holes in the base of flowers in order to “rob” them of their nectar, much like some species of robber hummingbirds.

Scaly Naped Pigeon

Patagioenas squamosa

Description:

The scaly napped pigeon is a dark gray pigeon with a purple head and a defining set of feathers on the back of its neck that look much like scales. It can be found in moist forests feeding on fruits, seeds, leaf buds, and snails.

Dimensions:

Length: 32-41cm

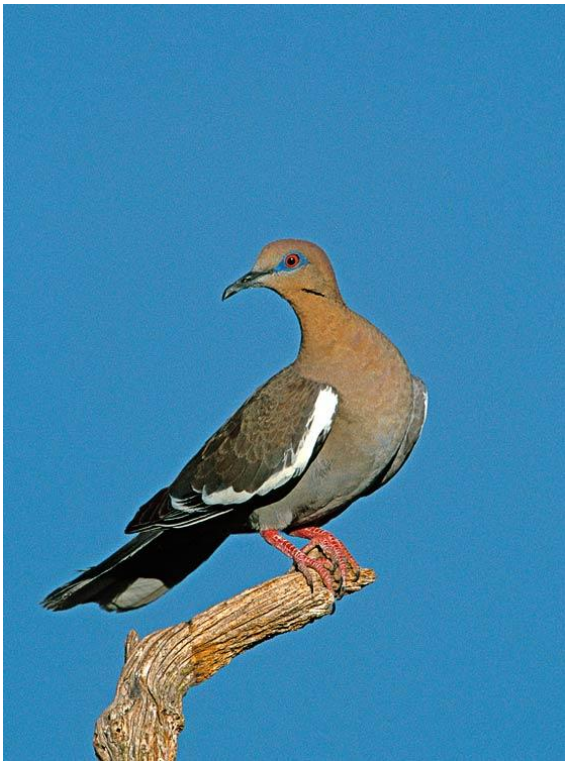
Weight: 250-326g

Conservation Status:

The scaly napped pigeon is a common, permanent resident on Puerto Rico. Despite the fact that it is the most commonly hunted of the four pigeon species on the island, it has benefited from the recovery of native forests in the twentieth century.

White Winged Dove

Zenaida asiatica



Description:

The white winged dove is gray-brown in color with a blue eye ring and a distinctive white patch on its folded wing. It lives in gardens, mangroves, and agricultural areas where it mainly forages on the ground for fruits and seeds.

Dimensions:

Length: 25-31cm

Weight: 125-187g

Conservation Status:

Although it is commonly hunted, the white winged dove remains a common, permanent resident on Puerto Rico.

Greater Antillean Grackle

Quiscalus niger

Description:

The grackle is an iridescent black bird with a long narrow bill and bright yellow eyes. It is easily recognized in flight by its prominent V-shaped tail. The grackle can be found in both open country and in towns feeding on fruits, nectar, seeds, frogs, lizards, and discarded human food. An aggressive bird, the grackle is a bully for food and commonly raids other species' nests.

Dimensions:

Length: 25-30cm

Weight: 65-85g

Conservation Status:

The grackle is a common, permanent resident in the Puerto Rican lowlands.

Puerto Rican Bullfinch

Loxigilla portoricensis

Description:

The Puerto Rican bullfinch is a thick billed, black forest bird that is easily identified by its large rust colored patches seen on its throat, forehead, and on the base of its tail. It can be commonly seen in dense, moist forest and coffee plantations feeding off seeds, fruits, buds, and insects.

Dimensions:

Length: 17-19cm

Weight: 30-33g

Conservation Status:

The Puerto Rican is a permanent, endemic resident throughout Puerto Rico although it is less often seen than heard.

Red Legged Thrush

Turdus plumbeus

Description:

The red legged thrush is a gray bird with black and white throat streaks that is easily recognized by its red legs, bill, and eye ring. It is seen in forests, coffee plantations, and wooded gardens feeding on fruit, caterpillars, and insects.

Dimensions:

Length: 25-28cm

Weight: 75g

Conservation Status:

The red legged thrush is a common, permanent resident throughout Puerto Rico.

Adelaide's Warbler

Dendroica adelaidae

Description:

The Adelaide's warbler is a small bird with gray upperparts and a yellow breast and throat. It can be found in dry, lowland forests, especially in the northern limestone hills where it gleans insects from upper level branches.

Dimensions:

Length: 12cm

Weight: 7g

Conservation Status:

The Adelaide's warbler is a common bird endemic to Puerto Rico and Vieques.

Interesting Facts:

The Adelaide's warbler is named in honor of Adelaide Swift, the daughter of its discoverer, Robert Swift.

Puerto Rican Woodpecker

Melanerpes Portoricencis

Description:

The Puerto Rican woodpecker has black upperparts with a bright red throat and breast and a white rump patch. It can be found in most forest habitats throughout Puerto Rico, where it gleans and drills for insects in tree bark.

Dimensions:

Length: 23-27cm

Weight: 70g

Conservation Status:

The woodpecker is common, endemic species found throughout Puerto Rican forests and woodlots.

Interesting Facts:

The Puerto Rican woodpecker has a barbed tongue with sticky saliva that helps it remove insects from holes it drills in trees.

Puerto Rican Tody

Todus mexicanus

Description:

The tody is a tiny, brightly colored bird that has a short tail, emerald green upperparts, yellow sides, and a bright red throat and lower bill. It can be found in all forest types that have dense thickets and vines where it sits quietly on branches with its bill tilted upwards in search of insects flying beneath the canopy.

Dimensions:

Length: 11cm

Weight: 5-6g

Conservation Status:

The tody is a common, endemic forest bird despite nest predation from the introduced mongoose.

Interesting Facts:

The female commonly lays 2-4 eggs, each roughly one quarter of its body weight.

The tody can lower its body temperature by up to 11 degrees Centigrade to conserve heat during cold weather.

Gray Kingbird

Tyrannus dominicensis

Description:

The gray kingbird is gray above and white below with a prominent black patch over the eyes and rarely visible orange crown feathers. It can be seen in open country, parks, forest edges, and city streets; basically anywhere there is an open flight path it can use for catching insects on the wing.

Dimensions:

Length: 22-25cm

Weight: 42-48g

Conservation Status:

The gray kingbird has adapted well to human settlement and remains one of the most common bird species in Puerto Rico.

Interesting Facts:

The kingbird is very aggressive, especially during the breeding season. It will commonly attack neighboring pairs, as well as potential predators including humans. In fact, a common Puerto Rican expression is “cada guaraguao teine su piterre,” which translates, “every hawk has its kingbird” (pestering it).

Mangrove Cuckoo

Coccyzus minor

Description:

The mangrove cuckoo is a slender bird with buff under parts, a gray cap, and a long tail with prominent white spots. It can be found in thick vegetation in mangroves, coastal scrub, low altitude mountain forests, and coffee plantations, where it moves slowly through thick vegetation in search of insects and small vertebrates such as lizards, frogs, and nestlings of small birds.

Dimensions:

Length: 33cm

Weight: 65g

Conservation and Status:

The mangrove cuckoo is a common and permanent resident of dense forests and thickets throughout Puerto Rico.

REFERENCES

Aide, T. M., & Grau, H. R. (2004). Globalization, migration, and latin american ecosystems. *Science, 305*(5692), 1915-- 1916.

Akers, J. P., & and Briggs, R. P. (1965). In Mann P. (Ed.), *Active tectonics and seismic hazards of Puerto rice, the virgin islands, and offshore areas*

Báez-Jiménez, J. A., Trejo-Ricaño, N. A., & Quinlan, C. (2005). *Eulalio Torres conservation easement proposal San Juan, Puerto Rico, 2005 rapid appraisal report on ecological values*

Baughman, M., & Serras, T. (2006). *Trail design for small properties.*, 2008, from http://images.google.com.pr/imgres?imgurl=http://www.extension.umn.edu/distribution/naturalresources/images/8425map.jpg&imgrefurl=http://www.extension.umn.edu/distribution/naturalresources/DD8425.html&h=456&w=700&sz=65&hl=en&start=1&um=1&tbnid=CpUidPZXAyTckM:&tbnh=91&tbnw=140&prev=/images%3Fq%3Dloop%2Btrail%2Bdesign,%2Buniversity%2Bof%2Bminnesota%26um%3D1%26hl%3Den%26sa%3DN

Black, P. E., & Fisher, B. L. (2001). Conservation. *Conservation of Water and Related Land Resources,*

Cote, S., Cox, K., & Rivera, M. (2007). *Sustainable development at the San Cristobal canyon* (IQP Retrieved from http://www.wpi.edu/Pubs/E-project/Available/E-project-042707-110050/restricted/Canyon_Final_Report.pdf

Garcia-Martino, A. R., Warner, G. S., & Scatena, F. N. (1996). Rainfall, runoff and elevation relationships in the luquillo mountains of Puerto Rico. *Caribbean Journal of Science, 32*(4) Retrieved from http://academic.uprm.edu/publications/cjs/VOL32/P413-424.pdf

Grau, R. H., Aide, T. M., Zimmerman, J. K., Thomlinson, J. R., Helmer, E., & Zou, X. (2003). The ecological consequences of socioeconomic and land-use changes in post agriculture Puerto Rico. [The Ecological Consequences of Socioeconomic and Land-Use Changes in Post agriculture Puerto Rico] *BioScience, 53*(12), 1159--1168. Retrieved from http://www.bioone.org/perlserv/?request=get-document&issn=0006-3568&volume=53&issue=12&page=1159

Green, M. J. B., & Paine, J. (1997). *State of the world's protected areas at the end of the twentieth century* Retrieved from http://www.unep-wcmc.org/protected_areas/archive/albany.pdf

Gross, M., Zimmerman, R., & & Buchholz, J. (2006). *Signs, trails, and wayside exhibits* (3rd ed.). Stevens Point, WI: UW-SP Foundation Press, INC.

Ham, H. S. (1992). *Environmental interpretation: A practical guide for people with big ideas and small budgets*. Golden Colorado: Fulcrum Publishing.

Helmer, E. H. (2004). Forest conservation and land development in Puerto Rico. *Landscape Ecology, 19*(1), 29--40. doi:10.1023/B:LAND.0000018364.68514.fb

Higgitt, D. L. (1996). The effectiveness of student-authored field trails as a means of enhancing geomorphological interpretation. *Journal of Geography in Higher Education, 20*(1), 35--44.

Houghton, R. A. (2003). Global effect of deforestation. *Handbook of Ecotoxicology, Second Edition*, 645--666. Retrieved from http://books.google.com/books?hl=en&lr=&id=qN0I3husm50C&oi=fnd&pg=PP19&dq=Global+Effects+of+Deforestation:+Handbook+of+Ecotoxicology,+Second+Edition&ots=GBO29RhrL1&sig=nl4_LvpXLaN4ZAvJxHv77SmYqhM#PPP20,M1

Hughes, M. Impact of trail-side interpretive signs on visitor knowledge. *Journal of Ecotourism,* 1--11.

James, A., Gaston, K. J., & Balmford, A. (2001). Can we afford to conserve biodiversity? *BioScience, 51*(1), 43-52. Retrieved from http://www.bioone.org/perlserv/?request=get-document&doi=10.1641%2F0006-3568(2001)051%5B0043%3ACWATCB%5D2.0.CO%3B2&ct=1

Johnson and Van Hook. *Watershed ecosystem dynamics.*, 2008, from www.epa.gov/watertrain/ecology/l21.html

Kingsland, S. E. (2002). Creating a science of nature reserve design: perspectives from history. *Environmental Modeling and Assessment, 7*, 61-69. Retrieved from http://www.springerlink.com/content/qh5jmdlbeqf7r4dh/fulltext.pdf

Larsen, M. C., & Torres-Sánchez, A. J. (1998). The frequency and distribution of recent landslides in three montane tropical regions of Puerto Rico. *Geomorphology, 24*(4), 309--331. doi: 10.1016/S0169-555X (98)00023-3

Lugo, A. E., & Helmer, E. (2003). Emerging forests on abandoned land: Puerto Rico's new forests. *Forest Ecology and Management, 190*(2-3), 145--161.

Mitchell, L. E. Developing a GIS of the bioluminescent bays on Vieques, Puerto Rico. Retrieved from http://gis.esri.com/library/userconf/proc04/docs/pap1018.pdf

Monlux, S. (1995). Geosynthetics for trails in wet areas. *Colorado Trail News,* Retrieved from http://atfiles.org/files/pdf/Geotextile.pdf

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, Gustavo A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*, 853--858.

Oberle, M. W. (2006). *Puerto Rico's birds in photographs* (2nd ed.). Seattle, Washington: Editorial Humanitas.

Pascarella1, J. B., Aide, T. M., Serrano, M. I., & Zimmerman, J. K. (2000). Land-use history and forest regeneration in the Cayey mountains, Puerto Rico. *Ecosystems, 3*(3), 217--228. doi:10.1007/s100210000021

Recreation trail management. (2000). http://www.tsa.gov.bc.ca/sites_trails/manual/chap10/chap10.htm

Roussy, K. R. (2006). *The water cycle.*, 2008, from http://www.atmos.uiuc.edu/earths_atmosphere/water_cycle.html

Starnes, D. (2008). Legal and tax implications of conservation easements. *Department of Agricultural Economics*

Trail construction and maintenance notebook. (9/24/2004). , 2008, from http://www.fhwa.dot.gov/environment/fspubs/00232839/page08b.htm

Tuffly, M. F., & Corner, P. J. (2005). Generating conservation scenarios for Puerto Rico., 1--91. Retrieved from http://gis.esri.com/library/userconf/proc05/papers/pap1931.pdf

Twumasi, Y. A. (2001). The use of GIS and remote sensing techniques as tools for managing nature reserves: The case of kakum national park in Ghana. *Geoscience and Remote Sensing Symposium, 2001. IGARSS '01. IEEE 2001 International, 7*, 3227--3229. Retrieved from http://ieeexplore.ieee.org/iel5/7695/21051/00978311.pdf?tp=&isnumber=&arnumber=978311

Yong, R. N., Mulligan, C. N., & Fukue, M. (2007). Geoenvironmental sustainability.

Zerbe, R. (2005). *What is a watershed?*, 2008, from http://www.co.berks.pa.us/conservation/cwp/view.asp?a=1360&q=447345