Caimito, Puerto Rico

Assessment of Land Use Suitability in the San Juan Metropolitan Area

Prepared by:
Amy Bliven
Jaclyn McHugh
Joshua Obal

May 2, 2001

May 2, 2001

Professor Ángel David Cruz
Professor Maritza Barreto
University of Puerto Rico-Río Piedras
Department of Geography
P.O. Box 23345
San Juan, PR 00931-3345

Dear Prof. Cruz and Prof. Barreto:

Enclosed is our report entitled *Assessment of Land Use Suitability in the San Juan Metropolitan Area*. It was written at the University of Puerto Rico-Rio Piedras during the period March 10 through May 3, 2001. Preliminary work was completed in Worcester, Massachusetts, prior to our arrival in Puerto Rico. Copies of this report are simultaneously being submitted to Professors Lew Yan Voon and Vernon-Gerstenfeld for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We thank you for the opportuity to work at the Univerity of Puerto Rico and appreciate the time which both of you have devoted to us.

Sincerely,

Amy L. Bliven

Amy Bliven

Jaclyn McHugh

Jaclyn McHugh

Josh Obal

Joshua Obal

Assessment of Land Use Suitability in the San Juan Metropolitan Area

Report Submitted to:

Professor Susan Vernon-Gerstenfeld

Professor Lok C. Lew Yan Voon

Puerto Rico Project Center

By:

Amy Bliven Amy L. Bliven

Jaclyn McHugh Jaclyn McHugh

Joshua Obal Josh Obal

In Cooperation With

Professor Ángel David Cruz, Professor of Geography

And

Professor Maritza Barreto, Professor of Marine Geography

University of Puerto Rico–Río Piedras

May 2, 2000

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of the University of Puerto Rico or Worcester Polytechnic Institute.

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.

Abstract

This report, prepared for the University of Puerto Rico-Río Piedras and the National Sea Grant Program, assessed the land use suitability of rural regions of San Juan. Maps were generated showing agricultural, urban, and conservation suitability of the land in the San Juan metropolitan area using Geographic Information Systems and remote sensing. The geographical integrity of the land was considered in the creation of the maps, as well as the social effects of urban sprawl. The assembled data shows areas suitable for conservation as well as areas that could be used for urban development or for agricultural purposes. This report also offers recommendations on how to combat the negative effects of urban sprawl.

Authorship Page

This project was a collaborative effort by Amy Bliven, Jaclyn McHugh, and Joshua Obal. All partners contributed equally to the report and worked as a team by approving all material contained herein.

Acknowledgements

We would like to acknowledge the following individuals, agencies, and corporations for the guidance, assistance, and generosity they offered throughout the completion of this report. We would also like to express our gratitude for the time and effort they gave toward the realization of this project.

Professor Susan Vernon-Gerstenfeld, Project Advisor
Professor Lok Chong Lew Yan Voon, Project Advisor
Professor Ángel David Cruz Baez, Project Liason
Professor Maritza Barreto, Project Liason
Ms. Beatriz Arsuaga, Local Project Coordinator
Ms. Erin Whitacker, Worcester Community Planning Office
Professor Carlos Guilbe, University of Puerto Rico-Río Piedras, Dept. of Geography
Professor Ernesto Rodriguez, University of Puerto Rico-Río Piedras, Dept of Economics
Mr. Augusto Gandía, Carolina Planning Board
Mr. Geraldo Irrizarry, Carolina Planning Board
Mr. Luis Estrada, San Juan Terrestrial Planning Office
Maricella Rodriguez, San Juan Terrestrial Planning Office
Carlos Ivan Mejias, San Juan Terrestrial Planning Office
Angela Lozada, Student, University of Puerto Rico-Río Piedras
United States Geological Survey
Puerto Rico Planning Board

Table Of Contents

List of Tables

List of Figures

Executive Summary

This report was prepared for the University of Puerto Rico-Río Piedras and the National Sea Grant Program to develop land use suitability maps for the undeveloped regions of metropolitan San Juan. It also assessed certain social impacts of urban sprawl and how the use of our generated maps could improve upon those effects. As established in the Interactive Qualifying Project *Assessing the Effects of Urban Sprawl in the San Juan Area, 1977-1995* (Brandl & McWilliams, 2000), the population of San Juan is haphazardly spreading south and east of the city.

Unorganized development of the land has resulted in negative social and environmental conditions. Efforts are being made in the individual municipalities in our study region to update the land use maps that are used for zoning. But one problem arising from the individual endeavors is the lack of continuity of zoning among the quadrants.

The main objective of this project was to generate land use suitability maps to assess the undeveloped regions of metropolitan San Juan. The study area included six topographic quadrants: Bayamón, San Juan, Carolina, Naranjito, Aguas Buenas, and Gurabo. The western limit was Río de La Plata, and Río Grande de Loíza served as the eastern limit. The study area was more urbanized in San Juan quadrant and the immediate borders of Bayamón and Carolina; however, all six quadrants include some rural land.

There is a need to reassess the rural regions of the San Juan area and the social implications of improper land use. Our maps are the first step in this reassessment. We used the 1977 Land Use Map and 1995 SPOT image of the San Juan region to determine the urbanized areas. We then combined maps in Geographic Information Systems software to determine the risks and benefits related to developing the rural land in our study area. The main considerations for urban suitability were distance from urban areas, slope, and geological composition of the land. For agricultural suitability, the main considerations were the permeability of the soil, slope of the land, and distance from urban areas. Conservation was recommended for areas prone to flooding or with a slope greater than fifty percent, as well as land adjacent to waterways and bodies of water. From this data, we generated our land use suitability maps.

A large consideration for development potential lies in the availability of infrastructure. Due to time constraints, we have limited our study to an investigation of the current and projected future adequacy of the transportation system in our study area. In particular, we have studied whether the planned routes for the urban train are compatible with the recommendations of our land use maps.

We recommend that municipal planning boards in the San Juan area use these land use suitability maps to avoid misuse of the land. The maps can be helpful for the zoning of land because they indicate land suitability for each type of development. They can also help the municipalities keep zoning continuity along their borders. We also recommend that the planning boards make development plans based on the path of the urban train. Keeping developments that will be heavily accessed by the public concentrated around the train will promote use of the train and reduce traffic problems.

Implementation and enforcement of our land use suitability maps will result in more efficient land use and conservation of natural resources. The maps will also enable developers to account for safety in their projects by having advanced knowledge of areas that are unsuitable for development. By helping to determine which areas are most suitable for development, it will be possible to plan ahead and provide necessary infrastructure to these regions. The lack of continuity for land assessment and planning that exists among the municipalities in the San Juan area can be improved upon as a result of our maps.

Chapter 1 Introduction

Urban sprawl occurs when the population of a city spreads into the surrounding suburbs. San Juan, Puerto Rico, is presently experiencing urban sprawl towards the south and east of the city. A land use suitability map shows what land is acceptable for development. Disorganized urban growth in San Juan has put unnecessary strain on its land and resources. The impact of this urban sprawl has resulted in elevated housing costs, floods, increased erosion, and other potentially harmful events. Generation of land use suitability maps would help the proper authorities to plan development and potentially prevent some of these problems in new developments.

The geography department at the University of Puerto Rico–Río Piedras and the SeaGrant Program asked WPI to collaborate in developing land use suitability maps. The objective was to generate a land use inventory for regions in San Juan*. Through this partnership, we produced land use suitability maps and specifications for the development and conservation of these areas.

A land use inventory accounting for topography, environmental constraints, and geography is instrumental for safe and efficient development. The results of this study will enable the proper authorities to reassess their current zoning policies and ordinances. These land use maps can provide direction for zoning laws and land planning.

To generate these maps, we first researched the natural hazards that affect the island and how land use might be affected by those hazards. We then collected data from previous maps and conducted our own assessment of the land by importing it into the GIS software ArcView and Idrisi. Based on our research and data collection, we made our recommendations on the areas most suitable for urban development, agricultural use, and conservation.

The University of Puerto Rico at Río Piedras is planning on using our findings to help the public make better use of the six quadrants of land in the San Juan region and to reduce the affects of urban sprawl in and around the city. The results of our study have been given to the planning boards of the municipalities within our study area. The different planning boards can use our report to aid in decision making when zoning and developing this land.

This project fulfills the requirements for the Interactive Qualifying Project (IQP) at WPI. The primary purpose of an IQP is to research, analyze, and report on a scientific, technological topic in relation to societal structures and impact. We are using Geographic Information Systems technology to create land use suitability maps for the six quadrants in the San Juan region. The creation of this land inventory will be used as a basis for development and more efficient land use while enabling the people of Puerto Rico to protect the environment and promote their own personal safety.

* This report was prepared by members of the Worcester Polytechnic Institute Puerto Rico Project Center. The affiliation among the Center, the University of Puerto Rico-Río Piedras, and the Sea Grant Program is presented in Appendix A.

Chapter 2 Literature Review

2.0 Guide to Literature Review

This project focuses on issues related to land use suitability and classification, the generation of land use maps, and to the analysis of the social impact of urban sprawl. The first section of this chapter gives some background information about our area of study. In the next section includes a discussion of urban sprawl and the problems associated with it. The literature review presents general geographical concepts such as slope, soil type, and topographical features. Information on some of the social implications of urban sprawl is located in Chapter 4. The succeeding sections contain the topics hydrology and natural hazards. This literature review also discusses environmental laws and policies that relate to this project. Geographic Information Systems and remote sensing play an essential role in studying the terrain and a brief review of each is included in this chapter.

2.1 Area of Study

The area that our project focuses on is the Metropolitan San Juan area. The US Geological Survey divided this region into six topographic quadrants: Bayamón, San Juan, Carolina, Naranjito, Aguas Buenas, and Gurabo as seen in Figure 2.1.

Source: IQP Report, Brandl & McWilliams, 2000

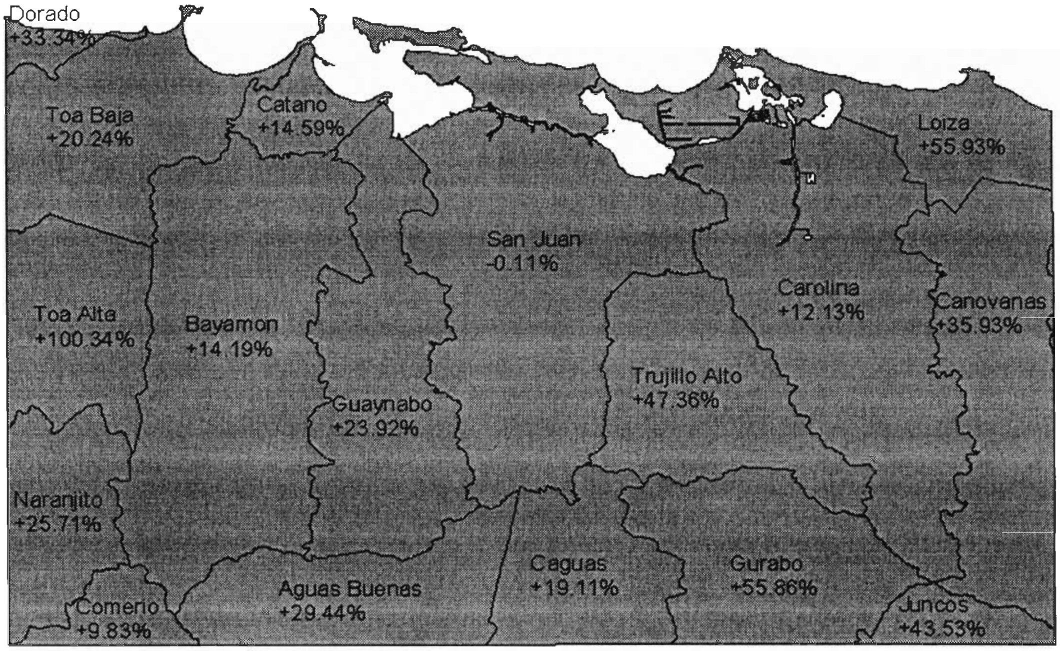
Figure 2.1 Area of Study

The coordinates that represent the boundaries of this area are 18°15' to 18° 30 north latitude and 65°52' 30" to 66° 15' west longitude. The relative geographic location of this region is between the Río de la Plata in the west, the Río Grande de Loíza in the east, the Atlantic Ocean in the north, and the central mountain range in the south (Brandl & McWilliams, 2000).

Bayamón, San Juan, and Carolina are all located along the coast of the Atlantic Ocean. These three quadrants include several types of coastal resources such as beach plains, mangrove shorelines, estuaries, and wetlands. Issues related to coastal resource management are of concern in these regions. Of the six quadrants, Carolina has the largest area of mangroves. Urbanization is prohibited in mangroves because of laws that protect them. San Juan is the most urbanized quadrant of these six. The well-protected harbor of San Juan has helped the city become the island's leading region in commerce. Several major water bodies are located in the San Juan quadrant, including San José Lagoon, Río Puerto Nuevo, Río Piedras, and the Martin Peña Canal. There cannot be a considerable amount of urban growth occurring in this region since it is already developed (Brandl & McWilliams, 2000).

Naranjito, Aguas Buenas, and Gurabo are located directly to the south of the other three quadrants and do not have any coastal resources. The main hydrologic considerations in these regions are rivers and tributaries. The biggest body of water in this region is Lago Loíza, located north of Caguas, an the topography of these regions is mostly hilly. These regions are most densely populated to the north (Brandl & McWilliams, 2000).

Our six quadrants of study encompass six municipalities and contain portions of eleven others. These municipalities can be seen in Figure 2.2. This map also shows the percentage increase in population from the years 1980 to 2000. This shows which municipalities were most affected by urban sprawl.



Source: US Census Bureau, Population Division

Figure 2.2 Municipalities within our study area

As seen in the map, San Juan is the only municipality within the study area to experience a decrease in population between 1980 and 2000. All other municipalities underwent an increase in population ranging from over 100 percent in Toa Alta to 9.83 percent in Comerio, both located on the western end of the study area. The greatest areas of increase are mainly in the eastern and southeastern sections of the study area, with the exception of Toa Alta on the western limit. Table 2.1 shows the total population numbers of these municipalities over a twenty-year range, and the increase or decrease in population.

Table 2.1 Population Statistics for Municipalities in San Juan Area

(Note: Those municipalities italicized are located entirely within the boundaries of our study area.)

Municipality	Population 1980	Population 2000	Population Increase
Toa Alta	31,910	63,929	32,019
Loíza	20,867	32,537	11,670
Gurabo	23,574	36,743	13,169
Trujillo Alto	*51,389*	*75,728*	*24,339*
Juncos	25,397	36,452	11,055
Canóvanas	31,880	43,335	11,455
Dorado	25,511	34,017	8,506
Aguas Buenas	22,429	29,032	6,603
Naranjito	23,633	29,709	6,076
Guaynabo	*80,742*	*100,053*	*19,311*
Toa Baja	78,246	94,085	15,839
Caguas	117,959	140,502	22,543
Cataño	*26,243*	*30,071*	*3,828*
Bayamón	*196,206*	*224,044*	*27,838*
Carolina	*165,952*	*186,076*	*20,124*
Comerio	18,212	20,002	1,790
San Juan	*434,849*	*434,374*	*-475*

Source: US Census Bureau, Population Division

2.2 Urban Sprawl

Urban sprawl is defined as the migration of a population away from the city and towards suburban areas. Land in the suburbs is generally less expensive and comes in larger lots than in the city. Therefore, more people move to the suburbs and more businesses begin to move there too. With this movement, the quality of life for the people moving is expected to improve with their new location. The suburbs begin to look similar to a city. People then start moving further away from the city and businesses follow and the process continues. The development of highways in Puerto Rico in the mid-1900's allowed city workers to move out of the city and into the suburbs. Thus, the San Juan area began to feel the effects of urban sprawl.

The environmental effects of urban sprawl are numerous. When the sprawl is haphazard and poorly planned, it can cause high erosion rates, reservoir sedimentation, an increase in the severity and frequency of floods, abandonment of agriculture, and increased land prices. According to José Molinelli (Ruíz, 1998), a professor of environmental science at the University of Puerto Rico, the city of Los Angeles, which epitomizes urban sprawl to many environmentalists, has green spaces that occupy 46 percent of its land area. By contrast, San Juan's remaining green areas amount to only 17 percent of its land area. Ruíz quotes Molinelli as saying that green areas, which consist of conserved areas with trees and other natural groundcover, are crucial because trees clean the air, remove harmful gases and dust from the atmosphere, and serve as a natural air conditioning system (Ruíz, 1998). The green areas also reduce the extremes of floods and droughts and reduce urban heat.

Urban sprawl has many social and economic effects on the communities in which it takes place. Often, according to Kunstle (1994), there are large negative effects on the poor and racial minorities who are concentrated in the inner city. Sprawl leads to the dispersal of job opportunities out of the city, and the poor cannot afford the transportation that is necessary to get to these jobs. Sprawl also absorbs large amounts of government spending for new infrastructure that could be used to deal with inner city problems.

Zoning laws specify areas in which development can or cannot take place; therefore, the laws affect the direction and magnitude with which sprawl takes place. In the 1920's, zoning laws that designated certain areas as "single-family-only" residences were created. Thus began the problem of social and economic segregation.

Kunstle (1994), author of several books on sprawl, feels that the zoning laws in America have turned into a system that corrodes civic life, defeats tradition and authenticity and confounds our yearning for an everyday environment worthy of our affection. For example, in many areas of Puerto Rico, the zoning laws have prohibited residences being built above stores. Without the greater availability of residences in commercial areas, people cannot always afford to live where they work. As a result, economic segregation is inevitable and the suburbs are divided into income brackets. According to Mark Aufflick (1995), author of "The Problems of Urban Sprawl in Victoria, [Australia]" some of the problems that can arise from economic division are: inadequate public transportation, lack of adequate services, poor quality housing, difficulties with household affordability, problems with the law, poor education facilities, and higher than average pollution and congestion.

2.3 Importance of Geographical Considerations

According to Douglas S. Way (1972), landforms are defined as terrain features formed by natural processes, which have a definable composition and range of physical and visual characteristics that occur wherever the landform is found. In order to apply the above definition, one must be able to recognize characteristics of a landform, even if it is found in a different climate and is subject to unusual weathering. Aerial photography can be useful in seeing those characteristics that are difficult to see from the ground. Typical descriptions of landforms are flat; flat table rocks; massive hills; soft, rounded hills; and steep, rounded hills. Other descriptions are used to indicate the slope of a landform.

2.3.1 Surface Characteristics

Land surfaces can be classified according to their topographical features, angle of slope, soil type, and drainage patterns. These classifications are necessary in order to be able to roughly visualize the surface, formulate general statements about it, and begin to think about its possible uses.

2.3.2 Soils and Land Usage

The soil composition of the surface determines whether the land is useful for agriculture, supporting buildings, or neither. Most of the earth's surface is covered with fine-grained soils that are easily eroded by water. The composition of the soil also determines the rate at which water is absorbed into the ground (Gerrard, 1981). Surfaces such as sand, rock, and marshland most likely could not be used for the same purposes (Threwartha, 1977).

The objective of soil classification and assessment is two-fold. First, analysis of the soils enables developers to avoid soil-related failures of the land. Secondly, the land can be used to its fullest potential without endangering the environment or natural resources (Boccheciamp, 1978). The Soil Conservation Service of the United States Department of Agriculture publishes soil surveys of the US and its territories. Soil scientists, conservationists, engineers, and many others contribute to the survey. The survey for the San Juan area was conducted in 1972, approved in 1973, and issued in 1978.

The nature of soils and their distinctive characteristics are compiled in the survey, in addition to data on erosion, drought, and flooding. The survey determines factors affecting the productivity and limitations on the soils under various uses. Planners and developers use the information presented in the surveys to evaluate the impact of a range of uses on overall productivity.

In 1978, the potential for agricultural use on the land was greater than what was being used at the time. As the acreage for farmland decreased and urbanization increased, erosion removed the surface layer of soil, thereby, reducing the productivity of the soil. Preservation of farmland leads to control of erosion in the future through plant root stabilization, which in turn minimizes the sediment pollution in streams. Water quality is, therefore, improved for human use, recreation, and wildlife. Protection of land best suited for agriculture minimizes the potential for damage to the surrounding environment (Boccheciamp, 1978).

2.3.3 Slope and Topography

Slope, defined as the inclination of land at a certain point, has a significant effect on land use (Threwartha, 1977). Topographic contour maps provide detailed information on the slope of the land; however, the maps must be interpreted to determine the impact of the slope. Slope classes must be created accounting for potential planning problems including landslides or flooding. These classes are created on a case-by-case basis taking into account criteria such as the maximum, minimum, and optimum slope conditions and natural limitations on the slope conditions. In addition, the standards can include condition and composition of the soils. Specific land uses are assigned from the classifications. Table 2.1 establishes guidelines for land development based on these classes. Costly environmental and structural damage could result if the guidelines are not followed.

Table 2.2 Slope Requirements for Various Land Uses

Land Use	Maximum	Minimum	Optimum
House sites	11.3-14°	0°	1.3°
Playgrounds	1.3°-1.8°	0.05°	0.5°
Public stairs	26.5°		14°
Lawns (mowed)	14°		1.3°-1.8°
Septic drainfields	8.5°*	0°	0.05°
Paved surfaces			
Parking lots	1.8°	0.05°	0.5°
Sidewalks	5.8°	0°	0.5°
Streets and roads	8.5°-9.5°		0.5°
20 mph	6.9°		
30 mph	5.8°		
40 mph	4.6°		
50 mph	4.1°		
60 mph	2.9°		
70 mph	2.3°		
Industrial sites			
Factory sites	1.8°-2.3°	0°	1.3°
Lay down storage	1.8°	0.05°	0.5°
Parking	1.8°	0.05°	0.5°

*Special drainfield designs are required at slopes above 5.8° to 6.9° percent

Source: Landscape Planning Environmental Applications, William Marsh, 1998

When evaluating slope, the potential for failure of developments must be assessed. According to the Soil Conservation Service (1978), several factors are indicative of possible failure, including loss of vegetation, change in drainage, and construction. Plant cover is extremely beneficial to the stability of the soil. The roots strengthen the soil and help to decrease erosion. Without the plant cover, change in drainage can occur due to rain-washes. The rain-washes increase surface saturation, which can lead to gullying, a weakening of the slope by cutting through the soil and subsoils. At this stage, the groundwater is exposed and liquefied masses of soil have the potential to create mudslides. Additionally, slopes that are cut through by roads, building foundations, utility lines, and other modifications can affect the overall stability of the land (Marsh, 1998).

Ideally, the natural slope of the land should not be significantly modified (Marsh, 1998). Development, also, should not occur where the slope of the surrounding land can affect the region in question. To determine the appropriate angles for development, the angle of repose must be taken into account. This angle is defined as the maximum angle for which any earth material can safely slope. If the slope of the land is greater than the angle of repose for a specific material, the material will be unable to support any weight without significant modification of the original slope. The angles range from less than ten degrees for loose, unconsolidated materials, to ninety degrees for strong bedrock (Marsh, 1998). All of these factors must be taken into consideration when generating land use guidelines to ensure the safety of the environment as well as the people involved.

2.4 Hydrology

The quality and availability of water in Puerto Rico has been slowly diminishing over the past couple of centuries (Larsen and Zack, 1997). High population density, the conversion of tropical forest to agriculture, and industrial and residential use have all had significant negative effects on water supply. Existing water supplies have been over-used, public reservoirs have been filled with sediment, and surface and ground water have been contaminated. According to the research of Larsen and Zack (1997), contamination is caused by accidental spills and leaking septic tanks. The contamination has left ground water and surface water supplies useless without proper treatment. There are man-made reservoirs all over the island constructed to collect runoff and to control flooding. The water that is collected is used as water supply for the island and power generation. The research also shows that 30 percent of the water used in Puerto Rico is ground water, and the other 70 percent is surface water. There is only one artesian aquifer, an underground well, on the north coast that is not contaminated, but its use is limited because of poorly designed wells. In some areas the water-table has been contaminated because of toxic chemicals which have been absorbed into the soil.

2.5 Natural Hazards

Puerto Rico is home to the only real-time hazard alert network in the Caribbean. Satellite and meteorological data from 122 hydrologic data sites is compiled into a computer database, analyzed, and posted on the World Wide Web. This system allows any potential storms, such as hurricanes and extreme rainfall that can cause floods and landslides, to be closely monitored. Regions affected by floods and landslides have significant limitations on their land uses.

2.5.1 Floods

According to USGS Water Reports (2000), the most common floods in Puerto Rico are flash floods. Flash flooding has been a problem on the island and is considered one of the most dangerous of the hydrologic hazards (Larsen and Zack, 1997). These floods happen as a result of steep terrain and rapid overflow of streams from excessive rainfall. Flash floods occur when a cloudburst sends considerable rain into a drainage basin. These floods last for a short amount of time. Flooding is most likely to occur where streams are short, there are steep gradients, and the channels are narrow and shallow. There are poor drainage systems on the flood plains, and as a result the likelihood of flooding in these areas is increased. Because these areas are generally densely populated, there is an increased risk of property damage.

As stated by Carter (1997), Puerto Rico has the greatest recurring threat to life and property due to flash flooding of any state or territory under the jurisdiction of the National Weather Service. He feels it is imperative that rainfall be accurately predicted on the island in order to save lives and property. Qualitative Precipitation Forecasts are generated at the San Juan National Weather Service Forecast Office every twelve hours. Carter believes that it is especially hard to forecast rainfall on the island because the variance in land and terrain causes local weather events. Nevertheless, the National Weather Forecast Office reports that rainfall is most intense in the afternoon and that the average duration of rainfall is less than one hour.

Two other types of floods affecting the San Juan Metropolitan Area are riverine floods and storm surges. Riverine floods result from extreme rainfall draining into rivers and streams causing the banks to overflow onto surrounding land. Storm surges take place in low lying coastal areas with a combination of low barometric pressure and onshore winds, causing ocean water to rush inland creating major damage (Nuhfer, 1993). The surges are mostly a result of winter storms in the Atlantic Ocean as well as hurricanes, affecting the northern coastal region of the island (USGS, 1998).

2.5.2 Landslides

A landslide is the downward movement of materials such as rock, soils, artificial fill, or any combination of these. Landslides usually occur in mountainous areas because there it is more likely for land to fall, slide, spread or flow. Landslides have been occurring throughout history as a result of such factors as erosion, excess water content of the soil, earthquakes, and other causes. The probability of a landslide is based on the geologic, hydrologic, and climatogic conditions of the area. However, in recent history landslides have become more prominent in areas experiencing large growth and construction. When engineers try to build on slopes or move materials to an area to assist in building, the likelihood of a landslide is increased.

Rainfall is the most common cause of landslides in Puerto Rico. Most of these landslides occur in the central mountains and foothills. Significant landslides have been triggered by rainfall on an average of one to two times per year in the last thirty years (Larsen and Simon, 1993). In a very serious one in 1989, more than 120 people died due to a landslide in Ponce, on the southern slopes of Puerto Rico, which was caused by Tropical Storm Isabel. An entire hillside of homes was destroyed.

The "wet" season in Puerto Rico is from May through November. Rainfall is mainly caused by tropical waves, depressions, storms and hurricanes. The annual rainfall ranges from 760 mm to more than 5,000 mm depending on location on the island. The annual occurrence of hurricanes in the Caribbean averages one or two. There have been three hurricanes reported in San Juan County, Puerto Rico, in the last three years. The first, and most destructive hurricane, occurred on September 21, 1998, and caused $1.7 billion in property damage and $301 million in crop damage; the second happened on October 20, 1999, and caused only $20 thousand in property damage; the third was on November 16, 1999, and left $91 million in property damage and $14 million in crop damage.

Earthquakes have caused the most destructive landslides that have occurred in Puerto Rico. Another leading factor for potential landslides is construction. Construction performed on hills to form highways and other urban features have had a significant impact. In 1971, construction of a mountaintop highway caused many small landslides and increased the time and cost of the project. In addition, deforestation, which has the tendency to change the slope of a hillside, can increase the risk of landslides.

A study performed by Larsen and Torres-Sanchez (1998) evaluated the frequency and distribution of landslides in Puerto Rico. They investigated three different areas of land that represent the general different types of land on the whole island. They noted that topography and the characteristics of rainstorms, as opposed to soil type, are probably the best features for estimating where landslides will occur. According to Larsen and Torres-Sanchez, predicting landslides cannot be based upon the consideration of only one topographical feature, because there are many variables that can contribute, including land use. For example, landslides on steep slopes in the middle of a forest may be less frequent than landslides on a flatter slope but in a highly populated region. Agriculture and construction, as well as urbanization, are big factors.

2.6 Environmental Laws and Policies

The importance of protecting the environment has become a vital issue, especially with regards to land development. Each state, commonwealth, and territory of the United States is subject to the laws of the United States as well as a combination of state and local laws. State laws have the ability to be more rigid, but also allow flexibility, provided they are in accordance with federal laws. The more localized governmental laws can create standards for wetlands protection, industrial zoning, and other land use issues. Based on its commonwealth standing, Puerto Rico falls under all federal, regional, and local laws based on its commonwealth standing (Bregman, 1996). The following pages explain environmental laws and policies related to the generation of a basis for efficient land use.

2.6.1 National Flood Insurance Program

The Federal Emergency Management Agency (FEMA) manages the National Flood Insurance Program. This program offers insurance coverage for regulation on state and local levels of flood hazard areas including wetlands that are adjacent to the ocean, streams, and rivers (Last, 1983). Building on or filling in the regulatory floodways is prohibited. These floodways provide a route for the floodwaters to recede. In addition, residences must be developed at an elevated height and non-residential buildings are required to be flood-proofed. Any structure erected on a known floodplain is mandated to be insured. This program regulates activities and has a widespread effect, especially on local zoning (McGregor 1996). In 1994, a reform act was passed for the National Flood Insurance Program necessitating a flood risk mitigation plan prior to development. To retain insurance coverage and funding, the plan must be approved by FEMA, before commencing construction (Godschalk, 1999). Regulations of this flood insurance program must be taken into consideration to correctly classify potential land usage.

2.6.2 Coastal Barrier Resource System

Passed in 1982, the Coastal Barrier Resources Act strived to attain three main objectives. These objectives were to curtail unnecessary spending of federal resources, discourage expansion in areas of high risk to protect human lives, and most importantly to protect the coastal barriers and their natural resources (Fish and Wildlife Service, 1998). The Coastal Barrier Improvement Act of 1990 broadened the definition of coastal barrier to encompass Puerto Rico and the US Virgin Islands, among other areas. The United States Fish and Wildlife Service is responsible for the creation and oversight of the Coastal Barrier Resource System, which was created from this Act. The system includes nearly 1,200 miles of shoreline and 1.3 million acres of undeveloped land and aquatic environments (Fish and Wildlife Service, 1998).

Otherwise Protected Areas (OPAs) are defined as undeveloped coastal barriers with prior classification such as wildlife refuges, national parks, or conservation areas. These OPAs are not eligible for Coastal Barrier Resource System status. Overall, this system cannot regulate development of the barriers; however, it can prevent federal spending on these areas, passing full responsibility onto the developer, thereby removing incentives for development (United States Department of Agriculture, 1996).

Table 2.3 National Fish and Wildlife Service Definitions of Coastal Barriers

Bay Barrier	Coastal barriers that connect two headlands, and enclose a pond, marsh, or other aquatic habitat
Tombolos	Sand or gravel beaches that connect offshore islands to each other or to a mainland
Barrier Splits	Coastal barriers that extend into open water and are attached to the mainland at one end
Barrier Island	Coastal barriers completely detached from the mainland
Dune or Beach Barrier	Broad, sandy barrier beaches with hills or ridges of sand
Fringing Mangroves	Bands of mangroves along tropical or subtropical mainland Shores

Source: http://www.fws.gov/cep/cbrfact.html; FWS, 1998

2.6.3 Wetland Reserve Program

Created as a voluntary program under the Flood Security Act of 1985 and later amended in 1990 and 1996 in Farm Bills, the Wetlands Reserve Program (WRP) was enacted to preserve and protect wetlands on private property. The WRP provides financial incentives for landowners. It asks the proprietor to discontinue farming wetlands and allow restoration of damaged wetlands. The landowner still has access to the land and can utilize the land for undeveloped activities including such activities as hunting and fishing. The WRP has many benefits including reduction of flooding, restoring habitats for fish and other wildlife, preserving essential ecosystems, and improvement of water quality (USDA, 1996).

2.6.4 The Coastal Zone Management Act

The Coastal Zone Management Act of 1972 has resulted in development of many programs protecting coastal zones. The Act's purpose is to protect and preserve the ecology, history, and beauty. Protection of these zones is achieved by restriction of new development and preservation of fish and other wildlife (Bregman, 1994). The National Oceanic and Atmospheric Administration (NOAA) provides the funding necessary to facilitate these wetland programs. Participation in these programs is optional; however, 93 percent of the nation's coastline composed of marine and Great Lakes is protected (McGregor, 1996).

2.6.5 Puerto Rico Coastal Management Program

As a subsection of the Coastal Zone Management Program, the Puerto Rico Coastal Management Program gained federal approval in September of 1978. The main agencies responsible for this program are the Department of Natural and Environmental Resources (DNER) and Planning Board. This program defines a coastal zone as a coastal strip reaching 1,000 meters inland from the shore as well as three nautical miles from the shore (Fiddler, 1996). The coastal zones of Puerto Rico include atypical features such as tropical rain forests, coral reefs, bioluminescent bays, mangrove lagoons, major turtle nesting sites and caves. This program affects over seven hundred miles of coast, which is home to over three million people. The Coastal Management Program manages issues of coastal hazards, erosion, sedimentation, and misuse of the maritime zone (NOAA, 2000).

2.6.6 Planning Board Organic Act

This Act allows the regulation of the coastal zones by the Planning Board with two specific aims. First the Planning Board Organic Act creates development requirements within the coastal zone to ensure public access to beaches. Secondly, the Act includes minimum distance requirements between structures and the maritime terrestrial zone (Fiddler, 1996).

2.7 Data Collection, Representation and Analysis Tools

In order to produce a land use suitability map of the land surrounding San Juan, it was necessary to collect data about that land and represent it in a way that made it easy to read. Remote sensing imagery makes it very easy for a researcher to collect detailed data about a region of any size. Geographic information systems allow data to be organized easily and displayed in a manner that is easy to understand. Specific software tools that were helpful to us in this project were Idrisi and ArcView. These enabled us to enter data about the land and store it in a database. Then, by using the tools available in this software, we created maps and charts for displaying our findings.

2.7.1 Geographic Information System

A geographic information system (GIS) is a software package that proved to be instrumental to our project because it can be used to keep track of the wide range of geographical data that was used to draw land use suitability maps for the San Juan area. A GIS system, with its many applications, makes it possible to keep track of geographical information concerning mountains, valleys, rivers and coastlines (Longley, Goodchild, Maguire & Rhind, 1999). People in many different professions including foresters and social scientists use GIS systems.

According to Peuquet and Marble (1990), one of the most successful geographic information systems is ARC/INFO. The ARC portion is used to store geographical coordinates and perform many operations on that data. INFO is a database management system that stores and performs operations on attributes that are not coordinates. Map features in ARC/INFO are stored as points, arcs or polygons. Feature attributes such as name and classifications can be stored in feature attribute tables.

Socioeconomic phenomena can be represented in GIS using points, lines, areas, and surfaces. An example of point related data would be the location of individual disease cases. Linear data could be, for instance, a path such as a person's journey to work. An area representation could be used for data such as property ownership. Finally, surfaces can be used for information such as population density (Longley et al., 1999).

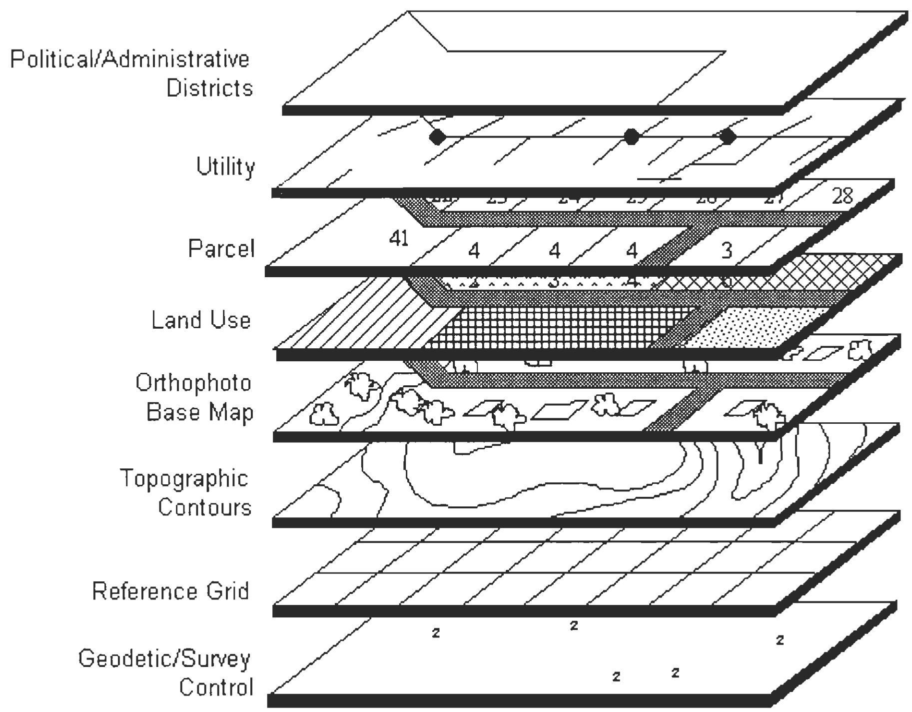
An important consideration for a project in the area of social sciences is information pertaining to population. This data can be represented in GIS as zones on a map or data relating to points. The method that uses geographical zones is the more popular of the two since there is available data on census zones, electoral constituencies, and local government areas. The representation of population as geographical zones forces the researcher to create artificial boundaries that may distort or misrepresent the data. If these boundaries are positioned in different ways, a researcher could arrive at much different results and erroneous conclusions. It is also very difficult to obtain an accurate representation of population by using points. In order to represent this data as points, each building must be considered as one data point. The difficulty here arises because the exact position of buildings is not always known, nor is the number of residents in each building (Longley et al., 1999).

Elevation contours are the principal data sources for Digital Elevation Maps (DEM) (Longley et al., 1999). They can easily be obtained from existing topographical maps, and they can accurately reflect surface structure. Sources of elevation data include surface-specific point elevation data, contour and streamline data, and remotely sensed elevation data. Characteristics of a DEM include scale, terrain parameters and terrain features. Scale is related to the choice of a good resolution, as in the choice of a map scale in cartography. Terrain parameters are related to topographical indices or surface shape and can be used for analyzing surface hydrology and ecological processes. Terrain features are associated with surface shape and drainage structure, and include mountains, valleys and rivers.

According to Longley et al. (1999), there are some limitations with GIS models. Because they are abstract models of real world entities, there are some concepts that cannot be accurately represented.

2.7.2 ArcView and Idrisi

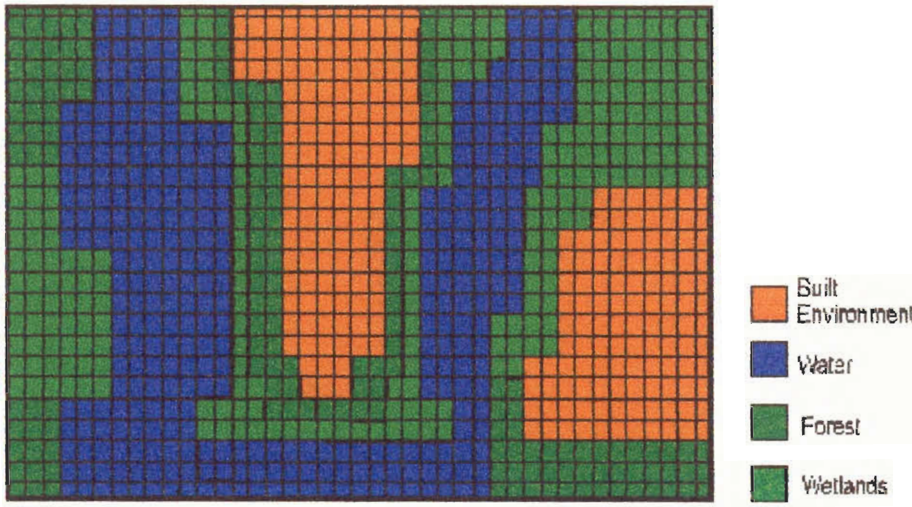
The two types of commercial GIS software that we will be using to generate the land use suitability map for the San Juan area are ArcView and Idrisi. Idrisi allows for the input, display, and analysis of geographic and remotely sensed data. Data can be entered into Idrisi or ArcView by opening an existing database, modifying it, or by creating a new one. The data is displayed as map layers, each layer representing a different theme or characteristic as seen in Figure 2.3. Although the layers in the figure differ from ones we used, the general concept of map layering is illustrated.



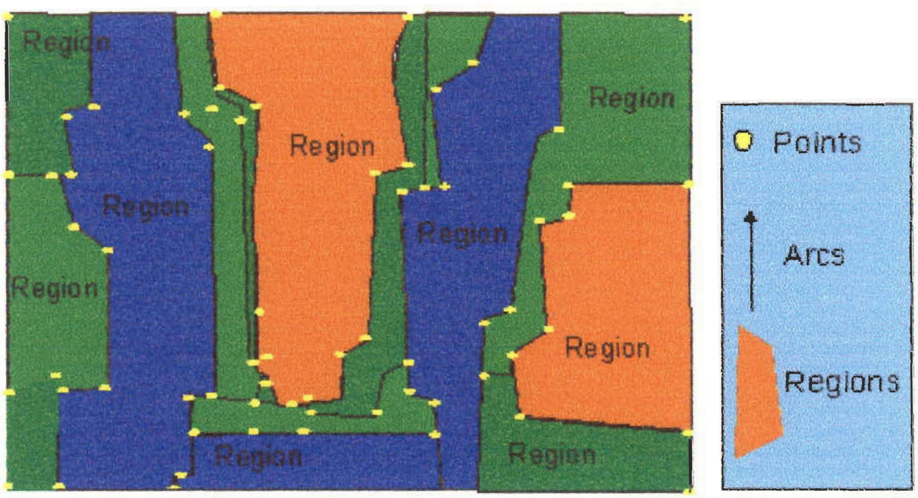
Source: *Tutorial on GIS Database Concepts*
http://www.urisa.org/GISDatabase.html

Figure 2.3 Layering of Maps Using Geographic Information Systems Software

Individual assessments can be done on each map and then the maps can be assembled to form a map composition. Map layers come in two basic forms, "raster image layers" and "vector layers." Idrisi allows for the use and manipulation of both forms (Eastman, 1999). A raster form of representation merges graphical representations of features and their attributes into unified data files. Information is divided into grid cells and each cell is given a numeric value that represents a feature, a qualitative code, or a quantitative value. Each cell represents a different characteristic of the land, just as each pixel on a computer screen represents a different color and contrast. The vector representation uses points that, when connected with lines, show a graphical representation of a feature. Coordinates are given to each point based on what features they represent. Idrisi has the capability of converting vector files to raster files, and the software is especially adept in working with the raster image layers (Eastman, 1999). Figures 2.4 and 2.5 illustrate the difference between vector and raster images. Idrisi is especially useful for projects that require the use of both kinds of maps.



Source: *The Geographer's Craft Database Concepts*
http://www.colorado.edu/geography/gcraft/notes/datacon/datacon_f.html
Figure 2.4 Geographic Information Systems Raster Image



Source: *The Geographer's Craft Database Concepts*
http://www.colorado.edu/geography/gcraft/notes/datacon/datacon_f.html

Figure 2.5 Geographic Information Systems Vector Image

Similar to Idrisi, ArcView is a software package that displays digital data of geographic locations through the creation of scales and projections. The major difference between the programs is that ArcView cannot work with the raster file format. Analyses of the data can be performed based on queries of the different attributes of the spatial data. These attributes can be anything from division of populations among municipalities to the slope of the land. They can be referred to as themes, and each them can be assigned a different color scheme to easily differentiate the data. Clicking on desired areas can identify specific map features. These features will be displayed in the form of a table with each column representing a different attribute and each row showing a different record (Environmental Science Research Institute Editors, 1999).

As in Idrisi, maps can be layered. To analyze the layers, a query can be conducted through the *Query Builder* tool. Attributes can be linked, highlighted, eliminated, in addition to other tasks, to perform the analysis. Charts can be generated based on the identification of one or more columns in the table. Creation of new maps can be displayed through a feature known as *Layout* (Environmental Science Research Institute Editors, 1999). This enables the user to combine all of the details of the analysis, including a map, chart and table, into one presentation.

2.7.3 Remote Sensing Imagery

Remote sensing can be defined as any process in which information is gathered about an object, area, or phenomenon without being in contact with it (Eastman, 1999). According to Wilke and Finn (1996), a scientist can use remote sensing to obtain data without actually having to be at the location to do analysis. The use of radar, satellite imagery or aerial photography can enable the scientist to assess the study area. These remote sensing systems generally work by measuring electromagnetic radiation that is emitted from virtually all objects on the ground.

Remote sensing is a useful tool in management of natural resources. It allows the user to easily view plants, water, soil and rock over large areas of terrain. Also, remote sensing is useful in meteorology, geology, agriculture, maritime, and urban planning (Hord, 1986). However, one must be very cautious when interpreting the images produced by remote sensing because of atmospheric interference, misrepresented results due to temperature, and varying moisture content of soils (Wilkie, 1996).

By using remote sensing imagery, one can determine a large amount of information concerning plants, water and soils. A scientist can determine the location, density and even condition of plants. According to Wilkie and Finn (1996), clear water in remote sensing imagery appears black. This is because all of the colors in the light spectrum are absorbed and none are reflected. If water is carrying sediments then its reflectance will change depending on the solids. Another factor that determines the appearance of water is the depth. If the body of water is shallow, light may reflect off of the ground underneath. Water in the atmosphere as clouds, fog, and haze can obscure objects on the ground. Dry, tan, silty soils generally appear red because they reflect mostly red and infrared light. The more water that the soil contains the darker and more like water it will appear.

Currently there are satellites that are used as remote sensors that can give information pertaining to the distribution of rain clouds, as well as the intensity of rainfall and temperature (Hord, 1986). Satellite-based remote sensing is important for Earth observation, and more specifically, a major resource for geographic information. In 1982, the Centre National d'Etudes Spatiales in France developed the SPOT Satellite Earth Observation System. This system consists of a series of spacecrafts and ground facilities responsible for satellite control and programming, as well as image production and distribution. The satellites collect data that can be used for cartography, the environment, and agriculture in addition to many others. The high-resolution images produced are especially helpful for land use planning, allowing regions to be seen in great detail. Close inspection of the images can reveal features as minute as houses and streams (SPOT Image, 2000).

Chapter 3 Methodology

This chapter outlines all of the procedures that were used in order to complete our project in both Worcester and San Juan. To provide ourselves with a frame of reference in order to conduct our project, we have researched map reading, land classification systems, and how to run GIS computer software. This knowledge was instrumental for our onsite activities, which involved land use classification of the San Juan metropolitan area. Our methodology for the onsite portion of our project was divided into three sections: data collection, organization of information, and analysis of results.

3.1 Data Collection

We collected data pertinent to our project by obtaining maps of our study area and by conducting interviews. To learn what technical data would be necessary for our study, we had interviewed Erin Whitaker from the Worcester Office of Planning and Community Development while still in the planning phase of our project. Whitaker is an expert in land use planning and Idrisi software and explained what data was necessary and how it could be organized using GIS.

To create a basis for land classification, we obtained digital maps from the San Juan Planning Board and USGS. We received maps that show elevation, geology, soil type, landslide susceptibility, and areas prone to flooding. Other maps that we obtained showed urban zoning and the location of municipalities. We also collected maps that show the location of rivers, roads, urban, and rural projects. Each of these maps enabled us to assess specific factors affecting land use suitability.

We combined the digital maps using GIS software and layering techniques to show the potential dangers or benefits of developing the land in our study area. These maps also enabled us to determine which areas were urban, which were rural, and which areas were undeveloped. The map showing the elevation of the land is a Digital Elevation Map (DEM). This map was crucial because it allowed us to calculate the slope of the land, which limits the kind of development that is possible. The geology map showed the geological composition of the land, including such geological types as sedimentary, volcanic, and artificial fill. The soils map gave detailed soil types that enabled us to classify areas for specific developments based on the strength and composition of the soil. Also, the soil type is the most important indicator of whether or not the land can support agriculture, livestock, forests, or construction. Maps displaying landslide susceptibility and areas prone to flooding take into account two pertinent natural hazards. We used these maps to determine the areas best left undeveloped because of the high risk of destruction. Delineations of urban zones and the municipalities were essential in classification of the land for specific uses. The locations of urban and rural projects show which areas in the San Juan metropolitan area are being developed most quickly. The presence and concentration of roads was a very good indicator of which areas were already developed, and helped us to evaluate the traffic patterns of the San Juan area.

In order to obtain information regarding the social aspects of urban sprawl, we conducted interviews with various government officials. Information regarding the existence of local zoning laws and the enforcement of laws was gained through an interview with Augusto Gandía and Geraldo Irrizarry of the Carolina planning board. In addition, Gandía and Irrizarry were interviewed in order to learn the specific social, economic, and environmental effects that urban sprawl is having on Carolina.

In order to learn how land use plans are made and used, we conducted a semi-structured interview at the Land Planning Office in San Juan with Luis Estrada, who evaluates projects that have requested permits; Maricella Rodriguez, an environmental analyst; and Carlos Ivan Mejias, a municipality planner. We learned about the social, economic, and environmental issues that are taken into consideration during the development of the land use plans.

To get the perspective of the community on the social issues involved with urban sprawl, we interviewed Ernesto Rodriguez and Angela Lozada. Ernesto is a resident of Caimito, an area of San Juan that is experiencing many new developments because of the construction of a highway and a new mall. He is also involved in a community group that is opposed to the development and is taking action against the developers. Rodriguez provided insight into the problems and concerns that the residents are having. Lozada is also active with the community group in Caimito and provided statistics regarding the availability of public works and services in the area. Both interviews were semi-standardized in that we prepared a list of questions to ask, but we let the interviewees decide what they thought were the most pertinent issues to discuss.

We contacted the Soil Conservation Service, which provided us with soil maps and soil classification data. The classification data was necessary to ascertain how each kind of soil can be used. Also, we researched population data from the U.S. Census Bureau from the years 1990 and 1999 from each of the six municipalities in our study. The last year that the census was conducted was 1990 and the only data available from 1999 is population estimates. This information aided in our analysis of urban sprawl by allowing us to determine which areas have experienced the most growth during the 1990s. We also collected information regarding the number of people who used public transportation to get to work in 1990 and how many people drove their own vehicle or were in a carpool to aid in our transportation analysis.

3.2 Organization of Data

The organizational step encompassed entering the quantitative information into ArcView and Idrisi. These software programs allowed us to compare results and make connections between different types of data. They also enabled us to display the information in organized tables and maps. Our objective in using GIS software was to take the existing maps that came from the Planning Board and use these to create land use suitability maps. When we received the maps, they were compatible only with the ArcView software and needed to be converted to Idrisi. It was also necessary to convert the maps to Idrisi because some of the modules for processing the data that we used were offered by Idrisi but not available in ArcView. We also reclassified the data on the maps to make it easier to use them for land use classification.

In order to combine the data on these maps to determine land use suitability, we needed to convert all of the maps so that they could be used with Idrisi. We used the SHAPEIDR import utility that converts ArcView shape files into Idrisi vector files to accomplish this. Originally, the maps were in vector format, which means that lines and polygons were used to represent areas on the maps with common attributes. For example, a region representing one municipality on the map of the municipalities would be represented by one polygon. In order to use the database editor that is offered by Idrisi, we had to convert the maps from vector to raster format. Raster format uses squares, or pixel type displays, as opposed to the vector and polygon formats of other software. This conversion was accomplished by using the POLYRAS reformat feature. (More information regarding vector and raster formats is found in section 2.7.2.)

Reclassification of the data was done by directly modifying the tables that represent the data in each map. We used the Database Editor utility to simplify map attributes such as geological composition into a few general values. For example, for the geology map we used the Database Editor to create an attribute that grouped the geology of our study area into 9 different types. There were originally over one hundred different attributes. We also made use of Idrisi's analysis utility RECLASS in order to group together multiple regions of a map that contained different values. For example, we used the RECLASS utility to group all areas that are prone to flooding and gather all other areas in a second group.

We combined the digital maps using GIS software and map combination techniques to show the potential dangers or benefits to developing the land in our study area. These maps also enabled us to determine which areas were urban, which were rural, and which areas were undeveloped. A utility offered by Idrisi called Image Calculator, enabled us to process the original maps and extract information that is relevant to land use suitability. This utility enabled us to conduct quick map combinations in order to analyze overlapping areas of maps. An example of this use was to use Image Calculator to find which urban regions were located in zones of potential flooding. We used the Image Calculator utility interchangeably with the Multi-Criteria Evaluation (MCE) utility, which also allows for the combination of multiple maps, but allows for maps to be assigned weights and therefore carry more influence in the calculation of the final map. In order to calculate the final land use suitability maps we use MCE and specified which maps were used as constraints and factors for the calculation. The constraints are maps that designate areas that are always unsuitable for use. An example of a constraint map is the map that shows the flood zones in our study area. The factors are maps in which the suitability changes over a range of values. An example of a factor map is the slope map, because the suitability of the land increases as the slope decreases. Factor maps must then be assigned a weight that determines how much the final suitability map is affected by each factor. The total weight of all factors is 1.0 and the weight of each factor must be a value between 0.0 and 1.0. Based upon the constraints and the weight of the factors MCE calculates a resulting map. In the way that we used this utility, we were able to generate land use suitability maps that showed the suitability of the land for urban development, agriculture, and conservation.

3.3 Analysis

Although a land use map for the San Juan metropolitan area is in existence, it does not indicate the suitability of the land, nor does it take into account development over the past twenty-four years. We analyzed all of the data that was collected, including the current land developments and population densities of the area, to reevaluate how the land is being used. We compared maps of slope, hydrology, geology and soil type of the land, in order to evaluate the suitability of the land for development or agriculture and create land use suitability maps for our study area. We then used Idrisi to compare zoning maps from the San Juan Planning Board and our SPOT image to the suitability maps that we generated. We also analyzed these maps for potential problems indicated by the maps of flood zones, landslides, and slope.

Chapter 4 Results and Analysis

This chapter contains the land use maps that we generated, as well as a detailed analysis of the information contained in them. There is also a discussion of the social issues relating to urban sprawl in the San Juan area that is based on our maps. We begin by discussing the land use suitability maps that we generated and our analysis of the land. We next discuss where development has taken place on land that is not suitable. Next, the kinds of problems that are being faced due to urban sprawl and the measures that are being taken to combat these problems are discussed.

4.1 Digital Maps Produced

We produced three maps that show the suitability of the land for urban, agricultural, and conservation uses. These maps served the purpose of showing the quality of land throughout our study area for each particular use. Combining certain factors that affect land use suitability enabled us to develop these maps.

The map that details the suitability for urban development is called a failure map because it shows areas that are prone to fail in supporting buildings constructed on top of them. The two components that determine whether or not the land will support a structure are slope and geology. For the purpose of developing a failure map, we first developed maps that classified the slope and geology of the land based on suitability. The map that shows suitability for agricultural uses takes into account slope, soil type and soil permeability, which also are maps that we generated. Land that should be used for conservation was determined by finding the location all of wetlands, rivers, regions prone to flooding, and areas where the land is unsuitable for urban development and agriculture. We also determined which areas were already developed through the use of the SPOT image and the 1977 land use map.

4.1.1 Maps of the Factors that Affect Land Use Suitability

The first map that we derived (Figure 4.1) was a reclassified map of the geology of San Juan.

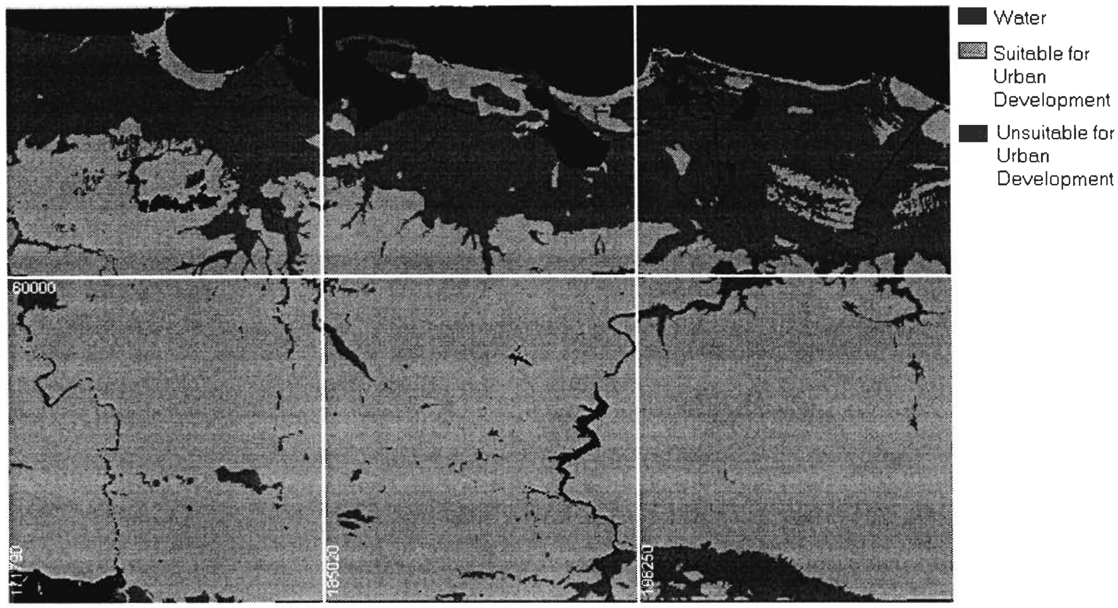


Figure 4.1 Urban Suitability of Geology

This map shows the geological composition of the land, which was classified into groups according to how the geology affects the potential use of the terrain as defined in "Landscape Planning Environmental Applications", by William Marsh. The geological types that are shown in this map are categorized as suitable or unsuitable for urban development. Six of these types provide a stable subsurface for urban development and, therefore, are suitable for urban development. They are volcanic, volcanic detritus, mixed volcanic and limestone, limestone, gravel, and sand. The next four geological types, alluvial, fine sediment, landslide deposits, and artificial fill are composed of finer sediments and are subject to soil saturation and erosion that are inhibiting factors in development of the land. They were grouped into the unsuitable category.

We also reclassified the 1977 land use map (Figure 4.2).

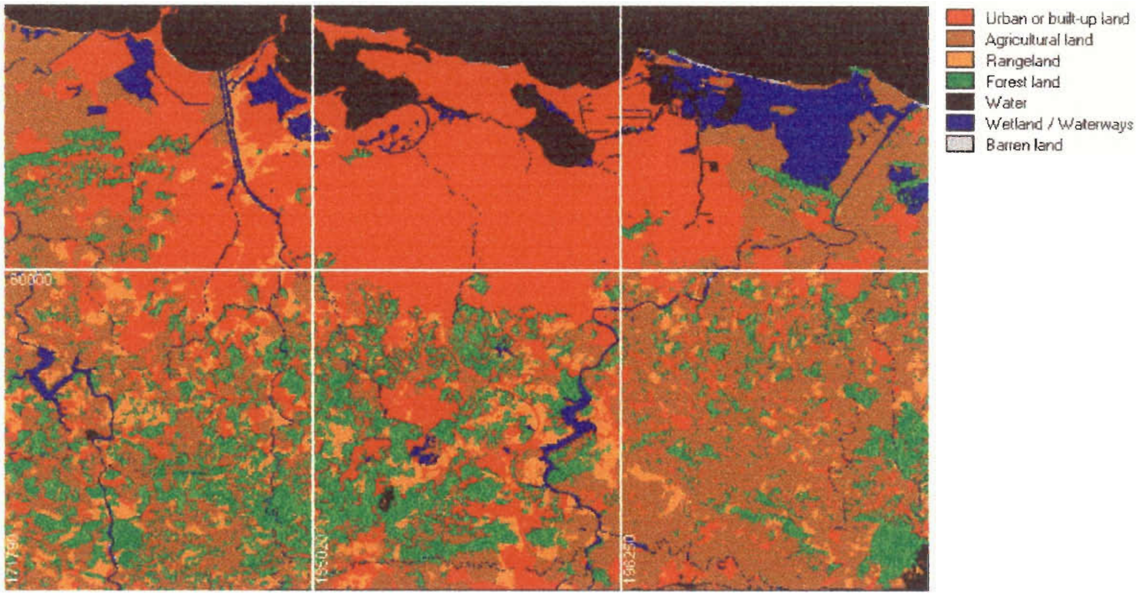


Figure 4.2 1977 Land Use Map

This map clearly indicates how the land in the San Juan area was used in 1977. We used the Anderson Land Use Classification System, which is given in Appendix B, as a guideline for deciding how to reclassify the map. The categories in the map are the seven applicable classes found in level one of the Anderson Classification System. This map shows exactly which parts of our study area were urbanized, and how the other areas were being used in 1977. It is important to note that most of the agricultural land on this map was used as pastures and not for farming. As is mentioned in our analysis of the agricultural land use suitability map that we produced, much of our study area is not suitable for agriculture.

The SPOT image (Figure 4.3) was used in conjunction with the 1977 land use map to determine any regions that had been developed between 1977 and 1995.

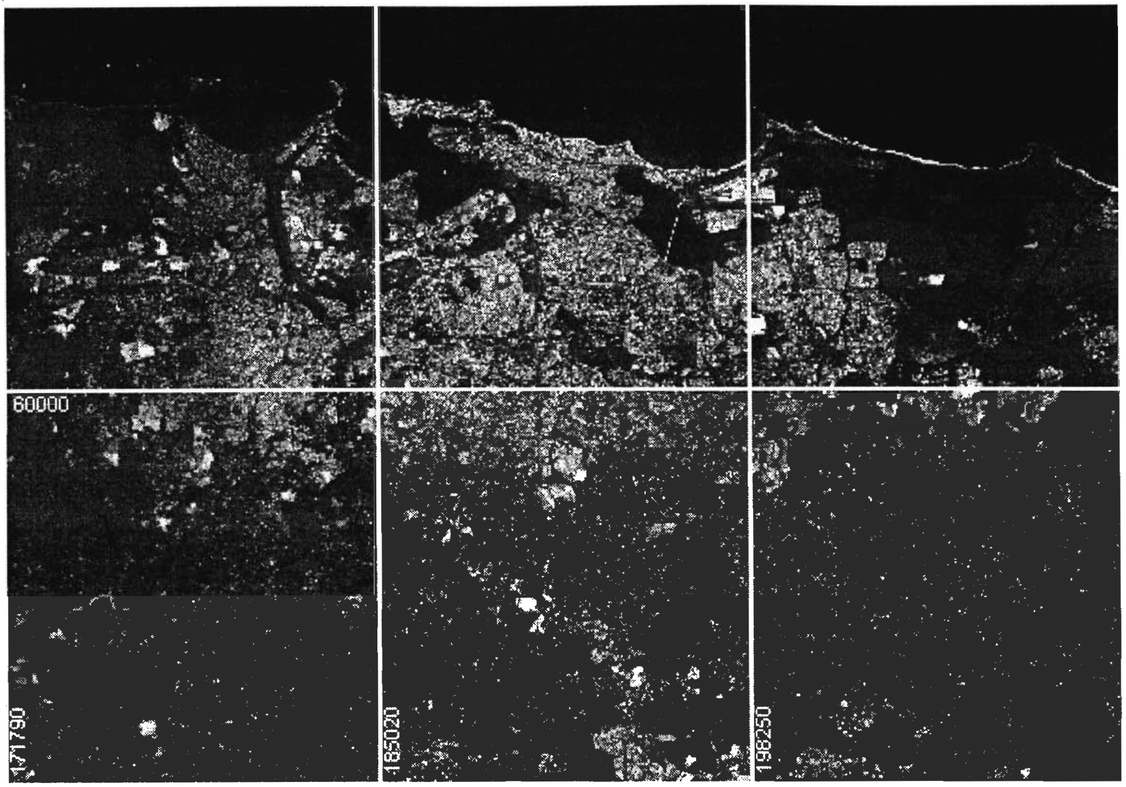


Figure 4.3 SPOT Image

The SPOT image was composed through geo-referencing into the coordinate system that we used for all of the maps. This system is the Lambert Conformal Conii which uses the State Plane Coordinate System, NAD27. Areas that reflect more light appear brighter on the map and areas of low reflectance are darker. The brightest areas on the SPOT image represent buildings and roads. The darkest areas represent bodies of water. The intermediary shades represent undeveloped land such as forests, rangeland and agricultural land.

In order to show the changes that have occurred to the urban landscape in San Juan, we combined the 1977 Land Use Map and the SPOT image to create an Urban Growth in San Juan (1977-1995) map (Figure 4.4).

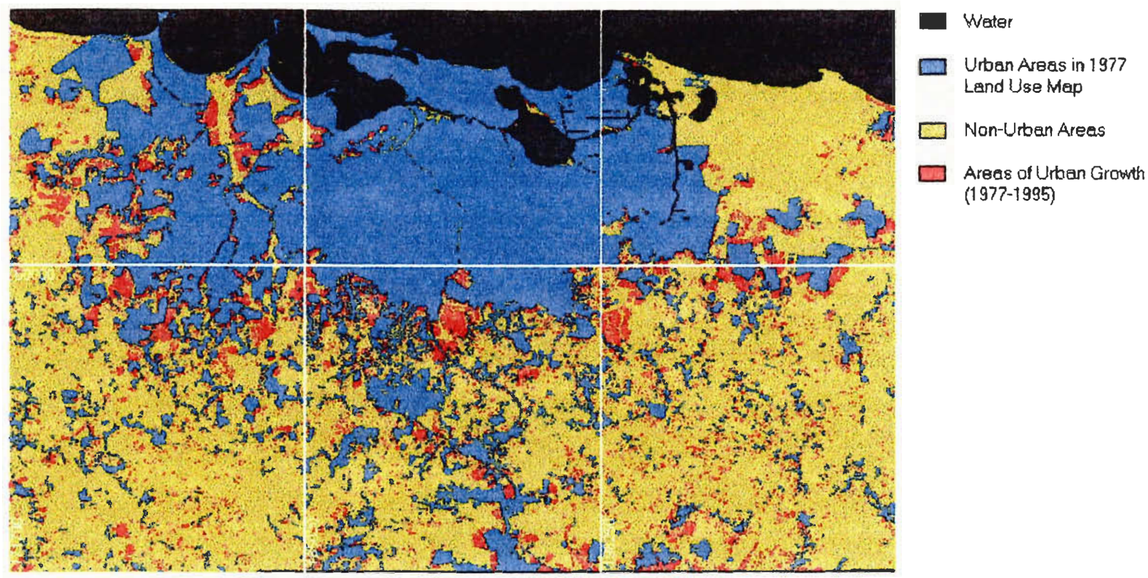


Figure 4.4 Urban Growth in San Juan (1977-1995)

The blue areas show the regions that were classified as urban in 1977. The yellow regions represent non-urban land as of 1995. Most importantly, the red areas are those that have become developed in the years between 1977 and 1995. Analysis of this map shows that urban developments have appeared in all directions outward from San Juan. This shows that no one area has been experiencing an unbalanced amount of growth.

The reclassified urban zoning map (Figure 4.5) allows one to see easily which areas in San Juan have been zoned for particular uses.

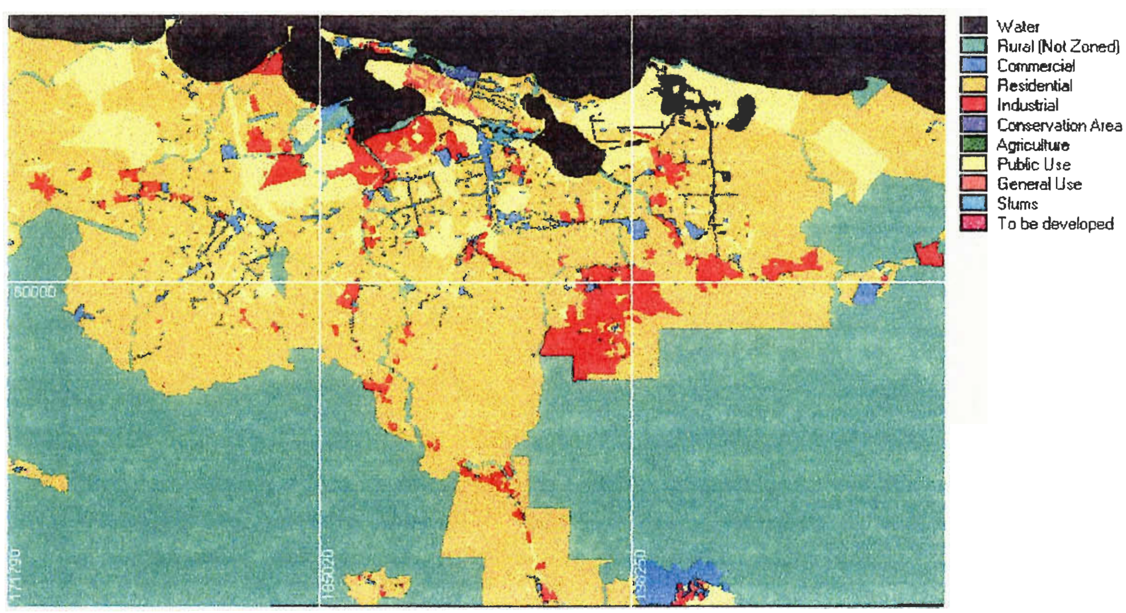


Figure 4.5 Urban Zoning

The original classification used on this map detailed over seventy-five types of zones, but the reclassified map uses only ten types. The classes contained on this map are: commercial, residential, industrial, conservation areas, agriculture, public use, general use, slums, areas to be developed, and unclassified. In terms of square meters, the residential sectors are, by far, the largest sections of the study area, followed by public use, industrial, and commercial zones. Our analysis of this map helped to determine some of the problems with the current zoning. By comparing the urban zones to the suitability of those regions for urban development, we were able to tell where problems could arise.

Another important map that we produced was a map showing the percent slope of the land in the San Juan area (Figure 4.6).

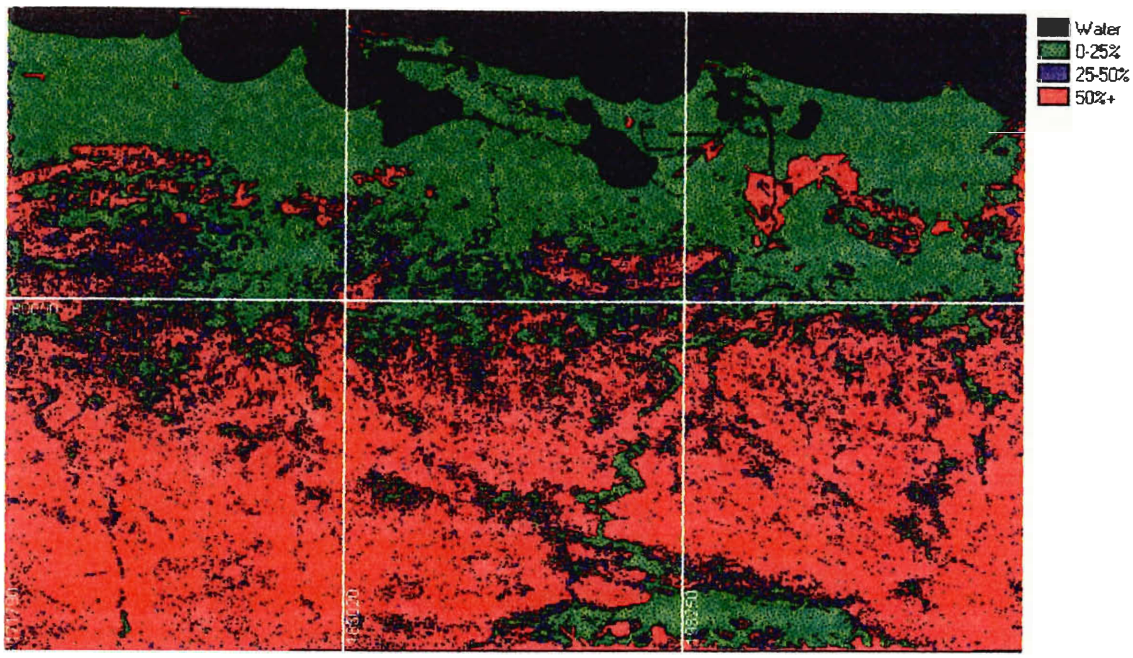


Figure 4.6 Percent Slope of Land in Study Area

This map is a simplified version of the one that was used to calculate the suitability of the land. The slope map that we used for calculations contained eleven separate divisions through the range of zero to twenty-five degrees of slope, which provided more detail for evaluating suitability. The slope map was derived from the Digital Elevation Map by using the Idrisi feature Surface Analysis/Topographic Variable/Slope. The slope of the land enabled us to evaluate which areas had a slope that was too severe for the purposes of urban development and which areas had an ideal slope for development. As described in Section 2.3.3, the optimum slope for urban development varies depending upon what type of structure is constructed. The greatest problems occur when the slope is too low to provide proper drainage, and when the slope is so severe that there is a risk of landslides and erosion. As described in Section 2.1, the three quadrants to the south of the San Juan metropolitan area are very hilly. This means that the slope of the land is often very severe, and therefore unsuitable for urban development and agriculture. When considering the slope of the land in calculating the suitability, we determined that the suitability decreases as the slope increases. Areas where the slope is very low and flooding is a problem were designated as areas that are unsuitable for development and agriculture. This map shows that the majority of the study area has a slope of 50 percent or more, making the land unsafe to use for most purposes. Most of the land that has a desirable slope has already been developed.

Finally, we produced a map that shows the suitability of the land for agricultural use based solely upon the types of soil (Figure 4.7).

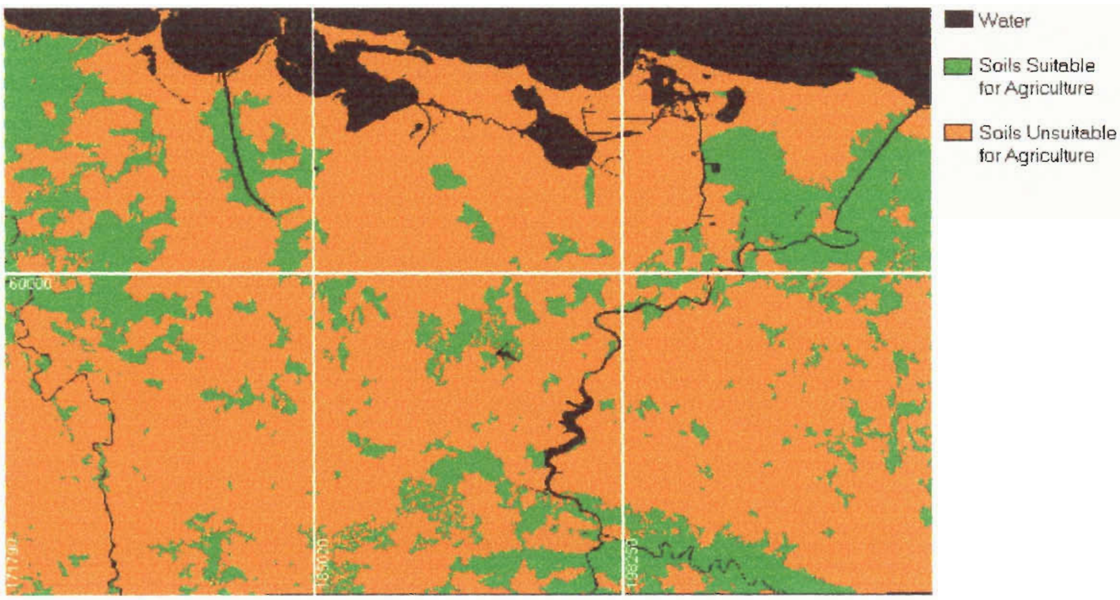


Figure 4.7 Suitability of Soil for Agriculture

We used this map and combined it with other factors that are important to agricultural suitability. The suitability of the soil is based upon the capability classes of the soil, designated by the U.S. Soil Conservation Service, which are described in Table 4.1. The capability class describes the limitations that restrict the use of the land for agriculture. These limitations are based upon the potential for erosion, and content of water and stones in the soil. The soil map that we obtained from the San Juan Planning Board contained the data for the capability class of the land in our study area. We chose to classify the first four capability classes as suitable agricultural land and the other four as unsuitable based upon the description of each capability class. Table 4.1 is used universally by the Soil Conservation Service and is applied to all soil surveys in Puerto Rico.

Table 4.1 Soil Capability Grouping Table

Capability Class	Limitations
Class I	Soils have few limitations that restrict their use.
Class II	Soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.
Class III	Soils have severe limitations that reduce the choice of plants or that require special conservation practices, or both.
Class IV	Soils have very severe limitations that reduce the choice of plants or that require very careful management, or both.
Class V	Soils are not likely to erode but have other limitations, impractical to remove, that limit their use mainly to pasture, woodland, or wildlife.
Class VI	Soils have severe limitations that make them gradually unsuited to cultivation and limit their use largely to pasture, woodland, or wildlife habitat.
Class VII	Soils have very severe limitations that make them unsuitable for cultivation and restrict their use mainly to grazing, woodland, or wildlife habitat.
Class VIII	Soils and landforms have limitations that preclude their use for commercial crop production and restrict their use to recreation, wildlife habitat, water supply, or esthetic purposes.

Source: Ponce Area Soil Survey

4.1.2 Results and Analysis of Land Use Suitability Maps

The map showing the potential use of the land in our six quadrants of study for urban development is contained in Figure 4.8.

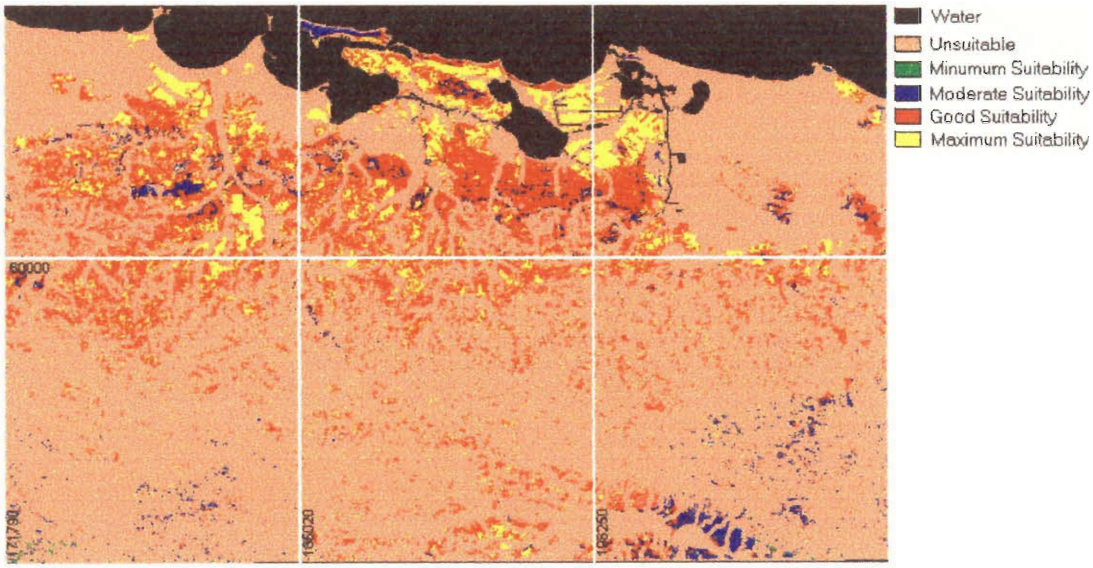


Figure 4.8 Land Use Suitability for Urban Developments

The factors used to determine the suitability of the land in our study area for urban development were slope of the land, geological composition, and the distance from the metropolitan area. According to the Idrisi32 Tutorial, which describes land use suitability evaluation in Idrisi, environmentalists recommend areas within one hundred meters of any body of water not be developed to prevent flooding and erosion. Land located in flood zones was designated as an area for which urban development is not appropriate. Also, land with a slope of fifty percent or greater is unsuitable for urban development. Analysis of the map shows that the suitability decreases as the distance from the center of San Juan increases. The most suitable land, according to the variables considered, is located in the metropolitan area and those regions directly surrounding it. However, these areas are divided by regions that are unsuitable for usage because of slope and waterways that pass through them.

According to this map, there are 194.5 square kilometers of land that meet or exceed the minimum suitability requirements for urban development in our area of study, which is 922 square kilometers. These numbers indicate that only 21 percent of the land in our study area is suitable for urban development.

Figure 4.9 shows the amount of remaining land that is suitable for urban development. Most of the land that we classified as suitable for urban development in Figure 4.8 has already been developed. There are only 41.1 square kilometers of remaining suitable urban land and they are shown in red in Figure 4.9. These areas include all regions that we determined to have at least the minimum suitability for urban development.

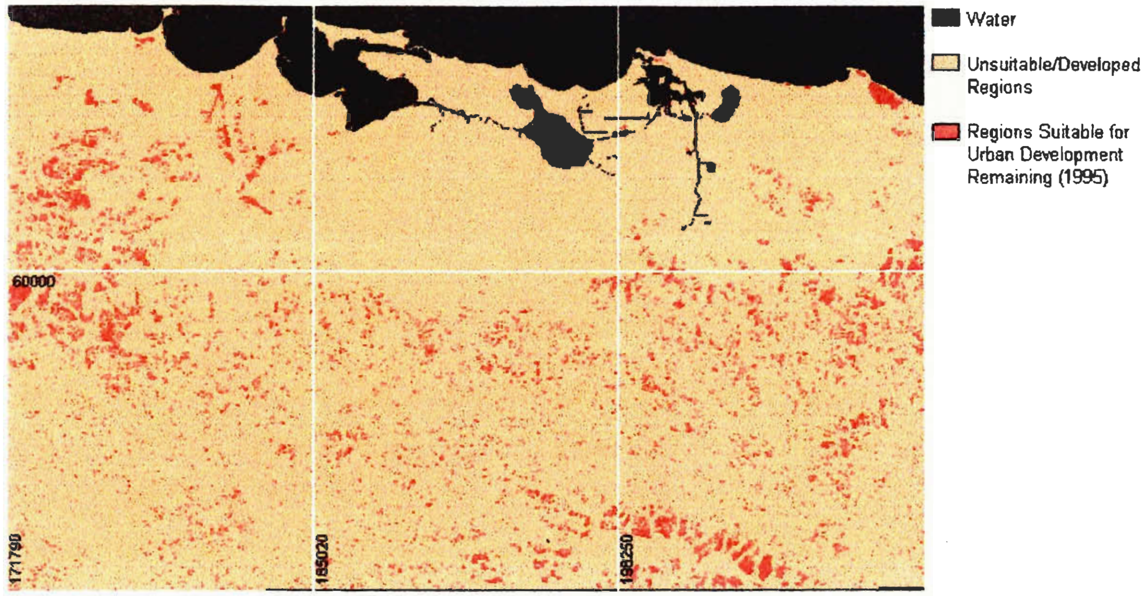


Figure 4.9 Undeveloped Suitable Urban Land

Figure 4.10 shows the land use suitability for agriculture. The total area of all regions that meet or exceed the minimum suitability for agriculture is 36.9 square kilometers. Unfortunately these areas are not contiguous and most of them are very small.

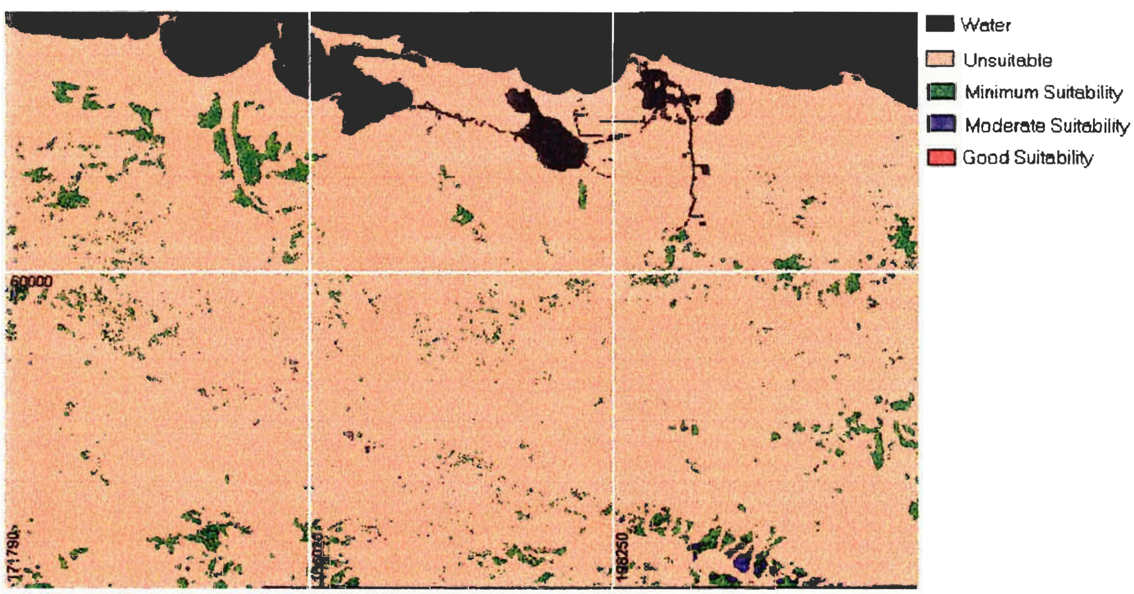


Figure 4.10 Land Use Suitability for Agriculture

The factors that were used to determine how appropriate land would be for agricultural use were soil type, slope of the land, soil permeability, and distance from the metropolitan area. Areas within one hundred meters of rivers and streams, as well as areas in flood zones, were used as constraints for which agriculture is not appropriate. The two largest areas that have the proper slope and soil type to yield good crops lie in the large flood plains in the northern parts of Bayamón and Carolina. These areas are wetlands, which cannot be used for agriculture because they are protected by law. Also, the ground is too saturated with water to be useful for most types of agriculture and the risk of flooding is very high. Much of the other land surrounding San Juan is not suitable for profitable agriculture. However, a high quality soil is not necessary for pastureland, and some of these other areas could be used for this purpose.

Figure 4.11 shows the land in our six quadrants of study that should be used for conservation purposes.

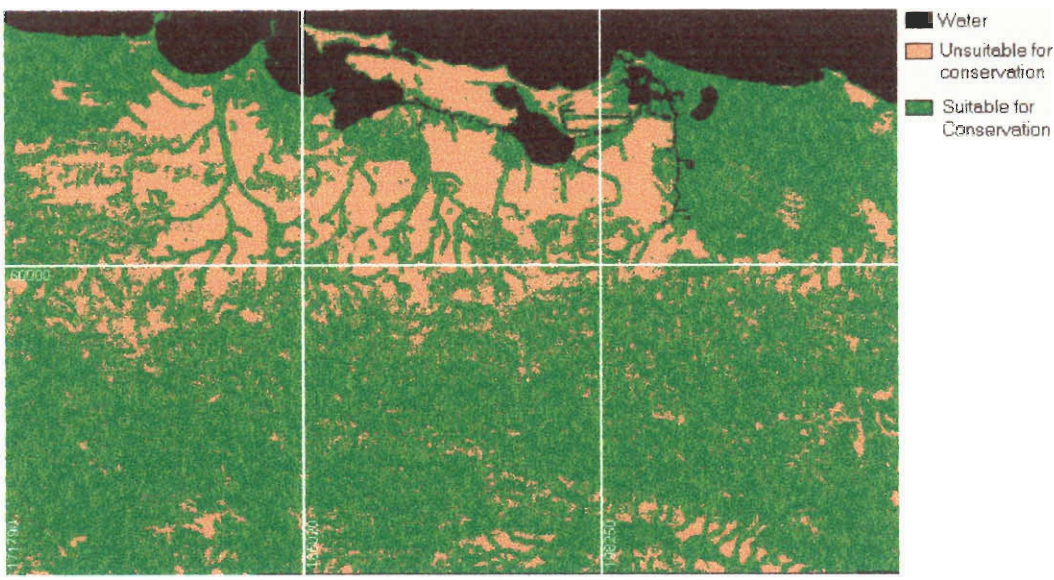


Figure 4.11 Land Use Suitability for Conservation

This consists of areas where the land is neither suitable for urban development nor agriculture. Wetlands and land within one hundred meters of rivers, streams, and bodies of water are also recommended as conservation areas. The largest grouping of land that is unsuitable for urban development and agriculture is located in the southeast corner of Gurabo and the southwest corner of the Naranjito quadrant. The largest areas prone to flooding are located in the northern parts of Carolina and Bayamón. These flood zones should be conserved because they contain wetlands that are protected by law. Furthermore, if these regions are used for agriculture or urban developments, there is the risk that flooding could occur and cause damage to crops or buildings.

4.2 Analysis of Land Misuse and Zoning Issues

Land that is unsuitable for development based upon our criteria has already been developed in many areas of metropolitan San Juan. Figure 4.12 shows land that was developed despite its unsuitability. By overlaying the SPOT image with our urban suitability map we were able to generate this map that shows which areas should not have been developed, but were anyway. The improperly urbanized areas are shown in red.

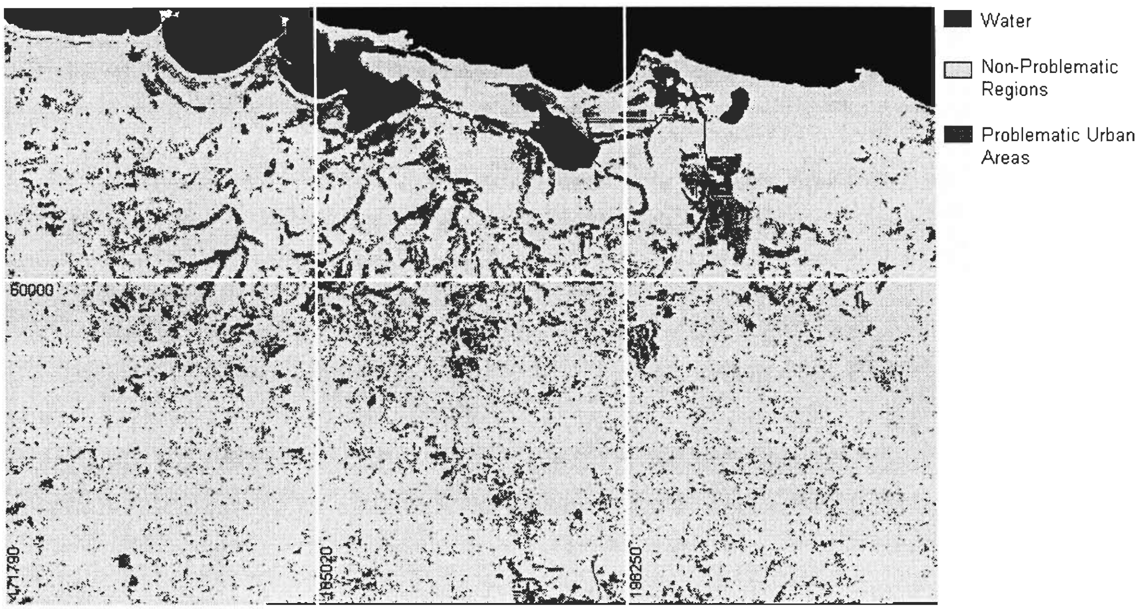


Figure 4.12 Developed Urban Land Despite Unsuitability

We used Idrisi's Image Calculator utility to combine the SPOT image with the flood map to show where development has taken place in regions that are prone to flooding. There are 58.8 square kilometers of land that are developed in flood zones and are, therefore, at risk for flood damage in addition to damage the environment. Figure 4.13 shows the areas that have been developed on flood zones in red.

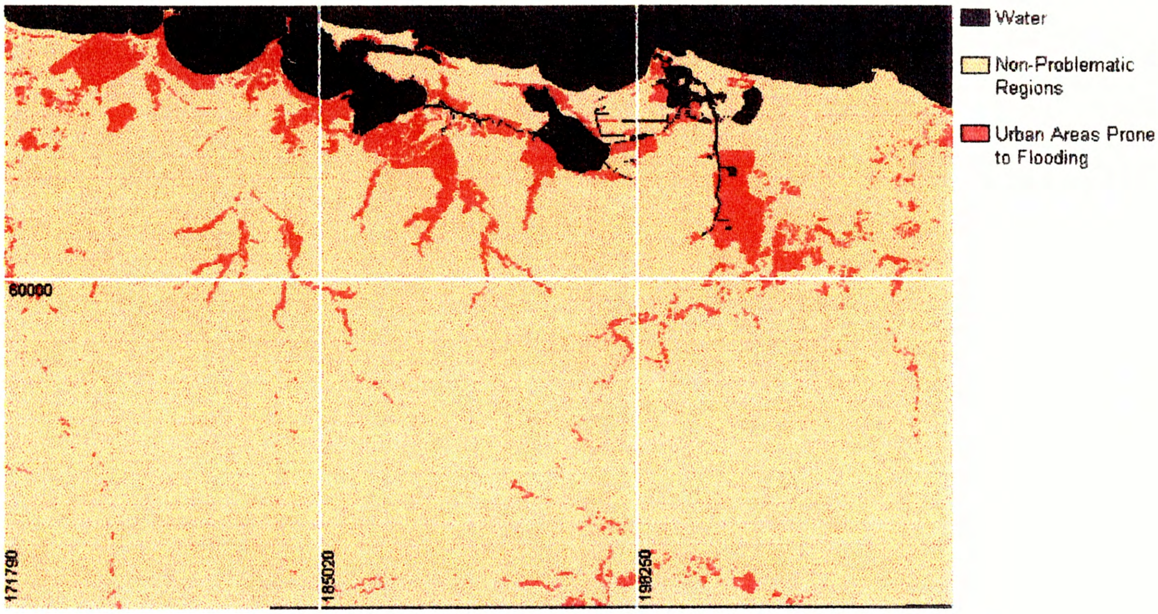


Figure 4.13 Land Developed in Flood Zones

Other problem areas in which development has already occurred are areas that are prone to landslides. One hundred and seventy-five square kilometers of land have been developed that are moderately susceptible to landslides. Another 15 square kilometers of land that is highly susceptible to landslides has been developed, and 1.5 square kilometers of land which have a very high susceptibility.

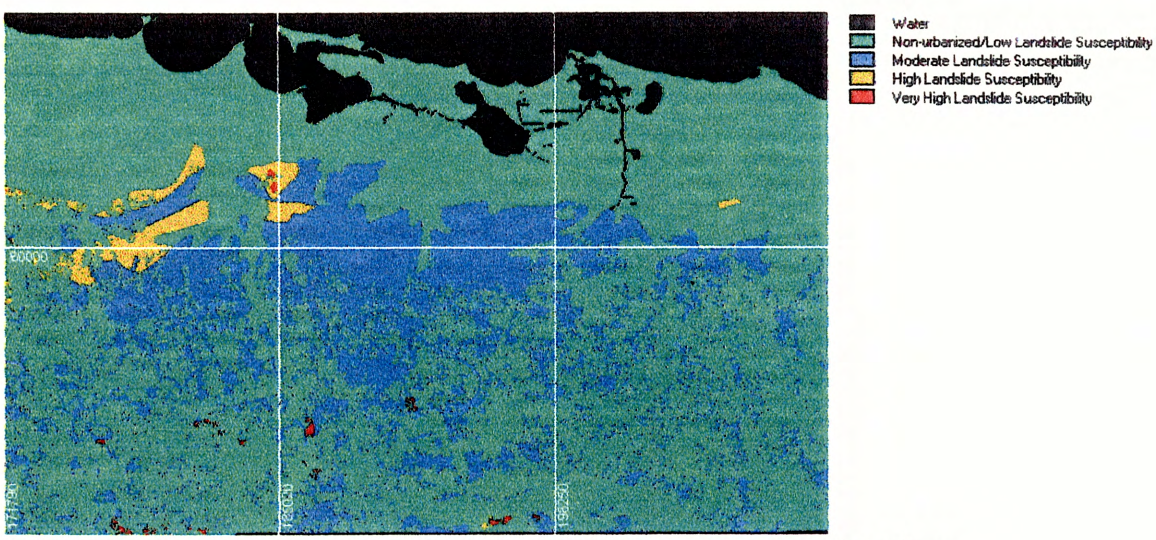


Figure 4.14 Landslide Susceptibility in Developed Regions

Some land in our study area is zoned improperly when compared with our suitability map for development. Figure 4.15 shows land that has been zoned incorrectly based on our study. Commercial areas that we have determined to be zoned incorrectly total 9.11 square kilometers of land and are shown in dark blue on figure 4.15. 219

square kilometers have been improperly zoned as residential and are shown in yellow in figure 4.13. 22.4 square kilometers have been improperly zoned as industrial and are shown as red in figure 4.14.

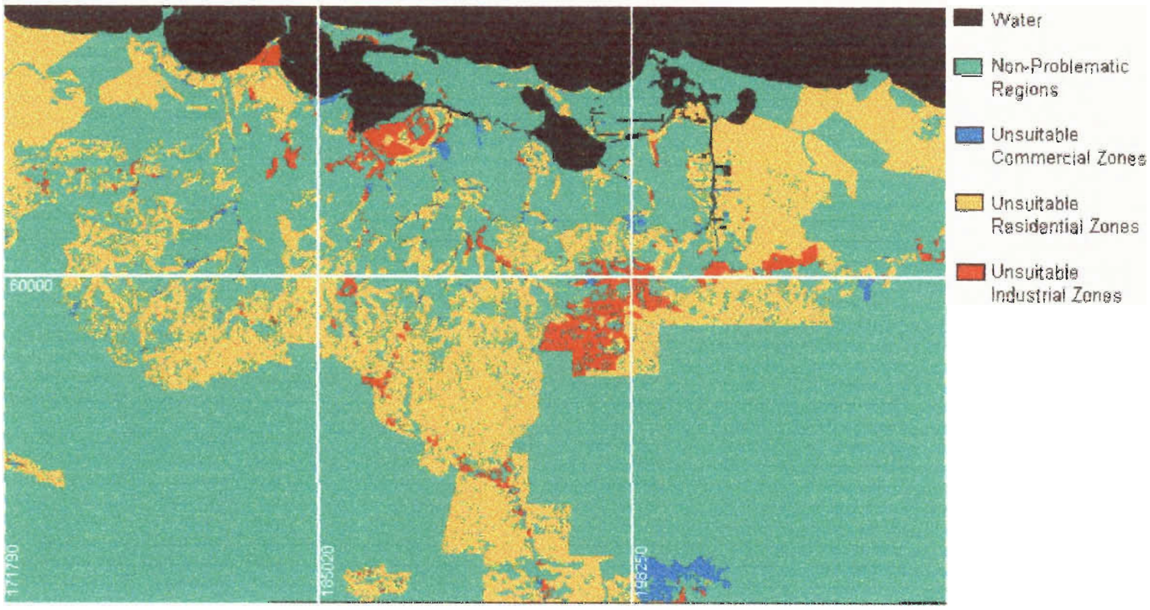


Figure 4.15 Improperly Zoned Land

4.3 Effects of Urban Sprawl

In our literature review, we defined the many problems that can be associated with urban sprawl, but through interviews with different people on the island, we established which effects are specific to the San Juan area. The existence and extension of infrastructure for urban and rural areas has become an important issue. Public utilities such as transportation, water, electricity, and sewage systems are essential to determine the feasibility of development. The potential for growth of an area is also contingent upon locations of, for example, schools, medical facilities, libraries, and stores.

The urban sprawl in San Juan has taken the form of low-density developments as individual houses or smaller housing developments instead of high-rise buildings (Guilbe, interview, April 5, 2001). The San Juan region is prone to many earthquakes and therefore, the number of high-rises constructed are kept to a minimum. Also, there is a high water table in San Juan that causes buildings to be unstable unless properly supported. Construction of high-rises is very expensive because extra measures have to be taken to ensure stability.

According to Guilbe, another reason for the popularity of low-density developments is that developers have taken urbanization models from the United States. These models represent housing developments being built in the suburbs as opposed to high-rise apartments being built in the cities. These plans are not compatible with Puerto

Rico because it is an island and eventually the amount of developable land will run out. Also, the land on the island is more expensive than in the US.

4.3.1 Case Study: Caimito

There are many problems that are caused by urban sprawl, but this report focuses on the transportation problems in the San Juan area and how they are being addressed. In order to give an overview of some of the other problems that are arising, we present a case study of the community of Caimito. The community of Caimito in San Juan is experiencing numerous negative effects from urban sprawl and shows some of the social and economic problems that can arise.

Caimito is located in the southern portion of the San Juan municipality. Once considered a middle-income area, the community of Caimito has experienced rapid growth over recent years. Currently, there are thirty-three housing projects that have been approved by the Planning Board and are under construction in the community. The new developments, called Montehiedra, are being built for people with higher incomes. Some of the major problems caused by the developments are: environmental depletion, increased traffic, and social segregation. The development of the Caimito area has led to concern over the environment and has caused legal action in two separate cases.

Legal action has been taken against AH Development, the company that is in charge of construction of the Montehiedra housing developments. In one area, the developers leveled a hill and deposited the generated fill into a creek, affecting the creek and provoking sedimentation (El Nuevo Día, Nov. 29, 2000). The Department of Natural and Environmental Resources determined that the developers did not have the proper permits to redirect and canalize the creek as they did. Removal of the fill and restoration of the creek was ordered (El Nuevo Día, Nov 15, 2000). Figure 4.16 is a picture of a hill in Caimito that has been leveled.

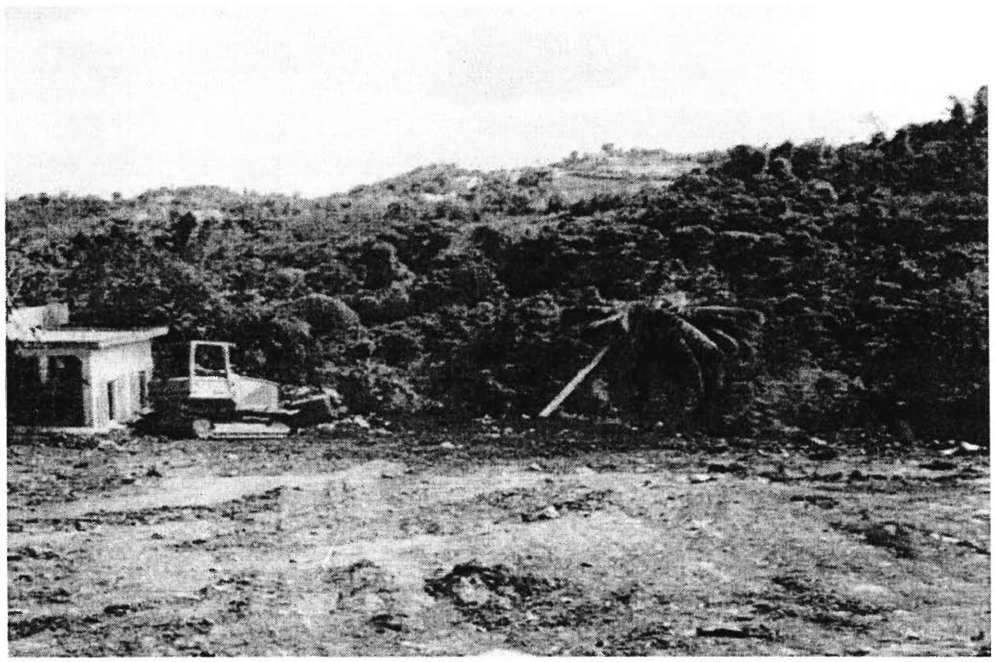


Figure 4.16 Leveled Hill in Caimito
Source: Angela Lozada

The other significant court case affecting the Caimito area includes a moratorium on construction that was proposed by the municipality of San Juan. The administration of the municipality indicated that they planned to raise the amount of rural land from 10 percent to 31 percent in order to extend the amount of currently protected land (El Nuevo Día, Nov. 30, 1999). This moratorium would legally block all construction in the areas of Caimito, Tortugo, Cupey, and Quebrada Arenas in order to conserve the environment in those communities. However, the San Juan Planning Board rejected this proposition saying that their mechanisms of planning were adequate. On Wednesday, December 6, 2000, the court of appeals made a ruling in favor of the municipality of San Juan and revoked the decision by the San Juan Planning Board to reject the moratorium that occurred on November 22, 1999 (El Nuevo Día, Dec. 6, 2000). We feel that this case is an example of a lack of communication between governing bodies because of their drastically different ways of handling urban development in this area.

With the influx of people to Caimito, traffic congestion has become a significant problem. Despite the high population increase, the number of roads in the area has remained at 110 over this time period. In 2000, construction of new roadways began as an attempt to relieve the overcrowding. Public transportation in Caimito is limited to públicos (Lozada, interview, April 23, 2001) and they are not a reliable form of transportation (information regarding públicos is presented in section 4.3.3).

Through an interview with Angela Lozada, a member of the Citizens for Rescuing Caimito group, we have learned that there is only one junior high school, no high schools, and no hospitals in the community. Students attend high schools in other areas such as Río Piedras, and according to Lozada they often have trouble getting there because of the lack of public transportation.

The case study of Caimito is an example of why land use planning is essential to the island. Haphazard development and sprawl have caused many problems for the area and have the potential to cause problems everywhere. It is our opinion that better land use plans that had incorporated infrastructure capabilities, environmental considerations, and the availability of government funding for public services, could have prevented some of the problems facing the community today. The government and the planning boards can use the case study of Caimito as an example for the importance of land planning, and the considerations that should be taken into account for future plans.

By looking at our urban suitability map it is clear that the area of Caimito is not suitable for urban development. Using the Stead Plane Coordinate System North American Datum 1927 (NAD27) we determined the coordinates of Caimito to be 191,117 meters east and 56,199 meters north. Using the other maps that we generated, we were able to see that this area is mainly composed of volcanic rock, which is suitable geology for development. However, most of the area has a slope of greater than 50 percent. A slope of greater than 50 percent is unsuitable for urban development and this is why the developers in the area have been leveling the land. Leveling contributes to flood and landslide risks and is not recommended. When land is leveled, something has to be done with the leveled soil and when the land was deposited over a stream, problems arose, as discussed earlier in this section.

Despite the geographical disadvantages of this location, Caimito is appealing to developers because of its location. Highway PR 52 runs through Caimito and provides access to San Juan for commuters. The land closest to San Juan has already been developed and available land is running out. The land that is suitable for development and closest to the urban center is most appealing for development because it can accommodate residents who want access to the city. Developers and planners are forced to weigh the geographical disadvantages with the social advantages when deciding what land should be developed. Our map considers the proximity to San Juan as an advantage but also makes recommendations based on the geography of the land.

4.3.2 Abandonment of Urban Core

As new buildings and businesses are built further from the urban core, more people move away from the core and the area becomes abandoned. As this movement occurs, the people find less of a need to travel back to that core. Gandía and Irrizarry feel that the overall appearance and original commercial appeal of the centers decrease as a result of the diminishing populations and stated that Carolina is in the process of investing in the revitalization of the core.

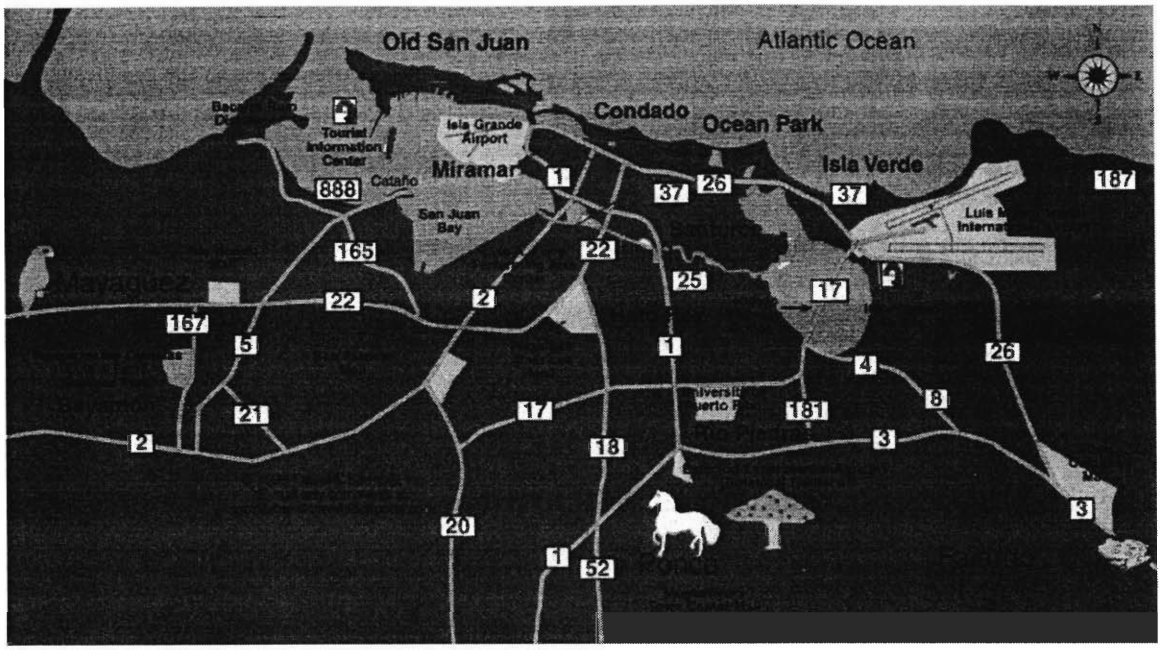
According to the 1990 U.S. Census, small businesses generate 63 percent of all new jobs in Puerto Rico and contribute 48 percent of the Gross National Product (GNP). Governor Sila Calderon feels that small businesses are the key to a thriving urban center. She states in an article in "Caribbean Business" that tax incentives, construction incentives, proper illumination, additional police presence, and cleanliness are all factors that could attract small businesses to urban centers (Gigante, 2000). These incentives have worked in Rio Piedras, and that area is considered a "success story" for the revitalization of urban centers (Gigante, 2000).

4.4 Transportation

San Juan has the worst traffic problems in the United States (Brehm, 1998). The island is the most densely populated U.S. state or territory aside from Washington, D.C. and there is more than one vehicle for every two people who live on it. More than one-third of the island's population lives in the San Juan metropolitan area and more than half of the population works there (Román, 2000). Approximately 135,000 passengers use the public buses in San Juan on a daily basis, not including the number of passengers who use the privately owned Metrobus (Garcia, 2000). Currently, an urban train is being built, which, in its first stage, consists of eleven miles of track that will link key businesses, government, educational, and medical centers in downtown San Juan. Current and future problems of the transportation system and possible solutions are discussed in this section.

4.4.1 Major Roadways

In the metropolitan San Juan region, three major roadways are subject to severe traffic congestion at least twice a day during rush hours. PR-22, which is between the centers of San Juan and Bayamón, averages 200,000 cars per day (Department of Transportation, 2000). Route 52 between San Juan and Caguas experiences similar traffic patterns. Both PR 22 and PR 52 are toll expressways. The center section of San Juan only has four North-South roads that are over one mile in length. As a result, smaller local roadways also become crowded as people try to avoid the busy main roads. The bridges crossing the Bayamón River and Martín Peña Channel also become backed up during commuting hours (Final Environmental Impact Statement: Tren Urbano, 1995). The road with the most significant problem is PR 3, starting in the city of San Juan, extending past Fajardo on the east coast. The major roadways in the San Juan region can be seen in Figure 4.17.



Source: *Qué Pasa!* 2001

Figure 4.17 Map of Major Roadways in San Juan Area

Another road, PR 66, is proposed to alleviate traffic congestion on PR 3 (Guilbe, interview, 2001). It would be located to the south of PR 3 and serve as an alternative for travel between Carolina and the center of San Juan. As an express toll road, PR 66 would interchange with PR 181 to provide access to the Luis Muñoz Marin airport, PR 1, and PR 18. Between PR 1 and PR 18, the proposed PR 66 would absorb the majority of the traffic, relieving congestion (Final Environmental Impact Statement: Tren Urbano, 1995). The current government is preparing an Environmental Impact Statement concerning the road, evaluating the benefits and damages the road would cause the environment.

The construction of PR 66 has been met with great opposition. According to the Associated Press (2000), Gerald Cruz, mayor of the town of Ceiba, believes that this project is too expensive and will benefit only commuters from the areas of Carolina and Canóvanas. The mayor feels that it is more important to solve the traffic problem at a regional level, by upgrading the 65th Infantry Avenue, the main road through Carolina, to an expressway (AP, 2000). Construction of this route was halted in early 2000 because the government discovered that the developers did not have the correct paperwork on environmental impacts associated with the project. The developers were cutting through a channel of the Río Grande. Once the Environmental Impact Statements are finished and reviewed, construction can recommence (Ghigliotty, 2000).

As of 1995, the roadway situation was poor, with thirty-six of the ninety roads exceeding capacity and another nineteen roads at 60 to 80 percent of capacity (Final Environmental Impact Statement: Tren Urbano, 1995). We believe this is inevitable with over 50 percent of the island's population working in the city of San Juan.

Major roadway improvement projects have been underway by upgrading existing roads, enlarging streets, creating new roads, and developing High Occupancy Vehicle

(HOV) lanes within new roads (Final Environmental Impact Statement: Tren Urbano, 1995). Many of these projects are ongoing. The constant improvements of the roadway system have begun to absorb some of the traffic congestion. PR 66 looks promising, providing relief for one of the busiest roads in the San Juan region. The addition of this expressway has the potential to help the flow of commuters between San Juan and Carolina.

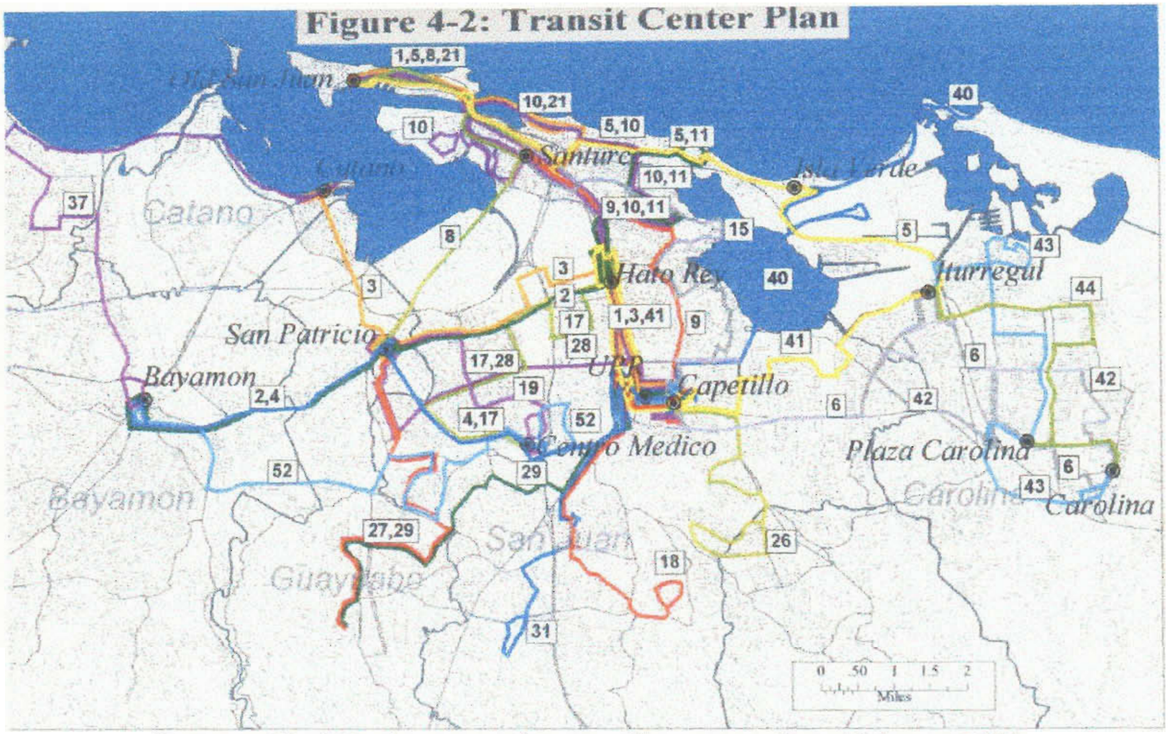
4.4.2 Dependence on Cars

Throughout the entire region there are major traffic problems due to the number of cars on the road. It is estimated that there are over 2,000,000 cars on the island (Guilbe, interview, April 5, 2001). The Department of Transportation and Public Works (2001) estimates that by the year 2003, there will be 210,000 more vehicles on the roads. With the manufacturing industry being the largest sector of the economy in terms of the Gross Domestic Product (GDP) on the island and the existence of industrial parks, more people have been forced to travel further to work (Puerto Rican Chamber of Commerce of South Florida, 2001). According to Dr. Carlos Guilbe, head of the Geography Department at the University of Puerto Rico, the car is looked upon as a social symbol and a reflection of a person's economic status on the island. He believes many citizens of the island are more likely to drive to work and sit in traffic than to take public transportation (Guilbe, interview, April 5, 2001). We feel that another reason for people's continued use of cars is the lack of available public transportation.

Parking rates in the city are very reasonable and do not encourage commuters to leave their cars at home. Some garages offer rates of \$0.50 to \$1 per hour and a flat rate of \$10 per day. Discounts and monthly rates make it affordable for people to use these parking areas. We believe that the low rates encourage commuters to drive their personal vehicles instead of seeking public transportation. As long as the rates remain low, people have little motivation to carpool or use mass transit. In addition, no carpool lanes exist, providing even less incentive to decrease traffic on the roads.

4.4.3 Public Transportation

Created in May of 1959, the Autoridad Metropolitana de Autobuses (AMA) services seven of the thirteen municipalities in the San Juan area including: San Juan, Guaynabo, Bayamón, Toa Baja, Trujillo Alto, Cataño, and Carolina. The mission of the AMA is to provide, develop, administer, and maintain a collective transportation system at a low cost to the metropolitan area (AMA website, 2000). The AMA aims to provide transportation for those people who have no other means of travel and reduce the amount of private automobile use. Figure 4.18 shows the bus routes in the San Juan metropolitan area.



Source: Final Environmental Impact Statement: Tren Urbano, 1995
Figure 4.18 Bus Route of San Juan Metropolitan Area

Throughout the seven municipalities, the AMA provides transportation by means of 152 buses on thirty-four different routes, with five express and twenty-nine regular routes. In the early 1980's, three hundred buses were running. The decrease in buses has contributed to the delays in routes. The cost of a ride on express buses is fifty cents. The regular route is twenty-five cents, but a discount fare of ten cents is given to the elderly and handicapped. No passes are available for unlimited weekly or monthly use. Most buses run between 5:30 am and 10:00 pm, Monday through Sunday at various intervals (AMA website, 2000). The low prices of service, we feel, are appropriate. However, we believe that the lack of unlimited use passes discourages some riders from using the buses on a regular basis.

Although a promising service, problems have arisen with the AMA services. Due to the high degree of congestion on the roads, many of the buses run behind schedule, especially during rush hours. For example, the B21 bus, which services Old San Juan, Condado, Plaza Las Americas Mall, and Parada 18, continually runs behind schedule. During the day, B21 is scheduled to run every twenty minutes. Instead, people often wait thirty to forty-five minutes for the bus to arrive. Though designed to relieve dependence on private vehicles, the buses fall behind schedule for various reasons, including the large number of cars on the road. Out of the thirty-four routes, sixteen take over 2.5 hours to complete a run (AMA website, 2000). Many of the streets the buses travel on have limited entry and exit points, also adding to the route time.

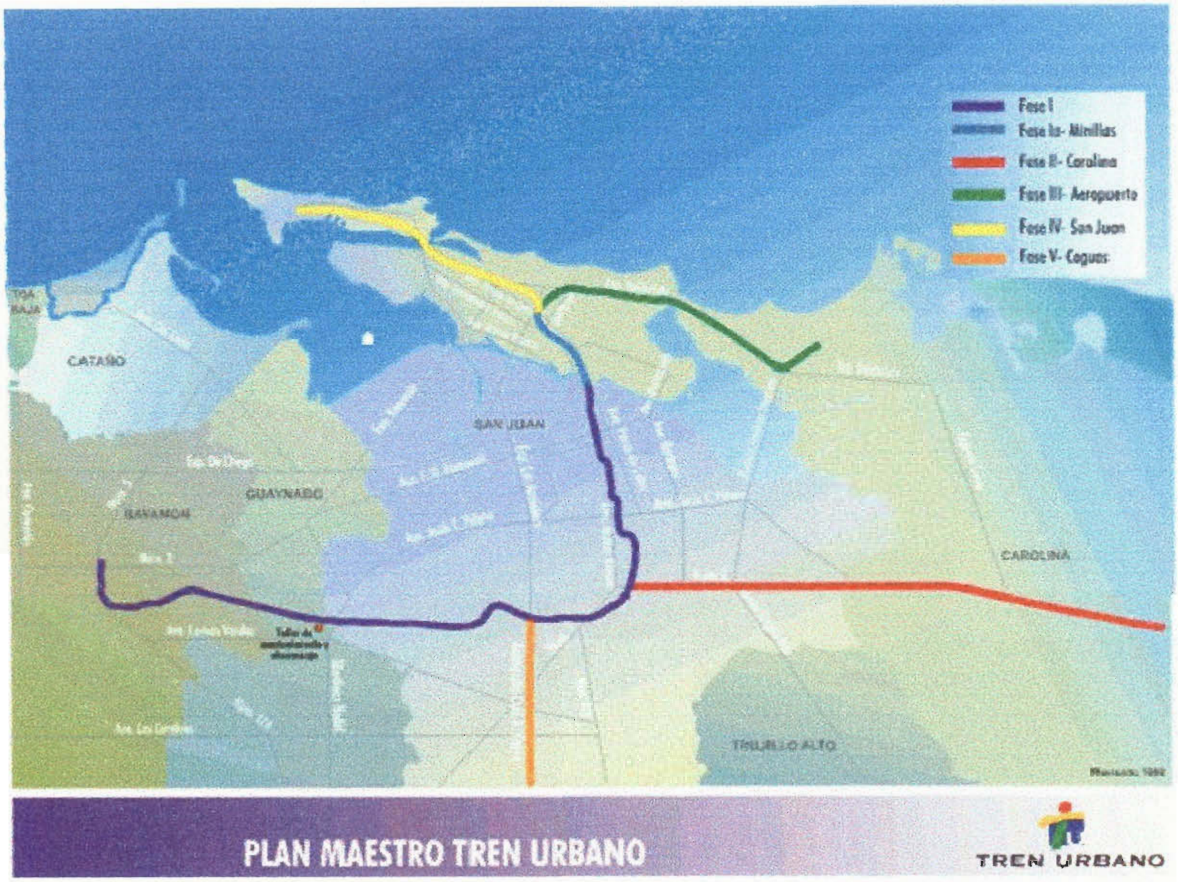
According to US census data from 1990, 60.6 percent of the work force used a car, truck, or van to get to work, 15.6 percent were in a carpool, and only 14.6 percent used public transportation. The majority of the people who use public transportation ride the buses because they have no other means of transportation. People who cannot afford personal vehicles accounted for 64.5 percent of mass transit trips in 1990 (Final Environmental Impact Statement: Tren Urbano, 1995). We believe that this is a good reason to increase public transportation and to keep fares low. The 2000 Census transportation data for Puerto Rico was not yet available for this report.

From 1964 to 1990, the percentage of commuters using buses dropped from 27 percent to 10 percent. We believe that this drop is a result of the delays from increased personal vehicle use and the inefficient layout of the many one-way streets. Also, we feel that there are not enough "bus only" lanes in the downtown region. Currently, 14.6 miles of bus lanes wind around the city, leaving the majority of routes to compete with commuter traffic (Final Environmental Impact Statement: Tren Urbano, 1995). We think that the increased traffic and lack of "bus only" lanes has hurt the bus service.

Privately owned vans known as públicos provide another transportation alternative. The vans generally seat ten to fifteen people and run 120 routes in the San Juan Metropolitan area. Problems arise from several sources. The frequency of público service is dependent upon the demand. The drivers talk among themselves to determine work schedules and routes. No fixed schedule exists and the públicos can run from as often as thirty times per hour to less than once per hour. Carolina and Río Piedras are major centers for público transit (Final Environmental Impact Statement: Tren Urbano, 1995). The average price of a público can range from \$0.50 to \$1 within the San Juan metropolitan area (Weissmann, 2000). We feel that although this system offers another choice for transit, it is unreliable and cannot be used as a sole source of transportation. The rates are inexpensive, but the lack of consistency in route times is a drawback. Also, públicos cannot travel in the bus only lanes, which severely impacts the running time of routes. In our opinion, públicos best serve as transportation for people on more common routes, or those not affected by time constraints.

4.4.4 Tren Urbano (Urban Train)

One possible solution for transportation problems lies in the construction of a rail transit system in San Juan. Construction began in 1998 and the metropolitan San Juan phase, the first of seven phases, is predicted to be finished in May of 2002. Projected total construction cost of Phase one of the train is \$1.676 billion. The US Federal Transit Authority (FTA) and US Federal Highway Administration (FHWA) are contributing \$708.3 million to the project, and \$967.7 million comes from local funds of the Puerto Rican Highway and Transportation Authority (Stefani, 2000). Future phases will link the train west through Santurce and into Old San Juan on one end and to the Luis Muñoz Marin International Airport and Carolina in the east. Figure 4.19 shows a 1998 version of the proposed phases of the Urban Train (Department of Transportation, 2000). It does not include the Mirimar phase, which will parallel Phase 4.



Source: Department of Transportation and Public Works, http://www.dtop.gov.pr
Figure 4.19 Master Plan of Urban Train Phases, 1998

At present, the rail transit system is being built in the metropolitan area of the San Juan municipality and will cover sixteen stations over 10.7 miles of track. The Department of Transportation in San Juan is projecting that more than 115,000 passengers will travel the rail each day. The elevated tracks, which start in Bayamón, continue through Guaynabo, go into a tunnel in Río Piedras, and return to elevated tracks in Hato Rey (Stefani, 2000). End to end, a trip on the Urban Train would cost $1 and take thirty minutes. During peak hours, the train would run every four minutes, after which it would depart every ten to twelve minutes.

Román (2000) quotes the former Transportation and Public Works Secretary Sergio Gonzalez as saying that the train will be used to combat the imbalance between the city and the suburbs that is caused by urban sprawl. The train was proposed after officials from the PRHTA determined that not enough highways could feasibly be built to alleviate the congestion on the roadways. Park and ride facilities will be available at the Bayamón station, in addition to other stations (Cho, 2000). These facilities allow easy access to the Urban Train, and developers hope that the facilities will encourage people to ride the rail in lieu of driving to work. People will be able to drive to, and leave their cars at stations such as Bayamón, outside the busy city roads.

We believe the train has the potential for easing traffic congestion within the city. However, out of the sixteen stations shown on the proposed map of the Urban Train, only six provide parking spaces totaling 2,004 spots (Department of Transportation, 2000). If the projected figure of 115,000 riders per day is correct, we believe that there will be an extreme shortage of parking for commuters. Furthermore, no parking facilities are available at the ten stations between Centro Médico and Minillas stations. Commuters entering metropolitan San Juan from areas in the east such as Carolina, do not have parking options at urban train stations. They have to seek other means of parking at nearby lots or garages. The lack of available parking from the Centro Médico to Santurce, we feel, will discourage commuters from the east to utilize the train in its first phase. If ample parking is provided at the Carolina stations, we believe there will be a significant increase in riders.

On a positive note, nearly all of the stations have access to the AMA bus services and taxis. One-third of the stations provide connections with público transport. The train will be able to provide connections for riders to work, shopping centers, health services, entertainment and schools (Department of Transportation, 2000). We think that the train will provide riders an additional, more efficient travel option with fewer delays and direct service routes.

There are conflicting views regarding the train according to Planning Director Jeffrey Squires of General Management and Architectural and Engineering Consultant Services, people are in favor of the train (Cho, 2000). As indicated by Manuel Herrero, lawyer and President of the Municipal Assembly of San Juan in 1995, the train will provide an alternative that is both practical and logical, connecting citizens from towns across the metropolitan area. He believes that the train will improve the quality of life for citizens within the metro area by reducing gas emissions and reducing the number of cars on the road. He also feels that the impact to ecosystems, historic areas, and noise levels along the line will be minimal to non-existent (Final Environmental Impact Statement: Tren Urbano, 1995).

However, some feel the implementation of the Urban Train will create more problems than it will solve. A letter drafted to developers of the urban train by ten organizations including community and environmental groups expressed concern regarding development. The letter explains the potential adverse effects this group anticipates, such as elevated noise and contamination levels, as well as increased crime and traffic within the residential area of Torrimar. The members of these organizations feel that the Torrimar station will create traffic problems and alter the residential character of the Torrimar community, which has been intact for over thirty-five years. They feel that the industrial character that the stations will introduce to the area will not integrate well with the residential community (Final Environmental Impact Statement: Tren Urbano, 1995).

We believe that traffic to the area should not significantly increase for several reasons. First, as stated in the letter to urban train planning officials, residents of the upper-class neighborhood of Torrimar will most likely not take the train to work. Their professional, economic, and social status encourage them to drive their cars rather than use mass transit. Second, the number of available parking spaces adds up to fifty. The parking facilities provide a limited number of spaces so that the number of commuters who would be able to leave their cars there is almost negligible.

In terms of noise and contamination levels, the impact of the urban train is mostly positive. The train is powered by electricity, emitting no pollutants into the air. Where necessary, noise barriers will be erected to minimize noise levels to surrounding residential areas, and resilient wheels on the trains will reduce noise. We believe that the planners of the urban train have taken into account many of the potential problems associated with development of this transit system. We feel that the train is very environmentally friendly; the technology of electricity-based vehicles will have a significant impact on better air quality. As with any form of mass transit, some noise pollution is expected (Final Environmental Impact Statement: Tren Urbano, 1995). It is our opinion that urban train developers have created solutions in the best interest of the affected communities.

The third phase of the Urban Train will be built in Carolina, as previously shown in Figure 4.17. The proposed track will come in through 65th Infantry Avenue and will coincide with the current bus and público routes, supplementing the mass transit in the Carolina area. The combination of the train and bus services, in addition to the públicos, provide the public the ability to travel to the airport, government buildings, stores, schools, and hospitals. Development within 500-meters of the rail is under watch so that new construction does not interfere with present or future phases (Department of Transportation, 2000). The Carolina planning board has developed a transit plan that includes the proposed extensions of the train into the center of Carolina as well as the Luiz Muñoz International Airport (Gandía, interview, April 26, 2001). We recommend that all of the municipalities through which the urban train passes consider the train in their transit plans. If development of urban or commercial areas occurs in places not accessed by the urban train or other forms of public transportation, commuters and consumers could have difficulties traveling to and from the new developments.

By comparing the urban train master plan with the SPOT image of our study area, we have determined the proposed track of the urban train lies almost completely within highly populated and urbanized areas, connecting major commercial and business centers from Bayamón to downtown Carolina, the Luis Muñoz Marín International Airport through Old San Juan, and downtown southward towards Caguas along PR 52. With all phases completed, riders from surrounding areas will be able to board the train in Carolina to the east, Bayamón to the west, and the middle to southern portion of San Juan to commute into the city. The train will not extend to the far south of the San Juan municipality because the land is being zoned as conservation area. According to the 2000 US Census, the largest populations within our study area are found in San Juan, Bayamón, Carolina, and Guaynabo, with populations ranging from 434,374 in San Juan to 100,053 in Guayanabo. The train directly services these municipalities and riders from neighboring municipalities can drive to stations along the line and commute into the city.

Overall, we believe that the urban train will be an excellent transportation option. The connections of the train with buses, públicos, and taxis provide access to key areas of the city. We feel that the train will relieve a significant amount of traffic congestion from personal vehicle use, especially with extra park and ride facilities implemented at all possible stations.

4.5 Government Role in Land Use

In 1990, the San Juan government switched from being centralized to autonomous. The municipalities within the San Juan metropolitan area became independent instead of being ruled by the one government located in San Juan. This change allowed the planning and regulation of land to be controlled by the individual municipalities in the metropolitan area. Previously, the land use planning for the metropolitan area was centralized at the Planning Board in San Juan. This switch to autonomous governments allowed each municipality to focus its attention on addressing problems specific to its area. When the new governments were established, the new officials had to begin planning from the first stages. As a result, detailed zoning maps are still in the process of being created in some municipalities.

As part of the planning process, the opinions of the citizens can be heard through a community board. There is one planning board in each municipality, and a separate community board is created for each planning board to represent every twenty five thousand citizens. The planning board evaluates cases for permits and is comprised of a member of the public works department, environmental personnel, and two representatives from each community. This board creates a forum in which the community can become directly involved with the planning process and differing opinions can be heard. The voice of the community helps the planning board to incorporate suggestions into the cases and, thereby, reduce conflict within the municipalities. Once a year, the local municipality planning boards hold a workshop for both the community board and the members of the community. During the workshop, the community members and members of the planning board discuss problematic permits and proposed developments (Gandía & Irrizarry, Interview, March 27, 2001). However, despite the opinions of the community, the planning boards have the final authority to make rulings.

Through interviews with Luis Estrada, Carlose Ivan Mejas and Maricella Rodriguez of the land planning office in the city of San Juan, we learned the office has over ninety-three different land use plans that they are proposing to the Planning Board. The land planning office advises the San Juan Planning Board. The office has taken into account the need for better transportation systems, a need to conserve environmental reserves, and suggests ways to reinvigorate the central areas. However, according to Luis Estrada of the San Juan land planning office, these plans cannot be put into effect without the support of the Planning Board.

In Carolina, some of the larger industrial areas and many low-density housing projects have been constructed on flood zones, with only a dike as a line of defense. According to Gandía, there have been no recent problems and the dikes have held, but the potential for damage remains. There are proposals to build in the south of the municipality, where the landscape is mainly hilly.

According to representatives from the Carolina planning board and the San Juan land planning office, a drawback to the autonomous governments is problems with communication between the municipalities with regard to land use. For example, San Juan has zoned the southern most part of their municipality as conservation land, but any of the surrounding municipalities are not required to zone adjacent areas in a similar fashion. Areas for urban expansion in one municipality can border a conservation area in another. Urban growth next to a conservation area can negate the intended conservation effects. Continuity of similar areas can aid in the preservation of these regions. Currently there are no efforts for collaboration that we have become aware of. We feel that our land use suitability map can be used by all of the municipalities as a frame of reference to promote continuity.

Chapter 5 Conclusions and Recommendations

This chapter presents our conclusions and recommendations. These include recommendations regarding what land in the San Juan metropolitan area we have concluded should be used for agriculture, urban, and conservation purposes. We included recommendations suggesting how our maps can help the municipal planning boards. Also, we present conclusions on some of the traffic issues facing San Juan and recommend locations where public transportation would be beneficial to help relieve the effects of urban sprawl.

The recommendations and conclusions that we present are divided into four categories. First we make recommendations for urban land use based on the analysis of our urban land use suitability map. We also make recommendations for improving some aspects of the urban planning process. Then, we present our recommendations and conclusions regarding the use of the land for agriculture. Next, we present our recommendations aimed at controlling the negative effects of urban sprawl on the environment. Finally, we make the recommendations on how to improve transportation in the city of San Juan, and how to avoid transportation problems in the future.

5.1 Urban Planning

We recommend that our land use suitability maps be used as a guideline for all of the municipal planning boards within its boundaries. Our land use suitability maps are based on geographical considerations, as well as environmental and population concerns.

We also recommend that the municipalities generate a plan for communication between their land use planning offices. The planning boards of each municipality have been developing separate land usage plans and there are discrepancies at the borders. Problems with continuity on the borders of municipalities could be eliminated if the planning boards use our maps as a guide.

We recommend urban developments be considered in the San Juan and Bayamón quadrants, where the majority of suitable land is found, as indicated on the map in Figure 4.8. In addition, land in the western and southern parts of Carolina, and the northern regions of the other three quadrants are suitable for urban development. This suitability is mainly due to the proximity to already developed regions, as well as the moderate slope of the land in these areas. Many of these regions have already been developed, and there is little remaining area that is suitable (as shown in figure 4.9).

In order to solve the problem of the abandonment of urban centers, we recommend that the government instate a program to encourage businesses to return to the area. Governor Calderon suggested that tax incentives, construction incentives, proper illumination, additional police presence, and cleanliness would all add to the revitalization of urban centers. We think that her suggestions should be acted upon. We also feel that the existence of the urban train in these centers will make the area more accessible and more appealing for consumers and businesspeople.

We recommend that municipalities build and revitalize urban areas around existing infrastructure. With the suitability maps showing the limited areas for urban expansion, revitalization of existing urban areas is a good alternative to high-risk developments on unsuitable land. The proper land and infrastructure already exists in urban areas and is suitable for development and revitalization.

5.2 Agriculture

We recommend using most of the non-developed land in the San Juan Metropolitan Area for pasture and conservation. We have concluded from the suitability map that we generated (figure 4.10), that the number of sites in our study area that are suitable for agricultural development is very limited. Virtually all of the land in the southern half of our study area has a slope that is too severe for agricultural uses. Much of the other land is either already developed, or too close in proximity to the metropolitan area. There is a large amount of urban development already in our study area and there is little room for agriculture. The permeability of the soil and type of soil also limits the land from agricultural use. In addition, we recommend that the Geography Department at the University of Puerto Rico explore regions further from the San Juan metropolitan area for their agricultural capacity.

5.3 Environmental Conservation

We recommend that as much land as possible be conserved and used for development only when absolutely necessary. We also recommend a buffer zone of at least one hundred meters on both sides of rivers and streams in order to protect water supplies from pollution and prevent flooding. Regions in which the slope is too severe or the soil is not suitable for urban development or agriculture are also best used for conservation. We recommend that the natural slope of the land not be modified as it was in Caimito because this increases erosion and the chance for landslides.

We strongly recommend that the flood zones in the San Juan area be left as conservation land. Many of these areas are wetlands, which are protected by law. We have concluded that all of the flood zones are high-risk areas if used for development or agriculture. The buffer zones around bodies of water should be even greater for industrial complexes because of the increased chance of pollution. These buffer zones provide protection not only against pollution but also help to reduce the amount of rainfall runoff. By allowing rainfall to absorb into the soil the buffer zone helps to prevent flooding.

For future analysis, we recommend that remote-sensing images of land cover be overlaid with our conservation map. The purpose of this combination would be to evaluate the conservation potential for forested regions. Although a region may be suitable for urban or agricultural development, it may be in the best interest of the environment to conserve additional forest areas.

5.4 Transportation

We recommend that the construction of PR-66 commence as soon as possible. The current roadways are not able to properly support the volume of traffic. Rush hours create extreme delays in commuting time, especially on Routes 3, 52, and 22. We feel that the proposed Route 66 will help to alleviate congestion on Route 3, the roadway with the worst delays. Expansion of roads and the addition of the urban train will help reduce the strain on existing roads.

We recommend that the Department of Transportation look into administering congestion tolls on all main roads leading into the downtown business district. As discussed in section 4.4.1, the increase in tolls in Singapore has kept traffic levels at a constant low. The implementation of the congestion tolls, we believe, will encourage people to carpool or use public transportation and thereby reduce the overall congestion of the roadways into and out of San Juan.

In order to reduce traffic on the roadways in and out of San Juan, we recommend raising parking prices within the downtown area. If the parking prices in the city were higher, people would be discouraged from driving because of the high cost. Keeping the prices of public transportation low could encourage people to use mass transit as opposed to paying the high prices associated with driving, including car repairs, parking, gas, and tolls. We also recommend the addition of carpool lanes on the major roadways leading into the San Juan metropolitan area to encourage people to use fewer cars.

We recommend increasing the frequency of buses on the busiest routes. Some of the factors delaying traffic are congestion due to the number of cars on the roadways, and limited entry and exit points on roads within the downtown area of San Juan. We recommend that services be extended in Carolina and Bayamón as these urban, commercial, and residential areas grow. As of now, limited service exists in both municipalities, as seen previously in Figure 4.17. Prices of the AMA and Metrobuses, as well as the públicos, are reasonable but incentives and promotion offers could increase the number of riders. We think that discounted weekly and monthly passes be made available for riders.

For the urban train, we recommend that discounted weekly and monthly passes be offered to provide an incentive to attract commuters. Because many people are skeptical about the efficiency of the urban train, promotional fares could increase the initial volume of riders.

We recommend that sufficient parking be made available at all train stations. The construction of the urban train is projected to absorb a significant amount of personal vehicle use. Commuters can drive their cars to the park and ride facilities located at six of the sixteen stations of Phase one. We believe that because of the lack of available parking facilities along the route, people will be discouraged from using the train. Future phases of the train will help to bring commuters from surrounding suburbs to the city, but sufficient parking at stations will have to be made available.

We recommend that the municipalities surrounding San Juan study the benefits of the urban train. The train will eventually expand into the surrounding municipalities of Carolina and Bayamón. We recommend that all municipalities that will be in the path of the train develop a transit plan like that of Carolina, which adjusts bus routes to work closely with the train. Planning developments around the areas that will be accessed by the train, as well as creating bus routes so that they can bring passengers to the train stations, would increase the efficiency of the train. The train should access major buildings and the areas most frequently used by the public of the municipalities. We recommend that the municipalities zone land around the proposed train routes for urban and commercial growth, allowing many people access to these resources.

Appendix A: The Sea Grant Program and UPR[1]

The National Sea Grant Program was started in 1966 with the passing of the National Sea Grant College and Program Act. This Act was established to initiate support of education and research of marine resources. The Sea Grant Program is a partnership between the National Oceanographic and Atmospheric Administration (NOAA), universities, and organizations throughout the United States.

The program is a network that uses the skills and resources of many universities around the country and has made the U.S. the leader in marine research and the development of coastal resources. Sea Grant programs are located in over thirty coastal and great lake states, as well as in Hawaii and Puerto Rico. In addition, more than two hundred universities across the United States and Caribbean are involved with the Sea Grant Program. The program's main objective is to promote the responsible use of coastal and marine resources through education and research.

Education is an important aspect of the program and is available for all students, as well as for industry and the general public. Funding is provided for education at all levels, including fellowships for college students in Washington D.C. and with private industry. The program has supported over 12,000 graduate students for their work in marine environmental research.

Sea Grant communicates its research findings and concerns to the marine industry, the government, and the general public at the local, regional, and national levels. This communication aids in the decisions of coastal businesses, marine industries, and the public with regard to the marine environment. The National Sea Grant Program is a federally funded program that has state partners that also make a large contribution to its efforts. In addition, NOAA and other small agencies provide some funding. NOAA conducts research on the global oceans, atmosphere, outer space and sun. This knowledge is then applied to science and service. NOAA also warns of dangerous weather, charts the seas and skies, guides our use and protection of ocean and coastal resources, and conducts research to improve the public's understanding of the environment. It uses strategic research to benefit society such as the potential for use of marine organisms for pharmaceuticals and development of multi-million dollar fisheries. Also, the Sea Grant Program has already established state-federal partnerships for promoting coastal economic growth and improving the quality of coastal environments.

The University of Puerto Rico (UPR) began research in 1980 in cooperation with the National Sea Grant College Program. The purpose of this joint endeavor was to conserve marine and costal resources in addition to promoting awareness of environmentally friendly development. Ten years of research and contribution to the commonwealth resulted in the Sea Grant organization designating the Marine Sciences Department of UPR, Mayagüez as a Sea Grant College Program site in 1990. The UPR Sea Grant College Program allows for improved economic and educational opportunities for Puerto Rico, the U.S. Virgin Islands, Latin America, and the Caribbean. The program works on regional, national, and international levels, creating both bilingual and bicultural links to the surrounding communities.

---

[1] Most of the information contained in this appendix was found at www.nsgo.seagrant.org, the website for the National Sea Grant Program, and from www.rmocfis.upr.clu.edu/~seagrant, the website for the National Sea Grant Program at the University of Puerto Rico.

The University of Puerto Rico Sea Grant College Program has contributed in many ways to the environment, economy, and to public health and safety. Striving to strengthen its leadership role, the UPR Sea Grant College Program focuses on marine advisory services, education, and research. The Marine Outreach Program (MOP) at UPR Mayagüez has increased consumer education on all levels through free books, television series, videos, and posters. In addition, MOP organizes beach cleanups, educational seminars for students from kindergarten through high school, as well as safety technique seminars for fishermen. The presence of the Puerto Rico Sea Grant has become an integral part of the marine sciences and coastal environmental protection in the Caribbean.

The Geography Department of UPR is located at its Río Piedras campus within the Social Sciences division. Approximately one hundred undergraduate students are part of the department. Many of the students continue on to graduate school for Master's degrees in planning, environmental management, laws, and other areas. Graduates work as close to home as the municipal planning boards, but as far away as the national level of the United States Geological Survey. The faculty is comprised of six full time members, all with PhDs, as well as other part time and adjunct professors.

Appendix B: Anderson Classification System

Level I		Level II	
1	Urban or built-up land	11	Residential
		12	Commercial and services
		13	Industrial
		14	Transportation, communications, and utilities
		15	Industrial and commercial complexes
		16	Mixed urban or built-up land
		17	Other urban or built-up land
2	Agricultural land	21	Cropland and pasture
		22	Orchards, groves, vineyards, nurseries, and ornamental horticultral areas
		23	Confined feeding operations
		24	Other agricultural land
3	Rangeland	31	Herbaceous rangeland
		32	Shrub and brush rangeland
		33	Mixed rangeland
4	Forest land	41	Deciduous forest land
		42	Evergreen forest land
		43	Mixed forest land
5	Water	51	Streams and canals
		52	Lakes
		53	Reservoirs
		54	Bays and estuaries
6	Wetland	61	Forested wetland
		62	Nonforested wetland
7	Barren land	71	Dry salt flats
		72	Beaches
		73	Sandy areas other than beaches
		74	Bare, exposed rock
		75	Strip mines, quarries, and gravel pits
		76	Transitional areas
		77	Mixed barren land

Appendix C: Personal Interview List

Whitacker, Erin. Personal Interview. February 15, 2001

Gandía, Augusto. Personal Interviews. March 27, 2001; April 26, 2001

Irrizarry, Geraldo. Personal Interview. March 27, 2001

Estrada, Luis. Personal Interview. April 2, 2001

Mejias, Carlos Ivan. Personal Interview. April 2, 2001

Rodriguez, Maricella. Personal Interview. April 2, 2001

Guilbe, Carlos. Personal Interview. April 5, 2001

Rodriguez, Ernesto. Personal Interview. April 5, 2001

Lozada, Angela. Personal Interview. April 23, 2001

References

Anderson, James R., Ernest E. Hardy, John T. Roach and Richard E. Witmer. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. Washington: U.S. Geological Survey, 1976.

Associated Press (2000). "Mayor of Ceiba Is Against Route 66." Retrieved on April 24, 2001, from the World Wide Web: http://www.estado51.com/2000/Agosto-2000/00-08-29f.htm

Aufflick, Mark. (1995) The Problems of Urban Sprawl in Victoria, and How to Solve Them. Retrieved March 28, 2001 from the World Wide Web: www.users.webtime.com.au/aufflick/publish/UrbanSprawl.html

Autoridad Metropolitana De Autobuses, AMA (2001). Retrieved on April 18, 2001, from the Word Wide Web: http://www.dtop.gov.pr/AMA/AMAHOMPG.HTM

Bennett, S.P., Carter, M.M. Carter, & Elsner, J.B. (2000). A quantitative precipitation forecast experiment for Puerto Rico. Journal of Hydrology, 239, 162-178.

Bernhardsen, Tor. (1992). Geographical Information Systems. Norway: Viak IT.

Boccheciamp, Rafael A. (1978). Soil Survey of San Juan Area of Puerto Rico. United States Department of Agriculture.

Braddock, Theda, & Huppman, L. Reed. (1995). Wetlands An Introduction to Ecology, the Law and Permitting. Rockville: Government Institutes, Inc.

Brandl, Jennifer, & Kathryn McWilliams. (2000). Assessing the Effects of Urban Sprawl in the San Juan Area (1977-1995). WPI IQP.

Bregman, J.I., Kelley, Craig, & James R. Melchor. (1996). Environmental Compliance Handbook. Boca Raton: CRC Lewis Publishers.

Brehm, Denise (1998). Tren Urbano breaks new ground. Cambridge: MIT News Office. Retrieved on April 23, 2001, from the World Wide Web: http://web.mit.edu/newsoffice/tt/1998/feb04/train.html

Casiano, Kimberly A. (2001). San Juan Metro Area Map. *Qué Pasa!* San Juan: Casiano Communications, Inc.

Cho, Aileen (2000, January 17). Twisting and Turning Through San Juan. Retrieved April 16, 2001 from the World Wide Web: http://www.enc.com/new/CD11700.asp

The Coastal Barrier Resources System – U.S. Fish and Wildlife Service. (7 May 1998). Retrieved January 20, 2001 from the World Wide Web:

Department of Transportation and Public Works (2001). Retrieved on April 24, 2001, from the World Wide Web: http://www.dtop.gov.pr

Eastman, J. Ronald. (1999). Idrisi 32 Tutorial and Manuals. Worcester: Clark Labs.

El Nuevo Día. "Declaran en rebeldía a un desarrollador." Nov. 15, 2000.

El Nuevo Día. Reves para la Junta de Planificación. Dec. 6, 2000.

El Nuevo Día. "San Juan Insistirá en la moratoria." Nov. 30, 1999.

El Nuevo Día. "Respaldo judicial al DRNA para restaurar a Chiclana." Nov. 29, 2000.

Environmental Science Research Institute Editors. (1999). Getting to Know ArcView GIS: The Geographic Information System (GIS) For Everyone. New York: ESRI, Inc.

Fiddler, Gonsalves, & Rodriguez. (1996). Puerto Rico Environmental Law Handbook. Rockville, Government Institutes.

Final Environmental Impact Statement: Tren Urbano (November 1995). San Juan: Department of Transportation.

Foote, Kenneth E. & Huebner, Donald J. Huebner. (2000). The Geographer's Craft Project. Retrieved April 3, 2001 from the World Wide Web: http://www.colorado.edu/geography/gcraft/notes/datacon/datacon_f.html

Garcia, Ivonne (2000, October 26) Jam Buster! The Puerto Rico Herald

Gerrard, A.J. (1981). Soils and Landforms. London: George Allen & Unwin.

Ghigliotty, Julio (2000). "Señalan responsabilidad por seguir con la Ruta 66." El Nuevo Dia. Retrieved on April 24, 2001, from the World Wide Web: http://endi.zonai.com/manual/Ruta66/asp/p10a18m5.asp

Gigante, Lucienne. (2000, November 16). The New Governor Means Business: Calderon To Focus on Technology, Manufacturing, and Regional Development. Caribbean Business.

Godschalk, David R., Beatley, Timothy, Berke, Philip, Brower, David J., & Kaiser, Edward J. (1999). Natural Hazard Mitigation Recasting Disaster Policy and Planning. Washington, D.C.: Island Press.

Hirasuna, Don (1999). Congestion Policy Brief. St. Paul: Minnesota House of Representatives Research Department.

Hord, Michael R. (1986). Remote Sensing, Methods and Applications. USA: John Wiley & Sons, Inc.

Hudson, Hugh H., Cragwell, Joseph S. Jr., et al. (1996). A History of the Water Resources Division U.S. Geological Survey: Volume VI, May 1, 1957, to June 30, 1966 the Years of Change. Denver: US Government Printing Office.

Kunstle, James Howard. (June 1994). The Geography of Nowhere. New York: Simon & Schuster Trade Paperbacks.

Larsen, Matthew and Allen Zack (1997). Island Hydrology: Puerto Rico and the U.S. Virgin Islands. Retrieved January 17, 2001 from the World Wide Web: http://dprsj35.er.usgs.gov/public/webb/webb010.html

Larsen, Matthew and Angel J. Torres-Sanchez. (1998). The frequency and distribution of recent landslides in three montane tropical regions of Puerto Rico. Geomorphology, 24, 309-331.

Larsen, M.C., Simon, A. (1993). Rainfall-threshold conditions for landslides in a humid tropical system. Puerto Rico Geographic Annual, 75A (1-2), 113-23.

Last, Michael P., Connors, Donald L., Davis, Robert C., Daylor, Robert F., Gaskell, Roderick, Hollands, Garrett, McGregor, Gregor, & Wright, Frank. (1993). Wetlands Regulations. Boston: Bateman & Slade.

Longley, Paul A., Goodchild, Michael F., Maguire, David J., & Rhind, David W. (1999). Geographical Information Systems. USA: John Wiley & Sons, Inc.

Marsh, William M. (1998). Landscape Planning Environmental Applications. New York: John Wiley & Sons, Inc.

McGregor, Gregor I. (1994). Environmental Law and Enforcement. Boca Raton: CRC Lewis Publishers.

Nuhfer, Edward B., Proctor, Richard J., & Moser, Paul H. (1993). The Citizens' Guide to Geological Hazards. Arvada: American Institute of Professional Geologists.

Peuquet, Donna J. & Marble, Duane F. (1990). Introductory Readings in Geographic Information Systems. Bristol, PA: Taylor & Francis Ltd.

Picó, Rafael. (1974). The Geography of Puerto Rico. Chicago: Aldine Publishing Company.

Puerto Rico Basic Facts (2000). Puerto Rican Chamber of Commerce of South Florida. Retrieved April 24, 2001, from the World Wide Web: http://www.boricua.com/facts

Puerto Rico Coastal Management Program, National Oceanographic and Atmospheric Administration. (19 January 2000). Retrieved January 16, 2001 from the World Wide Web: http//:www.ocrm.nos.noaa.gov/czm/czmpuertorico.html

Puerto Rico State Fact Sheet, United States Geological Survey. (19 February 1998). Retrieved January 16, 2001 from the World Wide Web: http://water.usgs.gov/pubs/FS/FS-051-96/

Puerto Rico State Fact Sheet, United States Geological Survey. (8 June 2000). Retrieved January 16, 2001 from the World Wide Web: http://water.usgs.gov/pubs/FS-040-99/

Roman, Ivan (2000, September 3). Puerto Rico Train Hopes on Rail Line. The Orlando Sentinel

Ruíz, Carmelo. (24 November 1998). Activists Win the Fight to Save the Forest. Retrieved March 28, 2001 from the World Wide Web: http://www.oneworld.org/ips2/nov98/18_39_085.html

Spot Image. (2000). Retrieved on April 3, 2001 from the World Wide Web: http://www.spotimage.fr/home/system/welcome.htm

Stefani, Alexis M. (2000, May 25). Report on the Finance Plan for the Tren Urbano Rail Transit Project. Federal Transit Authority.

Threwartha, Robinson, Hammond, & Horn. (1977). Fundamentals of Physical Geography. USA: McGraw-Hill, Inc.

Tutorial on GIS Database Concepts. (2000). Retrieved April 3, 2001 from the World Wide Web: http://www.urisa.org/GISDatabase.html

Way, Douglas S. (1973). Terrain Analysis. Stroudsburg, PA: Dowden, Hutchinson & Ross, Inc.

Weissmann Travel Reports (2000). Retrieved on April 23, 2001, from the World Wide Web: http://www.bolack.com/port.port.htm#1120

Wetlands Reserve Program Fact Sheet – 1996 Farm Bill Conservation Provisions, United States Department of Agriculture. (1996). Retrieved January 16, 2001 from the World Wide Web: http://www.nhq.nrcs.usda.gov/OPA/FB96OPA/WRPfact.html

Wilke, David S., & Finn, John T. (1996). Remote Sensing Imagery for Natural Resources Monitoring. New York: Columbia University Press.