The Effects of Land Use Changes on the Hydrologic Response to Rainfall in Puerto Rico

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Abstract

This project, submitted to the United States Geological Survey, Caribbean District, assesses land use changes between 1977 and 1995 in selected river basins of Puerto Rico and determines their significance for the hydrologic response to rainfall. A GIS software package was used to analyze these land use changes, and a statistical analysis was conducted to evaluate the significance of these changes in modeling basin discharge. Based on these analyses, we developed recommendations to mitigate the detrimental hydrologic effects of such changes.

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Executive Summary

This project, conducted by students of Worcester Polytechnic Institute in conjunction with the United States Department of the Interior, Geological Survey, assesses changes in land use between 1977 and 1995 in five river basins in Puerto Rico. Correlations were made between land use changes in each basin and river discharges leading to flood peaks during selected storms. By using the Geographic Information System software, ARC/Info®, comparisons were made between 1977 and 1995 land use data in the form of aerial photographs and Digital Orthophoto Quarter Quadrangles. The project team delineated, that is traced, the land use types in the software, so that the percentage area of the basin covered by each of four types of land use could be calculated. The four land use types were bodies of water, forests, agricultural land and pastures, and urbanized areas. Storms were selected for the time periods, 1974 to 1979, and 1991 to 1996, based on daily rainfall data taken from the National Oceanic and Atmospheric Administration. Corresponding mean daily river discharge data was obtained from the United States Geological Survey. A multiple linear regression analysis was performed, using the statistical analysis software Statit®, to establish the strength of the correlation between the dependent and independent variables in the analysis: discharge, precipitation, and land use respectively. Regression equations were also developed to estimate discharge as a function of the land use variables first, for each basin, then for all basins simultaneously.

Since over the past four decades the economy of Puerto Rico has shifted from primarily agricultural to industrial, there has been a general trend for an increase in

deforestation and urban development. As agricultural land was abandoned, movement to the city increased the need for housing and urban development. The hypothesis that deforestation and losses in permeable land result in increased runoff and river discharge was substantiated with a statistical analysis by demonstrating the significance of the land use variables in modeling discharge. When we analyzed all the basins simultaneously, we found that the basin drainage area, ground slope, channel slope, and urban development were significant in our model. Land use was found to be a significant variable in the individual basin regression models, confirming the premise that land use changes have a direct effect on the hydrologic response to rainfall. Specifically, increases in runoff and river discharge result from a reduction in permeable of land.

After conducting this research, we believe that land use should be a significant variable, included in hydrologic studies, specifically those pertaining to runoff, discharge, and flooding. These findings are significant for the following purposes:

- Inclusion of the land use variable in future hydrologic modeling at the United States Geological Survey, including discharge and water quality studies.
- Policy reform regarding approval for urban development, specifically to strengthen the role of environmental agencies, such as the Department of Environmental and Natural Resources.
- Implementation of public awareness programs to demonstrate the significance of land use in the hydrologic cycle, which includes increases in runoff and discharge resulting in flooding and the introduction of pollutants into the water supply.

Chapter 1: Introduction

This project conducted for the United States Department of the Interior, Geological Survey, targets the hydrologic effects of changing land use in Puerto Rico. The growing rate of urban development in Puerto Rico has resulted in significant changes in land use, specifically deforestation; moreover subsequent increases in pastures and other less permeable land have had a detrimental effect on its watersheds. It is generally accepted that reductions in land permeability causes greater runoff during wet periods and greater drought during dry periods. As a result of runoff, the groundwater supply that the public depends on is not recharged effectively, and during peak flows, flooding may occur. There may be a correlation between the changing land use in Puerto Rico and the increase in the amount of discharge, amplifying the possibility of flooding resulting in property damage and potential loss of life (United States Geological Survey, 1999).

The Federal Emergency Management Agency (FEMA), an independent agency of the federal government founded in 1979 (FEMA, 1999), as well as some other agencies, identify the peak discharge data of certain storms that have a rate and duration of rainfall so large that they are said to occur only once every 100 years. Such peak discharge storms are used to assess potential detrimental effects of flooding in low-lying areas. Areas prone to flooding change with time and must be updated to reflect land use changes.

The purpose of this project, conducted in five selected river basins of Puerto Rico, was to determine the magnitude of deforestation and urban development in Puerto Rico, and assess whether such changes have caused changes in the hydrologic response to rainfall. The project focuses on an analysis of the correlation between the loss of permeable land and an increase in peak flow occurrences by analyzing particular storm events.

The methodology for analysis included first classifying the land use type in the selected watersheds using 1993-1995 Digital Orthophoto Quadrangles (DOQ), a form of digital aerial photographs. The newly generated data for 1994-1995 land use was then compared to 1977 land use using the Geographic Information Systems (GIS) software, ARC/Info. Once land use classification was completed, rainfall and discharge data from 1977 and 1995 storms was used in a regression analysis in an attempt to show a statistically significant correlation between an increase in the amount of impermeable land and increases in peak discharge resulting in flooding (Larsen, 1999).

The social component of this project involves a study of the social processes that lead to the negative effects of land use change, such as deforestation and urban sprawl. These changes in land use cause an increase in flooding that has had a negative effect on the population of Puerto Rico through loss of life and personal property. We make recommendations to help mitigate the detrimental hydrologic effects of such changes. Loss of habitat, increased runoff, potential flooding, increased sedimentation in water resources, decreased marine life, and decreased bio-diversity are all possible effects of an increase in urbanization. The ability to accurately predict flooding is essential in the design of levees, dams, highway bridges, and other important public works projects. Flood plain development management and flood insurance rates are also based on the frequency and degree of flood flow. This project will address both the causal and resultant factors in land use change.

The technical component of this project is found in the research and experimentation conducted in the watersheds being studied. This project uses state-of-the-art GIS software to make direct comparisons between land use change over a seventeen-year period. This change is then correlated with gathered runoff and precipitation data. This project reveals the importance of the societal impacts of technology by describing the causes of land use change, the significance of land use changes, and their effects on society. The importance of public awareness in matters of deforestation and urban development is addressed in this project.

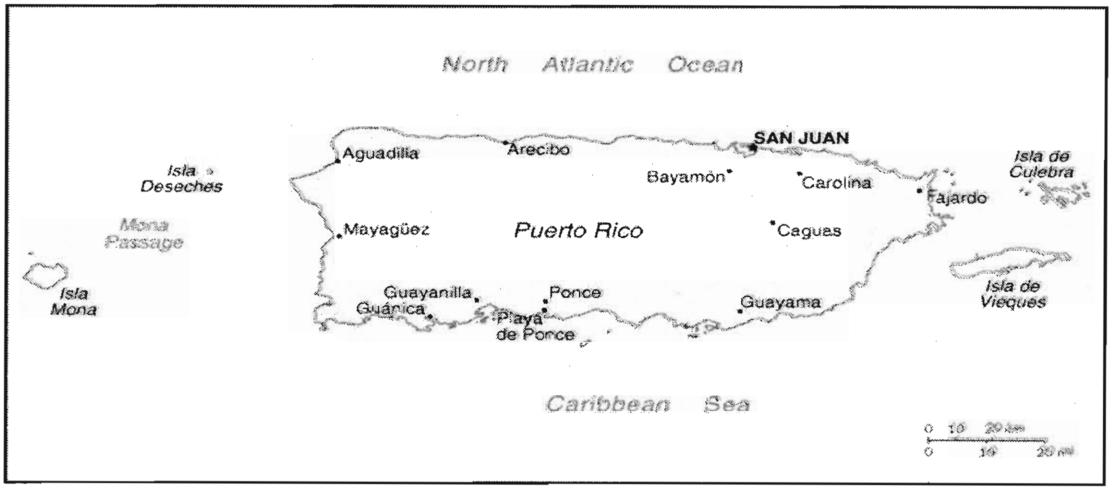
Chapter 2: Literature Review

The Literature Review is a review of the researched material and resources relevant to the project. It is a culmination of background information on Puerto Rico including geography, topography, climate, water and land use, and economy. Several important concepts and definitions pertinent to the hydrologic cycle and the effects of land use change on the hydrologic response to rainfall are introduced. Case studies performed in the area of hydrology and their relevance to the United States Geological land use project are discussed.

2.1 Geography

Puerto Rico is located at 18^0 15' North and 66^0 30' West. The area of the island is 3556 square miles (9,104 square kilometers), which is slightly less than three times the size of Rhode Island. Figure 2.1 is a map of Puerto Rico in its entirety.

Figure 2.1: Map of Puerto Rico.



Source: CIA, 1999.

2.1.1 Topography

The island is a mix of several different types of land, with a coastal plain belt in the northern section of the island, mountains stretching towards the sea on the west coast, and sandy beaches covering much of the coastal areas (CIA, 1998). The mountain ranges reach as high as 4000 feet in some areas, and are 15 to 20 miles east and south of San Juan (NOAA, 1998). The highest point of the island is Cerro de Punta, at an elevation of 4,389 feet. (CIA, 1998)

2.1.2 Climate

Puerto Rico has a climate that is described as tropical maritime, which is to say it is a tropical climate that has elements of climates typical of regions next to the ocean. The island's temperatures are not quite as high as in tropical climates that are not by the sea, and thus Puerto Rico is similar to other tropical islands in this respect (NOAA, 1998). The easterly winds that blow across the island, coupled with the effects of local topography and sea breeze, are one of the important features of the island (NOAA, 1998). During the daytime, the wind blows almost all the time off of the island, having a small impact on the interior of the island but having a greater effect on the outer regions, especially San Juan. The mean annual temperature range has only a 5 to 6 degree difference from the warmest to the coldest months. The interior sections of Puerto Rico have warmer afternoons and cooler nights, and in the mountain and valley ranges, the highest daily and annual temperatures occur. The record highest and lowest temperatures for Puerto Rico have been, respectively, 105 degrees and 40 degrees. Rainfall tends to vary on the island, with San Juan getting approximately 60 inches per year, while some of the heaviest rainfall, approximately 180 inches per year, occurs in the Luquillo Range, only 23 miles from San Juan. Other areas can be much drier, with 30 to 35 inches per year occurring annually in the southwest region of the island.

2.2 Population

Puerto Rico has consistently grown in population over the past half century, and in July of 1998 the number of people living on the island was 3,857,070 (CIA, 1999). The annual increase in population in Puerto Rico is largely a result of the ratio of 16.7 births per 1000 people to 8.08 deaths per 1000 people, putting the growth rate at .68 percent. As of 1995, the migration rate was 1.83 per 1000 people, which figures into the growth rate as well. Table 2.1 shows this data as well as other population data.

Table 2.1: Demographic Indicators: 1995 and 2000

	1995	2000
Births per 1,000 population....................	16	14
Deaths per 1,000 population....................	7	7
Rate of natural increase (percent).............	0.8	0.7
Annual rate of growth (percent)..............	0.2	0.2
Life expectancy at birth (years)...............	75.1	76.6
Infant deaths per 1,000 live births............	13	11
Total fertility rate (per woman)...............	2.0	1.8

Source: U.S. Bureau of the Census, International Database

People ages fifteen to sixty-five comprise 65 percent of the population with 1,206,385 males and 1,310,406 females. Table 2.2 predicts the growth of Puerto Rico's Population for the next fifty years based on 1995 data (U.S. Census Bureau, 1995).

Table 2.2: Midyear Population Estimates and Average Annual Period Growth Rates: 1950 to 2050 (Population in thousands, rate in percent)

Year	Population	Year	Population	Growth Period	Rate
1950	2,218	1996	3,819	1950-1960	0.6
1960	2,358	1997	3,826	1960-1970	1.4
1970	2,716	1998	3,833	1970-1980	1.7
1980	3,206	1999	3,841	1980-1990	1.2
1990	3,605	2000	3,850	1990-2000	0.7
1991	3,709	2010	4,017	2000-2010	0.4
1992	3,780	2020	4,227	2010-2020	0.5
1993	3,801	2030	4,345	2020-2030	0.3
1994	3,807	2040	4,374	2030-2040	0.1
1995	3,813	2050	4,318	2040-2050	-0.1

Source: U.S. Bureau of the Census, International Database

This table shows that the current growth of Puerto Rico's population is predicted to continue well into the future

2.3 Economy

Puerto Rico has an extremely active and changing economy, much more so than the rest of the Caribbean islands (Welcome, 1999). Agriculture, once the primary sector of economic activity and income, has now given way to industry. This has been encouraged by duty free access to the U.S. and by tax incentives, and by firms from the United States who have invested heavily in Puerto Rico since the late 1950's. These incentives are not as attractive now and United States corporations have recently cut some of their budgets for investment in Puerto Rico (Welcome, 1999).

2.3.1 Economic History

Throughout its history, the economy of Puerto Rico has fluctuated due to social and political factors. For centuries, agriculture was the largest sector of the economy. As agriculture developed, there was a need to deforest areas in order to create open fields for crops. Also, as agriculture grew, population grew, making it necessary to build bigger cities. This meant that more deforestation occurred as land was needed on which to build these cities.

In 1508, Juan Ponce de Leon landed on the island and established a colony near present day San Juan. This eventually led to the enslavement of the local indigenous people, and as the colony grew, more slaves were imported from Africa. During the 1600's, many countries realized the importance of Puerto Rico as a key entry point for trade with other nearby Caribbean countries. In 1625, the Dutch West India Company realized that its tobacco trade could be greatly enhanced by having Puerto Rico as a trading point. The government of Holland supplied the Company with the resources to take Puerto Rico from Spain, but after a brutal battle, the Dutch were defeated. This struggle for Puerto Rico goes to show how important other countries felt Puerto Rico was for potential economic development.

After ending the threat from the Dutch, the Spanish government decided to create a centrist or mercantilist economy, which meant that Spain was to oversee all trade through Puerto Rico. This policy led of tight imperial control provoked the development of a black market, through which the local inhabitants traded illegally with Mexico and Peru. Due to inflexible mercantilist policies and mismanagement of the sugar cane crop, the Spanish government never realized the full economic potential of the island. Ginger was also a considerable part of the economy in the mid-1600s. The Spanish government raised the tariff on ginger, however, and as a result the value of the crop declined. In addition to raising the tariffs on ginger, Spain implemented other mercantilist restrictions on trade. San Juan was declared the only legal trading port, which lead to the growth of smuggling cities, such as Ponce. As these cities grew, land use patterns changed with more deforestation occurring in order to build new shops and dwellings.

In the 18^{th} century, there was a drastic increase in population. During this time, coffee was brought to the island and became a major part of the local economy. Puerto Rico's agriculturally based economy flourished at this time, particularly after an uprising in Haiti, a major sugar cane producer, erupted during the French Revolution. The world turned to Puerto Rico to supply the demand for sugar cane. Trade relations with the United States prospered with the importation of U.S. lumber, fish and grain in exchange sugar, molasses, coffee, and rum. With the economy doing so well, the rich upper class created many new structures, including lavish homes and public buildings. The century brought a more extensive change in land use from forest to plantation agriculture and some urban areas grew into thriving manufacturing sectors due to a flourishing economy.

In 1873, slavery was abolished in Puerto Rico. As free peasant workers, small scale peasant farming replaced the plantations economy and there was a severe downturn in the island's prosperity. Twenty-five years later, in the Spanish-American War, the United States took control of the island from Spain. After the American take-over, there were some major a reforms in working conditions, but until the 1950's, the Puerto Rican economy developed slowly.

The 20th century proved to be a very turbulent century for the island's economy. In 1909, there was a labor movement to increase wages for agricultural workers, which had limited success. This lead to a 1915 strike among the cane sugar workers to improve working conditions. Times got somewhat better until two hurricanes within four years decimated local crops. Matters were made worse by the Great Depression in the 1930's.

Perhaps feeling uneasy about the islands colonial status, the United States realized that Puerto Rico needed help, and in 1935 the Puerto Rican Reconstruction Administration was created. The ultimate goal of this program was to stimulate agricultural development and to bring public works projects and electricity to the island. This caused a major boom in development and land use change after World War II. In 1944, the program Operation Bootstrap was launched to raise the standard of living on the island. This lead to further economic boom and a resultant increase in land use change occurred with new factories and urban growth.

In the 1960's there was a major turn in the economy. When Cuba closed its borders to outsiders and the U.S. embargo began, Puerto Rico became a very desirable tourist destination. There was a relative decrease in the agriculture sector of the economy. As the agricultural land was abandoned, fields in parts of the island became overgrown and turned into forest. With this change in the economy cheap rural labor could be attracted to the city for industrial work, a subsequent growth in the size of cities was the result. Once again as the cities grew in size, land needed to be cleared to make space for these urban dwellers and factories.

2.3.2 Current Economy

The economy of Puerto Rico has been highly dependent upon tax breaks, known as Section 936, given to companies from the U.S. if they had part of their operations in Puerto Rico. In 1993, the U.S. Government decided to replace Section 936 with a much less substantial tax break linked to wages paid by, rather than profits of, U.S. companies. One hundred thousand Puerto Ricans are estimated to be currently employed by companies operating under Section 936 (of which 23,000 are in pharmaceuticals) and another 200,000 are employed indirectly by 936 companies (Welcome, 1999).

The industries that are important to Puerto Rico are pharmaceuticals, electronics, textiles, petrochemical, and processed foods. Dairy production and some other livestock products in the agricultural sector have replaced sugar and coffee, staples of Puerto Rico's past economy. Tourism has become a very important part of the economy, with an estimated 3.9 million tourists visiting Puerto Rico in 1993.

The manufacturing industries have led the economy by promoting employee training and rewarding the skilled work force with higher wages. Workers in Puerto Rico receive the same minimum wage as U.S. workers receive, and while labor costs are below the mainland average, they are still higher than in other areas of the Caribbean. Increasing wages have raised the standard of living in Puerto Rico above that of other Caribbean and Latin American Countries. These living standards are reflected, in particular, in a high ratio of cars per capita and in substantial and unmet demand for housing. Both of these demands put pressure on existing land uses.

2.4 Causes of Land Use Changes in Puerto Rico

The land of Puerto Rico is very different from one region to the next, which results in varying uses for the land as well. Throughout all of Puerto Rico, currently only 4 percent is arable land not yet used, while 5 percent currently has crops, 26 percent of the island is used for pastures and 16 percent of the land is forests and woodlands. The other 49 percent is divided up between mountains, beaches, and urbanized areas that are unusable for agriculture in any form (CIA 1999).

Changes in the aforementioned land uses are the focus of this study. With the changing economy of Puerto Rico from primarily agricultural to industrial, the need for housing and urban development around the cities increased significantly. Agricultural land was abandoned and as sub-urbanization and movement into the cities increased so did population density. On the island of Puerto Rico, the population growth rate is unlike anywhere else in the United States. Because Puerto Rico is an island, there is an obvious limit to its development and it becomes apparent why land use is such an important issue. Also, on an island so susceptible to intense storms bringing rainfall and floods, the hydrologic effects of land use change deserve particular consideration.

Puerto Rico began with an agricultural economy primarily producing sugar and coffee. As the world market began changing, it became more cost effective to import crops rather than to grow them on the island. Also, the demand for sugar and coffee from Puerto Rico began declining. In the 1950s, Puerto Rico began making the transition from agriculture to industry and tourism. During this time, the coffee and sugar industries became less profitable. In some cases, although the reduction in the agricultural industry resulted in the abandonment of agricultural land and an increase in urban development, somewhat paradoxically an increase in forested area also resulted. Where there was limited forest cover serving to protect the coffee crops, in particular, the forest flourished after the area was abandoned.

Advances in transportation facilitated the new idea of sub-urbanization. People could now enjoy the comfort and security of suburbia, while still enjoying the benefits of city employment. This revolution resulted in the almost uncontrolled growth of cities, such as the municipality of San Juan. Attempts to control growth failed as green belts or buffer zones serving as pollutant filters were bulldozed over. Policies and objectives developed by urban planners and environmental agencies appeared to be seemingly lofty ideals that were obviously not followed. Development, which should not have occurred in certain areas, did occur because of cost efficiency or political connections. Development often emerged near existing roadways or telephone and electric infrastructure regardless of planning or zoning requirements.

People aware of the detrimental effects of urban development such as air and water pollution have apparently failed to recognize the significant consequences of runoff resulting from urban development and deforestation. As we demonstrate later, this runoff results in greater watershed discharge and flooding.

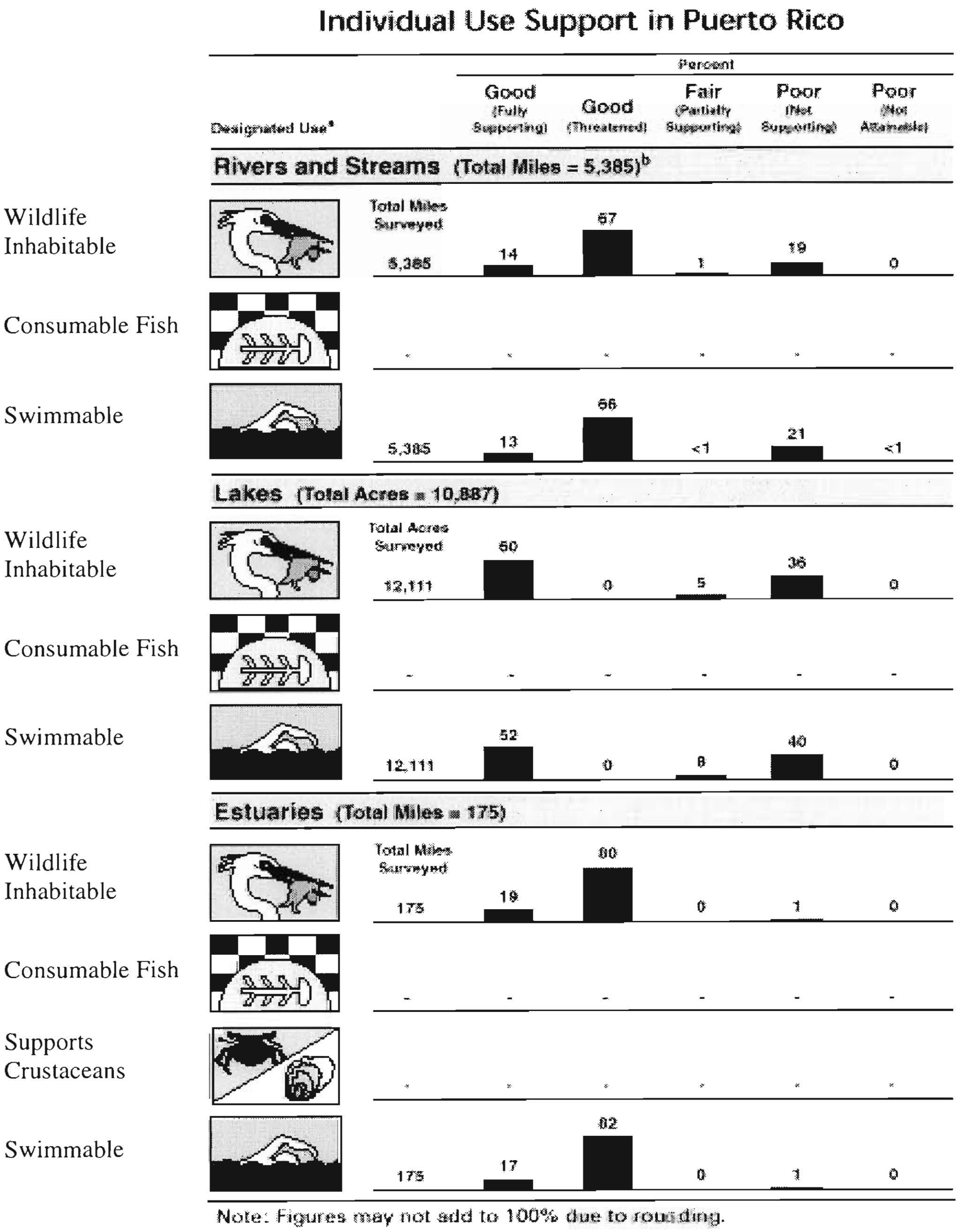
2.5 Water Usage and Quality

Eastern Puerto Rico, which includes all of San Juan, withdraws 20.75 million gallons per day of fresh surface water, as well as 225.95 million gallons of ground water. The water is used by the 1,935,040 people in that section of the island (Water-a, 1999). The 260,000 people in southern Puerto Rico use 87.66 million gallons of ground water and 96.95 million gallons of surface water per day (Water-b, 1999). The northern part of the island uses less water, with 41.73 million gallons per day of ground water and 48.82 million gallons per day of surface water being used for 464,170 people (Water-c, 1999). Finally, the western-most part of the island uses 5.51 million gallons per day of ground and 29.93 million gallons of surface water per day for 355, 000 people (Water-d, 1999).

In the rivers and streams of Puerto Rico, 81 percent of the miles of waterways surveyed by the EPA have good water quality that allow for all different types of uses (EPA, 1999). One percent of the waterways support limited water usage, and 19 percent does not support aquatic life uses. Swimming is not allowed in 21 percent of the rivers and streams that were surveyed by the EPA. The causes of most of the problems in rivers and streams are bacteria, low dissolved oxygen, metals, inorganic chemicals, flow alteration, and nutrients. Sixty percent of the surveyed acres of lakes is usable for any water-related purpose, while 5 percent support limited use, and 35 percent do not support any uses. Swimming is prohibited in 48 percent of the surveyed lake acres. Aquatic life and water that is safe for swimming were found in 99 percent of the estuaries' waters.

The most common sources of water quality degradation in rivers, lakes, and estuaries were disposal of land waste, municipal sewage treatment plants, urban runoff, agriculture, and natural disasters. These types of degradation also pollute beaches in Puerto Rico. Figure 2.2 illustrates the water quality data discussed in the paragraphs above (EPA, 1999).

Figure 2.2: Water Quality in Rivers, Streams, Lakes and Estuaries. EPA, 1999.



Source: EPA, 1999.

Amounts of organic compounds, including dichloromethane, 1,1,2-trichloro-ethane, and toluene were found in several wells below contaminant levels that would prohibit those wells from being used. Wells have been shut down due to bacterial contamination and volatile organic compounds like the ones found above. Septic tanks, livestock operations, agriculture, storage tanks, and landfills are the main causes of ground water contamination (EPA, 1999).

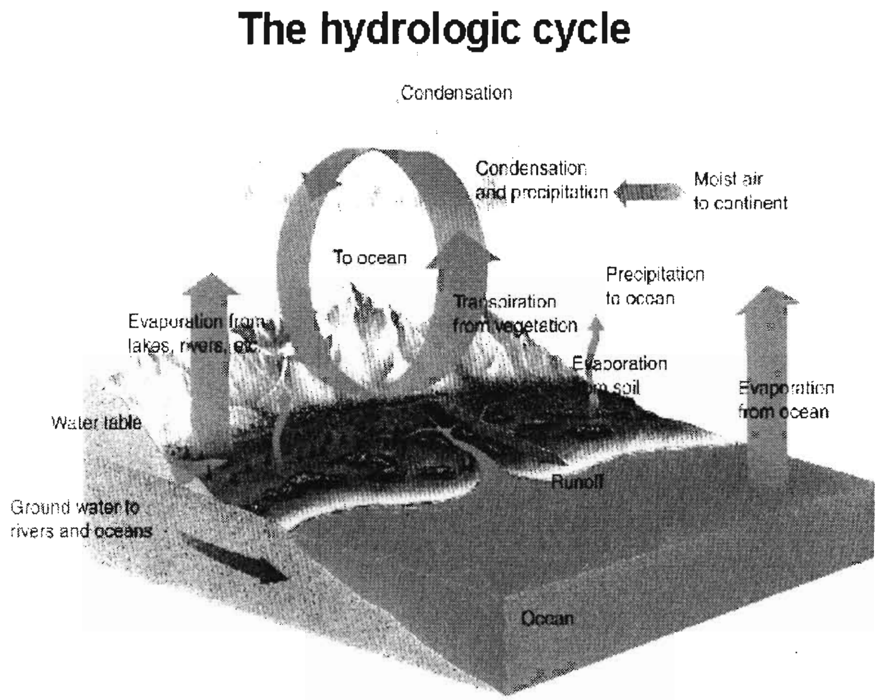
2.6 Hydrology

Carriere (1996) defines hydrology as the study of the life cycle of water. The hydrologic cycle consists of 5 processes: Evaporation, Transpiration, Condensation, Precipitation, and Runoff. Figure 2.3 on the following page is a model of the hydrologic cycle.

2.6.1 Evapotranspiration

According to Ward & Elliot (1995), evapotranspiration is the process of returning water to the atmosphere and completing the hydrologic cycle. Evapotranspiration is generally divided into two sub-processes: evaporation and transpiration. Evaporation occurs on the surfaces of open water sources and is the movement of water into the atmosphere in the form of vapor. Transpiration involves the removal of water from the soil through plant growth in the form of vapor (Ward & Elliot, 1995). Ward & Elliot (1995) distinguish "actual evaporation," a measure of the amount of water actually evaporated from a surface, accounting for surface as well as climatic conditions, from "potential evaporation," which accounts only for climatic conditions. The same categorization holds true for evapotranspiration.

Figure 2.3: The Hydrologic Cycle



Source: University of Iowa, 1999.

2.6.2 Infiltration, Percolation, Interflow, and Ground Water Recharge

Ward & Elliot (1995) define infiltration as the passage of water through pores in the soil surface into the soil profile. Infiltration processes are difficult to quantify. Infiltration methods are usually classified as theoretical mathematical models. The rate of infiltration is dependent on soil water content. Soil surface quality is also important in estimating infiltration.

The authors define percolation, a sub-process of infiltration, as the downward movement of water in the soil profile by gravity. Water moving downward through soil below the plant root zone toward the underlying geologic formation is classified as deep percolation. The replenishing of the ground water supply through the latter process is called ground water recharge.

According to Ward & Elliot (1995), groundwater comprises approximately 4 percent of the water in the hydrologic cycle. As water percolates it may reach a layer of soil or rock material that will restrict its downward movement, causing the water to move laterally along this layer, eventually discharging into surface water. The lateral flow of water is termed sub-surface flow or interflow. The through-flow of water is a culmination of the baseflow and interflow. The baseflow is considered to be groundwater flow above the streambed and results in a gradient towards the stream (Ward & Elliot 1995).

2.6.3 Runoff and Precipitation

The most important hydrologic processes within the scope of this project are runoff and precipitation. Runoff is the portion of precipitation that is neither evaporated nor absorbed by the soil and eventually accesses surface water systems. Understanding runoff is critical for designing flood protection systems for urban and agricultural areas and assessing how much water may be extracted from a river for water supply. The quantity of runoff resulting from a given rainfall event depends on a number of factors such as initial soil moisture content, land use, and slope of the catchment, as well as intensity, distribution, and duration of the rainfall. Contributions to runoff include surface runoff, interflow, and ground flows. Ward & Elliot (1995) state that once the precipitation rate exceeds the infiltration rate of the soil, depressions on the soil surface begin to fill. The water held in these depressions, also called surface storage, begins to move down slope as overland flow once the surface storage exceeds infiltration. Runoff may be identified and measured at a number of locations on the land surface according to the need for runoff data.

There are two primary processes classified as overland flow. The first process, called Horton overland flow, occurs when rainfall intensity exceeds the infiltration rate capacity of the soil. The second process occurs when the soil is so full of water that infiltration is no longer possible (Ward & Elliot, 1995).

The influences of precipitation on runoff processes are affected by the duration of the precipitation, the type of precipitation, and how the precipitation intensity varied throughout the storm. The plant canopy intercepts some precipitation. The amount intercepted depends on the season of the year, wind velocity, and the vegetation type and growth stage. Dense mature forests can intercept significant amounts of precipitation, while immature forests cannot (Ward & Elliot 1995).

2.6.4 Recurrence Intervals

Storms of significant magnitude can be predicted in intervals of years based on previous storm data. Within a certain time period, the worst case flood would be classified as a flood occurring on an interval of that period of time. For example, a 100-year interval flood is the "worst case" flood occurring within a 100 year period and is therefore said to have a 1 percent chance of occurring each year. The assumption then is that in 100 years, the 100-year interval flood is expected to happen once. The intervals typically examined are 2, 10, 25, 50, 100, and 500 years, some of which will be examined in the USGS project.

2.6.5 Flood and Flood Flow Frequency

According to Eloy Colón, in the field of hydrology a flood in the field of hydrology is defined as an event during which a body of water overflows its banks, due to excessive precipitation or discharge, causing a threat to human life or property. A peak flow is the highest value for the flow of a body of water, typically measured in ft^3/s, at any given time that usually results in a flood event. This data may then be expressed in terms of peak flow frequency. The peak flow frequency is the number of times a peak flow occurs over a given period of time.

There must be an accurate and consistent method for estimating flood flow frequency in order to attempt to prevent losses associated with flooding. The United States Department of the Interior (USDI) recommends that the Pearsons Type III model is used to accurately estimate flood flow frequencies. This method was developed by the United States Geological Survey (USGS) to deal with annual flood discharge data. It can also be used to evaluate other hydrologic data such as flood volumes. The model works best when there is extensive hydrologic data for the watershed of interest and includes annual or partial-duration data.

If there is a site that is not gauged, but does have gauged sites nearby, then this model may still be useful. A researcher may choose to go out in the field to an area of interest that is not gauged and measure river flow in the ungauged area. The research can then compare the measured rainfall amounts against a nearby gauging station. If the ungauged site physical characteristics differs by less than 50 percent from the gauged areas, then the data gathered at the gauged areas may be transferred to the ungauged area of interest (Price, 1979). The researcher may of the ungauged site of interest and do some field work in order to measure rainfall for a given storm and then compare the rainfall for that storm to the amount of rainfall measured at a nearby gauged site. If the two values agree to within 50 percent, then the analysis can be used for the ungauged site. This makes for a very versatile and useful model in predicting flood flow and its frequency.

2.6.6 Suspended Particulate Matter (SPM)

Suspended Particulate Matter (SPM) is caused by runoff introducing soil into the watershed. An increase in urbanization causes an increase in runoff and therefore an increase in SPM. The matter is either organic (carbon containing) or inorganic (non-carbon containing). SPM is an important factor in determining water quality for a watershed system (Miller, Cruise, Otero & Lopez 1994). The amount of SPM is a very important factor in determining the overall state of a watershed's biological health. The SPM travels through the watershed and empties into the ocean. SPM is a very important factor in determining water quality, which makes it important when considering the overall biological health of the watershed in question.

2.6.7 Water Quality Determination

Water quality is determined by taking water samples of a given body of water and subsequently running tests on the sample. The tests are to determine the concentration of nitrates, phosphates, SPM, dissolved oxygen, biotic factors and other water quality indicator properties. The researcher then consults a standard water quality table and locates the results of the test on this table for each test run. Based on the findings of the test, a quantitative value is assigned for that individual test. Once all of the appropriate tests have been run and scored, all of the individual scores are summed and the overall score determines the level of water quality. Typically, the smaller the value of the sum, the better the quality of the water is.

2.6.8 Water Use Determination

Based on the water quality tests, the researcher can then determine the water use for the area around where the water sample was taken. Water use is broken up into categories such as swimming, fishing, and drinking, with each category having an "acceptable" range of "summed" value of the water quality determination. These ranges are available to the researcher in the form of water use tables, which lists the water use type along with these "acceptable" ranges for that specific water use category. The researcher can then assign appropriate water uses based on the water quality for the area around where the sample was taken.

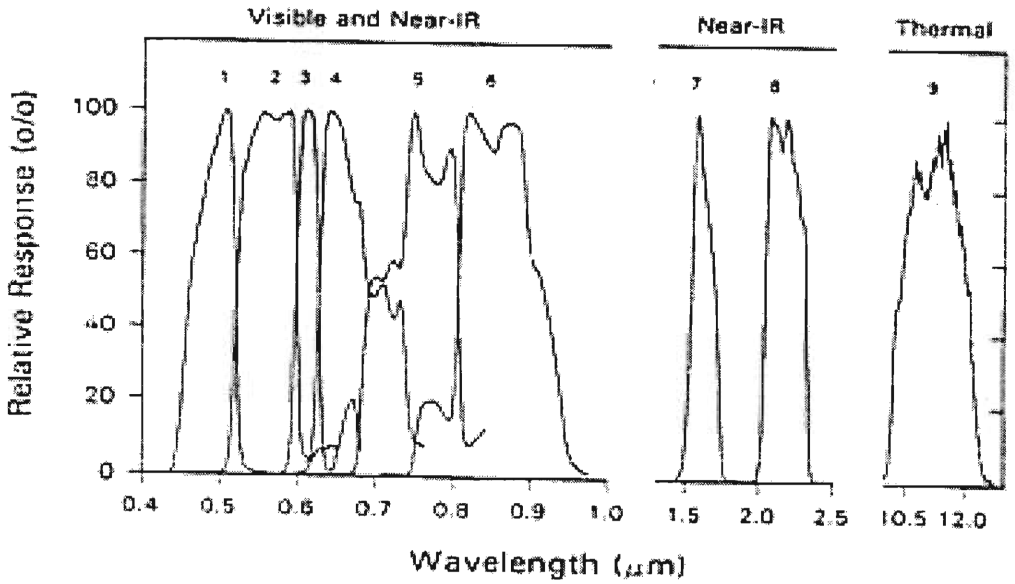
2.7 Data Collection Techniques

The following section addresses techniques typically used in the field of hydrology for data collection, their applications, advantages and disadvantages of various techniques, and some associated case studies. Some modeling techniques are also introduced.

2.7.1 Calibrated Airborne Multispectral Scanning (CAMS)

Calibrated Airborne Multispectral Scanning (CAMS) is a widely used method of data gathering that collects the amount of light that is being reflected by the test area. A special device is fitted to the underside of an aircraft that senses the amount of reflected light that is coming off the area that the airplane flies over. One of its applications is to collect data that the researcher uses to calculate the amount of suspended particle matter contained in a body of water. Another application of CAMS is the gathering of data for the surface soil moisture.

Figure 2.4: Relation of Wavelength to Channels of CAMS



Source: Cruise, J. F., & Miller, R. L. (1994, p. 421)

The Channels of CAMS absorb different wavelengths of light reflected from the earth. This figure shows the exact areas of the spectrum that are absorbed. Each channel of the CAMS is useful for showing different features of a test area.

There are nine separate sets of data that can be obtained using CAMS, corresponding to nine channels gathering the data. Each channel collects data pertaining to the reflected light, such as intensity and wavelength. Each set of data can then be analyzed and the researcher can obtain the necessary information to conduct an experiment, such as land use classification. Using the CAMS method of data gathering, the researcher can obtain data for large areas at one time. The CAMS data collection method is often preferred over the use of conventional data gathering methods, which may be laborious and time consuming. However, the CAMS data must be gathered on days when there are no clouds in the sky to ensure accurate data.

2.7.2 Experimental Study Examining CAMS Accuracy for SPM

In a study of the effects of land use change in relation to run off and SPM, researchers (Miller, *et al*, 1994) monitored the accuracy of the Calibrated Airborne Multispectral Scanner (CAMS) data. CAMS data was used to estimate the SPM that entered Mayaguez Bay via the Guananajibo and Ansco watersheds. To ensure accuracy in the data, the remotely sensed data was then cross-referenced to SPM samples taken by traditional methods using a field laboratory located on a boat in the Bay. Upon comparing the estimated data for SPM from the CAMS technique with the actual measure SPM values obtained from the boat, the researchers showed that the estimation was very accurate. This study proves that remotely sensed data can be used to accurately estimate physical data, which helps illustrate the usefulness of using remotely sensed data gathering technique.

2.7.3 Landsat Thematic Mapping

Landsat Thematic Mapping is a technique that gathers data in a similar manner as CAMS, except that Landsat gathers data on only 7 channels (Shih & Jordan, 1992). The Landsat equipment senses the amount of infrared light being reflected by the earth (Shih & Jordan, 1992). The area of land that the data gathered from is typically very large. Landsat cannot obtain data unless the data gathering satellite is in a precise position in its orbit. If there is atmospheric interference during this time, data cannot be gathered. The next data gathering session can only occur on the satellite's next pass over the test area, continually delaying the data gathering. CAMS tends to be preferred over Landsat data gathering since the conditions for data gathering using CAMS is less restrictive and the researcher is more likely to have ideal conditions for data gathering using CAMS techniques.

2.7.4 Advantages of Remote Sensing Techniques for Soil Moisture Data

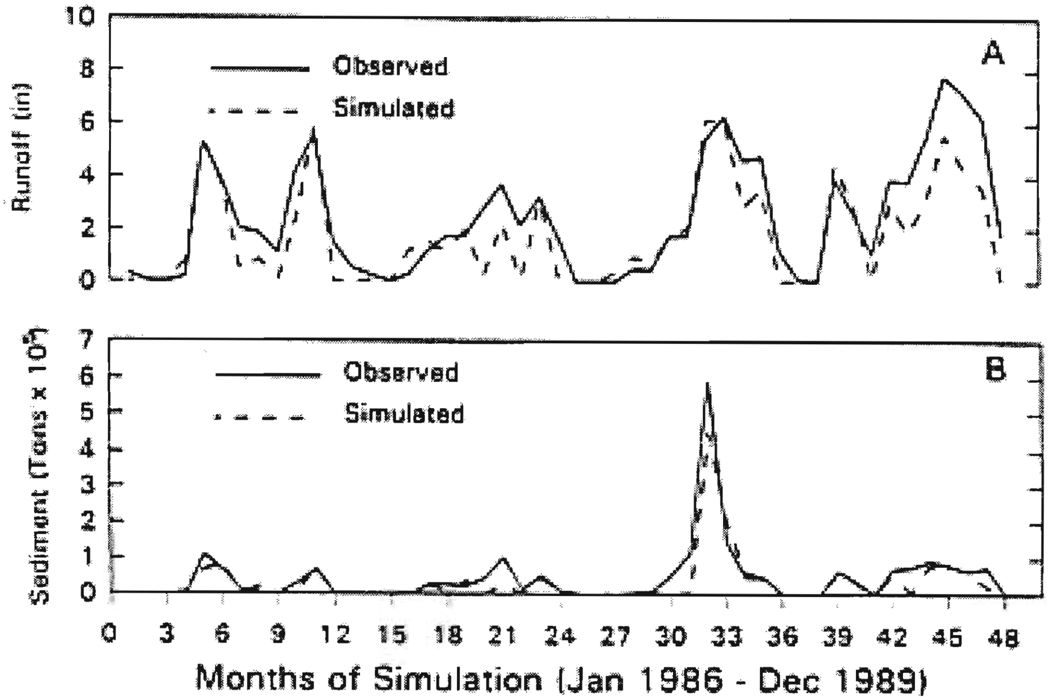
Remotely sensed data gathering techniques have many advantages over some of the conventional data gathering techniques (Shih & Jordan, 1992). Some conventional soil moisture data gathering techniques, such as Neutron Probing (see Glossary), include having to calibrate the necessary equipment for each type of soil that is being sampled, which does not have to be done when remotely sensed data is gathered.

Another conventional technique involves the use of a lysimeter, a device that weighs the soil sample water content. The data produced using this technique is often quite accurate for one sample but may not be representative of the whole test area involved in the study. With remote sensing techniques, the data produced is applicable to the full test area and not just one specific test area, as with the use of a lysimeter.

2.7.5 Field Sized Scale Runoff Model

The Groundwater Loading Effects of Agricultural Management System (GLEAMS) is an accurate and widely used model that analyzes and simulates sedimentation and runoff in a field sized test area (Cruise & Miller, 1993). This model is used to analyze the effects of deforestation and urbanization on runoff and sediment in a watershed. GLEAMS requires data, such as daily precipitation amounts, monthly maximum and minimum temperatures, mean monthly temperatures, soil properties, and land use. The data, once entered into a computer model, can be used to simulate and analyze runoff. The CAMS method is often used for data gathering pertinent to the land use and soil moisture. Other remotely sensed data, such as precipitation, may be used in this model. The GLEAMS method is included here as an example of a model that incorporates many of the other technologies and methods mentioned above. The regression analysis done by the project team used a similar model in assessing the change in land use in relation to an increase in runoff.

Figure 2.5: Comparison of Actual and Simulated Results for Field Scale Runoff Model



Source: Cruise, J. F. & Miller, R. L. (1994), p. 422.
The graphical analysis of a simulation using the model in the above case study versus actual data collected over that time period.

2.7.6 The Effects of Spatial Arrangement of Land Use on Suspended Particulate Matter

In a study that deals with the spatial arrangement of deforestation and the amount of SPM that is discharged, researchers determined that there is a correlation between the two factors (Cruise & Miller, 1994). The watersheds analyzed were the Guanajibo River, the Anasco River, and the Yaguez River on the western coast of Puerto Rico. The study area had coffee and dairy farms located in the rivers' flood plains, which comprised 40 percent of the area. Upstream, there is a mountainous landscape that comprises about 55 percent of the total area of the terrain studied. The remaining area (5 percent) was designated as urban. Using remote sensing data, Cruise & Miller (1994) showed that more sediment was introduced into the watershed when the agriculture land was located closer to the downstream end of the basin, where the basin discharges. When land was deforested and used for agriculture in an area where the terrain is more steep and mountainous, there was an increased amount of SPM introduced into the watershed through an increase in runoff. As the volume of runoff increased in the mountainous area, so too did the SPM. The amount of runoff is greater from August to November, which is in the heart of the rainy season. This study is included to show that spatial arrangement of land use patterns has a significant effect on the SPM loading of a water system. Therefore, land use change will effect water quality differently depending on its spatial arrangement.

2.8 Hydrologic Response to Urbanization

The following section addresses the hydrologic implications of land use changes in low lying watershed areas. Several case studies concerning modeling methods, statistical significance of flood data, and correlation between urbanization and increases in runoff and stream discharge are introduced.

2.8.1 Hydrologic Effects of Land Use Change

According to Bhaduri *et al,* (1997), changes in land use significantly affect patterns of surface water runoff. It is widely accepted in the field of hydrology that increasing urbanization leads to an increase in surface water runoff, due to reduced infiltration from loss of permeable land. Since runoff is defined as the difference between the total precipitation and the amount of water that infiltrates into the ground and is lost due to evapotranspiration, an increase in surface runoff frequently causes a decrease in groundwater recharge. The resulting loss of groundwater recharge may reduce residential and municipal water supplies, and it may threaten the health of local wetlands that draw moisture from soil and groundwater during dry periods of the year (Bhaduri *et al*, 1997).

In the opinion of Bhaduri *et al*, (1997), the most widely studied hydrologic effect of urbanization is the increase in peak discharge, or water movement that causes flooding. The author believes that urbanization has been linked to greater variability in the volume of water available for wetlands and small streams. This condition is sometimes characterized as a "flashy" or "flood-and-drought hydrologic regime" (Bhaduri *et al*, 1997).

Modifications in the vegetation cover also have effects on the energy balance of the evaporating surface. They have an effect on potential evapotranspiration, on the amount of moisture available from the aeration zone of the soil, also called the root zone, and on the rate of water storage in the vegetative canopy. Bultot and his associates (1990) believe that ultimately, changes in vegetative cover influence effective evapotranspiration, through-fall intensity, surface permeability, and percolation, therefore affecting surface runoff and subsurface flow.

Urbanization severely effects the health of watersheds by introducing harmful substances (Stilling, 1996). One kind of pollution is a "point source," which is defined as something that introduces pollutants from a specific location, such as a drainpipe or a power plant. The other kind of pollution, a "non-point source," is defined as one that has no specific location where pollutants are introduced into the surface water, such as runoff from a golf course. These pollutants often contain fertilizer rich in nutrients, causing an abundant growth of plants and upsetting the ecosystem. Often, the natural cycles, such as the nitrogen cycle, are disrupted.

2.8.2 Case Studies in Hydrology

Case studies in sub-Saharan Africa and Belgium relate increased urbanization to watershed response to rainfall. These case studies show the importance of the type of vegetative cover in the watershed in determining its response to rainfall. The results of the studies appear contradictory in that one concludes that deforestation resulting in runoff increases was beneficial, while the other does not. The watershed environment has a great effect on whether runoff is beneficial and must be taken into account. In a dry deciduous forest, there is a significant need for runoff to prevent drought. In a coniferous forest some of the precipitation evapotranspires and infiltrates the soil to recharge the groundwater. Any additional rainfall would result in increased runoff, adversely affecting the watershed and possibly flooding it. Deforestation in a coniferous forest would therefore have an adverse effect, because the reduced evapotranspiration directly results in increased runoff, due to the balance of the hydrologic cycle (Calder, *et al*, 1995).

During this century, both Lake Victoria and Lake Malawi in sub-Saharan Africa have experienced major changes in water level, the causes of which have been the subject of controversy (Calder *et al*, 1995). The following is a description of a modeling study of the effects of land use change from natural forest to agricultural land on large-scale catchment runoff in sub-Saharan Africa, entitled "Water Balance of African

Lakes"(Calder *et al*, 1995). This study in sub-Saharan Africa investigates how the conversion of natural dry deciduous forest to agriculture affects runoff and lake levels in the sub-Saharan African region. The case study area is the Lake Malawi catchment where measurements of rainfall extend back to the turn of the century.

Maps, aerial photographs, and satellite observations were used to estimate the land use pattern of Malawi for a land resources evaluation project in 1992. Interpreting that data resulted in an estimated catchment forest cover of 61 percent in 1990. Earlier work using aerial photographs estimated the forest cover to be 74 percent in 1967. A comparison between the 1967 and 1990 results suggested that forest cover in the Lake Malawi catchment declined by 13 percent. It is estimated that, without this decrease in forest cover, the lake level would have been about 1 meter lower during the southern African drought of 1992, because of the increase in evapotranspiration. The additional lowering would have compounded difficulties actually experienced during the drought (Calder *et al*, 1995).

A second case study performed in the Houille catchment in Belgium assessed the impacts of assumed land use changes by means of a conceptual hydrological model, developed at the Royal Meteorological Institute of Belgium. The mean effective evapotranspiration is a maximum for 100 percent coniferous forests (552 mm / year) and a minimum for pastures (477 mm / year), while the mean annual stream flow is a minimum for coniferous forests (556 mm / year) and a maximum for pastures (631 mm / year). The forest cover also shows more frequent low flow days (+14) and fewer flood days (-10). Intermediate results were found for the other vegetation types (Bultot *et al*, 1990). According to Bultot *et al,* commenting on Bosch and Hewlett (1995), the complete deforestation of a conifer-forested watershed causes an increase in stream flow in the range of 200-600 mm / year. Bultot *et al,* (1990) also states that the mean increase in flow, 400 mm, would in principle result in a 400 mm decrease in evapotranspiration, a value that in their opinion seems excessive for middle-sized catchments in maritime temperature climate regions. The case study reports that the enlargement of the impervious areas can significantly alter the natural water balance of the catchment. By augmenting such surfaces, the global infiltration for the whole basin and the evapotranspiration from the soil will be reduced. Deep percolation will be diminished resulting in less groundwater charge, less sustained flow, and a higher frequency of low-flow occurrences. Simultaneously, the surface runoff will be increased and will reach the outlet of the catchment in greater amounts and in a shorter period of time, resulting in more frequent flooding.

Another case study performed by the United States Geological Survey assesses flooding in river basins in Georgia, and demonstrates techniques for estimating the magnitude and frequency of floods with 2, 5, 10, 25, 50, and 100 year recurrence intervals (USGS, 1979). Data from 308 gauging stations with 10 or more years of record through September 1974 were used in the analyses. Individual relations of flood magnitude and frequency to drainage areas are provided for parts of the major rivers and graphic relations of maximum floods to drainage area at gauging stations are shown for each of the five regions delineated and for major rivers. The flood records used in this project were collected mainly by the USGS. Considering results of the previous flood-frequency studies and other data, five regional flood boundaries were delineated. A multiple linear regression provides a mathematical relation between a single dependent variable and several independent variables as well as a measure of the accuracy of the defined relation. A separate regression analysis was performed for each of the five regions. The drainage area of each basin was found to be the primary independent variable, followed by length, slope, rainfall intensity, and soil index. In none of the cases did the use of a parameter other than drainage area improve the standard error of estimate by more than 3 percent. The standard error of estimate was used to determine the accuracy of the computation for all of the regression equations compiled in this study (USGS, 1979).

Another study performed by the United States Geological Survey assessed the magnitude and frequency of floods in Nebraska. The study provided techniques to estimate the flood characteristics with recurrence intervals up to 100 years. The estimating equations and graphic solutions were based on regional relations between floods of a specific recurrence interval and selected basin characteristics, including vegetative cover. Nebraska was subdivided into 5 hydrologic regions. Flood characteristics were tabulated for 303 gauging stations having 13 or more years of record. The observed flood peaks at the aforementioned gauging stations as well as 57 short-term stations and 31 miscellaneous sites would be useful in designing flood control systems to provide protection from flood damage. Comparisons were made with observed floods throughout the United States. The scope of the study was limited to peak flows and did not account for shape or volume of the flood hydrograph. Regression equations, using the variables with the strongest correlation to flood peaks, and graphical solutions were developed in the study

2.9 Geographic Information Systems (GIS) Software

There are several uses for a GIS, which all fall under one large category, relating data to a specific land area. The data can range from geographic information such as topography, vegetation, or rainfall, to census data such as population density, land value, or urban development. Since most GISs are vector-based, any data that can be located at some point in space can be entered into a GIS. A GIS can also be used to convert existing information into a form the software can recognize and use. A satellite image of New York City can be analyzed to make a map-like document of traffic volume on its roadways (United States Geological Survey, 1999).

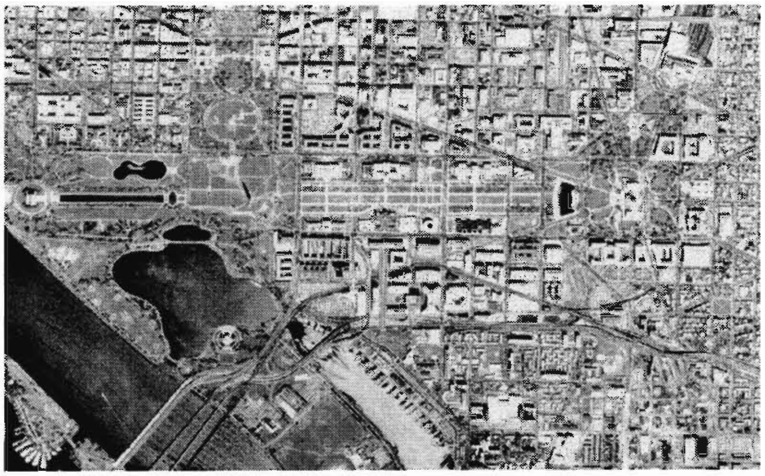
According to the United States Geological Survey (1999), one of the most difficult and time-consuming tasks in using GIS is entering the data. There are many sources of error in this process. When entering data through a keyboard, the user must be specific in the location and identity of an object on the map. When scanning a map, defects in the map or particles on the scanner surface can cause a blemish in the digital map that must be removed and replaced with the proper information (United States Geological Survey, 1999). Quite often a geographic information system requires two or more maps of the same area that contain different information in order to produce the desired output. In most circumstances, the map data are not to the same scale. This requires manipulation of the data to achieve the same scale, so that the GIS can integrate the data (United States Geological Survey, 1999).

2.9.1 Digital Orthophoto Quadrangles (DOQ)

The most common type of information entered into a geographic information system is a Digital Orthophoto Quadrangle. It is the digital image of an aerial photograph taken of a specific area that has had displacements caused by the photographic instrument removed. In essence, it is a scaled map with the physical characteristics of the land incorporated into it (NSDI, 1999).

The USGS standard digital orthophoto is either a black-and-white or color infrared quarter-quadrangle photograph. The standard Digital Orthophoto Quarter-Quadrangle (DOQQ) covers an area of 3.75 minutes of latitude and longitude (NSDI, 1999). In order to convert the DOQQs into a full DOQ, the images must be combined to form a large mosaic image. The DOQQs are taken with over-edge to provide continuity in the creation of the overall DOQ (NSDI, 1999). Overedge is where each DOQQ has slightly more of a picture around the 3.75 by 3.75 minute square, so that is can be digitally attached to adjacent DOQQs seamlessly.

Figure 2.6: Example of a DOQQ



Source: NSDI, 1999.

2.9.2 ARC/Info

ARC/Info is one of several types of software used to analyze hydrologic aspects of a watershed. Considered the industry standard by many leading companies, it is widely used in governmental and commercial industries and programs (ESRI-a, 1999). It is capable of running on a personal computer or a sophisticated operating system such as a SUN Workstation or UNIX system.

ARC/Info is based on the data model, which takes geographic data such as DOQs, and separates it into several data layers (ESRI-a, 1999). It is able to accept data in more than forty industry and government-standard formats (ESRI-b, 1999), is capable of using data obtained from outside applications generated by the user, and accepts all standards for GIS data (ESRI-a, 1999). This data is then graphically displayed in the form of polygons to create a three-dimensional textured map showing the hydrologic data in relation to the land use, slope, or cover. ARC/Info allows this to be done by setting up a database containing all the information relevant to the area being studied, and allowing the users to access the layers, or data sets, that they require for their research (ESRI-b, 1999). ARC/Info is capable of analyzing covers in terms of percentage that aids in the subsequent uses of the data generated from the software.

This project team used ARC/Info to assess the runoff changes caused by urbanization by analyzing land use data created by the software. However, Warwick and Haness (1994) feel that ARC/Info produces results that are no more accurate than results obtained manually comparing and analyzing graphs. They say the graphic output is more impressive than manual results, but no more accurate.

2.9.3 Case Studies Involving GIS

The greenhouse effect, acid rain, and deforestation are three of the major environmental problems we are facing today. One of the major advantages of a geographic information system is its ability to present the effects of such complex ecological events over time. Shamsi (1996), for example, stated in his research that it would be possible to predict storm water runoff in a particular urban area. Thus it would be possible to combine the data in GIS to simulate a certain event for a particular period of time (United States Geological Survey, 1999). By utilizing geographic information systems in this manner, it could be possible to foresee certain disasters and act to minimize the damage caused by them.

Geographic information software has already been used for storm-water management in the United States (Shamsi, 1996). Pennsylvania passed the Storm Water Management Act (Act 167) in 1978, which required detailed watershed-wide management of excess storm-water runoff. Pennsylvania was divided into 356 watersheds that were to be managed by the counties (Shamsi, 1996). A research team was given permission to develop a storm-runoff plan for a specific watershed and to determine adequate methods of preventing flooding by excess runoff. The first thing the team did was subdivide the watershed into major drainage routes, then into smaller sections called "reaches," and then into the smallest subdivisions which they called "subbasins" (Shamsi, 1996). The subbasins were designed to have a single reach for simplicity in naming. After subdividing the watershed into subbasins, the research team was able to analyze the specific area to get accurate data to be used in the GIS model.

When the research team designed the GIS model, they chose ARC/Info as their GIS program because of its versatility, efficiency, automatic editing, data display, and management (Shamsi on Bhaskar et al, 1996). The soil types, land use classes, and coverage of the subbasins were entered into the program as the primary GIS coverage. The slopes and the runoff curve numbers for the subbasins were then entered to create the secondary coverage, which used polygons to graphically display the information (Shamsi, 1996). The model was then calibrated and simulated test data was entered to predict the results of excessive storm runoff via a storm hydrograph (see Glossary).

By using a GIS to develop a hydrograph, the research team was able to successfully estimate the effects of excessive runoff in the given watershed, and they were able to come up with possible solutions to prevent damage caused by this runoff. They discovered that storing portions of the runoff and controlling its output rate could prevent damage to buildings or other structures, and possibly the loss of life (Shamsi, 1996).

In Greene's and Cruise's Urban Watershed Modeling Using GIS (1995), the authors state that the results of a GIS model can be used to predict the effects that changes in land use would have on a specific watershed area. The researchers developed a GIS model that would take into account the roughness and slopes of specific hydraulic response units to determine which areas would contribute to the flow downstream at a particular location. The researchers were particularly interested in the effects of changing a pervious into an impervious area.

Greene and Cruise conducted their research using a GIS and analyzed the changes in a hydrograph of an area, originally with a pervious surface, which was then changed to an impervious surface. The authors concluded that development of a certain area could prove detrimental to other developed areas due to the fact that the runoff generated by the original developments no longer had a place to infiltrate the ground (Greene and Cruise, 1995).

2.9.4 Future of GIS

There are several uses of GISs to this date, but more uses are being developed all the time. Geographical Information Systems are becoming a major tool in predicting the effects of human activity on the environment. It allows scientists and researchers to add the element of time to their studies in order to simulate the results of human activity. GIS can also take several sources of information and combine them to simulate their complex interactions. These developments could result in a wider application of the technology in business and governments throughout the world (United States Geological Survey, 1999).

2.10 Multiple Linear Regression Analysis

The following section is a brief description of the type of regression analysis that was performed by the USGS project team. A sample regression model is included to facilitate the explanation of data manipulation and dummy variable coding. In the USGS project, all relevant independent variables were input into a spreadsheet and statistical software package was used to perform the analysis.

2.10.1 Simple Linear Regression Model

The simple regression model is used to show a linear relationship between two related variables and involves fitting a least square line to a plot of the related independent and dependent variables. (Wonnacott, 1985)

The process for generating a least square line for potentially related data is as follows:

1. For each of the data points, calculate the sum $(X + Y)$ and product (XY) of the values for the independent and dependent variables; calculate the square of the independent value (X^2) and the square of the dependent value (Y^2); calculate the square of the sum of the values of the independent and dependent variables $(X + Y)^2$.
2. Calculate the sum of the values obtained above for all of the data points. For example, take the sum of the $(X + Y)$ values across all of the data points.

3. Calculate the arithmetic mean of X (X bar) and the arithmetic mean of Y (Y bar). Subtract the product of the number of data points (n), X bar, and Y bar, from the sum of (XY). Divide this value by the quantity of the product of n and $(X\ bar)^2$ subtracted from the sum of X^2. This value is the slope (b) of the least square line.

4. To calculate the y-intercept (a), subtract the product of the slope (b) and (X bar) from (Y bar).

5. The result is the equation describing the least square line:

$$Y_c = a + bX.$$

2.10.2 Standard Error of Estimate

To calculate the standard error of estimate:

1. Use the original independent variable X, substituting it into the equation, $Y_c = a + bX$ for each data point.

2. Calculate the difference, $(Y - Y_c)$ between the original dependant variable value and the value calculated from the least square equation for each data point.

3. Calculate the square of $(Y - Y_c)$.

4. The error estimate, δ, is equal to the square root of the quantity of the sum of $(Y\text{-}Y_c)$ squared across all data points divided by the number of data points, n.

Effectively, the preceding procedure is the calculation of the standard deviation of the data. Within one standard error, δ, there will lie sixty-eight percent of the data. Within two standard errors, 2δ, there will lie ninety-three percent of the data. A line with a vertical distance, δ, above and below the regression line is essentially the boundary of the data contained within one standard error (Wonnacott, 1985).

2.10.3 Data Correlation

The method for correlating the independent and dependent variables is to compare the calculated standard error of estimate, δ_{yx}, with the standard deviation of the independent variable, σ_y. The error may range from an ideal case, where all points lie on the regression line and the error is equal to zero, to the worst case, where the error is equal to the standard deviation of Y, the independent variable. The standard deviation is calculated as the square root of the quantity of the sum of $(Y - Y\ \text{bar})^2$ divided by $(n - 1)$. A coefficient of correlation, r, may now be calculated using the standard deviation of Y, and the standard error of estimate, by taking the square root of the quantity of the difference of 1 and the quotient of the squared standard error of estimate, and the squared standard deviation. The square of this r-value is the coefficient of determination and may be interpreted as the percentage of the variation in the dependent variables that is associated with a variation in the independent variables. It follows that an r^2 value of 1 implies a one hundred percent correlation between the independent and dependent variables, thus the r value would be 1, and all data points would lie on the regression line.

2.10.4 Dummy Variable Coding

According to Aiken & West (1991), Dummy Variable Coding is a procedure for representing categorical variables in a regression equation. The dummy variables are necessary for problems in which there is a relationship between categorical predictor variables having two or more levels and continuous predictor variables.

In the USGS project, the continuous predictor variable was precipitation amount. The categorical predictor variables included types of urban development, such as factories, apartment complexes, and houses, or land type, such as dense mature forests, pastures, and roads. For a regression equation representing a relationship between the independent and dependent variables, the regression lines may not be parallel, potentially indicating a relationship between the categorical continuous variable.

In general, the number of dummy variables is equal to one less than the number of groups or levels of the categorical variable in the data. An arbitrary comparison group is selected, and the coding is in matrix form, where the columns are the dummy variables, and the rows are the groups. The comparison group is assigned zeros and the remaining groups are coded in Reduced Row Echelon Form (RREF). The following is an example of a coding procedure that might be used in a land use analysis project. The difference is in the variables used. Let us consider land type vs. discharge for the regression analysis, where dense mature forests (DMF) are the comparison group. There are three dummy variables since there are four groups.

	D1	D2	D3
Dense Mature Forests (DMF)	0	0	0
Pastures (PAS)	1	0	0
Roads (RDS)	0	1	0
Sparse Mature Forests (SMF)	0	0	1

We may now determine which coefficients are relevant to each of the groups. Let us consider the simple regression equation, $Y = b1D1 + b2D2 + b3D3 + b0$. The variable b0 is the mean precipitation for the comparison group. For each of the other groups, the b coefficients are determined by substituting the dummy variables into the simple regression equation in following manner.

DMF $Y = b1(0) + b2(0) + b3(0) + b0 = b0$
PAS $Y = b1(1) + b2(0) + b3(0) + b0 = b1 + b0$
RDS $Y = b1(0) + b2(1) + b3(0) + b0 = b2 + b0$
SMF $Y = b1(0) + b2(0) + b3(1) + b0 = b3 + b0$

The continuous variable, precipitation, is added and centered by subtracting the mean precipitation from the original precipitation value for the entire sample. The product of the continuous variable and a new coefficient, b4, is added into the regression equation. The following are the resulting equations for each of the groups.

DMF $Y = b4(PRECIP) + b0 = b0$
PAS $Y = b1(1) + b4(PRECIP) + b0 = b1 + b4(PRECIP) + b0$
RDS $Y = b2(1) + b4(PRECIP) + b0 = b2 + b4(PRECIP) + b0$
SMF $Y = b3(1) + b4(PRECIP) + b0 = b3 + b4(PRECIP) + b0$

The interaction between the categorical and continuous variables is formed by multiplying the continuous variable by each of the dummy variables comprising the categorical variable. The resulting equation is the new multiple linear regression equation (Aiken & West, 1991):

$$Y = b1D1 + b2D2 + b3D3 + b4PRECIP + b3PRECIP + b4(D1 * PRECIP) + b5(D2 * PRECIP) + b6(D3 * PRECIP) + b0$$

Chapter 3: Methodology

This methodology is a description of the procedure that was followed while completing the United States Geological Survey land use project. We completed this project at the WPI Interdisciplinary and Global Studies Division project center in San Juan, Puerto Rico in D-term, 1999. To ensure the validity of our project in the field of hydrology, all methodological decisions made by the team were taken in consultation with experts in the USGS, including Dr. Mathew Larsen, Orlando Ramos Ginés, Rene Garcia, Richard Webb, Betzaida Reyes, John Parks, and Marilyn Santiago.

3.1 Geographic Information System Training

Before work could begin on the project, we had to be trained in the interpretation of Digital Orthophoto Quadrangles (DOQs) and their incorporation into the Geographic Information System (GIS), ARC/Info. We reviewed the necessary basic and advanced commands used in the ARC/Info software package upon our arrival at the Puerto Rico project center to complete the delineation of the river basins to be studied. Betzaida Reyes, John Parks, and Marilyn Santiago were very helpful in the training of ARC/Info.

Since the version of ARC/Info we used is Unix based, not a Microsoft® Windows based version, most of the commands were entered textually. A Windows based version would allow a user-friendly graphic interface in order to activate a command, while the Unix based version has a graphic interface on which the layers of data and the DOQs are projected, but a second window is required to enter the textual commands. The commands entered in text occurred in the graphical window, allowing us to edit the layers of data as necessary. ARC/Info work was done using dummy computer terminals.

Betzaida Reyes and other USGS employees who frequently use the software trained us in the use of the ARC/Info software. They showed us how to incorporate the data layers and DOQs into the program, and how to manipulate the data contained within them. Since there are hundreds of commands in the program, we concentrated on only those necessary for our project tasks. A list of these commands, with a description of each, can be found in Appendix C.

3.2 Data Acquisition

One of the main objectives of the project was to classify land use in five selected basins throughout Puerto Rico: Río Cibuco below Corozal, Río Grande de Loiza at Quebrada Arenas, Río Grande de Patillas, Río Inabón at Real Abajo, and Río Portugúes near Ponce. DOQ’s and ARC computer data layers were needed to complete this portion of the project. One ARC data layer that was needed, the boundaries of the basins, was obtained from existing records in the USGS computer network in the Puerto Rico office. These boundaries were then cross-checked using certified topographic and hydrologic maps provided by the USGS. Land use patterns in the form of arc data layers (see below for explanation) were also provided to us by the USGS.

The DOQ’s were provided to us by the USGS in the form of digital pictures placed on the SUN computer network. Due to limitations with the availability of DOQs, only 5 of an originally selected 10 basins were delineated and used in the multiple linear regression. A 15-degree wide swathe of data was missing from several DOQs covering eastern Puerto Rico due to cloud cover obstructing the aerial photographs. These DOQ's were needed for the analysis of the five basins not included in the originally planned project.

The next set of data necessary for our analysis was rainfall amounts for each of the basins. We gathered rainfall data for 10 storms per basin for the time periods of 1974 to 1979 and 1991 to 1996. We chose the storm data in years as close as possible to the corresponding land use data. To use a worst case storm for each year from 1977 to 1995 in our analysis, it would also have been necessary to project a rate of urbanization, so there would be corresponding land use data for each of the years. For this reason an essentially before and after analysis was done. Because the only available land use data were from 1977 and 1995, the only rate of change, which could be estimated, would have been linear, thus potentially representing the urbanization rate inaccurately. The year in which the storm took place was not the important factor, whereas corresponding land use was. The most important factor in selecting storms was to use data from storms of comparable magnitude and duration from each time period. It was also important to maintain consistency in method for acquiring discharge data corresponding to the rainfall data for each storm to avoid further error.

We obtained daily and monthly precipitation data for the years near the corresponding land use data from a National Weather Service computer spreadsheet, provided by Mr. Ginés. We reviewed the data for the days on which there was a significant amount of rain. Daily rainfall totals were recorded for a variety of storms to ensure a wide range of rainfall events, and storms of comparable magnitude were chosen for each period of time for each basin. When a period of intense rainfall was observed in a particular month, corresponding discharge data were obtained from the USGS Water Resources Data to determine whether the rainfall resulted in a peak flow.

National Oceanic and Atmospheric Administration (NOAA) rainfall gauging stations closest to the estuaries draining into the main channel of each basin were selected. Typically there would be at least two rainfall stations near each other, such that if the period of record for one did not coincide with the period of our study, the other station could be selected. The rainfall stations were selected such that rainfall amounts over the estuaries of each basin were represented. The selected stations corresponding to each river basin were as follows:

River Basin	NOAA Rainfall Station
Río Tanama near Utuado	Adjuntas Substation
Río Cibuco below Corozal	Negro Corozal
Río Grande de Patillas	San Lorenzo 3S
Río Inabón at Real Abajo	Adjuntas 1 NW
Río Portugúes near Ponce	Jayuya

The rainfall data gathered were in terms of inches of water. We assumed the rainfall amounts to be evenly distributed throughout the entire basin, since there was an insufficient number of stations to develop an average rainfall distribution. In addition to land use, precipitation, and discharge data, other independent constants for each basin, such as basin drainage area (DRG), depth to bed rock (DTR), main channel slope (MS), ground slope (GS), main channel length (ML), and soil permeability index (SP) were included in the multiple regression analysis. Mr. John Parks of the USGS provided assistance in obtaining these constants.

Finally, the project team, along with Dr. Larsen conducted a limited field study using the Global Positioning System, to acquire a sample of points in the Río Cibuco basin below Corozal. A hand held non-differential GPS receiver was used to acquire latitude, longitude, and elevation data for 10 sites, consisting of highway junctions, buildings, fields, and lots. A list of these locations can be found in table 3.1. The data points were compiled and then compared to the actual site locations in ARC/Info to assess the accuracy of the DOQs. The data obtained from the GPS was entered into ARC/Info and a new data layer was created. This newly created layer was then overlaid on the DOQ. The points where the latitude and longitude were taken were located on the DOQ. ARC/Info assigns that point latitude and longitude according to what it believes is the correct coordinate. The offset between the GPS acquired points and the corresponding points of the DOQ in ARC/Info was calculated to assess error. It is assumed that the error associated with delineating in ARC/Info is much more significant than the error in the GPS. This was done simply as a coarse spot check and to ensure that the DOQs the group used were accurately geo-registered and therefore not a significant source of error. Table 3.1 shows the actual coordinates for various locations located on the DOQs to assess error in them.

Table 3.1 Location of Reference Points

	Description of Site	Latitude	Longitude	Elevation
Site 1	North West corner of Central Plaza Corozal (to the left)	18 20'34.24"	66 19'03.98"	94 m
Site 2	Near baseball field (to left) with large bridge on right Heading 218°	18 20'38.42"	66 19'16.43"	81 m
Site 3	On small bridge Rio Cibuco Direction of road at 290°	18 20'03.46"	66 20'08.86"	79 m
Site 4	Junction Route 568 & 159 in front of shop heading 168°	18 19'33.20"	66 20'36.14"	216 m
Site 5	Left side river looking downstream 159° on bridge over river	18 19'43.26"	66 21'03.42"	181 m
Site 6	Outside parking lot of baseball diamond (right at the perimeter joint) east side of lot	18 20'30.99"	66 19'10.74"	91 m
Site 7	Junction Routes 159 & 164 outside basin (North-West part of intersection)	18 20'34.40"	66 18'21.41"	170 m
Site 8	Junction Route 803 & Route 164	18 19'25.01"	66 17'50.32"	234 m
Site 9	Junction Routes 803 & 808	18 17'10.18"	66 18'00.27"	470 m
Site 10	Junction Routes 808 & 811 (South side on intersection)	18 17'10.18"	66 16'40.15"	532 m

This table shows is a list of the actual coordinates for sites selected to verify DOQ accuracy gathered using GPS equipment.

The project team contacted government and local agencies including the National Oceanic and Atmospheric Administration (NOAA), the Junta de Planificacion (Planning Board), and the Federal Emergency Management Agency (FEMA) for information pertaining to the social aspects of flooding and land use change.

3.3 Data Entry and Manipulation

Once the training was completed, we began to edit the arc layers. First, the DOQs, the digital photos that show the area of interest in 1993-1995, were called up in a work window on the computer. Next, the arcs, or data layers representing the polygons which essentially "trace" basin feature boundaries, were called up and laid over the DOQ. The basin boundary layer was called up in order to define exactly what part of the DOQ represented the basin. This was done in most cases since the DOQs are of areas that are larger than the actual basin or the basin boundary spans over several DOQs. Next, we placed the existent 1977 land use arc layers over the DOQs. We used ARC/Edit to modify existing arcs, which represent physical aspects of the basin, by manipulating the polygons to mark the boundaries of the different types of land use as seen on the 1993-1995 DOQs. These manipulations included changing the shape of the polygons, deleting some polygons, and adding some new polygons. By doing so, we essentially “retraced” the land use patterns of the area so as to update them to 1993-1995 patterns. This process of manipulating the polygons to map distinct areas on the DOQ is known as delineation. In the delineation process, we frequently consulted each other to confirm the type of land use on the DOQ, and to maintain consistency in our interpretation of the photographs.

Next, we assigned a label, which consisted of one of four land use type codes (lucodes), to each polygon. Each of the four codes represented the type of land use that was present in each delineated polygon. The codes used for 1995 land use were 1000 for bodies of water, 1100 for forests, 1200 for agricultural land and pastures, and 1300 for urban area. We chose only four land use categories for simplification of the statistical analysis, while still differentiating between permeable and impermeable land.

The first category was bodies of water. This category is comprised primarily of rivers and estuaries. The main channel in each of the studied river basins accounts for the majority of water cover. This was selected, as a form of land use so there is not an overestimation of the other three land use classes. The second land cover type was forested area. This category was composed of dense mature and sparse mature forests of various heights and was considered to be one type of permeable land. The third land cover type was agricultural land. This included all farmland and pastures, natural fields, and grasslands. This category was considered to be another type of permeable land. We decided to keep agricultural land use separate from the forested area since even though they are both permeable, the rates of infiltration and runoff can be significantly different from those of the forested area. The last category was urbanized area, which includes industrial developments, residential developments, commercial areas, and major roads. This category was considered to be impermeable land since precipitation cannot permeate the surface.

The land use classification for 1977 was significantly more complex as it included many subcategories of the four simple categories that we used for the 1995 polygons. We combined all of the subcategories of the 1977 land use labels to form the same land use type categories (i.e., forest, agriculture, urban, and bodies of water) as we had for 1995. In the case of the 1977 data, the last zero was dropped from each code to avoid classifying our own land use covers as existing ones. For example, the land use code used for 1977 bodies of water was 100.

After combining the subcategories of the 1977 polygons, we encountered some major difficulties with the land use classification scheme. In 1977 aerial photographs, delineations for land use, planned urban development or zoning projected for 30 years were outlined and coded as impermeable land in ARC/Info. Since such areas were really permeable in 1977, it was necessary for us to reclassify some of the labels representing "planned urban development" as permeable areas in order to provide a more accurate representation of actual 1977 land use. Under the advisement of Richard Webb, the lucodes 1535 (non-developed areas inside an urban zone), 1540 (urban under construction), 1550 (rural low density), 1555 (rural medium density), 1560 (rural high density), 1565 (rural residential), and 1570 (temporary residential rural) were reclassified as 120 (agriculture) under our coding system. The 1977 classifications were sorted into the categories that we developed to delineate 1993-1995 DOQs. See the land use data manipulation error section in 4.6 Sources of Error for a more complete explanation of our actions.

ARC/Info was then used to merge the land use and basin boundary layers of the basins of interest for both the 1977 and 1993-1995 data sets. From this, Arc/Info was used to calculate and tabulate the total area encompassed by the arcs representing each labeled type of land cover. From the area, we then calculated percent cover of each type of land use based on the drainage area of the basin.

3.4 Data Analysis

Once we gathered sufficient data, we performed a multiple linear regression analysis in an attempt to develop a correlation between land use and stream discharge. Before the actual regression could be done, it was necessary to prepare the data for analysis by transforming it into comparable units. The project team summed rainfall data for each storm and calculated the total volume of rainfall by multiplying the amount of rainfall by the drainage area of the basin. If there was an evident correlation between the rainfall and a peak flow occurrence, the total discharge was recorded and the event was considered a storm with a duration equivalent to the rainfall duration. We summed the discharge data for each storm and calculated total volume of by multiplying the total discharge values by the total number of seconds in a day.

The rainfall was considered to be one independent variable. Each type of land cover for both 1977 and 1995 was treated as a separate variable. The constants for each basin, such as depth to bedrock, were deemed to be important to include in the regression analysis by Mr. Ramos Ginés, when making a comparison between basins. The dependent variable in this regression was the amount of discharge during the rainfall event.

In past case studies, an exponential relationship has been shown between peak discharge and several physical and climatologic variables in a basin. Because of this, we performed a log transformation on all the data to allow for a linear relationship between the independent and dependent variables, a standard in hydrologic modeling. We entered the data into Microsoft® Excel, where we performed any necessary conversion and sorting of data. We then imported the data into Statit®, statistical analysis software, where several regression analyses were performed. The regression analysis included comparisons between all five basins for the 1977 land use, between all five basins for the 1995 land use, and between storms of similar magnitude and duration from each time period, within each individual basin. Where comparisons were made between all basins, the physical constants for each basin, such as channel slope, ground slope, soil permeability, and depth to bedrock, were used in the analysis. For the time study, within each individual basin, only the land use and precipitation variables were included. The type of analysis used was Mallows Cp, a common type of regression analysis used at the USGS, which performed all possible regressions with the entered data. The analyses resulted in the best model with anywhere from 1 to n of n parameters or variables. The software calculated the standard error in each model and the confidence interval.

When we completed the multiple regression analyses, in which strength of correlation between the dependent and independent variables in the study was calculated, we developed final regression equations. Those associated with analyses of all basins were considered regional regression equations and those associated with each individual basin were considered local. The regression equations were functions of the variables showing the strongest correlation to river discharge in each basin. The equations could be used to make predictions as to the effect of future changes in any of the physical aspects of the basin on river discharge and if a strong correlation were found between land use and discharge, predictions could be made as the effect of projected land use over the next several years.

3.5 Organizational Charts

Figure 3.2 Task Chart

Tasks	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
USGS Training								
ARC/Info Training								
Statit Training								
Data Gathering								

Chapter 4: Data, Analysis and Results

In this chapter we discuss the data we acquired for each basin, along with the statistical analysis we carried out using this data. The data for each basin is arranged in a tabular format and explained in a short paragraph following each table. The regression equations developed from this data are also discussed. We also address some of the sources of error in our analysis.

4.1 Introduction to Basin Development

The reasons for urbanization in the each of the basins studied may vary significantly from basin to basin, however there are several commonalties. According to Colón, with population increases, a competition develops between man and nature with the need for urban development, resulting in an increase in impermeable land, thus disrupting the hydrologic cycle. In Puerto Rico, the competition is for development in low-lying areas coincident with basin flood plains, because of the inherent difficulty of developing on mountainsides.

According to Jose de Ruiz and Rafael Morales of the urban planning board, the transition from an agricultural to an industrial economy beginning in the 1950s resulted in significant changes in land use, including intense urban development. Changes in the market lowered the necessity and cost effectiveness of agriculture in Puerto Rico, since products could be imported more economically than they could be produced on the island. As industry became more prominent, people began moving into the city and the competition for housing intensified.

The idea of sub-urbanization was introduced to Puerto Rico as advances in transportation facilitated the development of residential areas for city workers outside of the city, allowing for even more urban sprawl. There has also been a general tendency to develop horizontally over vertical development within existing urban areas. It is often more expensive and less feasible to develop in zoned urban areas. Therefore, in combination with the competition for housing, it becomes much easier to develop in areas that are not zoned for urban development. The result is development where it is easiest and most cost effective, without regard to urban planning and recommendations from other agencies.

According to Hildelisa Gonzalez, an urban planner temporarily assigned to the Federal Emergency Management Agency (FEMA) Hazard Mitigation Program Development, urbanization often occurs where most "convenient," such as near existing infrastructure like electric and telephone lines, not necessarily where it is zoned. This convenience referred to as strategic zoning often results in developing on steeper slopes despite the associated difficulties. In addition to the increased effect of the spatial arrangement of the urbanization on runoff, implemented drainage systems that channel precipitation directly into the river result in an increased frequency of peak flow occurrences downstream. Also, as major roads are developed between urban areas, there is a tendency to develop along the road, resulting in an increase in the rate of urbanization with the addition of new developments.

4.2 Basin Data Tables

The following tables consist of the basin data used in the multiple linear regression analysis. The variables and constants used in the analysis and their corresponding abbreviation are listed below.

CS Channel Slope
GS Ground Slope
SP Soil Permeability Index
DR Depth to Rock
DA Basin Drainage Area
PCP Precipitation Amount During Storm
DSG Discharge Amount During Storm
BDW Percent Cover of Bodies of Water
FOR Percent Cover of Forested Area
AGR Percent Cover of Agricultural Area
UBD Percent Cover of Urban Development

The channel slope is the slope measured in feet per mile of the main channel in the river basin. The ground slope is the average gradient of the basin, given as percent rise. The soil permeability index is a measure of the average infiltration rate in in/hr of the soil in the basin. The depth to rock is the distance between the topsoil and the underlying bedrock. The precipitation and discharge amounts are the total amounts of precipitation and discharge, in cubic feet, measured during each storm. The remaining variables are the percent cover of each land cover type in the basin as classified by the project team. Storms 1 through 10 are from the 1974-1979 period and storms 11 through 20 are from the 1991-1996 period.

4.2.1 Río Cibuco below Corozal

Table 4.1 Basin characteristics for the Río Cibuco River below Corozal.

STORM	CS ft/mi	GS % rise	SP in/hr	DR in	DA mi^2	PCP ft^3	DSG ft^3	BDW %	FOR %	AGR %	UBD %
1	648.70	22.35	1.25	47.95	15.17	42291532.80	2600640.00	2.48	30.09	58.98	8.45
2	648.70	22.35	1.25	47.95	15.17	49340121.60	2592000.00	2.48	30.09	58.98	8.45
3	648.70	22.35	1.25	47.95	15.17	172690425.60	14307840.00	2.48	30.09	58.98	8.45
4	648.70	22.35	1.25	47.95	15.17	112777420.80	15206400.00	2.48	30.09	58.98	8.45
5	648.70	22.35	1.25	47.95	15.17	109253126.40	40262400.00	2.48	30.09	58.98	8.45
6	648.70	22.35	1.25	47.95	15.17	144496070.40	34905600.00	2.48	30.09	58.98	8.45
7	648.70	22.35	1.25	47.95	15.17	38767238.40	1641600.00	2.48	30.09	58.98	8.45
8	648.70	22.35	1.25	47.95	15.17	91631654.40	7430400.00	2.48	30.09	58.98	8.45
9	648.70	22.35	1.25	47.95	15.17	133923187.20	58579200.00	2.48	30.09	58.98	8.45
10	648.70	22.35	1.25	47.95	15.17	102204537.60	25056000.00	2.48	30.09	58.98	8.45
11	648.70	22.35	1.25	47.95	15.17	194893480.32	33514560.00	1.52	16.22	70.89	11.38
12	648.70	22.35	1.25	47.95	15.17	34185655.68	2194560.00	1.52	16.22	70.89	11.38
13	648.70	22.35	1.25	47.95	15.17	296040729.60	77155200.00	1.52	16.22	70.89	11.38
14	648.70	22.35	1.25	47.95	15.17	155068953.60	55814400.00	1.52	16.22	70.89	11.38
15	648.70	22.35	1.25	47.95	15.17	51454698.24	16934400.00	1.52	16.22	70.89	11.38
16	648.70	22.35	1.25	47.95	15.17	80353912.32	5097600.00	1.52	16.22	70.89	11.38
17	648.70	22.35	1.25	47.95	15.17	8105877.12	2540160.00	1.52	16.22	70.89	11.38
18	648.70	22.35	1.25	47.95	15.17	67314023.04	7136640.00	1.52	16.22	70.89	11.38
19	648.70	22.35	1.25	47.95	15.17	56388710.40	14860800.00	1.52	16.22	70.89	11.38
20	648.70	22.35	1.25	47.95	15.17	208285799.04	26438400.00	1.52	16.22	70.89	11.38

In the Río Cibuco below Corozal basin, there was a significant change in land use between the 1977 to 1995. Forest land use decreased from 30.09 percent to 16.22 percent. Agricultural land use increased from 58.98 to 70.89 percent of the basin. And, Urban development increased from 8.45 to 11.38 percent. The situation in Corozal is interesting in that although there have been significant increases in urban development and agricultural cover, the basin is relatively mountainous, and there is a large flood plain surrounding the Río Cibuco, making urban development difficult.

4.2.2 Río Grande de Patillas near Patillas

Table 4.2 Basin characteristics for the Río Grande River near Patillas.

STORM	CS ft/mi	GS % rise	SP in/hr	DR in	DA mi^2	PCP ft^3	DSG ft^3	BDW %	FOR %	AGR %	UBD %
1	730.75	36.06	2.26	34.72	18.34	134213587.2	98323200	0.98	76.60	22.02	0.40
2	730.75	36.06	2.26	34.72	18.34	106518720	42163200	0.98	76.60	22.02	0.40
3	730.75	36.06	2.26	34.72	18.34	289304843.5	23241600	0.98	76.60	22.02	0.40
4	730.75	36.06	2.26	34.72	18.34	247549505.3	34387200	0.98	76.60	22.02	0.40
5	730.75	36.06	2.26	34.72	18.34	177673225	68342400	0.98	76.60	22.02	0.40
6	730.75	36.06	2.26	34.72	18.34	98849372.16	43545600	0.98	76.60	22.02	0.40
7	730.75	36.06	2.26	34.72	18.34	289304843.5	145411200	0.98	76.60	22.02	0.40
8	730.75	36.06	2.26	34.72	18.34	95440773.12	38188800	0.98	76.60	22.02	0.40
9	730.75	36.06	2.26	34.72	18.34	290583068.2	278899200	0.98	76.60	22.02	0.40
10	730.75	36.06	2.26	34.72	18.34	136343961.6	54691200	0.98	76.60	22.02	0.40
11	730.75	36.06	2.26	34.72	18.34	18515904	134697600	0.64	76.91	21.26	1.19
12	730.75	36.06	2.26	34.72	18.34	22279488	169862400	0.64	76.91	21.26	1.19
13	730.75	36.06	2.26	34.72	18.34	2857536	10886400	0.64	76.91	21.26	1.19
14	730.75	36.06	2.26	34.72	18.34	31595520	98323200	0.64	76.91	21.26	1.19
15	730.75	36.06	2.26	34.72	18.34	11616000	57369600	0.64	76.91	21.26	1.19
16	730.75	36.06	2.26	34.72	18.34	4158528	52358400	0.64	76.91	21.26	1.19
17	730.75	36.06	2.26	34.72	18.34	10663488	92188800	0.64	76.91	21.26	1.19
18	730.75	36.06	2.26	34.72	18.34	6156480	17366400	0.64	76.91	21.26	1.19
19	730.75	36.06	2.26	34.72	18.34	20397696	47174400	0.64	76.91	21.26	1.19
20	730.75	36.06	2.26	34.72	18.34	51226560	363830400	0.64	76.91	21.26	1.19

The Río Grande de Patillas near Patillas was the largest basin that was examined. It had a minimal change in land use from 1977 to 1995. Agricultural land use decreased from 22.02 to 21.26 percent and urban development increased from 0.40 to 1.19 percent. It is interesting that the urban development appears to have occurred on land previously used for agricultural land. The changes in water and forest cover are relatively insignificant with less than a 0.40 percent change. Overall, the changes in land use do not appear to be numerically significant enough for the software to develop a correlation. The regression analysis may likely result in a weak correlation between land use and discharge.

4.2.3 Río Tanama near Utuado

Table 4.3 Basin characteristics for the Río Tanama neat Utuado.

STORM	CS Ft/mi	GS % rise	SP in/hr	DR in	DA mi^2	PCP ft^3	DSG ft^3	BDW %	FOR %	AGR %	UBD %
1	1231.93	31.00	1.16	57.58	17.98	123224851.20	23328000.00	0.88	86.42	10.09	.056
2	1231.93	31.00	1.16	57.58	17.98	98997592.32	27648000.00	0.88	86.42	10.09	.056
3	1231.93	31.00	1.16	57.58	17.98	134503057.92	77500800.00	0.88	86.42	10.09	.056
4	1231.93	31.00	1.16	57.58	17.98	223893288.96	14515200.00	0.88	86.42	10.09	.056
5	1231.93	31.00	1.16	57.58	17.98	155388625.92	84153600.00	0.88	86.42	10.09	.056
6	1231.93	31.00	1.16	57.58	17.98	243525722.88	87955200.00	0.88	86.42	10.09	.056
7	1231.93	31.00	1.16	57.58	17.98	159148028.16	28080000.00	0.88	86.42	10.09	.056
8	1231.93	31.00	1.16	57.58	17.98	59315013.12	18662400.00	0.88	86.42	10.09	.056
9	1231.93	31.00	1.16	57.58	17.98	287385415.68	57196800.00	0.88	86.42	10.09	.056
10	1231.93	31.00	1.16	57.58	17.98	60568147.20	18748800.00	0.88	86.42	10.09	.056
11	1231.93	31.00	1.16	57.58	17.98	170008523.52	36374400.00	0.82	79.1	19.74	.33
12	1231.93	31.00	1.16	57.58	17.98	175021059.84	29635200.00	0.82	79.1	19.74	.33
13	1231.93	31.00	1.16	57.58	17.98	114035201.28	3801600.00	0.82	79.1	19.74	.33
14	1231.93	31.00	1.16	57.58	17.98	696324837.12	203817600.00	0.82	79.1	19.74	.33
15	1231.93	31.00	1.16	57.58	17.98	23809547.52	15638400.00	0.82	79.1	19.74	.33
16	1231.93	31.00	1.16	57.58	17.98	214703639.04	39744000.00	0.82	79.1	19.74	.33
17	1231.93	31.00	1.16	57.58	17.98	386383008.00	93484800.00	0.82	79.1	19.74	.33
18	1231.93	31.00	1.16	57.58	17.98	168337678.08	37238400.00	0.82	79.1	19.74	.33
19	1231.93	31.00	1.16	57.58	17.98	143692707.84	52185600.00	0.82	79.1	19.74	.33
20	1231.93	31.00	1.16	57.58	17.98	106098685.44	59875200.00	0.82	79.1	19.74	.33

The Río Tanama near Utuado was the second largest basin that we examined. There was a general trend of land use change from forest cover toward agriculture and grassland. There was a decrease in forest land use from 86.42 to 79.1 percent, and a subsequent increase in agricultural land use from 10.09 to 19.84 percent of the basin. By comparison, where agricultural land use was nearly doubled in the basin, forest cover was decreased by only 8 percent. There was only a .27 percent change in land used for urban development. The changes in land use in this basin between 1977 and 1995 were intermediary in comparison with the other basins. The variance in the land use variable should be numerically significant enough to show a correlation between land use and discharge, however, it is expected that the correlation will not be as strong as in those basins where a more significant change in land use occurred.

4.2.4 Río Inabon at Real Abajo

Table 4.4 Basin characteristics for the Río Inabon at Real Abajo.

STORM	CS ft/mi	GS % rise	SP in/hr	DR in	DA mi^2	PCP ft^3	DSG ft^3	BDW %	FOR %	AGR %	UBD %
1	1170.52	43.10	1.29	40.07	8.80	61332480.00	39484800.00	1.71	51.53	46.76	0.00
2	1170.52	43.10	1.29	40.07	8.80	375559219.20	245635200.00	1.71	51.53	46.76	0.00
3	1170.52	43.10	1.29	40.07	8.80	47021568.00	19872000.00	1.71	51.53	46.76	0.00
4	1170.52	43.10	1.29	40.07	8.80	57652531.20	8899200.00	1.71	51.53	46.76	0.00
5	1170.52	43.10	1.29	40.07	8.80	40888320.00	7776000.00	1.71	51.53	46.76	0.00
6	1170.52	43.10	1.29	40.07	8.80	83821056.00	33609600.00	1.71	51.53	46.76	0.00
7	1170.52	43.10	1.29	40.07	8.80	75643392.00	18230400.00	1.71	51.53	46.76	0.00
8	1170.52	43.10	1.29	40.07	8.80	207712665.60	80870400.00	1.71	51.53	46.76	0.00
9	1170.52	43.10	1.29	40.07	8.80	97314201.60	33868800.00	1.71	51.53	46.76	0.00
10	1170.52	43.10	1.29	40.07	8.80	168664320.00	45792000.00	1.71	51.53	46.76	0.00
11	1170.52	43.10	1.29	40.07	8.80	367994880.00	81907200.00	1.71	85.86	10.15	2.28
12	1170.52	43.10	1.29	40.07	8.80	148629043.20	39312000.00	1.71	85.86	10.15	2.28
13	1170.52	43.10	1.29	40.07	8.80	92407603.20	27388800.00	1.71	85.86	10.15	2.28
14	1170.52	43.10	1.29	40.07	8.80	102220800.00	45878400.00	1.71	85.86	10.15	2.28
15	1170.52	43.10	1.29	40.07	8.80	42523852.80	3196800.00	1.71	85.86	10.15	2.28
16	1170.52	43.10	1.29	40.07	8.80	30257356.80	6912000.00	1.71	85.86	10.15	2.28
17	1170.52	43.10	1.29	40.07	8.80	165393254.40	18498240.00	1.71	85.86	10.15	2.28
18	1170.52	43.10	1.29	40.07	8.80	153331200.00	17798400.00	1.71	85.86	10.15	2.28
19	1170.52	43.10	1.29	40.07	8.80	120620544.00	31881600.00	1.71	85.86	10.15	2.28
20	1170.52	43.10	1.29	40.07	8.80	197490585.60	138214080.00	1.71	85.86	10.15	2.28

The Río Inabon at Real Abajo was the smallest basin in our study. In this basin, there was an extremely significant change in land use between 1977 and 1995. Forest cover increased from 51.53 to 85.86 percent. Agricultural land use decreased astoundingly from 46.76 to 10.15 percent of the basin acreage and urban development increased from zero to 2.28 percent. According to Ron Richards of the USGS, the increase in forest cover may be attributed to the loss of the coffee industry in the area, a typical example of the transition from an agricultural to an industrial economy in Puerto Rico. Forests, initially covering only a small portion of the agricultural land to protect the coffee, prevailed as the agricultural land was abandoned. The movement to the city may account for the increase in urban development.

4.2.5 Río Portugues near Ponce

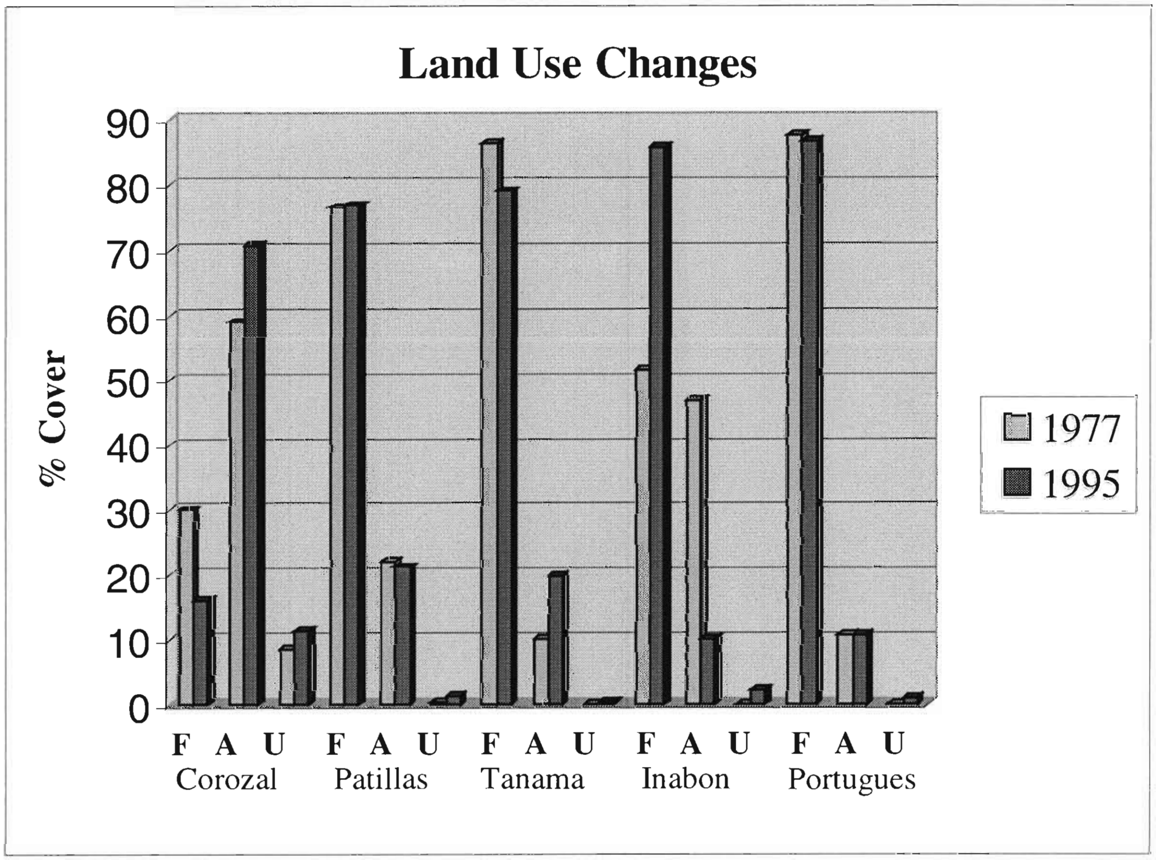
Table 4.5 Basin characteristics for the Río Portugues near Ponce.

STORM	CS ft/mi	GS % rise	SP in/hr	DR In	DA mi^2	PCP ft^3	DSG ft^3	BDW %	FOR %	AGR %	UBD %
1	1187.36	47.01	1.30	48.09	9.68	83356648.32	1261440.00	1.38	87.65	10.84	0.13
2	1187.36	47.01	1.30	48.09	9.68	262037677.44	233712000.00	1.38	87.65	10.84	0.13
3	1187.36	47.01	1.30	48.09	9.68	47731770.24	3715200.00	1.38	87.65	10.84	0.13
4	1187.36	47.01	1.30	48.09	9.68	38686391.04	26092800.00	1.38	87.65	10.84	0.13
5	1187.36	47.01	1.30	48.09	9.68	94350263.04	18662400.00	1.38	87.65	10.84	0.13
6	1187.36	47.01	1.30	48.09	9.68	51489081.60	26265600.00	1.38	87.65	10.84	0.13
7	1187.36	47.01	1.30	48.09	9.68	23100506.88	2877120.00	1.38	87.65	10.84	0.13
8	1187.36	47.01	1.30	48.09	9.68	47453450.88	11240640.00	1.38	87.65	10.84	0.13
9	1187.36	47.01	1.30	48.09	9.68	31589247.36	13392000.00	1.38	87.65	10.84	0.13
10	1187.36	47.01	1.30	48.09	9.68	141386234.88	11491200.00	1.38	87.65	10.84	0.13
11	1187.36	47.01	1.30	48.09	9.68	57194628.48	34819200.00	1.41	86.71	10.87	1.01
12	1187.36	47.01	1.30	48.09	9.68	34094121.60	28684800.00	1.41	86.71	10.87	1.01
13	1187.36	47.01	1.30	48.09	9.68	30615129.60	2246400.00	1.41	86.71	10.87	1.01
14	1187.36	47.01	1.30	48.09	9.68	27831936.00	3369600.00	1.41	86.71	10.87	1.01
15	1187.36	47.01	1.30	48.09	9.68	93097825.92	47088000.00	1.41	86.71	10.87	1.01
16	1187.36	47.01	1.30	48.09	9.68	46201013.76	13564800.00	1.41	86.71	10.87	1.01
17	1187.36	47.01	1.30	48.09	9.68	104369760.00	59339520.00	1.41	86.71	10.87	1.01
18	1187.36	47.01	1.30	48.09	9.68	84191606.40	64627200.00	1.41	86.71	10.87	1.01
19	1187.36	47.01	1.30	48.09	9.68	146813462.40	18282240.00	1.41	86.71	10.87	1.01
20	1187.36	47.01	1.30	48.09	9.68	134428250.9	217710720	1.41	86.71	10.87	1.01

The Río Portugues was the second smallest basin that we examined. In this basin, there were not significant changes in land use between 1977 and 1995. Urban development changed by almost a factor of 8 from 0.13 to 1.01 percent of the basin. The subsequent decrease was seen in forest cover. These changes, although they are significant in themselves, are relatively insignificant when the entire basin area is taken into account. This may result in a poor correlation between the land use variables and discharge. The changes in land use are comparable in magnitude to the Río Grande de Patillas near Patillas.

The following is a chart depicting land use changes between 1977 and 1995 across all 5 basins, for direct comparison. The letters F, A, and U stand for forested area, agricultural land and pastures, and urbanized areas, respectively.

Figure 4.1: Basin Land Use Changes Between 1977 and 1995



4.3 Multiple Regression Analysis Results

The multiple regression analysis performed in Statit®, statistical analysis software, was all-possible subset regression. The method used by Statit®, Mallow's Cp, provided the best model with n parameters, as described in the Methodology. Mallow's Cp is an estimate of the standardized mean square error of prediction. The Mallow's Cp value calculated by the software is a measure of the validity of the model. Any model with a Cp less than or equal to the number of variables in the model should be entertained. The software calculated a R^2 value, which is a measure of the linearity of the relationship between the data. An R^2 value of 1 is ideal, implying a completely linear relationship between the dependent and independent variables. The software calculated an adjusted R^2 value. The R^2_{adj} value is a way of re-scaling R^2 so those models involving different numbers of degrees of freedom can be compared. The best models have a R^2_{adj} near R^2. The software calculated a P(t) value, which is a measure of the confidence level of the correlation between the independent and dependent variables. The actual confidence level is 1 – P(t).

The first set of analyses served to determine the significance of the land use variables in correlation to storm discharge in each individual basin. The second set provided a comparison between all 5 basins and determined the significance of other physical aspects of the basin, such as channel slope, ground slope, soil permeability, depth to bedrock, and drainage area.

The first analyses resulted in an obviously significant correlation between precipitation and discharge, as well as a correlation between all of the land use variables and discharge. When a correlation analysis was performed, there was only a 31 percent correlation between each of the land use variables and the discharge amount. However, when the independent variable of precipitation was added, the land use variables became significant. The reader should be aware that these results were found to the best of our ability with the available data.

In the Río Cibuco basin below Corozal, there was a strong correlation between all land use variables and discharge, on an 85 percent confidence interval. The precipitation correlated to the discharge with 99 percent confidence. The forest cover variable held the linear relationship with discharge with the lowest standard error, 0.7470040. The multiple R square value was 0.9197842. A multiple R square value of 1 would indicate a completely linear correlation, as would a standard error equivalent to the standard deviation of the independent variable.

In the Río Grande de Patillas and Río Portugues basins there was an almost insignificant change in land use between 1977 and 1995. This minimal change was reflected in the regression analysis, which showed a relatively weak correlation between the land use and discharge. In the Río Portugues basin, the relationship was shown with 68 percent confidence. The R^2 value was 0.702, demonstrating a relatively weak linear relationship. In the Río Grande de Patillas basin, the results were extremely weak. The confidence of the relationship between land use and discharge was only 10 percent and the associated standard error was 125.156. The R^2 value was only 0.278. These results are a definite indication of poor data used in the regression and should be disregarded. In the Río Tanama near Utuado basin, there was a relatively small increase in urban development, only a 7 percent decrease in forest cover, and a 9 percent increase in agricultural land and pasture cover. The correlation between the land use variables and the discharge was only shown on a 63 percent confidence level. It became evident that the magnitude of land use change had a considerable impact on the strength of correlation between the land use and discharge variables. The varying degree of correlation as a function of land use change gives substance to our analysis in that the software did not develop a false correlation between the land use and discharge variables. Where land use did not change significantly, since there was no significant numerical evidence of a change, there could be no subsequent statistical evidence. However, where there was a reasonable change in land use, the analysis showed statistical significance between the land use and discharge variables. The detailed analyses are shown in Appendix D: Statit® Multiple Linear Regression Analysis Results.

In the Río Inabon at Real Abajo basin, where there was a notable increase in forest cover, there was a definite correlation between land use and discharge. The best model with two parameters included agricultural cover, precipitation, and discharge. Precipitation correlated to discharge with 99.92 percent confidence and a standard error of 0.1098303. Agricultural cover correlated to discharge with 98.33 percent confidence and a standard error of 0.1299856. The other land use variables, forest cover, and urban development, showed a correlation to discharge of equivalent strength, however, with a more significant standard error. The multiple R square value was 0.9859524, revealing an exceptional linear fit of the log transformed data.

The second analysis resulted in an apparent correlation between drainage area and ground slope in some cases. The correlation between land use variables and discharge was not as significant. The strongest correlations resulted between discharge and drainage area, discharge and ground slope, discharge and channel slope, and discharge and urban development in four separate regressions with precipitation as a constant independent variable. The correlation between discharge and ground slope was shown in the 1977 basin data on an 83 percent confidence level, with a standard error of 1.178949. The correlation between discharge and urban development was shown in the both data sets, 1977 and 1995, on an 83 percent confidence level. The standard error was less than 0.33 in both time periods and the R^2 values were 0.715 and 0.77 for 1977 and 1995 respectively. These correlations were notable enough to indicate significance of the variables in a discharge model. A correlation between discharge and channel slope was found in both 1977 and 1995. In 1977 the relationship was shown with 79 percent confidence, a standard error of 0.799, and an R^2 value of 0.858. In 1995 the relationship was shown with 83 percent confidence, a standard error of 1.487, and an R^2 value of 0.783. There was also a strong correlation shown in the 1995 basin data between discharge and drainage area on a 95 percent confidence level, however with a standard error of 2.937486.

4.4 Regression Equation Development

The regression equations were developed directly from coefficients and exponents provided as a result of the multiple regression analysis, by Statit®. The local regression equations for each individual basin could only be developed where the land use variables were found to be significant in the model. The coefficients and exponents provided by the software were in log form since the variable data was input in log form. In all of the following regression equations the log form of each variable must be used to calculate the discharge, Q. The regression equations are functions of the following variables:

Precipitation (P), Percent Forest Cover (F), Percent Agricultural Cover (A), Percent Urban Development (U), Channel Slope (CS), Ground Slope (GS), and Drainage Area (DA).

The following are the final local regression equations for calculating the discharge, Q, as a function of land use and precipitation.

Río Cibuco below Corozal $Q = -7.6554\ P^{2.1122}F^{-1.4373}$

Río Inabon at Real Abajo $Q = -7.6276\ P^{1.5018}A^{0.6312}$

The following are the final regional regression equations for calculating discharge, Q, as a function of channel slope, ground slope, drainage area, land use, and precipitation.

1977 $Q = -21.846\ P^{3.1245}CS^{1.4127}$

$Q = -12.4100\ P^{1.9708}GS^{2.4752}$

$Q = -14.5817\ P^{2.7579}UBD^{-0.4665}$

1995 $Q = -23.1180\ P^{2.6440}CS^{3.1704}$

$Q = -85.1918\ P^{13.0253}DA^{-11.7089}$

$Q = -0.6428\ P^{1.008}UBD^{-0.6914}$

Some physical aspects of the basins appear to be significant in 1977 but not in 1995. It could be argued that this is attributed to the basin conditions during the storms that we selected. During some of the storms in 1977, the soil saturation may have been lower than during the storms of 1995. If the soil saturation were lower, the infiltration rate would be such that the ground slope did not have a significant effect on the volume of runoff resulting in discharge. Conversely, if the soil were at its maximum saturation capacity, the ground slope would have a significant effect on discharge since all the rainfall would result in runoff. This same argument holds true for drainage area and channel slope. A more consistent method of storm selection would take all current basin conditions into account, so as not to introduce this uncertainty.

4.5 Sources of Error

There were several sources of error in our analysis, which need to be addressed. The first source of error was in our data gathering. We selected ten storms over a five-year period around the time of study (i.e. 1975-1979 for the 1977 study) from the NOAA rainfall distribution tables, then found the discharge data from the USGS discharge tables corresponding to the dates of the rainfall. The problem with the correlation was the rainfall data was the total daily rainfall for the basin, and the discharge data was the mean daily discharge. We did not know at what time of the day the storm began or ended, so we could not accurately correlate the rainfall data to the discharge data. There is also a time lag between the initial rainfall and the resulting discharge downstream due to infiltration, meandering of the river, and slope of the catchment. The result is a slight discrepancy in the compatibility of the acquired rainfall and discharge data. There were basins in which some precipitation and discharge data were either not available or estimated.

The second and one of the most important sources of error occurred when we assumed that rainfall was constant over the basin area. This, in fact, is very unlikely. Since the topography of the basin is very different over the area, the rainfall distribution will vary accordingly. If a storm is moving in from the east, and the basin has plains on the eastern side and mountains on the western, more rain will fall when the storm reaches the mountains. The change in elevation, and therefore a change in temperature, will cause the water vapor to condense more rapidly when over the mountains than it would over the plains. This would result in more precipitation and discharge over the western portion of the basin than over the east. We assumed an even distribution over the basin area because it was the only data available. When the data was gathered, it was gathered at one or two stations in the basin. Since there was an insufficient number of data-gathering stations, there was no way to accurately gauge the rainfall in separate portions of the basin. Due to the uncertainty in the accuracy of the data, we requested the opinion of Dr. Matthew Larsen on the subject. He recommended that we use a constant rainfall over the basin since there was no way to accurately distribute it over specific portions.

Another source of error had to do with the saturation of the soil at any rainfall event. The storms were selected on the basis that would allow for comparable rainfall amounts across the basins in addition to limitations due to the records of discharge data. The time period surrounding the storms was not considered, which means that the storms could have occurred during a wet period or a dry period. This would be indicative of how saturated the soil was at the time that the storm occurred. If we consider two storms of comparable magnitude that occur at different periods of "wetness", the hydrologic response will be different for them since the soil saturation will be different for each storm. We would expect to see more runoff for the storm for the storm during the "wet" period, since less water would be able to infiltrate. In acquiring land use data, there was some error associated with delineating the basins. The 1977 land use data was developed from aerial photographs, which were taken at 2,000 feet and were not corrected for vertical displacement. The 1995 land use data was developed from DOQQs, which were taken at 20,000 feet and corrected for vertical displacement. The DOQQs were combined to form a DOQ, which has a 1-meter resolution on a 7.5-minute by 7.5-minute photograph, clearly superior to the resolution of the aerial photographs used in 1977.

The largest source of error in the acquisition of land use data was human error involved in the delineation of the land use within the basins, since interpretation of the photograph or DOQ is left to the discretion of the GIS software user. Although the DOQs had a high resolution, it was still difficult to discern different land uses. Areas that are actually short forests may look very similar to cropland in a DOQ. This may cause the GIS user to mislabel the area, leading to incorrect data.

Another source of error in the land use data acquisition was the interpretation of the 1977 land use. The company that was hired to digitize the 1977 photographs was instructed to include projected development. In many cases, there were areas zoned for urbanization that were never actually urbanized. Since, in 1977, they expected that the urbanization would take place, they classified the area as if it were urbanized. When we began to evaluate the data for 1977, we originally took the land use at face value because we did not have any maps or photographs to verify the land use data and had to work strictly with the available data. Unfortunately, due to the errors caused by the misclassification, our data was very inaccurate. We were seeing an increase in forested area and a decrease in pastures and urbanized area. Since this did not follow our hypothesis that urbanization increased from 1977 to 1995, we had to reevaluate the 1977 data. After inquiring to several members of the USGS staff, Mr. Richard Webb was able to assist us in solving our problem. He revealed the land use codes that were inaccurately classified in the 1977 data, including medium and low-density rural areas, which were houses in the middle of large fields or pastures. We decided to classify this land as pasture, since most of the area was permeable, which significantly increased the accuracy of our data, however, by manipulating 1977 land use codes to fit our categorizations for land use. However, error is introduced due to the lack of consistency between 1977 and 1995 classification methods.

Chapter 5: Conclusions and Recommendations

The conclusions of this report have been drawn by the project group with the guidance of the USGS staff. The recommendations that follow represent the opinions of the IQP project team and do not necessarily reflect those of any agency involved with this study. Some key issues in the conclusions and recommendations are pollution, flood planning, flood prevention, and flood recovery.

5.1 Implications in the USGS Project

A multiple linear regression model was used to examine data for several storms in each basin. Regression analyses were also performed using all basins simultaneously to determine the significance of the relationship between the physical aspects of each basin and discharge. The focus of the analysis was to find the strength of the correlation between the increase in urbanization and deforestation within each basin between 1977 and 1995 and the amount of discharge resulting from a particular amount of rainfall during a storm event. The strength of the linear relationship between the dependent and each of the independent variables was determined by the regression analysis. The standard error of estimate was calculated for the regression analysis to determine the accuracy of the linear relationship. Regression equations were ultimately developed for estimating storm peak discharge amounts in each basin as functions of the variables with the strongest relationship to the dependent variable.

The results of this project are important to the USGS because they show that land uses have a significant effect on discharge. Because it is generally accepted that runoff has an impact on flooding and water quality, we can conclude that land use should be considered in those studies. The USGS may now chose to include the land use variable in future discharge and flood modeling. The anticipated future increase in urban sprawl and urbanization in Puerto Rico raises extremely controversial issues, pitting the need for housing developments against the increased risk of flooding from increases in storm discharge amounts.

5.1.1 Significance of Land Use in Hydrologic Modeling

One of the original goals of our project was to develop a correlation strictly between the loss of permeable land through urbanization and basin discharge. However, after calculating the percent area of our four land use classifications and running trial statistical analyses, we discovered that generally, urbanization was not the only significant factor relating to discharge. We then decided to analyze the significance of forest cover, agricultural cover, and urban development. The analyses demonstrated that all four land use variables are related to discharge. All four land use variables are related to basin drainage, in part, because they are related to each other. That is, the four categories of land use, by definition, make up 100 percent of land uses in the areas we studied. A decrease in one type of use must be offset by and increase in one or more of the others. For instance, a decrease in forest cover directly resulted in an increase in agricultural and pasture cover or urban development.

In most cases, the changes in types of permeable land were from forested area to agriculture or pasture. In our opinion, a small change from permeable to impermeable land can be as significant as a large change between forest and agriculture or pasture cover. Although the change in permeable land, from forest to agricultural cover for example, took place over a larger area, the land still has some degree of permeability and some infiltration still occurs.

The statistical analysis tends to be less meaningful when there is only a small change in an important variable. In our project, we were surprised to learn that there was relatively small change in the amount of impermeable land over this period of the study. The small change from permeable to impermeable land may have led to some error in our statistical analysis, but we believe such error would not change our conclusions. A change from permeable to impermeable land use results in no infiltration whatsoever, so all precipitation that falls on the impermeable land becomes runoff. This is why a small area becoming impermeable can have the same affect on runoff and discharge as a large area simply becoming less permeable.

When we analyzed all the basins simultaneously, we found that the basin drainage area, ground slope, channel slope, and urban development were significant in our model. In the case of urban development and ground slope, where the relationship to discharge was shown in one time period but not in the other, it could be argued that this is due to our storm selection. For example, if the storms in the 1995 all basin regressions occurred during a wet period, where the soil saturation may have been at its maximum capacity, the drainage area would have a significant effect on the rate of discharge. A steeper slope in the basin would cause the runoff to flow into the river much more quickly, resulting in discharge at a much higher rate, than if infiltration were occurring. Also, because rainfall would no longer be infiltrating the soil, a larger basin area would result in a greater amount of discharge.

These variables were expected to be significant to discharge because the hydrology literature suggests that they are critical factors relating to basin discharge rates. Because they were constant within each basin they were not included in the individual basin regression analysis, since a correlation would already be implied. We included these in the analysis to determine their significance in a comparison of basins and because a hydrologic study based only on land use practices would obviously be incomplete.

After conducting this research, we conclude that land use is a significant variable in hydrologic studies, specifically those pertaining to runoff, discharge, and flooding. Although our findings were not as conclusive as we anticipated, we believe that the correlations support our conclusion. Many of the studies and the modeling done by the United States Geological Survey could benefit from the addition of the land use variable, especially if a statistical analysis is involved. Since the rate of urbanization and deforestation in some areas of Puerto Rico are increasing at a seemingly exponential rate, land use variables are rapidly becoming a necessity in analyses. Since a correlation between land use changes and discharge has been shown, studies involving flooding, sediment loading, and water quality, would also benefit from the integration of the land use variable. Possibly one of the greatest benefits of our research was the development of predictive regression equations. It may now be possible to use regression equations as predictors of discharge as a function of precipitation and land use. Further studies would have to be conducted to determine the significance of other physical aspects of the river basins in the regression models. However, the regression equations we developed can still serve to estimate the effect on discharge given a change in the percentage cover of a certain type of land use.

5.1.2 Environmental Consequences of Land Use Changes

When considering the effects of land use change on the hydrologic cycle, it is important to also take into account the effects of these changes on the environment. These include impacts on the physical, chemical, and biological components of the environment, all of which are very sensitive to change. The increase in runoff resulting from land use changes causes chemicals, particulate matter, and biological agents to be introduced into the watershed. The increase in these elements often causes a detrimental effect on the watershed.

There are many important cycles, including the phosphorus and nitrogen cycles in the biological process of an ecosystem within a watershed. These cycles are found in every type of ecosystem and cause chemical transformations of certain molecules so as to be useful to the microorganisms and plants of the area. These useful forms for growth of flora of nitrogen and phosphorus molecules are often limiting agents in the growth of microorganisms and plants. Commercial fertilizers often contain high concentrations of the useful forms of these chemicals. When there is an increase in runoff that comes from grassy areas treated with fertilizers, such as agricultural fields or residential lawns, the useful forms of the chemicals are introduced into the watershed. This causes an increase in the growth of microorganisms and plant life that use other important chemicals needed for the growth of other plants and microorganisms, which eventually die due to a lack of these nutrients. The result is a disruption of the ecosystem and the subsequent death of other organisms, since an ecosystem consists of inter-reliant species.

Other chemicals introduced by runoff into surface water include pesticides and other toxic chemicals. These chemicals often poison many organisms at various levels of the food chain in the ecosystem. The pesticides kill algae and other small plant life and insects, which are at the bottom of the food chain. Since the base of the food chain is depleted, a chain reaction occurs in which many of the organisms higher up on the food chain will die of starvation. As for the toxins, they build up in the organisms of the food chain and cause death due to poisoning. If the consequences of pollution are severe enough, a whole species may be wiped out of an area. When the overall number of species decreases in an area, the biodiversity decreases, which is obviously very detrimental to the ecosystem of that watershed.

With an increase in runoff, there is often an increase in the amount of suspended particulate matter. SPM content is an important water quality indicator since it is indicative of the turbidity or the ability of light to pass through the water. If there is an increase in SPM, light cannot pass through the water and reach the algae. This too causes a collapse of the ecosystem since the algae cannot create its own food through photosynthesis. This SPM may also lead to an increase of sedimentation which might, in turn, effect the course of a river by leading to a change in the flow pattern of water, which has a new set of problems associated with is. Some organisms may need a specific flow pattern in order to thrive and therefore the change in the course of the river would be detrimental to that specific organism and any other organisms that are dependent on it.

An increase in SPM also displaces the dissolved oxygen of the water. Dissolved oxygen is another important factor in determining water quality since it is needed for the fish life of the ecosystem. Within the runoff, there are also other chemicals that are capable of being oxidized. The dissolved oxygen then reacts with these chemicals, which causes a further depletion in the dissolved oxygen of the water. The Biochemical Oxygen Demand (BOD) is the amount of oxygen needed for all life and chemical processes in a water system.

Other chemicals introduced are in a reduced form, which means they will not react with any other chemicals, or they are likely to react with an oxidant. This leads to a depletion of the dissolved oxygen due to an increase in the BOD and a decrease in water quality.

Another important factor to consider is the introduction of biological elements. This usually takes the form of coliform bacteria, a pathogenic agent, from fecal waste from animals. These bacteria then overtake the body of water and kill off the other organisms of the area. This occurs by either choking out the existing microorganisms or by infecting the animals of the area and subsequently killing them. Often, the storm water from catch basins is mixed with sanitary sewer systems, and in times of heavy rain, the treatment systems are overloaded. This leads to the release of raw sewage into the watershed system, which again introduces a wide variety of biological and chemical pollutants.

All of the consequences of an increase in pollutants affect people in several ways. First, the natural beauty of a watershed dies with each species eliminated from a watershed's ecosystem due to pollution. Secondly, if a body of water does not meet strict standards for water quality, then it cannot be used for recreational purposes such as swimming or fishing. Finally, the increased amount of pollutants may contaminate the drinking water supplies and potentially make people ill.

5.2 Land Use Recommendations

The following are recommendations developed by the project team based on interviews with FEMA and the urban planning board of the government of Puerto Rico. It is important to make clear that the public must actually resolve this land use problem through political reform. Change must ultimately come through grass roots political movements arising from concern over the land use approval process.

5.2.1 Spatial Arrangement of Land Use Changes

As mentioned earlier, urban development often occurs where most economically convenient, such as near existing infrastructure or roads. Since development is prohibited in the flood plain, the result is often urban development on steep hillsides in the river basin. One of the criteria for approval of a new development by the urban planning board is topography; if the development is to occur on a slope greater than 35 percent, it will not be approved. However, cost efficiency and construction feasibility often leads to illegal development. The lack of an economic incentive compelling builders to follow the recommendations of the Department of Natural and Environmental Resources and the Administration of Regulations and Permits presents a serious problem. Urban planning and actual urban development is not well coordinated.

To reduce the effects that result from the loss of permeable land, urban development must not occur on steep slopes where a greater effect on runoff will occur due to the lowered infiltration rate. Although the objectives of the planning board and other agencies for strategic urban planning are difficult to achieve and may seem lofty and ideal, the urban planning board must take dutiful care to ensure that developments follow all local agency and government regulations.

5.2.2 Urban Development Approval Process

The current approval process for urban development, followed by the urban planning board, involves the evaluation of several criteria at the proposed site and recommendations from other agencies. The criteria provided by ARP's Regulation 4 include topography, flood susceptibility, and land use. Areas prone to flooding are generally not to be developed and natural areas such as lagoons and forests are protected. These regulations are reflected in the objectives and public policies of the planning board under Law 75 of the government of the Commonwealth of Puerto Rico. The committee within the planning board, that ultimately approves or disapproves of urban development, consists of only four representatives: a President, José R. Caballero Mercado, Vice President William Figueroa Rodriguez, Associate Member Norma E. Burgos Andújar, and an Alternate Member Maria Gordillo. Several agencies, including the Department of Natural and Environmental Resources (DNER) and Administration of Regulations and Permits (ARP), make suggestions and recommendations, however the Junta has the authority to make the final decision. We recommend the implementation of a more integrated process for urban planning and development approval, a process incorporating the suggestions and recommendations of all agencies directly involved. This integration would assist in assuring that the regulations of the planning board are successfully followed. There is more to urban development than just cost efficiency, as demonstrated in planning board objectives and public policies.

5.2.3 Buffer Zones

According to representatives at the Junta de Planificacion, buffer zones, also referred to as "green belts," were developed on the island, but were then disregarded and bulldozed over. The "green belts" serve to filter runoff from the urban area, recharge ground water, and somewhat limit urban development. "Green belts" should be implemented around all metropolitan areas and any forest cover existing between cities should be maintained. This idea of implementing greenbelts seems to be a popular one among the general public of the US. In a Time magazine poll, 57 percent of the respondents said that they favor creating a "green belt" zone consisting of undeveloped land around areas of development (Lacayo, 1999). According to Phil Robakiewicz, an Ecologist at WPI, a greenbelt as wide as only 10 meters will have a significant effect on the reduction of pollutants introduced into a water system. The greenbelts serve not only as an effective means of filtration, they also provide a more aesthetically pleasing environment.

A second type of buffer zone that should be considered is a treatment wetland. The use of these wetlands to treat waste has been tried extensively in Europe with great success. Researchers have shown that nitrate levels can be reduced from 150 mg/l to under 10 mg/l through the natural process of the nitrogen cycle. Other studies have shown that Biochemical Oxygen Demand has been reduced by 73 percent, SPM by 72 percent, and phosphorus levels by 56 percent (Cole, 1998).

There is some opposition to using wetlands as a method to treat water. Critics say that the processes by which the wetlands purify the water are not completely understood. At the present time, the EPA does approve wetlands on a case by case basis and does not have a policy on the widespread use of wetlands. Constructed wetlands work well for treatment of pollution from non-point source factors. The construction of several small wetlands could be used to study the process by which the wetlands purify the water in addition to purifying the runoff before it enters the streams of the watershed. Based on the findings of these studies, the decision could then be made on whether to use this technology on a wide scale.

5.3 Flood Prevention

Throughout history, people have settled next to waterways because of the advantages they offer in transportation, commerce, energy, water supply, soil fertility, and waste disposal. Despite these benefits, however, the attraction of settling along rivers and streams has its disadvantages. According to FEMA, floods have caused a greater loss of life and property and have disrupted more families and communities in the United States than all other natural disasters combined. In Puerto Rico, 3940 deaths have been associated with flooding between 1899 and 1988 as well as $692 million in damages (USGS-NWS88, 1991). The United States, as it moves into the 21st century, is at a crossroads in the use of its floodplains. The nation may choose to use these flood-prone lands for the primary purpose of economic development, or it may take action to better balance our economic and environmental needs (FEMA, 1999).

5.3.1 Flood Plain Management and Flood Planning

Floodplain management is defined by FEMA as a decision-making process in an attempt to achieve prudent use of floodplains. Floodplain management attempts to achieve a reduction in the loss of life, disruption, and damage caused by floods; and the preservation and restoration of the natural resources of the floodplains. To achieve the objectives of floodplain management, the nation must adopt a new approach that takes advantage of all methods available to reduce susceptibility to damages and to protect and enhance the natural resources of the floodplain. This approach would achieve floodplain management by:

- avoiding the risks of the floodplain,
- minimizing the impacts of those risks when they cannot be avoided;
- mitigating the impacts of damages when they occur; and
- accomplishing the above in a manner that concurrently protects and enhances the natural environment.

The National Flood Insurance Program (NFIP) has played an important role in the application of the principles of flood plain management. Flood insurance is available to flood prone communities through the NFIP, which is administered by the Federal Emergency Management Agency. Prior to the NFIP, flood insurance was not generally available and state and local governments did not regulate flood plain management. Communities depended on the construction of flood control projects such as levees and dams to reduce flood damage. According to the NFIP, despite the expenditures of billions of dollars for these flood control projects, annual flood damages and disaster assistance costs were increasing at a rapid pace. In response to this worsening situation, congress created the NFIP in 1968 to reduce flood losses and disaster relief cost by guiding future development away from flood hazard areas where possible. The NFIP required flood resistant design and construction, and the transfer of the costs of losses to flood plain occupants through flood insurance premiums (FEMA, 1999).

The NFIP was modified by the Flood Disaster Protection Act of 1973, which requires the purchase of flood insurance as a condition for receiving any form of Federal financial assistance. According to the NFIP, flood plains have been mapped in 20,000 communities and over 18,400 communities now participate in the program. Many States and communities have established floodplain management programs and adopted regulations that go beyond NFIP requirements.

The National Flood Insurance Reform Act (NFIRA), signed into law in 1994, strengthened the NFIP by providing for mitigation insurance and establishing a grant program for State and community flood mitigation planning projects. The NFIRA also conceived the Community Rating System (CRS), established objectives for CRS and directs that credits be given to communities that implement measures to protect floodplains. The CRS is an incentive program in which communities that exceed the minimum requirements of the NFIP receive reductions in the flood insurance premiums for their residents. Approximately 940 communities in the United States are currently participating in CRS. The policies in the CRS communities represent over 60 percent of all NFIP flood insurance policies currently in place.

Examples of flood mitigation include elevating homes above the base flood level, relocating homes out of the floodplain, and minimizing the susceptibility to flood damage through both structural and nonstructural means.

The costs associated with disaster relief from insurance claims present another significant social impact from urbanization in low-lying flood plains. As of April 1999, the total value of all claims in Puerto Rico paid under the National Flood Insurance Program (NFIP) was $79,884,016. According to John Carrasquillo, an NFIP representative, also assigned to FEMA, for Hurricane Georges hazard mitigation, rates are based on the predominant flood occurrence interval within an area. In Puerto Rico, there are 434,000 inhabitants in areas subject to a 100-year flood occurrence and 145,000 in areas prone to a 500-year flood occurrence. Participation in the program is voluntary. There are currently 145,261 flood insurance policy holders (FEMA, 1999).

Typically, the urban planning board does not approve development in floodways, and the majority of new developments in floodways are illegal. There are, however, frequently small villages of shanty houses, which cannot sustain the damage brought by hurricanes and floods in such locations. According to Bonnie Galvin, Officer of Management and Budget at the US Department of Agriculture, National Resources and Conservation Service, it is often more cost effective to purchase land and move inhabitants out of the flood plain than to implement levees or other flood control system. The inherent difficulty is that the inhabitants are settled in the flood-prone area and it is not as simple as just removing the inhabitants. The government of Puerto Rico does make an effort to keep inhabitants out of extremely flood-prone areas, however other measures should be taken to ensure the well being of all inhabitants. The government of

Puerto Rico should implement a public awareness campaign, pertaining to the effects of urbanization on discharge and flooding.

An excerpt from the FEMA web site, addressing the issue of flood mitigation can be found in Appendix F. The document includes flood preparation and management guidelines.

5.4 Recommendations for Government Action

This portion of the project addresses some changes recommended to various government agencies to help mitigate the detrimental effects of land use change. We believe that without public awareness, reform cannot take place. If the public becomes more aware of what is happening to the environment, then enacting laws and regulations will become much easier, as will following them.

5.4.1 Public Awareness

One large problem is that the general public is not fully educated on many issues associated with urbanization. The government of Puerto Rico should launch a public awareness campaign that educates citizens about the dangers of building in certain areas, such as on steep slopes and in flood plains. The program should include information about the benefits of flood insurance and provide information on how to acquire flood insurance. The program might also educate the inhabitants of Puerto Rico about survival techniques in the case of a flash flood, as does FEMA. It should provide a brief flood history of the island, flood statistics, and flood plain management techniques. Information on the locations of all emergency shelters and the telephone numbers of important relief organizations should be included. We believe that an educational program such as this would ultimately reduce property damage and potential loss of life.

A second pamphlet containing information concerning pollution as a result of urban development should also be produced. This should include the types of pollution that are found in each municipality. It should enlighten people on how to reduce the amount of pollution that they might inadvertently introduce into runoff. Suggestions could be made regarding the moderation of the amount of fertilizer used on lawns to reduce nitrates and phosphates. Another pollutant that should be considered is motor oil and suggestions should be made to tell consumers where they can properly dispose of it.

The pamphlets should be sent out to the general public and made available at any government building that interacts with the public, such as city hall or post offices. If the resources are available, this information should also be made available in television and radio commercials to reach more of the public. In addition to the aforementioned information, all FEMA and NFIP regulations and suggestions for Flood Plain Management should be followed. The importance of having flood insurance through the NFIP should be stressed seeing as it would make it easier to allocate funds to victims after a disaster has occurred. Also, the money gathered from insurance premium payments could be invested by the government and money could be taken out of these funds after a disaster has occurred. This would help to decrease the amount of taxpayer dollars needed to assist flooding victims since the money from premium payments would earn interest and could be used instead of government funds to assist victims.

Unfortunately, there is insufficient time for the project team to develop detailed plans for the development of the aforementioned informational pamphlets or the implementation of the public awareness program. However, we feel that education is a key component in environmental awareness and the reform of current land use practices. We strongly suggest the implementation of an educational program as mentioned above.

5.4.2 Water Quality Management Plan

When considering plans for water quality management, it is imperative to take into account many factors including the local community's opinion, economic factors, and the feasibility of implementing a plan. The plans must accurately model the effects of any change made to the current system on the local inhabitants, the local economy, and the environment. Mathematical models are used to predict these changes, but water quality planners must use these models very carefully since a small miscalculation can have a very large impact on any of the factors mentioned above. The models would have to be selected carefully since each model works well for a specific situation.

A good plan should include the following course of action:

- Determine of a cause and effect relationship between waste and water quality of discharge
- Create specific objectives of the water quality desired to be obtained
- establish a realistic set of objectives created by a local water user advisory board
- Analyze the analysis in order to determine which set of objectives is most agreeable to the members of the water user advisory board
- Formulate final recommendations which are turned over to the decision making bodies of the local government

This course of action was followed in a Delaware River Estuary water quality management campaign in 1967 (Thomann, 1972). A three board system was created: a Policy Advisory Committee, a Technical Advisory Committee, and a Water Use Advisory Committee. The Policy Advisory Committee was made up of state, federal, and water regulation agencies. The Technical Advisory Committee was made up of state, federal, municipal and technical experts. The Water Advisory Committee was made up of the general public, industry, local planning and governmental agencies, and recreational agencies. These boards were created in order to open a formal line of communication among all of the people directly involved in water quality management.

The Water Use Committee was divided into subcommittees representing industry, local governmental agencies, the general public, and recreation, wildlife and conservation agencies. This Committee came up with several plans for how water use should be divided up along the river. The way water use is determined is by having certain standards for several categories of water quality. The river was first divided up into sections and each subcommittee came up with a proposal for how each section should be used, such as swimming, fishing, and water sports. All of the alternative water use plans were compared and one common set of interests was agreed upon after long debate.

Once a water use plan was set, a model was developed to determine what amount of waste could be introduced into the water system that would allow for how water use scheme that was devised. A very commonly used limiting factor in these models is Dissolved Oxygen Content, although other water quality indicators can be used to determine waste load introduction into the water system. A cost and benefit analysis can be done to evaluate the feasibility of the implementation of a plan.

From all of this information, a specific policy was developed by the governmental agencies with the help of the other Committees. To help ensure each of the Committees were represented in the policy making phase, it was necessary to hold numerous public hearings. The very difficult task of assigning the waste load output by each of the members of the local community had to be assessed. This often led to much dissension and therefore was the most difficult part of the plan to implement. This was also the part of the plan that had the greatest impact on the local economy since waste load purification is very expensive and may economically damage the businesses that were required to change their waste load output.

The plan as discussed above was used for the Delaware River Estuary, which is 150 miles long and runs through three states. This caused major problems in designing and implementing the water quality management plan. In Puerto Rico, this process would be simplified since the only agencies that would need to be involved would be local municipalities. In Puerto Rico, the Puerto Rico Department of Natural and Environmental Resources, the Regulatory committee for the Appropriation, Use, Conservation and Administration of Waters, and Municipality governments could compose the Policy Advisory Committee since they all have expertise in the water management of the island (USGS-NWS87, 1987). The USGS and other related agencies could represent the Technical Advisory Committee. The general public, the Puerto Rico Tourism Company and allied industry groups could represent the Water Use Committee since they would all be directly affected by any regulation implemented to ensure water quality. Any water quality management program would be costly and its creation would be a very long and drawn out process. It should be up to the local voters whether or not a water quality management project should be implemented.

5.5 Recommendations for Further Research

The purpose of this project was to study the changes in land use of specific basins from 1977 to 1995 and discover if these changes had a significant effect on stream discharge. After performing several statistical analyses, we came to the conclusion that there is a correlation between land use change and stream discharge, which could ultimately affect flooding in the basins of study. In addition to our analysis, there were several aspects, which we would have liked to study, but did not have the time to do so. The following are some recommendations for further research based on the results of our project.

One of the major aspects of the project, which we could not explore in great detail, was land use classifications. Due to time constraints on the project, we were unable to develop more than four classifications for land use. Since the runoff varies with the characteristics of the surface it is traveling over, a study involving more specific land use classifications should be conducted. The surface roughness and make-up will greatly influence runoff. If one type of surface is much smoother than another type, it is likely that the amount of runoff over that surface will be much greater. The composition of the surface will cause variations in the runoff also. The soil make-up has a major influence on the infiltration rate and capacity. Also, if the composition of one surface characteristically adheres to water significantly more than the surface of another, we would expect that the runoff would be slowed. For example, water would flow more rapidly across asphalt than cement pavement. Even though they have about the same roughness, the asphalt contains oils that would cause the water to flow more rapidly across its surface. Soil quality characteristics have a great deal to do with permeability of the area being analyzed.

The lag time between the rainfall and the subsequent discharge due to the soil saturation or infiltration rate, meandering of the river and slope of the catchment is a source of error in working with storm data. A more comprehensive precipitation-discharge model would take lag time into account, as well as the time that the storm began and its duration. Analysis of these aspects would help to predict the effects of land use change on runoff, stream discharge, and flooding in a more accurate manner.

Another project could take into account the average rainfall for the month that the storm occurred. This would center the data for each storm and would make the statistical analysis more accurate.

In our study, we did not have time to explore where urbanization had occurred within each basin. A new project could use the 1977 aerial photographs from the Department of Natural and Environmental Resources to delineate actual land use. This data could then be overlaid on the 1995 DOQs and topography maps in order to determine where land use changes occurred, i.e. if the area was flat or mountainous. This data could then be analyzed using statistical methods in order to explore any relationship between the spatial arrangement and an increase in runoff. This study could further the understanding of how the hydrologic cycle is affected by land use changes.

As mentioned above, when making approval decisions, the Junta takes suggestions made by the Department of Natural and Environmental Resources (DNER) and the Administration of Regulations and Permits (ARP) into account. A project could explore the possibility of the DNER playing a more active role in the review of urban development plans. The project could explore the likelihood that the DNER and ARP approve any proposed urban development after approval by the Urban Planning Board. Another possible area to study would be merging the DNER regulations with those of the urban planning board to ensure that environmental regulation is followed in the approval process.

A follow-up study could be done in which demographics are considered an independent variable in regression analysis. A study could take into account census information such as density of the urban areas or the overall population of the basin. A related project could do the same using information pertaining to the amount of industry or commerce within the basin and how it has grown between the two time periods explored in our study.

Another potential study could involve an assessment of how water quality has changed over recent decades. A project team could do a water quality analysis of the basins that were done in our study. This data could then be compared to data from previous years to see if there is a correlation between and increase in land use change and a decline in water quality. The National Water Quality Assessment (NAWQA) program, being conducted by the USGS, is already in place to assess water quality throughout the US, but the areas of study do not include any in Puerto Rico. This program could be extended to include test areas in Puerto Rico. The internet address for the NAWQA is http://www.usgs.gov/NAWQA (Hunt,1999).

5.6 Summary Statement

It is imperative that given the significance of land use changes on runoff and discharge, public awareness concerning the hydrologic effects of land use changes be an integral part of modern culture. As a society, we must all educate ourselves about the effects of urbanization, including the risk of flooding, potentially leading to loss of life and property damage, and the introduction of pollution into our ecosystem. By implementing scientific hydrologic knowledge, we can effectively manage urban development, flood plains, and our river basins to help maintain a balance that prevents tragic floods. Education and awareness is the key to fulfilling public obligation to our natural resources.

Glossary

Biochemical Oxygen Demand – The total amount of dissolved oxygen for all chemical and biological function to occur in the water system.

Catchment – A structure or area, such as a basin or reservoir, for collecting or draining water.

Condensation – Water changing from gaseous state to liquid state.

Dissolved Oxygen – The total amount of oxygen dissolved in a ml of water, which is often used as a water quality indicator.

Ecosystem – The interaction of organisms with each other and their environment.

Estuary – The part of the wide, lower course of a river where its current is met and influenced by the tides.

Evaporation – Water being changing from a liquid state to a gaseous state.

Evapotranspiration – The overall process of passing of water vapor into the atmosphere.

Hydrograph – A graphical representation of the flow of water in a specific area.

Infiltration – The passing of water into the soil surface.

Interflow – The horizontal flow of water beneath the ground surface along the bedrock.

Interval Storm/Flow – A storm with duration and intensity of precipitation so great that it is said to occur once every n years, where n is the interval.

Lysimeter – A device for measuring the water content in a soil sample.

Mitigation – A moderation of force or intensity.

Neutron Probing – The process of firing neutrons into the ground in order to determine ground water content.

Peak Flow – The maximum flow of water in a specific area.

Peak Flow Frequency – The number of times a peak low occurs over a give period of time.

Percolation – The downward movement of water in the soil caused by gravity.

Plantation Forestry – Short crop vegetation.

Precipitation – Water droplets or ice particles formed in the atmosphere which are significantly large enough to fall.

Runoff – Water that is unable to infiltrate into the soil, which forms pools on the surface or flows along the surface.

Sedimentation – The settling of solid particles in the water supply.

Transpiration – The passage of water vapor into the atmosphere caused by vegetation.

Watershed – A region draining into a river, river system, or body of water.

References

Aiken, Leona S. & Stephen G. West (1991). Multiple Regression: Testing and Interpreting Interactions. Newbury Park: Sage Publications.

Bhaduri, Budhendra, Matt Grove, Carmen Lowry, & Jon Harbor (1997). Assessing Long-Term Hydrologic Effects of Land Use Change, Journal of Water Resources Planning and Management, Volume 89, Number 11, 94-106.

Bultot, F., G. L. Dupriez, & D. Gellens (1990). Simulation of Land Use Changes and Impacts On the Water Balance - A Case Study for Belgium, Journal of Hydrology, Volume 114, Number 3, 327-348.

Calder, Ian R., Robin L. Hall, Heidi G. Bastable, Henry M. Gunston, Osborne Shela, Amon Chirwa, & Robinson Kafundu (1995). The Impact of Land Use Change on Water Resources in Sub-Saharan Africa: A Modeling Study of Lake Malawi, Journal of Hydrology, Volume 170, Number 3, 123-135.

Carrasquillo, John. (1999) National Flood Insurance Representative. Interview: Federal Emergency Management Agency.

Carrier, Patrick, Shahab, Mohaghegh, & Razi Gaskari (1996). Performance of a Virtual Hydrograph System, Journal of Water Resources Planning and Management, Volume 122, Number 6, 421-427.

Central Intelligence Agency (CIA), http://www.cia.gov/cia/publications/factbook/rq.html, 1/23/1999.

Cole, Stephen (1998). The emergence of treatment wetlands. Environmental Science and Technology, Volume 32, Number 9

Colón, Eloy (1999). Southeast River Forecast Hydrologist. Interview: National Oceanic and Atmospheric Administration. National Weather Service.

Cruise, J. F., & Miller, R. L. (1994). Hydrological Modeling of Land Processes in Puerto Rico Using Remotely Sensed Data, Water Resources Bulletin, Volume 30, Number 3, 419-428.

Díaz, P. L., Z. Aquino, C. Fgueroa-Alamo, R. J. Vachier, and A. V. Sánchez, (1996). Water Resources Data: Puerto Rico and the U. S. Virgin Islands, Water Year 1996. United States Geological Survey, Guaynabo, Puerto Rico.

Econopouly, Thomas (1999). Northeast River Forecast Hydrologist. Interview: National Oceanic and Atmospheric Administration. National Weather Service.

Environmental Protection Agency (EPA), http://www.epa.gov/OW/resources/9698/pr.html, 2/1/1999.

Environmental Search Research Institute, Inc. (ESRI-a). ARC/Info: The Professional Geographic Information System, http://www.esri.com/library/whitepapers/ai_lit.html 1/29/1999.

Environmental Search Research Institute, Inc. (ESRI-b). ARC/Info: The World's GIS, http://www.esri.com/library/whitepapers/ai_lit.html, 1/27/1999.

Garcia, Rene (1999). Hydrologist. Interview: United States Department of the Interior, Geological Survey.

Gonzalez, Hildelisa (1999). Urban Planner. Interview: Federal Emergency Management Agency.

Greene, R. G. and Cruise, J. F. (1995). Urban Watershed Modeling Using GIS, Journal of Water Resources Planning and Management, Volume 121, Number 4, 318-325.

Houseknecht, David W (1993). The United States Geological Survey: A Vision for the Twenty-first Century.

Hunt, Tara (1999). USGS 'National Summary' indicates land-use patterns are key. Water Environment and Technology, Volume 11, Number 10.

Hyman, Lizabeth. (1999). Hazard Mitigation Officer. Interview: Federal Emergency Management Agency.

Kite, G. W. and Kouwen, N. (1992). Watershed Modeling Using Land Classifications, Water Resources Research, Volume 28, Number 12, 3193-3200.

Lacayo, Richard (1999). The Brawl Over Sprawl, Time Volume 153, Number 11, 44-48.

Larsen, Matthew C. Ph.D. (1999). Hydrologist. Interview: United States Department of the Interior, Geological Survey.

McClone, P. (1979). Floods in Georgia, Magnitude and Frequency, techniques for estimating the magnitude and frequency of floods in Georgia with compilation of data through 1974. United States Geological Survey, Doraville, Georgia.

Miller, R. L., & Cruise, J. F., & Otero, E., & Lopez, J. M. (1994). Monitoring Suspended Particulate Matter in Puerto Rico Field Measurements and Remote Sensing, Water Resources Bulletin, Volume 30, Number 2, 271.

Nandakumar, N., & R.G. Mein (1997). Uncertainty in Rainfall-Runoff Model Simulations and the Implications for Predicting the Hydrologic Effects of Land-Use Change, Journal of Hydrology, Volume 192, Number 1, 211-231.

National Oceanic and Atmospheric Administration, http://www.ncdc.noaa.gov/ol/radar/radarresources.html; Search Puerto Rico, 1/23/1999.

National Spatial Data Infrastructure (NSDI). Digital Orthophoto Quadrangles, http://nsdi.usgs.gov/nsdi/products/doq.html, 1/23/1999.

Ramos, Orlando (1999). Hydrologist. Interview: United States Department of the Interior, Geological Survey.

Reyes, Betzaida (1999). Hydrologist. Interview: United States Department of the Interior, Geological Survey.

Richmond, Samuel B (1994). Statistical Analysis. New York: The Ronald Press Company.

Robakiewicz, Phil Ph.D. (1999). Ecologist. Email contact: Worcester Polytechnic Institute

Santiago, Marilyn (1999). Hydrologist. Interview: United States Department of the Interior, Geological Survey.

Shamsi, Uzair M. (1996). Storm-Water Management Implementation Through Modeling and GIS, Journal of Water Resources Planning and Management, Volume 122, Number 2, 114-127.

Shih, S.F. & Jordan, J. D. (1992). Landsat Mid-Infrared Data and GIS in Regional Surface Soil-Moisture Assessment, Water Resources Bulletin, Volume 28, Number 4, 713-720.

Thomann, Robert (1972). Systems and Analysis Water Control Management. New York: Charlotte Newmann Co.

United States Department of the Interior (USDI, 1988). Guideline for Determining Flood Flow Frequency, Bulletin #17B.

United States Geological Survey. Luquillo Water, Energy, and Biogeochemical Budgets Project. http://dprsj1.er.usgs.gov/public/webb/webb.html, 1/22/1999.

United States Geological Survey (USGS-NWS87, 1990). National Water Summary – 1987. Denver: United States Government Printing Office.

United States Geological Survey (USGS-NWS88, 1990). National Water Summary – 1988. Denver: United States Government Printing Office.

U.S. Census Bureau , http://www.bized.ac.uk/cgi-bin/idbsum.pl Search word: Puerto Rico, 1/23/1999.

United States National Oceanic and Atmospheric Administration. http://www.noaa.gov, 1/22/1999.

United States National Resources Defense Council. http://www.nrdc.org/nrdc, 1/22/1999.

University of Iowa Department of Geology. http://www.geology.uiowa.edu/~12_003/eh%26r98/webversion/ streams%20and%20rivers/sld004.htm, 2/2/1999.

University of Texas Department of Geography, http://www.utexas.edu/depts/grg/gcraft/ notes/gps/gps.html, 2/1/1999.

Ward, Andy D., and William J. Elliot (1995). Environmental Hydrology. New York: CRC Publishers.

Warwick, J. J. and Haness, S. J. (1994). Efficacy of ARC/Info GIS Application to Hydrologic Modeling, Journal of Water Resources Planning and Management, Volume 120, Number 6, 366-379.

Water Resources of the United States (Water-a), http://water.usgs.gov/cgi-bin/wuhuc?huc=21010005, 2/1/1999.

Water Resources of the United States (Water-b), http://water.usgs.gov/cgi-bin/wuhuc?huc=21010004, 2/1/1999.

Water Resources of the United States (Water-c), http://water.usgs.gov/cgi-bin/wuhuc?huc=21010003, 2/1/1999.

Water Resources of the United States (Water-d), http://water.usgs.gov/cgi-bin/wuhuc?huc=21010002, 2/1/1999.

Webb, Richard (1999). Hydrologist. Interview: United States Department of the Interior, Geological Survey.

Wonnacott, Ronald J. & Thomas H (1985). Introductory Statistics. New York: John Wiley and Sons.

Appendix A: Mission and Organization of the United States Geological Survey

Adapted from: Sediment from Landslides in Puerto Rico's Water. Written by Tim Doherty, Steve Manning, and Chris Seveney. May 7, 1996

The United States Geological Survey (USGS) was established 1879 by an act of Congress as an agency of the Department of the Interior. The act decreed that the USGS was to provide a permanent federal agency to conduct the systematic and scientific classification of the public lands and examination of the geological structure, mineral resources, and products of national domain. Hence, the USGS was primarily defined as a scientific fact-finding and research organization. It is now the main source of scientific and technical expertise in the earth sciences within the Department of the Interior and the Federal Government.

The headquarters of the USGS is located at Reston, Virginia. The agency employs approximately 8,600 permanent scientific, technical, administrative, and clerical personnel, organized into five sectors. Three of these are major program divisions (Geologic, National Mapping, and Water Resources), and the other two are supportive divisions (Administrative and Information Systems). Each division has its own set of responsibilities to support the overall agency mission.

As described in Houseknecht (1993), the USGS is divided into several divisions:

- The Geological Division provides geologic, geophysical, and geochemical information on land resources, energy and mineral resources, and geologic hazards of the Nation and its territories.
- The National Mapping Division provides geographic and cartographic information, maps, and technical assistance and conducts related research responsive to national needs.

- The Water Resource Division provides information on the occurrence, quantity, quality, distribution, and movement of surface and underground waters that constitute the Nation's water resources.
- The Administrative Division provides finance, personnel, contract negotiation and administration, property and space management, organization and methods, management analysis, and other administrative services to the USGS as a whole.
- The Information Systems Division provides guidance and advice to the Survey and to the Department of the Interior on all matters relating to USGS information technology and automated data processing.

The mission of the USGS, which during its first century focused on surveying the nation's lands and assessing the resources the nation needed to expand, has evolved to include the analysis of the earth's hazards and resources to assure sustained global health and prosperity. The USGS also provides unbiased earth-science information of value to current and future generations. Through collaborative scientific research, information is acquired on the past, present, and future conditions of the earth's environment, hazards, and resources. This essential information is communicated in forms that are effective for users and those concerned with the earth and its assets.

The USGS budget for Federal appropriations is the primary means by which the agency presents its mission and priorities to the Department of the Interior, the Office of Management and Budget, Congress, and agency employees. The budget of the USGS ideally should represent the mission and priorities of the agency and facilitate activities that contribute to the achievement of mission goals. Recent budgetary trends for the USGS have been on the decline because of Federal budget cuts. In 1995 there was talk of even eliminating the agency altogether when Congress was attempting to downsize the national budget.

The goals of the USGS, as stated in Houseknecht (1993) are:

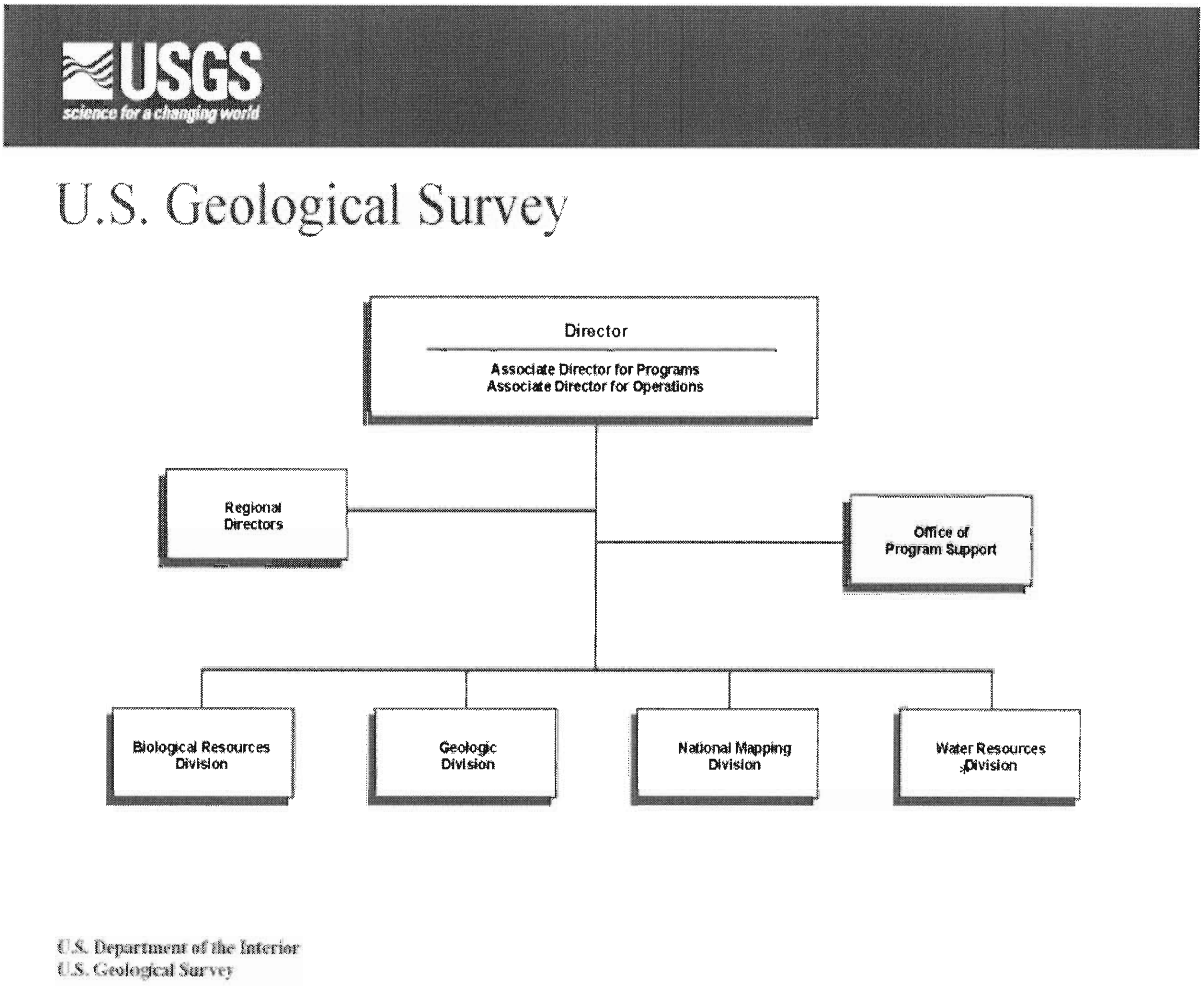
- To enhance understanding of earth systems and their mutual interactions so that knowledge is available to address emerging and future societal needs.
- To evaluate the influence of the earth systems and human activities on the global environment so that scientifically sound decisions can be made to avoid harmful perturbations of the earth's geosphere and biosphere.
- To characterize, assess, and predict chronic and catastrophic hydrologic and geologic hazards (e.g., natural and synthetic pollutants, floods, and earthquakes) for sustained global health and welfare.
- To provide earth-science data information that enhances the availability of sufficient resources (land, water, mineral, and energy) to support the Nation's infrastructure for the prosperity of future generations.
- To develop and implement state-of-the-art earth-science data and information systems (e.g., the National Spatial Data Infrastructure) coordinated through Federal, State, local, academic, and private partnerships for the enhanced availability of spatial and other types of data.
- To educate society on the earth's systems, environment, hazards, and resources so that the earth-science information will be fundamentally intertwined with public policy.

The objective of the USGS in Puerto Rico is to develop programs that are consistent with the vision and mission set by the USGS, attractive to the Department of the Interior, Office of Management and Budget, the President and Congress, and that meet the needs of the public.

The USGS in Puerto Rico follows the goals and mission stated by national headquarters. The district chief, Rafael W. Rodriguez Cruzado, oversees the daily operation of the agency. Maria M. Irizarry, the Associate District Chief, oversees all operations and research including the Water Energy and Biogeochemical Budget (WEBB) project. The rest of the agency is broken down into different subdivisions that have their own directors. We will be in the Water Resources Division. The position of our liaison, Matthew C. Larsen, a hydrologist within the USGS, is the WEBB Project Chief. His responsibilities include the oversight of all information and lab work related to the WEBB project.

The IQP with the USGS is related to the agency's mission, because it is an integral part of an ongoing study. This study is one of several ongoing projects and is aimed at gathering and quantifying data that can be used for the betterment of the management of the Puerto Rican water supply. Our results will be compared to similar data collected from other parts of the island and then used to determine specific areas of concern.

Figure A-1: Organization of the USGS.



Source: USGS, 1999

Appendix B: Commonly Used ARC/Info Commands

Commands for Arc/Info

append – creates one coverage out of many coverages from multiple DOQ's
append <new name> poly all

bc – back coverage: calls up a coverage
bc /gispr3/(two-letter doq name)/(layer category)/(layer name) (number of color)

Colors

1	White
2	Red
3	Dark Green
4	Dark Blue
5	Cyan
6	Purple
7	Yellow
8	Amber
9	Light Green

be – back environment: sets the feature that will be displayed
arc, line, pointer, node

build – updates statistics table for a given coverage after "clean" command
build <new cover name>

clean - ensures all polygons in a coverage are closed

clip – allows several coverages of interest to be merged into a new cover

frequency – allows analysis for a given coverage's statistics table
frequency <output from build.pat> <new name.freq>

help – opens help window

show – shows information about coverage name

draw – draws stuff

save – saves
save all y: saves all changes to all layers (y confirms)

mape - map extend – changes area that the computer is looking at
mape /gispr3/ey/hyd/eyst01

ec – edit coverage – allows you to select the coverage for each map.
ec /gispr3/ey/lu/ey77lu02: changes edit coverage to the listed layer
always followed by followed by "drawe" command

drawe – draws environment – arcs, labels, points, anno (annotations), node error (dangles) (puts box on all loose lines; immediately followed by "*nodecolor dangle 3*")

sel – select an element
sel many
ds – display selected

ef – edit feature
ef label: allows the label feature to be edited
(*add*)

ed * - allows you to change edit distance (larger area for selection)

calc – calculate
*calc LUCODE = (number)*if you select all of one LUCODE, you can change the overall name to with "*calc group = (number)*"

ia – intersect arcs: will connect two arcs within a given tolerance interval

oops – eliminates last command (infinite no. of times)

sel – select
-**many** - allows you to select several things at once
-**box** – allows you to select a box on the map

asel – allows you to select other objects in addition to the one already suggested.

v move – allows you to move the vertex of a line by increasing the number of vertices on the line

wt – changes
wt (number) smaller the number, the closer the ticks

spline – smoothes lines and eliminates dangles

textitem (coverage) (label) (lucode) – lets you output the actual coverage names or lucodes

To create a layered map with ARC/Info

1) At prompt, type "arc."
2) Copy (from) (to)
3) Then type "ae" for arc/edit.
4) Type "display 9999 3."
5) Create (name) (coverage to get data from)
6) be (feature)
7) mape (covername)
8) bc (covername) (color)
9) Ec (coverage name)
10) Drawe (feature)
11) draw
12) add (feature)

To Create New Window and Zoom In

1) Go to "Pan/Zoom" menu and select "Create" and then "New Window".
2) Type "sel box" and create a box (single click on corner, drag, single click to finish box).
3) Go to "Pan/Zoom" menu and select "Zoom In".

To Edit a Feature on a Created Map

1) Type ec (covertype).
2) Type drawe (feature).
3) Type draw.
4) Type ef (feature).
5) Type sel.
6) Go to the part of the map that is to be edited.
7) Type v move.
8) Go to the map and place the edit circle over the area of interest.
9) Follow the prompt on the screen to edit.
10) If the is a problem with the width of the line, then type wt 0.### (0.005 recommended)

To Build Clip a Coverage

1) Type append <*output cover name*>.
   -type layer name on interest at "first coverage" prompt
   -type another layer name of interest "second coverage" prompt
   -type "end" at final coverage prompt
2) Type clean <*append cover name*> <*new cover name*>.
3) Type build <*new cover name*>.
4) Type clip <*name of larger cover*> <*name of basin boundary coverage*> <*newly created name*>.

Appendix C: Storm Data

The following tables are data for the storms selected in each basin as described in the Methodology. The storm dates, rainfall, and discharge amounts are included. Total daily rainfall and discharge in cubic feet was calculated and the storm totals were used in the regression analysis. Despite our best efforts, we were unable to get each table on only one page, so some tables may be broken up.

Table C1-A: Storm Data for Río Cibuco below Corozal, 1977

	Date	Rainfall (in)	Discharge (cf)	Rainfall (cf)	Discharge (cf)
Storm 1	25-Aug-76	0.8	5.2	28194355.2	449280
	26-Aug-76	0.4	8.5	14097177.6	734400
	27-Aug-76	0	9.5	0	820800
	28-Aug-76	0	6.9	0	596160
Storm 2	07-Sep-76	1	15	35242944	1296000
	08-Sep-76	0.3	7.9	10572883.2	682560
	09-Sep-76	0.1	7.1	3524294.4	613440
Storm 3	25-Sep-76	0	4.9	0	423360
	26-Sep-76	1.1	7.1	38767238.4	613440
	27-Sep-76	0.1	7.2	3524294.4	622080
	28-Sep-76	0	5.4	0	466560
	29-Sep-76	1.3	11	45815827.2	950400
	30-Sep-76	2.4	107	84583065.6	9244800
	01-Oct-76	0	23	0	1987200
Storm 4	06-Oct-76	0.5	10	17621472	864000
	07-Oct-76	1.9	29	66961593.6	2505600
	08-Oct-76	0.8	103	28194355.2	8899200
	09-Oct-76	0	34	0	2937600
Storm 5	14-Oct-76	3.1	353	109253126.4	30499200
	15-Oct-76	0	67	0	5788800
	16-Oct-76	0	46	0	3974400
Storm 6	20-Jan-77	1.6	11	56388710.4	950400
	21-Jan-77	0.7	67	24670060.8	5788800
	22-Jan-77	1.4	200	49340121.6	17280000
	23-Jan-77	0.4	81	14097177.6	6998400
	24-Jan-77	0	30	0	2592000
	25-Jan-77	0	15	0	1296000
Storm 7	23-May-77	1.1	9.6	38767238.4	829440
	24-May-77	0	5.7	0	492480
	25-May-77	0	3.7	0	319680
Storm 8	07-Oct-77	0.6	39	21145766.4	3369600
	08-Oct-77	2	47	70485888	4060800

Table C1-A (cont.): Storm Data for Río Cibuco below Corozal, 1977

Storm 9	01-Nov-77	0.5	19	17621472	1641600
	02-Nov-77	1	54	35242944	4665600
	03-Nov-77	0.1	65	3524294.4	5616000
	04-Nov-77	2.2	474	77534476.8	40953600
	05-Nov-77	0	66	0	5702400
Storm 10	13-Nov-77	2.1	59	74010182.4	5097600
	14-Nov-77	0.6	136	21145766.4	11750400
	15-Nov-77	0.1	53	3524294.4	4579200
	16-Nov-77	0.1	42	3524294.4	3628800

Table C1-B: Storm Data for Río Cibuco below Corozal, 1995

Storm 11	12-Nov-93	0.18	9.9	6343729.92	855360
	13-Nov-93	0.02	16	704858.88	1382400
	14-Nov-93	1.22	40	42996391.68	3456000
	15-Nov-93	1.83	62	64494587.52	5356800
	16-Nov-93	1.07	70	37709950.08	6048000
	17-Nov-93	0.26	52	9163165.44	4492800
	18-Nov-93	0.39	46	13744748.16	3974400
	19-Nov-93	0.49	34	17269042.56	2937600
	20-Nov-93	0.03	25	1057288.32	2160000
	21-Nov-93	0	18	0	1555200
	22-Nov-93	0.04	15	1409717.76	1296000
Storm 12	11-Jan-94	0.85	16	29956502.4	1382400
	12-Jan-94	0.12	9.4	4229153.28	812160
Storm 13	09-Apr-94	1.21	73	42643962.24	6307200
	10-Apr-94	2.5	26	88107360	2246400
	11-Apr-94	0.17	705	5991300.48	60912000
	12-Apr-94	4.52	89	159298106.9	7689600
Storm 14	13-Apr-94	0	55	0	4752000
	14-Apr-94	1.39	228	48987692.16	19699200
	15-Apr-94	0.85	116	29956502.4	10022400
	16-Apr-94	1.33	98	46873115.52	8467200
	17-Apr-94	0.8	46	28194355.2	3974400
	18-Apr-94	0.03	32	1057288.32	2764800
	19-Apr-94	0	25	0	2160000
	20-Apr-94	0	46	0	3974400
Storm 15	21-Apr-94	0.76	129	26784637.44	11145600
	22-Apr-94	0.7	67	24670060.8	5788800
Storm 16	28-Apr-94	1.1	12	38767238.4	1036800
	29-Apr-94	1.18	19	41586673.92	1641600
	30-Apr-94	0	28	0	2419200
Storm 17	17-May-94	0.18	22	6343729.92	1900800
	18-May-94	0.05	7.4	1762147.2	639360
Storm 18	17-Oct-94	0.1	7.6	3524294.4	656640
	18-Oct-94	1.01	25	35595373.44	2160000
	19-Oct-94	0	24	0	2073600
	20-Oct-94	0.8	26	28194355.2	2246400
Storm 19	21-Oct-94	0.12	16	4229153.28	1382400
	22-Oct-94	0.48	35	16916613.12	3024000
	23-Oct-94	1	65	35242944	5616000
	24-Oct-94	0	34	0	2937600
	25-Oct-94	0	22	0	1900800
Storm 20	25-Feb-95	0	46	0	3974400
	26-Feb-95	2.67	59	94098660.48	5097600
	27-Feb-95	2.65	119	93393801.6	10281600
	28-Feb-95	0.59	82	20793336.96	7084800

Table C2-A: Storm Data for Río Grande de Patillas near Patillas, 1977

	Date	Rainfall (in)	Discharge (cf)	Rainfall (cf)	Discharge (cf)
Storm 1	22-Oct-75	0.4	178	17042995	15379200
	23-Oct-75	0.91	387	38772814	33436800
	24-Oct-75	0.4	149	17042995	12873600
	25-Oct-75	0.58	179	24712343	15465600
	26-Oct-75	0.72	143	30677391	12355200
	27-Oct-75	0.14	102	5965048.3	8812800
Storm 2	01-Feb-76	0.23	80	9799722.2	6912000
	02-Feb-76	2.01	302	85641051	26092800
	03-Feb-76	0.26	106	11077947	9158400
Storm 3	01-May-76	4.76	129	202811643	11145600
	02-May-76	1.28	73	54537585	6307200
	03-May-76	0.53	38	22581969	3283200
	04-May-76	0.22	29	9373647.4	2505600
Storm 4	22-May-76	0.54	23	23008044	1987200
	23-May-76	2.64	208	112483768	17971200
	26-May-76	0.32	20	13634396	1728000
	27-May-76	1.89	118	80528152	10195200
	28-May-76	0.42	29	17895145	2505600
Storm 5	04-Jun-76	0.51	92	21729819	7948800
	05-Jun-76	1.91	120	81380302	10368000
	06-Jun-76	0.09	51	3834673.9	4406400
	07-Jun-76	0.62	60	26416643	5184000
	08-Jun-76	0.41	328	17469070	28339200
	09-Jun-76	0.42	66	17895145	5702400
	10-Jun-76	0.21	74	8947572.5	6393600
Storm 6	25-Jul-76	0.41	91	17469070	7862400
	26-Jul-76	0.89	178	37920664	15379200
	27-Jul-76	1.02	235	43459638	20304000
Storm 7	07-Sep-76	0.23	22	9799722.2	1900800
	08-Sep-76	0.61	52	25990568	4492800
	09-Sep-76	0.7	60	29825242	5184000
	10-Sep-76	0.14	39	5965048.3	3369600
	11-Sep-76	1.81	80	77119553	6912000
	12-Sep-76	0.43	492	18321220	42508800
	13-Sep-76	0.68	96	28973092	8294400
	14-Sep-76	0.31	73	13208321	6307200
	15-Sep-76	0.06	74	2556449.3	6393600
	16-Sep-76	0.14	54	5965048.3	4665600
	17-Sep-76	0.32	46	13634396	3974400
	18-Sep-76	0.71	44	30251316	3801600
	19-Sep-76	0.5	48	21303744	4147200
	20-Sep-76	0.11	415	4686823.7	35856000
	21-Sep-76	0.04	88	1704299.5	7603200
Storm 8	05-Dec-76	0.69	125	29399167	10800000
	06-Dec-76	1.02	158	43459638	13651200
	07-Dec-76	0.53	159	22581969	13737600

Table C2-A (cont.): Storm Data for Río Grande de Patillas near Patillas, 1977

Storm 9	02-Aug-77	1.98	810	84362826	69984000
	03-Aug-77	0.34	779	14486546	67305600
	04-Aug-77	1.55	821	66041606	70934400
	05-Aug-77	0.89	431	37920664	37238400
	06-Aug-77	0.11	148	4686823.7	12787200
	07-Aug-77	0.06	103	2556449.3	8899200
	08-Aug-77	0.37	76	15764771	6566400
	09-Aug-77	1.52	60	64763382	5184000
Storm 10	21-Sep-77	0.38	102	16190845	8812800
	22-Sep-77	0.82	97	34938140	8380800
	23-Sep-77	0.83	138	35364215	11923200
	24-Sep-77	0.84	139	35790290	12009600
	25-Sep-77	0.16	66	6817198.1	5702400
	26-Sep-77	0.09	50	3834673.9	4320000
	27-Sep-77	0.08	41	3408599	3542400

Table C2-B: Storm Data for Río Grande de Patillas near Patillas, 1995

Storm 11	07-Nov-91	1.16	281	2694912	24278400
	08-Nov-91	1.98	618	4599936	53395200
	09-Nov-91	4.36	311	10129152	26870400
	10-Nov-91	0.23	174	534336	15033600
	11-Nov-91	0.19	101	441408	8726400
	12-Nov-91	0.05	74	116160	6393600
Storm 12	19-May-92	0.9	30	2090880	2592000
	20-May-92	1.42	27	3298944	2332800
	21-May-92	1.92	25	4460544	2160000
	22-May-92	0.6	24	1393920	2073600
	23-May-92	2.2	316	5111040	27302400
	24-May-92	2.1	382	4878720	33004800
	25-May-92	0	300	0	25920000
	26-May-92	0.18	609	418176	52617600
	27-May-92	0.07	166	162624	14342400
	28-May-92	0.2	87	464640	7516800
Storm 13	20-Feb-94	1.23	126	2857536	10886400
Storm 14	19-Sep-94	0.76	65	1765632	5616000
	20-Sep-94	6.54	353	15193728	30499200
	21-Sep-94	1.3	56	3020160	4838400
Storm 15	22-Oct-94	0.11	68	255552	5875200
	23-Oct-94	2.16	248	5018112	21427200
	24-Oct-94	1.45	180	3368640	15552000
	25-Oct-94	0.73	103	1695936	8899200
	26-Oct-94	0.55	65	1277760	5616000
Storm 16	05-Sep-95	0.53	21	1231296	1814400
	06-Sep-95	0.29	203	673728	17539200
	07-Sep-95	0.57	157	1324224	13564800
	08-Sep-95	0.23	162	534336	13996800
	09-Sep-95	0.17	63	394944	5443200
Storm 17	15-Sep-95	0.35	119	813120	10281600
	16-Sep-95	2.35	479	5459520	41385600
	17-Sep-95	1.62	307	3763584	26524800
	18-Sep-95	0.27	162	627264	13996800
Storm 18	01-Dec-95	0.81	46	1881792	3974400
	02-Dec-95	1.66	107	3856512	9244800
	03-Dec-95	0.18	48	418176	4147200
Storm 19	14-Aug-96	2.12	149	4925184	12873600
	15-Aug-96	1.94	98	4507008	8467200
	16-Aug-96	4.44	212	10315008	18316800
	17-Aug-96	0.28	87	650496	7516800
Storm 20	10-Sep-96	11.48	1770	26670336	152928000
	11-Sep-96	8.97	546	20839104	47174400
	12-Sep-96	0.24	416	557568	35942400
	13-Sep-96	0.09	407	209088	35164800
	14-Sep-96	0.16	335	371712	28944000
	15-Sep-96	0.46	414	1068672	35769600
	16-Sep-96	0.65	323	1510080	27907200

Table C3-A: Storm Data for Río Tanama near Utuado, 1977

	Date	Rainfall (in)	Discharge (cf)	Rainfall (cf)	Discharge (cf)
Storm 1	31-Oct-75	1.52	71	63492126.72	6134400
	01-Nov-75	0.43	125	17961588.48	10800000
	02-Nov-75	1	74	41771136.00	6393600
Storm 2	19-Nov-75	2.14	58	89390231.04	5011200
	20-Nov-75	0.22	100	9189649.92	8640000
	21-Nov-75	0.01	93	417711.36	8035200
	22-Nov-75	0	69	0.00	5961600
Storm 3	25-Apr-76	0.15	125	6265670.40	10800000
	26-Apr-76	3.07	480	128237387.52	41472000
	27-Apr-76	0	206	0.00	17798400
	28-Apr-76	0	86	0.00	7430400
Storm 4	21-Aug-76	1.22	27	50960785.92	2332800
	22-Aug-76	2.85	76	119047737.60	6566400
	23-Aug-76	1.25	42	52213920.00	3628800
	24-Aug-76	0.04	23	1670845.44	1987200
Storm 5	24-Sep-76	1.11	24	46365960.96	2073600
	25-Sep-76	0	125	0.00	10800000
	26-Sep-76	2.01	480	83959983.36	41472000
	27-Sep-76	0.17	206	7101093.12	17798400
	28-Sep-76	0.38	86	15873031.68	7430400
	29-Sep-76	0.05	53	2088556.80	4579200
Storm 6	26-Oct-76	0.33	94	13784474.88	8121600
	27-Oct-76	2.32	158	96909035.52	13651200
	28-Oct-76	0.7	64	29239795.20	5529600
	29-Oct-76	0	451	0.00	38966400
	30-Oct-76	1.35	152	56391033.60	13132800
	31-Oct-76	1.13	99	47201383.68	8553600
Storm 7	06-Jun-77	0.08	20	3341690.88	1728000
	07-Jun-77	0.26	20	10860495.36	1728000
	08-Jun-77	0.51	20	21303279.36	1728000
	09-Jun-77	0.13	30	5430247.68	2592000
	10-Jun-77	0.44	50	18379299.84	4320000
	11-Jun-77	0.97	100	40518001.92	8640000
	12-Jun-77	1.27	50	53049342.72	4320000
	13-Jun-77	0.15	35	6265670.40	3024000
Storm 8	24-Jun-77	0.3	14	12531340.80	1209600
	25-Jun-77	0	40	0.00	3456000
	26-Jun-77	0.69	96	28822083.84	8294400
	27-Jun-77	0.11	42	4594824.96	3628800
	28-Jun-77	0.32	24	13366763.52	2073600

Table C3-A (cont.): Storm Data for Río Tanama near Utuado, 1977

Storm 9	01-Nov-77	2	89	83542272.00	7689600
	02-Nov-77	0.32	57	13366763.52	4924800
	03-Nov-77	2.03	97	84795406.08	8380800
	04-Nov-77	2.53	252	105680974.08	21772800
	05-Nov-77	0	94	0.00	8121600
	06-Nov-77	0	73	0.00	6307200
Storm 10	07-Nov-77	1.45	159	60568147.20	13737600
	08-Nov-77	0	58	0.00	5011200

Table C3-B: Storm Data for Río Tanama near Utuado, 1995

Storm 11	01-May-93	1.29	45	53884765.44	3888000
	02-May-93	1.36	77	56808744.96	6652800
	03-May-93	0.72	106	30075217.92	9158400
	04-May-93	0.12	67	5012536.32	5788800
	05-May-93	0.12	66	5012536.32	5702400
	06-May-93	0.46	60	19214722.56	5184000
Storm 12	27-May-93	2.26	65	94402767.36	5616000
	28-May-93	0.65	119	27151238.40	10281600
	29-May-93	0.29	68	12113629.44	5875200
	30-May-93	0.99	91	41353424.64	7862400
Storm 13	13-May-95	0.73	21	30492929.28	1814400
	14-May-95	2	23	83542272.00	1987200
Storm 14	10-Sep-94	8.88	1390	370927687.68	1.2E+08
	11-Sep-94	6.26	439	261487311.36	37929600
	12-Sep-94	1.53	224	63909838.08	19353600
	13-Sep-94	0	153	0.00	13219200
	14-Sep-94	0	153	0.00	13219200
Storm 15	17-Dec-94	0.54	93	22556413.44	8035200
	18-Dec-94	0.03	49	1253134.08	4233600
	19-Dec-94	0	39	0.00	3369600
Storm 16	05-May-95	0.72	84	30075217.92	7257600
	06-May-95	1.11	29	46365960.96	2505600
	07-May-95	0.52	42	21720990.72	3628800
	08-May-95	1.45	105	60568147.20	9072000
	09-May-95	0.02	110	835422.72	9504000
	10-May-95	1.32	90	55137899.52	7776000
Storm 17	14-May-95	2	73	83542272.00	6307200
	15-May-95	1.03	204	43024270.08	17625600
	16-May-95	1.04	121	43441981.44	10454400
	17-May-95	0.13	69	5430247.68	5961600
	16-Sep-95	3.52	412	147034398.72	35596800
	17-Sep-95	0.94	114	39264867.84	9849600
	18-Sep-95	0.59	89	24644970.24	7689600
Storm 18	04-Sep-95	0.9	33	37594022.40	2851200
	05-Sep-95	0.13	49	5430247.68	4233600
	06-Sep-95	1.32	133	55137899.52	11491200
	07-Sep-95	1.25	110	52213920.00	9504000
	08-Sep-95	0.41	61	17126165.76	5270400
	09-Sep-95	0.02	45	835422.72	3888000
Storm 19	21-Feb-96	0.36	60	15037608.96	5184000
	22-Feb-96	1.15	154	48036806.40	13305600
	23-Feb-96	0.16	148	6683381.76	12787200
	24-Feb-96	0.67	121	27986661.12	10454400
	25-Feb-96	0.99	68	41353424.64	5875200
	26-Feb-96	0.11	53	4594824.96	4579200
Storm 20	20-Oct-96	1.73	96	72264065.28	8294400
	21-Oct-96	0.01	461	417711.36	39830400
	22-Oct-96	0.8	136	33416908.80	11750400

Table C4-A: Storm Data for Río Inabon at Real Abajo, 1977

	Date	Rainfall (in)	Discharge (cf)	Rainfall (cf)	Discharge (cf)
Storm 1	11-Nov-74	0.78	90.00	15946444.8	7776000
	12-Nov-74	1.56	220.00	31892889.6	19008000
	13-Nov-74	0.66	147.00	13493145.6	12700800
Storm 2	16-Sep-75	16.00	2500.00	327106560	216000000
	17-Sep-75	2.37	343.00	48452659.2	29635200
Storm 3	23-Oct-75	2.30	230.00	47021568	19872000
Storm 4	4-Sep-76	1.55	55.00	31688448	4752000
	5-Sep-76	1.11	30.00	22693017.6	2592000
	6-Sep-76	0.16	18.00	3271065.6	1555200
Storm 5	10-Sep-76	cum	50.00	-	4320000
	11-Sep-76	cum	25.00	-	2160000
	12-Sep-76	2.00	15.00	40888320	1296000
Storm 6	11-Oct-76	0.93	80.00	19013068.8	6912000
	12-Oct-76	1.33	130.00	27190732.8	11232000
	13-Oct-76	1.84	179.00	37617254.4	15465600
Storm 7	1-Nov-77	2.12	104.00	43341619.2	8985600
	2-Nov-77	1.58	107.00	32301772.8	9244800
Storm 8	23-Oct-78	1.03	83.00	21057484.8	7171200
	24-Oct-78	0.91	79.00	18604185.6	6825600
	25-Oct-78	2.00	92.00	40888320	7948800
	26-Oct-78	2.35	264.00	48043776	22809600
	27-Oct-78	2.75	175.00	56221440	15120000
	28-Oct-78	1.12	145.00	22897459.2	12528000
	29-Oct-78	0.00	98.00	0	8467200
Storm 9	4-Sep-79	2.11	107.00	43137177.6	9244800
	5-Sep-79	2.45	161.00	50088192	13910400
	6-Sep-79	0.20	124.00	4088832	10713600
Storm 10	18-Jul-79	3.40	300.00	69510144	25920000
	19-Jul-79	4.85	150.00	99154176	12960000
	20-Jul-79	0.00	80.00	0	6912000

Table C4-B: Storm Data for Río Inabon at Real Abajo, 1995

Storm 11	5-Jan-92	2.00	173	40888320	14947200
	6-Jan-92	12.00	686	245329920	59270400
	7-Jan-92	4.00	89	81776640	7689600
Storm 12	5-Sep-92	1.75	43	35777280	3715200
	6-Sep-92	0.5	86	10222080	7430400
	7-Sep-92	2.3	68	47021568	5875200
	8-Sep-92	0.55	53	11244288	4579200
	9-Sep-92	0.27	69	5519923.2	5961600
	10-Sep-92	1.75	81	35777280	6998400
	11-Sep-92	0.15	55	3066624	4752000
Storm 13	23-Oct-92	0.42	78	8586547.2	6739200
	24-Oct-92	2.1	98	42932736	8467200
	25-Oct-92	1.7	84	34755072	7257600
	26-Oct-92	0.3	57	6133248	4924800
Storm 14	26-May-93	0.60	82	12266496	7084800
	27-May-93	2.00	222	40888320	19180800
	28-May-93	2.40	143	49065984	12355200
	29-May-93	0.00	84	0	7257600
Storm 15	21-Feb-95	0.40	12	8177664	1036800
	22-Feb-95	1.55	13	31688448	1123200
	23-Feb-95	0.13	12	2657740.8	1036800
Storm 16	17-Apr-95	0.80	49	16355328	4233600
	18-Apr-95	0.40	19	8177664	1641600
	19-Apr-95	0.28	12	5724364.8	1036800
Storm 17	4-May-95	0.30	5.1	6133248	440640
	5-May-95	0.63	28	12879820.8	2419200
	6-May-95	0.95	24	19421952	2073600
	7-May-95	1.20	26	24532992	2246400
	8-May-95	0.83	31	16968652.8	2678400
	9-May-95	1.70	79	34755072	6825600
	10-May-95	2.48	21	50701516.8	1814400
Storm 18	15-Aug-95	0.24	7.7	4906598.4	665280
	16-Aug-95	0.40	24	8177664	2073600
	17-Aug-95	1.90	7.3	38843904	630720
	18-Aug-95	2.00	60	40888320	5184000
	19-Aug-95	2.00	68	40888320	5875200
	20-Aug-95	0.46	24	9404313.6	2073600
	21-Aug-95	0.50	15	10222080	1296000
Storm 19	16-Sep-95	2.00	183	40888320	15811200
	17-Sep-95	1.90	118	38843904	10195200
	18-Sep-95	2.00	68	40888320	5875200
Storm 20	9-Sep-96	1.88	6.7	38435020.8	578880
	10-Sep-96	2.00	754	40888320	65145600
	11-Sep-96	2.00	317	40888320	27388800
	12-Sep-96	0.40	163	8177664	14083200
	13-Sep-96	0.00	131	0	11318400
	14-Sep-96	1.58	135	32301772.8	11664000
	15-Sep-96	1.80	93	36799488	8035200

Table C5-A: Storm Data for Río Portugues near Ponce, 1977

	Date	Rainfall (in)	Discharge (cf)	Rainfall (cf)	Discharge (cf)
Storm 1	11-Sep-75	4.10	61	57055468.80	5270400
	12-Sep-75	1.72	42	23935464.96	3628800
	13-Sep-75	0.17	43	2365714.56	3715200
Storm 2	15-Sep-75	0.46	90	6401345.28	7776000
	16-Sep-75	16.00	2440	222655488.00	210816000
	17-Sep-75	2.37	175	32980844.16	15120000
Storm 3	24-Sep-75	3.22	24	44809416.96	2073600
	25-Sep-75	0.21	19	2922353.28	1641600
Storm 4	22-Oct-75	0.23	34	3200672.64	2937600
	23-Oct-75	2.30	212	32006726.40	18316800
	24-Oct-75	0.25	56	3478992.00	4838400
Storm 5	9-Dec-75	0.43	12	5983866.24	1036800
	10-Dec-75	0.77	51	10715295.36	4406400
	11-Dec-75	3.54	64	49262526.72	5529600
	12-Dec-75	1.32	55	18369077.76	4752000
	13-Dec-75	0.72	34	10019496.96	2937600
Storm 6	1-Nov-77	2.12	163	29501852.16	14083200
	2-Nov-77	1.58	141	21987229.44	12182400
Storm 7	10-Feb-78	0.16	6.2	2226554.88	535680
	11-Feb-78	1.50	18	20873952.00	1555200
	12-Feb-78	0.00	9.1	0.00	786240
Storm 8	16-Apr-78	2.05	5.1	28527734.40	440640
	17-Apr-78	0.28	24	3896471.04	2073600
	18-Apr-78	0.93	15	12941850.24	1296000
	19-Apr-78	0.01	56	139159.68	4838400
	20-Apr-78	0.14	30	1948235.52	2592000
Storm 9	17-Aug-78	1.39	110	19343195.52	9504000
	18-Aug-78	0.62	24	8627900.16	2073600
	19-Aug-78	0.26	21	3618151.68	1814400
Storm 10	23-Oct-78	1.03	18	14333447.04	1555200
	24-Oct-78	0.91	17	12663530.88	1468800
	25-Oct-78	2.00	15	27831936.00	1296000
	26-Oct-78	2.35	15	32702524.80	1296000
	27-Oct-78	2.75	13	38268912.00	1123200
	28-Oct-78	1.12	32	15585884.16	2764800
	29-Oct-78	0.00	23	0.00	1987200

Table C5-B: Storm Data for Río Portugues near Ponce, 1995

Storm 11	26-May-93	1.18	85	16420842.24	7344000
	27-May-93	2.18	225	30336810.24	19440000
	28-May-93	0.75	93	10436976.00	8035200
Storm 12	4-Oct-93	0.30	61	4174790.40	5270400
	5-Oct-93	1.75	46	24352944.00	3974400
	6-Oct-93	0.00	25	0.00	2160000
	7-Oct-93	0.20	128	2783193.60	11059200
	8-Oct-93	0.20	72	2783193.60	6220800
Storm 13	3-Jun-94	2.20	26	30615129.60	2246400
Storm 14	1-Oct-94	2.00	39	27831936.00	3369600
Storm 15	5-May-95	0.63	48	8767059.84	4147200
	6-May-95	0.95	34	13220169.60	2937600
	7-May-95	0.10	105	1391596.80	9072000
	8-May-95	0.83	208	11550253.44	17971200
	9-May-95	1.70	109	23657145.60	9417600
	10-May-95	2.48	41	34511600.64	3542400
Storm 16	28-May-95	2.00	23	27831936.00	1987200
	29-May-95	0.72	7	10019496.96	604800
	30-May-95	0.28	86	3896471.04	7430400
	31-May-95	0.32	41	4453109.76	3542400
Storm 17	15-Aug-95	0.24	6.8	3339832.32	587520
	16-Aug-95	0.40	45	5566387.20	3888000
	17-Aug-95	1.90	27	26440339.20	2332800
	18-Aug-95	2.00	110	27831936.00	9504000
	19-Aug-95	2.00	286	27831936.00	24710400
	20-Aug-95	0.46	141	6401345.28	12182400
	21-Aug-95	0.50	71	6957984.00	6134400
Storm 18	16-Sep-95	2.00	402	27831936.00	34732800
	17-Sep-95	1.90	110	26440339.20	9504000
	18-Sep-95	2.00	78	27831936.00	6739200
	19-Sep-95	0.03	88	417479.04	7603200
	20-Sep-95	0.12	70	1669916.16	6048000
Storm 19	16-May-96	0.40	40	5566387.20	3456000
	17-May-96	2.00	10	27831936.00	864000
	18-May-96	1.83	5.6	25466221.44	483840
	19-May-96	2.00	100	27831936.00	8640000
	20-May-96	2.10	40	29223532.80	3456000
	21-May-96	2.22	9.7	30893448.96	838080
	22-May-96	0.00	6.3	0.00	544320
Storm 20	9-Sep-96	1.88	6	26162019.84	518400
	10-Sep-96	2.00	1470	27831936.00	127008000
	11-Sep-96	2.00	728	27831936.00	62899200
	12-Sep-96	0.40	220	5566387.20	19008000
	13-Sep-96	0.00	32	0.00	2764800
	14-Sep-96	1.58	49	21987229.44	4233600
	15-Sep-96	1.80	9.8	25048742.40	846720
	16-Sep-96	0.00	5	0.00	432000

Appendix D: Statit® Multiple Linear Regression Analysis Results

Río Cibuco below Corozal

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                        All Possible Subsets Regression

                              Dependent variable

                          V2   DSG

                            Independent variables

                          V6   UBD
                          V4   FOR
                          V5   AGR
                          V1   PCP

                            Valid cases   =      6
                            Missing cases =      0
                            Method        = Mallow’s Cp
                            Max subsets   =      4


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   9.25803    -2.484  0.09693 -0.12884  0.5090114 UBD
```

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V6 UBD

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	4.70193	-12.188	0.82080	0.77600	0.1010051	PCP
2	3.00000	-15.011	0.91978	0.86631	0.0602842	PCP, UBD
1	31.77411	-2.484	0.09693	-0.12884	0.5090114	UBD

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Best Model with 1 Parameter

Mallow's C(p)	=	4.701929
Akaike's Info Crit.	=	-12.18829
Multiple R-square	=	0.8207997
Adjusted R-square	=	0.7759997
Residual Mean Square	=	0.1010051

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	1.850555	1.850555	18.32139	0.01284
Residual	4	0.4040205	0.1010051		
Total	5	2.254575			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.109521	0.4928384	4.280	0.0128
	Intercept	-9.566668			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-15.01099
Multiple R-square	=	0.9197842
Adjusted R-square	=	0.8663070
Residual Mean Square	=	0.0602842

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	2.073723	1.036861	17.19955	0.02272
Residual	3	0.1808527	0.0602842		
Total	5	2.254575			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.112177	0.3807479	5.547	0.0116
V6	UBD	2.983480	1.550634	1.924	0.1500
	Intercept	-12.54554			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V2   DSG

Independent variables

V1   PCP
V4   FOR

Valid cases   =   6
Missing cases =   0
Method   = Mallow's Cp
Max subsets   =   2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	4.70193	-12.188	0.82080	0.77600	0.1010051	PCP
2	3.00000	-15.011	0.91978	0.86631	0.0602842	PCP, FOR
1	31.77411	-2.484	0.09693	-0.12884	0.5090114	FOR

Best Model with 1 Parameter

Mallow's C(p)   =   4.701929
Akaike's Info Crit.   =   -12.18829
Multiple R-square   =   0.8207997
Adjusted R-square   =   0.7759997
Residual Mean Square =   0.1010051

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	1.850555	1.850555	18.32139	0.01284
Residual	4	0.4040205	0.1010051		
Total	5	2.254575			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.109521	0.4928384	4.280	0.0128
	Intercept	-9.566668			

Best Model with 2 Parameters

Mallow’s C(p)	=	3.000000
Akaike’s Info Crit.	=	-15.01099
Multiple R-square	=	0.9197842
Adjusted R-square	=	0.8663070
Residual Mean Square	=	0.0602842

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	2.073723	1.036861	17.19955	0.02272
Residual	3	0.1808527	0.0602842		
Total	5	2.254575			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.112177	0.3807479	5.547	0.0116
V4	FOR	-1.437265	0.7470040	-1.924	0.1500
	Intercept	-7.655394			

The ‘best’ subset determined by Mallow’s C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V5 AGR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	4.70193	-12.188	0.82080	0.77600	0.1010051	PCP
2	3.00000	-15.011	0.91978	0.86631	0.0602842	PCP, AGR
1	31.77411	-2.484	0.09693	-0.12884	0.5090114	AGR

Best Model with 1 Parameter

Mallow's C(p)	=	4.701929
Akaike's Info Crit.	=	-12.18829
Multiple R-square	=	0.8207997
Adjusted R-square	=	0.7759997
Residual Mean Square	=	0.1010051

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	1.850555	1.850555	18.32139	0.01284
Residual	4	0.4040205	0.1010051		
Total	5	2.254575			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.109521	0.4928384	4.280	0.0128
	Intercept	-9.566668			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-15.01099
Multiple R-square	=	0.9197842
Adjusted R-square	=	0.8663070
Residual Mean Square	=	0.0602842

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	2.073723	1.036861	17.19955	0.02272
Residual	3	0.1808527	0.0602842		
Total	5	2.254575			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.112177	0.3807479	5.547	0.0116
V5	AGR	4.828739	2.509688	1.924	0.1500
	Intercept	-18.33055			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

Río Inabon at Real Abajo

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                        All Possible Subsets Regression

                              Dependent variable

                          V2   DSG

                            Independent variables

                          V1   PCP
                          V6   UBD

                            Valid cases   =      6
                            Missing cases =      0
                            Method        = Mallow's Cp
                            Max subsets   =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1  24.57925   -14.045  0.87554  0.84443  0.0741178 PCP
   2   3.00003   -25.134  0.98595  0.97659  0.0111543 PCP, UBD
   1 187.96489    -2.245  0.11049 -0.11189  0.5297282 UBD

                       Best Model with 1 Parameter

                    Mallow's C(p)        =        24.57925
                    Akaike's Info Crit.   =        -14.04539
                    Multiple R-square     =        0.8755429
                    Adjusted R-square     =        0.8444286
                    Residual Mean Square  =        0.0741178

                             Analysis of Variance

     Source     Df         SS              MS          F-Ratio     P(F)

    Regression    1      2.085644       2.085644      28.13959  0.00607
    Residual      4     0.2964711      0.0741178
    Total         5      2.382115

                          Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V1   PCP                    1.501828    0.2831141   5.305 0.0061
     Intercept             -4.783617
```

Best Model with 2 Parameters

Mallow's C(p)	=	3.000027
Akaike's Info Crit.	=	-25.13445
Multiple R-square	=	0.9859524
Adjusted R-square	=	0.9765874
Residual Mean Square	=	0.0111543

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	2.348652	1.174326	105.2798	0.00166
Residual	3	0.0334630	0.0111543		
Total	5	2.382115			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	1.501759	0.1098303	13.673	0.0008
V6	UBD	-0.8117002	0.1671601	-4.856	0.0167
	Intercept	-4.573683			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V4 FOR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	24.57925	-14.045	0.87554	0.84443	0.0741178	PCP
2	3.00003	-25.134	0.98595	0.97659	0.0111543	PCP, FOR
1	187.96489	-2.245	0.11049	-0.11189	0.5297282	FOR

Best Model with 1 Parameter

Mallow's C(p)	=	24.57925
Akaike's Info Crit.	=	-14.04539
Multiple R-square	=	0.8755429
Adjusted R-square	=	0.8444286
Residual Mean Square	=	0.0741178

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	2.085644	2.085644	28.13959	0.00607
Residual	4	0.2964711	0.0741178		
Total	5	2.382115			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	1.501828	0.2831141	5.305	0.0061
	Intercept	-4.783617			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000027
Akaike's Info Crit.	=	-25.13445
Multiple R-square	=	0.9859524
Adjusted R-square	=	0.9765874
Residual Mean Square	=	0.0111543

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	2.348652	1.174326	105.2798	0.00166
Residual	3	0.0334630	0.0111543		
Total	5	2.382115			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	1.501759	0.1098303	13.673	0.0008
V4	FOR	-1.888483	0.3889109	-4.856	0.0167
	Intercept	-1.340486			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V5 AGR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	24.57925	-14.045	0.87554	0.84443	0.0741178	PCP
2	3.00003	-25.134	0.98595	0.97659	0.0111543	PCP, AGR
1	187.96489	-2.245	0.11049	-0.11189	0.5297282	AGR

Best Model with 1 Parameter

Mallow's C(p) = 24.57925
Akaike's Info Crit. = -14.04539
Multiple R-square = 0.8755429
Adjusted R-square = 0.8444286
Residual Mean Square = 0.0741178

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	2.085644	2.085644	28.13959	0.00607
Residual	4	0.2964711	0.0741178		
Total	5	2.382115			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	1.501828	0.2831141	5.305	0.0061
	Intercept	-4.783617			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000027
Akaike's Info Crit.	=	-25.13445
Multiple R-square	=	0.9859524
Adjusted R-square	=	0.9765874
Residual Mean Square	=	0.0111543

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	2.348652	1.174326	105.2798	0.00166
Residual	3	0.0334630	0.0111543		
Total	5	2.382115			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	1.501759	0.1098303	13.673	0.0008
V5	AGR	0.6311871	0.1299856	4.856	0.0167
	Intercept	-5.627686			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

Río Portugues near Ponce

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                        All Possible Subsets Regression

                              Dependent variable

                          V2   DSG

                            Independent variables

                          V1   PCP
                          V6   UBD

                            Valid cases   =      6
                            Missing cases =      0
                            Method        = Mallow's Cp
                            Max subsets   =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   2.41962   -14.129  0.56236  0.45295  0.0730932 PCP
   2   3.00000   -14.454  0.70293  0.50489  0.0661534 PCP, UBD
   1   7.11418    -9.786  0.09749 -0.12814  0.1507336 UBD
                       Best Model with 1 Parameter

                   Mallow's C(p)         =         2.419615
                   Akaike's Info Crit.   =        -14.12891
                   Multiple R-square     =         0.5623571
                   Adjusted R-square     =         0.4529463
                   Residual Mean Square  =         0.0730932

                             Analysis of Variance

     Source     Df        SS             MS          F-Ratio     P(F)

    Regression    1     0.3756898      0.3756898      5.139871  0.08600
    Residual      4     0.2923729      0.0730932
    Total         5     0.6680627

                          Variables in the equation

       Variable         Coefficient   Std error  T-value  P(T)

V1   PCP                    2.208362    0.9740791   2.267 0.0860
     Intercept             -9.837563
```

Best Model with 2 Parameters

Mallow's C(p)	=	2.999998
Akaike's Info Crit.	=	-14.45355
Multiple R-square	=	0.7029316
Adjusted R-square	=	0.5048861
Residual Mean Square	=	0.0661534

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.4696024	0.2348012	3.549343	0.16191
Residual	3	0.1984603	0.0661534		
Total	5	0.6680627			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.299130	0.9298104	2.473	0.0899
V6	UBD	-0.2539707	0.2131561	-1.191	0.3191
	Intercept	-10.64479			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V2   DSG

Independent variables

V1   PCP
V4   FOR

Valid cases	=	6
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.41962	-14.129	0.56236	0.45295	0.0730932	PCP
2	3.00000	-14.454	0.70293	0.50489	0.0661534	PCP, FOR
1	7.11418	-9.786	0.09749	-0.12814	0.1507336	FOR

Best Model with 1 Parameter

Mallow's C(p)	=	2.419615
Akaike's Info Crit.	=	-14.12891
Multiple R-square	=	0.5623571
Adjusted R-square	=	0.4529463
Residual Mean Square	=	0.0730932

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3756898	0.3756898	5.139871	0.08600
Residual	4	0.2923729	0.0730932		
Total	5	0.6680627			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.208362	0.9740791	2.267	0.0860
	Intercept	-9.837563			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999998
Akaike's Info Crit.	=	-14.45355
Multiple R-square	=	0.7029316
Adjusted R-square	=	0.5048861
Residual Mean Square	=	0.0661534

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.4696024	0.2348012	3.549343	0.16191
Residual	3	0.1984603	0.0661534		
Total	5	0.6680627			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.299130	0.9298104	2.473	0.0899
V4	FOR	10.81962	9.080849	1.191	0.3191
	Intercept	-31.61518			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V2   DSG

Independent variables

V1   PCP
V5   AGR

Valid cases   =   6
Missing cases =   0
Method   = Mallow's Cp
Max subsets   =   2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.41962	-14.129	0.56236	0.45295	0.0730932	PCP
2	3.00000	-14.454	0.70293	0.50489	0.0661534	PCP, AGR
1	7.11418	-9.786	0.09749	-0.12814	0.1507336	AGR

Best Model with 1 Parameter

Mallow's C(p)   =   2.419615
Akaike's Info Crit.   =   -14.12891
Multiple R-square   =   0.5623571
Adjusted R-square   =   0.4529463
Residual Mean Square =   0.0730932

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3756898	0.3756898	5.139871	0.08600
Residual	4	0.2923729	0.0730932		
Total	5	0.6680627			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.208362	0.9740791	2.267	0.0860
	Intercept	-9.837563			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999998
Akaike's Info Crit.	=	-14.45355
Multiple R-square	=	0.7029316
Adjusted R-square	=	0.5048861
Residual Mean Square	=	0.0661534

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.4696024	0.2348012	3.549343	0.16191
Residual	3	0.1984603	0.0661534		
Total	5	0.6680627			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	2.299130	0.9298104	2.473	0.0899
V5	AGR	-1.327740	1.114364	-1.191	0.3191
	Intercept	-9.270046			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

Río Grande de Patillas near Patillas

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                        All Possible Subsets Regression

                              Dependent variable

                          V2   DSG

                            Independent variables

                          V1   PCP
                          V6   UBD

                            Valid cases   =      6
                            Missing cases =      0
                            Method        = Mallow's Cp
                            Max subsets   =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   1.01939   -15.678  0.27334  0.09168  0.0564593 PCP
   2   3.00000   -13.717  0.27801 -0.20332  0.0747958 PCP, UBD
   1   2.12404   -13.808  0.00749 -0.24064  0.0771151 UBD

                       Best Model with 1 Parameter

                   Mallow's C(p)         =        1.019387
                   Akaike's Info Crit.   =        -15.67820
                   Multiple R-square     =        0.2733405
                   Adjusted R-square     =        0.0916756
                   Residual Mean Square  =        0.0564593

                            Analysis of Variance

     Source     Df        SS              MS           F-Ratio     P(F)

    Regression    1     0.0849510      0.0849510      1.504641  0.28722
    Residual      4     0.2258373      0.0564593
    Total         5     0.3107883

                          Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V1   PCP                    0.8209490    0.6692675   1.227 0.2872
     Intercept               1.027123
```

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-13.71685
Multiple R-square	=	0.2780061
Adjusted R-square	=	-0.2033231
Residual Mean Square	=	0.0747958

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0864011	0.0432005	0.5775799	0.61348
Residual	3	0.2243873	0.0747958		
Total	5	0.3107883			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	0.8171958	0.7707900	1.060	0.3668
V6	UBD	-0.0655714	0.4709386	-0.139	0.8981
	Intercept	1.046757			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V4 FOR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.01939	-15.678	0.27334	0.09168	0.0564593	PCP
2	3.00000	-13.717	0.27801	-0.20332	0.0747958	PCP, FOR
1	2.12404	-13.808	0.00749	-0.24064	0.0771151	FOR

Best Model with 1 Parameter

Mallow's C(p)	=	1.019387
Akaike's Info Crit.	=	-15.67820
Multiple R-square	=	0.2733405
Adjusted R-square	=	0.0916756
Residual Mean Square	=	0.0564593

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0849510	0.0849510	1.504641	0.28722
Residual	4	0.2258373	0.0564593		
Total	5	0.3107883			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	0.8209490	0.6692675	1.227	0.2872
	Intercept	1.027123			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-13.71685
Multiple R-square	=	0.2780061
Adjusted R-square	=	-0.2033231
Residual Mean Square	=	0.0747958

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0864011	0.0432005	0.5775799	0.61348
Residual	3	0.2243873	0.0747958		
Total	5	0.3107883			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	0.8171958	0.7707900	1.060	0.3668
V4	FOR	-17.42621	125.1563	-0.139	0.8981
	Intercept	33.90762			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V5 AGR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.01939	-15.678	0.27334	0.09168	0.0564593	PCP
2	3.00000	-13.717	0.27801	-0.20332	0.0747958	PCP, AGR
1	2.12404	-13.808	0.00749	-0.24064	0.0771151	AGR

Best Model with 1 Parameter

Mallow's C(p) = 1.019387
Akaike's Info Crit. = -15.67820
Multiple R-square = 0.2733405
Adjusted R-square = 0.0916756
Residual Mean Square = 0.0564593

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0849510	0.0849510	1.504641	0.28722
Residual	4	0.2258373	0.0564593		
Total	5	0.3107883			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	0.8209490	0.6692675	1.227	0.2872
	Intercept	1.027123			

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Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-13.71685
Multiple R-square	=	0.2780061
Adjusted R-square	=	-0.2033231
Residual Mean Square	=	0.0747958

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0864011	0.0432005	0.5775799	0.61348
Residual	3	0.2243873	0.0747958		
Total	5	0.3107883			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	0.8171958	0.7707900	1.060	0.3668
V5	AGR	2.024207	14.53800	0.139	0.8981
	Intercept	-1.645314			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

Río Tanama near Utuato

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                        All Possible Subsets Regression

                              Dependent variable

                          V2   DSG

                            Independent variables

                          V1   PCP
                          V6   UBD

                            Valid cases   =      6
                            Missing cases =      0
                            Method        = Mallow's Cp
                            Max subsets   =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   2.16020   -19.103  0.58271  0.47839  0.0319020 PCP
   2   3.00000   -19.065  0.69909  0.49848  0.0306736 PCP, UBD
   1   7.15041   -14.374  0.08217 -0.14729  0.0701689 UBD

                       Best Model with 1 Parameter

                   Mallow's C(p)         =         2.160198
                   Akaike's Info Crit.    =        -19.10331
                   Multiple R-square      =        0.5827122
                   Adjusted R-square      =        0.4783902
                   Residual Mean Square   =        0.0319020

                             Analysis of Variance

     Source     Df         SS              MS          F-Ratio     P(F)

    Regression    1     0.1781954      0.1781954      5.585710  0.07737
    Residual      4     0.1276081      0.0319020
    Total         5     0.3058035

                          Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V1   PCP                  -2.083005    0.8813555  -2.363 0.0774
     Intercept             24.71325
```

Best Model with 2 Parameters

Mallow's C(p)	=	3.000004
Akaike's Info Crit.	=	-19.06500
Multiple R-square	=	0.6990852
Adjusted R-square	=	0.4984753
Residual Mean Square	=	0.0306736

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.2137827	0.1068913	3.484799	0.16507
Residual	3	0.0920208	0.0306736		
Total	5	0.3058035			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	-2.148576	0.8663616	-2.480	0.0893
V6	UBD	0.2004482	0.1860960	1.077	0.3603
	Intercept	25.42680			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V4 FOR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.16020	-19.103	0.58271	0.47839	0.0319020	PCP
2	3.00000	-19.065	0.69909	0.49848	0.0306736	PCP, FOR
1	7.15041	-14.374	0.08217	-0.14729	0.0701689	FOR

```
                     Best Model with 1 Parameter

                 Mallow's C(p)         =         2.160198
                 Akaike's Info Crit.   =         -19.10331
                 Multiple R-square     =         0.5827122
                 Adjusted R-square     =         0.4783902
                 Residual Mean Square  =         0.0319020

                         Analysis of Variance

     Source     Df        SS              MS          F-Ratio     P(F)

    Regression    1     0.1781954      0.1781954      5.585710  0.07737
    Residual      4     0.1276081      0.0319020
    Total         5     0.3058035

                       Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V1   PCP                    -2.083005    0.8813555  -2.363 0.0774
     Intercept               24.71325


                     Best Model with 2 Parameters

                 Mallow's C(p)         =         3.000004
                 Akaike's Info Crit.   =         -19.06500
                 Multiple R-square     =         0.6990852
                 Adjusted R-square     =         0.4984753
                 Residual Mean Square  =         0.0306736

                         Analysis of Variance

     Source     Df        SS              MS          F-Ratio     P(F)

    Regression    2     0.2137827      0.1068913      3.484799  0.16507
    Residual      3     0.0920208      0.0306736
    Total         5     0.3058035

                       Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V1   PCP                    -2.148576    0.8663616  -2.480 0.0893
V4   FOR                    -4.017146     3.729517  -1.077 0.3603
     Intercept               32.95554

----------------------------------------------------------------------
The 'best' subset determined by Mallow's C(p) is with 1 parameter.
----------------------------------------------------------------------
```

All Possible Subsets Regression

Dependent variable

V2 DSG

Independent variables

V1 PCP
V5 AGR

Valid cases = 6
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.16020	-19.103	0.58271	0.47839	0.0319020	PCP
2	3.00000	-19.065	0.69909	0.49848	0.0306736	PCP, AGR
1	7.15041	-14.374	0.08217	-0.14729	0.0701689	AGR

Best Model with 1 Parameter

Mallow's C(p) = 2.160198
Akaike's Info Crit. = -19.10331
Multiple R-square = 0.5827122
Adjusted R-square = 0.4783902
Residual Mean Square = 0.0319020

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.1781954	0.1781954	5.585710	0.07737
Residual	4	0.1276081	0.0319020		
Total	5	0.3058035			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	-2.083005	0.8813555	-2.363	0.0774
	Intercept	24.71325			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000004
Akaike's Info Crit.	=	-19.06500
Multiple R-square	=	0.6990852
Adjusted R-square	=	0.4984753
Residual Mean Square	=	0.0306736

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.2137827	0.1068913	3.484799	0.16507
Residual	3	0.0920208	0.0306736		
Total	5	0.3058035			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	PCP	-2.148576	0.8663616	-2.480	0.0893
V5	AGR	0.5297898	0.4918567	1.077	0.3603
	Intercept	24.64403			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

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```
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                       All Possible Subsets Regression

                             Dependent variable

                         V7   DSG

                           Independent variables

                         V6   PCP
                         V11  UBD

                           Valid cases   =      5
                           Missing cases =      0
                           Method        = Mallow's Cp
                           Max subsets   =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   5.30125   -10.767  0.10516 -0.19312  0.0869301 PCP
   2   3.00000   -14.505  0.71598  0.43196  0.0413870 PCP, UBD
   1   3.62723   -12.311  0.34289  0.12385  0.0638360 UBD

                      Best Model with 1 Parameter

                  Mallow's C(p)        =         3.627233
                  Akaike's Info Crit.   =        -12.31132
                  Multiple R-square     =        0.3428885
                  Adjusted R-square     =        0.1238514
                  Residual Mean Square  =        0.0638360

                            Analysis of Variance

     Source     Df        SS              MS          F-Ratio     P(F)

    Regression    1     0.0999311      0.0999311      1.565436   0.29956
    Residual      3     0.1915079      0.0638360
    Total         4     0.2914390

                         Variables in the equation

      Variable          Coefficient   Std error  T-value  P(T)

V11  UBD                  -0.3897354    0.3114958  -1.251 0.2996
     Intercept              7.578518
```

Best Model with 2 Parameters

Mallow's C(p)	=	2.999995
Akaike's Info Crit.	=	-14.50539
Multiple R-square	=	0.7159815
Adjusted R-square	=	0.4319630
Residual Mean Square	=	0.0413870

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.2086649	0.1043325	2.520897	0.28402
Residual	2	0.0827741	0.0413870		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.099119	0.6781012	1.621	0.2465
V11	UBD	-0.5679724	0.2738605	-2.074	0.1738
	Intercept	-1.340317			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V9 FOR

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.03868	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-10.859	0.41104	-0.17793	0.0858236	PCP, FOR
1	1.51273	-11.718	0.26005	0.01339	0.0718838	FOR

Best Model with 1 Parameter

Mallow's C(p)	=	1.512725
Akaike's Info Crit.	=	-11.71765
Multiple R-square	=	0.2600462
Adjusted R-square	=	0.0133950
Residual Mean Square	=	0.0718838

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0757876	0.0757876	1.054307	0.38007
Residual	3	0.2156514	0.0718838		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V9	FOR	0.7037595	0.6853945	1.027	0.3801
	Intercept	6.220554			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999997
Akaike's Info Crit.	=	-10.85876
Multiple R-square	=	0.4110358
Adjusted R-square	=	-0.1779284
Residual Mean Square	=	0.0858236

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.1197918	0.0598959	0.6978960	0.58896
Residual	2	0.1716471	0.0858236		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6450726	0.9008753	0.716	0.5483
V9	FOR	0.7688582	0.7544059	1.019	0.4153
	Intercept	0.8428076			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V10 AGR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.05158	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-8.895	0.12766	-0.74468	0.1271169	PCP, AGR
1	1.28402	-10.231	0.00378	-0.32830	0.0967793	AGR

Best Model with 1 Parameter

Mallow's C(p) = 1.051578
Akaike's Info Crit. = -10.76738
Multiple R-square = 0.1051627
Adjusted R-square = -0.1931164
Residual Mean Square = 0.0869301

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0306485	0.0306485	0.3525649	0.59446
Residual	3	0.2607904	0.0869301		
Total	4	0.2914390			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	0.5344283	0.9000568	0.594	0.5945
	Intercept	3.119087			

Best Model with 2 Parameters

```
Mallow's C(p)          =        2.999998
Akaike's Info Crit.    =       -8.894695
Multiple R-square      =        0.1276604
Adjusted R-square      =       -0.7446792
Residual Mean Square   =        0.1271169
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0372052	0.0186026	0.1463425	0.87234
Residual	2	0.2542337	0.1271169		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6002762	1.126350	0.533	0.6474
V10	AGR	-0.1152118	0.5072899	-0.227	0.8414
	Intercept	2.741601			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V5 DA

```
Valid cases   =      5
Missing cases =      0
Method        = Mallow's Cp
Max subsets   =      2
```

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.39431	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-9.667	0.25253	-0.49494	0.1089208	PCP, DA
1	1.22899	-11.125	0.16695	-0.11073	0.0809278	DA

Best Model with 1 Parameter

Mallow's C(p)	=	1.228989
Akaike's Info Crit.	=	-11.12512
Multiple R-square	=	0.1669497
Adjusted R-square	=	-0.1107337
Residual Mean Square	=	0.0809278

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0486557	0.0486557	0.6012233	0.49462
Residual	3	0.2427833	0.0809278		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V5	DA	0.7306400	0.9422918	0.775	0.4946
	Intercept	6.655448			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999999
Akaike's Info Crit.	=	-9.667127
Multiple R-square	=	0.2525312
Adjusted R-square	=	-0.4949375
Residual Mean Square	=	0.1089208

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0735974	0.0367987	0.3378485	0.74747
Residual	2	0.2178415	0.1089208		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	-1.964141	4.104539	-0.479	0.6795
V5	DA	2.796644	4.453653	0.628	0.5942
	Intercept	20.34956			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V4 DR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.28570	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-11.250	0.45532	-0.08937	0.0793712	PCP, DR
1	1.78300	-11.598	0.24207	-0.01057	0.0736300	DR

Best Model with 1 Parameter

Mallow's C(p) = 1.782999
Akaike's Info Crit. = -11.59764
Multiple R-square = 0.2420709
Adjusted R-square = -0.0105721
Residual Mean Square = 0.0736300

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0705489	0.0705489	0.9581539	0.39984
Residual	3	0.2208901	0.0736300		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V4	DR	-1.579244	1.613361	-0.979	0.3998
	Intercept	10.08906			

Best Model with 2 Parameters

```
Mallow's C(p)          =        2.999999
Akaike's Info Crit.    =       -11.24955
Multiple R-square      =       0.4553152
Adjusted R-square      =      -0.0893697
Residual Mean Square   =       0.0793712
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.1326966	0.0663483	0.8359241	0.54468
Residual	2	0.1587424	0.0793712		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.7859221	0.8881748	0.885	0.4696
V4	DR	-1.961502	1.729887	-1.134	0.3745
	Intercept	4.310811			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V3 SP

```
Valid cases   =      5
Missing cases =      0
Method        = Mallow's Cp
Max subsets   =      2
```

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.57557	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-11.672	0.49947	-0.00106	0.0729368	PCP, SP
1	1.18590	-13.228	0.45295	0.27060	0.0531442	SP

Best Model with 1 Parameter

Mallow's C(p)	=	1.185903
Akaike's Info Crit.	=	-13.22786
Multiple R-square	=	0.4529464
Adjusted R-square	=	0.2705952
Residual Mean Square	=	0.0531442

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.1320062	0.1320062	2.483924	0.21310
Residual	3	0.1594327	0.0531442		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V3	SP	1.551244	0.9842629	1.576	0.2131
	Intercept	7.248099			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000001
Akaike's Info Crit.	=	-11.67226
Multiple R-square	=	0.4994710
Adjusted R-square	=	-0.0010580
Residual Mean Square	=	0.0729368

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.1455653	0.0727827	0.9978863	0.50053
Residual	2	0.1458737	0.0729368		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.3604556	0.8360074	0.431	0.7084
V3	SP	1.467664	1.169253	1.255	0.3362
	Intercept	4.320494			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V2 GS

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	5.40782	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-14.589	0.72070	0.44141	0.0406988	PCP, GS
1	5.58383	-10.632	0.08058	-0.22589	0.0893180	GS

Best Model with 1 Parameter

Mallow's C(p)	=	5.407816
Akaike's Info Crit.	=	-10.76738
Multiple R-square	=	0.1051627
Adjusted R-square	=	-0.1931164
Residual Mean Square	=	0.0869301

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0306485	0.0306485	0.3525649	0.59446
Residual	3	0.2607904	0.0869301		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.5344283	0.9000568	0.594	0.5945
	Intercept	3.119087			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000001
Akaike's Info Crit.	=	-14.58923
Multiple R-square	=	0.7207043
Adjusted R-square	=	0.4414086
Residual Mean Square	=	0.0406988

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.2100413	0.1050207	2.580435	0.27930
Residual	2	0.0813977	0.0406988		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.970816	0.9205176	2.141	0.1656
V2	GS	2.475179	1.178949	2.099	0.1706
	Intercept	-12.41047			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V1 CS

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.13514	-10.767	0.10516	-0.19312	0.0869301	PCP
2	3.00000	-9.094	0.16180	-0.67640	0.1221421	PCP, CS
1	1.37179	-10.242	0.00598	-0.32536	0.0965651	CS

Best Model with 1 Parameter

Mallow's C(p)	=	1.135140
Akaike's Info Crit.	=	-10.76738
Multiple R-square	=	0.1051627
Adjusted R-square	=	-0.1931164
Residual Mean Square	=	0.0869301

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0306485	0.0306485	0.3525649	0.59446
Residual	3	0.2607904	0.0869301		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.5344283	0.9000568	0.594	0.5945
	Intercept	3.119087			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-9.094304
Multiple R-square	=	0.1617998
Adjusted R-square	=	-0.6764004
Residual Mean Square	=	0.1221421

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0471548	0.0235774	0.1930324	0.83820
Residual	2	0.2442842	0.1221421		
Total	4	0.2914390			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.7188759	1.178978	0.610	0.6041
V1	CS	0.5340014	1.452617	0.368	0.7484
	Intercept	0.0223477			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

1977 All Basin Regression 2

All Possible Subsets Regression

Dependent variable

V7   DSG

Independent variables

V6   PCP
V11 UBD

Valid cases   =   5
Missing cases =   0
Method   = Mallow's Cp
Max subsets   =   2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	8.24481	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-18.183	0.92132	0.84263	0.0198337	PCP, UBD
1	21.35205	-8.114	0.12063	-0.17249	0.1477744	UBD

Best Model with 1 Parameter

Mallow's C(p)   =   8.244807
Akaike's Info Crit.   =   -12.52875
Multiple R-square   =   0.6362926
Adjusted R-square   =   0.5150568
Residual Mean Square =   0.0611195

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000001
Akaike's Info Crit.	=	-18.18332
Multiple R-square	=	0.9213163
Adjusted R-square	=	0.8426327
Residual Mean Square	=	0.0198337

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.4644699	0.2322350	11.70912	0.07868
Residual	2	0.0396674	0.0198337		
Total	4	0.5041373			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	2.757895	0.6113272	4.511	0.0458
V11	UBD	-0.4665419	0.1733315	-2.692	0.1148
	Intercept	-14.58178			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V9 FOR

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.24119	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-12.943	0.77557	0.55114	0.0565713	PCP, FOR
1	5.94547	-8.718	0.22062	-0.03917	0.1309713	FOR

Best Model with 1 Parameter

```
Mallow's C(p)          =        2.241194
Akaike's Info Crit.    =        -12.52875
Multiple R-square      =        0.6362926
Adjusted R-square      =        0.5150568
Residual Mean Square   =        0.0611195
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

```
Mallow's C(p)          =        3.000000
Akaike's Info Crit.    =        -12.94272
Multiple R-square      =        0.7755719
Adjusted R-square      =        0.5511439
Residual Mean Square   =        0.0565713
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.3909947	0.1954974	3.455771	0.22443
Residual	2	0.1131425	0.0565713		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.258494	1.015583	2.224	0.1562
V9	FOR	0.6545528	0.5875229	1.114	0.3812
	Intercept	-11.86211			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V10 AGR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.21036	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-11.029	0.67091	0.34181	0.0829541	PCP, AGR
1	4.63925	-7.846	0.07208	-0.23723	0.1559331	AGR

Best Model with 1 Parameter

Mallow's C(p) = 1.210359
Akaike's Info Crit. = -12.52875
Multiple R-square = 0.6362926
Adjusted R-square = 0.5150568
Residual Mean Square = 0.0611195

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999999
Akaike's Info Crit.	=	-11.02879
Multiple R-square	=	0.6709066
Adjusted R-square	=	0.3418132
Residual Mean Square	=	0.0829541

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.3382290	0.1691145	2.038651	0.32909
Residual	2	0.1659082	0.0829541		
Total	4	0.5041373			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	2.340631	1.226950	1.908	0.1967
V10	AGR	-0.1648358	0.3593932	-0.459	0.6915
	Intercept	-11.12612			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V5 DA

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.23669	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00001	-12.936	0.77526	0.55052	0.0566504	PCP, DA
1	2.64110	-11.940	0.59085	0.45446	0.0687562	DA

Best Model with 1 Parameter

Mallow's C(p)	=	2.236685
Akaike's Info Crit.	=	-12.52875
Multiple R-square	=	0.6362926
Adjusted R-square	=	0.5150568
Residual Mean Square	=	0.0611195

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000010
Akaike's Info Crit.	=	-12.93574
Multiple R-square	=	0.7752582
Adjusted R-square	=	0.5505165
Residual Mean Square	=	0.0566504

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.3908366	0.1954183	3.449551	0.22474
Residual	2	0.1133007	0.0566504		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	17.88208	13.95895	1.281	0.3286
V5	DA	-12.13663	10.91368	-1.112	0.3819
	Intercept	-122.3705			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V4 DR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.00269	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-10.535	0.63678	0.27356	0.0915564	PCP, DR
1	4.48903	-7.487	0.00314	-0.32915	0.1675185	DR

Best Model with 1 Parameter

Mallow's C(p) = 1.002685
Akaike's Info Crit. = -12.52875
Multiple R-square = 0.6362926
Adjusted R-square = 0.5150568
Residual Mean Square = 0.0611195

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000001
Akaike's Info Crit.	=	-10.53546
Multiple R-square	=	0.6367800
Adjusted R-square	=	0.2735600
Residual Mean Square	=	0.0915564

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.3210245	0.1605123	1.753152	0.36322
Residual	2	0.1831127	0.0915564		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.406026	1.288096	1.868	0.2027
V4	DR	-0.0936612	1.807732	-0.052	0.9634
	Intercept	-11.71466			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7   DSG

Independent variables

V6   PCP
V3   SP

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.00306	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-10.536	0.63685	0.27370	0.0915392	PCP, SP
1	3.90323	-8.053	0.10969	-0.18708	0.1496128	SP

```
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                         Best Model with 1 Parameter

                     Mallow's C(p)         =         1.003058
                     Akaike's Info Crit.    =         -12.52875
                     Multiple R-square      =         0.6362926
                     Adjusted R-square      =         0.5150568
                     Residual Mean Square  =         0.0611195

                               Analysis of Variance

     Source     Df        SS              MS           F-Ratio     P(F)

    Regression    1     0.3207788      0.3207788      5.248389  0.10587
    Residual      3     0.1833585      0.0611195
    Total         4     0.5041373

                            Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V6   PCP                    2.399501     1.047389   2.291 0.1059
     Intercept             -11.81716


                         Best Model with 2 Parameters

                     Mallow's C(p)         =         2.999998
                     Akaike's Info Crit.    =         -10.53640
                     Multiple R-square      =         0.6368482
                     Adjusted R-square      =         0.2736964
                     Residual Mean Square  =         0.0915392

                               Analysis of Variance

     Source     Df        SS              MS           F-Ratio     P(F)

    Regression    2     0.3210589      0.1605295      1.753670  0.36315
    Residual      2     0.1830783      0.0915392
    Total         4     0.5041373

                            Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V6   PCP                    2.369655     1.390733   1.704 0.2305
V3   SP                    0.0775304     1.401550   0.055 0.9609
     Intercept             -11.58919

-----------------------------------------------------------------------
The 'best' subset determined by Mallow's C(p) is with 1 parameter.
-----------------------------------------------------------------------
```

All Possible Subsets Regression

Dependent variable

V7   DSG

Independent variables

V6   PCP
V2   GS

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.43449	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-13.232	0.78820	0.57641	0.0533874	PCP, GS
1	8.19681	-7.604	0.02607	-0.29857	0.1636644	GS

Best Model with 1 Parameter

Mallow's C(p) = 2.434494
Akaike's Info Crit. = -12.52875
Multiple R-square = 0.6362926
Adjusted R-square = 0.5150568
Residual Mean Square = 0.0611195

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000003
Akaike's Info Crit.	=	-13.23235
Multiple R-square	=	0.7882029
Adjusted R-square	=	0.5764058
Residual Mean Square	=	0.0533874

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.3973624	0.1986812	3.721499	0.21180
Residual	2	0.1067748	0.0533874		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	3.267677	1.218062	2.683	0.1154
V2	GS	1.346318	1.124085	1.198	0.3537
	Intercept	-20.85707			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V1 CS

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	4.12448	-12.529	0.63629	0.51506	0.0611195	PCP
2	3.00000	-15.233	0.85805	0.71610	0.0357809	PCP, CS
1	13.04573	-7.487	0.00311	-0.32919	0.1675230	CS

Best Model with 1 Parameter

Mallow's C(p)	=	4.124477
Akaike's Info Crit.	=	-12.52875
Multiple R-square	=	0.6362926
Adjusted R-square	=	0.5150568
Residual Mean Square	=	0.0611195

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3207788	0.3207788	5.248389	0.10587
Residual	3	0.1833585	0.0611195		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.399501	1.047389	2.291	0.1059
	Intercept	-11.81716			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000001
Akaike's Info Crit.	=	-15.23316
Multiple R-square	=	0.8580509
Adjusted R-square	=	0.7161018
Residual Mean Square	=	0.0357809

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.4325754	0.2162877	6.044778	0.14195
Residual	2	0.0715618	0.0357809		
Total	4	0.5041373			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	3.124502	0.9002525	3.471	0.0739
V1	CS	1.412748	0.7992382	1.768	0.2192
	Intercept	-21.84652			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

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```
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                        All Possible Subsets Regression

                              Dependent variable

                          V7   DSG

                            Independent variables

                          V6   PCP
                          V11  UBD

                            Valid cases    =      5
                            Missing cases =      0
                            Method         = Mallow's Cp
                            Max subsets    =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   5.16491    -4.997  0.29150  0.05533  0.2756628 PCP
   2   3.00000    -8.626  0.77015  0.54030  0.1341445 PCP, UBD
   1   1.90434    -8.760  0.66622  0.55496  0.1298669 UBD

                       Best Model with 1 Parameter

                   Mallow's C(p)        =        1.904338
                   Akaike's Info Crit.   =        -8.760353
                   Multiple R-square     =        0.6662201
                   Adjusted R-square     =        0.5549601
                   Residual Mean Square  =        0.1298669

                             Analysis of Variance

     Source     Df         SS              MS          F-Ratio     P(F)

    Regression    1     0.7776377      0.7776377      5.987959  0.09192
    Residual      3     0.3896008      0.1298669
    Total         4      1.167238

                          Variables in the equation

       Variable          Coefficient   Std error  T-value  P(T)

V11  UBD                   -0.7824823    0.3197681  -2.447 0.0919
     Intercept               7.313276
```

Best Model with 2 Parameters

```
Mallow's C(p)          =        3.000001
Akaike's Info Crit.    =       -8.625643
Multiple R-square      =        0.7701507
Adjusted R-square      =        0.5403013
Residual Mean Square   =        0.1341445
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.8989495	0.4494748	3.350676	0.22985
Residual	2	0.2682890	0.1341445		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.008090	1.060069	0.951	0.4420
V11	UBD	-0.6914311	0.3388022	-2.041	0.1781
	Intercept	-0.6428258			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V9 FOR

```
Valid cases   =      5
Missing cases =      0
Method        = Mallow's Cp
Max subsets   =      2
```

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.33861	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-5.559	0.57557	0.15114	0.2477046	PCP, FOR
1	2.80786	-4.339	0.19192	-0.07744	0.3144081	FOR

Best Model with 1 Parameter

Mallow's C(p)	=	2.338609
Akaike's Info Crit.	=	-4.997012
Multiple R-square	=	0.2915000
Adjusted R-square	=	0.0553334
Residual Mean Square	=	0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-5.559046
Multiple R-square	=	0.5755716
Adjusted R-square	=	0.1511432
Residual Mean Square	=	0.2477046

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.6718293	0.3359146	1.356110	0.42443
Residual	2	0.4954092	0.2477046		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.882972	1.400430	1.345	0.3110
V9	FOR	0.9245309	0.7990884	1.157	0.3668
	Intercept	-9.311535			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V10 AGR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.68518	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-6.053	0.61549	0.23097	0.2244092	PCP, AGR
1	3.95912	-3.512	0.04658	-0.27123	0.3709577	AGR

Best Model with 1 Parameter

Mallow's C(p) = 2.685180
Akaike's Info Crit. = -4.997012
Multiple R-square = 0.2915000
Adjusted R-square = 0.0553334
Residual Mean Square = 0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-6.052874
Multiple R-square	=	0.6154869
Adjusted R-square	=	0.2309738
Residual Mean Square	=	0.2244092

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.7184200	0.3592100	1.600692	0.38451
Residual	2	0.4488184	0.2244092		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.626994	1.527135	1.720	0.2275
V10	AGR	-1.053195	0.8113080	-1.298	0.3238
	Intercept	-12.15793			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V5 DA

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	4.43157	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-7.992	0.73912	0.47824	0.1522560	PCP, DA
1	5.42762	-4.155	0.16157	-0.11790	0.3262145	DA

Best Model with 1 Parameter

Mallow's C(p)	=	4.431568
Akaike's Info Crit.	=	-4.997012
Multiple R-square	=	0.2915000
Adjusted R-square	=	0.0553334
Residual Mean Square	=	0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-7.992415
Multiple R-square	=	0.7391177
Adjusted R-square	=	0.4782354
Residual Mean Square	=	0.1522560

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.8627266	0.4313633	2.833146	0.26088
Residual	2	0.3045119	0.1522560		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	11.91713	5.663521	2.104	0.1700
V5	DA	-12.51686	6.756927	-1.852	0.2052
	Intercept	-72.58749			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V4 DR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.73751	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-4.567	0.48238	-0.03525	0.3020949	PCP, DR
1	1.94361	-4.634	0.23816	-0.01579	0.2964163	DR

Best Model with 1 Parameter

Mallow's C(p) = 1.737511
Akaike's Info Crit. = -4.997012
Multiple R-square = 0.2915000
Adjusted R-square = 0.0553334
Residual Mean Square = 0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

```
Mallow's C(p)          =         2.999999
Akaike's Info Crit.    =        -4.566524
Multiple R-square      =         0.4823767
Adjusted R-square      =        -0.0352466
Residual Mean Square   =         0.3020949
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.5630487	0.2815243	0.9319069	0.51762
Residual	2	0.6041898	0.3020949		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.489581	1.533446	0.971	0.4338
V4	DR	2.820220	3.283965	0.859	0.4810
	Intercept	-9.237351			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V3 SP

```
Valid cases   =      5
Missing cases =      0
Method        = Mallow's Cp
Max subsets   =      2
```

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.20283	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-3.480	0.35674	-0.28653	0.3754215	PCP, SP
1	2.10909	-3.274	0.00002	-0.33331	0.3890735	SP

Best Model with 1 Parameter

Mallow's C(p)	=	1.202826
Akaike's Info Crit.	=	-4.997012
Multiple R-square	=	0.2915000
Adjusted R-square	=	0.0553334
Residual Mean Square	=	0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999999
Akaike's Info Crit.	=	-3.479984
Multiple R-square	=	0.3567356
Adjusted R-square	=	-0.2865287
Residual Mean Square	=	0.3754215

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.4163956	0.2081978	0.5545708	0.64326
Residual	2	0.7508429	0.3754215		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.975757	1.876072	1.053	0.4027
V3	SP	-1.299335	2.885084	-0.450	0.6966
	Intercept	-8.210100			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V2 GS

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.35488	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-5.583	0.57763	0.15526	0.2465030	PCP, GS
1	3.60261	-3.416	0.02800	-0.29600	0.3781855	GS

Best Model with 1 Parameter

Mallow's C(p) = 2.354882
Akaike's Info Crit. = -4.997012
Multiple R-square = 0.2915000
Adjusted R-square = 0.0553334
Residual Mean Square = 0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-5.583359
Multiple R-square	=	0.5776305
Adjusted R-square	=	0.1552609
Residual Mean Square	=	0.2465030

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.6742325	0.3371162	1.367595	0.42237
Residual	2	0.4930060	0.2465030		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.622646	1.625681	1.613	0.2480
V2	GS	2.664770	2.289334	1.164	0.3645
	Intercept	-17.60229			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V1 CS

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	5.54719	-4.997	0.29150	0.05533	0.2756628	PCP
2	3.00000	-8.926	0.78357	0.56714	0.1263120	PCP, CS
1	6.80394	-4.119	0.15550	-0.12600	0.3285769	CS

Best Model with 1 Parameter

Mallow's C(p)	=	5.547191
Akaike's Info Crit.	=	-4.997012
Multiple R-square	=	0.2915000
Adjusted R-square	=	0.0553334
Residual Mean Square	=	0.2756628

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.3402500	0.3402500	1.234298	0.34760
Residual	3	0.8269885	0.2756628		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	1.619471	1.457683	1.111	0.3476
	Intercept	-5.597358			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000001
Akaike's Info Crit.	=	-8.926453
Multiple R-square	=	0.7835711
Adjusted R-square	=	0.5671422
Residual Mean Square	=	0.1263120

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.9146144	0.4573072	3.620456	0.21643
Residual	2	0.2526241	0.1263120		
Total	4	1.167238			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	2.643961	1.097473	2.409	0.1376
V1	CS	3.170452	1.486791	2.132	0.1666
	Intercept	-23.11797			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

1995 All Basin Regression 2

```
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                        All Possible Subsets Regression

                              Dependent variable

                          V7   DSG

                            Independent variables

                          V6   PCP
                          V11  UBD

                            Valid cases    =      5
                            Missing cases =      0
                            Method         = Mallow's Cp
                            Max subsets    =      2


 In
Model   C(p)       AIC   R-Square  Adj Rsq    MSE      Variables in
Model

   1   1.22101   -13.279  0.19616 -0.07179  0.0526030 PCP
   2   3.00000   -11.803  0.27614 -0.44771  0.0710529 PCP, UBD
   1   1.63973   -12.415  0.04461 -0.27385  0.0625201 UBD

                       Best Model with 1 Parameter

                   Mallow's C(p)        =         1.221008
                   Akaike's Info Crit.   =        -13.27904
                   Multiple R-square     =         0.1961551
                   Adjusted R-square     =        -0.0717932
                   Residual Mean Square  =         0.0526030

                             Analysis of Variance

     Source     Df         SS              MS          F-Ratio     P(F)

    Regression    1     0.0385087      0.0385087      0.7320634
0.45511
    Residual      3     0.1578091      0.0526030
    Total         4     0.1963178

                          Variables in the equation

       Variable          Coefficient    Std error  T-value  P(T)

V6   PCP                    0.6887535    0.8049881   0.856 0.4551
     Intercept               2.071109
```

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-11.80311
Multiple R-square	=	0.2761441
Adjusted R-square	=	-0.4477118
Residual Mean Square	=	0.0710529

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0542120	0.0271060	0.3814904	0.72386
Residual	2	0.1421058	0.0710529		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.7573361	0.9468731	0.800	0.5077
V11	UBD	0.1125375	0.2393831	0.470	0.6846
	Intercept	1.489839			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7   DSG

Independent variables

V6   PCP
V9   FOR

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.01821	-13.279	0.19616	-0.07179	0.0526030	PCP
2	3.00000	-11.324	0.20341	-0.59318	0.0781926	PCP, FOR
1	1.41345	-12.385	0.03873	-0.28169	0.0629046	FOR

Best Model with 1 Parameter

Mallow's C(p)	=	1.018208
Akaike's Info Crit.	=	-13.27904
Multiple R-square	=	0.1961551
Adjusted R-square	=	-0.0717932
Residual Mean Square	=	0.0526030

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0385087	0.0385087	0.7320634	0.45511
Residual	3	0.1578091	0.0526030		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6887535	0.8049881	0.856	0.4551
	Intercept	2.071109			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000000
Akaike's Info Crit.	=	-11.32435
Multiple R-square	=	0.2034077
Adjusted R-square	=	-0.5931846
Residual Mean Square	=	0.0781926

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0399326	0.0199663	0.2553473	0.79659
Residual	2	0.1563853	0.0781926		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6532962	1.016013	0.643	0.5861
V9	FOR	-0.0618823	0.4585880	-0.135	0.9050
	Intercept	2.469528			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V10 AGR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.00738	-13.279	0.19616	-0.07179	0.0526030	PCP
2	3.00000	-11.297	0.19911	-0.60178	0.0786145	PCP, AGR
1	1.26234	-12.681	0.09406	-0.20793	0.0592843	AGR

Best Model with 1 Parameter

Mallow's C(p) = 1.007380
Akaike's Info Crit. = -13.27904
Multiple R-square = 0.1961551
Adjusted R-square = -0.0717932
Residual Mean Square = 0.0526030

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0385087	0.0385087	0.7320634	0.45511
Residual	3	0.1578091	0.0526030		
Total	4	0.1963178			

Variables in the equation

Variable	Coefficient	Std error	T-value	P(T)
V6 PCP	0.6887535	0.8049881	0.856	0.4551
Intercept	2.071109			

Best Model with 2 Parameters

Mallow's C(p)	=	3.000002
Akaike's Info Crit.	=	-11.29745
Multiple R-square	=	0.1991097
Adjusted R-square	=	-0.6017807
Residual Mean Square	=	0.0786145

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0390888	0.0195444	0.2486104	0.80089
Residual	2	0.1572290	0.0786145		
Total	4	0.1963178			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V6	PCP	0.6263875	1.222950	0.512	0.6595
V10	AGR	0.0441449	0.5139332	0.086	0.9394
	Intercept	2.521353			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V5 DA

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	16.99602	-13.279	0.19616	-0.07179	0.0526030	PCP
2	2.99993	-22.264	0.91067	0.82133	0.0087688	PCP, DA
1	18.63178	-12.844	0.12309	-0.16921	0.0573844	DA

Best Model with 1 Parameter

Mallow's C(p)	=	16.99602
Akaike's Info Crit.	=	-13.27904
Multiple R-square	=	0.1961551
Adjusted R-square	=	-0.0717932
Residual Mean Square	=	0.0526030

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0385087	0.0385087	0.7320634	0.45511
Residual	3	0.1578091	0.0526030		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6887535	0.8049881	0.856	0.4551
	Intercept	2.071109			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999928
Akaike's Info Crit.	=	-22.26423
Multiple R-square	=	0.9106673
Adjusted R-square	=	0.8213346
Residual Mean Square	=	0.0087688

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.1787802	0.0893901	10.19411	0.08933
Residual	2	0.0175376	0.0087688		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	13.02564	3.102004	4.199	0.0523
V5	DA	-11.70872	2.927486	-4.000	0.0572
	Intercept	-85.19122			

The 'best' subset determined by Mallow's C(p) is with 2 parameters.

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All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V4 DR

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.96134	-13.279	0.19616	-0.07179	0.0526030	PCP
2	3.00000	-13.242	0.45711	-0.08578	0.0532897	PCP, DR
1	1.74617	-13.656	0.25456	0.00608	0.0487808	DR

Best Model with 1 Parameter

Mallow's C(p) = 1.746168
Akaike's Info Crit. = -13.65622
Multiple R-square = 0.2545637
Adjusted R-square = 0.0060850
Residual Mean Square = 0.0487808

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0499754	0.0499754	1.024489	0.38600
Residual	3	0.1463424	0.0487808		
Total	4	0.1963178			

Variables in the equation

Variable		Coefficient	Std error	T-value	P(T)
V4	DR	-1.329175	1.313193	-1.012	0.3860
	Intercept	9.876381			

Best Model with 2 Parameters

```
Mallow's C(p)          =        2.999999
Akaike's Info Crit.    =       -13.24152
Multiple R-square      =       0.4571084
Adjusted R-square      =      -0.0857832
Residual Mean Square   =       0.0532897
```

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0897385	0.0448693	0.8419882	0.54289
Residual	2	0.1065793	0.0532897		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6999508	0.8103054	0.864	0.4787
V4	DR	-1.345886	1.372678	-0.980	0.4302
	Intercept	4.205123			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V3 SP

```
Valid cases    =      5
Missing cases  =      0
Method         = Mallow's Cp
Max subsets    =      2
```

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.88511	-13.279	0.19616	-0.07179	0.0526030	PCP
2	3.00000	-14.599	0.58619	0.17238	0.0406189	PCP, SP
1	1.05642	-16.460	0.57452	0.43269	0.0278432	SP

Best Model with 1 Parameter

Mallow's C(p)	=	1.056419
Akaike's Info Crit.	=	-16.45996
Multiple R-square	=	0.5745184
Adjusted R-square	=	0.4326912
Residual Mean Square	=	0.0278432

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.1127882	0.1127882	4.050834	0.13763
Residual	3	0.0835296	0.0278432		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V3	SP	1.433887	0.7124307	2.013	0.1376
	Intercept	7.466265			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999999
Akaike's Info Crit.	=	-14.59906
Multiple R-square	=	0.5861921
Adjusted R-square	=	0.1723843
Residual Mean Square	=	0.0406189

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.1150800	0.0575400	1.416580	0.41381
Residual	2	0.0812379	0.0406189		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.1889645	0.7955392	0.238	0.8344
V3	SP	1.328706	0.9677439	1.373	0.3034
	Intercept	5.943339			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V2 GS

Valid cases = 5
Missing cases = 0
Method = Mallow's Cp
Max subsets = 2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	1.16898	-13.279	0.19616	-0.07179	0.0526030	PCP
2	3.00000	-11.685	0.25878	-0.48244	0.0727571	PCP, GS
1	1.68386	-12.214	0.00534	-0.32621	0.0650899	GS

Best Model with 1 Parameter

Mallow's C(p) = 1.168983
Akaike's Info Crit. = -13.27904
Multiple R-square = 0.1961551
Adjusted R-square = -0.0717932
Residual Mean Square = 0.0526030

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0385087	0.0385087	0.7320634	0.45511
Residual	3	0.1578091	0.0526030		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.6887535	0.8049881	0.856	0.4551
	Intercept	2.071109			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999999
Akaike's Info Crit.	=	-11.68460
Multiple R-square	=	0.2587823
Adjusted R-square	=	-0.4824353
Residual Mean Square	=	0.0727571

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0508036	0.0254018	0.3491314	0.74122
Residual	2	0.1455142	0.0727571		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.9898299	1.196955	0.827	0.4952
V2	GS	0.5481066	1.333342	0.411	0.7209
	Intercept	-1.224762			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

All Possible Subsets Regression

Dependent variable

V7 DSG

Independent variables

V6 PCP
V1 CS

Valid cases	=	5
Missing cases	=	0
Method	=	Mallow's Cp
Max subsets	=	2

In Model	C(p)	AIC	R-Square	Adj Rsq	MSE	Variables in Model
1	2.01776	-13.279	0.19616	-0.07179	0.0526030	PCP
2	3.00000	-13.336	0.46726	-0.06549	0.0522934	PCP, CS
1	1.02677	-15.269	0.46013	0.28017	0.0353289	CS

Best Model with 1 Parameter

Mallow's C(p)	=	1.026765
Akaike's Info Crit.	=	-15.26940
Multiple R-square	=	0.4601274
Adjusted R-square	=	0.2801698
Residual Mean Square	=	0.0353289

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	1	0.0903312	0.0903312	2.556866	0.20811
Residual	3	0.1059866	0.0353289		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V1	CS	-1.130444	0.7069601	-1.599	0.2081
	Intercept	11.04967			

Best Model with 2 Parameters

Mallow's C(p)	=	2.999998
Akaike's Info Crit.	=	-13.33588
Multiple R-square	=	0.4672574
Adjusted R-square	=	-0.0654851
Residual Mean Square	=	0.0522934

Analysis of Variance

Source	Df	SS	MS	F-Ratio	P(F)
Regression	2	0.0917310	0.0458655	0.8770792	0.53274
Residual	2	0.1045869	0.0522934		
Total	4	0.1963178			

Variables in the equation

	Variable	Coefficient	Std error	T-value	P(T)
V6	PCP	0.1570909	0.9601690	0.164	0.8851
V1	CS	-1.038046	1.028948	-1.009	0.4193
	Intercept	9.495141			

The 'best' subset determined by Mallow's C(p) is with 1 parameter.

Appendix E: Interview Documentation

The interviews conducted with the National Oceanic and Atmospheric Administration, National Weather service were two-fold. The first interview was conducted with Tom Econopouly, a hydrologist, of the Northeast River Forecast center in Taunton, Massachusetts. The interview provided information pertinent to flood forecasting and river and flood modeling using several remote sensing and data manipulation techniques. The second interview was conducted with Eloy Colón, a hydrologist, of the Southeast River Forecast center, in Isla Verde, Puerto Rico. The interview with Mr. Colon primarily addressed the social implications of land use change, including the causal factors for housing development in low lying areas and the resulting risks of peak flow and flooding.

The interviews conducted with the Federal Emergency Management Agency, Hazard Mitigation Program officers presented us with an array of information including the history of the island, as pertains to the changes from agriculture to industry and the move to urbanization, hydrologic effects of land use change, national disaster relief, and flood insurance policies. Ms. Lizabeth Hyman, hazard mitigation officer, Ms. Hildelisa Gonzalez, urban planner, and Mr. John Carasquillo, National Flood Insurance Program representative, were available to provide useful information relevant to our project work. A detailed account of the issues discussed during the interview is included in the Results section.

Several interviews were conducted with members of the United States Geological Survey staff regarding technical issues associated with the project, such as land use data manipulation, storm data acquisition, and statistical data analysis. Mr. Rene Garcia, Mr. Orlando Ramos Ginés, Mr. Richard Webb, Dr. Matthew Larsen, Ms. Marilyn Santiago, and Ms. Betzaida Reyes were all consulted on several occasions and in some cases interviewed informally to acquire immediately necessary information.

In an interview with Jose de Ruiz and Raphael Morales of the Junta de Planificacion, the urban planning board, a significant amount of information was obtained pertaining to procedures and regulations in the approval process for urban development in Puerto Rico. A brief history of the social-economic causal factors in urbanization was discussed. A copy of urban development approval criteria, regulations, and a description of the planning board functionality were obtained. A detailed account of the information acquired from the Urban Planning Board can be found in the Land Use section of the Literature Review and in the Results section.

Appendix F: FEMA Recommendations for Flood Preparation

FLOODS AND FLASH FLOODS

Mitigation pays. It includes any activities that prevent an emergency, reduce the chance of an emergency happening, or lessen the damaging effects of unavoidable emergencies. Investing in mitigation steps now such as constructing barriers such as levees and purchasing flood insurance will help reduce the amount of structural damage to your home and financial loss from building and crop damage should a flood or flash flood occur.

BEFORE

Find out if you live in a flood-prone area from your local emergency management office or Red Cross chapter.

Ask whether your property is above or below the flood stage water level and learn about the history of flooding for your region.

Learn flood-warning signs and your community-alert signals.

Request information on preparing for floods and flash floods.

If you live in a frequently flooded area, stockpile emergency building materials. These include plywood, plastic sheeting, lumber nails, hammer and saw, pry bar, shovels, and sandbags.

Have check valves installed in building sewer traps to prevent flood waters from backing up in sewer drains. As a last resort, use large corks or stoppers to plug showers, tubs, or basins.

Plan and practice an evacuation route.

Contact the local emergency management office or local American Red Cross chapter for a copy of the community flood evacuation plan.

This plan should include information on the safest routes to shelters. Individuals living in flash flood areas should have several alternative routes.

Have disaster supplies on hand.

- Flashlights and extra batteries
- Portable, battery-operated radio and extra batteries
- First aid kit and manual
- Emergency food and water
- Non-electric can opener
- Essential medicines
- Cash and credit cards

- Sturdy shoes

Develop an emergency communication plan.

In case family members are separated from one another during floods or flash floods (a real possibility during the day when adults are at work and children are at school), have a plan for getting back together.

Ask an out-of-state relative or friend to serve as the "family contact." After a disaster, it's often easier to call long distance. Make sure everyone in the family knows the name, address, and phone number of the contact person.

Make sure that all family members know how to respond after a flood or flash flood.

Teach all family members how and when to turn off gas, electricity, and water.

Teach children how and when to call 9-1-1, police, fire department, and which radio station to tune to for emergency information.

Learn about the National Flood Insurance Program.

Ask your insurance agent about flood insurance. Homeowners policies do not cover flood damage.

DURING A FLOOD WATCH

- Listen to a batter-operated radio for the latest storm information.
- Fill bathtubs, sinks, and jugs with clean water in case water becomes contaminated.
- Bring outdoor belongings, such as patio furniture, indoors.
- Move valuable household possessions to the upper floors or to safe ground if time permits.
- If you are instructed to do so by local authorities, turn off all utilities at the main switch and close the main gas valve.
- Be prepared to evacuate.

DURING A FLOOD

If Indoors:

- Turn on battery-operated radio or television to get the latest emergency information.
- Get your pre-assembled emergency supplies.
- If told to leave, do so immediately.

If Outdoors:

- Climb to high ground and stay there.

- Avoid walking through any floodwaters. If it is moving swiftly, even water 6inches deep can sweep you off your feet.

If In A Car:

- If you come to a flooded area, turn around and go another way.
- If your car stalls, abandon it immediately and climb to higher ground. Many deaths have resulted from attempts to move stalled vehicles.

DURING AN EVACUATION

- If advised to evacuate, do so immediately.
- Evacuation is much simpler and safer before flood waters become too deep for ordinary vehicles to drive through.
- Listen to a batter-operated radio for evacuation instructions.
- Follow recommended evacuation routes--shortcuts may be blocked.
- Leave early enough to avoid being marooned by flooded roads.

AFTER

Flood dangers do not end when the water begins to recede. Listen to a radio or television and don't return home until authorities indicate it is safe to do so.

Remember to help your neighbors who may require special assistance--infants, elderly people, and people with disabilities.

Inspect foundations for cracks or other damage.

Stay out of buildings if floodwaters remain around the building.

When entering buildings, use extreme caution.

- Wear sturdy shoes and use battery-powered lanterns or flashlights when examining buildings.
- Examine walls, floors, doors, and windows to make sure that the building is not in danger of collapsing.
- Watch out for animals, especially poisonous snakes that may have come into your home with the floodwaters. Use a stick to poke through debris.
- Watch for loose plaster and ceilings that could fall.
- Take pictures of the damage--both to the house and its contents for insurance claims.

Look for fire hazards.

- Broken or leaking gas lines
- Flooded electrical circuits
- Submerged furnaces or electrical appliances
- Flammable or explosive materials coming from upstream

Throw away food--including canned goods--that has come in contact with floodwaters.

Pump out flooded basements gradually *(about one-third of the water per day)* to avoid structural damage.

Service damaged septic tanks, cesspools, pits, and leaching systems as soon as possible. Damaged sewage systems are health hazards.

INSPECTING UTILITIES IN A DAMAGED HOME

Check for gas leaks--If you smell gas or hear blowing or hissing noise, open a window and quickly leave the building. Turn off the gas at the outside main valve if you can and call the Gas Company from a neighbor's home. If you turn off the gas for any reason, it must be turned back on by a professional.

Look for electrical system damage--If you see sparks or broken or frayed wires, or if you smell hot insulation, turn off the electricity at the main fuse box or circuit breaker.

If you have to step in water to get to the fuse box or circuit breaker, call an electrician for advice.

Check for sewage and water lines damage--If you suspect sewage lines are damaged avoid using the toilets and call a plumber. If water pipes are damaged, contact the Water Company and avoid the water from the tap. You can obtain safe water by melting ice cubes.

EMERGENCY INFORMATION

1. Floodwaters can be extremely dangerous. The force of six inches of swiftly moving water can knock people off their feet. The best protection during a flood is to leave the area and go to shelter on higher ground.
2. Flash flood waters move at very fast speeds and can roll boulders, tear out trees, destroy buildings, and obliterate bridges. Walls of water can reach heights of 10 to 20 feet and generally are accompanied by a deadly cargo of debris. The best response to any signs of flash flooding is to move immediately and quickly to higher ground.
3. Cars can be easily be swept away in just 2 feet of moving water. If floodwaters rise around a car, it should be abandoned. Passengers should climb to higher ground.

DANGER ZONES

Floods and flash floods occur within all 50 states. Communities particularly at risk are those located in low-lying areas, near water, or downstream from a dam.

WHAT IS A FLOOD?

Floods are the most common and widespread of all-natural disasters--except fire. Most communities in the United States can experience some kind of flooding after spring rains, heavy thunderstorms, or winter snow thaws. Floods can be slow, or fast rising but generally develop over a period of days.

Dam failures are potentially the worst flood events. A dam failure is usually the result of neglect, poor design, or structural damage caused by a major event such as an earthquake. When a dam fails, a gigantic quantity of water is suddenly let loose downstream, destroying anything in its path.

WHAT IS A FLASH FLOOD?

Flash floods usually result from intense storms dropping large amounts of rain within a brief period. Flash floods occur with little or no warning and can reach full peak in only a few minutes.

HELP YOUR COMMUNITY GET READY

The media can raise awareness about floods and flash floods by providing important information to the community. Here are some suggestions:

1. Publish a special section in your local newspaper with emergency information on floods and flash floods. Localize the information by printing the phone numbers of local emergency service offices, the American Red Cross, and hospitals.
2. Interview local officials about land use management and building codes in floodplains.
3. Work with local emergency services and American Red Cross officials to prepare special reports for people with mobility impairments on what to do if an evacuation is ordered.
4. Periodically inform your community of local public warning systems.

DID YOU KNOW

- Individuals and business owners can protect themselves from flood losses by purchasing flood insurance through National Flood Insurance Program. Homeowner's policies do not cover flood damage. Information is available through local insurance agents and emergency management offices.
- Flooding has caused the deaths of more than 10,000 people since 1900. Property damage from flooding now totals over $1 billion each year in the United States.
- More than 2,200 lives were lost as a result of the Johnstown, Pennsylvania flood of 1889. This flood was caused by an upstream dam failure.
- Nearly 9 of every 10 presidential disaster declarations result from natural phenomena in which flooding was a major component.