Floodplain Population Estimation in San Juan, Puerto Rico

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CHAPTER 1: INTRODUCTION

The number of people living in San Juan, Puerto Rico, increased dramatically from the early 1900's to the 1970's and this influx of people facilitated the formation of slums where the standard of living is low (Mignucci, 2008). To deal with the growing slums in and around San Juan, the Puerto Rican government began building public housing projects over a period of two decades (Mignucci, 2008). The government of Puerto Rico constructed many of these residential projects on flood plains and other flood prone areas until the 1970's when federal and local laws prohibited people from building on or moving into these areas. Enforcement of these laws is difficult to carry out due to the high population densities in this area and the lack of alternative housing for the residents. Despite legislation against floodplain settlements, people continue to move into these areas in order to take jobs in the city and a large number of people are now living in these hazardous areas. Another issue facing floodplain residents are the laws regarding flood insurance. Federal laws require that residents have flood insurance in certain zones designated as floodplains and that after receiving an insurance payment the recipients must make improvements to their homes in order to prevent future damage. The number of residents without insurance or receiving repeated payments for flood damage is not known.

A floodplain is an area that is in close proximity to a river, stream, lake, bay, or other body of water that is subject to flooding (H. Vargas, et al, 2010). The floodplain is made up of two parts, the floodway and the flood fringe. The floodway is the area that carries the bulk of the water away from the floodplain; this is usually a stream or river located in the center of the floodplain (*Flood terminology*). The flood fringe refers to the outer sections of the floodplain. The flood fringe, unlike the floodway, is not usually under water. In fact, for most parts of the year this area is dry enough for people to settle on. Those living on the floodplains find themselves in circumstances that are very dangerous during the rainy season.

Flooding is a large problem in Puerto Rico, especially in and around San Juan. In 2008, San Juan reported 54.7 inches (138.9 cm) of rainfall, just 0.15 (0.38 cm) less than the year before (National Weather Service, 2009). All of that rainfall does not necessarily fall slowly; hurricanes and other tropical storms cause periods of heavy rain during hurricane season, which runs from June through November. Between September 21st and September 23rd, 2008, some parts of Puerto Rico reported nearly 30 inches (76.2 cm) of rain due to Hurricane Kyle. This rain

resulted in flooding that caused 5 deaths (*Devastating floods*, 2009). The amount of rainfall that Puerto Rico receives combined with its geography has created zones around San Juan that are at considerable risk for flooding.

Hurricane Katrina, which made landfall in the south eastern United States in August, 2005, revealed the dangers associated with large numbers of people living in flood prone areas. The flooding that comes with a hurricane can leave thousands dead or homeless if proper emergency management plans are not in place and followed promptly at the beginning of a disaster. The flooding of the Mississippi river was responsible for 1,464 deaths (Louisiana Department of Health and Hospitals, 2006). Furthermore, thousands of people lost their homes and months later were still homeless (Van Heerden & Bryan, 2007). The governmental response drew criticism from scientists, politicians, and the press who all believed that the existing plans were inadequate and much of the damage could have been reduced. According to Ivor Van Heerden, a marine scientist whose model closely predicted the damage caused by Hurricane Katrina, New Orleans' "plan amounted to a 'good samaritan' response" which was "not good enough" and he states that the actions in the plan "could never evacuate more than mere thousands, when the problem was tens of thousands" (Van Heerden & Bryan, 2007). Proper plans for evacuation and mitigation of damages are essential for reducing loss of life and property when an emergency such as a flood threatens an area. With more available information and disaster planning already in place, flood risk mitigation can be rendered much more smoothly.

Puerto Rico's unique status within the United States allows it a certain degree of autonomy, with the local government headed by a popularly elected governor. Several agencies whose missing is to enhance the quality of life in Puerto Rico are at the governor's disposal. This study will work in conjunction with one such agency, La Junta de Planificación de Puerto Rico (The Planning Board of Puerto Rico). According to its mission statement, this body is dedicated to improving the lives of Puerto Rico's citizens through "conservation, protection, preservation of the natural environment…and economic progress" (Vargas, 2008). This body addresses issues involving zoning, provides forms and publications regarding health, safety and construction laws to the public, and has a library of maps of Puerto Rico. The problem facing La Junta de Planificación and the other organizations involved in emergency management in San Juan is that they do not know how many people would be affected by a serious flooding event.

La Junta de Planificación has no any information about the insurance that the residents of the floodplains may have or about the insurance claims that they have made in the past. The information on the location of floodplains provided by La Junta de Planificación will be vital in assessing risk to residents living in these floodplains.

This project will take existing aerial photos, census data from 2000, and flood maps and will layer this data into one map which will show authorities the number of people living in the regions designated as floodplains. This process will serve as a template for future efforts to estimate the population of floodplains in other areas of Puerto Rico. Additionally, we will conduct a survey to collect information on the flood insurance history of the residents of the floodplains.

CHAPTER 2: LITERATURE REVIEW

Throughout the past 150 years, social, economic, and environmental factors have led to the settlement of floodplains in Puerto Rico. Floods occurring in these areas often threaten the lives and property of the floodplain residents. Hence, the Puerto Rican government is trying to mitigate this risk, both by relocating the residents and by developing risk management strategies. This chapter presents the factors that led to settlement of floodplains, describes floodplains and the hazards they present, summarizes floodplain insurance laws, regulations, the current insurance situation, and reviews ArcGIS and other software that this project will use to incorporate population and flooding data into a risk map.

2.1 History

There are two groups of people in Puerto Rico currently living in floodplains. The first group includes people who are living in public housing built by the government of Puerto Rico prior to the 1970's, while the second group live in informal settlements that have sprung up illegally on government or private land. Both groups arrived in their respective situations because of a sharp increase in population density and a rapid rise in the overall population of San Juan. There simply is not enough safe and affordable housing or land for all of the people that immigrated to the San Juan area and many of them are forced to settle in floodplains to shorten their commuting time to jobs in the city.

Prior to the Spanish-American War, cash crops such as tobacco, sugar, and coffee drove the Puerto Rican economy. When Spain ceded Puerto Rico to the United States after the Spanish-American War, several factors produced an emigration from the mountains to the coastal cities. In 1899, the island was struck by Hurricane San Ciriaco, causing not only immense loss of life, but also the destruction of the coffee plantations that had been the foundation of the Puerto Rican economy. Emigration from the mountains into the cities, especially into San Juan, was one of the few available paths for escaping this adversity (Picó, 1988).

After the crippling of the existing coffee trade by Hurricane San Ciriaco, the sugar trade began to dominate the Puerto Rican economy. The Foraker Act, passed in 1900 in the United States opened Puerto Rico up to a substantial influx of American capital. Agricultural advances

tripled the yield per acre on sugar farms owned by businesses based in the United States. However, because these advances were unavailable to most of the existing farms, many of the Puerto Rico-owned farms were forced out of business (Bryan, 2000). These farm owners were "forced to leave the haciendas and move to the cities or take jobs as hired hands and cut sugarcane" (Bryan, 2000). Between 1898 and 1934, San Juan's population increased by 105,000 (Mignucci, 2008).

During the 1940's and 1950's, another factor began to drive immigration to San Juan and other cities. Puerto Rico launched a program called Operation Bootstrap in 1947 which "was a massive effort to attract U.S capital and investors" in order to industrialize Puerto Rico (Bryan, 2000). The program offered tax exemptions, low interest loans, and research assistance to businesses from the United States. The industrialization of San Juan brought even more people to the city seeking work in the factories and manufacturing facilities. The population of San Juan rose from 237,537 in 1940 to 368,576 in 1950 (Mignucci, 2008). With industry and the population continually growing throughout the 1950's, San Juan's population reached 451,658 by 1960 (Mignucci, 2008).

Begun as a small, fortified city, San Juan simply did not have adequate living spaces for these immigrants within the city walls. These people settled in the areas surrounding San Juan using only materials they could salvage and the living conditions very quickly became unsanitary (Mignucci, 2008). Taking notice of the slums growing outside of San Juan, the government of Puerto Rico founded the Homestead Commission in 1921. The Homestead Commission was authorized to establish settlements for workers around San Juan (Descartes, 1943). The Commission's first act was to construct single-family homes in an area prone to flooding known as the Barrio Obrero (Mignucci, 2008). Construction on similar projects continued until the election of Luis Muñoz Marín to the office of governor in 1947.

Luis Muñoz Marín "committed himself to improve the living conditions of the poor through social justice and economic development programs" (Mignucci, 2008) which greatly changed the philosophy driving construction of public housing in Puerto Rico. Marín and his administration viewed large, multi-family buildings as only a temporary solution to slums, preferring to build single-family homes to promote home-ownership (Dinzey-Flores, 2007). Marín's intention was for families living in slums to move into the public multi-family buildings until they could afford to buy a single-family home.

Although the Puerto Rican government never intended for people to live permanently in these buildings, according to Zaire Dinzey-Flores, the majority of families live "long-term and multi-generational lives" in public housing projects (Dinzey-Flores, 2007). Furthermore, the residents develop an attachment to their location. The residents are proud of their neighborhoods and feel comfortable there (Dinzey-Flores, 2007). These public housing projects are located in areas susceptible to flooding known as floodplains. Since the 1960's the Puerto Rican government has been trying to reverse the trend of increased development and restrict the number of people living in public housing with the *Law for the Building Control in Flood Zone Areas* passed in 1961, and *Acts 75* and *76* passed in 1975 (Vargas, Mirabel, Rivera, Crespo, & Sanchez, 2010). The chief restriction in these laws concerns development in floodplains. Violations may technically result in fines or imprisonment and the demolition of the building or structure (Titulo 23: Planificación y Fomento Público, 1961). These laws are normally difficult to enforce due to the number of structures already on floodplains.

Despite the laws against building or living in these areas, people remain because they have established communities in these areas or because they have nowhere else to go. Furthermore, it is difficult for the government of Puerto Rico to remove them. Not all of the slums were replaced with public housing projects and there are still illegal, informal settlements around San Juan. In one such community, called the Villas del Sol, the Puerto Rican government is trying to move the residents because it is located in an area that is dangerous due to the likelihood of flooding. The residents, some of whom have lived there for fifteen years, stated in August, 2009, that they are willing to fight to stay (CB Online Staff, 2009).

By January 27, 2010 the residents negotiated a timeline for leaving the settlement with the Puerto Rican Land Authority. The residents are hoping for either an exchange of land or an opportunity to buy land from the Land Authority (Vega, 2010). Both the community leaders and the Puerto Rican government are having trouble finding a place to house the 200 families that live in the Villas del Sol. Like the resident of the Villas del Sol, communities facing eviction or demolition of their homes are rarely able to find an alternative location. A potential solution, a 17-acre tract of land in Arecibo donated to the community by Eduardo Ibarra was later found to be in an "environmentally sensitive" area and the community could not legally relocate to that land (Vega, 2010).

The problems facing Puerto Ricans living in floodplains are difficult for the government to solve due to the lack of safe, available land. Therefore, the government is searching for methods to protect both the property and the lives of the people who live in these hazardous areas. Governmental agencies have had trouble creating these mitigation strategies because they do not have current population data from floodplains; in fact, the floodplain designations change with the publications of new flood maps.

2.2 Flooding

The consequences of living on a floodplain can be devastating regardless of the legality of the settlement. Floodplains are common on the island of Puerto Rico, and flooding is an important issue for citizens and government officials throughout the island. According to the National Flood Insurance Program (NFIP), "Flood risk isn't just based on history, it's also based on a number of factors: rainfall, river-flow and tidal-surge data, topography, flood-control measures, and changes due to building and development" ("Flood Risks Overview", 2010). Unfortunately, Puerto Rico is frequently subject to all of these factors. To fully understand how and why the people situated on the floodplains experience hardships, it is necessary to know about floodplains in Puerto Rico and the causes of flooding.

A floodplain is an area of land "adjacent to a river, stream, lake, estuary, or other water body that is subject to flooding" ("Flood terminology", 2010). Flooding is defined by the NFIP as "a general and temporary condition where two or more acres of normally dry land or two or more properties are inundated by water or mudflow" ("Flood Risks Overview", 2010). A floodplain contains two regions, the floodway and the flood fringe. The floodway is defined by the NFIP "the channel of a river or stream, and the overbank areas adjacent to the channel" ("Flood terminology", 2010). The floodway discharges the majority of the flood water away from floodplain. In most cases there are strict laws and regulations that prevent development in the floodway (Vargas et al., 2010). The flood fringe begins on the outskirts of the floodway, and makes up the outer portion of the floodplain. The flood fringe is subject to regular flooding, yet development on a floodplain normally occurs in the flood fringe ("Flood terminology", 2010). Since a major component of our project will be to identify the populations settled in the floodplains in the Municipality of San Juan, this definition will be very useful.

The Commonwealth of Puerto Rico Office of the Governor Planning Board defines these terms in the Special Flood Hazard Areas Regulations Manual. Since our investigation focuses on San Juan, we will abide by their definitions:

> "Floodplain – Usually dry, low- or semi-low lands susceptible to being inundated by waters from any natural source. These low areas usually lie next to a river, creek, brook, ocean or lake affected by the highest flood elevations known in the history of the region, or by the base flood, as illustrated in presently available studies and maps. Floodplain also means the Flood having a one percent (1%) chance of being equaled or exceeded in any given year, the 100 year recurrence, the Special Flood Hazard Areas"(Vargas et al., 2010)

> "Floodway – The bed of a river, brook or natural storm drainage, plus those portions of neighboring lands that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than 0.30 meters. In case of a new detailed study (Zone A, section 7.02) taking into consideration fill deposit, Section 7.07, the maximum increase to be allowed will be 0.15 meters, as determined by the hydrologic-hydraulic study" (Vargas et al., 2010).

Although these definitions appear very similar to the more commonly accepted definitions, the differences are important. The major difference in the definition of floodplain is that, according to the Municipality of San Juan, a floodplain is only considered a floodplain if there is a "one percent (1%) chance of [the base flood] being equaled or exceeded in any given year." The Municipality of San Juan defines a floodplain in terms of measureable specifications, making it more difficult to determine if a region is a floodplain

Floodplains are very dangerous for multiple reasons. The risks associated with flooding change in Puerto Rico due to seasonal variance in rainfall. Flooding often occurs during hurricane season, between the months of June and November ("Hurricane Season", 1995). Hurricanes can cause a surge of water that causes flooding in its bays, rivers, and other waterways. For example, in 2008 after Hurricane Ike, John Marino wrote, "In Puerto Rico, the U.S. territory's southern coast was hardest hit by flooding. Several rivers, including the Rio

Grande de Arecibo and Rio de la Plata, surged over their banks. Scores of roadways were flooded and two major highways were partly closed because of mudslides" (Marino, 2008). Storm surges are not the only danger hurricanes present. Hurricanes also increase rainfall, which also results in flooding. In September of 1996, Puerto Rico received over 12 inches (30.5 cm) of rain in a 30 hour period, due to Hurricane Hortense (Bennett, 1996). Similarly, in 2008 between September 21st and September 23rd, some parts of Puerto Rico reported nearly 30 inches (76.2 cm) of rain, which resulted in flooding that caused 5 deaths ("Devastating Floods Hit Puerto Rico", 2009).

Although average rain fall more than doubles during the hurricane season, Puerto Rico regularly experiences other significant rainfalls that are capable of causing floods. In 2008, San Juan reported 54.7 inches (138.9 cm) of rainfall, just 0.15 inches (0.38 cm) less than the year before ("2008 climate review for Puerto Rico", 2009) and in the mountainous areas of the island they received 200 inches (508 cm) (Rivera, 2010). The heavy, year-round rainfall experienced by Puerto Rico is a constant cause of dangerous flooding.

There are three other factors that contribute to the danger of flooding in Puerto Rico. First, Puerto Rico is an island with multiple waterways. Puerto Rico has nearly 70 rivers and streams, originating in the central mountain range that are susceptible to flooding ("Floods and Droughts", 1996). The numerous waterways, combined with the fact that during a hurricane all of its ports and bays are at risk, confirm that the entire island is susceptible to flooding. Another factor that increases flood risk in Puerto Rico is the topography of the island. Since the rivers and streams stem from the mountain range, the "stream valleys are narrow, relatively short, and [there are] steep-features that make the streams susceptible to flooding, particularly flash flooding" ("Floods and Droughts", 1996). The Federal Emergency Management Agency (FEMA) reported in 2008, "[t]he torrential rainfall resulted in severe flooding of rivers, streams and roads, causing sinkholes, landslides, mudslides and structural collapses across the southern part of the island" ("Devastating Floods Hit Puerto Rico", 2009). The frequency and dangerous nature of flooding in Puerto Rico poses a significant problem to the people living on the floodplains, and being able to determine population density on a specific floodplain would facilitate the task of national agencies accessing emergency resources much more easily and more effectively.

2.3 La Junta de Planificación

La Junta de Planificación, the name of the government of Puerto Rico's planning board, is responsible for regulating flood-prone areas. Working closely with FEMA, La Junta de Planificación disburses money and other resources during an emergency. Much of this money comes from FEMA; to help rebuild following Hurricane George in 1998, FEMA granted Puerto Rico 190 million dollars ("FEMA Issues Federal Action Plan", 1999). FEMA requires La Junta de Planificación to enforce specific regulations in order to receive federal funding.

As stated earlier, there are far too many people settled in hazardous regions for the government to easily relocate the entire population. Therefore, La Junta de Planificación needs an accurate estimate of the population at risk in order to protect them. The Special Flood Areas Hazard Regulation Manual states that action is mandatory wherever flooding hazards provide dangers to the well-being of the citizens (Vargas et al., 2010). Hence, La Junta de Planificación identifies and removes illegal structure or fill that impedes water flow. La Junta de Planificación needs more information about floodplain populations to continue cooperating with FEMA to develop strategies to mitigate flood damage.

2.4 Local Flood Awareness

Flood awareness in Puerto Rico is important to this project because a significant part of the population is at risk to suffer from flood damage. Even though citizens of Puerto Rico reside in areas not suitably protected from heavy rain and floods, few are able to reduce their risk. Risa Palm and Michael Hodgson (1993) studied the strategies the residents of floodplains employed to reduce risk from flooding. Only approximately 5% of those surveyed had taken any steps to prevent flood damage, but the survey also indicated that those steps had been successful in mitigating flood damage. Subjects living in the most vulnerable structures, however, had not tried to reduce the risk of flood damage. They reported not protecting their homes from flooding because they are "powerless within the household" and due to the "lack of money to adopt the measures" to reduce the flood risk. Palm and Hodgson also found that the subjects were unwilling to move because they were partial to an area after having lived there for some time (Palm & Hodgson, 1993).

A study conducted in 2007 addresses the attitudes of settlers in floodplains in the flood prone areas of Lusaka, Zambia. Lusaka is experiences flooding due to heavy rainfall and faulty dams. Economic factors in Zambia's history have forced poor people to live in these regions because of overcrowding in the cities. Many of the subjects reported settling in hazardous areas because "there was no other land available" (Nchito, 2007). They also indicated that poverty was the most common reason given for not being able to find safe land to build on and that they knew about the risks associated with flooding in the area (Nchito, 2007). This study confirms that settlers may risk the dangers of flooding when they cannot find elsewhere to live.

A study by Howard Kunreuther in 2006 further discusses resident attitudes on floodplains. Kunreuther notes that even though governments take action to reduce flood risk, it may not be adequate and sometimes creates a false sense of security for the people who live in these areas. He asserts that the residents are also partly responsible for their exposure to flooding, as they are "resistant to disasters and do not voluntarily adopt mitigation measures" (Kunreuther, 2006). Individuals in the risk area resist protecting themselves from the imminent danger presented by hurricanes and resulting floods. For residents without economic means, they may not be able to relocate or protect themselves, but residents with economic resources still resist moving if they feel their homes are comfortable.

Kunreuther also suggested a number of mitigation strategies for both low and high-income settlers. His first suggestion is to implement building codes such that any structures built in the vicinity of a floodplain must meet specific standards of structural integrity. He also suggests that those who take steps to protect themselves should receive tax incentives if their households meet certain benchmarks. Finally, he states that there must be a link between homeowners and insurance. If a homeowner owns property in an area that has high flood risk, they should be required to purchase insurance that appropriately "reflect[s] the risk of living in the area" (Kunreuther, 2006). These methods are extremely effective for people that can afford to pay for this insurance, but will likely be ineffective for settlers without the resources to purchase insurance.

An example from a 2007 study in Cape Town, South Africa demonstrated the effectiveness of appealing directly to residents of low-income settlements with instructions and recommendations for improving their houses' integrity. The authors created guidelines for the structures and suggested various methods for the city of Cape Town to provide information to

those living in the region. They suggested pallets, concrete blocks, and stilts to increase structural resistance to flood damage as well as suggesting strategies for preventing the build-up of debris in drains and other water channels. They evaluated each suggestion's feasibility for residents without many resources. The authors also developed a method to determine flood risk for the city of Cape Town. They determined that small improvements could reduce the risk of death and property loss for settlements where monetary resources are scarce (Bouchard, Goncalo, Susienka, and Wilson, 2007).

2.5 Flood Insurance

Flood insurance in the United States is provided by FEMA through the NFIP, although residents purchase their NFIP flood insurance policy from private insurers acting as agents for FEMA. Private insurers offer supplementary flood coverage, but adverse selection prevents them from providing basic flood coverage (Kron, 2009). Residents of high-risk regions buy flood coverage, but those living in low-risk region do not. Hence, the cost to a company would need to be carried by relatively few customers and the premiums would be very high. As they can't set their premiums above those set by FEMA, the federal insurance policies are the only available coverage.

FEMA provides two types of flood insurance policies, content coverage and building coverage. Content coverage insures personal belongings, electronics, and small appliances, and building coverage insures against damage to the building, plumbing, electrical systems, and large appliances ("Summary of coverage", 2009). A claimant will receive a payment equal either to the Replacement Cost Value (RCV), the cost to replace the building, or the Actual Cash Value (ACV), the value of the destroyed property. Content insurance always pays the ACV of the personal property damaged by flood ("Summary of coverage", 2009).

FEMA requires residents in regions designated as high-risk, defined as a 1% or greater chance of flooding each year, to buy an insurance policy. The policy will change if FEMA decides that a property is a "severe repetitive loss property" and which meets one of two criteria: either four claims have been made on it of at least $5,000 or two claims have been made which total more than the value of the property ("Summary of coverage", 2009). Owners of severe repetitive loss properties are required to relocate, elevate, or demolish their homes or they will be charged higher premiums or lose their coverage.

2.6 Geographical Information Systems

A Geographical Information System (GIS) is any system that stores and displays geographical information. GIS differs from cartography because GIS normally refers to computer-based geodatabase software that records and analyzes spatial data in order to assess real world problems (Dempsey, 2008). GIS software is typically categorized into two primary data types used to display spatial data; geodatabase data and documentation data. Geodatabase data serves as the visual representation of the map and contains two types of data; vector and raster. Vector data is spatial data represented as points, lines, and polygons (Dempsey, 2008). Vector data normally represents a geographical object with Cartesian coordinates. Raster data is data given by the group of individual cells that compose the entire map in GIS software. Any raster cell, which is similar to a pixel in a digital image, can contain values ranging from discrete data such as land-use and soil data, or continuous data like temperature, elevation, satellite images, and aerial photos (Dempsey, 2000). Data represented in multiple formats, such as rainfall totals, can be stored as either a raster or a vector.

Documentation data, also known as metadata, are text files that contain content quality, creation, and spatial information about a dataset, while a dataset contains information that describes the geodatabase file. Most GIS software uses another program to automatically manage this data. Common data stored by GIS involves title, publisher, spatial content, data theme, and content type. Our project will use ArcGIS, a popular GIS program. ArcGIS makes use of ArcCatalog to organize collected data for the ArcGIS metadata service, called ArcIMS. Metadata makes spatial information more useful by making it easier to locate and document datasets (Dempsey, 2000).

Geographical Information Systems are used in a variety of fields such as archeology, animation, urban planning, environmental impact assessment, logistics, and geographic history. FEMA uses Hazus-MH, an extension for ArcGIS developed by FEMA, to monitor and predict environmental impact. In 2005, researches using GIS software predicted the high water marks and storm surge heights that the victims of Hurricane Katrina witnessed. A high water mark refers to the mean height of the offshore waves of water that strike a coast during a hurricane, cyclone, or other tropical storm. The storm surge height is the maximum height of an offshore wave observed during a tropical storm. The night before Hurricane Katrina made landfall in the United States, Talbot Brooks, director of the Center for Interdisciplinary Geospatial Information

Technologies at Delta State University in Mississippi, used ArcGIS in association with Hazus-MH to determine the threat the incoming hurricane presented. His ArcGIS predictions suggested that the Louisiana-Mississippi border would experience the highest storm surge ranging from 16 – 32ft (Talbot, 2005). The distance between the Louisiana border and Bay St. Louis, Mississippi is roughly 20 miles. A Peak storm surge of about 29 feet was documented near Bay St. Louis, Mississippi after the hurricane, according to a study performed by USGS Mississippi Water Science Center (Turnipseed, Wilson, Stoker, & Tyler, 2007).

In another case, until recently, there had been no mapping or record of the Baltic Sea, located just south of Finland and which borders many European countries. Rain that falls in the drainage basin around the Baltic Sea eventually flows into the sea itself. The Baltic Sea's drainage basin contains many distinct geological regions. In 1996, a group of scientists from universities including the Royal Swedish Academy of Sciences and Stockholm University created a GIS database encompassing the drainage basin. By using multiple sets of map layers, which encompassed the varying geological regions, they were able to generate information on the landscape characteristics and population distribution in the drainage basin of the Baltic Sea (Sweitzer, Langaas, & Folke, 1996). From this, they were able to determine nutrient outflow, nutrient retention, and population densities through statistical analysis of the GIS data.

The Census Bureau of the United States also uses ArcGIS to aid in the collection of U.S. population information and the creation of media to make this data more presentable. According to Tim Trainor, Chief of the Geography Division of the United States Census Bureau, ArcGIS "is enabling the Census Bureau to efficiently collect quality data about the nation's people and economy" (Mitchell, 2009). The Census Bureau also stated that ArcGIS is useful due to its capabilities such as collecting, tabulating, and dissemination statistical data (Mitchell, 2009).

GIS software is a powerful tool that is used to predict disasters and analyze risk and spatial or statistical data. In relation to the development of population maps, ArcGIS is highly recommended by many organizations, including the U.S. Census Bureau. It has the ability to layer the multiple attributes, both geological and ecological, that serve to mimic the characteristics that form real life regions of the world.

One of the deliverables of this project is a population map of the studied floodplains. ArcGIS will be utilized to organize and present the data collected and make the layers that will be combined into a population map. We will layer population and flood data over aerial

photographs. FEMA and La Junta de Planificación will then use these maps to plan mitigation strategies to reduce flood damages.

2.7 Summary

This chapter has presented the reasons people live in areas where they face serious flooding, discussed flooding and the organizations that attempt to mitigate flood damage, examined the steps that people take to protect themselves, physically and with insurance, and reviewed ArcGIS, a computer program that will be a useful tool throughout this investigation. In general, floodplain residents do not have the resources to move their homes or protect themselves adequately from a severe flooding event. Historical and socio-economic factors have forced them to live in these high-risk regions. FEMA and La Junta de Planificación are trying to minimize the risks, but they do not have complete current information on the population on the floodplains. Our research intends to fill this gap in knowledge by making ArcGIS maps of three floodplains that governmental organizations will use to estimate population. It will also provide FEMA and La Junta de Planificación with information regarding the strategies used by floodplain residents with respect to their flood insurance.

CHAPTER 3: METHODS

La Junta de Planificación and Dr. Angel Cruz of the University of Puerto Rico have requested the development of a methodology for producing a population map of floodplains in San Juan, Puerto Rico. Dr. Cruz also requested a survey to collect data regarding flood insurance and the population on these floodplains. To accomplish this, first we will collect the data to develop the population map and a method for collecting this data. Section 3.1 describes the methods used to collect data concerning average household sizes and average number of residences living in each type of residential housing in San Juan. Section 3.2 details the procedure to create the population map of each floodplain; important aspects of a map include the map type, the program used to create it, the color scheme, legend, and distance scale. Section 3.3 discusses the contents and purpose of the survey. The survey will collect data concerning the history and policies of flood insurance within the floodplains of San Juan. It also contains questions to verify and supplement the population collection and estimations described in section 3.1.

3.1 Population Data Collection

A major deliverable of our project in San Juan is the creation of a population map of floodplains. This map will estimate population density in areas at risk of flooding and to create an interactive resource for FEMA and La Junta de Planificación. The method for collecting population data will be documented for use as a template for adaption in other floodplains.

In order to estimate the population density of the floodplains, we will examine aerial photographs and then multiply the number of houses by the average number of people per household as found in 2006-2008 US Census Community Survey data. Aerial photographs of San Juan are available and will be invaluable in determining the number of homes on the flood plains. Below is an example of an aerial photograph of a high-risk flood zone of San Juan.

Figure 1: Community on a San Juan floodplain

The best source of population and other related data is the United States Census Bureau. Every ten years the agency delves into a multi-facetted study of the United States population. The census data provides useful statistics including educational level, age, average number of people per household and each household's socio-economic status (US Census Bureau, 2006). The average number of people per household will be used in a preliminary estimation of population. The census information alone will not provide an accurate estimate, but it will serve as a starting point. These data will be adjusted later to account for various building size and occupancy based on field work findings. The most current data states that there are 2.78 persons per household with a margin of error of ± 0.03 persons (US Census Bureau, 2006). In order to calculate the population density, it will be necessary to count households within the floodplains and use this data to create an approximate density. We will count the number of houses in an area using aerial photographs. If the housing is too dense to accurately count individual houses, houses in a smaller area will be counted and an average house per area calculated. This number will then be multiplied by the area, to yield an estimate of houses. Since apartment buildings and larger homes will complicate this process, it will be necessary to visit some of these complexes

and record the number of residents living there. If there are too many apartment buildings, averages will once again calculated based on similar sized complexes to account for the differences in number of people per building.

As stated before, estimations based on aerial photography and census data may not necessarily be accurate. To improve the accuracy, a survey will be administered in part to determine the number of people living in the household. The data from the survey will provide an average number of people per household to adjust the census data and give a more accurate approximation of the population density. This will aid in understanding different flooding risks faced by different socio-economic classes. The survey is discussed later in this chapter.

Our data will be entered into an Excel spreadsheet similar to the table below.

Building Type	**Number of Buildings (From Aerial Photos)**	**People per Building (From Survey and Census Data)**	**Number of People per Building Type (Calculated)**
Small Household			
Medium Household			
Large Household			
Small Apartment Complex			
Medium Apartment Complex			
Large Apartment Complex			

Table 1: Sample Spreadsheet for Population Data Entry

It will sort buildings by size and will show the estimated number inhabitants per building type. This estimate will be multiplied by the number of buildings to give a figure for the number of people per building type. This column will be summed to give a total number living in the region. Once these data are compiled and an accurate density found, we will be able to quickly estimate population by aerial inspection in each flood plains. The total population will be entered into ArcGIS as a new layer and that layer will be added to existing flood maps. This method will then be adapted for use in other regions.

It will also be necessary to gather population, flooding, and zone boundary information from La Junta de Planificación while researching population densities in San Juan. As they are

responsible for zoning, they will have established zones that will be ideal for population estimation. In order to overcome potential language barriers, we will be assisted by University of Puerto Rico students or faculty.

3.2 ArcGIS Population Map

Maps have two main purposes; to store information, and to display spatial information through visuals means ("Basics of making", 2007). Maps generally can be made in two formats; topographical maps and thematic maps. Topographical maps provide information that illustrate where objects are in relation to one another. The kinds of map we will be concerned with are thematic maps. Thematic maps are used to convey information about a given theme, such as land use, health statistics, or population ("Basics of making", 2006).

For our project, we will create a thematic population map. The purpose of our map will be to store information regarding the population the floodplains and to display this information in a manner that allows the user to determine population in an indicated area. The program we will be using to create our population map is ArcGIS, which uses two types of data; raster data and vector data. For our population map we will be using raster data. Most population density maps display population per square mile. In our population map one raster cell will represent a fixed area of land. Each raster cell will display the number of people living in that region by means of different colors. The information within each raster cell will be the population density within the given area and the corresponding population density color. Figure 2 is an example of a population density map that uses this technique.

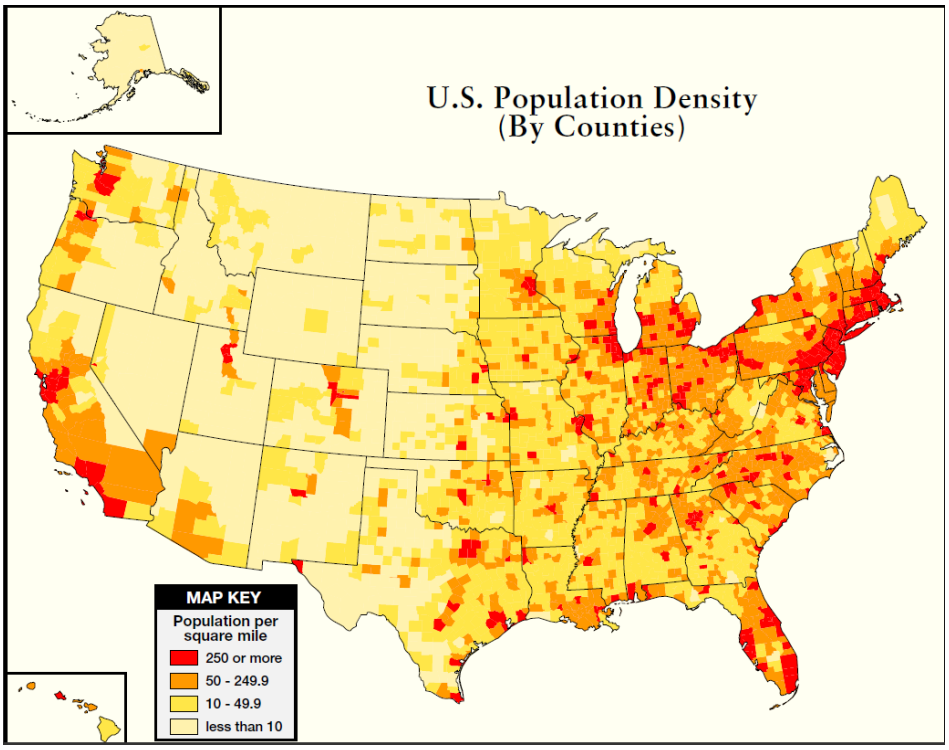

Figure 2: Population Map of U.S retrieved from
http://www.census.gov/dmd/www/pdf/512popdn.pdf

To denote population density we will use a color gradient from pale yellow to dark red. Each color will describe how densely populated the area is, yellow being the least densely populated and red being the most. These population rasters will be overlaid onto a map of the regions and borders of San Juan. The user can then locate an area of interest and find out how densely populated it is there by the color in that area. Using the scale, the user can then measure the area and calculate the population in that region by multiplying the population per square mile by the area of the region, resulting in the total population of the region.

A legend will display the population density corresponding to each color. In Figure 2 only four colors are used. We will use more shades in order to create a more detailed map. Another method to increase map detail is to add more rasters; this effect is shown in Figure 3, below. The map with more rasters show more information in the same amount of space. Other important aspects of our map will be the title, scale bar, and north arrow. The title will describe the content of the map. The scale bar is used to allow the user to determine the physical distance between two objects. This will be used to determine the area of a region. Finally, the north arrow orients the map in the traditional position. Figure 3 is an example of a complete population map.

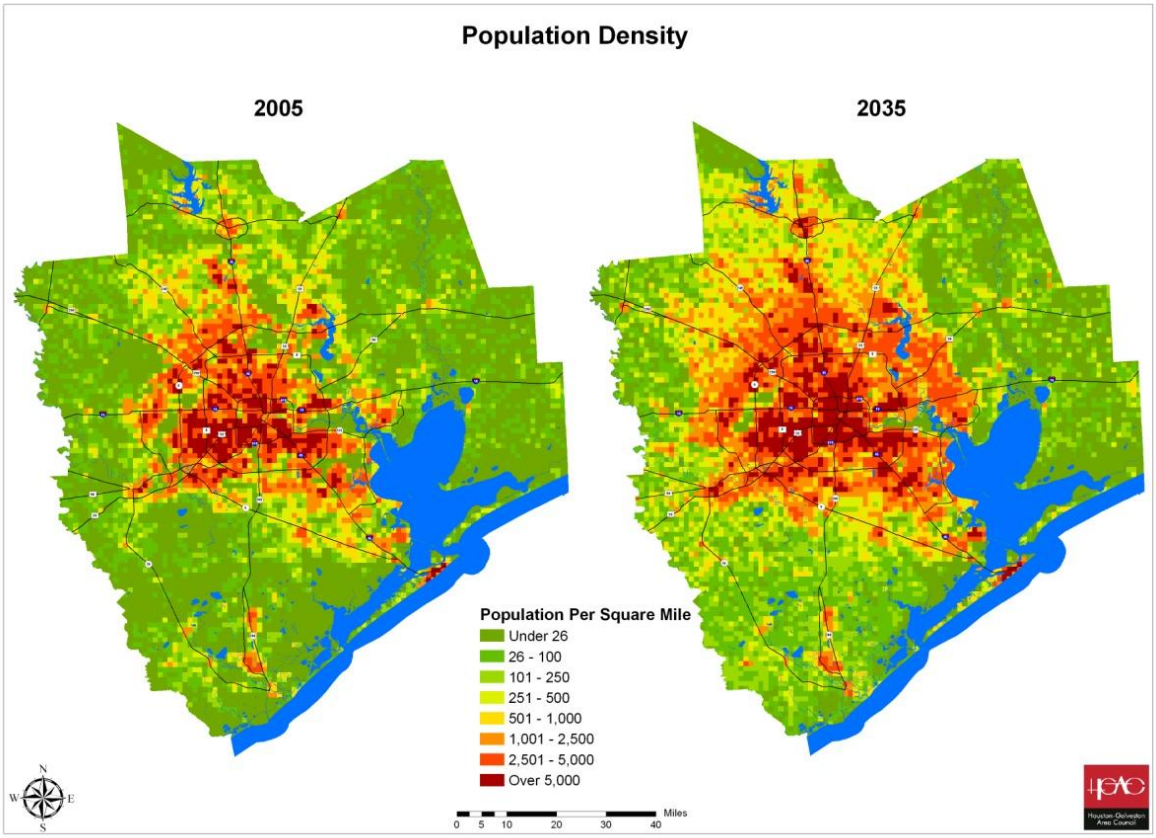

Figure 3: Population density map retrieved from http://ntis04.hgac.com

3.3 Survey

Another aspect of our project will be to design and conduct a survey that will provide data about the flood insurance history of the residents living on the floodplains (see Appendix A). Federal laws require citizens living in these zones to have flood insurance. However, due to the poor economic status of some of these areas, the Puerto Rican government often pays for, or subsidizes these insurance payments. If a flood occurs, the flood insurance should cover a significant portion of the damage, and should even enable the victims of such floods to protect their homes in preparation for future flooding. The purpose of the survey is to determine if residents collect money from their insurance claims and how they use this money. Our sponsor is concerned that the residents spend the money on other expenditures that the residents believe are more important. The survey will be administered in three economically different communities in Puerto Rico and we hope to determine how the money is being used in these three communities in the Municipality of San Juan.

A concern while administering the survey is that the questions must not imply that the subjects are being investigated or that their actions are wrong. Avoiding the sense that their answers incriminate them is of the utmost importance because people taking our survey that arrive at this conclusion will be unlikely to complete our survey accurately. Inaccurate surveys would prevent us from drawing the type of general conclusions we are looking for and ultimately skew our data so that we will not be able to use it to help governmental organizations mitigate flood risks.

The survey will be administered door to door in communities with which our sponsor is familiar. A student of the University of Puerto Rico will act as a translator. At each house we will request to speak with the head of the household. One team member will interview the subject and another will record responses. For this reason, it is vital to keep the survey short and simple. If the survey looks short and simple it will be more likely that the residents will be more willing to participate. We estimate the survey will take less than 10 minutes. This ensures that the participants actually fill out the survey, in a reasonable amount of time, since the project has a strict time limit on it. We will attempt to collect surveys from one-third of the residents in each floodplain. This data will then be entered into a password-protected Excel spreadsheet in order to ensure confidentiality and the information will only be used to draw general conclusions about flood insurance on floodplains.

3.4 Summary

By the end of this project, we will have a survey that is used to collect information regarding flood insurance policies and flood history, as well as information on population data that can be used as a supplement to our estimates of average household size and average households per building style in floodplain zones. We will have a population map of the floodplain regions of San Juan that can be used to calculate the population in a specified area within any floodplain in San Juan and we will have developed a methodology for creating population maps that can be applied to other floodplains in the territory of Puerto Rico.

CHAPTER 4: CONCLUSION

We have researched the history of the flood zone residents, examined geographical and environmental causes of severe flooding events, reviewed case studies, and researched software that we will use to present this data. This project will examine the current situation of floodplains in the Municipality of San Juan by estimating the population on floodplains and by collecting and analyzing data regarding flood insurance. This data will allow FEMA and La Junta de Planificación to mitigate the risk and aide in the evacuation of the floodplains in San Juan. Future efforts to estimate population on floodplains will use this project as a template. We will also develop and administer a survey about flood insurance. This survey will serve two purposes. It will allow us to collect information about past flooding events and the resident's use of insurance payments. The survey will also allow us to gather information regarding population densities of floodplains by determining the average number of people living in each building.

In order to estimate the population of a particular floodplain, we will be using the Census 2006 American Community Survey, along with aerial photographs of each of the communities to estimate the population. We will begin making this estimation by determining how many households are in the specific area. Then using the data provided by the U.S. Census Bureau of how many people per household there are in the Municipality of San Juan, we can estimate how many people reside on the specific floodplain. We will then verify our estimate with data we receive from the survey. If further adjustments are needed, we will adjust our estimate to reflect any necessary changes.

At the conclusion of our project we will present our sponsor with two deliverables. We will have developed a population density map of the three study communities using ArcGIS software. We will have produced and administered a survey that we used to collect information on flood awareness and flood insurance, as well as the results of the survey. These results will be analyzed and presented to our sponsors.

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APPENDIX A: SURVEY

FLOOD INSURANCE IN SAN JUAN

The information you provide will be used to draw general conclusions about flood insurance, flood awareness, and demographics in your neighborhood. All answers will be kept confidential and will not be used to identify you. You may stop taking this survey if at any time you feel uncomfortable or are unwilling to continue.

DEMOGRAPHIC INFORMATION

1. What is your age?

- ☐ 0-15
- ☐ 16-25
- ☐ 26-35
- ☐ Older than 35

2. What is your gender?

- ☐ Male
- ☐ Female

3. How many people live at this residence?

- ☐ 1-3
- ☐ 4-6
- ☐ 7 or more

HOUSING INFORMATION

4. How many years have you lived at this residence?

- ☐ 1-4
- ☐ 5-10
- ☐ 11-15
- ☐ 16 or more

5. Where does the owner of this residence live?

- ☐ I own this residence
- ☐ In this building
- ☐ Nearby
- ☐ Outside neighborhood
- ☐ Unsure

FLOOD INSURANCE INFORMATION

6. Do you have any type of flood insurance?

- ☐ Yes
- ☐ No
- ☐ Unsure

7. How many floods have you experienced while living at this residence?

- ☐ 0
- ☐ 2-5
- ☐ 6 or more

8. If you have ever experienced a flood at this residence, what is the highest flood you have experienced (in feet)?

- ☐ 0-2
- ☐ 3-5
- ☐ 6 or more

9. How many times have you experienced flood damage to this residence?

- ☐ 0
- ☐ 1-3
- ☐ 4-6
- ☐ 7 or more

10. Have you ever been compensated for flood damage at this residence? If so, on how many occasions?

- ☐ I have never been compensated
- ☐ 1-3
- ☐ 4-6
- ☐ 6