USING HAZUS-MH AND ARCGIS FOR A PARCEL-BASED CASE STUDY OF THE EFFECTS OF SEA LEVEL RISE IN THE TAMPA BAY REGION WITH A DETAILED ANALYSIS OF RESIDENTIAL PARCELS IN PINELLAS COUNTY, FLORIDA

By

KENWYN DIEGO HARRILAL

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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To my parents and wife

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LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FGDL	Florida Geographic Data Library
FIMA	Federal Insurance and Mitigation Administration
FIPS	Federal Information Processing Standard
FIS	Flood Insurance Study
IPCC	Intergovernmental Panel on Climate Change
JV	Just Value
MPH	Miles Per Hour
NOAA	National Oceanic Atmospheric Administration
PPM	Parts Per Million
SLR	Sea Level Rise
UN	United Nations
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Abstract Of Thesis Presented To The Graduate School
Of The University Of Florida In Partial Fulfillment Of The
Requirements For The Degree Of Master Of Arts In Urban And Regional Planning

USING HAZUS-MH AND ARCGIS FOR A PARCEL-BASED CASE STUDY OF THE EFFECTS OF SEA LEVEL RISE IN THE TAMPA BAY REGION WITH A DETAILED ANALYSIS OF RESIDENTIAL PARCELS IN PINELLAS COUNTY, FLORIDA

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December 2012

Chair: Paul Zwick
Cochair: Richard Schneider
Major: Urban and Regional Planning

This thesis sets out to investigate the potential effects of sea level rise on the Tampa Bay region, with an emphasis on Pinellas County. Two software programs were utilized in conducting the analysis: Hazus-MH to run natural disaster simulations and ArcGIS to run data analysis. First, there is an outline of the warning signs and implications of how sea level rise could affect the Tampa Bay region. Subsequently, instructions for conducting a sea level rise analysis in Hazus-MH and running the necessary analyst tools in ArcGIS are provided.

The sea level rise maps generated during the analysis vividly demonstrate how sea level rise could affect the Tampa Bay region. Within the regional analysis, empirical analysis focused on Pinellas County also supports the visual data. From the baseline model, the number of total parcels and single-family parcels affected increases dramatically, and the incremental increase is relatively consistent. Total parcels increased an average of 46,130 parcels (average 32% increase) for each model and

single-family parcels increased an average of 25,874 parcels (average 38.5% increase) for each model. Furthermore, as the parcels increased, the total projected cost was consistent with similar increases.

Of primary concern during a significant storm – particularly with the continuing trend of sea level rise – is the protection of people and property. The conclusions drawn from this analysis offer recommendations for evacuation planning. Finally, this thesis concludes that educating the public on the risks they face in the event of sea level rise will be the most effective mitigation strategy.

CHAPTER 1
INTRODUCTION

Understanding Hazards

The Earth is an ever-changing complex system. This complex system is dynamic and responds to changes within the system, however they are created, natural or man-made. These changes can be relatively abrupt, slow paced, or non-linear. An example in the geological system would be the recycling of Earth's mantle; this process can generate earthquake responses that are not easily predicted. However, one element of Earth's natural systems that is always under close observation is weather. Meteorology on Earth is a difficult process for humans to predict precisely on a long-term model; anything beyond 5 to 7 days is subject to fluctuations in its accuracy (Williams, 2005).

When humans add or subtract resources from our current environment, the Earth will have responses that result in both positive and negative consequences. Using the resources of the Earth in reprocessed formats, such as burning fossil fuels or changing the eco-system through development, present a potential threat for aggressive and frequent weather hazards, referred to as hazard from now on. A hazard can be defined as follows,

> A condition with the potential to cause injury, illness, or death or personnel (people); damage to or loss of equipment or property; or mission degradation. (U.S. Department of Defense, 2005)

Additionally, the book, "*Environmental Hazards: Assessing Risk and Reducing Disaster*" defines hazard as "*more extreme events that directly threaten human life and property by means of acute physical or chemical trauma on a scale sufficient to cause a 'disaster'*" (Keith 2004 p.8). The two definitions combined give an accurate idea of the scale and scope of a hazard. For this thesis, the hazard definition will be defined as both natural and human-caused, demonstrating the significant loss potential for both life and property (FEMA). The hazard that will be examined for this thesis will be a natural one: a hurricane. The impact a hurricane can have on a state, county, or community can be exponential when preparation is insufficient. Developing plans to handle concerns before, during, and after a storm are critical to success in both saving lives and preparing property.

Providing citizens with information regarding the potential for loss and educating them on how to prepare for hazardous situations can be the key to helping minimalize the losses that the community may suffer. This thesis will examine the affect of a hurricane physically on the Tampa Bay Region (Pinellas, Manatee, and Hillsborough Counties) and how sea level rise (SLR) can exacerbate a storm's potential damage. This thesis will examine the region as a whole, but will pay particular attention to Pinellas County to develop estimates on the damage expected. A 100-year storm (Hurricane) could affect Pinellas County with wind speeds of up to 121 miles per hour and develop a storm surge of more than 16 feet. Considering the effects of a hurricane disaster (100-year storm), this thesis attempts to analyze in detail the potential losses of single-family housing in a demonstration of the potential impact of SLR.

Study Area

The study area of this thesis is Tampa Bay, Florida and a breakout section of the region, which is Pinellas County, Florida. Tampa Bay was selected because of its coastal location, valuable natural resources, and because a realistic hurricane scenario could be run on the county. Additionally, the focus on Pinellas County was chosen because in one Hazus-MH model, the average wind speed in Pinellas County is predicted as the highest wind levels produced by a 100-year storm in the Tampa Bay

Region. Lastly, the data and information available for this area makes this analysis feasible to perform. Floridian coastal counties have a realistic threat of a hurricane landing on its shores during hurricane season. Although the threat may not be realized in a few years, or even decades, the risk is always present. The map of the Tampa Bay Region is Figure 1-1 and Pinellas County is Figure 1-2, which are the study areas.

Tampa Bay Geographic Location

The total area of the Tampa Bay region is 2,770 square miles (both land and water) and is composed of the following:

- Pinellas County: 608 square miles
- Manatee County: 893 square miles
- Hillsborough County: 1266 square miles

The Tampa Bay region is located on the west coast of Florida, with its western border facing the Gulf of Mexico and the remaining borders facing the surrounding counties.

Political boundaries for the Tampa Bay region include the following:

- West: the Gulf of Mexico
- North: Pasco County
- South: Sarasota County
- East: Polk, Hardee, and Desoto Counties

These boundaries are depicted in Figure 1-1.

Pinellas County Geographic Location

The total area of Pinellas County is 273.80 square miles in 2010. The County is 38 miles long from tip to tip, and is 15 miles wide at its broadest point. The Federal Information Processing Standard (FIPS) Code for this county is 103 (Quick Facts, Census 2010).

Political boundaries for Pinellas County include the following**:**

- West: the Gulf of Mexico and Tampa Bay.

- North: Pasco County
- East: Hillsborough County

These boundaries are depicted in Figure 1-2. Pinellas County has 24 incorporated municipalities. The area of Pinellas is in the Tampa-St. Petersburg-Clearwater, FL Metro Area. Based on the factfinder2 website, Pinellas County has 295 blocks, 290 census tracts, and 844 census block groups (U.S. Census Bureau, 2012).

Pinellas County Demographics

The population in Pinellas County is 916,542 people, according to the 2010 Census. There was a 0.5% decrease in the population of Pinellas County from the 921,482 residents according to the 2000 Census. The average total households from 2006-2010 were 405,649 households, with an average person per household rate of 2.21. The total housing unit in the county is about 503,634 units. Additionally, Pinellas County is the most densely populated county in Florida, with a population density of 3,347.5 persons per square mile in 2010.

Sea Level Rise Planning

Planning for sea level rise (SLR) poses challenging issues for many counties in Florida. SLR doesn’t just harm the coastline, beaches, and ocean front property owners – it affects many other parties. A rise in sea level can cause an increased height in storm waves, which will create a stronger storm surge, resulting in more areas that are vulnerable to storm surge damage. (State of Delaware, 2011) This thesis will address the concept of how SLR can affect storm surge in the Tampa Bay region and, specifically, Pinellas County. On the regional level, there will be an examination of how a current 100-year storm surge will affect the Tampa Bay region, compared to a 1-meter and 2-meter sea level rise. Additionally, the wind component of the storm will be added to the mix to understand fully how the affects of a hurricane plus SLR will act on Tampa Bay. Empirically, this thesis will show the impact of SLR storm surge and wind from a hurricane using single-family housing as an indicator. Running models to show the extent of flooding and predicted damage from wind on the single family residential home will give a numerical understanding of possible damage.

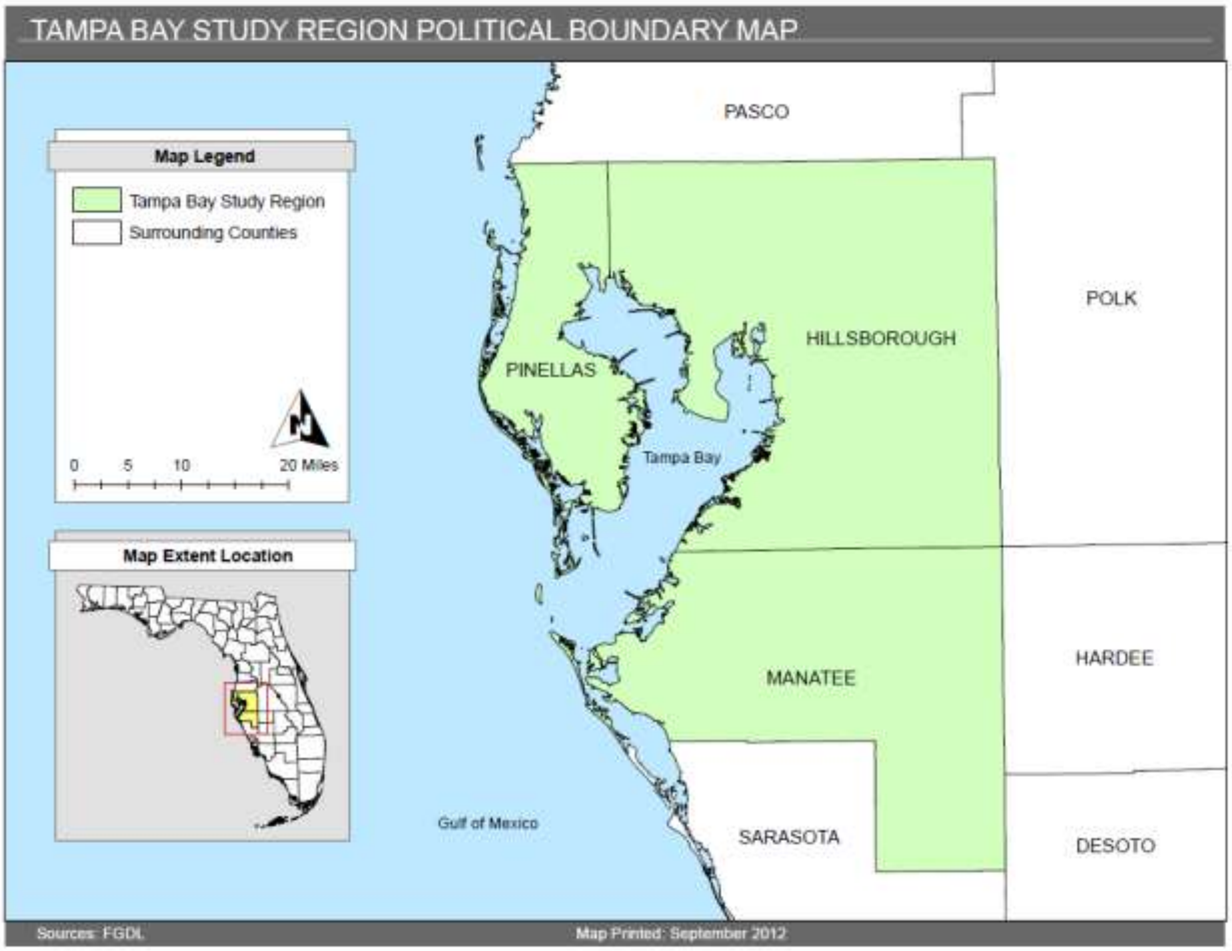

Figure 1-1. Tampa Bay Region Political Map (Harrilal, Tampa Bay Region Political Map, 2012)

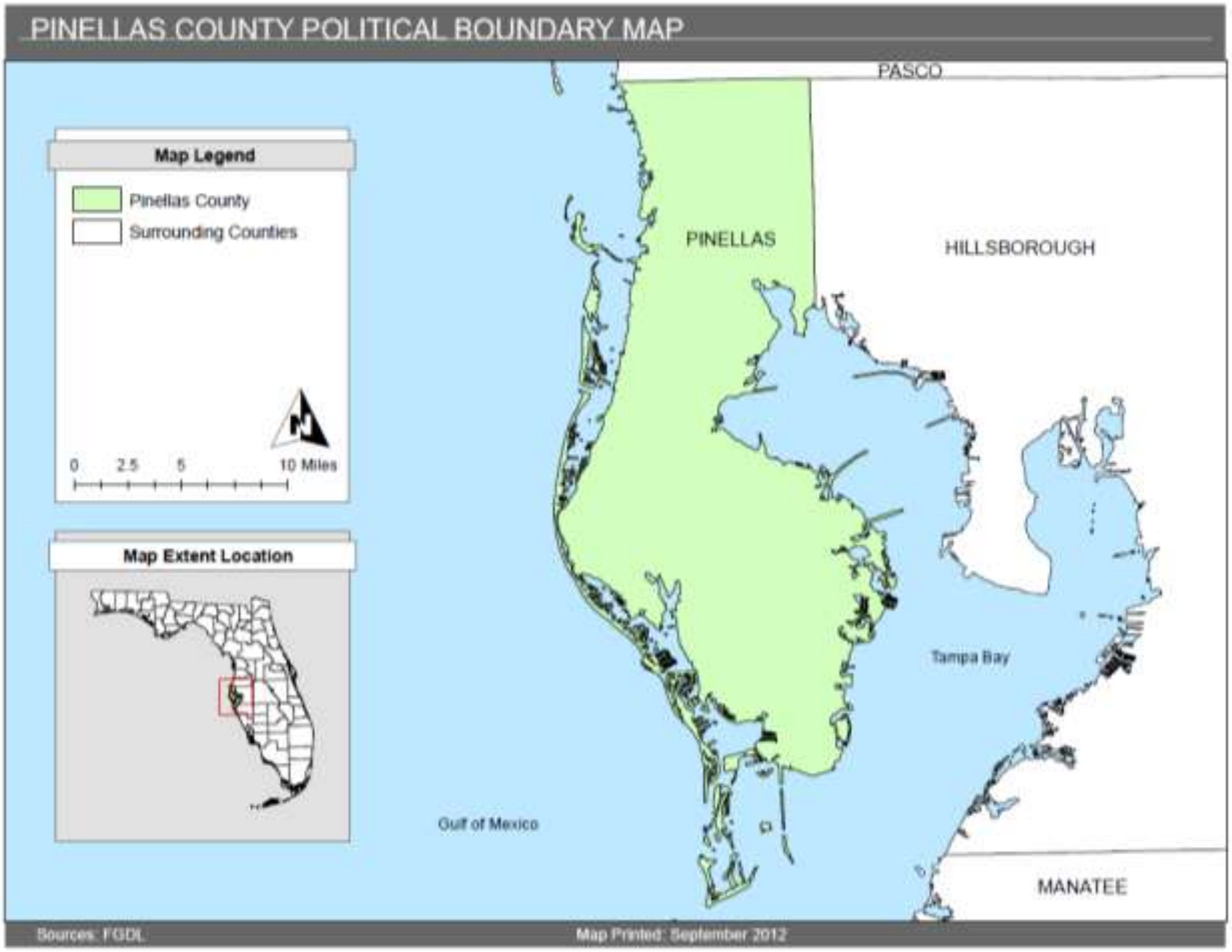

Figure 1-2. Pinellas County Political Map (Harrilal, Pinellas County Political Map, 2012)

CHAPTER 2
LITERATURE REVIEW

In accordance with the analysis and review conducted in this thesis, Chapter 2 reviews disaster effects, the importance of mitigation, Hazus modeling as a mitigation tool, and understanding evacuation planning.

The Effects of a Natural Disaster

The Federal Emergency Management Agency (FEMA) was established in 1979 as an independent agency in charge of disaster mitigation efforts. FEMA's mission is as follows:

> FEMA's mission is to support our citizens and first responders to ensure that as a nation we work together to build, sustain and improve our capability to prepare for, protect against, respond to, recover from and mitigate all hazards. (Federal Emergency Management Agency, 2012)

FEMA characterizes a disaster in many forms, such as –

> a hurricane, an earthquake, a tornado, a fire or hazardous spill, an act of nature or an act of terrorism. (Federal Emergency Management Agency, 2012)

The examples of hazards from the list above are categorized into two types: natural and technological. Specifically, the list of natural disasters includes earthquakes, landslides, volcano eruptions, floods, tsunamis, and hurricanes. This thesis will focus on hurricane hazards and their effect on emergency planning, specifically, evacuation planning.

Hurricane Hazard

Hurricane hazards bring destructive winds, storm surge, torrential rain, flooding, and tornados (USGS, 2006). A hurricane hazard is a form of tropical cyclone. A strong hurricane can generate storm surges along the coastlines in excess of 18 feet and winds that can exceed 150 miles per hour. These two specific threats – wind and storm surge – are the main hazards that will underline this thesis analysis. This thesis will explore the various consequences of storm surge and wind from a hurricane on coastal communities. The issues dealing with impending hurricane threats will also be addressed, as well as how to deal with the migration of people during an evacuation.

Storm Surge Hazard

Storm surge is defined as,

> An abnormal rise of water generated by a storm, over and above the predicted astronomical tides. (NOAA, 2012)

A storm surge will occur when water is being pushed on and past the shoreline due to a hurricane's negative pressure as shown in the figure 2-1. Storm surges will cause damage along the coastline, both from the physical damage of the moving water over the land, as well as the prolonged flooding that can occur. This damage suffered may cause the demolition of part or complete buildings – either immediately, or in the near future due to sustained damage. Damages could range from eroding buildings or highways, loss of lives, and destruction of vegetation or animals. Damages that maybe irreparable can be expected.

Wind Hazard

Wind is one of the components that make hurricanes extremely dangerous. The strong hurricane force winds are dangerous to anything within the storm's reach. Winds are able to damage any surficial structure such as buildings, mobile homes, or vegetation. Damage from wind can create more damage because of flying debris within the hurricane. The potential risk to high-rise buildings becomes amplified because wind speeds are increased as altitude increases. Additionally, the winds are strongest in the northeast quadrant of the hurricane as depicted in Figure 2-2. As stated by the NOAA,

> Wind speed usually decreases significantly within 12 hours after landfall. Nonetheless, winds can stay above hurricane strength well inland. (NOAA, 2012)

Figure 2-3 discusses the Saffir-Simpson Hurricane Scale and includes an approximate damage description, the possible wind levels, and the level of storm surge expected.

Sea Level Rise Hazard

Sea level rise is defined as

> *a mean rise in sea level.* (UN Atlas of the Oceans, 2010)

The primary factor that is attributed with sea level rise is the concept of global warming. Global warming is broadly defined as the relatively recent accelerated increase in production of carbon dioxide (CO_2). CO_2 is the main by-product of using fossil fuels to power our world. People may not believe in global warming or how it affects the global sea level, however, the scientific evidence demonstrates that there is a correlation between sea level and CO_2 levels which is hard to ignore. Figure 2-4 depicts how increasing the amount of CO_2 in our atmosphere produces a warming effect on the Earth.

The rapid increase in CO_2 levels has allowed our planet to rapidly (in historical terms) increase in its over all global temperature. A rising global temperature affects the quantity of ocean water, increasing the volume of water from melting of glacier ice and melting of ice sheets (United States Environmental Protection Agency, 2012). Additionally, the thermal expansion of the water in oceans is affects the volume; as water heats up, it expands taking up more space. Some other factors to consider are the

> pumping of ground water for human use, impoundment in reservoirs, wetland drainage, and deforestation. (Federal Emergency Management Agency, 2012)

The effects from sea level rise are demonstrated in the following examples (United States Environmental Protection Agency, 2012):

- Erosion occurs along the shores and results in land loss. Additionally, the habitat that resides in coastal areas is also affected, such as coral reefs.
- When storms and flooding occur, the sea level rise increases the vulnerability of coastal areas and the population located in those areas. Shores are vulnerable because storms occur at higher bases of water and existing shore erosion cause no protection to the beach.
- Salt-water intrusion is another effect of sea level rise. When sea level rise transpires, the level of the sea water table rises and brings the salty water on to the land. Once the water has evaporated, the residue will remain during dry periods. Consequently, high salinity occurs and adversely affects plants and animals that are sensitive to the salinity.

The average level of sea level rise in the world throughout 20th century has been about 4.4-8.8 inches, while the U.S. has seen a sea level rise of about 0.08 - 0.12 inches per year along most of the U.S. Atlantic and Gulf Coasts (FEMA). Currently a total global increase of 1 meter (approximately 3 feet) by the year 2100 is “widely accepted as a serious possibility. (Rahmstorf, 2012)” The U.S. Army Corps of Engineers recommends planning for as much as 1.5 meters (approximately 5 feet) of SLR (U.S. Army Corps of Engineers, 2011). Other accounts demonstrate that SLR tracking at the upper range of the Intergovernmental Panel on Climate Change (IPCC) projections, factoring in the ice loss from Greenland and Antarctica, SLR by 2100 could hit the 2-meter mark (Cook, 2012). Another historical indicator that could indicate that the sea level will rise is data from the last ice age. During the last ice age, carbon dioxide (CO_2) had risen to 300ppm, with a rise in sea level of 6 to 9 meters (Figure 2-5). Currently, CO_2 is at 390ppm and, according to history, a 6 to 9 meter sea level rise would not be out of the question. With these projected levels in mind, the problem becomes increasingly complex because over half of the nation's population lives on coastlines, including 85% of Florida's residents.

> Additionally nearly four million citizens already live within three feet of today's high tide level, with hundreds of billions of dollars of infrastructure at risk. (Strauss, Ziemlinski, Weiss, & Overpeck, 2012)

This level of threat is not limited to one specific area; both the east and west coasts are severely exposed to SLR damage. For an east coast example outside of Florida, residential structures within the current 100-year floodplain for New York City and Nassau, Suffolk, and Westchester counties have already totaled an estimated value of over $125 billion (New York State Sea Level Rise Task Force, 2010). For a west coast example, a 1.4-meter SLR endangers approximately 480,000 people on the California coast from its Oregon border down to Mexico; assuming that population stays the same (Heberger, Cooley, Herrera, Gleick, & Moore, 2011). These are some examples of how vulnerable our coastlines truly are and why we need to develop strategies and policies to help mitigate the losses due to SLR. In addition to the immediate loss of buildings and infrastructure of an area, the additional loss of the tax revenue base in the medium- and long-term could cripple government-operating budgets.

The Importance of Mitigation Planning

Mitigation is defined as:

> the efforts undertaken to reduce the frequency or severity of loss. (Florida Commission on Hurricane Loss Projection Methodology, 2010)

In the context of disaster, mitigation efforts cultivate the preparations needed for facing a possible natural disaster. The return on this effort is that people in the areas predicted to be affected by a natural disaster can reduce their risk of damage to themselves and their property.

Taking into consideration the importance of mitigation for citizens, FEMA has created a sub-organization whose focus is disaster mitigation – the Federal Insurance and Mitigation Administration (FIMA). This organization's effort is focused on reducing damage to homes, businesses, schools, public buildings, and other important facilities due to natural disasters. FIMA's website lists qualities to demonstrate the value of mitigation efforts to society which include (Federal Insurance and Mitigation Administration, 2012):

1. Mitigation creates safe communities by reducing losses of life and property.
2. Mitigation enables individuals and communities to recover more rapidly from disasters.
3. Mitigation lessens the financial impact of disasters on individuals, the Treasury, the State, tribal and local communities.

Specifically, The State of Florida has the Florida Commission on Hurricane Loss Projection Methodology, which highlights the importance of hurricane mitigation in Florida (Florida Commission on Hurricane Loss Projection Methodology, 2010). In the published document, *Windstorm Mitigation Discounts Report* (2010), the commission stated that besides having fewer injuries and deaths from hurricanes, the importance of windstorm mitigation is to stabilize and strengthen the insurance market in Florida.

One of the important processes in mitigation efforts is conducting risk assessments. A risk assessment examines the risk of exposure to property of life for future disasters. Risk assessments are the basis for mitigation planning process and consist of four key steps, enumerated below:

1. Identifying hazards,
2. Profiling hazard events,

3. Inventorying assets, and
4. Estimating losses (Federal Emergency Management Agency, 2006).

Based on the key steps to performing a risk assessment, a hurricane simulation is needed to generate needed data. As a user of the software, Hazus-MH, you can generate nationwide simulation models of hurricanes to conduct a risk assessment for multiple hazards.

Hazus Modeling in Mitigation

According to FEMA,

> Hazus-MH is a nationally applicable standardized methodology and software program that contains models for estimating potential losses from earthquakes, floods, and hurricane winds. (FEMA, 2012)

Hazus-MH is a program that runs in conjunction with ESRI's ArcGIS software to provide a visual estimation of the hazard's damage, as well as calculate an approximate numerical estimate of damage. Hazus-MH's ability to calculate damage can be as detailed as estimating the physical damage for buildings, facilities, infrastructure, economic losses, and social impacts. Hazus-MH is a useful application for conducting a general mitigation assessment, dealing with recovery efforts, emergency preparedness, and emergency services response.

The State of Florida has been using Hazus-MH as a tool for risk assessment since its first version in 1997, specifically for hurricane disaster simulations. Florida is a leader in utilizing Hazus-MH and is cited as a good case study for best practices for Hazus-MH utilization (FEMA, 2012). Additionally, the State of Florida has demonstrated a commitment to using Hazus-MH through the creation of the Florida Hazus User Group in January 2006 to foster Hazus-MH use.

Currently Hazus-MH is on version 2.1 (64-bit compliant only) and is compatible with ArcGIS's 10.0 version. Although Hazus-MH still defaults to using the results of 2000 Census, this thesis utilizes the 2010 Census data during analysis to provide a more up-to-date and accurate simulation. The complete data requirements to perform a Hazus-MH assessment and the data needed for the ArcGIS spatial analyses are explained in the data section.

Project Data Sources

In this thesis, data for performing the analysis are explained based on the order of the analysis steps:

- Hazus-MH analysis
- ArcGIS spatial analysis
- Property loss analysis

Hazus-MH Analysis

A Digital Elevation Model (DEM) and the stillwater elevations for Pinellas County will be utilized for the Hazus-MH analysis. First, a DEM map was obtained from Florida Geographic Data Library (FGDL). "*The Florida Geographic Data Library is a collection of Geospatial Data compiled by the University of Florida, GeoPlan Center with support from the Florida Department of Transportation"* (Florida Geographic Data Library). Second, the Stillwater elevations data were obtained from the Flood Insurance Study (FIS) for each county and additional data was provided by the Engineering and Technical Support Division, Department of Environment and Infrastructures (David A. Talhouk, personal email).

ArcGIS Spatial Analysis

The Hazus-MH results were incorporated into the next analysis sequence completed in ArcGIS Spatial Analyst. The resulting layers from Hazus-MH are the 100-

year storm wind map, 100-year storm surge coastal flooding map, and the 100-year storm flood with sea level rise maps (for detailed maps, reference Chapter 3).

Property Loss Analysis

Lastly, data was added regarding the administrative boundaries and parcel data for Pinellas County that was accessed from the Florida Geographic Data Library (FGDL).

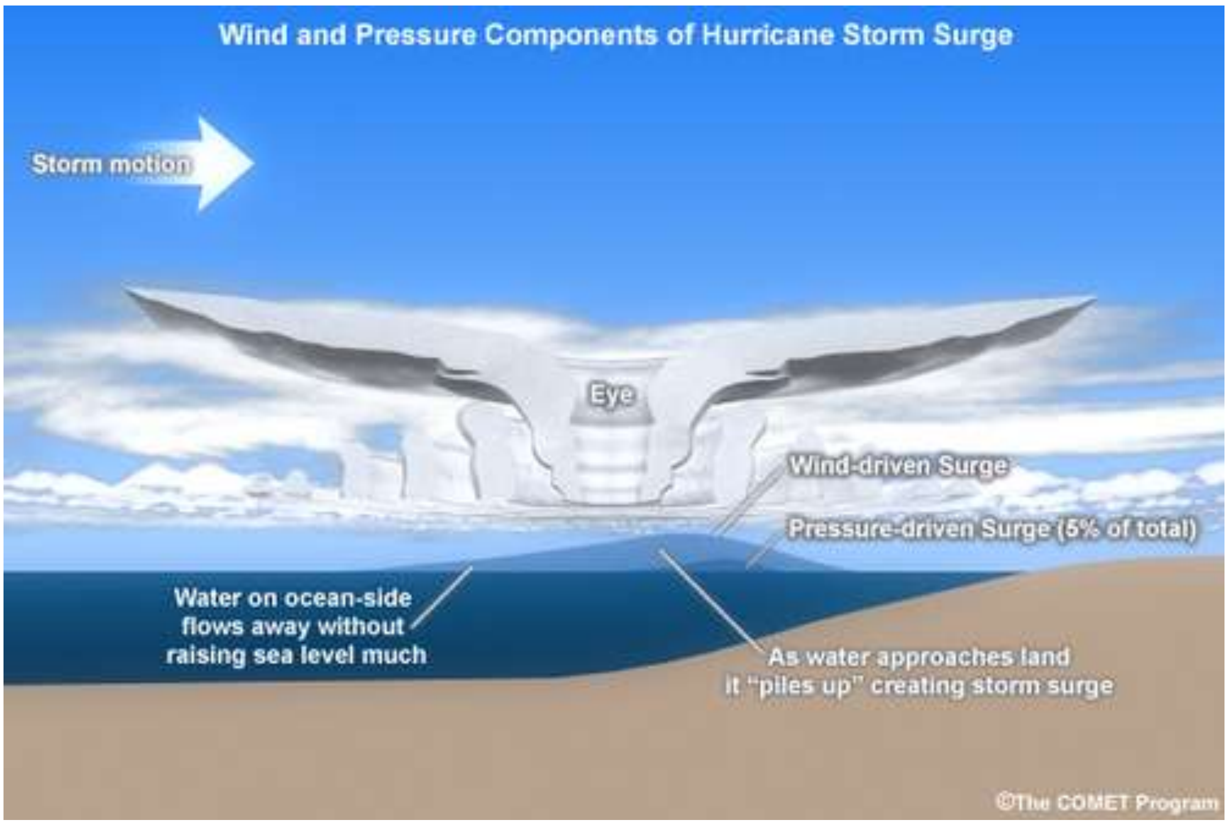

Figure 2-1. Wind and Pressure Components of Hurricane Storm Surge (NOAA, 2012)

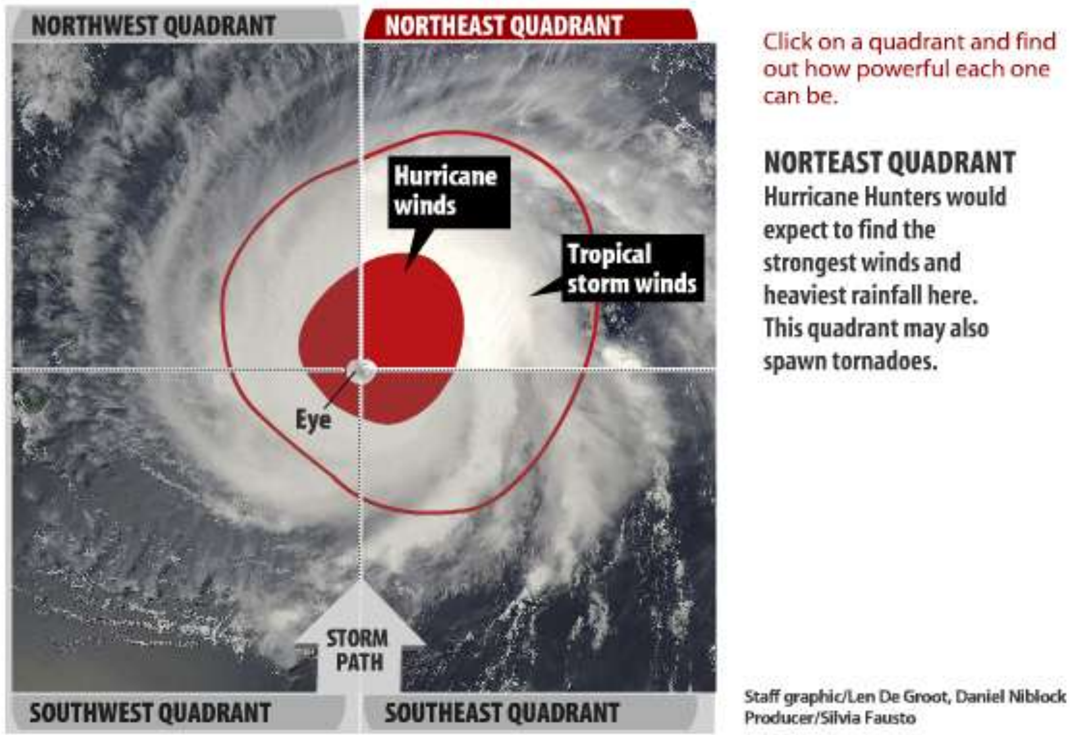

Figure 2-2. Hurricane Strength Based On Quadrants (De Groot, Niblock, & Fausto, 2012)

SAFFIR-SIMPSON HURRICANE SCALE			
SCALE NUMBER (*Category*)	SUSTAINED WINDS (*MPH*)	DAMAGE ESTIMATE	STORM SURGE (*FEET*)
1	74-95	**Minimal**: Unanchored mobile homes, vegetation and signs	Range 4-5
2	96-110	**Moderate**: All mobile homes, roofs, small crafts, flooding	Range 6-8
3	111-130	**Extensive**: Small buildings, low-lying roads cut off	Range 9-12
4	131-155	**Extreme**: Roofs destroyed, trees down, roads cut off, mobile homes destroyed. Beach homes flooded.	Range 13-18
5	More than 155	**Catastrophic**: Most buildings destroyed. Vegetation destroyed. Major roads cut off. Homes flooded.	Range greater than 18 Feet

Figure 2-3. Saffir-Simpson Scale (Adapted from (scioly.org, 2011))

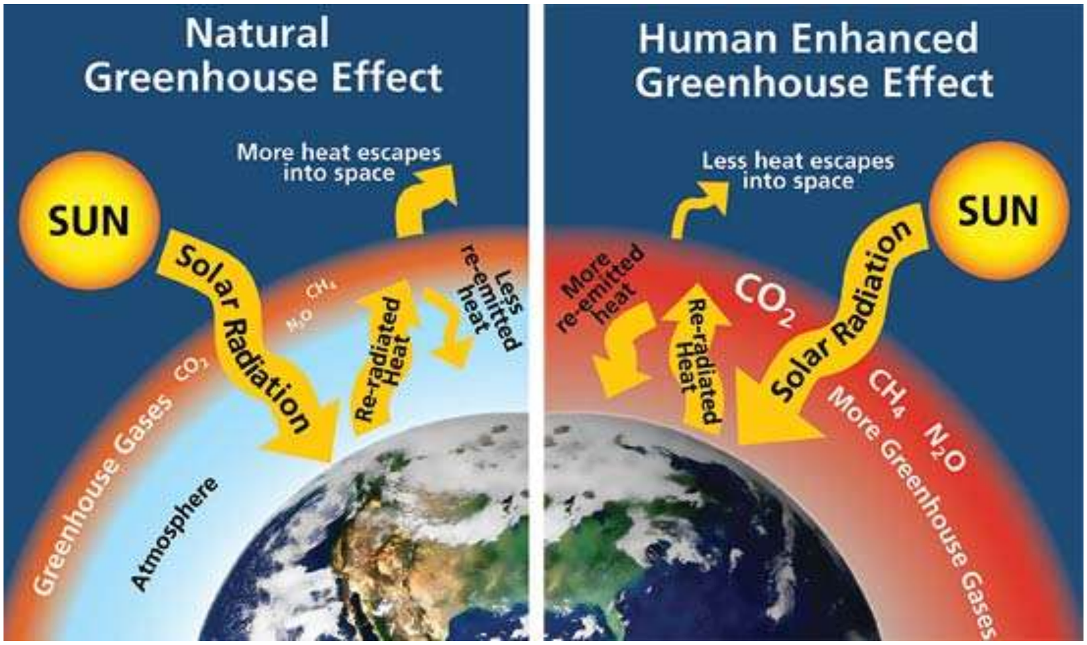

Figure 2-4. Greenhouse Effect Diagram (National Park Service, 2012)

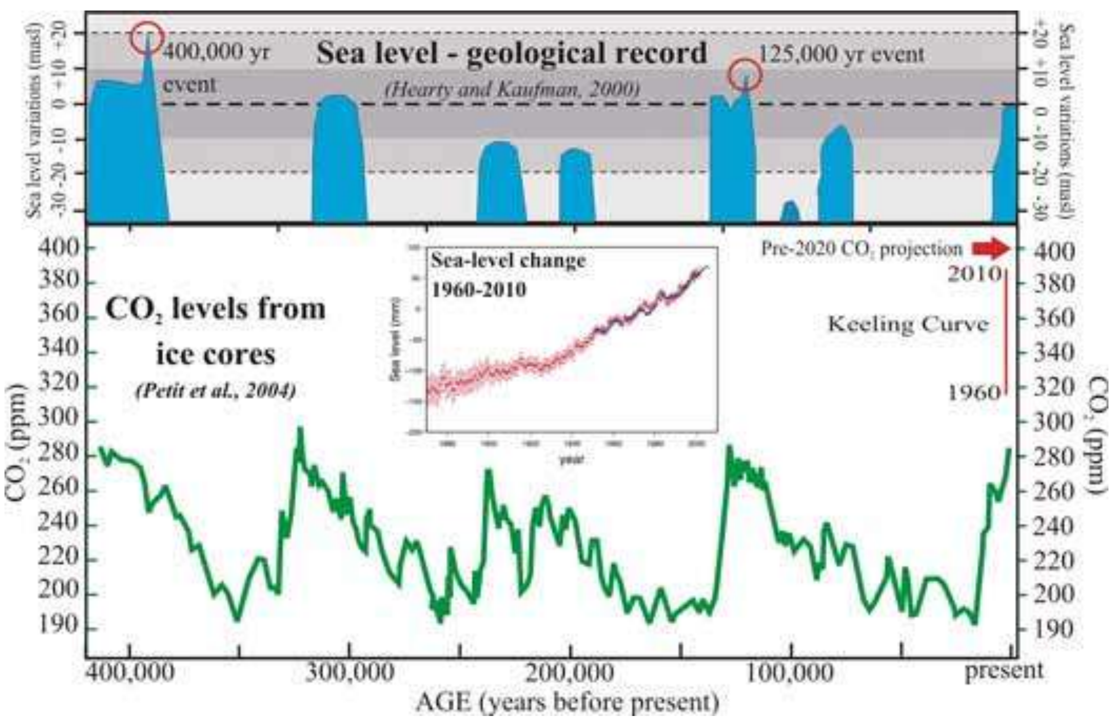

Figure 2-5. Sea-Level Rise vs CO_2 ppm Levels (Hearty & Kaufman, 2000) (Petit, 1999)

CHAPTER 3
METHODOLOGY

Hazus Models

Chapter 3 will explain how the Hazus-MH software developed several models: the wind level projection for a 100-year storm, the coastal flooding projections for a 100-year storm surge, the combination of a 1 and 2 meter SLR with storm surge. Chapter 3 will also discuss some of the parameters.

Model 1 – Wind Grid (100-Year Storm)

Tropical storm-force winds are powerful enough to cause substantial damage. Emergency managers typically plan evacuations to happen before the onset of winds at tropical storm-force. Once winds reach hurricane-force, they are strong enough to destroy buildings and mobile homes. Another dangerous element is the debris that can be picked up and launched as projectiles. Typical debris may include signs, roofing material, siding, and small household items left outside (NOAA/National Weather Service, 2012). Hurricanes can have sustained wind gusts of more than 100 mph well inland. Additionally, the stronger the hurricane the higher the sustained wind speed will be, causing those same projectiles to become increasingly dangerous.

Wind Modeling

The wind model (Figure 3-1) was generated using the hurricane option in Hazus-MH. This wind grid was developed with a 100-year storm index. Appendix B will discuss further the process of producing a wind grid and demonstrate the resulting wind raster.

Model 2 – Coastal Flood (100 Year Storm)

> 100-year storm or flood means an extreme condition of that magnitude has a 1 percent chance of happening in any year. (U.S. Geological Survey, 2012)

The effect of a 100-year flood is more severe to a particular location that receives reoccurring interval floods. For example, an area that receives regular interval flooding would have soil that could be saturated, which would retain less water and cause a free flowing stream which would lead to more damage. A 100-year storm will not always cause a 100-year flood; it will depend on the rainfall in the watershed region, soil saturation before the storm, and the relationship between the size of the watershed and the duration of the storm. The mitigation efforts for an area have to consider the probability of those components together to effectively estimate the results; Hazus-MH is a tool to help with this analysis.

Coastal Flood Modeling

While the wind grid model (Figure 3-2) was generated using Hazus-MH, the storm surge model was created using the flood option. This depth grid was developed with a 100-year storm index. Appendix B will discuss further the process of producing a flood depth grid and demonstrate the resulting flood depth raster.

Model 3 – Coastal Flood with Sea Level Rise (100-Year Storm Surge Plus SLR)

Sea Level Rise Modeling

Coastal flooding due to storm surge is something coastal counties have to face any time there is a hurricane. The final models attempt to demonstrate how a 100-year storm surge changes with the addition of a 1-meter (3.28 feet) or a 2-meter (6.56 feet) sea level rise. The 1-meter and 2-meter levels were selected based on their plausibility, as demonstrated in Chapter 2). A 1-meter SLR is listed as probable by 2100. Additionally, the IPCC believes that at a 2-meter SLR is possible when considering unexpected ice melting. While the plausibility of a 2-meter increase is not a widely held belief, as a researcher, examining what a worst-case scenario could do to the coastal region would be prudent in planning for mitigation. Hazus-HM does not specifically address a sea level rise simulation, nor does it have a formal option or process to generate a sea level rise flood grid. However, you are able to simulate a sea level rise by lowering the DEM and running a new scenario, which would in turn produce an artificial simulation of a sea level rise. The steps in Appendix B are listed to create a sea level rise adjusted grid.

After the last step listed in the Appendix B, you would have a DEM layer that has been adjusted for sea level rise and a simulated storm surge SLR polygon. If you compared the two, you would be able to see that the difference between the 100-year storm surge is just the difference of the calculated sea level rise. However, this does not account for any fluctuation a storm might encounter, as it is a uniform increase. To create a more accurate model with regard to the storm track and parameters of the storm, a new scenario will need to be run over the new DEM.

There is one critical step to running a SLR simulation before you begin. When dealing with Hazus-MH it is strict about how files are stored and run. Because there is no default option in Hazus-MH (i.e. Earthquake, Flood, and Hurricane) to run a SLR model, there needs to be some manipulation within the Hazus-MH system. Hazus-MH defaults to a file called “clipdem” as the DEM used to run its scenario model. To use the new SLR rise model, it is necessary to replace the original DEM (clipdem) with the new SLR DEM for Hazus to recognize the replaced DEM. The steps need to replace the DEM are listed in Appendix B.

This model is not the definitive answer as to how SLR would affect the area, however, it does give you at least an introduction to how sea level rise would or could affect the coastal counties. From the map (Figure 3-3) you can see how much storm surge will affect the county and region and how mitigation planning will be needed to help prepare for this type if disaster if SLR does occur.

100-Year Wind Grid Analysis

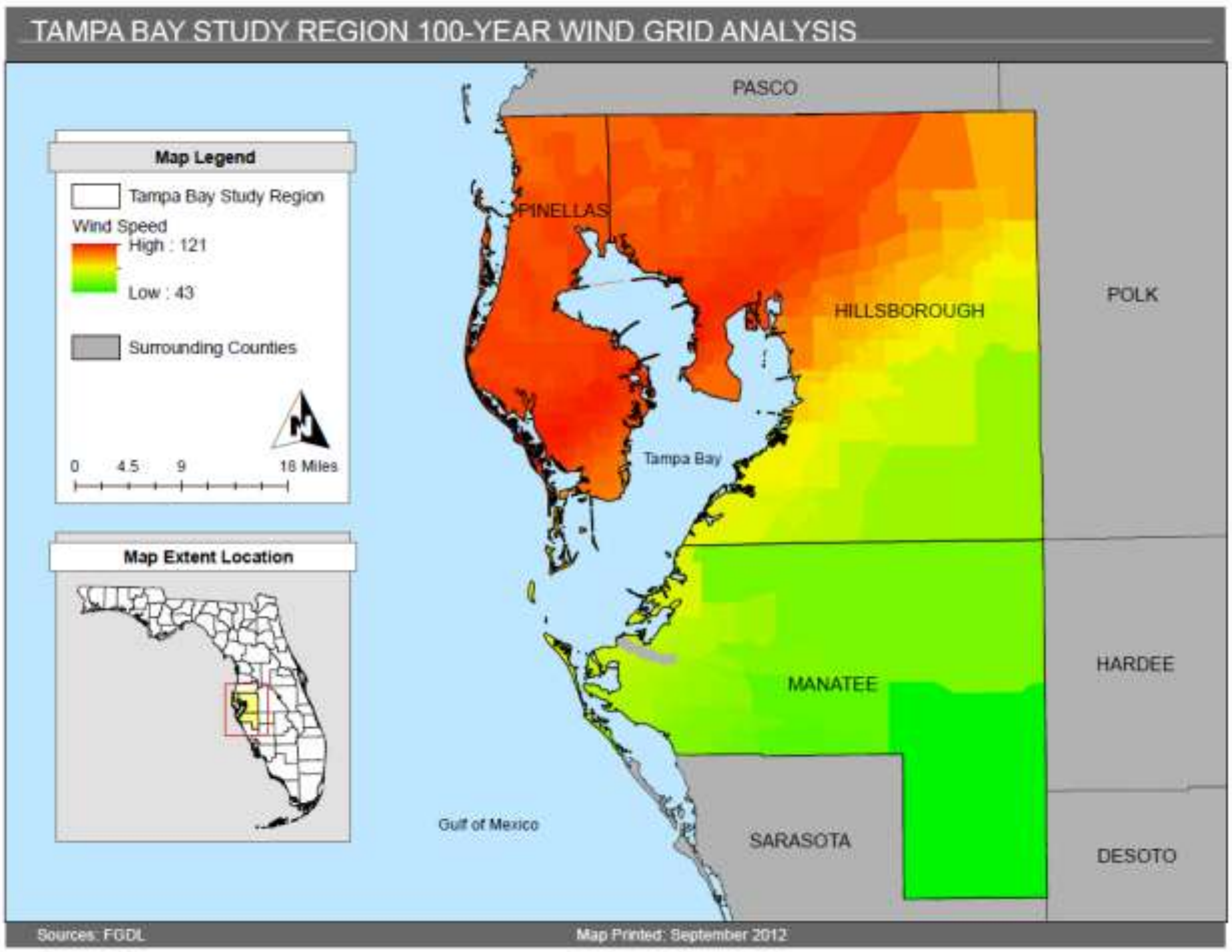

Figure 3-1. 100-Year Wind Grid Analysis (Harrilal, 100-Year Wind Grid Analysis, 2012)

100-Year Storm Surge Depth Analysis

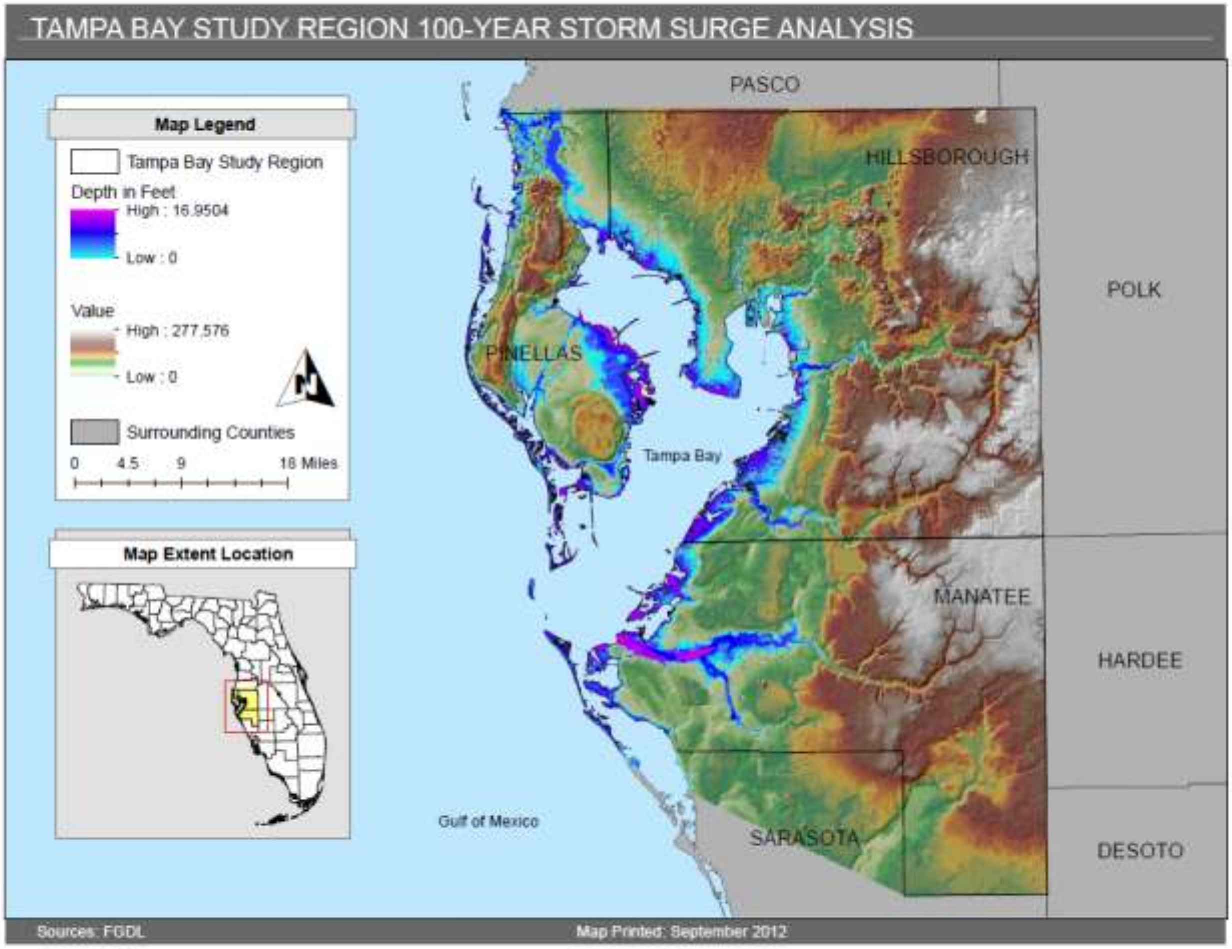

Figure 3-2. 100-Year Storm Surge Depth Analysis (Harrilal, 100-Year Storm Surge Depth Analysis, 2012)

100-Year Storm Surge with 2M Sea Level Rise

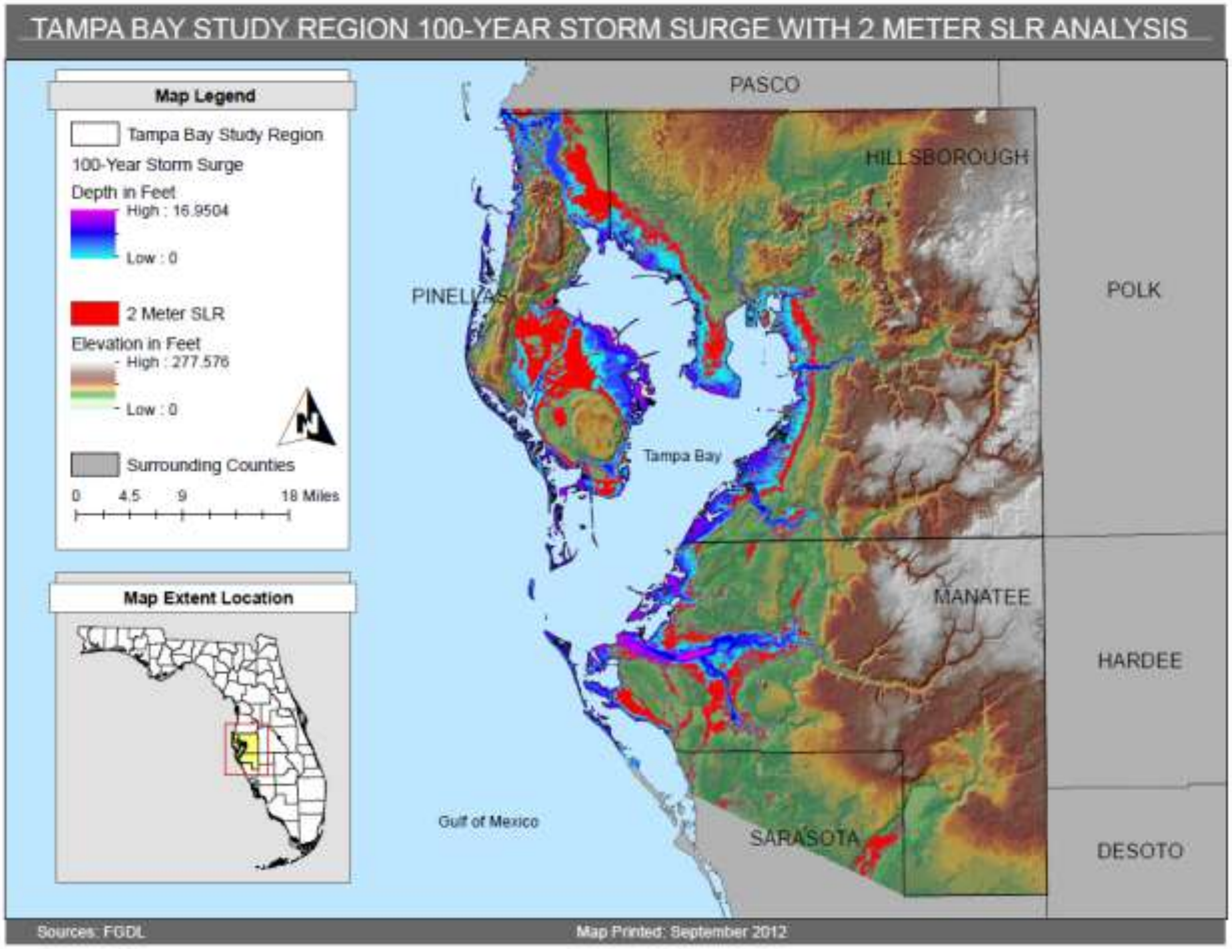

Figure 3-3. 100-Year Storm Surge with a 2 Meter SLR (Harrilal, 100-Year Storm Surge with a 2-Meter SLR, 2012)

CHAPTER 4
ANALYSIS/RESULTS

Data Analysis Parameters

The analysis conducted for this thesis was comprised of two major steps. First, a Hazus-MH storm analysis (both hurricane and coastal storm surge) was performed. This generic analysis produced reports regarding the predicted quantities of building damages and infrastructure losses. The second step was analyzing the detailed losses at a parcel level by running the spatial analyst tools in ArcGIS. This level of analysis produced detailed information that enabled an understanding of the specific losses at the parcel level.

For the analysis, a storm was selected within Hazus-MH mimicking the strength and path that has the probability of occurring once every 100 years. The detailed storm track is diagramed in Figure 4-1. From the figure, looking at the map extent, you can see the full track of the storm. The storm making its way through the Gulf of Mexico comes from the southwest and makes landfall in northern Pinellas County. This storm track places the strongest part of the storm, the northeast quadrant as diagramed in Figure 2-2, over the Tampa Bay area.

For the regional analysis, there will be no empirical data analysis. This region will not be examined at a detailed level due to the time constraints and the amount of data that would be required to analyze the region as a whole. The analysis was conducted for an understanding of how the region could be impacted based on the storm strength and their location with regard to the bay. Using the created maps, it allows an insight into vulnerable areas within the region. When examining an area for disaster analysis, it is important to examine the surrounding areas. The ability to forecast not only your emergency need, but those around you is important when determining where to have evacuees go during an evacuation. Additionally, understanding how the bay region on the macro-scale would be impacted in the long term due to SLR can help collaborative prevention efforts. If the local areas are facing similar challenges pooling effort together can be beneficial to all, in both the short and long term. However, there will also be a detailed analysis run to demonstrate an example of how SLR can impact an area empirically. For this thesis, a detailed loss calculation was conducted for Pinellas County. From this analysis, conclusions could be drawn in terms of potential damage estimates, not only for Pinellas County, but also for the region.

In the detailed loss calculation, there are four different loss scenarios that were examined looking directly at single-family residential homes:

1. Losses that would be incurred based on the 100-year wind damage (Figure 4-7)
2. Losses that would be incurred based on the 100-year storm surge (Figure 4-13)
3. Losses that would be incurred based on the 100-year storm surge, assuming a 1-meter SLR (Figure 4-15)
4. Losses that would be incurred based on the 100-year storm surge, assuming a 2-meter SLR (Figure 4-8)

Additionally there will be a comprehensive examination as to how the three different storm surge damage estimates compare in terms of affected parcels.

Regional Analysis Diagrams

100-Year Wind Grid - Tampa Bay Region

For the first regional analysis, the map (Figure 4-2) depicts the effect of the wind on the Tampa Bay region. As you follow the storm track, the regional perspective provides some insight as to the hardest hit areas. You are able to parallel the storm track with the path of the storms eye wall, where the storm would expose its peak strength for the longest duration. This dark red area experiences the highest wind speed in the entire diagramed region, with a max at 121 mph. It also demonstrates the difference in storm strength that Hillsborough County will experience. There is a noticeable divide in the middle of the county showing that the upper northwest corner to the middle divide will be hardest hit. With regard to wind speed, a significant amount of damage will occur in Pinellas County and half of Hillsborough County.

100-Year Storm Surge - Tampa Bay Region

For the second analysis, this map (Figure 4-3) depicts how the storm surge will affect the Tampa Bay region under current conditions with a 100-year probabilistic storm. From the map, the storm surge is predicted to get as deep as 16.9 feet in some areas. There is one particular area in Manatee County where flooding as deep at 16 feet occurs as far as 9 to 10 miles inland. Storm surge as a whole tends to be more aggressive in the bay compared to the coastline facing the Gulf of Mexico. Much of the deeper flooding is occurring on Tampa Bay shores, which further demonstrates their vulnerability to the flooding. Another critical area of concern with regard to flooding is Pinellas County. There are two points where flooding will occur and possibly cut off access out of the area. Even though the flooding is modeled to be shallow, Pinellas County could be split in two due to flooding. One affected region is near its border with Hillsborough County, and the other is slightly below the center of the county.

100-Year Storm Surge with 1 & 2 Meter SLR - Tampa Bay Region

For the final analysis, this map (Figure 4-4) provides a contrast to how a current storm surge will measure up to one with the addition of a 1-meter SLR and a 2-meter SLR. When examining this map compared to the previous (Figure 4-3), you can see that areas that were of concern initially become extremely susceptible to flooding and damage. Looking at the increase for a 1-meter sea level rise, it shows that the areas of main concern are the middle of Pinellas County and the border between Pinellas and Hillsborough County. These two areas would see a significant increase in flooding, both in depth and reach. However, once you increase to 2 meters of sea level rise, there are more areas drastically affected. Building upon the normal SLR and 1-meter rise, Pinellas County becomes two large islands due to the storm surge alone, not accounting for the additional wind. Additionally, the storm surge will push water further into Manatee County with additional depth. Also, Hillsborough County's peninsula becomes fairly heavily flooded compared to before. Understanding how the rise in water affects the bay shores can demonstrate what critical areas need to be protected. Between the areas that are at risk to flood – coastlines that face the Gulf of Mexico or Tampa Bay shores – combined with the high winds that the coast will experience, these areas very dangerous to reside in with an incoming storm due to their exposure to the hazards.

Modeling SLR in Pinellas County

100-Year Wind Grid – Pinellas County

This model addresses the how the wind levels are distributed across Pinellas County. Because of the strength of the storm, based on the Saffir-Simpson scale (See Figure 2-3), there are only two wind categories that are present in Pinellas County. In Pinellas County, the wind speed ranges from 98-121 mph, which fall into a category 2 and 3 storm. From Figure 4-5, you can see the range of wind speed and its mean. From Figure 4-6, you can see the general model used to obtain this model. This model took the two basic layers (Peak wind and Pinellas parcels) and converted them to raster layers, with an additional step for parcels. For the parcels layer, the parcels were turned into point data then converted to a raster with the parcel information and the wind speed in one document for analysis.

For Figure 4-7 the wind speed at scale 2 (yellow), there are 5,488 parcels selected. The total area that is affected by this level of wind is 128,198 acres. Because the wind area is wide and covers the total county area, the percentage of each a parcel that gets affected is extremely high, at about 98% on average. For the wind speed at scale 3 (red), there are 35,108 parcels selected. The total area that is affected by this level of wind is 260,281 acres. The percentage of parcel that is affected by the winds impact is 98% on average.

The actual cost damage will not be calculated for the wind grid because this hazard will not change due to SLR. Comparing the wind levels as SLR increases will not provide a change in damage amount; only a shift in storm strength will change how much damage the wind will cause. However, the storm surge models will examine damage to illustrate the different due to SLR.

Analyzing Residential Property Loss

Before looking at the parcel level results, an examination of Hazus-MH's general results of property losses is a way to conduct a quick damage assessment. These results are available after running the probabilistic storm performed in the steps listed in models 1 through 3 (Chapter 2). Several figures are also generated through the quick assessment, i.e. building damage by general occupancy, by building types, and by general occupancy. The figures 4-8 through 4-11 will account for all three counties in the simulation, however, we will be discussing and evaluating the values for Pinellas County only. As such, when numbers are referenced in the following sections, they will refer to Pinellas County unless otherwise stated.

The building damage by general occupancy figure shows that most occupancy types are within the same range, however, when you factor in the square footage residential and commercial have the highest probability. Complete information about building damage by general occupancy is as shown on Figures 4-8.

In Pinellas County, the building damage reflected in Hazus show that again residential property would be most affected, both in severity and building count. In each category (none, minor, moderate, severe, and destruction), residential dominates the numbers of buildings damaged as shown in Figure 4-9.

In Pinellas County, most of the buildings that are affected are masonry, concrete, and wood structures. In certain categories of damage – moderate and severe – concrete and steel buildings represent a significant number of the buildings affected. However, manufactured homes are fairly resistant to damage on most damage levels as shown in Figure 4-10

The last figure is the Direct Economic Losses for Buildings. It provides a macro-level total for how much losses could be incurred due to building loss on a monetary level. For Pinellas County, it is projected that the building losses would cost $3.3 billion dollars and the cost of the contents of the building would cost about $1 billion dollars. However, those are just physical damage costs; from the figure you are also able to see potential incomes losses as well as shown in Figure 4-11.

Storm Surge Analysis

For the flood analysis, the flooding levels were broken up into five categories classifying coastal flooding, based on the Saffir-Simpson Hurricane Level scales listed in Figure 2-3. Figure 4-12 is the level classification for Models 1-3. Additionally, the losses information is derived from the just value (JV) listed in the parcel data.

Model 1 - 100-Year Storm Surge – Pinellas County

The map in Figure 4-13 diagrams the probabilistic 100-year storm surge and shows that the depth ranges from 0 to almost 17 feet of water. Any area that is located in the color orange or red can be considered severely damaged due to flooding, at least at the first floor level. From the analysis using current parcel data, this level of flooding means 123,142 parcels would be affected due to flooding alone. Upon further examination, 55,664 of those parcels are single-family homes. If those homes were to suffer damage related to flooding, the total damage could rise as high as $13.8 billion, with a mean average loss of $248,223. These numbers would only account for the physical damage to property, not including any other indirect losses. Figure 4-14 demonstrates the losses in graphic form.

Model 2 - 100-Year Storm Surge with 1 Meter SLR - Pinellas County

The map in Figure 4-15 diagrams the probabilistic 100-year storm surge with 1-meter of SLR and shows that the depth ranges from 0 to a little over 20 feet of water. Any area that is located in the color orange or red can be considered severely damaged due to flooding, at least at the first and second floor level. From the analysis using current parcel data, this level of flooding means 166,585 parcels would be affected due to flooding alone. Upon further examination, 80,047 of those parcels are single-family homes. If those homes were to suffer damage related to flooding, the total damage could rise as high as $17.4 billion with a mean average loss of $216,761. These numbers would only account for the physical damage to property, not including any other indirect losses. Figure 4-16 demonstrates the losses in graphic form.

Model 3 - 100-Year Storm Surge with 2 Meter SLR – Pinellas County

The map in Figure 4-17 diagrams the probabilistic 100-year storm surge with 2 meters of SLR and shows that the depth ranges from 0 to a little over 23.5 feet of water. Any area that is located in the color orange or red can be considered severely damaged due to flooding, at least at the first and second floor level. From the analysis using current parcel data, this level of flooding means 215,402 parcels would be affected due to flooding alone. Upon further examination, 107,412 of those parcels are single-family homes. If those homes were to suffer damage related to flooding, the total damage could rise as high as $20.8 billion with a mean average loss of $193,497. These numbers would only account for the physical damage to property, not including any other indirect losses. Figure 4-18 demonstrates the losses in graphic form.

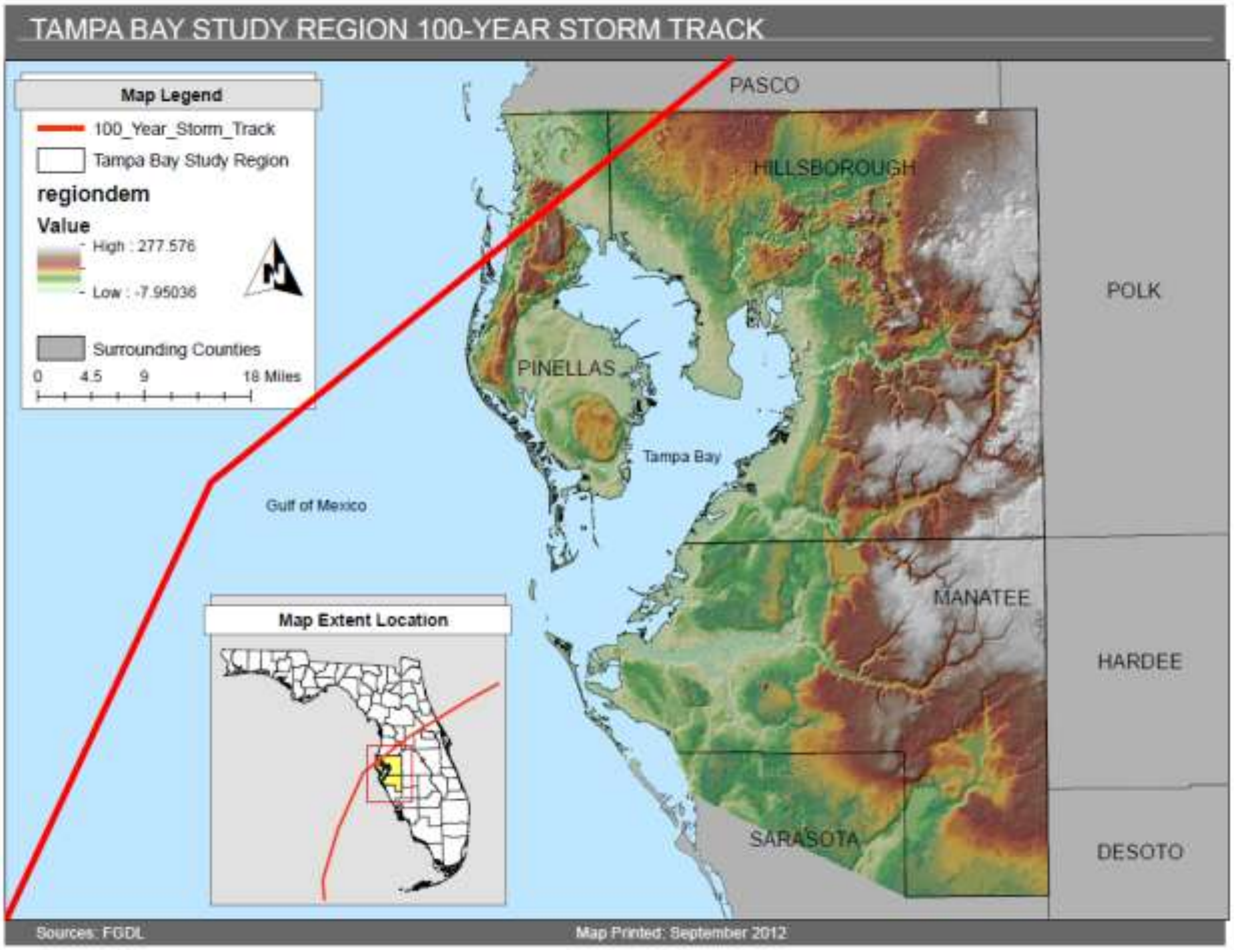

Figure 4-1. 100-Year Probabilistic Storm Track (Harrilal, 100-Year Probablistic Storm Track, 2012)

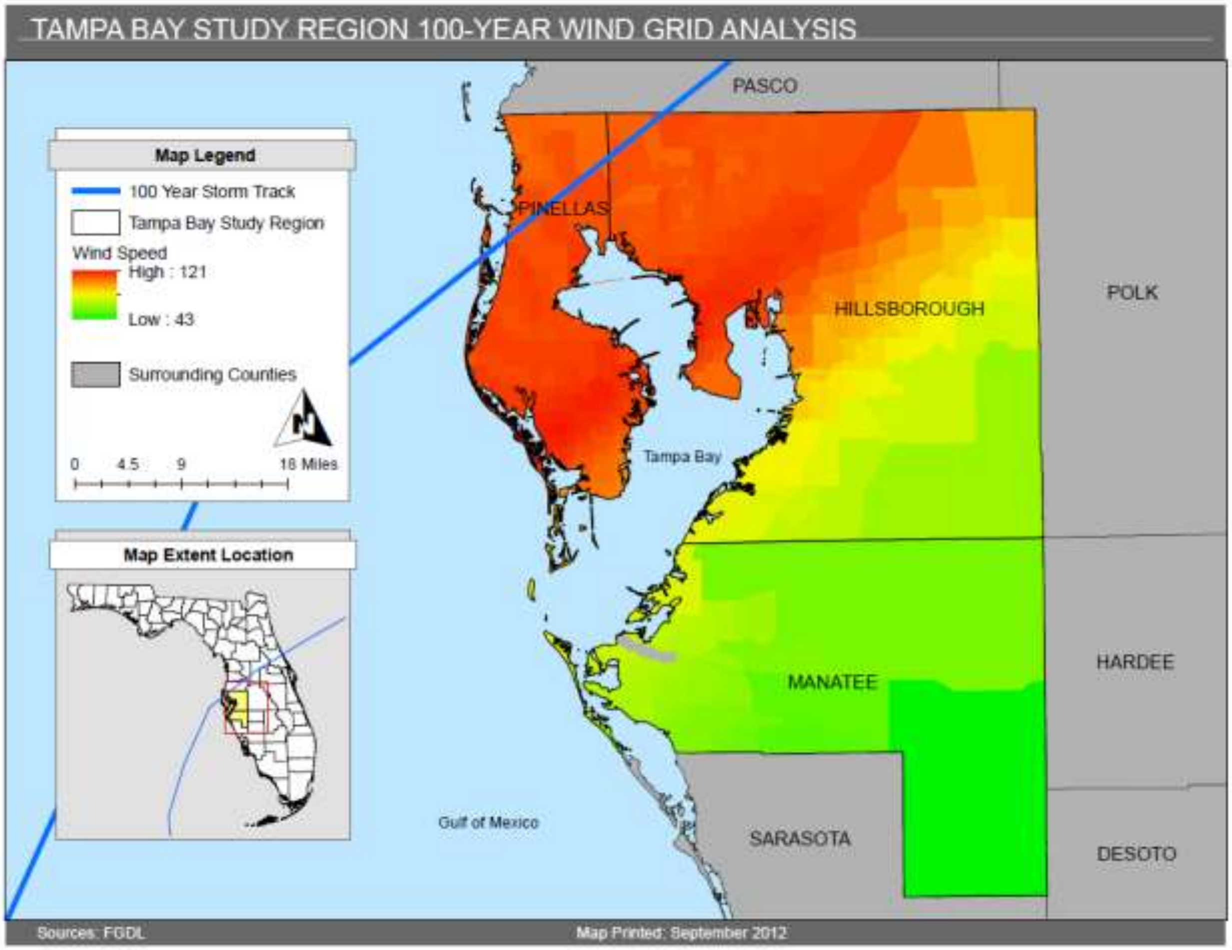

Figure 4-2. 100-Year Wind Grid Tampa Bay Region (Harrilal, 100-Year Wind Grid Tampa Bay Region, 2012)

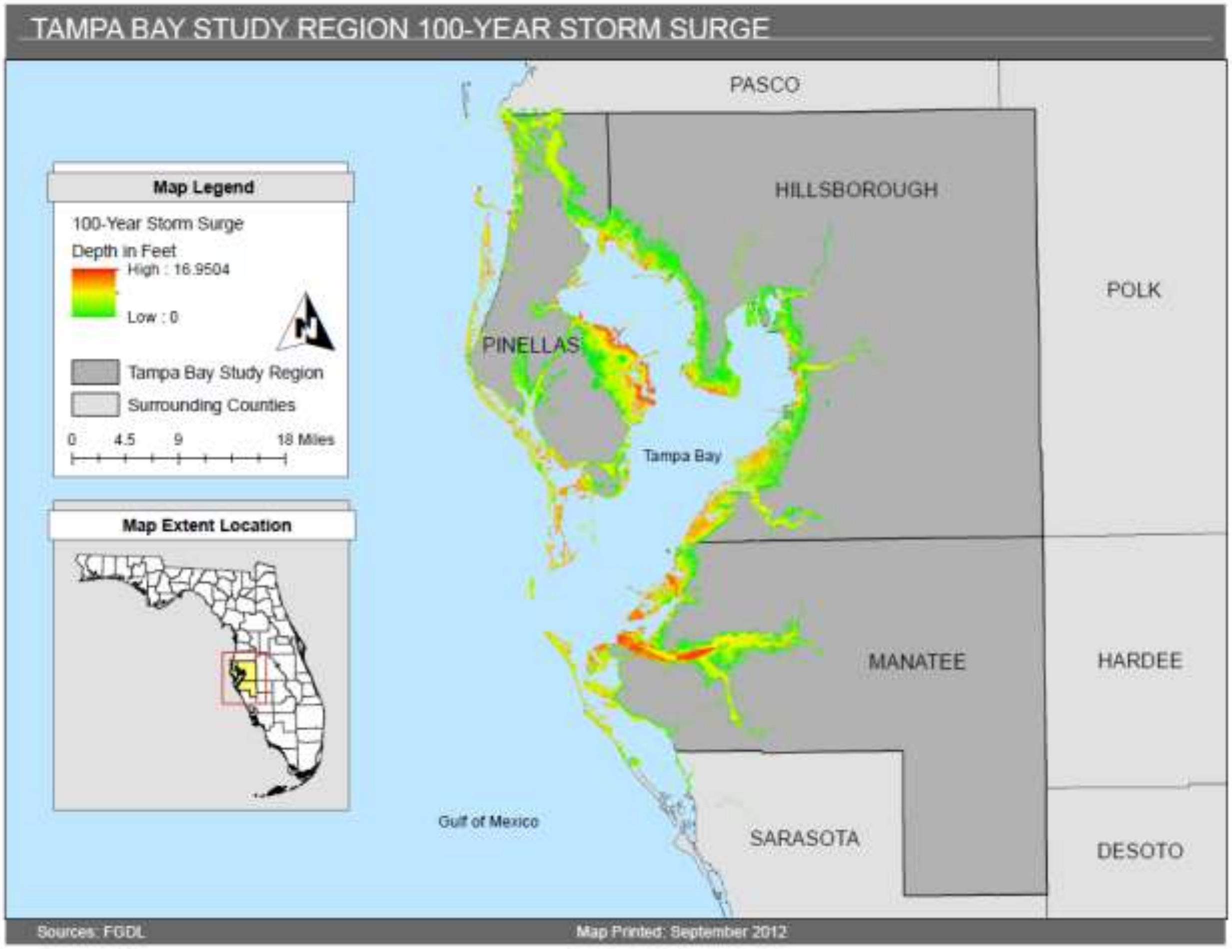

Figure 4-3. 100-Year Storm Surge Tampa Bay Region (Harrilal, 100-Year Storm Surge Tampa Bay Region, 2012)

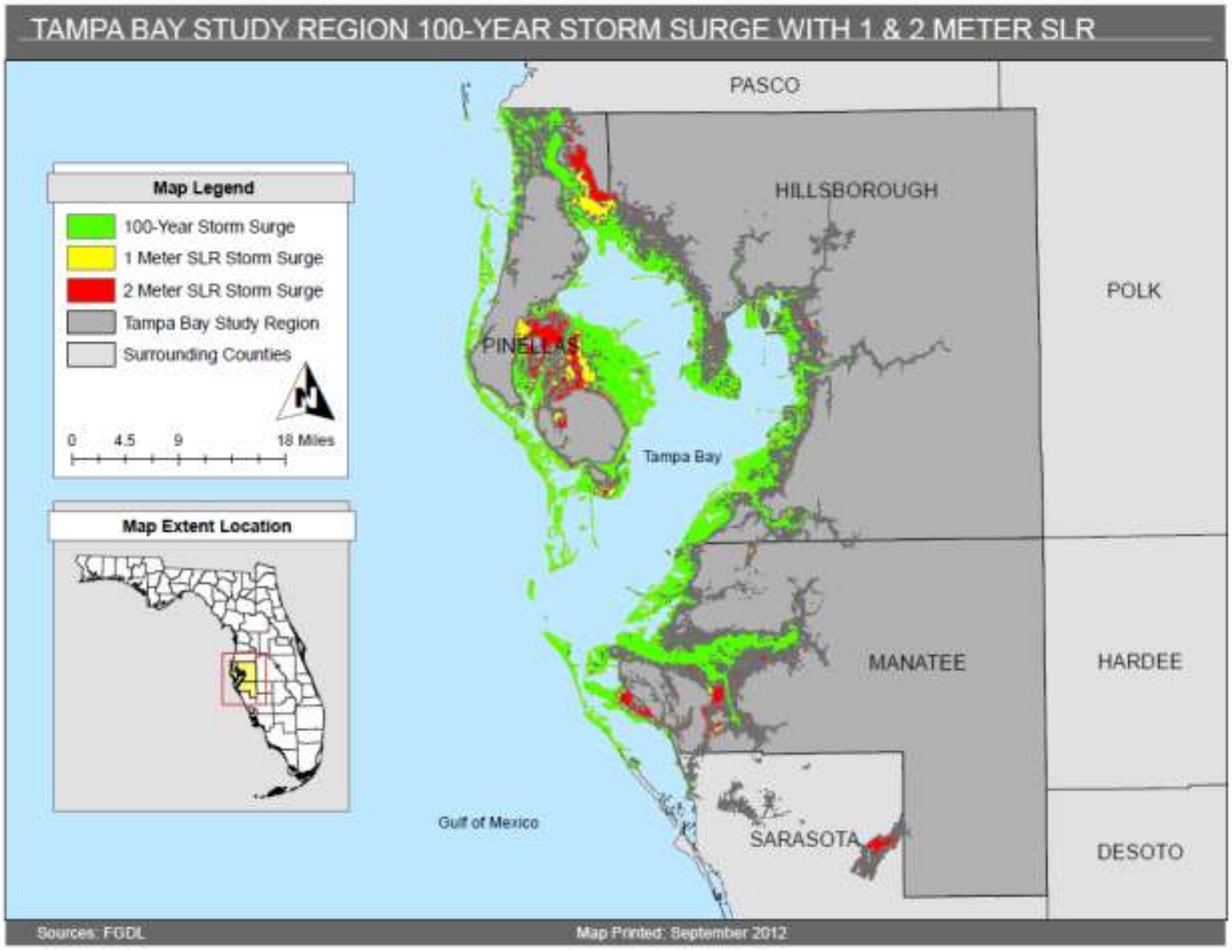

Figure 4-4. 100-Year Storm Surge with 1 & 2 Meter SLR - Tampa Bay Region (Harrilal, 100-Year Storm Surge with 1 & 2 Meter SLR - Tampa Bay Region, 2012)

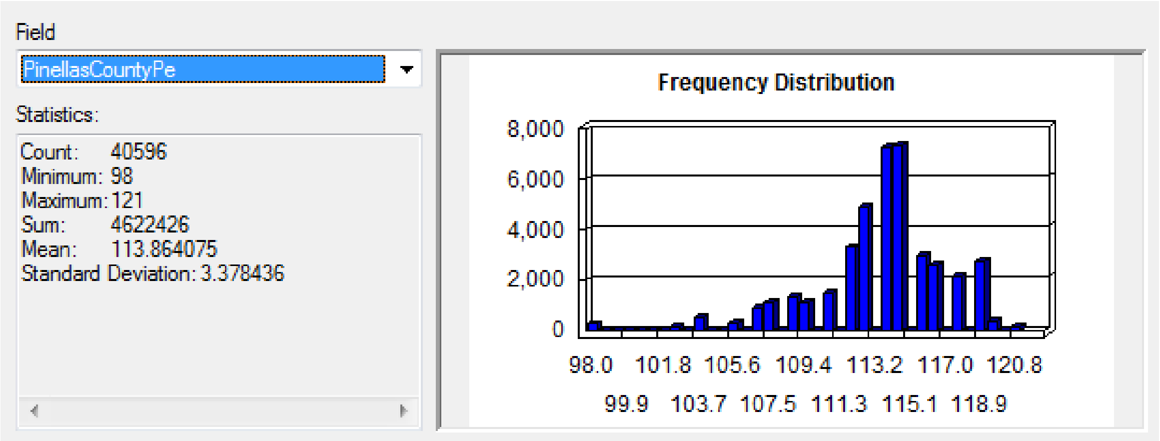

Figure 4-5. Wind Speed Statistics (Harrilal, Wind Speed Statistics, 2012)

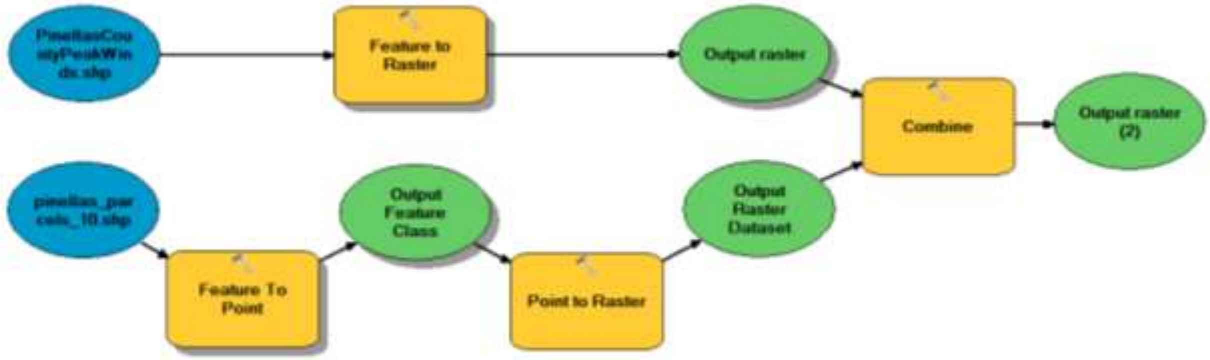

Figure 4-6. General Model for Wind Grid Model (Model 1) (Harrilal, ArcGIS Model, 2012)

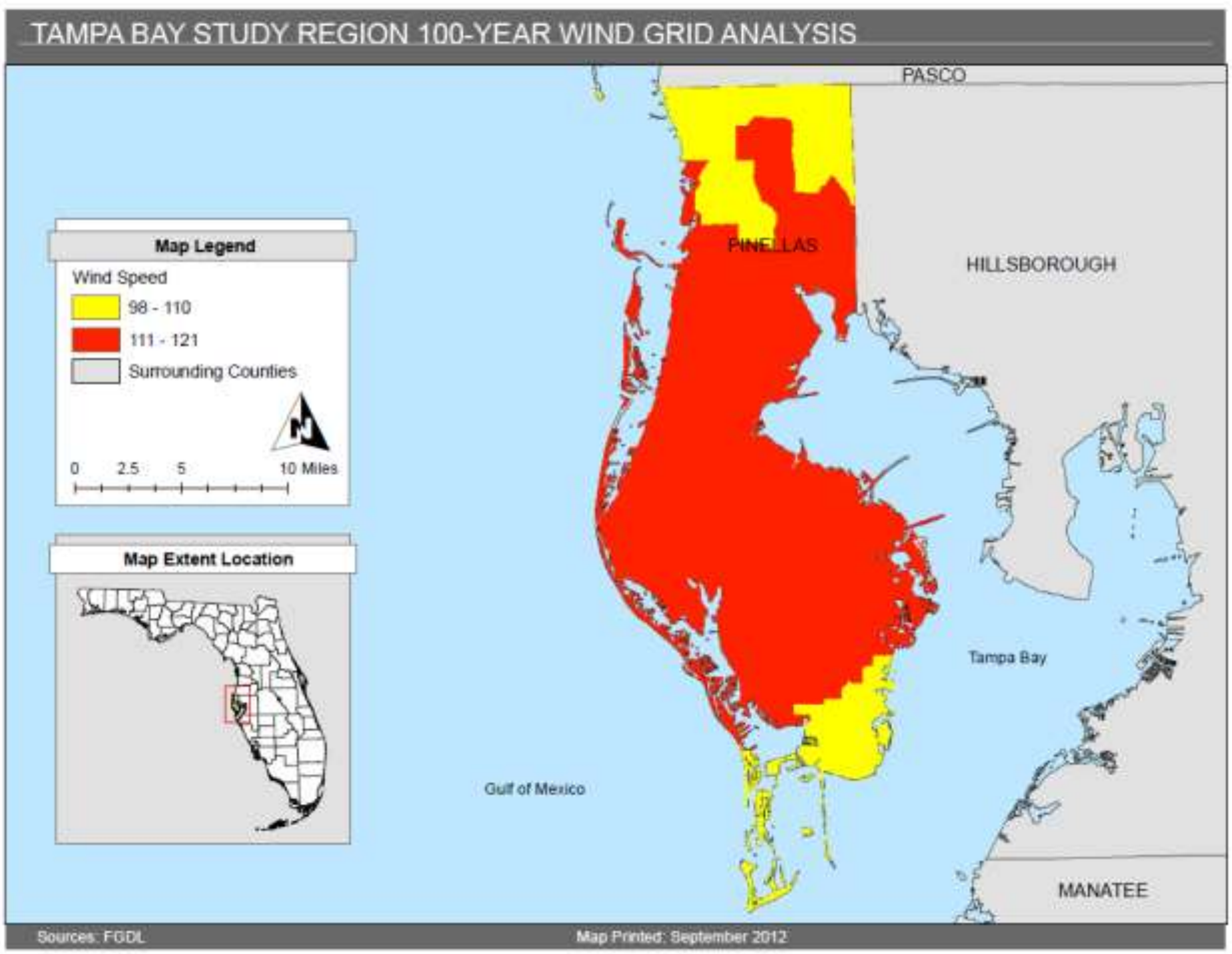

Figure 4-7. 100-Year Wind Grid Pinellas County (Harrilal, 100-Year Wind Grid Pinellas County, 2012)

Building Damage by General Occupancy: 100 - year Event

September 24, 2012

	Square Footage (Thousand. sq.ft)	Damage State Probability (%)				
		None	Minor	Moderate	Severe	Destruction
Florida						
Pinellas						
Agriculture	2,732.44	46.74	28.72	14.77	8.24	1.53
Commercial	120,264.43	48.24	24.35	21.23	6.06	0.11
Education	4,312.26	51.58	24.53	18.05	5.84	0.00
Government	5,310.56	51.03	24.00	18.96	6.01	0.00
Industrial	47,184.00	49.62	23.64	18.99	7.43	0.33
Religion	9,934.36	50.90	28.54	15.90	4.66	0.00
Residential	646,605.44	54.50	30.78	12.63	1.48	0.61
Total	836,343.50	54.01	30.25	13.28	1.90	0.57
Total	1,920,881.34	66.17	22.69	9.43	1.33	0.38
Study Region Average	1,920,881.34	66.17	22.69	9.43	1.33	0.38

Study Region : Tampa Region Wind
Scenario : Probabilistic

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Figure 4-8. Building Damage by General Occupancy (Harrilal, Building Damage by General Occupancy, 2012)

Building Damage by Count by General Occupancy 100 - year Event

September 24, 2012

	# of Buildings					
	None	Minor	Moderate	Severe	Destruction	Total
Florida						
Hillsborough						
Agriculture	1,088	300	138	74	13	1,613
Commercial	15,367	5,082	4,238	1,157	19	25,862
Education	481	162	114	35	0	792
Government	321	117	87	27	0	551
Industrial	4,346	1,259	889	311	13	6,819
Religion	1,343	475	244	65	0	2,128
Residential	252,632	82,197	28,631	3,093	1,143	367,696
Total	**275,579**	**89,592**	**34,341**	**4,761**	**1,188**	**405,461**
Manatee						
Agriculture	540	2	0	0	0	542
Commercial	6,472	36	1	0	0	6,510
Education	140	1	0	0	0	141
Government	129	1	0	0	0	130
Industrial	2,127	10	0	0	0	2,137
Religion	630	2	0	0	0	632
Residential	121,983	259	15	0	0	122,257
Total	**132,021**	**311**	**17**	**0**	**0**	**132,349**
Pinellas						
Agriculture	669	411	212	118	22	1,432
Commercial	12,075	6,095	5,314	1,518	28	25,031
Education	280	133	98	32	0	543
Government	289	136	107	34	0	566
Industrial	3,453	1,645	1,322	517	23	6,959
Religion	920	516	287	84	0	1,807
Residential	211,902	119,648	49,094	5,764	2,367	388,775
Total	**229,588**	**128,585**	**56,434**	**8,066**	**2,440**	**425,113**
Total	**637,187**	**218,487**	**90,793**	**12,828**	**3,628**	**962,923**

Study Region : Tampa Region Wind
Scenario : Probabilistic

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Figure 4-9. Building Damage by Count by General Occupancy (Harrilal, Building Damage by Count by General Occupancy, 2012)

Building Damage by Building Type: 100 - year Event

September 24, 2012

	Average Damage State (%)				
	None	Minor	Moderate	Severe	Destruction
Florida					
Hillsborough					
Concrete	63.07	17.48	15.88	3.57	0.00
Masonry	66.13	22.24	10.11	1.26	0.26
Manufactured Homes	97.53	1.17	0.88	0.07	0.34
Steel	63.71	15.34	15.95	4.90	0.10
Wood	66.66	25.88	6.43	0.74	0.28
Total	69.45	17.54	10.60	2.22	0.20
Manatee					
Concrete	99.39	0.60	0.00	0.00	0.00
Masonry	99.70	0.29	0.01	0.00	0.00
Manufactured Homes	100.00	0.00	0.00	0.00	0.00
Steel	99.39	0.60	0.02	0.00	0.00
Wood	99.84	0.14	0.01	0.00	0.00
Total	99.64	0.35	0.01	0.00	0.00
Pinellas					
Concrete	45.89	23.04	25.00	6.07	0.00
Masonry	50.78	30.64	16.14	1.95	0.49
Manufactured Homes	96.57	1.53	1.26	0.11	0.53
Steel	47.20	20.47	24.50	7.66	0.17
Wood	52.52	35.44	10.21	1.34	0.49
Total	55.67	23.81	16.61	3.57	0.34
Total	67.41	18.06	11.79	2.51	0.23
Study Region Average	67.41	18.06	11.79	2.51	0.23

Study Region : Tampa Region Wind
Scenario : Probabilistic

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Figure 4-10. Building Damage by Building Type (Harrilal, Building Damage by Building Type, 2012)

Direct Economic Losses For Buildings: 100 - year Event

September 24, 2012 *All values are in thousands of dollars*

	Capital Stock Losses				Income Losses				
	Cost Building Damage	Cost Contents Damage	Inventory Loss	Loss Ratio %	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss
Florida									
Hillsborough	2,573,286	840,773	15,164	3.26	368,871	46,794	62,648	180,120	4,087,655
Manatee	9,535	889	0	0.05	255	0	0	221	10,900
Pinellas	3,399,193	1,084,437	23,798	4.82	504,163	56,613	75,040	254,990	5,398,233
Total	5,982,014	1,926,099	38,962	3.52	873,288	103,407	137,688	435,331	9,496,788
Study Region Total	5,982,014	1,926,099	38,962	3.52	873,288	103,407	137,688	435,331	9,496,788

Study Region : Tampa Region Wind
Scenario : Probabilistic
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Figure 4-11. Direct Economic Losses for Buildings (Harrilal, Direct Economic Losses for Buildings, 2012)

REVISED SCALE	
Feet	**Scale**
0' - 1'	1
1' - 4'	2
4' - 6'	3
6' - 8'	4
8' - Max	5

Figure 4-12. Storm Surge Modified Scale (Adapted from (Watson, 2012))

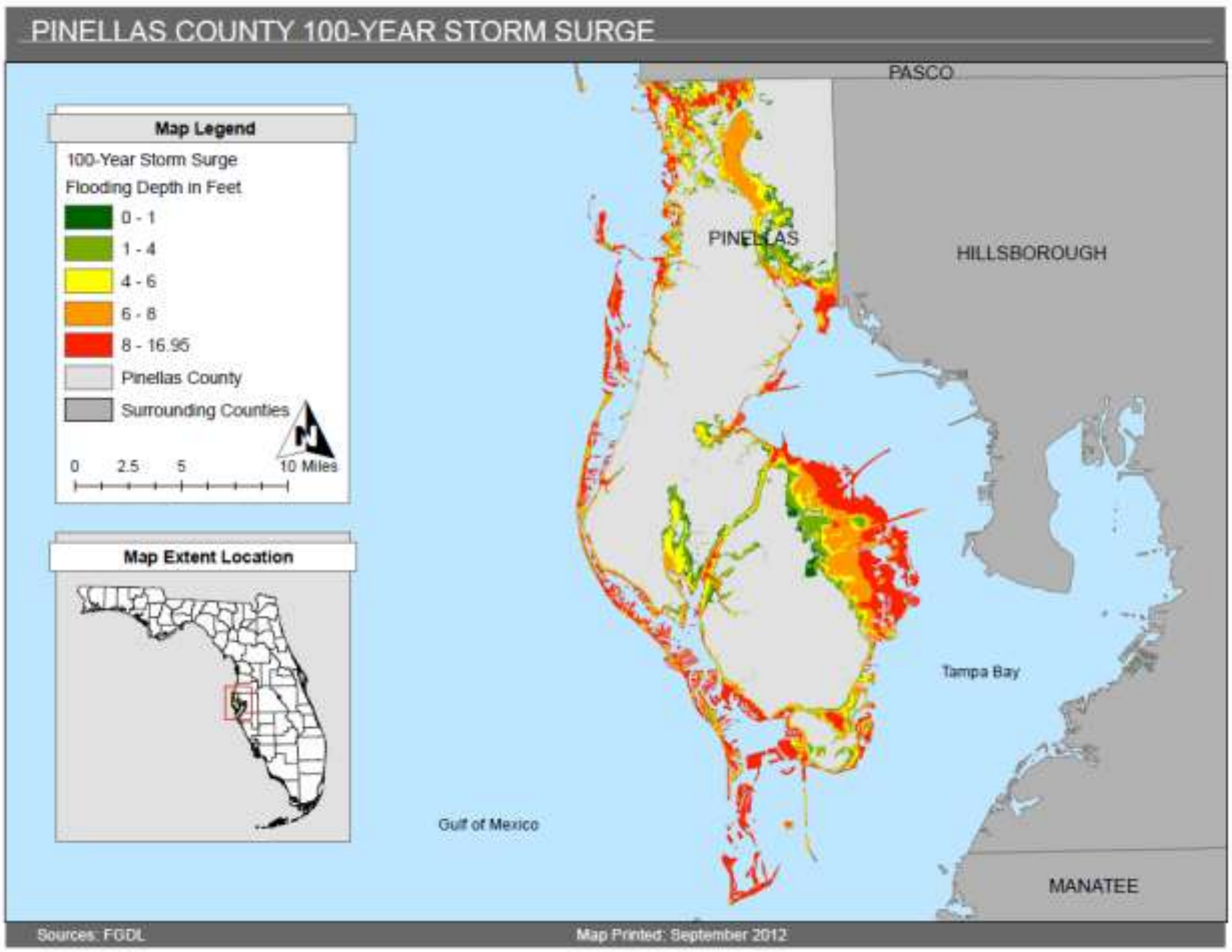

Figure 4-13. 100-Year Storm Surge Pinellas County (Harrilal, 100-Year Storm Surge Pinellas County, 2012)

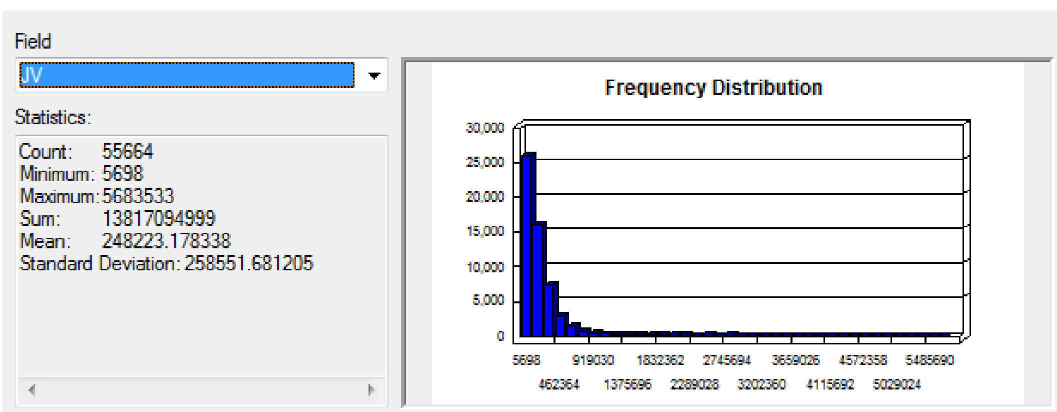

Figure 4-14. 100-Year Flooding JV Statistical Statistics (Harrilal, 100-Year Flooding JV Statistics, 2012)

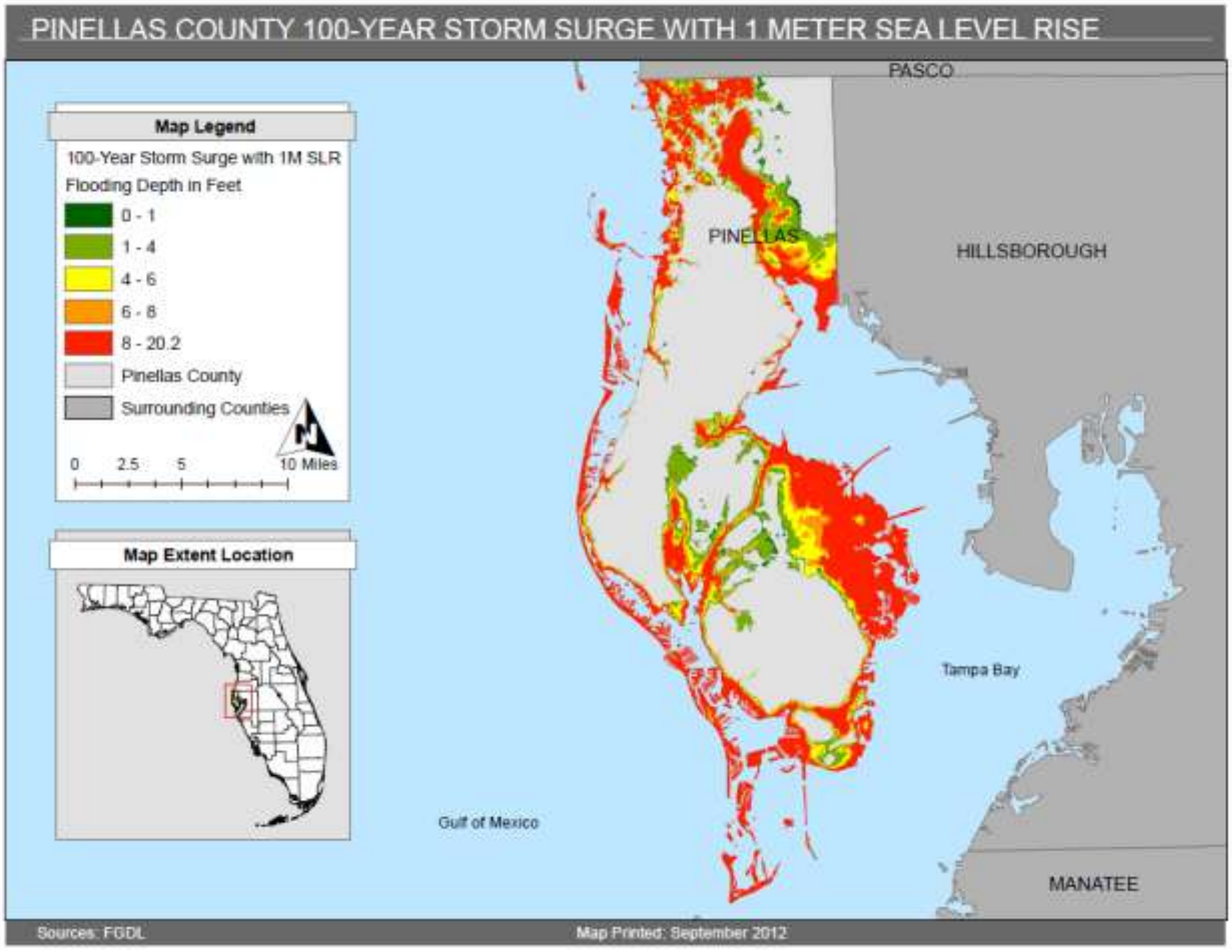

Figure 4-15. 100-Year Storm Surge with 1 Meter SLR – Pinellas County (Harrilal, 100-Year Storm Surge with 1-Meter SLR - Pinellas County, 2012)

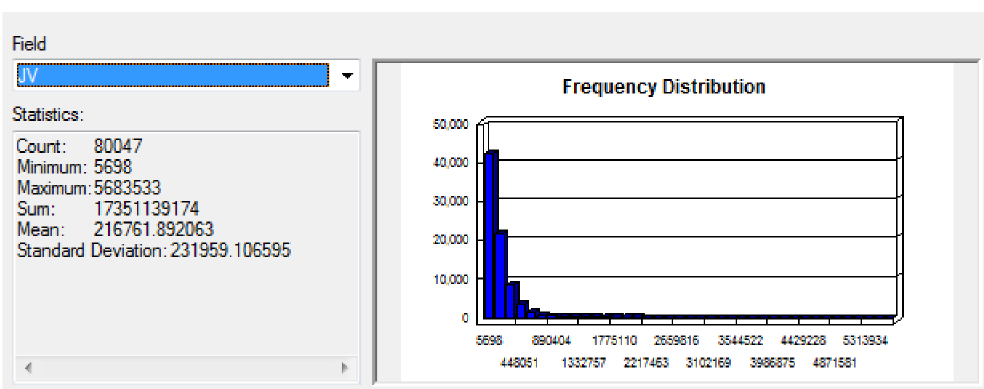

Figure 4-16. 100-Year Flooding with 1 Meter of SLR JV Statistics (Harrilal, 100-Year Flooding with 1-Meter of SLR JV Statistics, 2012)

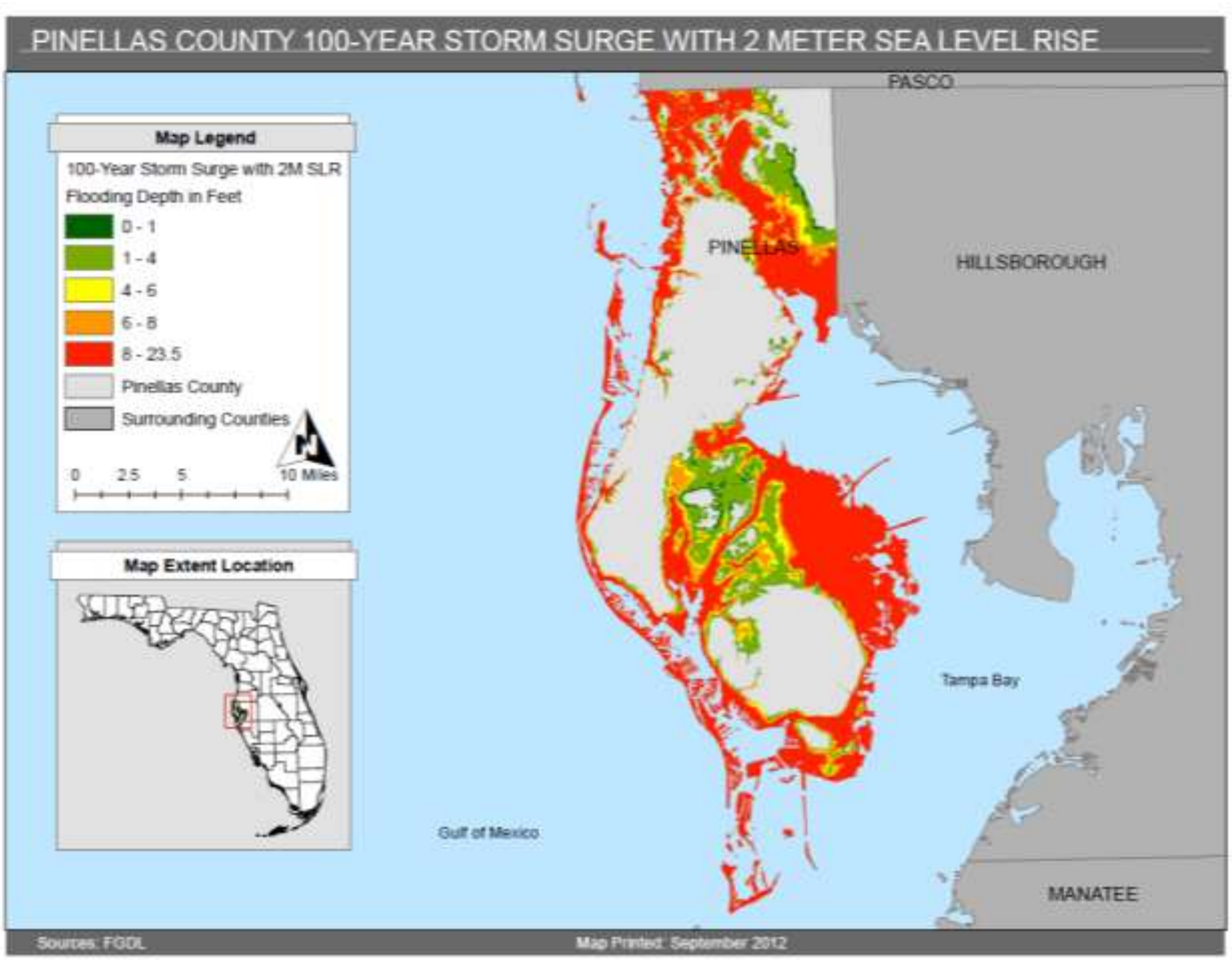

Figure 4-17. 100-Year Storm Surge with 2 Meter SLR – Pinellas County (Harrilal, 100-Year Storm Surge with 2-Meter SLR - Pinellas County, 2012)

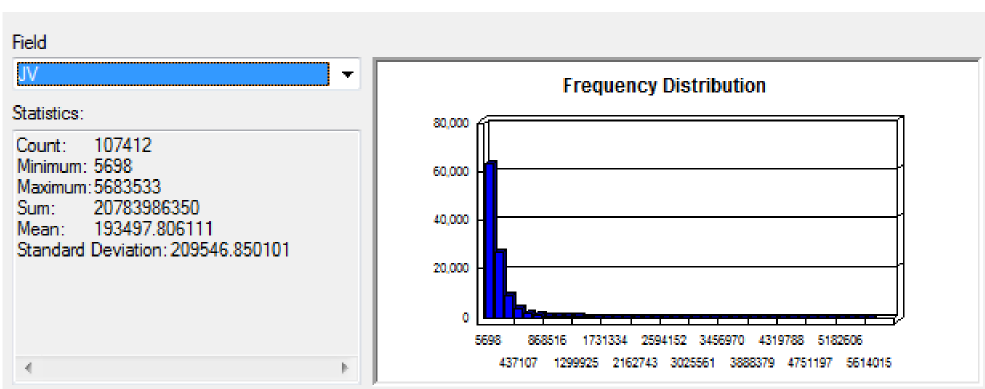

Figure 4-18. 100-Year Flooding with 2 Meters of SLR JV Statistics (Harrilal, 100-Year Flooding with 2-Meters of SLR JV Statistics, 2012)

CHAPTER 5
CONCLUSIONS

Understanding the Analysis

Preparing for a natural disaster is no easy task at any level of government. No matter how much analysis is conducted or emergency management policies are written, the efforts cannot stop a storm from forming and making landfall. However, preparing for life after the storm is one of the best steps we can take to help prevent the loss of lives and to start back on the road to recovery after a natural disaster. From the data that was analyzed, it shows that if there were to be a 1-meter or 2-meter sea level rise with a 100-year storm, Pinellas County and the Tampa Bay region would be in serious trouble. This storm would wreak havoc for Pinellas County in all three phases: pre-storm, during the storm, and post-storm.

Regional Analysis Conclusions

After looking at the Tampa Bay region, few key conclusions were observed. First, it was apparent that the Tampa Bay shorelines are more susceptible to intense flooding compared to the coastline facing the Gulf of Mexico. Similarly, Pinellas and Manatee County are more affected than Hillsborough in the Tampa Bay region. However, in the 2-meter simulation, Hillsborough becomes increasingly affected, with nearly the entire peninsula flooded. It was also determined that the areas that were not directly submerged would not be excused; they would be beaten and battered by sustained hurricane force winds. The winds would range from 98-121 mph, with the strongest winds affecting the center of Pinellas County.

Additionally, it was clear that Pinellas County would require evacuation. Anyone evacuating would need to leave Pinellas County and should not expect to find safety in northern Hillsborough County, where wind levels will be strongest (Figure 3-1). The evacuees should be instructed to head south into Manatee County and further inland to ensure safety.

Pinellas County Analysis Conclusions

From the analysis conducted on Pinellas County, there were a few major conclusions. From the maps produced, it was evident that the shifting sea level would produce increasingly higher levels of storm surge. As expected, when there is an addition of 1-meter (3.28 feet) or 2-meters (6.56 feet) of SLR on top of a normal storm surge, the water depth will rise accordingly. The base level of a normal storm surge was approximately 17 feet, and rose to 20 feet with 1-meter of SLR, and 23.5 feet with a 2-meter SLR. The water depth will react differently based on the terrain, which is demonstrated in the maps. Figures 4-13, 4-15, and 4-17 demonstrate how much more damage is possible due to flooding from the increase in water of approximately 6 feet. Figure 5-1 further outlines how parcels were affected by the storm surge.

The Total Affected Parcels compares the affected parcels from the different storm surge models. From model to model, the number of total parcels and single-family parcels affected increases dramatically, and the incremental increase is relatively consistent. Total parcels increased an average of 46,130 parcels (average 32% increase) from each model and single-family parcels increased an average of 25,874 parcels (average 38.5% increase) for each model. As the parcels increased, the total projected cost paralleled with a similar consistent increases.

Figure 5-2 shows the projected losses for tax revenue that would be incurred by the county if the storm surge at a 100-year level damaged all of the homes. It is understood that all homes within the surge area may not be extremely damaged, however, if SLR were to occur, those current surge areas would be increasingly damaged. Figure 5-2 lists the number of homes affected and their value. The millage rate is the number used by the tax collector's office to determine the amount of taxes a property owner is charged (Mohr, 2012). Although each city has their own calculated millage rate, an average of 20 (0.02%) is used for this analysis (Nelson, 2011). The calculations determined that the average household would pay approximately $4,000 in taxes to the county and Pinellas County would stand to lose over $220 million annually. The ad valorem tax (real estate property taxes) collected for the fiscal year 2011 was $297 million collected; a loss of $220 million would leave Pinellas County with a new ad valorem of $77 million, even without consideration of the additional loss of property value throughout the county (Pinellas County, 2012).

Analysis Conclusions

From the analysis conducted, it is clear that a 100-year storm would create a severe challenge for Pinellas County. The billions of dollars in infrastructure that would be damaged, not including homes and businesses, would more than likely leave this county's coast and shorelines damaged. From the data analysis, it is clear if a 100-year storm should threaten Pinellas County, and especially if there is a sea level rise of 2 meters, Pinellas County's main focus should be on the evacuation of its citizens. The probability of someone on a coastline or in Pinellas County surviving a 100-year storm is not favorable, with both the threat of severe flooding and high-sustained winds. Evacuation routes and detailed emergency plans should be prepared before any disaster – it is the local government's duty to act in the best interest of its citizens. The analysis presented information that demonstrates that there are a number of parcels that will need an immediate response to be evacuated because they have multiple impacts from the hurricane.

Model	Total Parcels		Single-Family Parcels		Total Single-Family Projected Cost	
100-Year Storm Surge	123,142		55,664		$ 13,817,094,999.00	
1 Meter SLR	166,585		80,047		$ 17,351,139,174.00	
	Increase of	43,443	Increase of	24,383	Increase of	$ 3,534,044,175.00
2 Meter SLR	215,402		107,412		$ 20,783,986,350.00	
	Increase of	48,817	Increase of	27,365	Increase of	$ 3,432,847,176.00

Figure 5-1. Total Affected Parcels by Model Comparison (Harrilal, Total Affected Parcels by Model Comparison , 2012)

Projected Loss of Tax Revenue in Pinellas County		
Affected Homes for Pinellas County		55,664
Average Value of Home	$	248,233
Homestead Exemption	$	50,000
Pinellas County Average Millage Rate		20.000
Average Home Value After Homestead Exemption	$	198,233
Average Cost of Property Tax	$	3,964.66
Project Total Cost of Tax Revenue Lost/Year	**$**	**220,688,834.24**
Millage is Calculated as (Millage Rate / 1000)		
Property Tax is Calculated by (Home Value * Millage Rate)		

Figure 5-2. Projected Loss of Tax Revenue in Pinellas County (Harrilal, Projected Loss of Tax Revenue in Pinellas County, 2012)

CHAPTER 6
RECOMMENDATIONS

Preparing for Disaster

Realizing the extreme importance to evacuate Pinellas County citizens, the recommendations after this research focus on these measures. Because of the strength and potential for damage, evacuation is the best option for preserving life in Pinellas County. First, there will be an examination of the need for an evacuation due to wind and flooding. Next, it will be considered which citizens should evacuate prior to a storm of this magnitude. Then, the idea of preparing for sea level rise will be addressed. Finally, what actions are currently being taken and should be taken in the future regarding planning and land use.

Evacuation for Flooding and Wind

When trying to understand the implications of the probabilistic storm, a map can be the most useful tool. Figure 4-13 (from Chapter 4) provides a graphic understanding of how much storm surge flooding will have occurred. Any section of land within the county in light grey will not have been affected by storm surge, but this does not mean it has not been affected by rainwater flooding. Nevertheless, it would be safe to assume that there would be at least a base level of flooding occurring from rainwater everywhere in the peninsula that is already prone to flooding. Specifically addressing the areas of heavier coastal flooding, those areas will need to be evacuated based on the premise that the flooding will exceed tolerable levels (6 feet and above), and citizens left in those critical areas could be underwater or forced out of their home in search of higher ground. The search for higher ground during the storm would then expose them to the hazards of the storm, especially the wind and any debris flying around.

Examining Figure 4-7, the wind grid map, is helpful in understanding the levels of wind. This map depicts the levels of wind speed that the peninsula will experience with this simulated storm. The wind speed throughout the peninsula will experience wind speeds between 98 mph and 121 mph, a range of 23 mph. It would be safe to assume that all of Pinellas County will suffer at least maximum sustained wind gusts of 98 mph. This level of wind can take loose debris or elements from the natural environment and make them destructive projectiles. Additionally, the pressure and strain the storm winds will place on buildings and infrastructures can cause long lasting damage. Anyone that is caught outside in these high winds would be placing their life in jeopardy.

Based on the assumptions made regarding flooding and wind, an evacuation of the whole peninsula would be needed. First and foremost, evacuation is needed due to the direct hazards of the storm: wind, rain, and flooding. Next, it would be unsafe for anyone during the storm to be isolated in the potentially flooded areas. Finally, after the storm, it would be extremely difficult to provide people that do survive with aid and supplies needed for survival.

When Should Citizens Evacuate

When determining when to evacuate citizens, understanding the storm forecast is a critical component. Officials need to have an understanding of how the forecast models are projected to plan effectively. Evacuation routes and staging would depend upon roadway capacity and the amount of people that would be using them. This ratio would be calculated be local planning and transportation officials. Based on this ratio, the areas that would be impacted first would have first priority of evacuation. Considering most of the population will leave the county via vehicles, accommodations will need to be made for those who are unable to drive. Additionally, the cities where all of these people will exodus to will need to be considered; they will be entering the surrounding counties and heading further inland. Understanding the surrounding counties' ability to sustain these citizens for the present and immediate future will depend on their planning efforts.

Planning for Sea Level Rise

Planning for sea level rise is not an easy topic to discuss. Many citizens do not want to think about the concept of the mean sea level rising, let alone the impact that it may have on their daily lives. Business and coastal property owners do not want to consider what will happen if the beach erodes itself up to their constructed sea wall and the impact it will have on businesses and tourism. However, these are the critical realities planners must try to understand, and develop plans and strategies to handle this phenomenon. Dealing with such a complex issue has no easy fix; it will take the work of many, not just in one week or year, but also over the course of decades. To develop a way to mitigate the problems associated with sea level rise, it will take the efforts for our generation and the ones to come to develop the plan to help sustain our way of life.

Mitigation policies needs to take place in all aspects of time; the past, present, and future. Dealing with the past, it is necessary to examine how to grandfather current property owners into new policies and shifting their liability from other entities to themselves. In the present, understanding how to slow coastal development in an efficient way to mitigate losses that could be occurred by property developers is paramount. Finally, for the future, policies to reduce or restrict future projects or property development on coastlines that are at risk to potential property loss due to SLR need to be developed and put into place.

Developing an early mitigation system is important to lessen the loss of property and life. Another important subject is to keep the potential threat of SLR in the public eye, spreading information for residents to understand the issues. By distributing information on SLR, people will become more aware to protect their own property and life, so less damage or loss will occur. Education is always a key component in dealing with any issue, so steps need to be taken to ensure that the people that will be affected by SLR should understand the problem and the options that will be available to them. In the end, the choice to act will be left in the citizens' hands, however, planners are tasked with providing the essential data and the viable possible policies to prevent potential losses of life and property.

Current Planning Efforts

Political Implications

Sea level rise isn't just a problem for coastal residents; it is a nightmare for policymakers. Creating policies regarding land use that could jeopardize property owners land value is an extremely risky business. There are many risk mitigation options in which policies would attempt to shift losses or damages to the property owner in an effort to mitigate the losses incurred by the state and insurance companies. When dealing with citizens' property, there is likely to be a strong resistance towards any policy no matter how much research backs the decision.

Decisions also need to be made regarding sensitive or critical coastal areas, forcing policymakers to determine which areas need to be fortified and protected from SLR. Additionally, policymakers do not have to deal with only the physical issues of land loss, but also the issues of handling the sources of SLR. Policymakers must look at the causes of global warming and understand how to prevent future damage to help slow the losses that could be incurred due to loss of land. The actions of planners the community overall require vigilance to prevent more damage.

The anecdote about a frog being boiled alive is a good metaphor for how we can get complacent and end up in trouble before we even realize it. In the anecdote, a frog is placed in cold water and the temperature is raised slowly. The frog's body adjusts to the slowly rising temperature and perceives that there is no danger. The water temperature continues to increase and by the time the frog realizes the danger, it is too late to react. This scenario mirrors the struggle for citizens to understand the threat posed by SLR. As the sea level increases over time, current and future generations need to act now to mitigate the danger.

Possible Future Policies

There are different types of strategies for mitigating SLR; a combination of design regulations good policy would help absorb potential future losses. Design regulation can help to develop ways to stop floodwaters from encroaching on the coastline through various tactics. Placing levy systems or building higher human-built barriers are options, but are very costly. Another option is to build sponge-like retention areas to help reduce flooding, which would reduce construction requirements. A final option is retrofitting coastal properties or requiring new coastal properties to adhere to new construction regulations that are more equipped to handle SLR. These construction regulations could require an owner build their property on stilts or increase their grade up to an appropriate level based on the location.

In addition to design requirements, policies can be implemented to help fund some of these efforts. For example, a type of impact fee could be charged for building within a certain buffer zone of the coastline. This impact fee should be based on the level of risk based on location. As citizens pay into the fund, the local government should use the funding to help start building preventative measures that would benefit communities as a whole.

Finally, the one option that is most controversial is retreating from the shoreline entirely. This option would be the most difficult to pursue due the amount of infrastructure and loss of potential revenue citizens would face. A full retreat from the current coastline would undoubtedly have the largest impact on the country. However, the increased threat of natural disasters with SLR could lead to this result out of pure necessity.

Additional Research

After examining the data and drawing conclusions, there is one last issue to be addressed – there is more research needed on the topic of SLR. From the research presented in this thesis, it is evident that further analysis needs to be conducted on the effects of SLR and how a possible SLR event count affect any coastal area. Based on the limitations encountered in this thesis, such as limited data size (scale and scope) and imperfect models (Hazus-MH parameters), others could build upon this research and provide better analysis. This data analysis was conducted on 30-meter cell size and could be improved upon by using 10- or 5-meter cell sizes, or even LiDar data. Using a higher level of resolution for the data would yield better results regarding flooding depth and removing more data errors. Additionally, due to time restrictions, others with more knowledge using Hazus-MH may be able to create a more effective model using different parameters. Beyond the SLR topics explored in this thesis, sea level rise needs to be examined by other disciplines to further understand its far-reaching effects.

APPENDIX A
ADDITIONAL HAZUS-MH SUMMARY REPORTS

This appendix will contain a summary report generated by Hazus-MH when conducting the flooding analysis for the Tampa Bay region. The summary report is 11-pages long and will be listed in its entirety.

Hazus-MH: Hurricane Event Report

Region Name: Tampa Region Wind

Hurricane Scenario: Probabilistic 100-year Return Period

Print Date: Monday, September 24, 2012

Disclaimer:
Totals only reflect data for those census tracts/blocks included in the user's study region.

The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific Hurricane. These results can be improved by using enhanced inventory data.

Table of Contents

General Description of the Region

Hazus is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of Hazus is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

The hurricane loss estimates provided in this report are based on a region that includes 3 county(ies) from the following state(s):

- Florida

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 2,129.60 square miles and contains 517 census tracts. There are over 918 thousand households in the region and has a total population of 2,184,432 people (2000 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 962 thousand buildings in the region with a total building replacement value (excluding contents) of 170,120 million dollars (2006 dollars). Approximately 91% of the buildings (and 74% of the building value) are associated with residential housing.

Building Inventory

General Building Stock

Hazus estimates that there are 962,923 buildings in the region which have an aggregate total replacement value of 170,120 million (2006 dollars). Table 1 presents the relative distribution of the value with respect to the general occupancies. Appendix B provides a general distribution of the building value by State and County.

Table 1: Building Exposure by Occupancy Type

Occupancy	Exposure ($1000)	Percent of Tot
Residential	125,125,310	73.6%
Commercial	31,494,437	18.5%
Industrial	6,879,014	4.0%
Agricultural	591,744	0.3%
Religious	2,909,642	1.7%
Government	1,078,265	0.6%
Education	2,041,166	1.2%
Total	**170,119,578**	**100.0%**

Essential Facility Inventory

For essential facilities, there are 37 hospitals in the region with a total bed capacity of 9,570 beds. There are 763 schools, 64 fire stations, 48 police stations and 2 emergency operation facilities.

Hurricane Scenario

Hazus used the following set of information to define the hurricane parameters for the hurricane loss estimate provided in this report.

Scenario Name:	Probabilistic
Type:	Probabilistic

Building Damage

General Building Stock Damage

Hazus estimates that about 107,248 buildings will be at least moderately damaged. This is over 11% of the total number of buildings in the region. There are an estimated 3,628 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 6 of the Hazus Hurricane technical manual. Table 2 below summarizes the expected damage by general occupancy for the buildings in the region. Table 3 summarizes the expected damage by general building type.

Table 2: Expected Building Damage by Occupancy : 100 - year Event

	None		Minor		Moderate		Severe		Destruction	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	2,298	64.05	713	19.89	349	9.73	192	5.35	35	0.97
Commercial	33,914	59.08	11,214	19.54	9,554	16.64	2,674	4.66	47	0.08
Education	902	61.08	296	20.05	212	14.37	66	4.50	0	0.00
Government	739	59.28	253	20.29	194	15.55	61	4.88	0	0.00
Industrial	9,926	62.37	2,915	18.31	2,211	13.89	828	5.20	36	0.22
Religion	2,893	63.34	993	21.74	532	11.64	150	3.28	0	0.00
Residential	586,516	66.75	202,104	23.00	77,741	8.85	8,857	1.01	3,510	0.40
Total	**637,187**		**218,487**		**90,793**		**12,828**		**3,628**	

Table 3: Expected Building Damage by Building Type : 100 - year Event

Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	26,510	59.68	7,989	17.99	7,948	17.89	1,970	4.43	0	0.00
Masonry	324,811	64.18	120,839	23.88	51,913	10.26	6,722	1.33	1,777	0.35
MH	115,995	97.12	1,605	1.34	1,249	1.05	101	0.08	487	0.41
Steel	24,107	59.10	6,638	16.27	7,577	18.58	2,419	5.93	50	0.12
Wood	159,883	63.44	69,684	27.65	19,090	7.57	2,430	0.96	946	0.38

Essential Facility Damage

Before the hurricane, the region had 9,570 hospital beds available for use. On the day of the hurricane, the model estimates that 1237 hospital beds (only 13.00%) are available for use. After one week, 17.00% of the beds will be in service. By 30 days, 60.00% will be operational.

Table 4: Expected Damage to Essential Facilities

		# Facilities		
Classification	**Total**	**Probability of at Least Moderate Damage > 50%**	**Probability of Complete Damage > 50%**	**Expected Loss of Use < 1 day**
EOCs	2	0	0	2
Fire Stations	64	0	0	64
Hospitals	37	35	10	5
Police Stations	48	2	0	48
Schools	763	152	0	180

Induced Hurricane Damage

Debris Generation

Hazus estimates the amount of debris that will be generated by the hurricane. The model breaks the debris into four general categories: a) Brick/Wood, b) Reinforced Concrete/Steel, c) Eligible Tree Debris, and d) Other Tree Debris. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 2,298,904 tons of debris will be generated. Of the total amount, 517,015 tons (22%) is Other Tree Debris. Of the remaining 1,781,889 tons, Brick/Wood comprises 68% of the total, Reinforced Concrete/Steel comprises of 2% of the total, with the remainder being Eligible Tree Debris. If the building debris tonnage is converted to an estimated number of truckloads, it will require 49571 truckloads (@25 tons/truck) to remove the building debris generated by the hurricane. The number of Eligible Tree Debris truckloads will depend on how the 542,622 tons of Eligible Tree Debris are collected and processed. The volume of tree debris generally ranges from about 4 cubic yards per ton for chipped or compacted tree debris to about 10 cubic yards per ton for bulkier, uncompacted debris.

Social Impact

Shelter Requirement

Hazus estimates the number of households that are expected to be displaced from their homes due to the hurricane and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 20,391 households to be displaced due to the hurricane. Of these, 5,426 people (out of a total population of 2,184,432) will seek temporary shelter in public shelters.

Economic Loss

The total economic loss estimated for the hurricane is 9496.8 million dollars, which represents 5.58 % of the total replacement value of the region's buildings.

Building-Related Losses

The building related losses are broken into two categories: direct property damage losses and business interruption losses. The direct property damage losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the hurricane. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the hurricane.

The total property damage losses were 9,497 million dollars. 3% of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 73% of the total loss. Table 4 below provides a summary of the losses associated with the building damage.

Table 5: Building-Related Economic Loss Estimates

(Thousands of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Property Damage						
	Building	4,753,201.51	896,313.94	188,913.71	143,584.89	5,982,014.05
	Content	1,270,856.27	449,958.38	130,482.99	74,800.75	1,926,098.39
	Inventory	0.00	12,140.13	25,750.33	1,071.69	38,962.16
	Subtotal	**6,024,057.78**	**1,358,412.45**	**345,147.03**	**219,457.33**	**7,947,074.60**
Business Interruption Loss						
	Income	5,980.40	87,562.28	2,777.00	7,087.12	103,406.79
	Relocation	585,770.94	225,153.11	21,857.17	40,506.72	873,287.94
	Rental	307,132.09	120,553.00	2,837.46	4,808.10	435,330.66
	Wage	14,095.92	83,090.49	4,579.53	35,921.58	137,687.51
	Subtotal	**912,979.35**	**516,358.88**	**32,051.15**	**88,323.52**	**1,549,712.90**
Total						
	Total	**6,937,037.13**	**1,874,771.33**	**377,198.18**	**307,780.85**	**9,496,787.50**

Appendix A: County Listing for the Region

Florida
- Hillsborough
- Manatee
- Pinellas

Appendix B: Regional Population and Building Value Data

	Population	Building Value (thousands of dollars) Residential	Non-Residential	Total
Florida				
Hillsborough	998,948	55,881,645	23,067,840	78,949,485
Manatee	264,002	16,075,167	4,605,537	20,680,704
Pinellas	921,482	53,168,498	17,320,891	70,489,389
Total	**2,184,432**	**125,125,310**	**44,994,268**	**170,119,578**
Study Region Total	**2,184,432**	**125,125,310**	**44,994,268**	**170,119,578**

APPENDIX B
DETAILED METHODOLOGY

Wind Modeling

Creating a Hazus File

1. Open Hazus
2. Click → Create a new region
3. Name study region → Choose a name to describe the file (*i.e. WilmaWindSimulation*) – also the option to add an additional description is available
4. Choose hazard type → Select hurricane
5. Click Yes in the pop-up window that will appearing asking about creating a study region with the Hurricane Scenario Wizard
6. Choose aggregation level → Choose county
7. Choose the scenario operation → Choose create new scenario
8. Choose the storm definition type → Choose define storm track manually
9. Name the new scenario → Choose a name to describe the file (*i.e. WilmaAdjustTrack*)
10. Let the storm track definition method default to the standard options (*times, radius to maximum winds, and maximum wind speeds are the default hurricane parameters*)
11. Fill in the chart with the predetermined characteristics of the storm (*categories ranging from translation speed to central pressure*)
12. After filling in the tables, Hazus-HM will verify the points and then run the windfield calculation

13. After the calculation is complete, you will then choose the study area
14. Choose aggregation level → Choose county
15. Choose state selection → Choose state or select from map (*i.e. Florida*)
16. Choose county selection → Choose county or counties (*i.e. Levy*)
17. Click ok in the pop-up stating that the aggregation was successful
18. Next, you will need to open up a new region
19. Select region → Choose created file (*i.e. AdjustedStormTrack*)
20. After clicking Finished, the created file will open in ArcGIS

Creating a New Scenario Model (i.e. Wind/Hurricane)

1. Go to hazards → Scenario
2. Choose the hurricane scenario that was created (*i.e. AdjustedStormTrack*) → Make sure Activate is the selected option from the choices listed to the left of the files
3. Select Yes stating that you want to activate the scenario
4. Click Next to continue through the next three windows as Hazus allows you to review the storm track data
5. Click Finish and it will generate the wind loads for a 100-year storm
6. Hazus running in ArcGIS will make the wind grid
7. Click Results → Storm track → File name (*i.e. WilmaAdjustStormTrack*)
8. At that point the storm track will be on the map and a completed wind simulation model will have been created. (Figure 3-1)

After completing the Hazus wind grid, functionality in ArcGIS allows you make the wind levels useful information. By converting the wind grid into a raster file you can apply the data to individual parcels for the county or area and it will allow you to gauge how the area is actually being affected at the parcel level.

Coastal Flood Modeling

Creating a Hazus File

1. Open Hazus
2. Click → Create a new region
3. Name study region → Choose a name to describe the file (*i.e. TampaBaySimulation*) – also the option to add an additional description is available
4. Choose the hazard type → Select flood
5. Choose aggregation level → Choose county
6. Choose state selection → Choose state or select from map (*i.e. Florida*)
7. Choose county selection →Choose county or counties (*i.e. Pinellas, Manatee, Hillsborough*)
8. Click → Finish to complete the region creation wizard
9. Hazus-MH will begin processing the study region and, once finished, the original Hazus-MH prompt will appear
10. Click → Open a Region
11. Choose selected region → Choose the created file (*i.e. TampaBaySimulation*)
12. Click finish on the final screen and it will open up the file in ArcGIS

Adding a Digital Elevation Model (DEM)

1. Open the working file through Hazus, which will pull up ArcGIS (*i.e. TampaBaySimulation*)

2. Choose the type of flood hazard type → Hazard → Flood hazard type
3. Choose riverine, coastal, or both riverine and coastal (*i.e. Coastal*)
4. Go to access the DEM

   → Hazard → User Data

   → Click "determine required DEM extent"

   → Click the box that says, "navigate directly to the DEM download" in the center of the DEM extent window

   a. Before clicking the center box on the DEM extent window, make sure you are connected to the Internet
   b. It will default to a 30M grid, however, you can change the setting at the website to 10M grid or 3M (30M is also equivalent to ¼ Acre – *30M=1 Arc Second, 10M=1/3 Arc Second, 3M=1/9 Arc Second*)
5. Follow the directions from the pop up Internet browser window to download the file
6. After downloading the file, unzip and place into an appropriate folder for access
7. Go back to ArcGIS, and close the DEM extent window
8. Click browse on the user data window and find the DEM file location
9. The DEM layer should be listed in the table of contents tab

Creating a New Scenario Model (i.e. Flood)

1. Go to Hazards → Scenario → New
2. Name the file and add an optional description (*i.e. TampaBay_Flood*)
3. Choose the map layer type (*i.e. coastal shorelines*) in the Edit Scenario window and choose to add to selection

4. Select the shoreline, verifying it is selected in its entirety, and then click Save to finalize the selection
5. Verify the start line, end line, and break line in the Shoreline Limits window will pop up, – once satisfied click next
6. Enter the 100-year stillwater elevation, which is required for an accurate model and can be found in the Flood Insurance Reports (*FIRM's*)
7. Check the vertical datum, choosing which spheroid to use
8. Click Finish
9. Delineate the floodplain by clicking the following → Hazards → Coastal → Delineate Floodplain
10. Check the settings in the window for coastal hazard analysis and then click OK
11. Click yes to continue in a warning pop-up window asking about rastering the flood layer
12. Now, you will have a completed coastal flood simulation model created (See Figure 3-2)

Sea Level Rise Modeling

Lowering the DEM

1. Open up the raster calculator by clicking the following:

   → Spatial Analyst Tools → Map Algebra → Raster Calculator
2. Add the DEM layer to the calculator and enter the formula as stated below (in feet)

   → [DEM + (-sea level rise in feet)]

3. Clip the raster to fit the county boundary (if you don’t have items that are less than zero)
4. Using the raster calculator, select all the cells that are less than or equal to zero
5. Make everything equal to 0, equal to 1
6. Finally convert the raster to a polygon to get a final polygon (raster that has a value of 1) by clicking the following:
   a. → Conversion Tools → From Raster → Raster to Polygon

Replacing the Old DEM

1. Export the new SLR DEM to a folder where you can access it, name it “clipdem” and copy the file folder
2. Go to the user data folder for Hazus-MH

   → Go to the C: drive → Hazus User Data → Regions
3. Choose the folder in which your working file is located
4. Find the clipdem folder and rename it to “clipdem2”
5. Paste the copied file into the directory folder
6. At this point, Hazus will now recognize the new SLR DEM

Creating a New Scenario Model with New DEM

1. Go to → Hazards → Scenario
2. Create a new hurricane scenario (*i.e. SLRStormSurge*)

   → Make sure Activate is the selected option from the choices listed to the left of the files
3. Select Yes stating that you want to activate the scenario

4. Hazus will then run the probabilistic storm data over the new DEM
5. Click Finish to generate the storm surge flood levels for a 100-year storm
6. Hazus running in ArcGIS will produce the storm surge polygon and depth raster grid
7. The new polygon and depth grid will reflect how a change in SLR would affect the same area

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BIOGRAPHICAL SKETCH

Kenwyn Diego Harrilal was born in Trinidad & Tobago and moved to the United States when he was 3 years old. He went to school in South Florida and graduated from Miramar High School in 2004. Kenwyn received his undergraduate degree from the University of Florida, graduating Cum Laude from the M.E. Rinker, Sr. School of Building Construction in 2010. After completing his undergraduate studies, Kenwyn began his master’s degree in 2011 at the University of Florida in urban and regional planning.