THE IMPACTS OF HURRICANE MITIGATION ON THE COSTS OF EXTREME EVENTS

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This work would not be what it is if not for a friend with an uncanny ability to engage in creative destruction and an unexplainable and perpetual willingness to do so.

Abstract

Costs associated with hurricanes have been rising steeply since well before the record-breaking Atlantic hurricane season of 2005; the rise has been especially dramatic since 1980. Many researchers, including van der Vink et al. (2005), have demonstrated that these costs are driven by a small number of extreme events. Such events generally overwhelm most or all protection mechanisms in place. When these mechanisms fail, many areas which were "protected" suffer damages tantamount to the damages which would have occurred without any protection. When this occurs, the best proxy for the cost of the hurricane is simply the amount of people and property in the way of the hurricane.

There are several benefits to hurricane mitigation. Any mitigation effort will decrease the expected damages in an area affected by a hurricane provided that the mitigation mechanisms do not fail. Mitigation efforts will also lessen the probability that these mechanisms are overwhelmed. However, mitigation efforts also decrease the perceived risk of moving people and property into the area they are designed to protect, which can be counter-productive to the goals of the mitigation.

Mitigation is counter-productive if it results in more people and property in a vulnerable area, since in this situation it will increase the expected loss for an event which exceeds mitigation mechanisms. Even if it is unlikely that mitigation is exceeded, the overall expected loss in a given year still increases. As overall expected losses increase, the net benefit of the mitigation efforts will decrease.

This study finds that the decreased benefits of mitigation are not currently taken into account in cost-benefit analyses of mitigation. It examines quantitative relationships between mitigation efforts, population increases, and the resulting changes in expected losses. While it cannot be proven that mitigation efforts in the United States are not cost-effective, the decrease in the net benefits represents a substantial portion of the estimated benefits of mitigation. This decrease should be taken into account whenever new mitigation projects are undertaken.

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Chapter 1: Hurricanes and Mitigation in the United States

At the turn of the 20th century, a small but rapidly growing town on the Gulf Coast was poised to become the major deep water port of Texas, as well as a leading port for the United States as a whole. Long in competition with Houston for this right, the town of Galveston had secured contracts with several major shippers, and it looked as if Galveston had decisively pulled ahead of Houston once and for all.

However, one of the worst natural disasters in the history of the United States stopped the burgeoning city dead in its tracks. In the fall of 1900, a hurricane swept across Florida and then the Gulf of Mexico, headed directly for Galveston. By the time the Category 4 storm passed, over 6,000 people were dead, the city itself lay in complete ruins, and Houston had effectively won the race to become the major port city of Texas.[1]

As Galveston began to recover, city officials looked back at how, and where, Galveston had been built. In hindsight, it must have seemed as though the city had been built to tempt the fate it had just endured. Large portions of the city were completely unprotected and at elevations below or barely above sea level. As the location of the city and the possibility of rebuilding were questioned, officials gave residents a choice. Residents would either protect their homes by raising them to an adequate elevation or the home would be purchased by the government and bulldozed.

[1] Larson, Erik. "Isaac's Storm". Vintage Publishing. 2000. This work was instrumental in providing background information, as well as inspiration, for this study.

Since this disastrous event, the residents of the Gulf Coast and their representative governments have taken many steps to defend against hurricanes. The 1900 Galveston hurricane was so devastating primarily because of inadequate and inaccurate prediction systems – residents had little to no warning and even up to the moment that the hurricane made landfall had little knowledge of its severity.

The nature of the United States' response to hurricanes has changed substantially since that event. Prediction has improved to the point where hurricane forecasts made two and three days in advance are generally accurate, and predictions of landfall locations up to five days in advance are not uncommon. This level of accuracy in advance warning is generally sufficient to prevent the majority of deaths which might be associated with a hurricane, and thus improved prediction has helped to spur a decline in the number of deaths in the United States due to hurricanes since 1900.

Figure 1 displays this trend, as well as the increase in US population over this same time period. The figure indicates that as a percentage of the US population, deaths from hurricanes have certainly declined since 1900.[2]

[2] Data on the deaths from hurricanes comes from Centre for Research on Epidemiology of Disasters (CRED) in the form of their EM-DAT database; population data comes from the US Census Bureau.

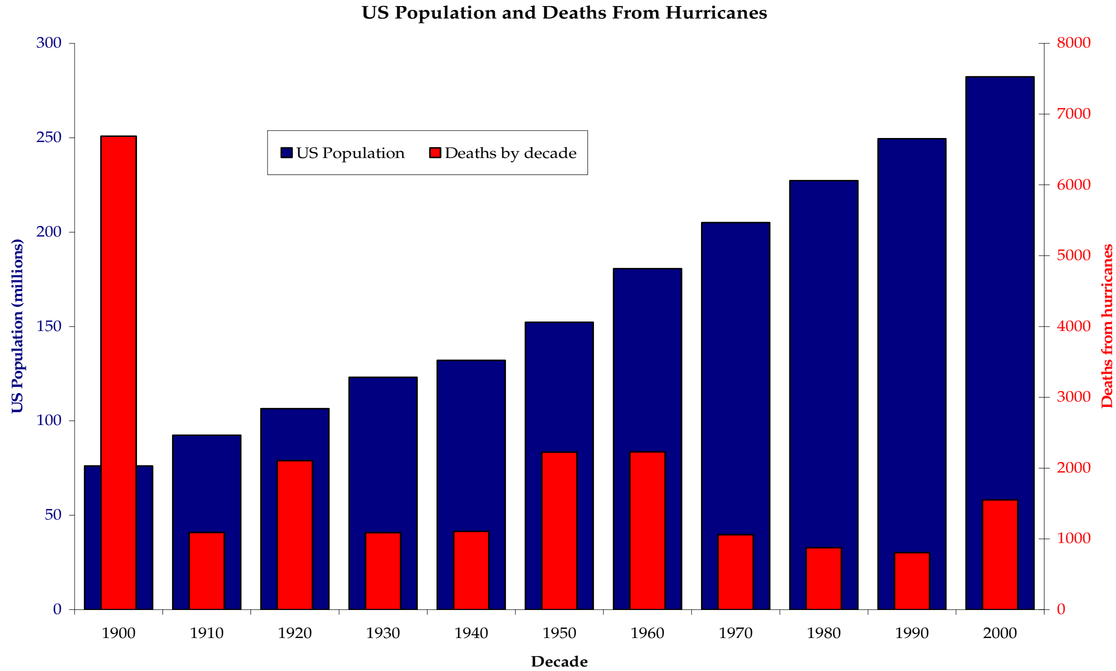

Figure 1: US Population and Deaths From Hurricanes

In stark contrast to the decline in the number of deaths from hurricanes, the estimated cost of hurricanes in the United States has skyrocketed, particularly since 1980. This trend is robust even after adjusting for inflation. The record-breaking Atlantic hurricane season of 2005 accentuated this trend, but even if 2005 is ignored, the increase in costs has been steep.[3]

The rising cost trend does not appear to be explained by any sort of parallel increase in hurricane intensity. Figure 2 plots the estimated annual cost of hurricanes since 1900 along with a measure of the intensity of the season. The measure of a season's intensity used by the National Oceanic and Atmospheric

[3] Pielke, Roger, and Christopher Landsea. Normalized Hurricane Damages in the United States: 1925–95. American Meteorological Society. 1998. Much of the analysis in this study is based upon the findings of Pielke and Landsea.

Administration (NOAA) is the Accumulated Cyclone Energy (ACE) Index; however, this index is only available since 1950. Therefore a different index, developed by the GEO 499 class at Princeton University, is used so that the data extend back to 1900. In years when both indices are available, the two track each other very well. A comparison is given later in this study.[4]

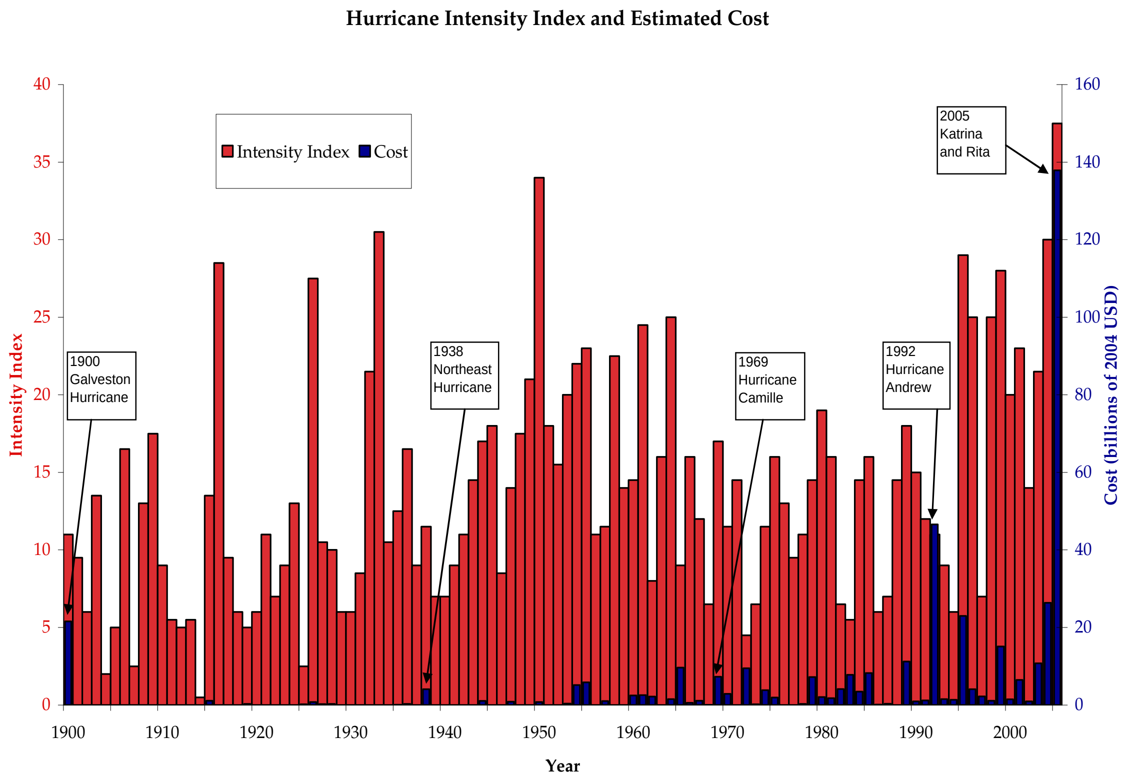

Figure 2: Hurricane Intensity Index and Estimated Cost

This sharp increase in costs is of particular interest because of the changes in the government's role in hurricane mitigation and disaster relief since 1900. In addition to funding mitigation projects such as levees and floodwalls to attempt to reduce hurricane damages, the federal government has effectively become the

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[4] Data on the annual cost of hurricanes for Figure 2 comes from the aforementioned EM-DAT database. Data on the Intensity Index comes from Gregory van der Vink, et al., via personal communication, 2007

insurer of last resort for those living in hurricane-prone areas.[5] This shift in the government's role combined with skyrocketing costs has major implications, which this study will explore.

Hidden inside of the trend of rising costs is another important fact about the costs of hurricanes in the United States. The costs are driven primarily by extreme events where mitigation mechanisms are overwhelmed. These events account for a large percentage of the total costs due to hurricanes in a given year. Since 1900, the most costly hurricane in a given year accounted for, on average, 89% of the total costs for that year.[6] The primacy of these extreme events in the total cost of hurricanes in the U.S. has been demonstrated by van der Vink et al. in the November 2005 issue of *Geotimes*.[7]

Up to this point, all of the facts and statements put forth are ones generally accepted by the scientific and policy community. They serve as both an inspiration and a jumping off point for this study. Taken together, they raise a number of questions which this study intends to answer through quantitative analysis of available data.

Since extreme events are the cost drivers, it makes sense to focus on those events in a study of the costs of hurricanes. It makes intuitive sense that in such

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[5] "Insurer of last resort" is a term commonly used to describe the entity which will loan money to other insurance and reinsurance firms in times of dire crisis. The term is commonly applied to government since it has effectively infinite reserves and a vested interest in keeping insurance and reinsurance firms afloat in such situations.
[6] EM-DAT database
[7] "The Rising Cost of Natural Disasters." The Geosciences 499 Class, Princeton University. *Geotimes*. November 2005. p. 18-25.

events, any protection or mitigation mechanism will be compromised or exceeded. Hurricane Katrina provides a powerful example of a case where such mechanisms are overwhelmed. As will be discussed later, Katrina was a unique event in many ways beyond its tremendous cost and intensity.[8]

In any case, if a hurricane is powerful enough to overwhelm whatever protection mechanisms are in place, the amount of damage inflicted by that hurricane simply depends on how much is in its path. It has been demonstrated, again by van der Vink et al. and reproduced here as Figure 3, that for large-scale hurricanes (Category 3 and greater), the damages inflicted correlate well with the population density in the county where the hurricane makes landfall. The population density is used as a proxy measure of how much is in the path of the hurricane.

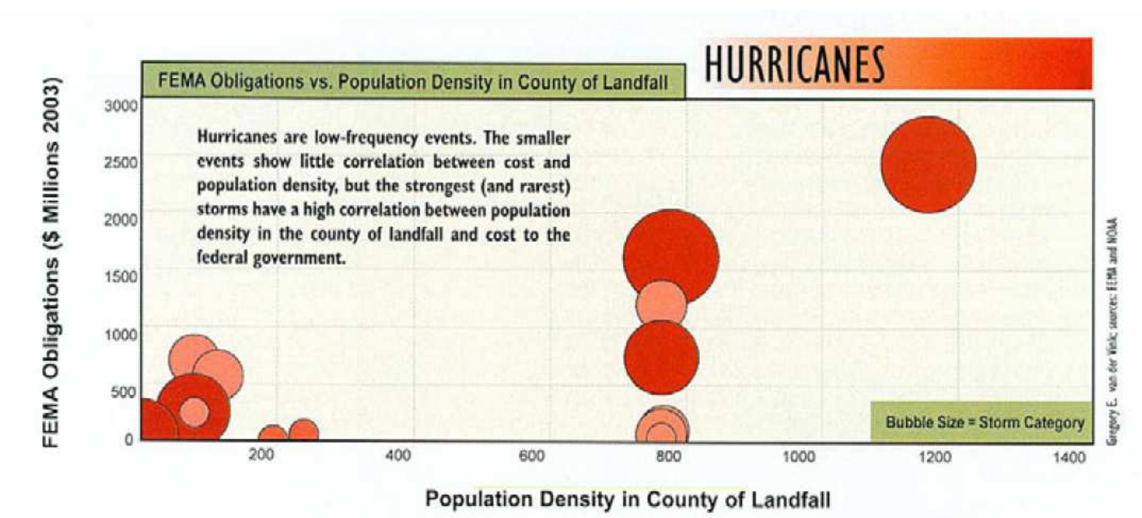

Figure 3: FEMA Obligations vs. Population Density in County of Landfall[9]

[8] van Heerden, Ivor, Ph. D. et al.. "The Failure of the New Orleans Levee System During Hurricane Katrina." December 18, 2006.

[9] "The Rising Cost of Natural Disasters." The Geosciences 499 Class, Princeton University. *Geotimes*. November 2005. p. 23.

As will be discussed in more detail later, the population in the United States living in hurricane-prone areas has been rising even faster than overall population over the last century.[10] There are many reasons for this influx; however, the reason germane to this discussion is the attempt by federal and local governments to decrease risk to citizens living along the coast by mitigating against hurricanes.

Any mitigation effort designed to protect an area from hurricanes will necessarily lower the risk to an individual property owner in that area. Let us consider a person buying a $100,000 home in an area with the following annual probabilities for different levels of hurricanes (Table 1-1). These are feasible probabilities, though they do not represent any hurricane prone area in particular.

Table 1-1

Category:	**1**	**2**	**3**	**4**	**5**
Annual Risk:	**5%**	**4%**	**2%**	**1%**	**0.25%**

These are risks which cannot be changed; they simply reflect an estimate of the probability that a hurricane of each level will strike that area in a given year.

[10] Population Trends Along the Coastal United States: 1980-2008. US Department of Commerce. NOAA. National Ocean Service. September 2004.

Without any mitigation, we might expect this person's expected losses from each of the different hurricanes to look something like the following:

Table 1-2

Category:	**1**	**2**	**3**	**4**	**5**
Expected Loss:	**$10,000**	**$20,000**	**$50,000**	**$60,000**	**$70,000**

If mitigation is put in place, however, we might reason that the expected losses for the lower-intensity hurricanes would be smaller, since the protection mechanisms would prevent most of those losses from happening. However, if we follow the reasoning outlined above, losses due to high-intensity events would remain the same, or nearly the same, since protection mechanisms will be overwhelmed. The table of expected losses would now look something like this:

Table 1-3

Category:	**1**	**2**	**3**	**4**	**5**
Expected Loss:	**$1,000**	**$4,000**	**$10,000**	**$55,000**	**$70,000**

It is clear that for this individual, mitigation decreases the expected loss due to hurricane damage. Buying the property is now a more attractive proposition. A conclusion that might be drawn, then, is that mitigation efforts in fact spur development in the areas they are designed to protect since they make the purchase of property there more appealing.

Therefore, if mitigation efforts do in fact spur development in the area they are designed to protect, the mitigation efforts themselves might be at least partially leading to the rising costs of hurricanes in the United States.

Further verification of this conclusion is necessary, however, and one of the aims of this study is to quantitatively analyze the available data to assess the extent to which this conclusion is an accurate reflection of reality. The idea that mitigation efforts might lead to increased hurricane cost is highly informed by the events of Hurricane Katrina, and so the application of this conclusion to those events will be a focus of this investigation. It will be a challenge to examine the extent to which this conclusion fits generally with all mitigation efforts.

Even the possibility that mitigation efforts could be counter-productive raises interesting questions, which this study will also address. The majority of mitigation efforts are wholly or mostly funded with federal or local government money. As with all government spending, it is important that the spending be justified. For most projects, this justification comes in the form of cost-benefit analysis. Mitigation has been the subject of many such studies, particularly in the wake of Hurricane Katrina.[11] The potential for mitigation to be counter-productive is not typically included in cost-benefit analyses. This consideration

[11] See Kunreuther, 2005. "Disaster Mitigation and Insurance: Learning from Katrina." The ANNALS of the American Academy of Political and Social Science 2006; 604; 208.

could severely alter the overall costs and benefits to society, especially since public projects analyze costs and benefits at the macro level, examining population trends over the entire protected area. This study aims to determine the extent to which these changes in population change the cost-benefit analyses already carried out and determine if such analyses should be done differently in the future to account for these effects.

To summarize, this study will focus on the arguments outlined above and assess their validity using available data. Specifically, the following questions will be examined:

- When protection mechanisms are subjected to events which are more intense than those that they are designed to protect against, what characterizes the resulting damages to the area intended for protection?
- To what extent is the influx in coastal population due to efforts to mitigate against hurricanes?
- Given that any mitigation will make the purchase of coastal property more attractive to the individual, are current cost-benefit analyses overly optimistic in their assessment of the effects of mitigation?
- How do the findings of this study relate to the events surrounding Hurricane Katrina?
- Are the findings of this study specific to the events surrounding Katrina or can they be generalized to all hurricanes?

Answering the above questions will undoubtedly raise some interesting points regarding current attitudes and mitigation practices; therefore, this study will conclude with an examination of these topics and a discussion of how this study's findings are related to current mitigation practices.

Chapter 2: An Analysis of What Makes Hurricanes Costly

In 1992, Hurricane Andrew swept across southern Florida. Andrew, a Category 5 hurricane at its peak, inflicted several billion dollars worth of damage before moving on toward the Gulf of Mexico and heading for Louisiana. When it first made landfall on the eastern coast of Florida, Andrew had weakened to approximately a Category 4 hurricane. Thirteen years later, two more Category 5 hurricanes, Katrina and Rita, grew strong in the Gulf and made landfall in Louisiana and Texas. These storms were both approximately Category 3 storms at landfall.

While the storms were similar in their intensities at landfall, they were markedly different in the damages that they caused. A major reason for this difference is the population density in the areas that the hurricanes affected. The range of the total estimated costs associated with each one spans an order of magnitude. The population density in the area affected by each hurricane also spans an order of magnitude. These quantities are summarized in Table 2-1 below.[1]

Table 2-1

Event	Cost, Billions of 2004 US Dollars (EM-DAT)	Population Density in Affected Area (per sq. mi.)
Katrina	**$120**	**2,159**
Andrew	**$35**	**969**
Rita	**$10**	**< 200**

[1] US Census Bureau, 2000 Census data.

A third Category 5 hurricane further illustrates the correlation between population density and cost. Hurricane Emily resulted in less than $1 billion in damages, a full two orders of magnitude less than the cost of Katrina, despite the fact that it made two landfalls, once as a Category 4 hurricane in the Yucatan Peninsula and once as a Category 3 hurricane in Southern Texas.[2] Both of the affected areas had relatively sparse populations, and so the event caused relatively little damage. In fact, the name Emily was not even retired by the World Meteorological Organization (WMO), as is typical of hurricanes which are deemed to have caused significant damage or loss of life.

In contrast to Emily, Tropical Storm Allison had its name retired by the WMO in 2002. Allison made landfall in a major metropolitan area, Houston, and causing several billion dollars in damages. Allison certainly caused more damage than Emily, despite the fact that Emily was far more intense.

A major determinant of the costliness of hurricanes is the population density of the county where the storm makes landfall. The US population density in coastal, hurricane-prone counties has increased by a factor of 10 since 1900, compared to a factor of four for the US population as a whole. Using U.S. Census data for individual counties, Figure 4 displays the population density of the counties in 1900; Figure 5 displays the population density in 2000.[3]

[2] EM-DAT

[3] Population density data comes from US Census Bureau; boundary layer files come from the Census Bureau as well, via Wangyel Shawat in the Princeton University Geosciences map library.

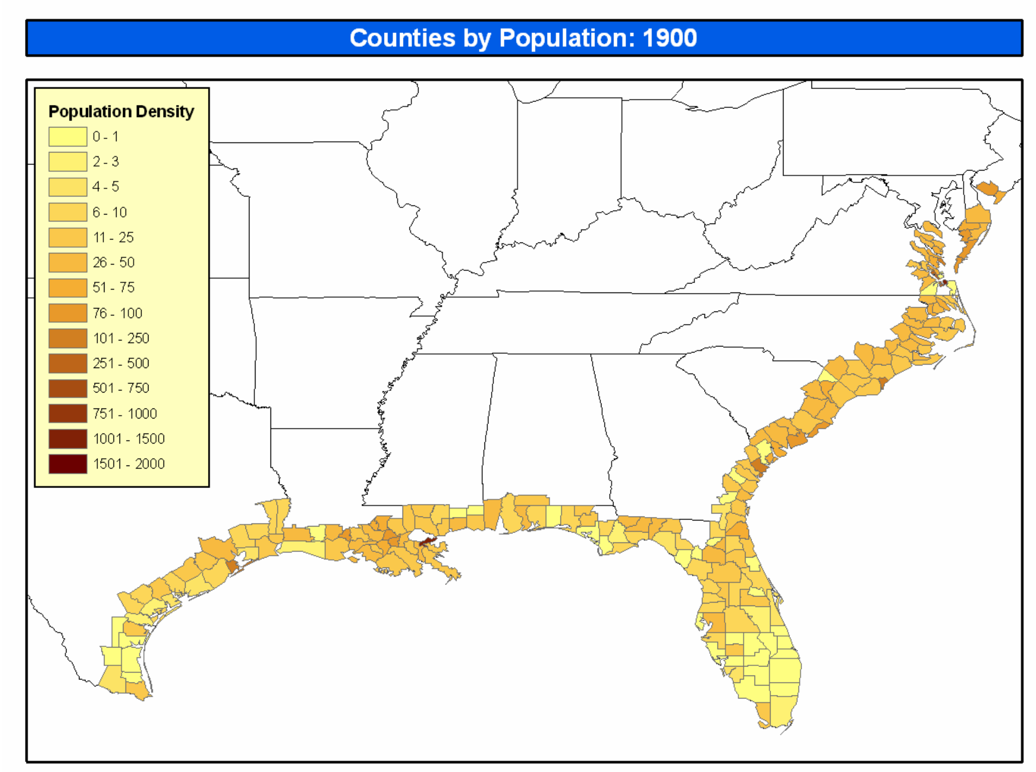

Figure 4: Population Density by County, 1900

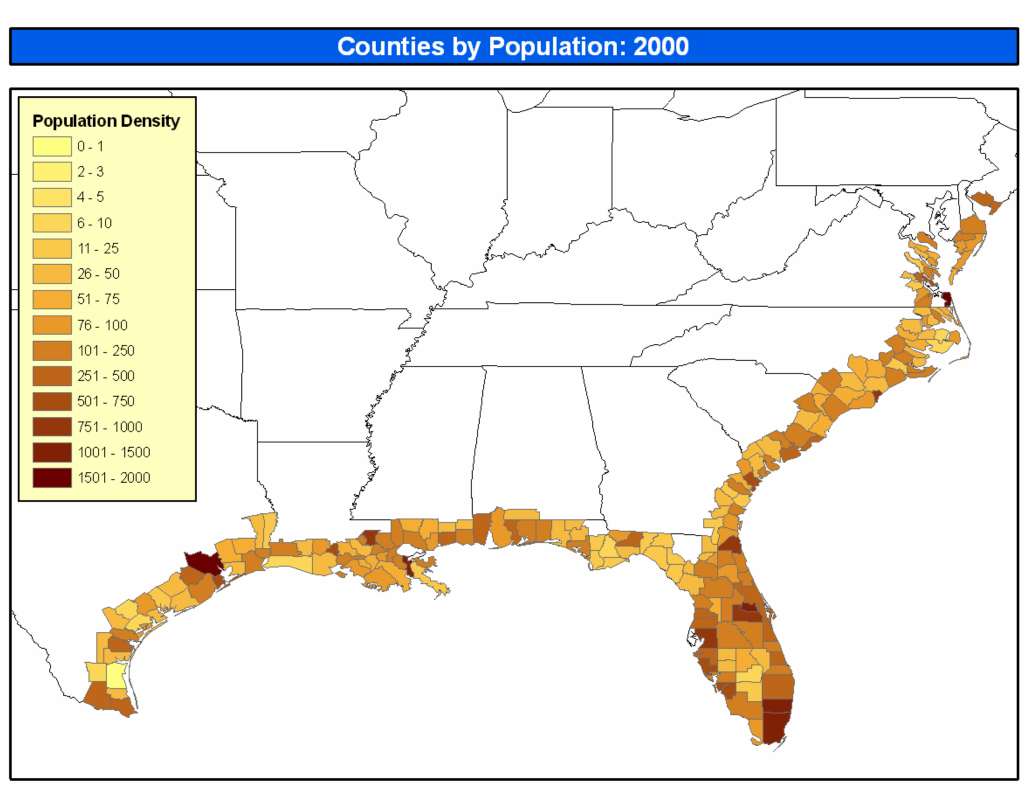

Figure 5: Population Density by County, 2000

Using ArcGIS, the relationship between population density, hurricane cost, and hurricane category is depicted geospatially in Figure 6. Data on hurricane tracks and the strength of the hurricane at each segment of the track is taken from the National Oceanic and Atmospheric Administration (NOAA). Data on the cost associated with each hurricane is based on the EM-DAT database. Population density from the U.S. Census Bureau is overlain on the land surface.[4] Each hurricane track is composed of two parts, a colored line which represents its cost and a gray buffer. The buffer's thickness represents the hurricane's category at that point in its track.

[4] Hurricane track data comes from the NOAA and is available at http://maps.csc.noaa.gov/hurricanes/viewer.html. Cost, as noted, comes from EM-DAT. Population density data comes from the US Census Bureau via layers provided by Wangyel Shawat in the Geosciences map library at Princeton University.

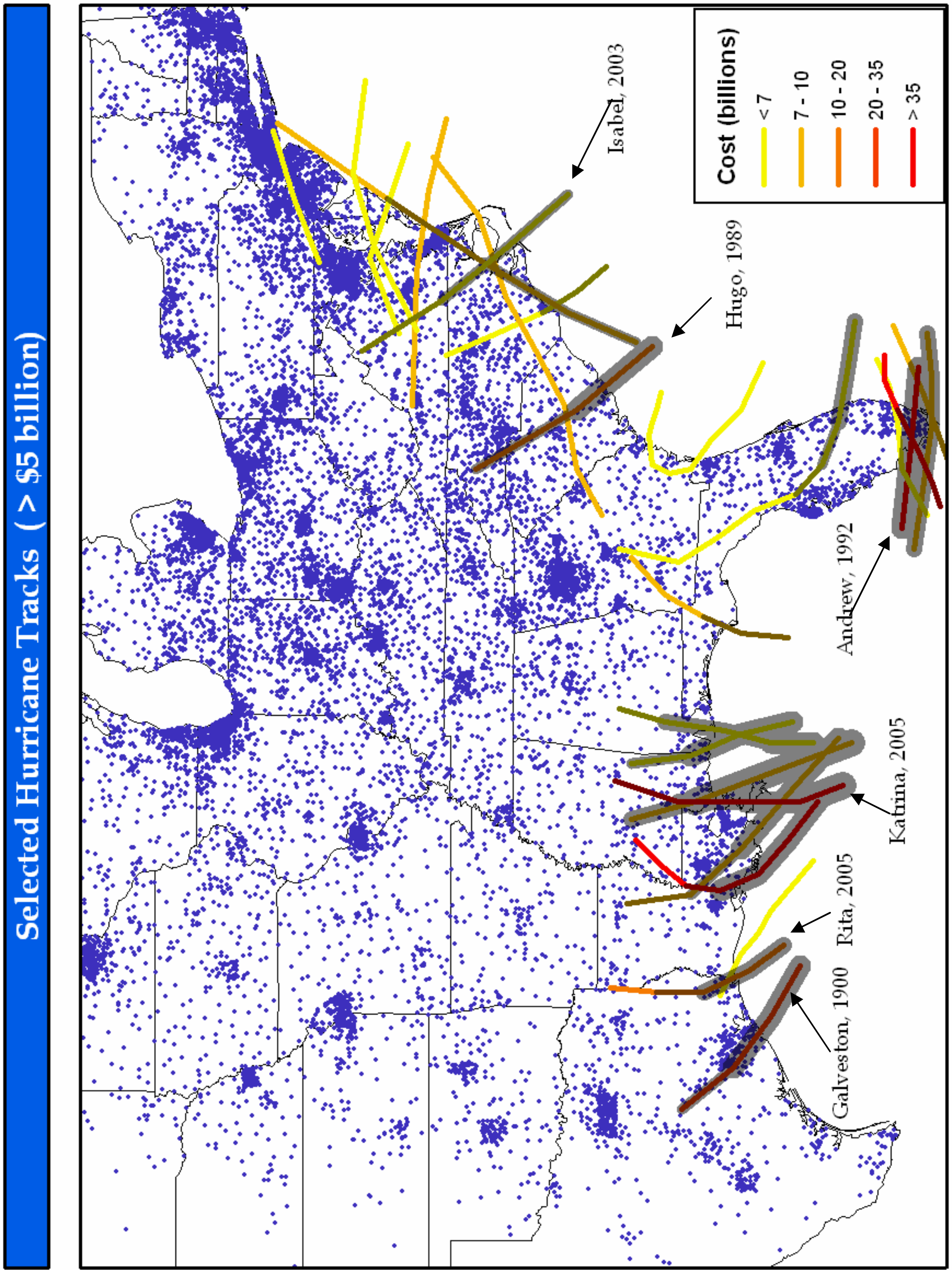

Figure 6: Selected Hurricane Tracks, $5 billion Events and Above

Figure 6 is noteworthy for a number of reasons. First, it provides a visual representation of the effect of population density on hurricane cost. All of the hurricanes depicted on the map were very costly. Since the cost of hurricanes increases with population density, and all hurricanes on the map resulted in over $7 billion in damages, low-category hurricanes on the map tend to pass over more populated areas. The figure also displays hurricanes that appear to refute this logic; for many of these hurricanes, however, this map design does not show the true reasons why the hurricane was costly.

To further explore the validity of the correlation between population density of the affected area and the cost of the hurricane, this study creates a figure similar to Figure 3 created by van der Vink et al. (Figure 5). The method used here incorporates more data points (hurricanes) and also makes use of county-level census data dating back to 1900 in order to measure the population density in the county of landfall as accurately as possible. This method also differs in that it uses cost figures from EM-DAT rather than Federal Emergency Management Agency (FEMA) obligations, which represent the event's cost to the government. These obligations measure the damage to government buildings and infrastructure and the cost of recovery efforts, whereas the totals from EM-DAT reflect losses from the private sector as well.

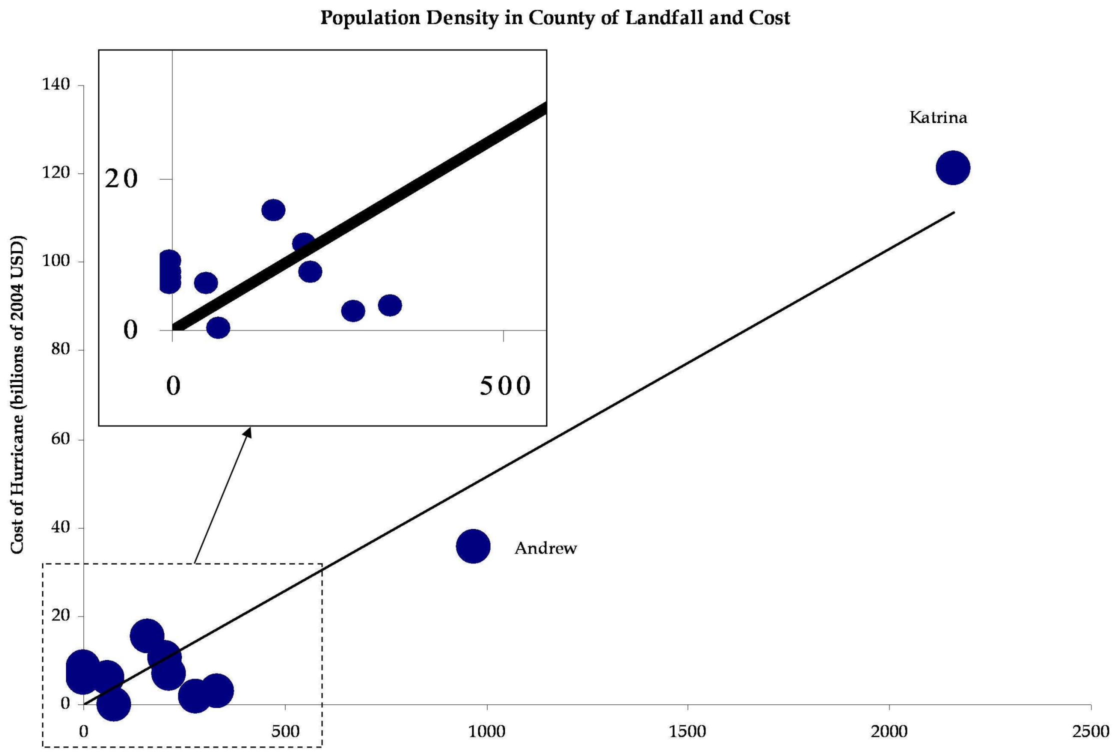

Figure 7: Population Density in County of Landfall and Cost

The inclusion of Katrina in 2005 reinforces the previously seen trend for the high-intensity hurricanes, and in general the additional points added to the figure also reinforce the connection between population density and cost. An auxiliary figure is included which zooms in on the points closer to the origin, since Katrina makes these points hard to distinguish. While the trend is not as clear here, there still appears to be some correlation. In any case, as noted previously, this study is not as concerned with less costly events that do not drive the rapidly increasing cost of hurricanes in the United States.

Whenever such a plot is produced, the idea of prediction of the cost of a hurricane is not far behind. In this instance, the question would be how accurately the cost of a hurricane could be predicted, if perfect information about its track, strength, and the population density of the affected area were provided.

As an additional variable, median income of the affected area might also be useful. Since the cost of a hurricane will depend on the amount of property value in its path, it makes sense to predict that if the county of landfall is both a densely populated county and also a high-income county, more property value will be at risk and the cost will be higher than if the affected county was a low-income county. This reasoning, of course, only reflects monetary damages. The reverse may very well be true when assessing the human toll of the hurricane and the difficultly associated with evacuating the population at risk. These considerations, however, fall outside the scope of this study. More detailed analysis which incorporates the relationship between the median income of a county, its population density, and the potential for damages will be carried out in Chapter 4.

This method of predicting costs by examining population density and median income to estimate damage potential, while more complicated than simply using the population density in the county of landfall, is still simple and straightforward, and deliberately so. More complex methods of predicting costs from hurricanes given similar information but in vastly more detailed form have been developed by FEMA. FEMA freely distributes a software program, HAZUS-MH (short for Hazards United States, Multi-Hazard and abbreviated as simply HAZUS here), which takes as input detailed information about the storm track, building inventory in the affected area, topography of the region and other parameters to produce output which predicts, at the county and even sometimes census block level, the damages from a given hurricane. This information can be also be combined with information about expected return intervals for different levels of storms to produce overall hurricane risk maps for a given area.

While HAZUS is useful if such fine-grain data is available, its utility is limited when exploring the topics related to this study. This study's focus on the impacts of mitigation and movements in population are outside the realm where the use of HAZUS would in line with the goals and scope of this study. Therefore, HAZUS is not used here.[5]

While the importance of the population in county of landfall should be clear by this point, a discussion of the factors which make hurricanes costly would not be complete without briefly touching upon the methods which are used to measure hurricane intensity. From the beginning of this study it was assumed that the reader was somewhat informed about the Saffir-Simpson Hurricane Scale, which assigns each event to a hurricane category or other classification if the event does not reach hurricane status. A hurricane's category is primarily based on the sustained winds of the hurricane; other characteristics such as storm surge and central pressure generally fall within a range given a

[5] HAZUS is available at http://www.fema.gov/plan/prevent/hazus/

certain value for the sustained wind speed.[6] However, it is important to note that while a hurricane may be classified as a certain category based on wind speed, other attributes of the hurricane may be more characteristic of hurricanes of higher or lower categorization. For this reason, a statement might be made that, for example, a Category 3 hurricane had a Category 4 storm surge.

The other physical characteristic of a hurricane which plays a role in its potential for damage is its speed. Slow-moving hurricanes generally have more damage potential because their precipitation is concentrated over a small area, generally leading to more flooding. In order to be conservative, protection mechanisms designed to withstand flooding and storm surge from a certain category of hurricane are generally designed with a slow-moving hurricane in mind.

To measure the energy associated with a hurricane or a season of hurricanes, the NOAA uses a metric called Accumulated Cyclone Energy (ACE) index.[7] This index is based on basic physical principles; namely that kinetic energy is proportional to the square of velocity. The ACE index is calculated by measuring, at six-hour intervals, the maximum sustained wind speed of the hurricane and squaring this value. From this measurement the ACE index for an individual hurricane over its lifespan can be calculated. The ACE index of an

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[6] "The Saffir-Simpson Hurricane Scale." The National Hurricane Center. Available: http://www.nhc.noaa.gov/aboutsshs.shtml
[7] More detail on the ACE index is available on the NOAA website:
http://www.cpc.noaa.gov/products/outlooks/background_information.shtml

entire hurricane season can be calculated by summing the totals for individual events.

As previously mentioned, the Geo 499 "Intensity Index" is calculable back to 1900 and can be used in place of the ACE index. Figure 8 displays the relationship between the two indices.[8] The figure provides justification for using the Geo 499 "Intensity Index" as a proxy during the period 1900-1950, since in years when both indices are available, they track each other very closely. This is to be expected since the velocity of the storm is the primary datum used as the basis for calculating both indices.

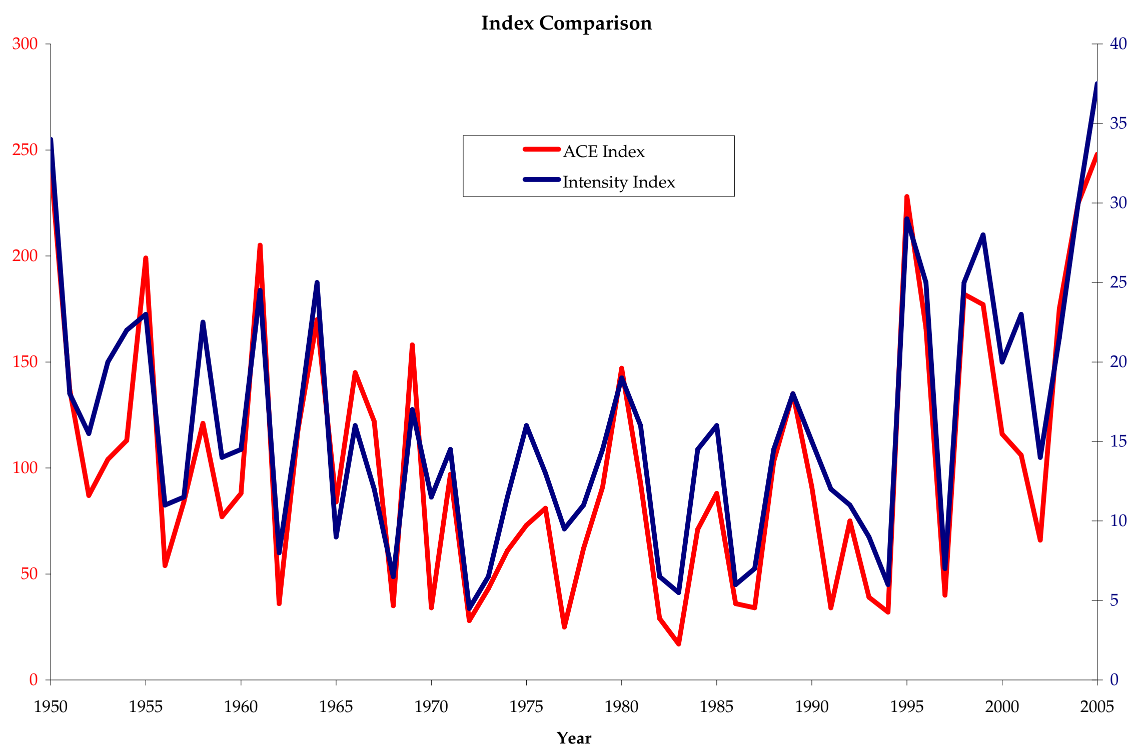

Figure 8: Comparison Between ACE Index and Intensity Index

[8] Yearly ACE index data is available from the NOAA at: http://www.cpc.noaa.gov/products/outlooks/hurricane2004/May/figure5.gif. Data on the Intensity Index comes via Greg van der Vink, personal communication, 2007.

This chapter has shown, however, that the intensity of a hurricane or a hurricane season is not the primary driver of whether or not that event or year will be a costly one. Rather, the track of an individual hurricane and the amount of people and property which are in its path are far better predictors of cost and influence the cost of the event more than any other characteristic. This conclusion is reinforced by comparing US Census data for coastal counties to hurricane costs from EM-DAT, over the time period 1900-2005, displayed below as Figure 9. These findings are essential to the remaining analyses of population trends and cost-benefit analyses of mitigation efforts.

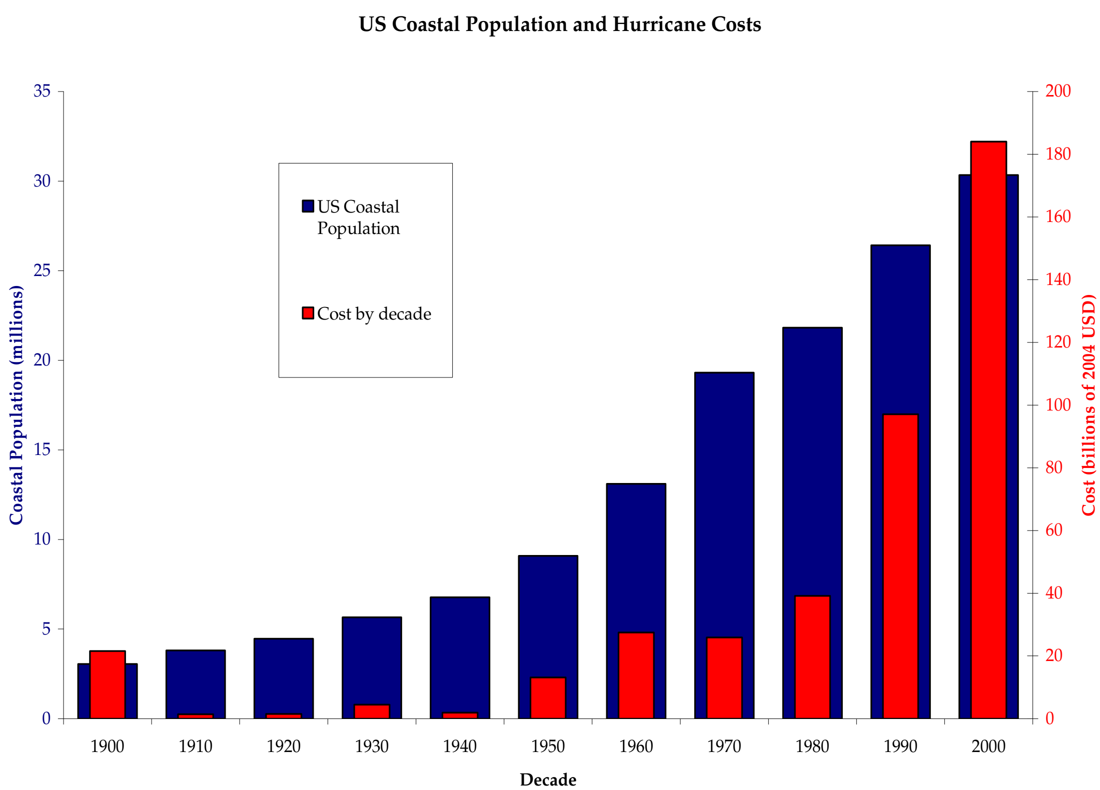

Figure 9: US Coastal Population and Hurricane Costs

Chapter 3: The Impacts of Hurricane Mitigation on Population

Having explored the link between population density and hurricane costliness in Chapter 2, this study will now explore the link between mitigation projects designed to protect an area and population changes in that area. This will establish a relationship between all three of these elements. Once the extent of these relationships is clear, mitigation efforts can be quantitatively tied to the damages associated with hurricanes by comparing a cost-benefit analysis (CBA) for the mitigation projects to the cost of hurricanes. Mitigation and damages can also be quantitatively linked by using geospatial data on the effects of the event. These two quantitative methods are introduced here in order to bring the connections full circle. These methods, as well as the findings of Chapter 2, will then be applied to a specific event in Chapters 4 and 5 to analyze what happened in New Orleans before, during, and after Hurricane Katrina.

Mitigation and Population

As mentioned in Chapter 1, it makes intuitive sense that if a mitigation project is built to protect a certain area, living or investing in that area becomes more attractive and therefore the population will be higher than it would be without the mitigation project in place. The challenge, however, lies in establishing exactly how much of the population change is the result of the mitigation effort.

One approach to answer this question would be to compile fine-grain data on population changes and perform statistical analyses to control for all the other different factors which influence population to highlight those areas with populations appear to be abnormally high. To determine if mitigation is responsible for those anomalies, the location of mitigation projects could then be depicted geospatially along with the areas with high populations.

There are several problems with this approach, however. First of all, it is difficult to obtain the data which would be necessary, since much of the information regarding federally-funded mitigation projects is contained in the National Emergency Management Information System (NEMIS) database.[1] The database is only available to users with appropriate clearance since much of the database contains private individual information. In addition, since FEMA is now organizationally under the Department of Homeland Security (DHS), additional safeguards are in place and much of the data cannot be accessed in its raw form, hindering its analysis for purposes other than explicit government use.[2] Population data is also not available on the scale or time interval that would be required to perform such an analysis.

While the data available for these analyses is less than desirable, it is clear that even if all the data which could be reasonably expected were available, a number of hurdles would still remain. Some of these challenges will now be discussed.

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[1] Full details on NEMIS are available at: www.fema.gov/doc/library/conops.doc as of this date of printing in April 2007.

[2] Personal communication via e-mail, Darryl Madden, January 2007.

One reason that directly linking mitigation to a specific population increase is difficult is that a single mitigation project typically affects multiple regions or areas, often in different ways. A project may completely protect one area and simply reduce the impacts of the hurricane in another. Later chapters will use New Orleans as an example to demonstrate how breached levees and floodwalls in one area of the city had effects on other parts of the city in ways which were not clear cut, and different events will certainly stress the mitigation efforts in different ways and produce different results.

Another complication in making the link between a population increase and a mitigation project is the threat of "chicken-and-egg" complications. If an area experiences high growth, it is likely that the area will be projected to experience high growth in coming years. Government officials may see this and fund projects which are designed to protect the area, which then grows in the future. A certain amount of this growth was bound to happen regardless of whether the mitigation was built. Many people also might move into an area believing that with enough growth, mitigation measures will be put in place. In general, there are countless factors, many of which are outside the scope of this thesis and indeed this department, which influence such decisions.

Furthermore, even if people have perfect information about the risks from hurricanes in an area, this does not imply that they will necessarily incorporate this information into their decision on where to live. There are many other competing factors which influence such a decision, and a low-probability event such as a hurricane may be far down on this list of factors. Even if a homebuyer incorporates hurricane risks into his decision, there is no guarantee that he will do it rationally. While most economic models and studies treat humans as rational agents, a growing literature supports the idea that this is not actually the case and that people's decisions can in fact be quite irrational.[3]

For all these reasons it is clear that using data to quantitatively prove this link is close to impossible. Therefore, to make this link, this study relies on the strength of the logic outlined in Chapter 1, namely, that mitigation makes investing or living in an area more attractive and therefore the population there will be higher that it would have been with no mitigation. There are still methods to quantitatively analyze the data that is available in a meaningful way, and two of these methods are described below.

Cost-Benefit Analysis

After extreme events such as Katrina, it seems natural to build mitigation projects which are able to withstand even these extreme events. Many people, moved by emotion and a vivid memory of the event, strongly favor such measures. However, such projects are generally not cost-effective. This assertion is reinforced by the fact that there are currently no large-scale mitigation projects which are designed to withstand a Category 5 hurricane.[4] To examine why such

[3] See the work of Daniel Kahneman for examples.
[4] Carter, Nicole T. "New Orleans Levees and Floodwalls: Hurricane Damage Protection." CRS Report for Congress. Congressional Research Service. Library of Congress. 6 September 2005.

projects are usually not cost-effective, a brief primer on CBA for hurricane mitigation is included here.

All CBAs rely on the sound calculation of both the costs and benefits of a project. In a typical CBA for a hurricane mitigation project, the cost of the project is simply the cost to construct and maintain the project. Benefits, however, are a more complicated calculation. The benefits are calculated by estimating the damages which are prevented because the project is in place. Since hurricanes are uncertain events, probability analysis must be included as well. The basic information required to calculate the benefits is included in the Table 3-1 below. The actual numbers are fabricated but are again plausible numbers for a CBA of a project which is designed to protect against a Category 3 hurricane. The total benefits of the project are determined by summing the benefits incurred for each event after incorporating its probability.

Table 3-1

Hurricane Category	Annual Probability	Cost of Event Without Mitigation (millions USD)	Cost of Event with Mitigation (millions USD)	Benefit (millions USD)
1	5%	10	1	9
2	4%	20	2	18
3	2%	40	4	36
4	1%	100	80	20
5	0.25%	1000	900	100

Returning now to the cost-effectiveness of mitigation against Category 4 and 5 hurricanes, one major reason why it is difficult to build such projects cost-effectively because the cost of a mitigation project such as a levee or floodwall rises nonlinearly with the category that it is designed to withstand. The probability of a hurricane also decreases nonlinearly with its category, and since benefits are discounted based on that probability, the actual benefit of upgrading a protection system to withstand a Category 5 storm can be small.

Geospatial Analysis

Data on the amount of flooding that takes place during and after a hurricane is generally readily available for analysis. Of particular interest is what happens during a hurricane when mitigation measures fail, since this is where the negative effects of mitigation are most visible.

When studying the effects of events which compromise mitigation measures, it is useful to study hurricanes where the damage is primarily the result of storm surge and flooding rather than wind. This is desirable for two reasons. First, wind mitigation techniques typically encompass an individual structure; there is no analogous structure to a flood wall or levee designed to protect a large group of structures from the wind at once. Second, levees and flood walls have a definite point where they become broken or breached.[5] Before

[5] The distinction between the two ways that hurricanes cause damage has been at the heart of the recent controversy over insurance policy claims from Hurricane Katrina. State Farm Insurance is the most prominent among a host of insurance companies that are entangled in a legal battle over

this point flood damage is minimal, and after it damage is extensive. Again, wind mitigation lacks this feature, which is helpful (and even necessary in some sense) in such analyses.

One essential question in such an analysis is whether mitigation failure results in conditions which are equivalent to those which would have resulted from no mitigation being in place at all. There is an important distinction to note here. Even if 'no mitigation' and 'broken mitigation' result in equivalent *conditions*, this does not imply that the *damages* from these two scenarios would be equal. Indeed, a central tenet of this study holds that even if the conditions are equivalent, the damages will be worse under the 'broken mitigation' scenario since this will have encouraged more people to move into the area, resulting in more damages.

To compare the conditions that result from these two scenarios, it is necessary to make an assumption about what conditions will look like under the "no mitigation" scenario, since there are few examples of events where this is the case. The critical assumption is that the elevation of the free water surface will be approximately equal in this situation, since there is no mitigation to prevent water from flowing anywhere but the lowest elevations. Therefore, the only data needed to produce a set of hypothetical flood depths for various "no mitigation" scenarios is the elevation data for the area that the hurricane strikes.

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whether they are obligated to pay some claims from the storm because the policy covered wind damage but not damage due to storm surge.

The "broken mitigation" scenario, unfortunately, is usually not a hypothetical one. The critical criterion used to compare the two scenarios is the free water surface elevations. Comparing the maps of the free water surface elevation for each scenario yields valuable information about whether the broken mitigation resulted in conditions which were similar to the conditions which would have resulted if no mitigation had been in place.

Next Steps

Keeping in mind the caveats and difficulties of quantitatively proving a direct link between mitigation and population, this study will now rely on the logic from Chapter 1, the findings of Chapter 2, and the tools from this chapter to analyze the relationships between population, mitigation, and damages in the context of a specific hurricane. The city of New Orleans and Hurricane Katrina have far and away the most data available out of any hurricane in history and therefore will be the event which is analyzed.

Chapter 4:
New Orleans: Population and the Extent of Flooding After Katrina

Even before the water levels began to recede in New Orleans, both citizens and government officials began to ask the impertinent question: "Was this really a natural disaster?" The topography of the city and the large populations of people living in the areas of low elevation have raised questions about the extent to which rebuilding of the city should take place at all. The interplay of race, politics, and massive government spending on projects designed to prevent or at least reduce damages from hurricanes served as fuel for much outrage at the way the events in early September 2005 unfolded.

This chapter attempts to answer the question of whether Katrina was, in some part, not a natural disaster but rather a man-made disaster that could have been either avoided or lessened with more appropriate planning. Examining the geospatial relationship between population trends and mitigation measures is the first tactic used to shed light on this question.

A large portion of what would be considered metropolitan New Orleans lies within Orleans Parish. Orleans Parish taken together with Jefferson Parish includes the majority of the urban area of New Orleans and the population of the immediate region. These two counties in aggregate have increased in population by a factor of three over the course of the 20th century.[1]

This large urban population is protected from hurricanes by numerous government mitigation projects. One facet of the protection mechanisms in essence forms a low outer wall around the far borders of the city. Additional

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[1] US Census Bureau.

protection mechanisms are higher and protect the inner parts of the city, not including eastern New Orleans. Lastly, several canals enter the city from Lake Pontchartrain to the north. These canals assist the pumps that remove water in the event of a flood from the numerous parts of the city which are below sea level.[2]

Hurricane Katrina is one example of an event where these mitigation measures were overwhelmed, and therefore provides valuable information on what happens during events when mitigation fails. Katrina is particularly amenable to study here because its damage primarily resulted from the flooding and storm surge associated with the hurricane, rather than the wind damage. As mentioned in the previous chapter, this is desirable characteristic of an event which is to be studied in the context of mitigation failure.

Because of Hurricane Katrina's high profile, many useful maps have already been constructed which contain a variety of information about the sequence of events in late 2005. The New Orleans *Times-Picayune* has created dozens of such maps which provide background information for the purposes of this study. One map, reproduced here as Figure 10, outlines the protective measures which were in place in New Orleans and the locations of the various breaches, as well as other major landmarks. The full timeline of the events starting before Katrina's landfall is expertly animated by the *Times-Picayune* at

[2] "Last Line of Defense: Hoping the Levees Hold." New Orleans Times-Picayune. Available: http://www.nola.com/hurricane/popup/nolalevees_jpg.html

http://www.nola.com/katrina/graphics/flashflood.swf for the interested reader.

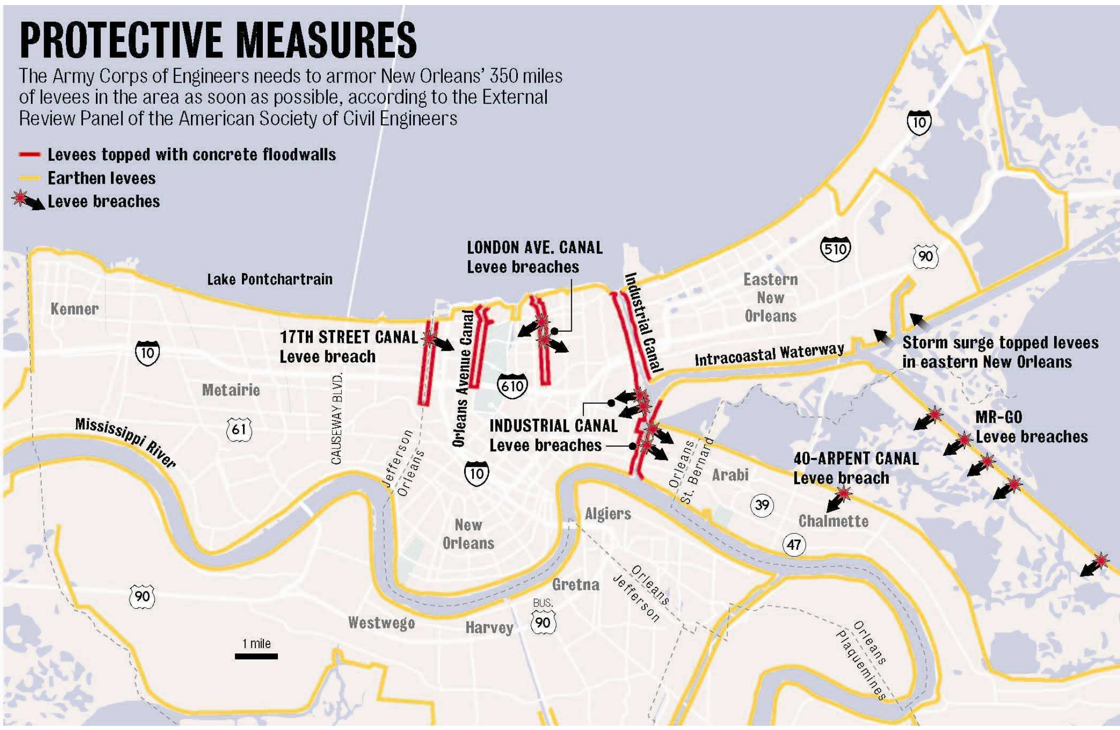

Figure 10: Breaches of Levees and Floodwalls During Katrina

<u>Flooding During Katrina</u>

To gain additional insights into how the mitigation mechanisms affected the conditions that resulted from Katrina, an analysis is presented here using elevation data from the United States Geological Service (USGS) and flood depth data from FEMA. To provide background, Figure 11 first depicts the simple land elevation of New Orleans.[3] The city's inherent vulnerability is apparent in this

[3] USGS. Available: http://ned.usgs.gov/

figure, especially when this map is coupled with the knowledge that many parts of the city are actually subsiding with time.[4]

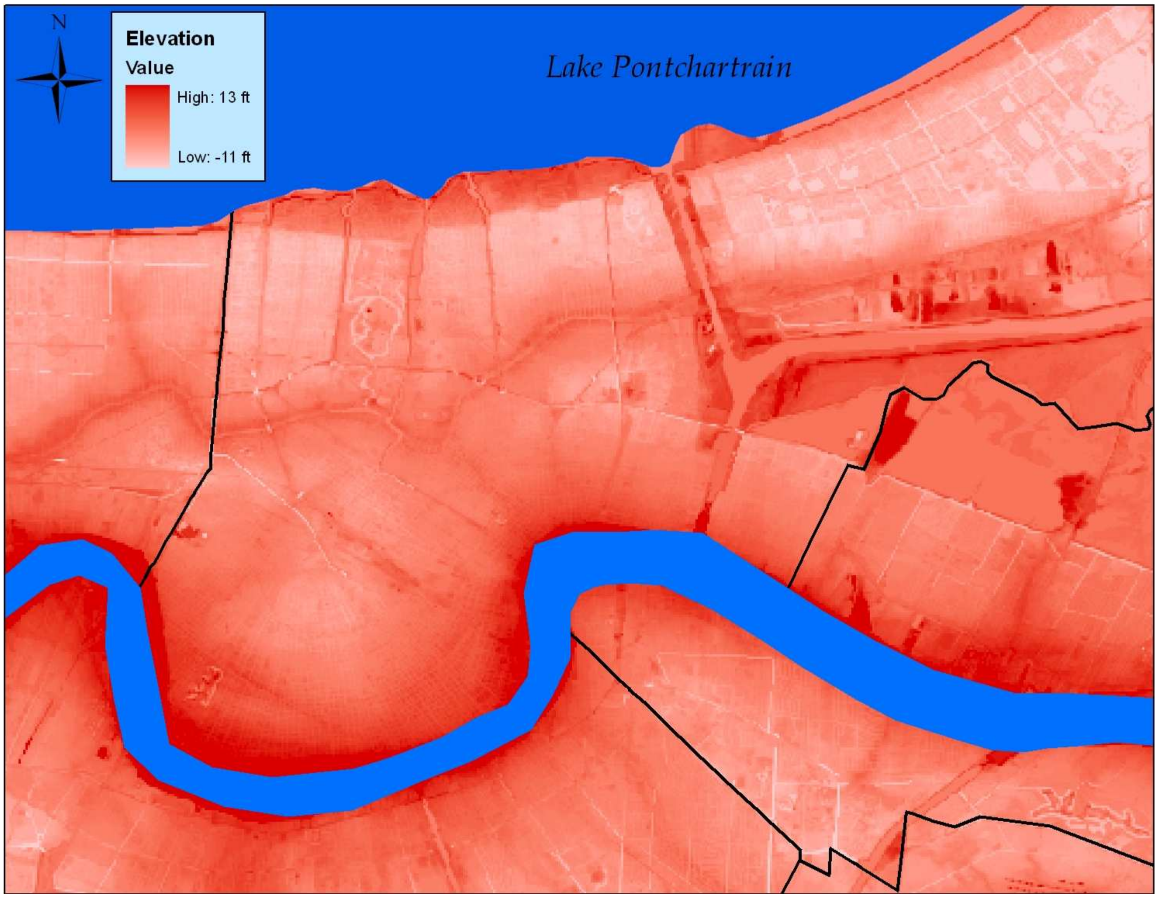

Figure 11: Elevation of New Orleans

[4] Dixon, Timothy, et al. "Space Geodesy: Subsidence and flooding in New Orleans." *Nature*. June 2006.

Figure 12 displays where flooding took place after Katrina.[5] This figure will be compared to an estimation of the flooding in a scenario where no mitigation was in place. For this analysis it is assumed that in such a scenario, flooding would take place with a uniform free water surface elevation. This idea of the free water surface elevation is essential to understanding the next three figures in this analysis. The free water surface elevation is the sum of the land elevation at a point and the depth of flooding at that point. For example, if the free water surface elevation is two feet above sea level at a point on the map with an elevation of three feet below sea level, that point has a flood depth of five feet. When the free water surface is said to be uniform over an area, this implies that the depth of the flooding in that area is therefore based simply on elevation, and the elevation data are all that is needed to determine the depth of flooding at every point. A water level of 2 feet above sea level was decided upon as a representative level to display here. The flooding that would take place under these conditions is depicted in Figure 13.

[5] FEMA

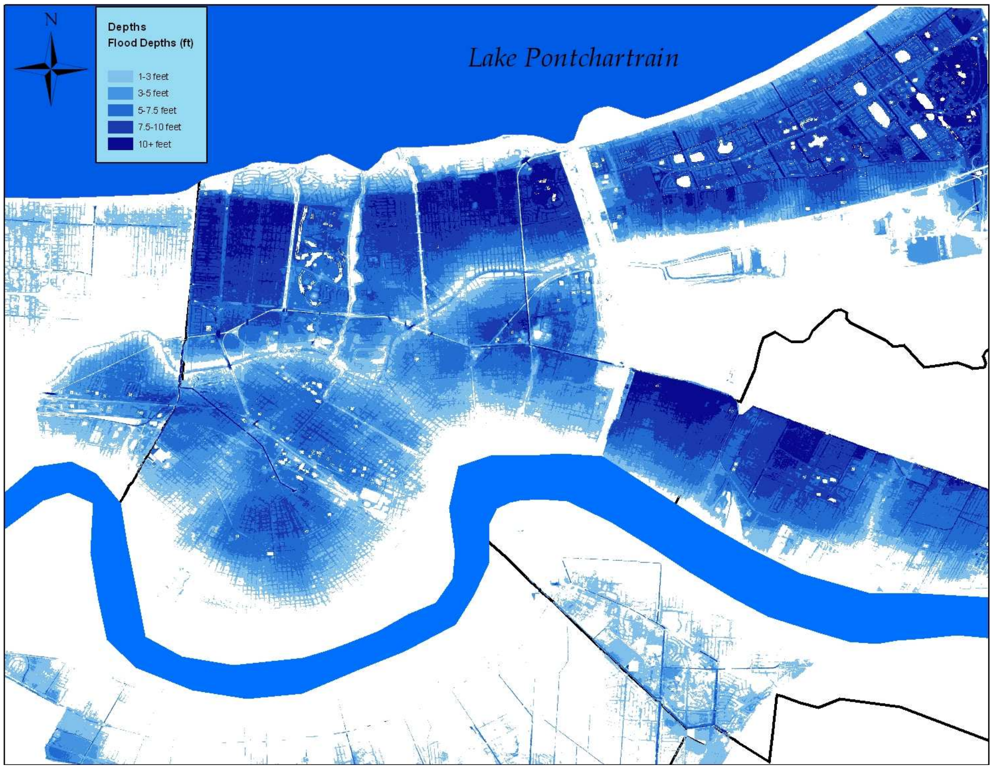

Figure 12: Flood Depths in New Orleans

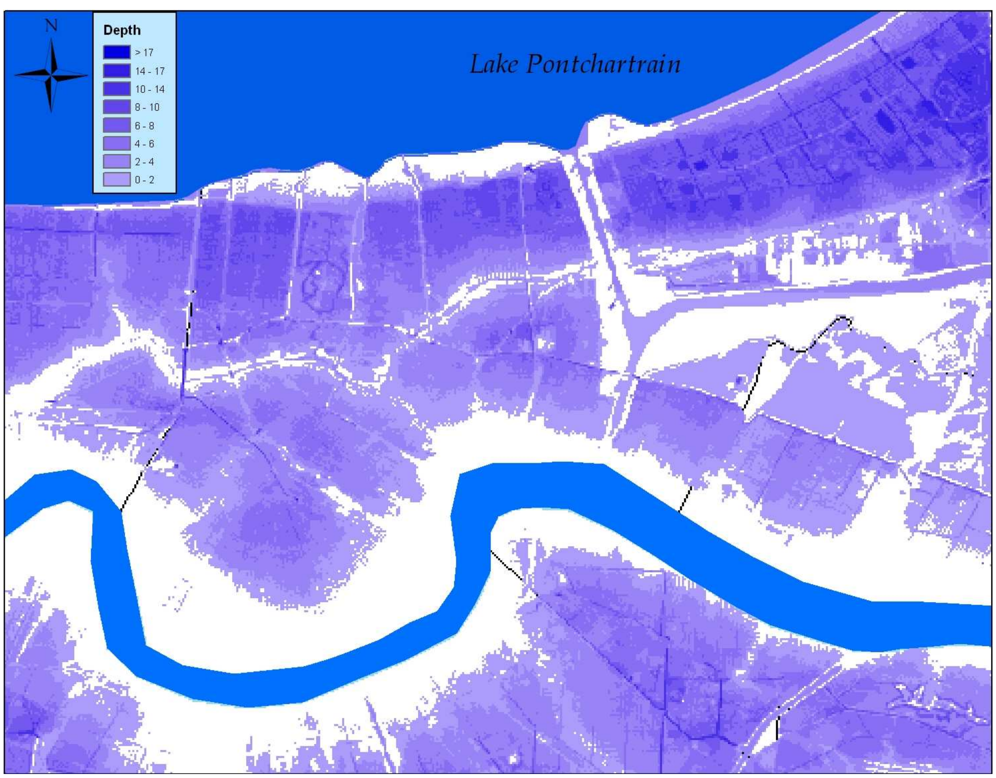

Figure 13: Flood Depth with Uniform Water Surface Elevation of 2 feet

It is clear from the juxtaposition of these two figures that the flooding that actually took place in New Orleans after Katrina was different than the flooding that would have taken place if no mitigation were in place at all. Also to be inferred is the fact that simply looking at Figures 11 and 12 side by side indicates that the free water surface elevation was not the same throughout the city. To follow up on this idea, Figure 14 plots the elevation of the water surface by combining elevation data with flood data.

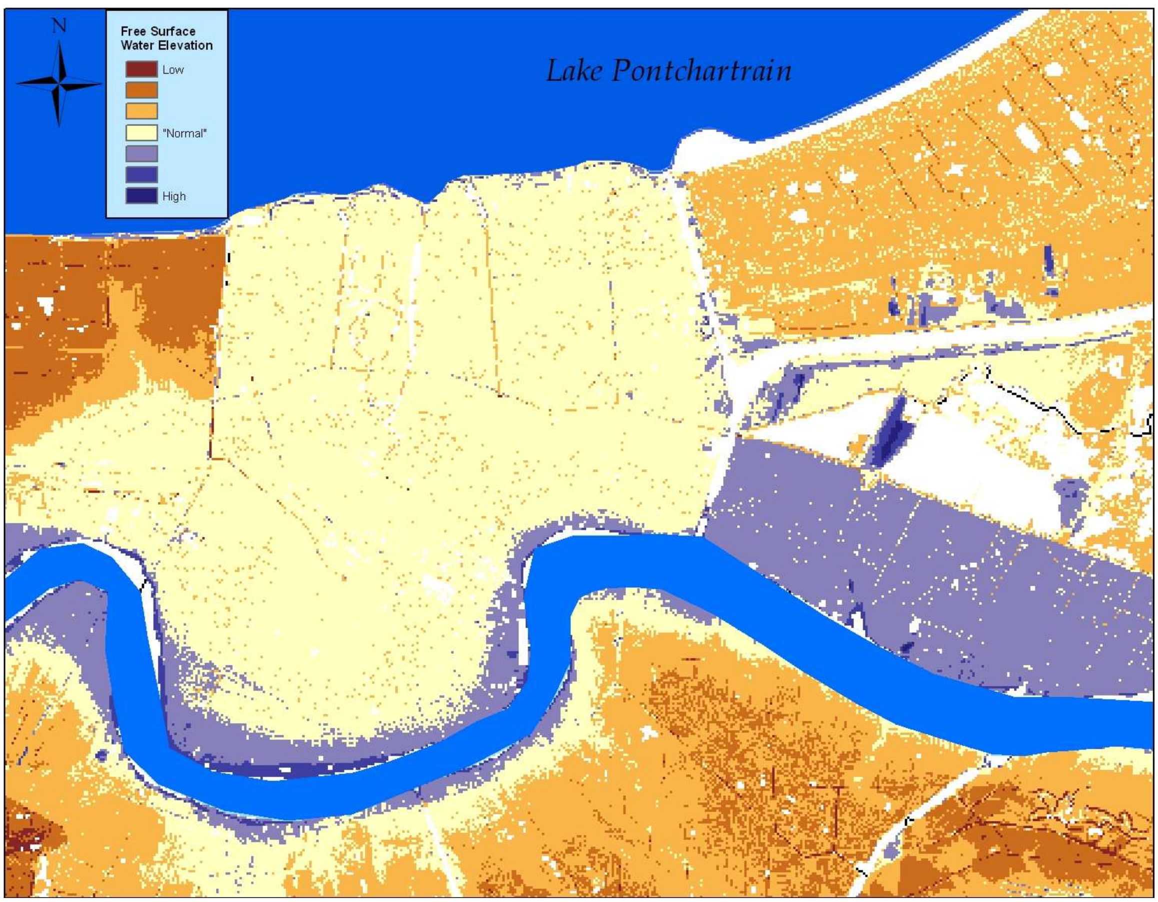

Figure 14: Free Water Surface Elevation at Peak Flood Levels During Katrina

Based on Figure 14, the main part of the city experienced a uniform free water surface elevation, depicted as tan on the map. Other parts of the city, however, experienced different free water surface elevations. Of particular interest is the area immediately to the west of the city, displayed in brown on the map, which had small flood depths and therefore a high free water surface elevation. This is the result of the 17th Street Canal failure on its east bank. Another are of interest is the Lower 9th Ward, depicted in purple on the map, which indicates that free water surface elevations here were greater than those in the rest of they city. Based on this analysis and the way that the system was originally constructed, the protection system clearly resulted in a different pattern of flooding than would have resulted without mitigation, since the free water surface elevation is different in different parts of they city.

Using water level as the critical criterion has its flaws in that some of the flooding is the result of simple rainfall and not flooding. The assumption, however, is that the rain water will be more or less evenly distributed throughout the city. Another possible flaw is that the flow of water to the lowest elevations in the city might be impeded by structures apart from those specifically designed as mitigation, such as buildings and infrastructure. This level of impedance is not likely to be the same in all parts of the city, even though it is assumed to be so when the water level is examined in this way.

Depicting Damage Potential Geospatially

In order to develop a sense for where property value is concentrated within the city, and therefore where the potential for damages is highest when a hurricane strikes, GIS data from the US Census Bureau on population density and median income is used to produce Figure 15. Each census tract is shaded based upon a simple index calculated by multiplying the population density in that county by the median income. This measure serves as a rough estimate of the amount of property value located in that census block. This metric is obviously not perfect; in urban locations, the median income of a census tract may underestimate the potential for damage since the high-value businesses which are present will add to this potential value despite the fact that their high-income employees do not necessarily reside in the same census tract.

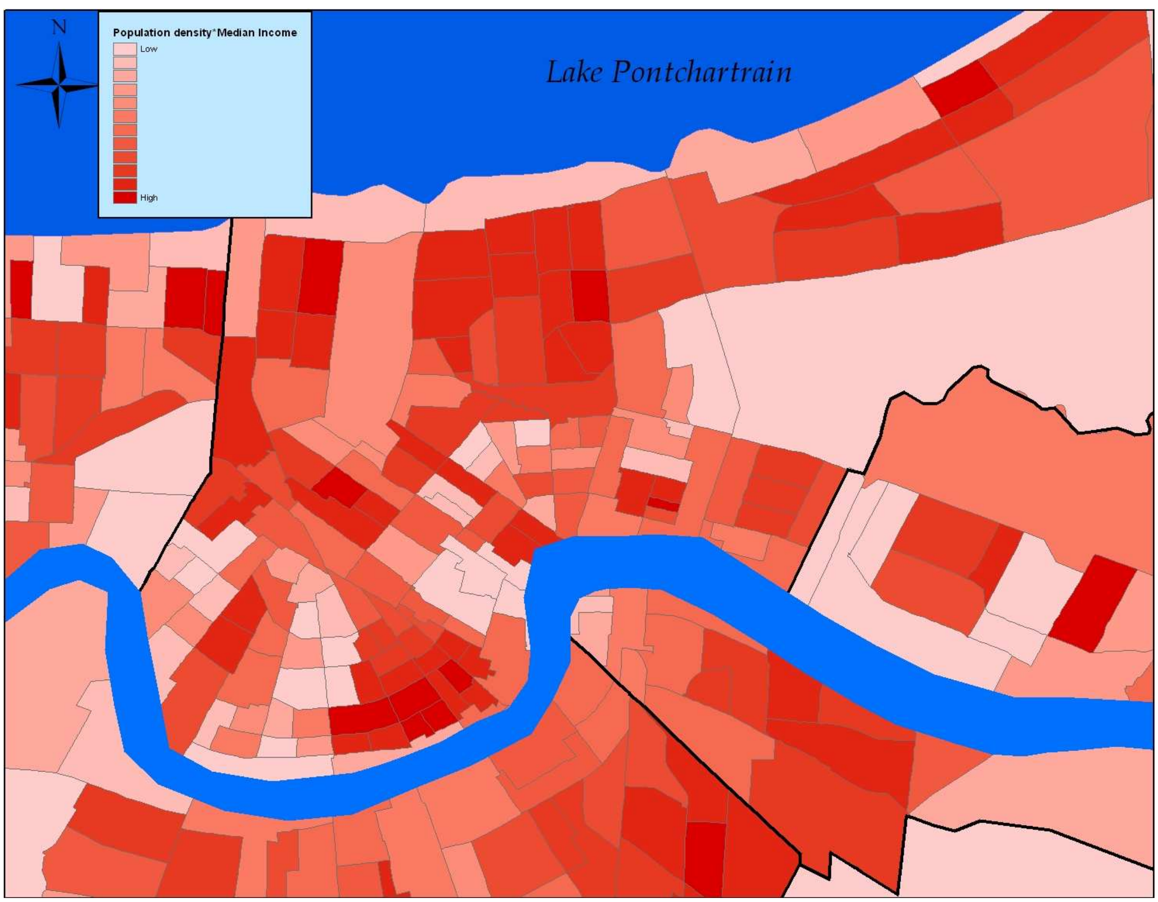

Figure 15: Index of population density and median income

Next Steps

The discussion and findings in this chapter provide some first insights into the impacts that mitigation can have on population trends in a particular city, and the results of those population changes. In order to further tie these components together, additional information will be used to explore the impacts that population trends might have on cost-benefit analyses performed for mitigation projects.

Chapter 5: New Orleans: Population Trends, Mitigation, and Cost-Benefit Analyses

A cost-benefit analysis (CBA) is an integral part of any sound engineering project; indeed, these analyses are also essential to many decisions that people and organizations make every day. Choosing between tradeoffs and working under constraints is a fact of life, even if formal cost-benefit analyses are not carried out in detail.

Cost-benefit analyses are routinely carried out on hurricane mitigation projects, especially if a project is funded with federal money. These analyses were certainly carried out in detail for the myriad of projects which currently protect New Orleans. One CBA, which analyzed a wide range of mitigation projects including flood, hurricane, and earthquake mitigation, was conducted by the Multi-Hazard Mitigation Council and is hereafter referred to as the MMC Report.[1] The Council estimated that every federal dollar spent on mitigation results in four dollars in savings to society from reduced future damages. Many CBAs, including the MMC report, generally do not consider situations in which protection mechanisms are overwhelmed. Instead they compare the costs of construction and maintenance of the project itself against the benefits of the reduced hurricane damages.

Previous chapters have demonstrated that during extreme events when protection mechanisms fail, areas which were theoretically protected by mitigation experience conditions which may or may not be better than the

[1] "Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities." The Multi-Hazard Mitigation Council. Washington D.C. 2005.

conditions which would have occurred without the protection mechanisms in place. Previous chapters have also demonstrated that when protection mechanisms are put into place, living in the protected area becomes more attractive. This chapter will analyze this increase in the population of protected areas of New Orleans and estimate what changes the increases might have had on the cost-benefit analyses of hurricane mitigation projects there.

Population Trends in New Orleans

As a first step, it is useful to have a sense of population trends specific to the greater New Orleans area, particularly from the present dating back to 1960, since this is the time frame when many mitigation projects were constructed.[2] The US Census Bureau defines the New Orleans metropolitan area as seven parishes: Jefferson, Orleans, Plaquemines, St. Bernard, St. Tammany, St. Charles, and St. John the Baptist.[3] However, a fair portion of the land which is protected by the New Orleans levee system is contained in only one parish, Orleans Parish. For this study, a subset of the seven parishes has been selected so as to include the entire area protected by the levee system. This subset consists of four counties: Orleans, Jefferson, St. Bernard, and Plaquemines.

The change in population of each of these definitions of the New Orleans metropolitan area since 1960 is presented in Table 5-1. The table also reflects the

[2] Carter, Nicole T. CRS Report.
[3] US Census Bureau

suburbanization that has taken place in New Orleans and most other American cities since the 1960s. As a reference, the population of the United States as a whole is also provided.

Table 5-1

Area	Population, 1960	Population, 2000	Change
Orleans Parish	**627,525**	**461,304**	**- 26%**
Metro area – 4 parishes	**891,025**	**1,003,938**	**+ 13%**
Metro area – 7 parishes	**969,326**	**1,289,412**	**+ 33%**
United States	**180,671,158**	**282,216,952**	**+ 56%**

The fact that the population in Orleans Parish declines over this period and that growth in all three definitions of the city of New Orleans is outpaced by that of the growth in the US as a whole may seem to undermine the idea that mitigation designed to protect those areas caused the population in the areas to increase and therefore increased potential for hurricane damages. However, the line of reasoning which runs throughout this study still holds. The population does not necessarily have to increase at all for this logic to stand, since the argument simply says that mitigation will make living in an area more attractive than if there were no mitigation. In other words, without the mitigation in place, the population of Orleans Parish would be expected to drop even lower than it actually did since 1960.

Focusing on the four-parish metropolitan area in Table 5-1, an approximate upper bound for the increase in population due to mitigation since

1960 might be 100,000, since this is the total population increase. However, if no mitigation were put in place since 1960, the population in 2000 would not be expected to be as high as it was and might be expected to fall below its level in 1960. So the true upper bound, i.e. the amount of population increase due to mitigation assuming mitigation projects are the only driver of increased population, would be somewhat greater than 100,000. The true estimate of the upper bound is extremely difficult to obtain, since it is difficult to imagine a situation wherein no mitigation projects were undertaken to protect New Orleans over a 40-year time period.

As previously mentioned, it is very difficult to prove that a mitigation project specifically caused a certain percentage of a population increase. Two opposing arguments can be made for using very conflicting percentages. For example, it could be argued that the population in an area is bound to increase or decrease based on other factors such as individual decision making, surrounding economic development, government policy, tax laws, or any number of other factors, and that mitigation has only a small influence on population trends. The opposite point could be argued by saying that mitigation is a necessary prerequisite for any development to take place in an area, and that mitigation is not only responsible for any increase in population in an area but also responsible for preventing a severe drop over a certain time period.

These opposing arguments are at the crux of determining the effects of mitigation on population changes and the resulting negative effects of mitigation on the increased costs of hurricanes. The complexity inherent in the relationship between mitigation and population change reveals part of the reason why a clear answer about this link has not yet been reached. Even with perfect, complete data on all population trends and all mitigation projects, the role of politics and especially individual human decision making would prevent a clean, direct correlation between mitigation and increased costs from being extracted.

This study will not attempt to make an assumption about the precise amount of population increase that is the result of mitigation. It will instead explore a range of potential population changes and estimate what the effects would be given a certain population change.

Hypothetical Cases

The easiest case to examine is the boundary case where mitigation is assumed to have had no effect on the population. This case assumes that even without the mitigation measures in place, current population would be exactly what it is today. In the definition of New Orleans which includes four parishes, this would be approximately one million. This represents an increase of about 100,000, or 11%, over the population in 1960. In this case, the methods used in previously conducted cost-benefit analyses would be considered valid, since these methods use extensive data to account for all possible benefits of the mitigation project if mitigation does not affect population.

However, a central tenet of this study holds that the construction of mitigation projects does in fact lead to an increase in population in the area that the project protects. That is, if the mitigation projects had not been constructed, the population in the area would be significantly less than if the project had been constructed.

Two other cases are therefore examined here. The first assumes that if mitigation had not been constructed, population would have remained constant since 1960 at approximately 900,000. The second assumes that without mitigation, population would have decreased by 100,000, or 11%, to 800,000. A summary of all three cases is included as Table 5-2.

Table 5-2

Impact of Mitigation of Population:	Estimated Population in 2000 Without Mitigation	Approximate Actual Population in 2000	Percent Increase Due to Mitigation
No impact	**1,000,000**	**1,000,000**	**0%**
Small impact	**900,000**	**1,000,000**	**11%**
Large impact	**800,000**	**1,000,000**	**25%**

Since the area over which this population is spread remains constant, a given increase in population will lead to a corresponding increase in population density.

Application to Cost-Benefit Analyses

Up to this point, this study has linked the cost of hurricanes to the population in the area they affect. Increases in population are linked in turn to mitigation efforts, which implies that mitigation efforts may be partially driving the rapid increase in the cost of hurricanes. In order to tie all of these links together, a simple, hypothetical cost-benefit analysis will be performed which modifies the way these analyses are currently performed in order to account for the relationship between damages, population density, and mitigation.

All other things being equal, a mitigation project or series of projects which leads to a certain percentage increase in the population density in a given area, call it X%, will also result in an X% increase in the cost of an event which strikes that area and overwhelms protection mechanisms. This is based on Chapter 2, which indicated the correlation between the population density in the county of landfall and the costliness of high-intensity hurricanes.

If a mitigation project is thus assumed to make a high-intensity hurricane more costly by a certain percentage, the next step in assessing the additional cost or decreased benefit of that project would be to assess the probability that such an event will occur and overwhelm the mitigation mechanisms. A common estimate of the probability of a Category 5 storm hitting New Orleans is approximately one in five hundred, or 0.2%, in a given year.[4] Given that New Orleans has experienced three storms greater than or equal to Category 3 over

[4] Carter, Nicole T. CRS Report.

the past century, the annual probability of a storm of that magnitude occurring is estimated to be roughly 3%.

Since the storm surge from Katrina was arguably stronger than a Category 3 storm, the likelihood of such a surge occurring is most likely slightly less than the 3% quoted above, perhaps 2%, since a hurricane Category 4 storm surge is more rare than a Category 3 hurricane. In other words, the probability of a storm overwhelming New Orleans' 2005 hurricane mitigation might be estimated at 2%. This probability takes the floodwalls and levees at their face value for the level of protection they were designed to provide. That is, the probability is not raised to account for the fact that the mitigation did not actually provide this protection and a weaker storm than the design storm did in fact cause failures.

The total cost of constructing the New Orleans protection system is estimated here at $1 billion. This is based on the estimate of $738 million for the Lake Pontchartrain and Vicinity Hurricane Protection Project.[5] The additional cost comes from various other projects not encompassed by the Lake Pontchartrain project as well as a rough adjustment to allow for inflation and to ensure a conservative estimate.

While the ostensible purpose of all mitigation measures is to protect lives and property, some projects are simply more able to perform this task under a given set of conditions than others. The waters of the Mississippi River flowing

[5] Ibid.

through the middle of New Orleans are surrounded by levees designed to protect against a Mississippi flood which occurs, on average, once every 800 years.[6] The floodwalls and levees designed to protect against hurricanes were, as a system, designed to protect the city against a Category 3 hurricane. Since 1900, 3 hurricanes of Category 3 strength or greater have passed within 50 miles of New Orleans.[7] While the exact return period for a Category 3 or greater hurricane for the metropolitan New Orleans area can be debated, it is certainly less than 800 years.

After Katrina, many people proposed the possibility of not just restoring but actually upgrading the city's defenses to be able to withstand a Category 4 or even a Category 5 hurricane. The cost of such upgrades is estimated by state officials to be $32 billion for Category 5 protection.[8] The cost of a typical mitigation measure rises exponentially as protection against additional categories is built; that is, to upgrade from Category 3 protection to Category 4 protection is less costly than upgrading from Category 4 to Category 5. Therefore, other cost-benefit analyses have assumed, based on the $32 billion figure for Category 5 protection, that Category 4 protection would cost approximately $5 billion.[9]

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[6] Grunwald, Michael, and Susan B. Glasser. "The Slow Drowning of New Orleans. *The Washington Post*. 9 October, 2005. p. A01.
[7] NOAA, National Hurricane Center.
[8] Schwartz, John. "Full Flood Safety in New Orleans Could Take Billions and Decades." *The New York Times*. 22 November 2005.
[9] Hallegatte, Stéphane. "A Cost-Benefit Analysis of the New Orleans Flood Protection System." AEI-Brookings Joint Center for Regulatory Studies. March 2006.

Having estimated the costs of potential mitigation projects, the costs of the project can now be compared to its benefits. Benefits are derived, as explained in Chapter 4, based on the damages which the mitigation prevents. While the total estimated damages of Hurricane Katrina were well over $100 billion, the damages specific to New Orleans make up only a portion of the total.[10] Based on estimates from risk management firms, this study will use a total cost of $40 billion as the cost of damages in New Orleans.[11] This number is important because it will be used to calculate the benefits of mitigation under traditional CBA after the return period of such an event is determined.

Table 5-3

Scenario	Cost	Total Expected Benefit, Traditional CBA	Annual probability of an event which overwhelms mitigation	Expected Impact on Population
No rebuild	**< $1 million**	**0**	**5-10%**	**Severe decrease**
Rebuild to Category 3 protection	**$1 billion**	**$2 billion**	**2%**	**Small decrease/no change**
Rebuild to Category 4 protection	**$5 billion**	**$4 billion**	**1%**	**Increase at rate typical of major city**
Rebuild to Category 5 protection	**$32 billion**	**$5 billion**	**0.5%**	**Increase at higher rate**

[10] Ibid.
[11] RMS, 2005. Hurricane Katrina: Profile of a Super Cat, Lessons and Implications for Catastrophe Risk Management, available on www.rms.com

In the above table, the costs of protecting New Orleans from a Category 5 hurricane appear to far outweigh the benefits, even though the table does not consider the effects of mitigation on population). For a Category 3 hurricane, the benefits do outweigh the costs; however, the benefit-cost ratio is much lower than the ratio of 4:1 calculated for all mitigation spending in the MMC report.

It is important to note that the CBA cited above makes the assumption that "there is little difference between no levees and broken levees." This is a critical assumption which this study does not take for granted but rather explores in the preceding chapters by examining water levels in New Orleans after Katrina.

Comparing the situation where mitigation is not reinstalled and the situation where Category 3 protection is rebuilt shows that the expected impact on population is different. Rebuilding to Category 3 protection would impact the population in the area in that the population would be higher than it would be without mitigation. If the increase in population is, for example, 10%, the cost of an event which overwhelms the mitigation would likely be on the order of 10% more costly. Using the estimated cost of Katrina of $40 billion as above, a 10% change in cost would mean a difference of $4 billion.

Since the increased cost of the event only occurs when mitigation fails, the annual probability of such an event occurring is needed. In the Category 3 scenario, the return period is 50 years. Therefore, the average expected time until such an event would be 25 years. Discounting $4 billion at a 5% discount rate for

25 years gives a net present value of approximately $1 billion.[12] This figure is far from insignificant compared to the costs and benefits in the table above.

Even a conservative assessment of the relationship between mitigation and population would still grant that mitigation does lead to a small increase in population. This small increase in population leads to a small *percentage* increase in the costs of extreme events. However, since those events are so costly to begin with, this increase in cost is fairly large in absolute terms. The increase in cost is so large that even when properly discounted to net present value, it is on the same order of magnitude as the other figures in the CBA. This indicates clearly that these population changes should be incorporated into cost-benefit analyses in the future. This conclusion provides justification for connecting the three major elements that this study examines (damages, population, and mitigation) since doing so reveals a major flaw in the way CBAs are currently conducted.

Premature System Failure

Apart from the fact that Katrina was by far the most costly hurricane in history, the event distinguishes itself for another reason. When Hurricane Katrina made landfall, it had weakened to a Category 3 hurricane. Despite the fact such an event fell within the design of the protection mechanisms, many portions of levees were compromised. In cost-benefit analyses, the assumption is

[12] Net present value discounting is a common procedure used in CBA. The discount rate chosen is intended to be a typical discount rate. Discounting is explained particularly well here: http://www.investopedia.com/articles/03/082703.asp

usually made that mitigation measures will withstand events which are weaker than their design event. In other words, if an event occurs and it is less powerful than the event that the protection mechanisms are designed for, the probability that the protection mechanisms will fail is estimated to be slim to none, and typically zero. Katrina therefore raises an interesting question about whether the assumption should be made that protection mechanisms will always withstand events they are designed for with one hundred percent certainty.

As mentioned, Katrina's storm surge was arguably stronger than a Category 3 storm. However, there is much evidence to indicate that there were many levee breaches where the storm surge did not overtop the levee (and therefore the design event was not exceeded for that particular section of levee). This indicates that the levees in these instances failed for other reasons. Researchers at Louisiana State University (LSU) reached this conclusion after they performed extensive data collection and analysis immediately after the storm and collected first-hand accounts of high-water marks, which were later rendered unreadable due to recovery and rescue efforts. The most supported hypothesis for why most of the failed levees did in fact fail is that they were originally built on land which was unstable, subsiding, and which was undermined by other flooding.[13]

[13] van Heerden, Ivor, Ph. D. et al.. "The Failure of the New Orleans Levee System During Hurricane Katrina." December 18, 2006.

Moving Forward

The biggest challenge of extending the lessons of Katrina to mitigation projects in general is the simple fact that the method employed to protect New Orleans is by no means a universally applied method. A good percentage of mitigation money spent is not actually spent on New Orleans-type projects but rather on evacuation planning, education, and other "process" mitigation.

While it is difficult to extend conclusions reached here to all mitigation spending, one lesson that can be learned is the benefit of systems which "bend but don't break." Current systems, once breached, are severely compromised, but provide near-complete protection up to that point. Mitigation systems do not necessarily have to be designed this way. A Category 3 protection system which also substantially limits the damages associated with a Category 4 or 5 event could very well be more cost effective than a system designed to prevent nearly all damages from a Category 5. Projects to restore coastal wetlands and which therefore reduce damages from all events by acting as a buffer and decreasing storm surge are examples of such projects, and though they fall outside the scope of this study, provide an interesting counterpoint to the "higher and stronger" levees and floodwalls approach.

The main lesson to be learned, however, is that even with conservative assumptions about the connection between mitigation and population increases, mitigation is found to be partially counter-productive. These negative impacts are significant enough that the relationships between damages, mitigation, and population should be included in future cost-benefit analyses.

Chapter 6: Conclusion

The events surrounding Hurricane Katrina, despite being a year and a half removed from the date of this printing, still weigh heavily on the city and the United States as a whole. The city and the region are still struggling to recover from these devastating impacts, as the population in the region remains a fraction of its pre-Katrina level. Officials and policymakers continue to debate over the correct course of action to take in rebuilding the city, securing it against future hurricanes, and attracting the populace back to restore the vibrant public life which has become a New Orleans trademark.

One intent of this study was to shed light on the numerous issues surrounding Hurricane Katrina by investigating the impacts of hurricanes and mitigation against hurricanes in the United States. By starting with some basic facts about what makes a hurricane costly, this study attempts to take the next steps in examining what policy makers and individuals can do to help prevent the costs of hurricanes (and other natural disasters) from continuing their exponential rise.

The majority of the damages due to hurricanes in any given year are encompassed by focusing on the most extreme events, which are typically the events which cause protection mechanisms to fail. As Katrina is both a recent and relevant example of such an event, a good deal of the analyses in this study focus on Katrina. However, many of the lessons learned from this event can be generalized to mitigation projects as a whole, and in particular to the rebuilding efforts which are currently taking place in New Orleans.

During extreme events, specifically during Katrina, it has been shown that the conditions which result when mitigation mechanisms fail are not necessarily equivalent to the conditions which would have resulted had there been no mitigation at all. It is indeed difficult to imagine a situation where significant mitigation measures would fail to make even a small impact on the conditions during and after a hurricane.

While conditions after hurricanes may be improved by mitigation, this study asserts that mitigation also leads to population increases relative to what the population would have been if no mitigation were put in place. Mitigation's precise impacts on populations are impossible to define. However, examining a range of plausible figures indicates that even a small change in population can significantly alter the costs and benefits of a project, since building the project will increase the population in the area and therefore increase expected losses in the event of a high-intensity hurricane.

Mitigation projects constructed in an area necessarily make the purchase of land, homes, and businesses in that area more attractive to an individual, since the expected loss on that property in the event of a hurricane decreases due to the mitigation. Mitigation is therefore something that benefits individuals but has its drawbacks for society as a whole. However, this disconnect between individuals' interest and the actions which are most beneficial to society as a whole is not a problem unique to hurricanes. Parallel problems exist in other areas of public policy, and solutions have been devised to bring the two opposing forces more into balance. It is certainly not a problem that can be entirely handled by either government or private insurance companies alone. Indeed, after Hurricane Andrew, hurricane insurance rates skyrocketed in areas which were hit the hardest by the event, even though areas 50 miles away that had the same theoretical risk from future hurricanes experienced no such increase in rates.

While the areas hit hardest by Andrew may have insurance rates which are higher than are rationally justifiable, government mitigation also results in an imbalance between the premium paid and the risk faced by the party. Since federal taxpayer money is spent on mitigation, each taxpayer essentially pays a hurricane insurance premium to the government. The premium, however, does not depend on the risk that that taxpayer faces, and so groups with low hurricane risk essentially wind up subsidizing the high hurricane risk groups living in low coastal areas. This is one end of the spectrum, where premiums do not depend at all on the risk. The other end is represented by private insurance companies, which theoretically base their premiums entirely on the risk.

The costs of hurricanes and indeed most disasters in the United States began their rapid increase long before the terms “global warming” or “climate change” became part of the parlance of our times. Those realities, however, will only increase the impetus for society to develop ways to intelligently deal with the risks and costs associated with extreme events, both hurricanes and other natural disasters. There is certainly a fair amount of intractability at the core of this problem; if there were not, there would be no motivation for studies such as this. However, with continued study and particularly with increased ubiquity of geospatial data, especially social geospatial data, there is hope that society will continue to improve its mechanisms for coping with the risks and costs associated with hurricanes. This study finds that currently, cost-benefit analyses performed for hurricane mitigation projects do not account for a significant aspect of mitigation, namely that mitigation leads to increased population and therefore increased damages during extreme events. Including this aspect would represent a significant improvement in the way society deals with hurricanes, because it would convey a more accurate picture of the tradeoffs involved in hurricane mitigation.

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