Modeling the Effectiveness of Hurricane Preparedness Damage Mitigation Strategies in Southeastern Virginia

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Abstract – **September 11, 2001 and Hurricane Katrina have recently demonstrated that American preparedness and disaster response efforts require improvements. Locally, the Southeastern region of Virginia is at risk for a major hurricane which could cost billions of dollars in damage. This project seeks to provide information to decision makers about the risks and tradeoffs involved in preparedness and response to a major hurricane. This project uses the HAZUS disaster modeling tool with other tools and models to analyze the decision options of evacuation, boarding up windows, and taking no action. The results of the analysis show that an evacuation for a 100-year storm would cost over $1 billion more than sheltering in place, although may cost more lives. Boarding up a fraction of windows does reduce damage. If this conclusion continues to be supported, Virginia policy makers need to focus their efforts and money on contingent emergency supply chains rather than on complicated lateral evacuation plans.**

I. Introduction

A. *What is the problem?*

In 1975, White and Haas [1] collaborated to publish an assessment of natural disasters research. They found that the previous research has failed to produce a significant impact on disaster reduction due to a lack of social, economic, and political factors [1]. More than 30 years later, policy makers and researchers of the United States still face the same problems. Since September 11, 2001 and Hurricane Katrina, however, much of America has articulated a greater need for increased preparedness and enhanced recovery in emergency response scenarios. Although many policy makers have striven to improve the preparedness of their region, their efforts are perceived by many to remain inadequate. Herein lies the problem of this project – modeling the effectiveness of hurricane preparedness and damage mitigation strategies in Southeastern Virginia for policy makers.

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B. *Why is it important?*

Billions of US dollars have been spent on disaster preparedness in the last several years, yet we still lack confidence in the amount and allocation of funds for preparedness. By quantifying the efficacy of available options in terms of hazard probabilities, capital, production losses, and lives, policy makers can better understand the tradeoffs in various allocations that protect their people, economy, and infrastructure. In doing so, individuals, businesses, and other pertinent components can reduce preparedness spending and recover from disasters in an acceptable time and cost.

C. *What has been done?*

The federal government, in collaboration with the Department of Homeland Security (DHS), published several documents in response to the demand for increased preparedness. The National Response Plan (NRP) was an all-encompassing framework authored by the federal government in the event of an emergency [2]. DHS also published various Homeland Security Presidential Directives (HSPD) that focus on topics such as management of domestic incidents, critical infrastructure protection, and national preparedness [3]. The Target Capability List (TCL) and Universal Task List (UTL), resulting from HSPD-8, has been constructed specifically to guide local governments in their efforts by defining preparedness functions across prevention, protection, response, and recovery broad preparedness missions, and by defining broad capabilities that regions need to perform these function effectively [4,5]. These documents are too broad to serve as useful metrics, but provide a starting point for more detailed analysis of a region's preparedness state.

D. *Project Mission*

This project develops a risk-based framework that informs people and businesses of the tradeoffs inherent in decisions made across preparedness and response to a major hurricane. By modeling various hurricanes and hurricane forecasts in the Hampton Roads region of Virginia, we can evaluate and analyze the risks and tradeoffs associated with implementing different decisions. An optimal scenario can then be used to develop a framework that will focus on an efficient response based on the mitigation of damage, casualties, and economic loss.

II. Review of Major Literature

A. Governmental Initiative

On December 17, 2003, HSPD-8

> "tasked the Secretary of Homeland Security, in coordination with the heads of other appropriate Federal departments and agencies and in consultation with State and local governments, to strengthen the preparedness of the United States to prevent and respond to threatened or actual domestic terrorist attacks, major disasters and other emergencies" [3].

It was not until HSPD-8 that the United States began to stress the need for a National Preparedness Goal (NPG). The Interim National Preparedness Goal was released by the Department of Homeland Security (DHS) on March 31, 2005, and the vision for the goal is stated as follows:

> "To engage Federal, State, local, and tribal entities, their private and non-governmental partners, and the general public to achieve and sustain risk-based target levels of capability to prevent, protect against, respond to, and recover from major events in order to minimize the impact on lives, property, and the economy," [3].

To this end, the DHS created the Universal Task List (UTL) which serves as the basis for defining capabilities as required by the NPG [4]. The DHS also prepared the Target Capabilities List (TCL) which is a list of the thirty-six specific capabilities and levels of capability that all levels of government, including states and localities, will be expected to develop and maintain to achieve the NPG [5].

The four documents mentioned above have led to multiple government contracts to research preparedness. This project falls under one of those contracts and has made use of both the TCL and UTL to help define scope and direction.

B. Virginia Preparedness Surveys

Several surveys of Virginians were used to parameterize various aspects of preparedness modeling. Bacot et al. [6] studied hurricane preparation among Virginia residents to quantify preparedness actions Virginians take and how they view the emergency response of their government. Urban [7] studied Virginians' attitudes towards emergency preparedness and identified similar values for preparedness in hurricanes, as well as studying general preparedness knowledge of residents. A quantitative understanding of the preparedness level of Virginians improves that ability to model behavior in a hurricane.

C. Hampton Roads Evacuation Simulation

The Virginia Transportation Research Council (VTRC) created a micro-simulation to model the Hampton Roads Hurricane Evacuation Plan [8,9]. Their research produced estimates of the number of vehicles which would be unable to evacuate due to traffic congestion – a factor contributing to the number of individuals seeking shelter in our study.

D. HAZUS-HM

FEMA has created a program that is designed to estimate potential losses from disasters. The potential losses the program, HAZUS (Hazards U.S.), includes are:

Physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure;

Economic loss, including lost jobs, business interruptions, repair and reconstruction costs; and

Social impacts, including estimates of shelter requirements, displaced households, and population exposed to scenario floods and hurricanes. [10]

We used the HAZUS technology to set up hurricane scenarios and estimate the damage from various probabilistic storms.

III. Methodology

Hurricane modeling and the quantification of preparedness and response decision effectiveness results from the integration of several modeling and simulation activities. This section describes the various activities and how they will be integrated to produce estimates of tradeoffs among preparedness options.

A. Evacuation Capabilities

An important decision in hurricane preparedness is determining whether conditions warrant the removal of citizens from areas at high risk to wind and water damage. In the low-lying Hampton Roads region, a hurricane storm surge could place citizens in considerable danger. Because there are over 300,000 estimated vehicles which would need to evacuate the region [9], it is essential to know if the roadway infrastructure can support this traffic volume in a reasonable amount of time. If vehicles would not be able to evacuate, they would impact the volume of citizens seeking shelter. Because this number is critical for our analysis, a thorough examination of the evacuation process was conducted. The Hampton Roads Hurricane Traffic Control Plan [9] is the document which outlines the order of events and the roles of involved parties during an evacuation. The plan states that the evacuation takes place in two phases: the first focused on removing citizens from regions bordering the Chesapeake Bay and Atlantic Ocean, and the second phase targeting the evacuation of the inland population [9]. To facilitate smooth traffic flow and deter congestion, different "metering rates" were established for highway on-ramps, which dictate the number of vehicles which will be allowed to enter specific ramps per hour. Using these figures, the Traffic Control Plan estimates that for both phases "more than 27 hours will be needed to completely evacuate potential traffic volumes generated by the 'at risk' population," [9]. To understand if this estimate holds true for a 100-year storm, and thus if 24-hours would be insufficient, the VTRC simulated the Hampton Roads evacuation in modeling language VISSIM. Details of the Traffic Control plan, such as the established metering rates and the level of hotel occupancy, which alters potential evacuees decision to evacuate or not, were coded into the model. The simulation proved that for a 100-year storm the 24-hour period is sufficient to evacuate the entire at risk population. When hotel occupancy is low, a Category 1 or Category 2 hurricane would allow for all evacuees to exit the region [8]. Because of these findings, vehicles denied entry on evacuation routes was not a factor in calculating the number of citizens seeking shelter.

B. Work Loss Estimates

The Bureau of Economic Analysis maintains many databases with detailed regional economic data. The "Personal income and detailed earnings by Industry" database was used to calculate the total annual economic output of the Hampton Roads region [11]. This personal income is a metric that can be used to measure regional productivity and the value of lost production in the region resulting from an evacuation. This study used these data in combination with estimates for evacuation rates to establish work loss estimates for the evacuation scenarios.

C. Damage Uncertainties

Tropical depressions are monitored and analyzed long before they ever strike the United States' coastlines. The National Hurricane Center (NHC) uses analytical tools to forecast the track and intensity of these storms to try and recognize and warn local authorities of approaching threats. The opportunity cost of making decisions in disaster scenarios is so great that it is imperative policy makers have accurate and precise information. Models that forecast the hurricanes have been constantly improving over the last few decades, but there is still a significant amount of uncertainty as seen in Figure 1.

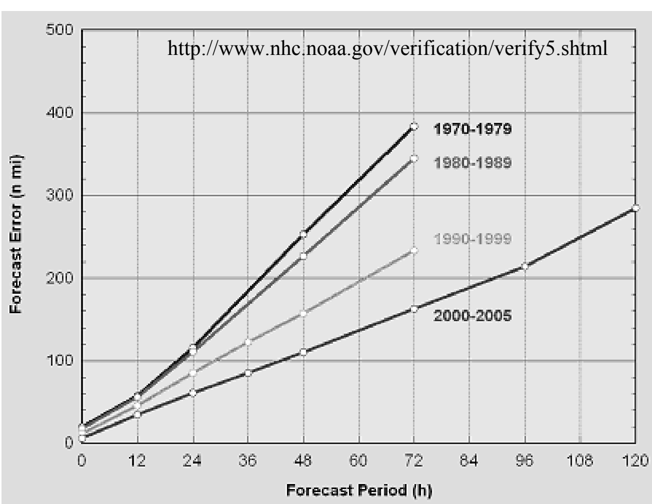

Figure 1: Forecast Track Errors by Decade for Atlantic Storms [12]

Once a forecast has been made, the storm can take one of three paths. It can get stronger, stay the same size and strength, or it can decrease in size and intensity.

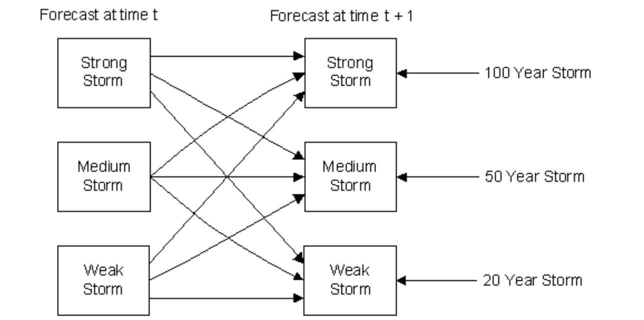

Figure 2: Possible Changes in Storm Strength

The probability of a storm changing levels is an important variable in the decision making process because of the opportunity cost of being wrong. In order to find the uncertainties from the forecasts, we analyzed data from all Atlantic storms hitting the East Coast for the last fifteen years. This amounted to over 6,000 forecasts. The forecast errors were plotted for all 24 hour and 48 hour forecasts. The distribution of the forecast errors are graphed in the results section.

Assuming that a storm forecast predicts a direct hit to the Hampton Roads area we can use the data to predict approximately how often the forecasts will have an error great enough to change the level of the storm. Based on the characteristics of hurricanes it is imperative to analyze the error in wind speed but also the error in position of the hurricane. As you move away from the center of the hurricane the wind dissipates. Using data from prior hurricanes we estimate that the wind speed decreases at a mean rate of 0.144 knots per nautical mile away from the center.

Data from the HAZUS simulations was used to determine the thresholds for different level storms. While running the different scenarios we looked at the peak wind speeds for not only the historical storm but also the probabilistic values for a 100-year storm, 50-year storm, 20-year storm. For the purposes of this project we assume that a "weak" storm is associated with a 0-20 year storm, a "medium" storm is associated with a 50-year storm, and the "strong" storm is a storm with a 100 year return period. From the table below we can deduce that a fifteen mile per hour change in wind speed will change the level of the hurricane. Specifically, a probability distribution describing the joint probability of a forecast resulting in either a wind speed or track error was partitioned according to the specific geography of the region and the average characteristics of hurricanes to produce estimates of the probability of a specific impact, given the 24-hr forecast of the 100-yr probabilistic storm.

Table 1: Peak Wind Speed

Storm	Peak Wind Speed (mph)	
	West of Track	East of Track
100-year	80-110	110-125
50-year	80-95	95-110
20-year	65-80	80-95

This data, coupled with the rate of decay of wind speed away from the center of the hurricane, tells us that the wind will cross a threshold every 90 nautical miles.

D. Hurricane Damage Estimates

HAZUS-MH is a GIS-based software simulation package produced by FEMA for assessing potential losses from floods, hurricane winds, and earthquakes [13]. It integrates current scientific and engineering knowledge with state-of-the-art GIS technology to produce estimates of hazard-related damage, including building damage, debris generation, persons displaced from their homes, and other useful metrics [13].

IV. Results and Discussion

A. Potential Impact of a 100-yr Probabilistic Hurricane

Figure 3 below, generated using HAZUS, illustrates the peak gust wind speed of a 100-year storm. The darker areas indicate the highest wind speeds.

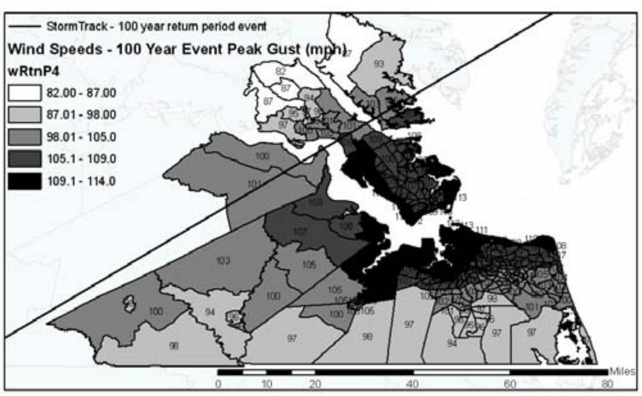

Figure 3: Peak Gust Wind Speeds for 100-year Storm

Figure 4 illustrates the economic damage, by census tract, to the Hampton Roads region for a 100-year storm. The darker areas are the most heavily impacted. This map corresponds closely with the peak wind speed, and it can be seen that the coastal areas bear the highest costs.

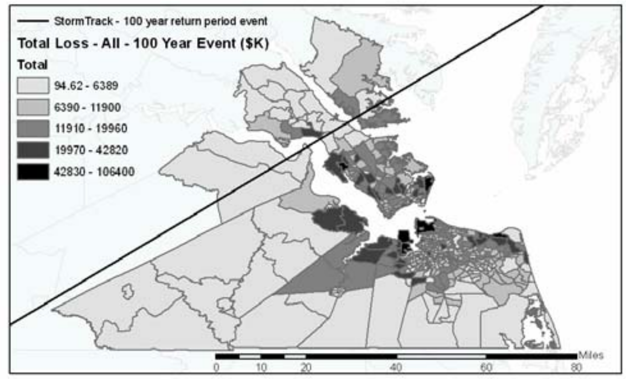

Figure 4: Economic Loss for 100-year Storm

Figure 5 illustrates the displaced household for a 100-year storm. The coastal regions are the most heavily affected.

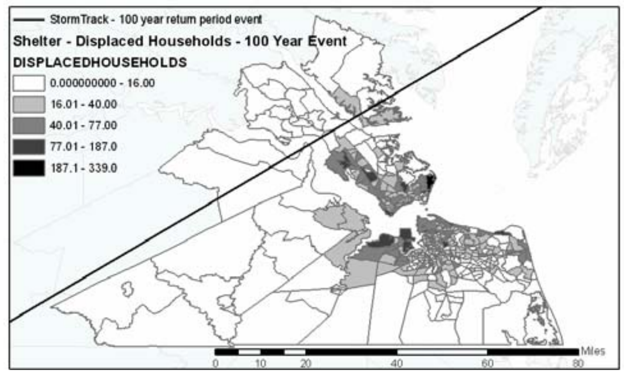

Figure 5: Displaced Households for 100-year Storm

Figure 6 illustrates the volume of tree debris for a 100-year storm. The inland areas of the Hampton Roads region experience the most tree debris.

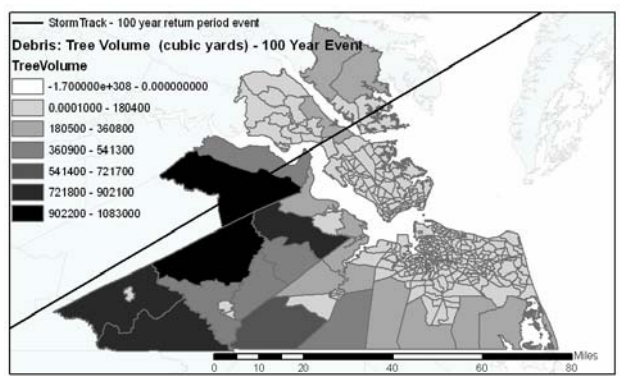

Figure 6: Tree Debris for 100-year Storm

In this analysis, two measures of impact to the Hampton Roads region were extensively examined: people seeking shelter (as a representation of loss of life) and economic loss. The economic loss figure is a combination of building damage and work loss factors. This project does not presume to attach a value to loss-of-life, but instead presents an analysis of tradeoffs across the multiple objectives.

After the HAZUS simulation was run for a probabilistic scenario, data could be gathered for storms of various severities. The capstone team chose the 100-year storm to analyze, since it is the most severe storm that has a probable chance of occurring within our lifetimes. This storm has sustained wind speeds roughly equal to a Category 1 or Category 2 hurricane. The HAZUS simulation results show that a 100-year storm, without any mitigation efforts, would result in approximately $4.2 billion of economic loss to the region. Additionally, approximately 2,800 people would require short-term shelter.

A number of mitigation scenarios were run to investigate the effects they would have moderating the damage of the storm. The first scenario involved the fortification of buildings using plywood boards. A survey by our team showed that, given 24-hour notice of a hurricane, 25% of Hampton Roads residents would choose to apply boards to their buildings [6]. Figure 7 below presents the economic loss and shelter required for the board scenario. It is easy to see that this mitigation strategy results in significant reductions to both measured variables. There is a 9.7% reduction in economic loss and 19.3% reduction in people seeking shelter. This amounts to $411 million and 537 people.

According to the HAZUS building inventory, there is approximately one billion square feet of residential and commercial space in the region. Given the ratio of 0.1 square feet of window to every square foot of building space [14], an average price of six dollars for a 4' by 8' sheet of ½-inch plywood, and a 25% boarding rate [6], twenty-seven million square feet of windows would need to be covered at an approximate cost of $3.3 million (about $20 per household).

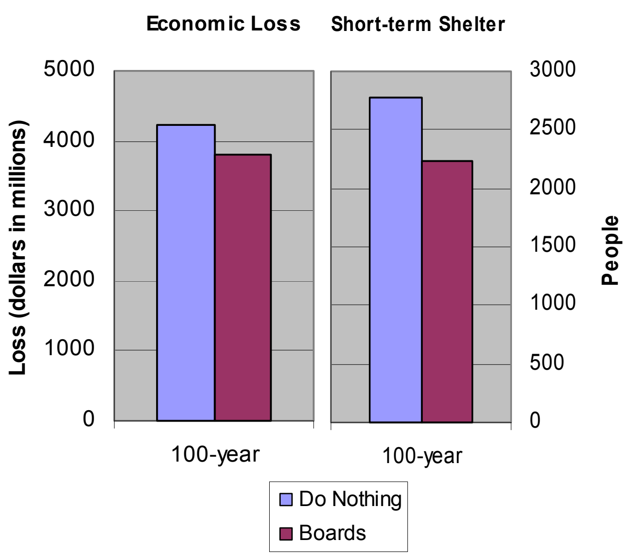

Figure 7: Results from Board Scenario

The second scenario considered was an evacuation of Hampton Roads residents. Given our study of 24-hour notice, approximately 21% of Hampton Roads residents would choose to evacuate the area [6]. Figure 8 below compares the economic loss and shelter needed for the evacuation scenario to the base case scenario.

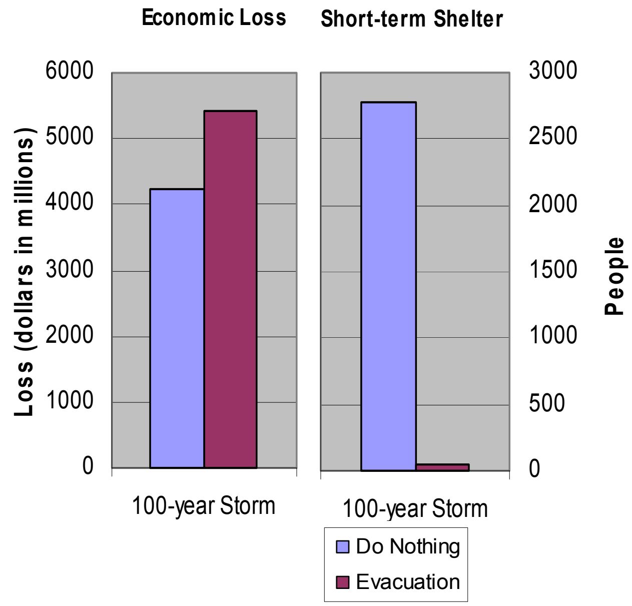

Figure 8: Results from Evacuation Scenario

An evacuation would result in increased economic loss due to the decreased economic output resulting from a lower number of working people in the area. This amounts to a 28.3% increase in economic loss, or approximately $1.19 billion. The HAZUS simulation returned that, in an evacuation, there would not be anyone seeking shelter. In an evacuation, demand for shelter resources would be greatly decreased, and it is assumed that temporary accommodations could handle all residents forced out of their homes.

B. Tradeoffs

The analysis of the track errors and intensity errors for the forecasts show that the effects of the storm are a combination of the two variables. To determine the transition thresholds we looked at the tradeoff between wind speeds and track distance and realized that the two variables are inversely correlated. Furthermore, wind speeds are proportional to the square-root of the track error. This allowed the team to create our thresholds by using the wind speed and track error values to solve for needed parameters.

Creating a model in Excel allowed us to determine the amount of forecasts that fell into each bin. Figure 9 below shows the uncertainty of 24-hour forecasts for a 100-year storm. The data tells us that when 100-year storm is forecasted 24 hours before expected impact, there is a 40% chance that the storm will be weaker when it reaches the Hampton Roads area.

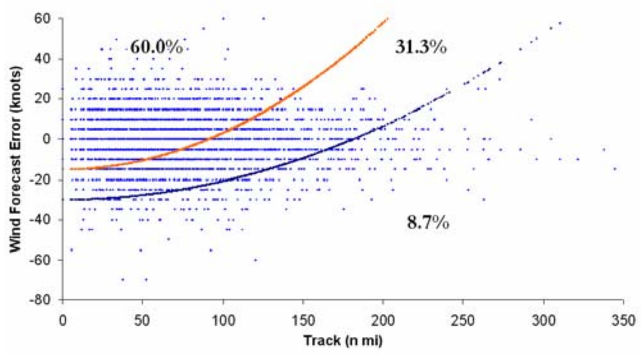

Figure 9: Transition Probabilities for 24-hr Forecast of a 100-yr Storm

The storm is uncertain and a 24-hr forecast of a 100-yr storm could result in a final storm with varying characteristics. Policy makers need to understand the efficacy of the information in order to lead an effective preparedness effort.

Table 2 below provides further information on damage results for hurricanes of other recurrence rates. Note that for a 20-year storm, putting up boards no longer decreases economic damage.

Table 2: Hurricane Losses Results Given a 24-hr Forecast of 100-yr Storm

	100 year storm 60%		*50 year storm 31.3%*		*20 year storm 8.7%*	
Decision	shelter	losses	shelter	losses	shelter	losses
Mandatory evac.	0	$5.41 B	0	$1.40 B	0	$1.47 B
Boards	2240	$3.81 B	581	$1.35 B	13	$.28 B
Nothing	2777	$4.22 B	679	$2.59 B	33	$.28 B

C. Summary of Results

The simulation showed that the use of boards would lower both economic loss and loss of life (through lowering people seeking shelter) by substantial margins. An evacuation would potentially eliminate loss of life, but results in a drastic increase in economic loss to the area – on the order of $1.19 billion.

D. Recommendation

In the end, it will be up to policymakers to determine which tradeoffs are appropriate for the region. Given the results of the simulation, the team would like to note the effectiveness of boards given a Category 2 storm, and the ineffectiveness given a weaker storm. An evacuation appears too costly to ever be a reasonable decision, even within 24-hr of a 100-yr storm.

E. Future Work

This work is meant to serve as a starting point for future iterations of the project. Disaster preparedness efforts have come into the forefront of homeland security planning in recent years, and it is likely that new data and methodologies will be available to planners in the future. This team recommends that improved and emerging resources be used to refine the results presented in this report and to conduct new analyses.

It is the hope of this Capstone team that future teams will draw upon the resources (data, literature, personnel, etc.) identified during this project to further the disaster preparedness effort.

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