Fourth International Conference on Construction in the 21st Century (CITC-IV)
"Accelerating Innovation in Engineering, Management and Technology"
July 11-13, 2007, Gold Coast, Australia

Hurricane Wind Damage Simulation for Coastal and Inland Communities in Florida

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Abstract
An unprecedented six major hurricanes made landfall along Florida and neighboring Gulf states during the past two years. The latest and by far most devastating was Katrina, the worst natural disaster in U.S. history in terms of reconstruction costs and populations displaced (>500,000). In response, the University of Florida has begun hurricane and flood damage simulations for both inland and coastal communities in Florida. The simulation software used for this study, "hazards US" (HAZUS), computes estimates of potential damage to residential, commercial, and industrial buildings as well as critical infrastructure and services based on the quantities and characteristics of these assets.

Researchers have generated hurricane scenarios based on historical storms and probabilistic storms ranging in intensity from Category 1 to 5. Simulations use population, building, topographical and tree cover data from the US Geological Survey and the U.S. Census Bureau. GIS outputs to be presented include maximum wind speed and flood level mapping, critical facilities impact, building inventory impact, shelter and temporary housing requirements and debris generation specific to hurricane intensity, track and other characteristics. The intent of this research effort is to correlate the extent of hurricane damage and debris generation to wind speed.

Keywords
Hurricanes, Buildings, Damage, Debris, Economic Loss

1. Introduction

HAZUS-MH is a natural hazards loss estimation tool distributed by the U.S. Federal Emergency Management Administration (FEMA). HAZUS software generates rapid estimates of damage and losses from hurricane events and other hazards. A total of eleven hurricane scenarios were modeled in HAZUS for Nassau and Alachua counties, representing coastal and inland communities respectively. Five events were recreations of actual hurricanes dating back to 1896. Four storms were hypothetical "worst case" hurricanes having a one-time chance of occurrence in 100 and 200 years respectively. The final two scenarios were coastal and inland recreations of Katrina-like category 4/5 storms. The intent of this study was to define the correlations between wind speed generated by these Saffir-Simpson category 1-5 storms and damage to critical infrastructure, shelter requirements, building damage, debris generation and economic loss.

2. Methodology

HAZUS estimates the losses caused by hurricanes with a methodology that directly ties economic losses to building damage estimates generated by the model. Using a dynamic "hazard-load-resistance-damage-loss" methodology (Vickery et al., 2006), the model calculates wind forces for each geographic unit in the study area. Census tracts are the default unit of analysis for hurricane scenarios. Once the wind field data has been calculated for the study area, HAZUS estimates wind loads and the effects on structures, as well as the resistance of different building types, and then applies specific functions to produce estimates of damages and economic losses for building occupancies and types within each census tract. HAZUS has by default over two hundred layers of information for use in analysis. Default layers used in this study include US Census (2000) demographic data, USGS vegetation, land use/land cover data, essential facilities, historic hurricane data from HURDAT (1886-2001), and building inventories (2000). Economic losses are expressed in U.S. dollars (2002).

3. Results

Coastal Hurricane Scenarios: Nassau County

Nassau County is an Atlantic coastal region of 1,728 km^2 land area and contains 8 census tracts. There are over 21,000 households in Nassau County which has a total population of 57,663. There are an estimated 23,000 buildings in the Nassau County with a total building replacement value (excluding contents) of $US 3.1 billion. Approximately 99% of the buildings and 87% of the building value are associated with residential housing.

Storm of century (1898)

This historical scenario modeled the impact of a category 4 hurricane making landfall north of Nassau County. Data supplied by the U.S. National Weather Service (NWS) produced estimated maximum wind gusts of 275 km/h and maximum sustained winds of 217 km/h (Figure 1). Damage to buildings and essential facilities in Nassau County are extensive. The model predicted 24% of all buildings in the area would be destroyed; 48% of buildings would have at least severe damage. Severe damage is defined as major window damage or roof sheathing loss, roof cover loss, and water damage to building contents. Amelia Island, which has the most exposure to wind hazard in this scenario, suffers the greatest damage and concentration of debris. The storm will displace an estimated 11,000 households and shelters will need to accommodate at least 2,500 people. Total economic losses are calculated to be $US 2.5 billion, $US 2.1 billion of which are building losses.

Hurricane Dora (1964)

This scenario originates from the HAZUS historical database. When the hurricane made landfall about 95 km south of Nassau County, Dora was a strong category 2 storm. Winds in the study area showed maximum gusts of 153 km/h and 105-120 km/h maximum sustained winds. Damage is slight, with the majority of damage to buildings categorized as minor (5% of total structures). The model predicted displacement of thirty households. Total economic losses are estimated at $US 32 million, $US 30 million of which are building losses.

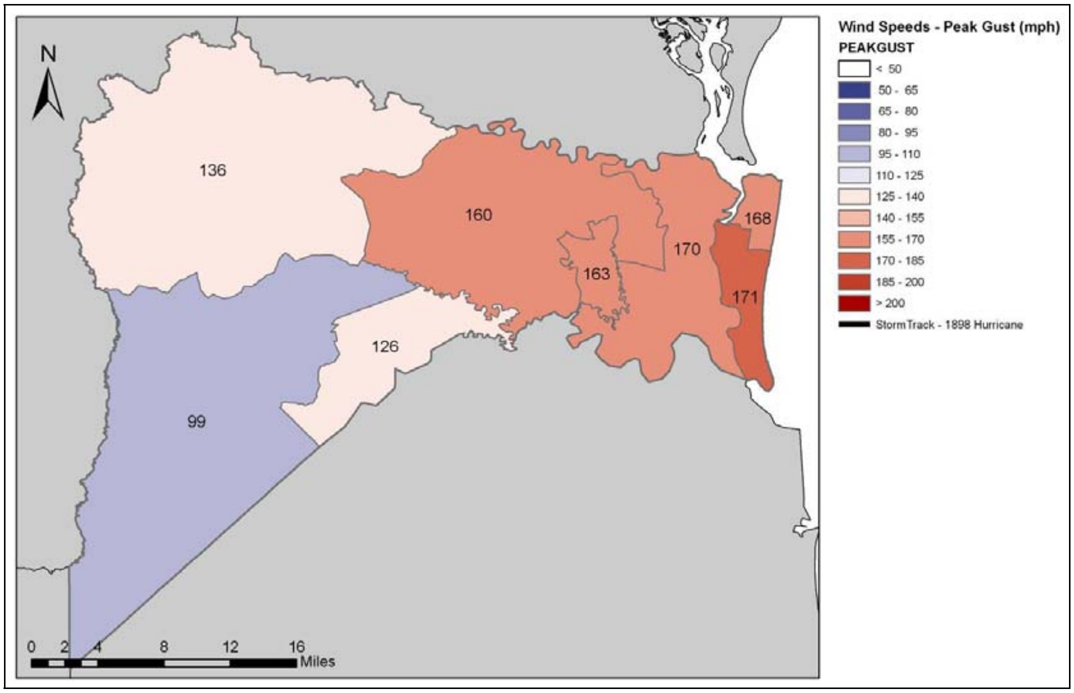

Figure 1. Peak wind gusts (miles per hour, 1.0 mph = 1.6 km/h) from "storm of century" (1898), Nassau County, Florida, U.S.

Hurricane "Katrina"

The parameters of this hypothetical category 4 storm were designed to mimic the now infamous Hurricane Katrina so that maximum winds and storm surge would impact Amelia Island, Nassau County's economic and population center. Storm landfall, similar to Dora, takes place 65 km south of Nassau County. Winds are strongest at the coast with 264 km/h maximum gusts and 193-207 km/h maximum sustained winds. Like the 1898 hurricane, Nassau County is expected to have major damage. HAZUS predicts 20% of all buildings will be destroyed and that 46% will have at least severe damage. Essential facilities are hard hit and have >50% probability of receiving at least moderate damage. The storm will displace an estimated 11,000 households and shelters will need to accommodate at least 2,500 people. An estimated 18,000 truckloads will be required to clean up debris in the aftermath of the storm. In total, the model predicts economic losses to top $US 2.3 billion, $US 2 billion of which are property related from windstorm alone. The U.S. National Weather Service (NWS) provided a SLOSH (Sea, Lake, and Overland Surges from Hurricanes) simulation for this model to evaluate the storm surge produced by the hurricane. Results show peak surge heights of 14.9 feet. Were storm surge modeling in HAZUS possible, it is likely that total economic losses for this scenario would exceed those of the 1898 hurricane.

100 and 200 year probabilistic hurricanes

A 100-year probabilistic storm has a 1 in 100 chance of occurring in any single year. HAZUS predicted a storm tract that skirted the western edge of Nassau County, sparing Amelia Island from the worst winds. Peak gusts in the study area were estimated at 193 km/h. Building damages in Nassau County are expected to be minor, with 20% of total structures damaged, 77% of which HAZUS categorized as minor. 170 households are displaced by the storm. No essential facilities are predicted to have >50% chance of moderate damage. The 100 year storm is expected to produce greater loss than Hurricane Dora. Total economic loss is $US 90 million, $US 79 million of which is property loss. The 200-year probabilistic storm, like the 100-year, follows an inland route. The storm track is closer to Amelia Island, however, unleashing higher, more damaging winds. Peak gusts are 193-196 km/h. The number of damaged buildings increases to 32% of total structures, although the majority of damage (65%) is minor. Moderate damage now comprises 28% of the total damage. Essential facilities have a low probability of suffering moderate damage. The number of displaced households increases three fold from the 100-year scenario to 507 households. Total economic losses increase to $US 225 million, $US 190 million of which is related to property loss.

Inland Hurricane Scenarios: Alachua County

Alachua County is an inland region of 2,512 km^2 land area within <150 km of the Atlantic coast and contains 43 census tracts. There are over 87,000 households in the region and has a total population of 217,955. There are an estimated 68,000 buildings in Alachua County with a total building replacement value (excluding contents) of $US 15.4 billion. Approximately 98% of the buildings (and 67% of the building value) are associated with residential housing.

Storm of century (1896)

This scenario produced damage and loss estimates that are similar to that of the 100 year probabilistic scenario. The storm track did not pass directly through Alachua County, sparing urban areas from the impact of 172 km/h maximum wind gusts. Damage to essential facilities was minimal. Economic losses were estimated at $US 104 million for property damage and totaled $US 115 million.

Hurricanes Frances and Jeanne (2004)

Frances and Jeanne in 2004 were very recent storms that were used to compare simulated damage to actual damage and debris. Results for Frances found that HAZUS estimates were far below those recorded by Alachua County. Combined, HAZUS underestimated the actual tree debris collected in Alachua County by nearly a factor of three. HAZUS estimated property damage losses of $US 1.1 million from Hurricane Frances, $US 700,000 of which was from damage to buildings. This estimate is dwarfed by the $US 10.7 million in actual structural damages that Alachua County registered. For the Hurricane Jeanne scenario, HAZUS overestimated losses from storm damage to buildings. The actual recorded losses in Alachua County were $US 2.9 million. From HAZUS, estimated losses from Hurricane Jeanne came to a total of $US 4.2 million, with $US 3.2 million from building damage alone. The discrepancy between simulated loss estimates by HAZUS for Frances and Jeanne and the estimates collected by Alachua County after the storms may have shown a weakness in HAZUS to accurately model these low intensity (subcategory 1) wind storms. In addition, both of these storms struck Alachua County within 4 weeks of each other. HAZUS default values do not have the ability to model structures partially damaged by previous storms, or, soil saturation and tree damage which in actuality, caused the vast majority of structural damage to buildings.

Hurricane "Katrina"

The storm track of the hypothetical "Katrina" storm approximates that of the 1,000 year probabilistic storm envisioned by HAZUS. The predicted maximum wind gusts are 272 km/h, more than 56 km/h over those for the 1,000 year storm, making this scenario an extremely unlikely event. Were this scenario to take place the result would be catastrophic according to the HAZUS loss estimates. All essential facilities would have more than a 50% chance of having at least moderate damage. Approximately 47,000 households would be displaced. Alachua County would suffer over $US 10 billion of property losses and have a total of $US 11.8 billion in total economic losses. The losses predicted exceed the $US 2.2 billion total losses for a 1,000 year probabilistic storm scenario by a factor of five.

100 and 200-year probabilistic hurricanes

The 100 year event had lower peak wind gusts than the 1896 hurricane scenario but produced more damage to buildings. One reason for this may be that the path of the 100 year storm was closer to dense urban areas in Alachua County whereas the 1896 storm had the greatest impact on the northwest portion of the county. Total economic loss was calculated at $US 188 million, $US 162 million of which was property damage. HAZUS, in contrast to Alachua County's MEMPHIS software assessment, showed more intense damage to structures from wind. The 200 year storm event generated maximum wind gusts of 169-193 km/h and resulted in greater and more intense damage than the 100 year storm. HAZUS estimated total economic loss at $US 422 million, $US 347 million of which was property loss. These losses are more than twice those of the 100 year storm.

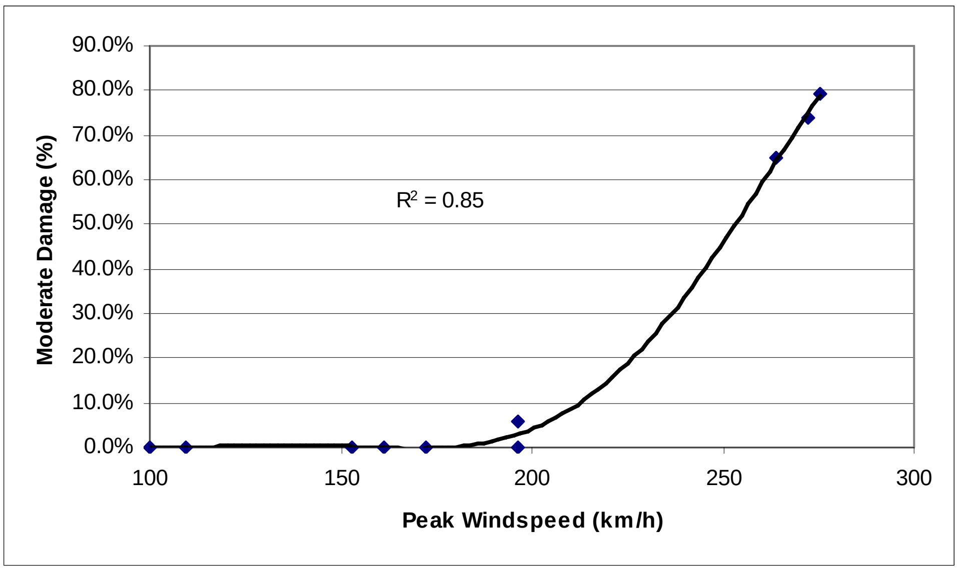

Figure 2. Percentage of critical facilities sustaining moderate damage vs. peak wind speed.

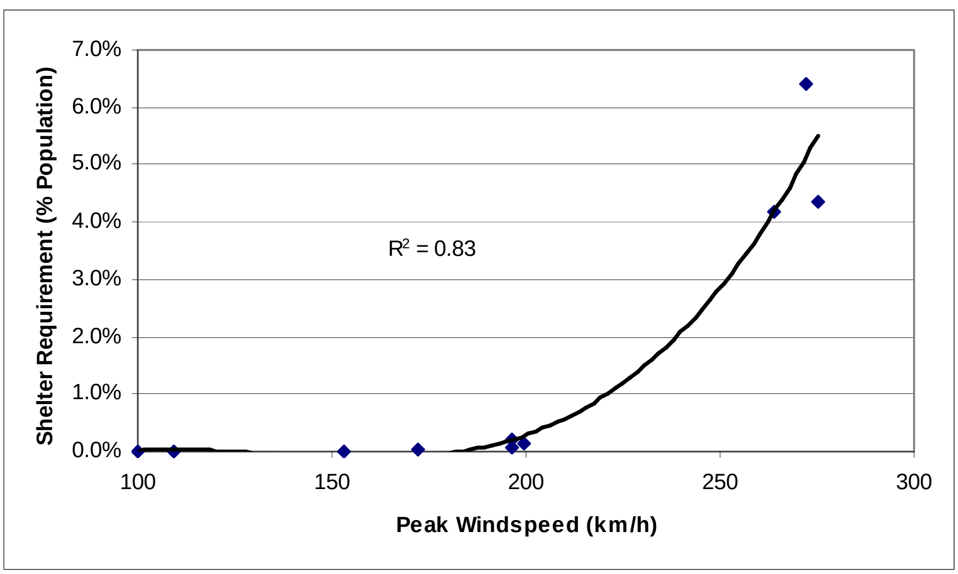

Figure 3. Percentage of population requiring temporary shelter vs. peak winds peed.

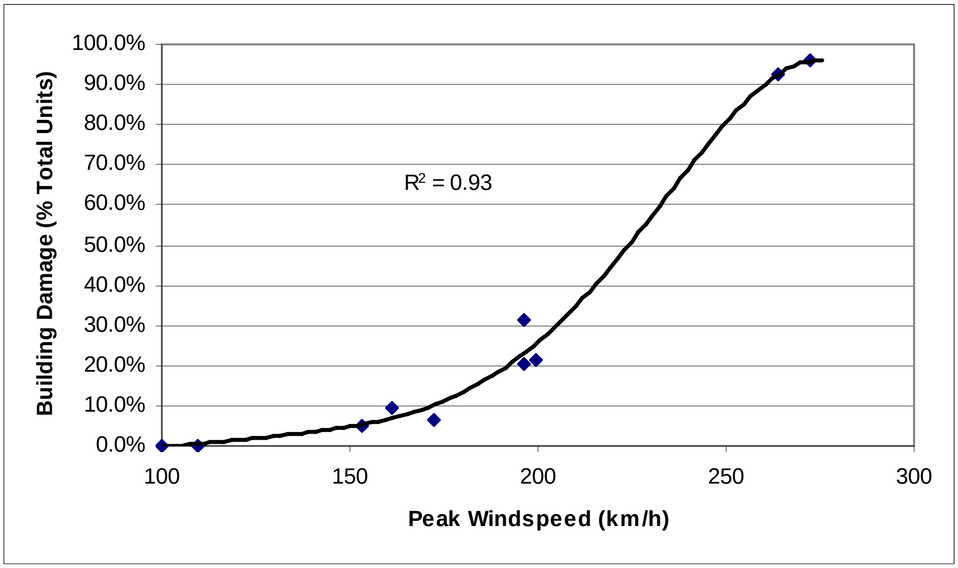

Figure 4. Percentage of buildings sustaining damage vs. peak wind speed.

Using the eleven scenarios representing hurricanes in each Saffir-Simpson category (1-5), trend analyses were prepared to determine the extent of damage to buildings and critical facilities, shelter requirements, debris generation and economic loss associated with intensity of peak and sustained wind speeds (Figures 2-6). Results conclude that in all of these areas, the increase in damage, shelter requirements, debris generation and economic loss is exponential with respect to increases in peak and sustained wind speeds beyond certain thresholds.

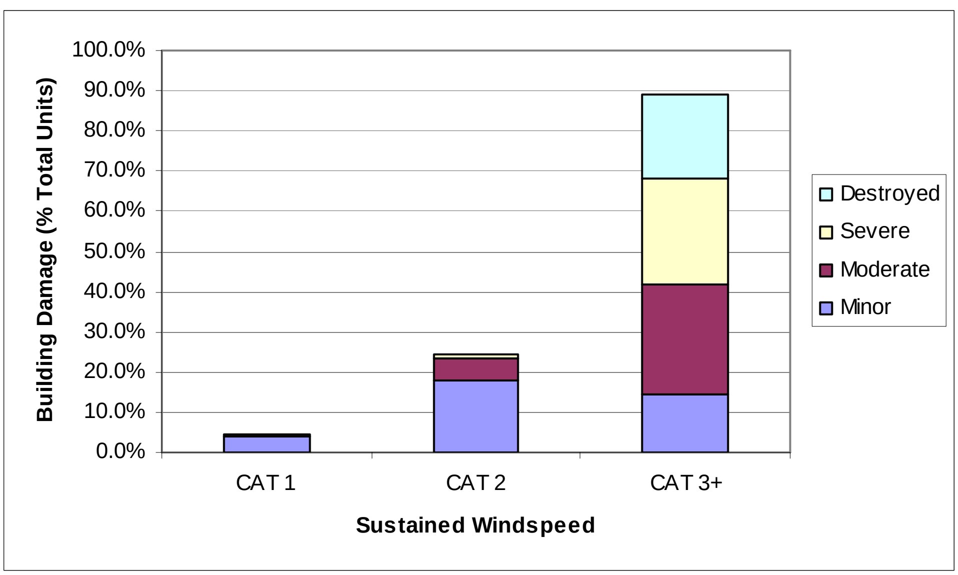

Figure 5. Percentage of buildings sustaining minor, moderate, severe or total destruction vs. hurricane category.

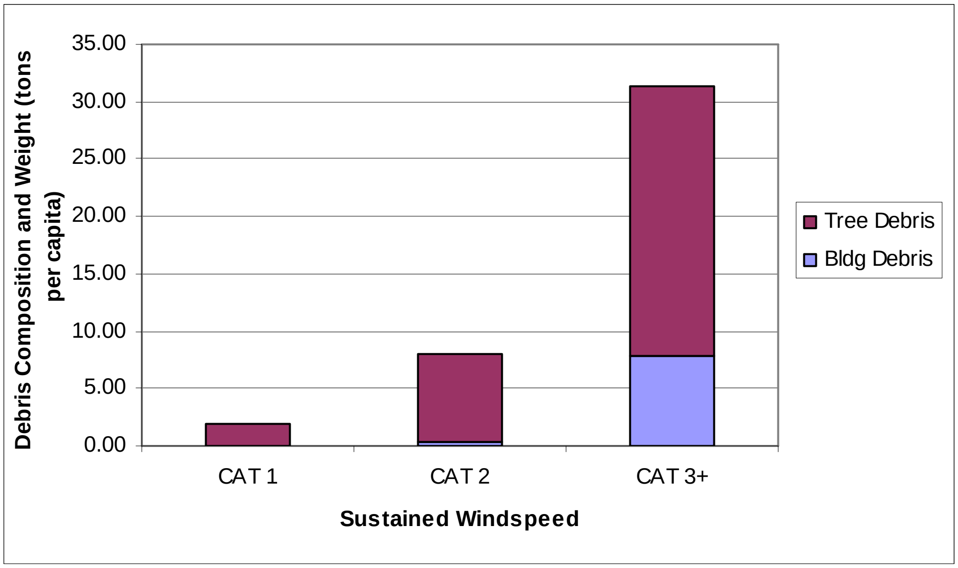

Figure 6. Percentage of building and tree debris generated vs. hurricane category.

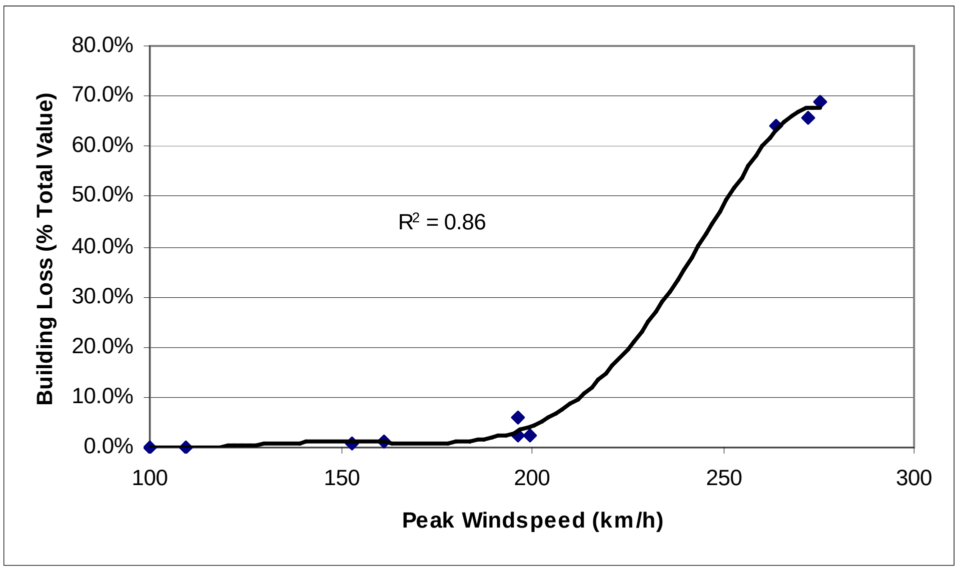

Figure 7. Building loss (% of replacement value) vs. peak wind speed.

4. Summary

Results show that HAZUS estimates of building and critical facility damage, temporary shelter requirements, debris generation and economic loss following actual and hypothetical Saffir-Simpson category 1-5 hurricane simulations in both Nassau and Alachua counties follow a similar, non-linear pattern (r = 0.83-0.93). Results indicate that little building damage occurs until peak wind speeds exceed approximately 185 km/h. Beyond this point, damage, displaced populations, and economic loss increases exponentially with respect to increases in peak wind speed. However, as shown in this study and verified by others (Vickery et al., 2006), HAZUS is more likely to underestimate losses and damage associated with low intensity storms and lower wind speeds. In addition, HAZUS demonstrated difficulty in combining windstorm damage with building damage resulting from falling trees (a concern for rural communities), coastal surge and flood damage, and damage conditions caused by a preceding storm.

5. References

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