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Hurricane Preparedness: Community Vulnerability and Medically Fragile Populations

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Hurricane Preparedness: Community Vulnerability and Medically Fragile Populations

by Joshua G. Behr & Rafael Diaz

Introduction

In August 2011, Hurricane Irene originated off the coast of Africa as thunderstorms and reached full-blown storm status near Martinique. The storm then traveled through the Caribbean, making landfall and achieving hurricane status over Puerto Rico. The storm continued on to make U.S. landfall as a strong tropical storm in the Outer Banks of North Carolina. Then it passed through Hampton Roads and traveled along the Atlantic Coast through New Jersey and New York.

As the storm developed in the Atlantic and headed for the U.S., both the news media and emergency officials warned of its impending severity, and satellite imagery was widely broadcast (**Figure 1**). The event brought over 20 inches of rainfall to several Hampton Roads localities and resulted in extensive property damage and flooding in the Mid-Atlantic and New England regions. Irene is ranked by the National Oceanic and Atmospheric Administration (NOAA) as one of the costliest Category 1 storms in the nation's history causing an estimated damage totaling $15.8 billion and resulting in 41 direct deaths in the U.S.[1,2]

Severe storms are characterized as a public risk because the impact is broad-based, overwhelming and viewed as beyond the control of the individual. While the hazard itself is beyond individual control, household evacuation is a widely accepted action that may substantially lessen suffering, emotional trauma and discomfort associated with remaining in flood- and wind-ravaged communities. In addition, evacuation may thwart acute injury that otherwise may occur during and in the immediate aftermath of the storm.

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There is a perception that evacuation is a function of individual resources, such as access to transportation, cash-on-hand and access to credit. Another perception is that the propensity to evacuate is proportional to vulnerability. Households with elderly and medically fragile populations, for example, are least able to cope with storm-related disruptions to normal routines and are more prone to acute injury. All else equal, one would expect the propensity to evacuate to be higher for the elderly and medically fragile relative to less vulnerable populations, even when controlling for income and resources. Yet this is not the case. Our nation's low evacuation rates, including those estimated for hurricanes Irene and Isabelle, inform us that many Virginia and North Carolina residents with means and ability, as well as those with chronic medical

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"…frequent encounters with "close call" storms may engender household complacency and a false sense of security in dealing with the next storm event."

Figure 1. Satellite Imagery of Hurricane Irene

Hurricane Irene approaching the Outer Banks of North Carolina on August 26, 2011.
Source: National Oceanic and Atmospheric Administration. http://www.nnvl.noaa.gov/Default.php

conditions, do not necessarily evacuate. Clearly the reasoning leading to decisions to stay, rather than to evacuate, must be better understood.

Ongoing research conducted at Old Dominion University's Virginia Modeling, Analysis and Simulation Center (VMASC) is beginning to untangle the factors that contribute to citizens' perceptions of risk and social vulnerability, including those factors weighed in the household decision to stay or leave in the face of an impending severe storm, aptly referred to as the household decision calculus. We are finding evidence that supports an intuitive understanding of how populations prepare for and respond to severe storm events. We now know, for example, that evacuation and sheltering decisions are made as a household unit within the broader context of familial and social networks. These social capital networks, which surround the household, include extended family, friends, associates and colleagues upon which the household may coordinate and draw financial, emotional and knowledge-based resources. Assessments of impending risk, how to prepare for storms, what resources may be available, and exit strategies, routes, and destinations are shared within these networks. Further, the medical disposition and fragility of members within a household's network are fundamental anchoring factors that tie the household to shelter in place rather than evacuate.

We also know that frequent encounters with "close call" storms may engender household complacency and a false sense of security in dealing with the next storm event. Close calls feed skepticism about the messaging surrounding the severity of the next storm leading to a tendency for some households to engage in discounting, a process whereby households may downplay the forecasted category of the storm and perceive it to be a lesser category, which in turn impacts the propensity of the household to evacuate. In addition, past exposure to storm-related loss may reinforce a sense of fatalism. Not surprisingly, households tend to draw upon past experiences, giving disproportionate weight to the most recent storm, to evaluate their need to prepare for a future event. If households have modestly prepared for past severe weather events and have recovered from them satisfactorily, then there is a sense that they will be able to manage more serious future storm events. Essentially, these past experiences form a type of benchmark and individuals may tend to underestimate the seriousness or risk of future severe weather events.

Community Vulnerability Indices

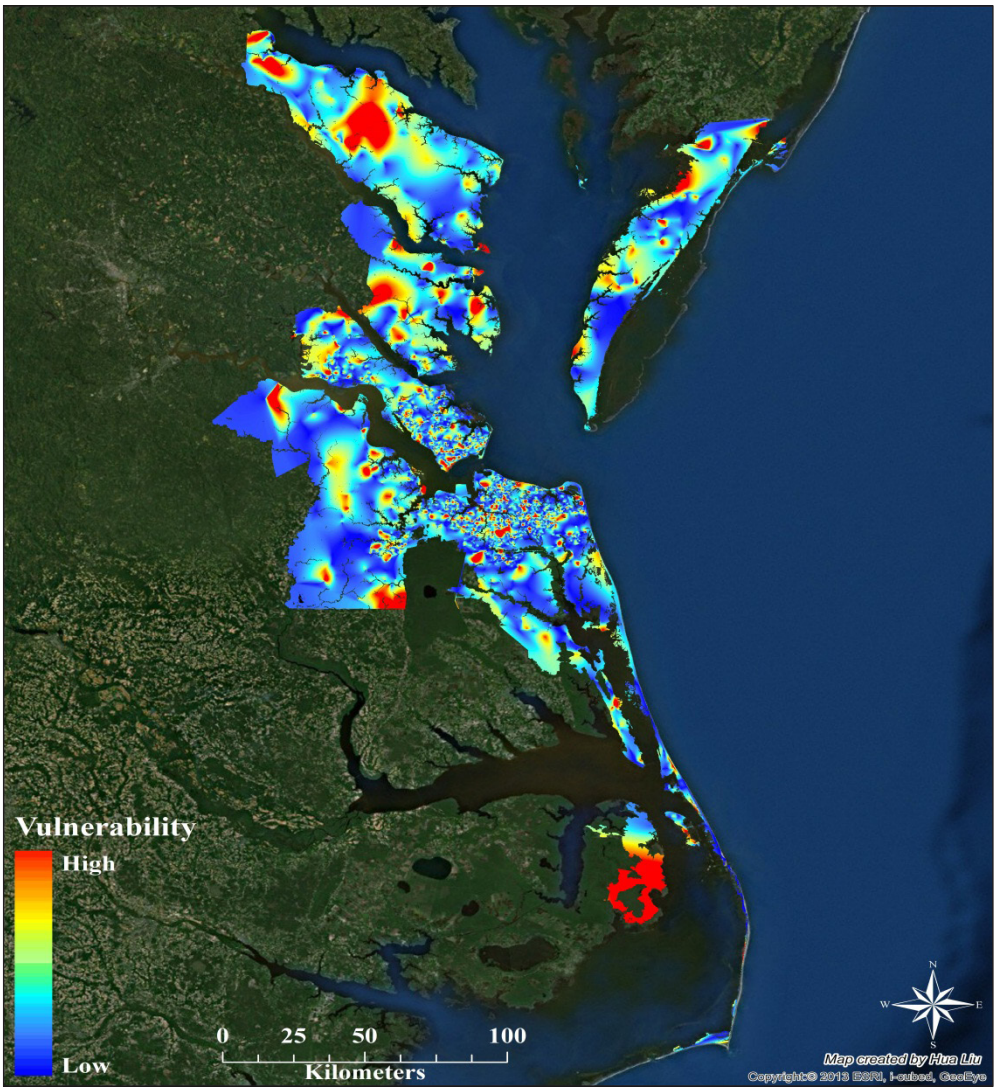
To better explain sheltering and evacuation decisions, we have characterized multiple dimensions of household vulnerability and illustrated how these may vary across Southeast Virginia and Northeast North Carolina by developing vulnerability maps. The maps stem from our interviews of over 7,000 households across 24 localities following Hurricane Irene. **Table 1** lists these various dimensions of vulnerability.

Understandably, since particular populations and geographies may exhibit characteristics along any number of these types of vulnerability, it is possible to construct further composite measures of vulnerability that capture the cross-pressure or synergistic dynamic at work in geographic areas that are especially likely to suffer from a severe storm event. **Figure 2** illustrates the most general overall composite measure of vulnerability for the greater Hampton Roads Region, defined here as the 24 localities in the Virginia Beach-Norfolk-Newport News, VA-NC Metropolitan Statistical Area (MSA), in which all vulnerability indices are combined; it is a further weighted index of the other indexes of vulnerability listed in Table 1.

Table 1. Measured and Mapped Vulnerability Indices

Financial	Assistance–activities of daily life
Risk perception	Social-familial network
Fatalism-efficacy	Personal responsibility
Mobility	Aged
Sensory	Dependent children
Mental cognition	Single parent household
Medical regimen	Preparation-mitigation
Healthcare access	Theft perception

Figure 2: Overall Composite Vulnerability



Map generated by ODU project team member Dr. Hua Liu.

Conceptualizing Vulnerability

The American collective conscious retains images of the destruction wrought in flooded communities stemming from severe weather events, whether it is swollen rivers in the Midwest, engorged streams in the Mountain States, or storm surge in the Gulf Coast, Mid-Atlantic, and Northeast coastal zones. These images include rooftops of suburban neighborhoods inundated with water, stranded people, livestock, and pets being ferried by emergency responders, and orderly rows of cots within a local high school gymnasium being used as an emergency shelter. Such images are accompanied with heart-wrenching stories of adversity and personal loss, family breakup, psychological scarring, and dashed dreams.

The concept of vulnerability is both at once familiar and ambiguous. Through the lens of shared media, Americans have an awareness of the fragile nature of both our social and built systems (buildings, roads, bridges, tunnels, sewerage and water, electrical and communication systems, etc.). We have an appreciation of not only how our physical environment and infrastructure may be vulnerable, but also a sense of the violent impact these events have on the fabric of household and communities. Traditionally, vulnerability assessments have focused on buildings and critical infrastructure. However, a more realistic understanding of vulnerability must also consider the social, psychological and resource dispositions of households. As we all understand, people and society interact with, and are conditioned by, the environment, so it is a challenging undertaking to conceptually untangle and differentiate among the different types of community vulnerability, let alone specify practical measures for them.

A fundamental insight is that community vulnerability neither falls equally across society nor is equally distributed spatially across our

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"Even a low category storm, downgraded tropical storm, or a near-miss event may alter the normal patterns of regional work and commerce, impacting the functioning of many households."

geography. In addition, particular populations or geographies are likely to simultaneously exhibit multiple vulnerability characteristics. There is an interaction dynamic at play when an area or population is experiencing several vulnerabilities at once. This compounded, or "hyper-vulnerability" as we have coined it, can explain dissimilarities among households in their preparation for an impending storm, in weathering the actual storm, and in managing post-event hurdles in the process towards wholeness and recovery. As one may imagine, many types of vulnerability, such as those associated with chronic medical conditions, disability or aging, may be exacerbated in an environment of limited financial resources.

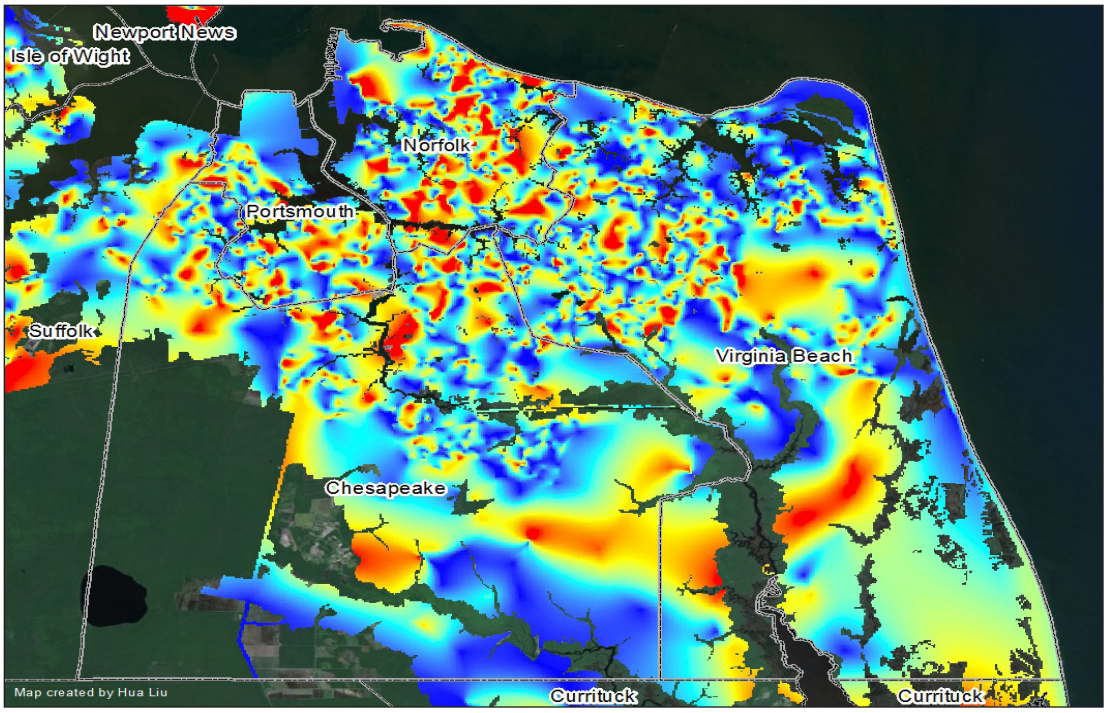
Financial Vulnerability

Financial vulnerability is a household's capacity to absorb the financial impact of a disrupting severe storm event. Even a low category storm, downgraded tropical storm, or a near-miss event may alter the normal patterns of regional work and commerce, impacting the functioning of many households. Workers may be furloughed without compensation prior to and after the storm. Storm-related preparation in the form of food, fuel and logistics may impose demands upon the household's finances. These disruptions in work patterns and household income as well as the expenditure of household resources for preparation and evacuation have financial implications. Households with modest resources or limited familial and social networks to draw upon are least able to manage financial perturbations that have the potential to overtax the resources of the household and place the household in untenable financial straits. Unplanned costs or disruptions in normal income may jeopardize the ability to cover rent or mortgage payments, which may have long-term consequences for the stability of the family unit long after the storm has passed.

The following are five indicators of household financial vulnerability: (1) loss of pay; (2) loss of vacation time or sick time; (3) difficulty of covering next month's rent or mortgage payment due to the loss of one week's pay; (4) difficulty of covering next month's rent or mortgage payment due to the loss of one month's pay; and (5) absence of enough cash or credit to support the household for five days outside the region. We conducted interviews with households shortly after Irene to gather empirical information related to each of these five indicators.

Through a structured process of engaging subject matter experts across the region, these indicators are weighted in their relative importance and then combined to form an index of financial vulnerability. **Figure 3** illustrates the mapping of this financial vulnerability index for the South Hampton Roads portion of the region. Red gradient areas are suggestive of concentrations of households that do not have the full capacity to handle the cost of storm-related preparations and evacuation as well as the larger economic vicissitudes

Figure 3: Financial Vulnerability



Map generated by ODU project ream member Dr. Hua Liu.

stemming from the threat of a severe storm. Blue gradient areas indicate concentrations of households that are better able to muster resources necessary for preparation and evacuation and are less subject to the long-term consequences of broader economic developments.

Notice that our non-traditional conceptualization of financial vulnerability has little to do with the ability of a household to manage the financial stresses associated with real property, such as the primary dwelling, which may be damaged or destroyed due to wind and surge in a catastrophic event. Certainly, with few exceptions, households suffering major structural damage to the primary home will face challenges. Yet our approach is not nearly so blunt and registers the financial toll of severe weather events even when property is not damaged as well as providing an indication of propensity to evacuate, both of which are essential to emergency planners interested in estimating evacuation and as well as forecasting communities' speed and ability to recover.

Medical Fragility Vulnerability

The concept of medical fragility addresses households that have conditions or impairments that limit what would be otherwise the normal activities of daily living. A generally accepted measure of disability is loss of some or all functions that one must be able to adequately perform to live independently. The capability to perform instrumental activities of daily living (IADL) includes actions such as the ability to use a phone, shop, prepare food, manage finances, or follow a medication regimen. The inability to adequately perform these activities suggests diminished independence and a reliance on others to assist where one is experiencing a deficit, whether that is skilled nursing assistance, home health care services, or family and neighbor assistance. These deficits may stem from normal age-related functional decline such as diminished motor skill and strength, failing eyesight, etc. as well as disease or a chronic condition.

The concept of medical fragility, more specifically, centers on the management of disease or chronic conditions. Often management of these conditions is through the supervision of medical professionals and prescription medications. For example, treatment of diabetes, hypertension, chronic obstructive pulmonary disease (COPD), arthritis and cancer requires good nutrition, medications and regular access to professional medical care, including pain management or outpatient treatment venues such as dialysis providers. Other medically fragile persons may rely on home-based durable electrical medical equipment such as continuous positive airway pressure (CPAP) devices or refrigeration for medications. While the medical support arrangement customized for the patient may not be able to return the person fully to independence, the support system that surrounds the person ideally ought to be calibrated to optimize, as best as possible, the ability of the person to exercise self-determination and engage in normal daily activities. Access to the support system, medical records, medical regimens, and nutrition that define this dependence on others may be easily upset or disrupted with the occurrence of a severe storm, placing the person at higher risk for adverse health outcomes or, more simply, resulting in a decline in health and more suffering. Medically fragile persons, by definition, do not have a reserve capacity to cope with the disruption, which, in turn, may cause a managed, tertiary condition to become an acute condition.

The heightened dependence upon others for well-being necessarily implies the importance of social and familial network ties. An individual's social and familial network provides access to resources and opportunities that the individual with weak network ties otherwise may not have. By association and inclusion in the network, the individual is made aware of these resources. The network provides the resources to better prepare for, endure and recover from the event. Through inclusion, one may have increased access to financial assistance, free labor, consultation and advice, sympathy and empathy, and an enhanced sense of not being alone. Social network ties may help an individual avoid trauma and manage the stressors associated with the storm. Households with weak networks have diminished capacity to engage in mitigation activities, leverage resources, and recover from the storm in comparison to households with strong social and familial networks.

Mobility, Sensory and Mental Cognition

Households that have members who are dependent upon equipment to get into a car or van or have members who are largely bedridden are less likely to leave the home to gather supplies in anticipation of the storm or to evacuate the region altogether. Those households with members who have difficulty walking or rely on a walker or wheelchair may be less able to navigate debris fields, such as felled organic materials and shifted household items, both inside and outside the home, thus increasing the likelihood of post-event acute injuries. Household members with sensory-related limitations, including hearing and sight disabilities, may have difficulty hearing and understanding information necessary to assess the

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risk of the impending severe storm as well as being more likely to suffer acute injury. Households with members that have a limiting mental or cognitive disability also may be less able to understand or assess risk. In fact, the event itself may engender disorientation, confusion or fear. There may be an unwillingness of household decision-makers to travel or locate in safer sheltering venues due to discomfort with unfamiliar environments. In addition, often treatment of a chronic or medical condition requires professional consultation and medication, both of which may be disrupted by the severe weather event. Despite their vulnerability, we have documented that such households are less likely to evacuate relative households without these conditions.[3]

Sandtrina: A Theoretical Severe Storm Event

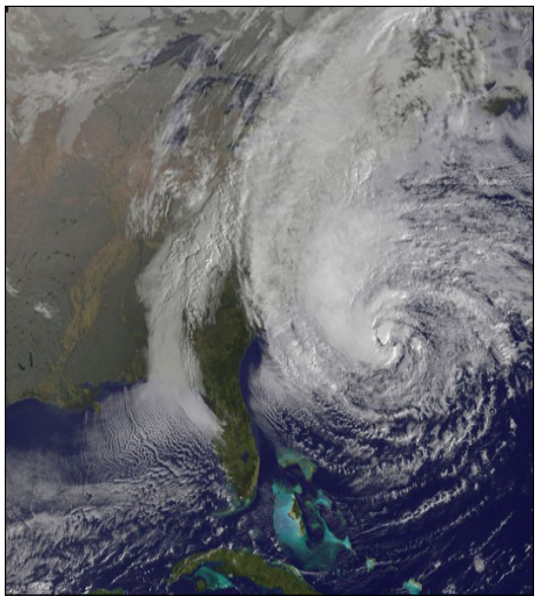
It may be understandably difficult for both citizens and emergency planners to conceptualize severe weather scenarios with physical magnitudes beyond historical experience. Hampton Roads has felt neither a punishing blow the magnitude of Katrina that hit the Gulf Coast in August 2005 nor the destructive havoc of Sandy that hit the Northeast in October 2012. The Chesapeake-Potomac Hurricane of August 1933 is noted to be the most significant hurricane within the past century for the Hampton Roads area. It crossed directly over downtown Norfolk as a Category 2 storm.[4] Prior to this, it was September 1821 when a hurricane last traced over Norfolk chastising the area with flooding and structural damage.[5]

The ability to visualize scenarios that are outside of the region's living historical experience, yet have reasonable similarities to real Atlantic Coast storms, could yield profound returns in terms of lives saved and suffering averted. There is value in thinking about catastrophic event scenarios that push the envelope beyond living experience, yet are still tangible enough to be within the realm of comprehension. Although they may have a low probability of occurrence, the consequences of such "black swan" events indeed could be costly in terms of loss of life and property.

"Black swans" are those events that are generally unforeseen or unexpected, have a major disrupting impact, and are viewed, in hindsight, as predictable. They often have a common retrospective assessment along these lines: "given the knowledge and indicators we had at the time, the potential event and its aftermath should have been recognized as a possibility, one which we should have anticipated and trained for." Although the probability that such a black swan event will breech the threshold of collective experience is relatively low, the impact of such an event would be catastrophic, fundamentally and permanently reshuffling the physical and social fabric of the region, leaving a return to pre-event normalcy difficult, if not impossible.

The breadth of Hurricane Sandy, popularly known as "Superstorm Sandy" and illustrated in **Figure 4**, was tremendous relative to historical experience. A region's future ability to deflect or absorb a storm's punishing blow—and to recover from the physical, psychological and economic impact—stems in part from the capacity to recognize lessons learned, drawing upon both direct experience and analysis of other storms, envisioning scenarios that are outside the proverbial box, and being proactive in understanding the geographic variations in household vulnerabilities.

Figure 4: Superstorm Sandy



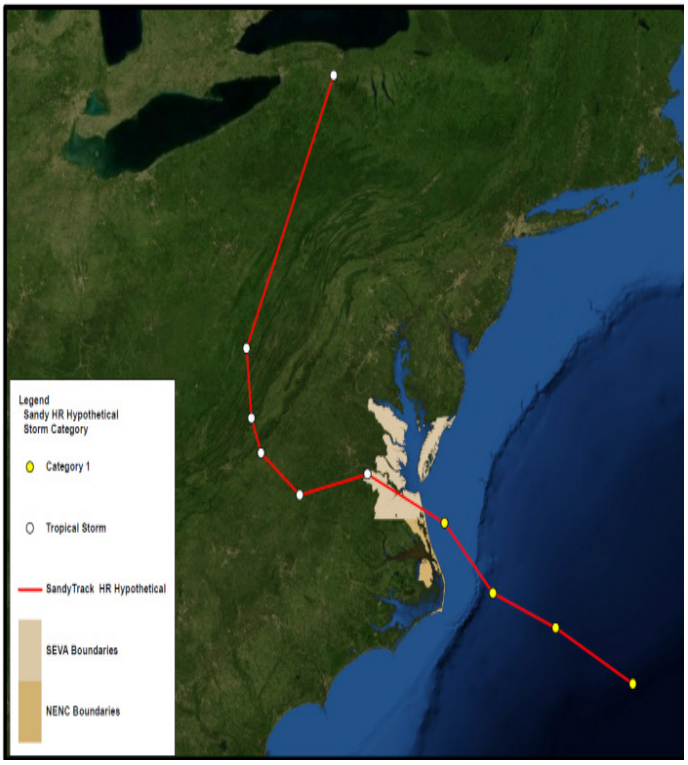
Superstorm Sandy off the Mid-Atlantic Coast on October 28, 2012 from National Oceanic and Atmospheric Administration NOAA GOES-13 satellite.
Source: NOAA Archives.
http://www.nasa.gov/mission_pages/hurricanes/archives/2012

We posit that systems of social networks, literacy, risk perceptions, and public health may be equally, if not more, important to the long-term recovery and well-being of communities than the resilience of buildings and infrastructure. This assertion underpins a radical shift in emergency planning thinking, one that may signal more meaningful consideration of community vulnerabilities for preparation and planning exercises. Juxtaposing vulnerability maps with models of scenarios drawn from real-world knowledge of storms allows emergency preparedness planners and agencies to visualize and quantify the displacement of populations and better forecast not only the immediate pre- and post-event needs for

shelters, housing and healthcare, but the long-term transition times towards stability and wellness of the impacted communities.

This has been done to a preliminary extent with a simulation of a theoretical major storm event in the Hampton Roads Region, which we have dubbed "Sandtrina"—a compound name based on hurricanes Sandy and Katrina. The parallel with Southeast Louisiana was chosen because of the close similarity of Southeast Virginia and Northeast North Carolina to greater New Orleans in terms of topography, demographics, economy and industry and the belief that Katrina illustrates the complexity of community vulnerability and of the struggle towards recovery. In addition, the proximity of the relatively slow-moving Superstorm Sandy, perhaps now understood as a black swan event, skirting the region, has heightened awareness among planners and encouraged thinking outside the box of historical Hampton Roads storms. For these reasons, Katrina and Sandy are viewed as laboratories that may yield insights into potential vulnerability applied to Virginia and North Carolina.

Figure 5: Hypothetical Santrina Scenario



Source: Modeling of Sandrina storm track by the authors.

Figure 5 illustrates one of several storm tracks for the Sandtrina scenario based on Superstorm Sandy with an altered storm path that traverses the region using the same time window and under similar speed and wind breadth. The images characterizing a Sandtrina scenario and theorized inundation are worst-case and are intended to be illustrative only; the images and associated narrative have not been validated or approved by official sources.

By adapting the breadth of wind field and surge of Superstorm Sandy as a theoretical scenario for the region, we have learned quite a bit without actually having to directly experience such a storm. The intersection of behavioral data contained within vulnerability maps and storm simulation data from Sandtrina can help us visualize the extent of physical damage and flooding, as well as provide estimates of displaced populations. Projecting estimates of displaced populations must necessarily involve knowledge of which households are likely to evacuate as well as the placement, composition, needs and resources of those that seek shelter in the region. Importantly, understanding the needs and characteristics of those displaced populations is also essential to forecasting the demand for immediate post-event shelter housing and transition times as populations move from one stage of housing recovery to the next. For example, as introduced above, knowledge about financial and social networks of households has much utility in forecasting the rate of progress toward self-sustained housing for those populations that were initially displaced. This information may inform federal and state housing policy as well as support emergency management planning and recovery exercises.

Primary Care Venues as Critical Infrastructure

Thus far we have illustrated how we are currently intersecting the physical modeling of storms with knowledge of household vulnerability to provide insights into evacuation behavior, displaced populations, and housing needs. This modeling is also currently being intersected with other newly developed primary care system capacity data. For example, if a storm is truly catastrophic in terms of inundation and severe flooding, then devastation of medical treatment venues may mean severely reduced primary care capacity as many venues may require complete restoration, which may take many months, prior to resumption of clinical activities. For those venues suffering relatively less damage, even after restoration of power,

"… if a storm is truly catastrophic in terms of inundation and severe flooding, then devastation of medical treatment venues may mean severely reduced primary care capacity as many venues may require complete restoration…"

which may take weeks, some venues will nonetheless still lack the equipment, staff, administration or financial resources to resume operations. **Figure 6** illustrates the placement of medical venues that deliver primary care; it shows the venues that would be inundated (red dots) and those that would not be inundated (green dots) under an unlikely theoretical catastrophic scenario.

Many chronic conditions require on-going treatment and conscientious management of medical regimens such as those with chronic conditions that need the attention of pain management or dialysis. Disruption in continuity of the medical regimen intended to manage the condition may result in worsening of the condition and further medical complications. Retrieval of medical records may be restricted, access to prescriptions and dosages may be limited, and the prevalence of self-treatment—or the absence of treatment altogether—are common in environments that are in disorder. The disruptive nature of a severe storm event may also limit longer-term access to health professionals. Due to damage of the home, patients may be sheltering in or relocated to locations distant from familiar doctors and neighbors or friends who usually provide transportation. The predictable decrease in primary care capacity relative to the expected demand for services will result in congestion, truncated flexibility in available appointment times, decreased face time with health professionals, and appointments that are either much delayed or postponed indefinitely.

"The ability to integrate storm scenario data with regional healthcare capacity is currently allowing us to measure the mid- and long-term storm impacts in terms of quality life years, general public health, and overall cost to the medical system."

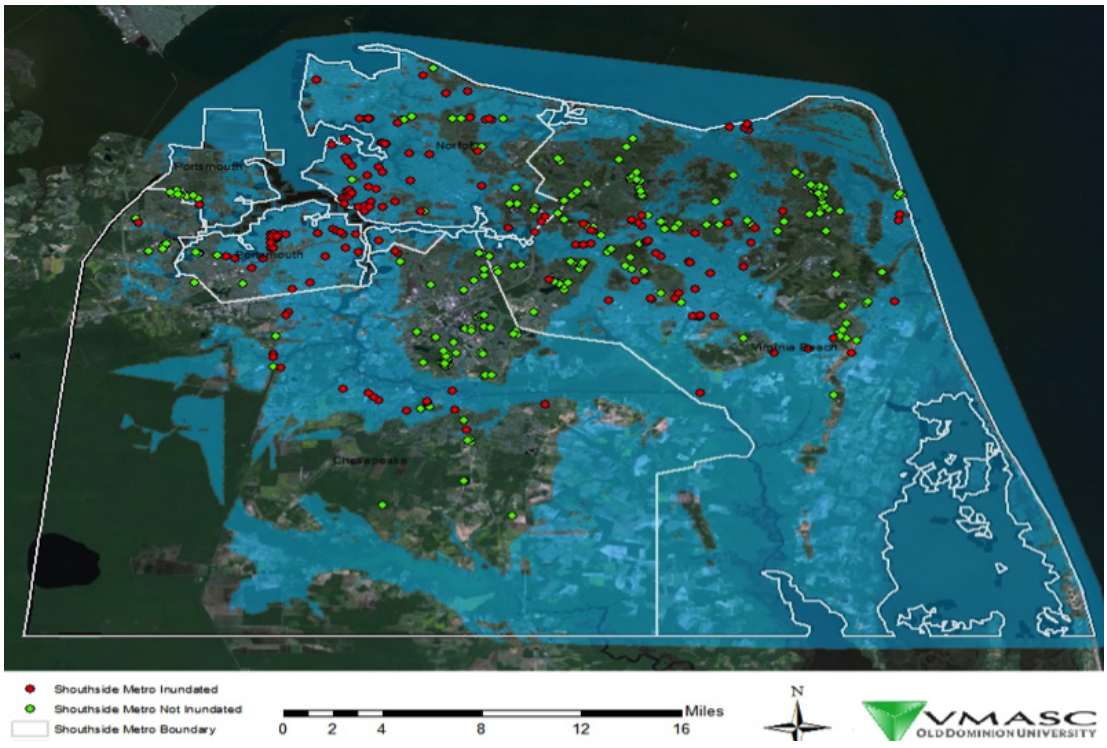
The ability to integrate storm scenario data with regional healthcare capacity is currently allowing us to measure the mid- and long-term storm impacts in terms of quality life years, general public health, and overall cost to the medical system. Similar capacity maps for mental health networks also may be constructed. In addition, the placement of low-level waste producers, such as tire and oil change venues inventoried by the Environmental Protection Agency (EPA), may be incorporated to assess the longevity of post-event contaminated standing water in proximity to households.

System Dynamics Models: Testing Mitigation Investments

While theroretical maps and simulations of the types discussed in this article will, in part, help refine and advance our understanding of vulnerability on several levels, these efforts also are part of broader efforts to develop tools that provide insight into how various mitigation investments, interventions and policy choices made today may condition the social, health and economic impacts stemming from modest-sized storms.

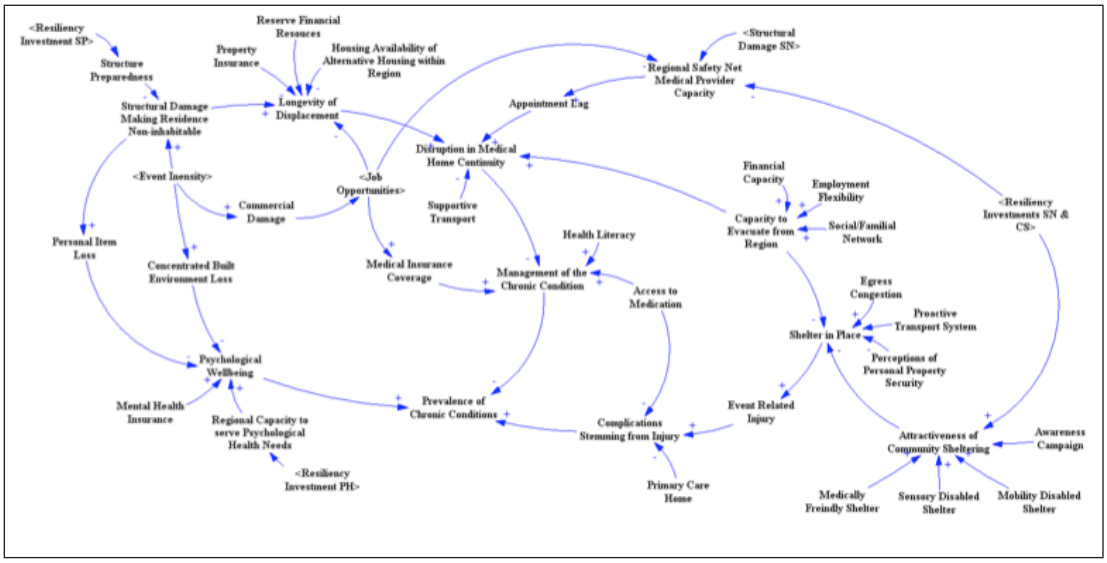
For example, we are currently developing dynamic models that specify within one system the key behavioral and built environment

Figure 6: Healthcare as a Critical Infrastructure



Source: Capacity and inundation scenario by the authors.

Figure 7: System Dynamics Causal Loop Diagram, Modeling Over Time Public Health Impact of Storm Scenarios



Source: Causal loop diagram of key components and relationships by authors.

components that characterize our healthcare delivery. These models allow us to quantify the short-, medium-, and long-term disparate impacts that severe weather events may have on various population segments. In addition, these models allow us to test and measure the return on investment (ROI) over time in terms of health care costs and disease prevalence stemming from various mitigation interventions, thus allowing us to make comparative statements about the value of competing efforts. **Figure 7** is a system dynamics causal loop diagram representing one of several sub-models used to forecast the impact upon public health. The ability to model and simulate relative returns under different policy options may allow us to identify, well before actually experiencing a catastrophic storm event, an optimal combination of investments and interventions intended to minimize incidence of disease and mortality as well as to hasten a return to regional economic vitality.

While Southeast Virginia and Northeast North Carolina are arguably culturally distinctive, our region's behavioral and health dynamics have many commonalities with other regions. This is important because key components specified within these emerging models are intended to represent fundamental dynamics found across American coastal communities.

Conclusion

The drivers of vulnerability are not unique to the Hampton Roads region, Miami-Dade, New Orleans, Gulfport-Biloxi, or New York-New Jersey. While the physical geography and urban landscape may be different, many of the social dynamics and constraints remain the same. What this says to researchers and emergency planners is that an understanding of the impact of a severe storm requires knowledge beyond its meteorological and physical characteristics. Efforts to mitigate storm-related harm in the form of death, injury, destruction and psychological trauma must incorporate knowledge of household variation in behavior, risk perception, and social networks across multiple dimensions of vulnerability.

Many of our planning, response, and recovery efforts may be enhanced by knowledge of the communities and population segments most likely to be impacted by the severe weather event and the relative resilience of these groups to absorb the punishing blow and climb back towards something akin to pre-event normalcy. There are many examples where this knowledge may be leveraged. An understanding of the psychology involved in which factors are weighed in the decision if, let alone when and how, a family evacuates the forecasted area in anticipation of an impending storm will be of use to planners interested in facilitating or coordinating the dynamics of evacuations. A refined understanding of the medical needs and options for continuity in care, especially for chronic conditions, will assist medical and special needs planners. An understanding of how various populations process storm-related messaging and warnings to form risk perceptions and how these perceptions in turn condition pre-event mitigation behaviors is especially informative for awareness campaigns. Also, an understanding of the extent and needs of displaced vulnerable and medically fragile populations will assist housing and policy planners.

In sum, in addition to tracking and warning about major storms, we need to better understand

"... an understanding of the impact of a severe storm requires knowledge beyond its meteorological and physical characteristics."

community vulnerability and the challenges facing medically fragile populations and their families. Knowledge relating to the factors that either facilitate or frustrate hurricane preparedness, including risk perceptions, financial constraints, and social networks, contributes to a more realistic picture of the dynamics of evacuation and forecasting of displaced populations and their needs.

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