2007

Hurricane modeling in GIS: an investigation of threshold storm events affecting special medical needs populations in coastal Louisiana

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HURRICANE MODELING IN GIS: AN INVESTIGATION OF THRESHOLD STORM EVENTS AFFECTING SPECIAL MEDICAL NEEDS POPULATIONS IN COASTAL LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Natural Sciences

in

The Interdepartmental Program in Basic Sciences

by
Kathryn Emily Streva
B.S., Saint Francis University, 1995
December, 2007

ACKNOWLEDGEMENTS

I would like to thank my committee members and graduate advisors at Louisiana State University (LSU), Drs. Andrew Curtis and Michael Leitner, Department of Geography & Anthropology; Dr. Martin Hugh-Jones, DVM, MPH, Department of Pathobiological Sciences and Department of Environmental Studies; Dr. Ivor van Heerden, Department of Civil and Environmental Engineering; and Dr. Hassan Mashriqui, PE, of the LSU Ag Center.

Additionally, thank you to Dr. Zaki Bassiouni, Dean of Engineering for support of my graduate studies through the College of Engineering Employee Education Award.

A number of researchers and agencies supported this work. Research was funded through the Louisiana Board of Regents Millennium Trust Health Excellence Fund, Contract HEF(2001-06)-01, with additional support from the McKnight Foundation. Supporting agencies include the Louisiana Department of Health and Hospitals, Offices of the State Medical Examiner and State Epidemiologist. Thank you to my colleagues, fellow hurricane and health researchers at LSU: Sait Ahmet Binselam for LIDAR and GIS data and guidance; Ezra Boyd for sharing Hurricane Katrina data and articles for this study; Carol Friedland for your explanations of hurricane wind effects and proficiency in HAZUS; Drs. Marc Levitan and Elizabeth English for your expertise in hurricane engineering; Hampton Peele, DeWitt Braud, Rob Cunningham, and Young S. Yang for your GIS shapefiles and mapping expertise. Additionally, thank you to David Gisclair, Josh Kent, Craig Johnson, Dr. Jim Mitchell, and Farrell Jones for your pioneering efforts in LIDAR and GIS for the state of Louisiana, enabling coastal and environmental research for many projects statewide.

Finally, John Streva, thanks for taking *el diáblo* all those weekends; bringing us dinners - especially from Kamado's - and giving up so much of your own time.

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ACRONYMNS AND DEFINITIONS

ADCIRC – Advanced Circulation Model for Ocean Hydrodynamics. A high resolution storm surge prediction model for coastal Louisiana

AMO - Atlantic Multidecadal Oscillation. A climate cycle that may increase the average number of US hurricane landfalls over the next few decades

ABFE – Advisory Base Flood Elevation. Re-evaluated flood elevation values along the coast following a 2006 FEMA initiative to incorporate storm surge risks into **FIRMs -** Flood Insurance Rate Maps, previously using **BFE** – Base Flood Elevation values

CDC – US Centers for Disease Control and Prevention, Atlanta, GA

CTN – Critical Transportation Needs, **CTNS** - Critical Transportation Needs Shelter

DHHS – US Department of Health and Human Services, the Federal health agency

DHS – Department of Homeland Security, **FEMA** – Federal Emergency Management Agency

ENSO – El Niño Southern Oscillation (and La Niña). A seasonal fluctuation over the Pacific Coast of Mesoamerica that may affect hurricane formation

FMS – Federal Medical Station, such as a **PHS** - US Public Health Service Rapid Deployment Force, **DMAT** - Disaster Medical Assistance Team, **EMED** - Emergency Medical Team, **CSH** - Combat Support Hospital or US Navy Hospital Ship

GPS – General Population Shelter <OR> Global Positioning System, a handheld device for determining coordinates

HFW – Hurricane Force Winds, indicating windspeeds over 75 miles per hour

HPS – New Orleans Hurricane Protection System. The levees and canals surrounding New Orleans south of Lake Pontchartrain, along the Mississippi River and Gulf of Mexico

LA DHH - Louisiana State Department of Health and Hospitals, **BEMS -** Bureau of Emergency

Medical Services within the **OPH** - Office of Public Health

LIDAR - Light Detection and Ranging. An emerging technology in land elevation measurement

MMP – Medical Marshalling Point. For this study, further denoted as an **MMP-A** - airfield/ airport or **MMP-T -** train station

MRGO – Mississippi River Gulf Outlet, a navigation canal east of New Orleans

MSN - Medical Special Needs, **MSNS –** Medical Special Needs Shelter

NAVD88 – North American Vertical Datum of 1988. Louisiana LIDAR, the latest elevation survey methods for Louisiana, and FEMA ABFEs will reference this datum

NGVD29 – National Geodetic Vertical Datum of 1929. The NOAA SLOSH storm surge model and many Louisiana FEMA FIRMs will reference this datum

NOAA - The National Oceanic and Atmospheric Administration, **CSC -** Coastal Services Center also, **AOML -** Atlantic Oceanographic and Meteorological Laboratory**, NHC –** National Hurricane Center, **HRD –** Hurricane Research Division, and **NWS** – National Weather Service

PPP – Parish Pick up Point, or **CPPP** - Coastal Parish Pick up Point. Planned locations along the coast where hurricane evacuees without cars can go to get transportation to a CTNS

SLOSH – Sea Lake and Overland Surge from Hurricanes, **MEOW** – Maximum Envelope of Water, **MOM** – Maximum of Maximums. All denote NOAA models for storm surge analysis

SpNS – Special Needs Shelter. State-operated shelter generally reserved for special needs hurricane evacuees

TMOSAs – Temporary Medical Operations Staging Area. Decontamination, triage, treatment and transport point for patients brought in from hurricane affected areas by search and rescue

TSFW – Tropical Storm Force Winds, indicating windspeeds over 39 miles per hour

USACE – US Army Corps of Engineers

ABSTRACT

Recent hurricane events in coastal Louisiana have emphasized the severe vulnerability of medical special needs (MSN) patients during flood disasters. MSN populations may be comprised of hospital, nursing home or hospice patients; the physically or mentally disabled; medically-dependent individuals requiring life-sustaining equipment or medicines; and frail elderly.

Over 150 hospital and nursing home fatalities resulted from Hurricane Katrina in New Orleans. More than four hundred elderly over the age of seventy perished. Chronic diseases and mental health illness were among the top conditions reported in field hospitals, emergency rooms and shelters immediately following the storm.

Louisiana MSN facilities and residences in the southern-most parishes continue to face daunting risks from even minor storms. Principal risks include storm surge and high winds made worse by coastal land loss. Few structures have been designed to withstand hurricane forces and many depend on coastal hurricane protection systems. Many are located in close proximity to industrial facilities or hazardous material sites.

Meanwhile, MSN patients and decision-makers lack access to the latest hurricane science. This prevents them from conceptualizing their true hurricane vulnerability. Indications were that high numbers of MSN patients remained in the risk area even while Category 5 Hurricane Katrina loomed towards Louisiana. Many still plan to shelter in place for hurricanes.

This manuscript reviews the health and hurricane risks of MSN patients in evacuation vs. sheltering in place in coastal Louisiana. The latest hurricane models are incorporated with critical MSN location data in a Geographic Information System (GIS) to determine threshold

events. Solutions are explored to communicate risk, visualize data, and share hurricane research and GIS tools with MSN decision-makers at the local level.

Based on scientifically accredited modeling and associated research, this study has determined the threshold storm event for coastal Louisiana MSN patient evacuation to be a tropical storm. Particularly, rapid hurricane intensification has historically supported that even lower order storms may intensify enough within 48 hours of landfall to create unsafe flood and wind levels. Thus, full MSN patient evacuation south of the Louisiana interstates is recommended upon a tropical storm entering the Gulf of Mexico.

CHAPTER 1   INTRODUCTION AND BACKGROUND

1.1 Medical Patient Vulnerability in Hurricane and Flood Disasters

Recent hurricane events in Louisiana have emphasized the severe vulnerability of Medical Special Needs (MSN) patients during flood disasters. Some of the strongest recent evidence comes from Hurricane Katrina, which made landfall in Louisiana on 29 August 2005 as a Category 3 hurricane, resulting in levee breaches and flooding throughout much of the city of New Orleans. Of 1464 fatalities in Louisiana, over 150 occurred at medical facilities, including approximately 85 deaths at hospitals and 65 at nursing homes (LA DHH 2006c, Boyd 2006). Approximately 37 hospitals and 34 nursing homes had to evacuate southeast Louisiana following Hurricane Katrina, with 19 nursing homes evacuating prior (LA DHH 2007b). Hurricane Rita months later prompted the early evacuation of 24 nursing homes, but later required the evacuation of 21 hospitals across southwest Louisiana (ibid).

Hurricane Katrina further demonstrated the severe risk of hurricanes and floods to elderly residents.

Number of Hurricane Katrina Fatalities by Age

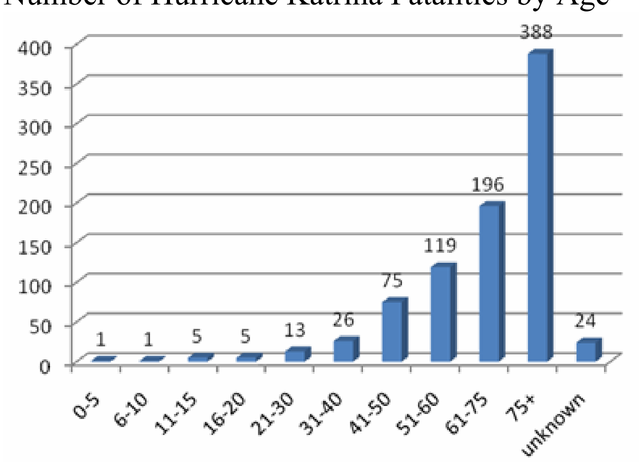

Figure 1. Preliminary deceased victims data for Hurricane Katrina in Louisiana indicate a positive association between age and mortality (LA DHH 2006b).

Elderly often have existing medical conditions or extreme physical difficulties which may qualify them as MSN patients. Preliminary data from Hurricane Katrina indicate a positive association between age and mortality, with older Louisiana residents disproportionately affected by the storm (see also, Appendix C). Over 400 fatalities at age seventy or above were recorded (Figure 1) (LA DHH 2006b). Supported by just over half of the total data (853 of 1464 records), it is unclear whether future data when completely tabulated will support the same association.

From the existing data however, 51 percent of elderly recovery locations (places where deceased elderly were recovered or documented after the disaster) were identified as residences. This indicates that many elderly remained in their homes and did not evacuate a risk area that was at one time being threatened by a Category 5 hurricane (Figure 2) (LA DHH 2006b, Boyd 2006). Hospitals (18%) and nursing homes (14%) accounted for the second and third largest number of recoveries of deceased elderly (ibid). Deceased elderly victims were also recovered from hospice settings (2%), airport medical staging areas (2%), the Convention Center (2%) and the Superdome (1%) (Figure 2, 3a-c) (ibid).

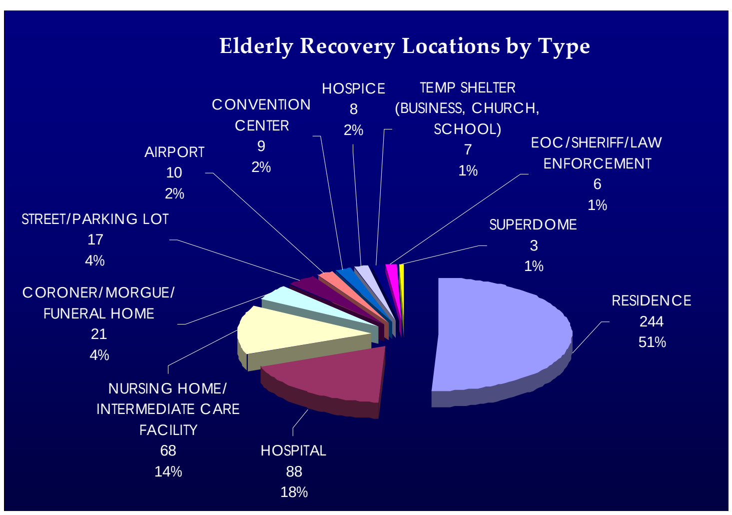

Figure 2. Current fatality datasets identify the primary recovery locations for deceased victims 65 and older as residences, hospitals, and nursing homes (State Medical Examiner, LA DHH 2006b, Boyd 2006).

Although not always reflected in the data, there are other indications that high numbers of MSN patients remained in the risk area as Hurricane Katrina approached Louisiana. In some instances, MSN patients are well documented in accounts provided by officials with the Louisiana Department of Health and Hospitals (LA DHH), nurses, doctors, emergency medical technicians, search and rescue teams, emergency responders, journalists, and other individuals that experienced the medical emergency as it unfolded following the levee breaches.

Figures 3a-c. The situation became critical for elderly medical special needs patients following Hurricane Katrina. Above, an overwhelming number of elderly and MSN patients were brought to airport medical staging areas and the New Orleans Convention Center (LA DHH, Katrinahelp.com).

For example, approximately 500 MSN patients had been evacuated from the Superdome to Baton Rouge before Hurricane Katrina made landfall (Cataldie and Kosak pers comm 2006). Many additional patients were evacuated the day of landfall at pick up locations near the Bonnet Carre Spillway at LaPlace, before winds had technically even died down (ibid). Yet, by that evening and the subsequent levee breaches, over 500 additional MSN patients are recorded to have entered the Superdome, resulting in numbers which escalated to over a thousand (ibid). These individuals were separated from the general population and where possible, evacuated by Military Deuces until buses could finally arrive (ibid).

Additional accounts and images provided by the media, internet and other outlets support that substantial numbers of MSN patients, including elderly and disabled, were present and had

not evacuated the risk area. These also served to document the critical situation faced by MSN patients following the disaster (Figures 3a-c, 4a-c).

Figures 4a-c. There are indications that high numbers of MSN patients remained in the risk area for Hurricane Katrina. Photos above show numerous individuals requiring mobility aids, as well as frail elderly. Left: Residents waiting to enter the Superdome, a shelter of last resort, before the storm (wikinews). Middle: MSN patients are evacuated long distances to shelter (Florida DMAT). Far right: MSN patients await transport to shelter facilities (Katrinahelp.com).

Further evidence of MSN patient vulnerability in disasters is indicated by the cases of exacerbated chronic disease reported after the storm. Similar chronic conditions were reported at medical staging areas and triage sites, field hospitals, emergency rooms and shelters. Heart problems, diabetes, and mental illness were among the major conditions reported (CDC MMWR 2006a-b, LA DHH 2005a-c, 2007b, Ford et al 2006, Mokhad et al 2005). Of Hurricane Katrina evacuees sheltering in Texas, “41 percent of Houston shelter residents reported chronic health conditions such as heart disease, hypertension, diabetes, or asthma” (Brodie et al 2006, p 1403).

Medical special needs are therefore a serious concern in hurricane and flood disasters, as strongly evidenced by recent hurricane events such as Hurricane Katrina in coastal Louisiana.

1.2 Defining Medical Special Needs

Medical Special Needs (MSN) patients, for the purpose of this research, are generally considered those individuals who, for health reasons, should be very near medical professionals during a disaster. It is accepted that many MSN patients may not have appropriate levels or

access to health care even *prior* to a disaster. However, MSN patients for this study are conceptualized as those individuals who should be accounted for, and for whom we should be *immediately prepared* to receive in any disaster situation, to fulfill their basic medical needs.

MSN populations for this study are considered a subset of overarching "special needs" and "vulnerable" populations. MSN populations may be differentiated from these larger groups in that MSN individuals will have an **existing medical problem** that **requires prompt, professional medical care;** otherwise serious harm may result. MSN individuals can also be described as "…medically dependent individuals who have physical or mental conditions that limit their ability to function on their own… (Bridges and Garcie 2006, p. 4)." These individuals can be found in hospitals, nursing homes, their own residence, in adult day service programs, assisted living facilities, foster and group homes, and long term care facilities (ibid, USFA EMI 2003, GOHSEP 2005, DOJ CRD/DRS 2004, Lapolla 2003, Prats 2003). The discerning factor for MSN individuals is that if medical assistance is not received immediately, or within the short term of a few days of an emergency or disaster situation, injury or death can result.

Definitions of the special needs population are more inclusive, and comprise larger numbers of "…individuals in the community with physical, mental or medical care needs who may require assistance before, during and/or after a disaster or emergency after exhausting their usual resources and support network (ibid, p.1.3)." This group differs from the MSN subset in that, if prepared and supported at the onset of an emergency, special needs individuals will usually not encounter problems navigating an evacuation or sheltering in place. With basic support, they have the capacity to proceed as normal, often times on their own, without any resulting medical emergency (ibid). Special needs definitions will typically incorporate the disabled and mentally ill. However, the important distinction for MSN disabled and mentally ill

which separates them out from general special needs populations, is that again, these individuals will have an immediate medical need and will not be able to care for themselves. They might require medication they cannot dispense without medical assistance, need help in the operation of medical equipment, or demand some level of professional medical care or supervision. Specific categories of MSN disabled and mentally ill are discussed in more detail in Section 3.1.1, but as an example, may include traumatic brain injury patients, bariatric[1] patients, or the seriously mentally ill, such as schizophrenic patients.

Along the same lines, vulnerable populations are a larger and more inclusive designation than MSN. These individuals are somewhat more at risk in an emergency, but are generally not likely to be emergency medical patients. In the broadest definition, those included in within vulnerable populations may range from young children entirely dependent on adults for their care; to pregnant women; to the immuno-compromised; to individuals facing socio-economic problems such as poverty; to individuals located near hazardous materials sites. One important subset within vulnerable populations in the case of a hurricane disaster are those with Critical Transportation Needs (CTN) (LA DHH App 9). CTN individuals may not be able to "provide for or arrange their own transportation or sheltering outside a risk area (ibid)." This leaves them potentially stranded in a hazard area, and subject to harm. Where MSN patients might separate from vulnerable populations are in instances such as medically dependent children, pregnant women who are high risk or late term, or low-income residents with untreated medical conditions living in high risk areas (e.g., low elevations, near levees or hazardous sites).

In either case, it is important to note that the larger group definitions of "special needs" and "vulnerable" individuals are inevitably going to be the next series of MSN patients if a disaster situation becomes dire (USFA EMI 2003). That is, individuals from these groups are

[1] treatment for obesity, such as gastric bypass

most likely to deteriorate into emergency medical patients and amplify the MSN population shortly after a disaster such as a hurricane, if their primary needs are not met and if they are overwhelmed by an extensive or severe storm.

Although just a subset of vulnerable or special needs populations, MSN categories are nonetheless quite inclusive and often overlapping. The MSN designation may incorporate many more individuals with medical conditions and needs in a disaster, particularly the elderly and as previously discussed, the disabled. These individuals may live at home or in assisted living, community care or retirement settings (ibid, Bridges and Garcie 2006, GOHSEP 2005, DOJ CRD/DRS 2004, Lapolla 2003, Prats 2003).

Many elderly or senior citizens (considered in most cases to be age 65 and older) may be self-supporting and completely healthy. However, the elderly that comprise MSN populations will require varying levels of assistance and medical care and will have other special, medical or transportation needs (USFA EMI 2003, p.1.9). "Medically fragile" may be considered a classification of patients within MSN populations that often include the very elderly and bedridden who are totally dependent (Lapolla et al 2003). Medically fragile patients are becoming much more common in nursing homes (Prats 2003) and are present in hospice settings. At the same time, medically fragile patients simultaneously include those who have difficulty swallowing; those requiring electrical equipment to sustain life; insulin-dependent diabetics who are unable to monitor their own blood sugar or self-inject; those requiring continuous IV therapy; and individuals with critical medications and labs requiring daily monitoring (Lapolla et al 2003).

Individuals with disabilities also comprise much of the MSN population. In general, disability types include (1) Sensory, including the blind, deaf, or individuals with varying levels

of loss of sight or hearing; (2) Mobility: those with limited stamina, or who use mobility aids such as a cane, wheelchair, walker, scooter, or crutches; e.g., individuals with Cerebral Palsy, Multiple Sclerosis or Muscular Dystrophy (3) Mental: including the mentally ill, developmentally disabled (e.g., Autism), those with traumatic brain injury, and learning or cognitive disability; and (4) Medical: renal dialysis patients, diabetics, oxygen or respirator-dependent (USFA EMI 2003, US DOJ 2004). As with the elderly, not all disabled individuals have immediate medical needs, but may simply have special needs. Many disabled can function well on their own or with basic support (ibid). However, anyone with a disabling condition listed above that requires immediate medical attention or supervision at the onset of a disaster could be considered an MSN patient.

Of note, according to 2000 Census data, *over twenty percent* of residents in Louisiana aged 5 years and older had some type of disability, including physical, employment (preventing them from working), mobility, mental, sensory and self care disabilities, respectively (St. Bernard Parish Health Profile 2004). Disability rates for elderly Louisiana residents far exceeded those of younger residents, while *over twenty percent* of Louisiana households had at least one child with a special health care need (ibid). Such statistics underscore the importance of special needs and MSN patient disaster planning in Louisiana.

Providing even more overlap, disabled residents have higher rates of chronic medical conditions, emergency room visits and “hospitalization for a primary disabling condition (ibid).” As discussed, chronic conditions were some of the most commonly reported emergency medical problems reported in field hospitals and hurricane shelters immediately following Hurricane Katrina (CDC MMWR 2006 and others).

Similar to CTN individuals, which were discussed under "vulnerable" populations, transportation for individuals with disabilities can be likewise disrupted. This may be due to overcrowding, blocked streets or sidewalks, or systems that are closed on account of the impending storm, rather than a lack of resources (USDOJ 2004). Many people with disabilities cannot use usual modes of transportation, but instead require lift-equipped school or transit buses (ibid).

In summary, MSN patients may include a wide range of individuals who will need access to medical professionals immediately during and following a disaster, or they risk injury or death. MSN populations require immediate medical attention or supervision, medicines, access to equipment, or other resources in a disaster and may be comprised of many overlapping categories of individuals. These include hospital, nursing home or hospice patients; the physically or mentally disabled; medically-dependent individuals requiring life-sustaining equipment, medicines or varying levels of care; frail elderly; and those with chronic medical conditions. Special needs and vulnerable populations are often the first to add to the MSN population in the case of a large-scale event when their usual support network has been disrupted (USFA EMI 2003).

1.3 Evacuate or Shelter in Place? Patients Face Life-or-Death Decisions

Both evacuation and sheltering in place carry inherent risks for patients with special medical needs during hurricanes (ibid, Dosa et al 2007, Bridges and Garcie 2006, GOHSEP 2005, DOJ CRD/DRS 2004, Lapolla 2003, Prats 2003).

Successful hurricane evacuations require careful planning and sufficient time before the onset of tropical storm force winds, rain and congested roadways. Evacuation is costly and highly dependant on well-trained staff, available transportation and supplies (Dosa et al 2007,

DHHS/OIG 2006, Bascetta/GAO 2006). Each of these pieces is crucial for a successful evacuation; none can be missing or the entire operation may fail. Yet, there are nearly insurmountable challenges facing facility mangers in each of these aspects of an evacuation (DHHS/OIG 2006, Cutter 2006). Evacuation risks include long commutes, heat exposure, temporary dehydration, injury, lack of immediate access to medical care or medicines, lack of appropriate levels of care in transit or at receiving facilities, and stress, among many others (ibid, Dosa et al 2007, Gray and Hebert 2007, Klein and Nagel 2007, Mutter and R'id 2007, Kuba et al 2004).

Sheltering in place presents another set of risks, as hurricanes can rapidly intensify, shift in track, or cause a host of other unanticipated problems (Keim/SRCC 2007, NOAA 2007b-c). Tornadoes and extreme rainfall often accompany hurricanes (ibid), followed by downed trees and power lines which may block access routes and disrupt electrical utilities, water supply and communication. In coastal Louisiana, levee breaches or hazardous chemical releases may also result (van Heerden et al 2006, Pardue et al 2005). Low elevations and other coastal factors expose facilities to serious flooding, and few have been designed to withstand high winds (LSU HC 2007, Levitan pers comm 2007).

As an example, most nursing homes in coastal Louisiana are one-story buildings built decades ago (ibid). Similar to coastal Louisiana residences, even if constructed to the most conservative building codes of the time, these structures would not likely be safe or able to withstand hurricane force winds, because such stringent standards were not required at that time (ibid). Safe shelter spaces are generally limited to halls without windows (unless hurricane rated) and between secure fire-protected doors or within secondary barriers (unless doors are hurricane rated). Safety is dependant on factors such as a continuous loadpath (a building

designed or mitigated to withstand wind forces as a complete unit, from the roof to the floor) and other factors which are sometimes not easily confirmed or reasonably expected (ibid). In short, most nursing homes and other one-story residential structures in coastal Louisiana will provide little if any protection from high wind events such as tornadoes, and are not likely to fare much better during hurricanes.

MSN patients sheltering in place may suffer injury, heat exposure, dehydration, lack of caregivers or appropriate medical care, isolation, non-functioning medical equipment, and stress (Dosa et al 2007, Gray and Hebert, 2007, Mutter and R'id 2007, Fernandez et al 2002). In extreme cases, storm injuries or death may result from drowning, lack of basic needs (e.g., water or food) or untreated medical conditions when emergency responders can not reach them (ibid).

1.4 Current Hurricane Risks to Coastal Louisiana MSN Facilities and Residences

Hurricanes cause a wide range of public health impacts that most seriously affect MSN populations within the community. Louisiana facilities and residences, particularly in the southern-most parishes, are now faced with daunting hurricane risks from even minor hurricanes.

There are over 560 hospitals and nursing homes in the state of Louisiana (LA DHH 2007a, Louisiana GIS Digital Map 2007). Approximately 305 - over half - are located in the twenty-six coastal Louisiana parishes that have some portion of land south of interstates I-10 and I-12 (ibid, listed in Appendix B). These estimates *exclude* hundreds more facilities and residences dotting the coastal communities that may house MSN individuals who are physically or mentally disabled, medically dependent or elderly (ibid, HRSA 2007, US Census Bureau 2000). As previously discussed, health risks to MSN patients are high during hurricane disasters; additional factors increase the overall hurricane risks to coastal Louisiana facilities and residences.

Examples of coastal hurricane risk factors are prevalent in recent history, even prior to 2005 Hurricanes Katrina and Rita. New Orleans had already been enduring rainfall events and minor storms that were resulting in major floods, including the floods of 1995, 2001 Tropical Storm Allison (that flooded Houston and New Orleans, to a lesser extent), and tropical storm Isidore in 2002 (Robbins/SRCC 2004). Post-Katrina storm surge models now predict serious coastal flooding in some areas of New Orleans and the Louisiana coast beginning at Category 1 and 2 storm levels (NOAA SLOSH Display Program, version 1.4.3, May 9, 2007). Storm surge is defined as a "large dome of water, 50 to 100 miles wide, that sweeps across the coastline near where a hurricane makes landfall. ...The level of surge in a particular area is primarily related to the intensity of the hurricane and slope of the continental shelf (NOAA 1999, p. 13)."

Land loss and other coastal changes in Louisiana have substantially increased the hurricane and flood risk to coastal communities over time (van Heerden/CCEER 2004). Estimates range from approximately forty (Barras/USGS 2006) to one hundred acres of wetland loss *per day* (van Heerden/CCEER 2004)[2]. Outer defenses to hurricane wind and surge are also damaged by extreme storm events, as demonstrated most recently by once-Category five hurricanes Katrina and Rita in 2005, resulting in significant erosion to the protective barrier islands and already fragmented Louisiana marsh (Barras/USGS 2006). USGS estimates indicated over two hundred square miles of marsh were converted to open water in coastal Louisiana on account of both storms (ibid). Both storms retained their Cat 5 storm surge effects even though making landfall in Louisiana as lower order storms (Levitan pers comm 2007).

Meanwhile, the coastal parishes of Louisiana are located over a subsiding basin with a series of natural geologic faults (Figure 5) (van Heerden pers comm 2007) resulting in a drastic drop in elevation south of interstates I-10 and I-12.

[2] Earlier estimates rely more on interpretations of aerial photography than remotely-sensed imagery.

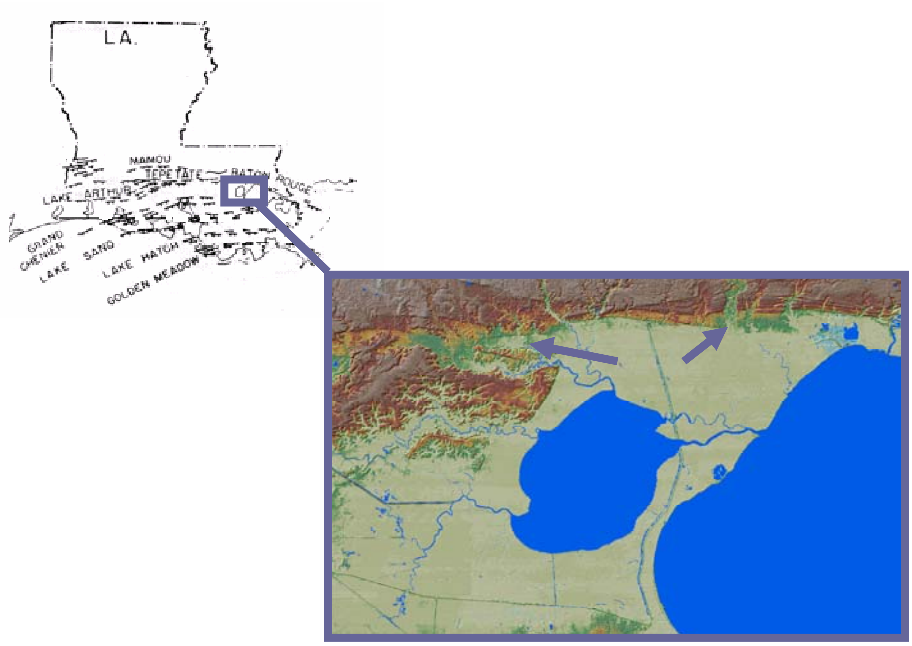

Figure 5. Louisiana fault systems (Murray 1961, from Cazes 2004). Fault scarps can be better visualized with LIDAR elevation data (Binselam and van Heerden 2004) to demonstrate the quick drop-off in elevation south of the interstates in coastal Louisiana.

The cumulative effects of wetland and barrier island loss over the past century, made worse by man-made canals and other factors, are likely the primarily culprit bringing hurricanes 'closer in' to the coast with each passing season (van Heerden 1994, 2004, van Heerden and Bryan 2006). Although the specific metrics vary, every healthy mile of wetland will reduce hurricane storm surge and wind speed to some degree (ibid). One estimate is that for every approximate 2.7 miles of healthy wetland, one foot of hurricane storm surge reduction will be realized (van Heerden et al 2006, p. 107).

Added to wetland loss and a dynamically changing landscape, Louisiana's coastal residents are exposed to relatively rapid sea level rise (van Heerden pers comm 2007); increased coastal populations and development; continuing industrial, oil and gas expansion; and the

uncertain future of levee repairs and rebuilding which have become requisite to protecting their communities.

1.5 Lost in Translation: Bridging Science and Technology to MSN Decision-Makers in an Emergency

Given the health considerations and heightened hurricane risk in coastal Louisiana, an important facet of evacuation and sheltering planning for MSN patients emerges: identifying who makes the decisions to go or stay in a hurricane emergency. Once identified, further questions become: Are coastal Louisiana MSN decision-makers aware of the extent of hurricane risks to their facilities? Furthermore, are they able to access the latest science and technology, including developments in hurricane models or GIS mapping?

1.5.1 MSN Decision-Makers

Some aspects of hurricane evacuation and sheltering decisions are coordinated, and to an extent decided, between local, state and possibly Federal emergency management agencies and officials. For example, decisions made on the local or state emergency management level include whether or not to recommend or call for evacuation of a risk area, and how an evacuation will be timed and executed (LA DHH 2007c).

Yet, notwithstanding communication problems (e.g., the inability of a nursing home to contact local emergency management or the state health agency), miscommunication/ misunderstandings, or lack of resources (e.g. transportation assets), the ability to enforce an evacuation order remains elusive and subject to debate. In short, hospitals, nursing homes and other MSN facility managers and residents cannot be physically forced to leave an area. While some entities may be sanctioned or censured for not complying with an evacuation order; technically, all have the prerogative to shelter in place if they decide this to be in their patient(s) best interests (ibid, Gray and Hebert 2007, Nursing Home Administrators pers comm 2007).

Therefore, local MSN facilities and residents play a significant role in determining their own risk, and also in deciding whether or not they will evacuate a risk area for a given storm.

In reality, beyond individual MSN residents, those entrusted to make decisions regarding the care of medically vulnerable patients in a hurricane situation will include hospital directors and officials/CEOs, local nursing home administrators, facility owners, home health agency officials, family members, and on-site medical support personnel such as nurses and other caregivers (Dosa et al 2007, Gray and Hebert 2007, Kirkpatrick and Bryan 2007, DHHS/OIG 2006). These men and women rely heavily on information assets such as the damage history of their facility; combined experience; their local, regional and state emergency managers; sister or parent facilities; facility owners; the media; and particularly the individualized needs and potential for risk to their patients when they decide to evacuate or shelter in place (ibid). There is anecdotal evidence that family members of MSN patients weigh their decisions heavily on the media and on potential medical risks to moving or relocating their family members (Mutter and R'id 2007, Callimachi 2006). Assisting with the immediate implementation of hurricane emergency plans may be other staff, maintenance personnel, patient and staff family members, members from the community who show up at the facility, and other volunteers (Nursing Home Administrators pers comm, Butcher pers comm 2006).

In summary, in the majority of cases, MSN decision-makers may actually be comprised of MSN patients themselves, as well as nursing home administrators, family members, and the many other non-governmental, non-emergency management local residents listed above.

1.5.2 Accessing Hurricane Research and Models

Perhaps surprisingly, even after the 2005 hurricanes, some administrators of hospitals and nursing homes have still indicated that they "generally see evacuation as a last resort"

(Bascetta/GAO 2006, p. 5). During recent hurricanes along the US Gulf Coast, local MSN decision-makers have chosen to shelter in place rather than evacuate for a number of reasons. These are discussed in further detail in section 3.1.1; however, in one example, a nursing home administrator explained:

> "…the facility structure was sound enough to withstand expected winds, location limited the degree of expected flooding, staff were proficient in emergency response and willing to shelter in place with residents, the community was likely to augment facility resources, and the poor condition of residents made travel dangerous… (US DHHS/OIG 2006, p. 9)"

Added to this were negative past experiences with evacuation (ibid). Numerous other factors appear to weigh in to decisions to evacuate or shelter in place as previously described; but the latest hurricane models and up-to-date, facility-specific information on physical hurricane or flood risks do not appear to be a deciding factor.

In the case of St. Rita's nursing home in St. Bernard, a well-known example in Louisiana, thirty-five nursing home patients lost their lives and administrators were subject to a criminal investigation. They were adamant that the facility 'had not flooded in twenty years' (Parker/USA Today 2006). This indicates some reliance on past experience but points to no other reference such as the latest hurricane data, research or models. St. Rita's was but one of a number of area nursing homes in the area that did *not* evacuate. The fact that they sheltered in place there with extended family, including grandchildren (CNN 2006), may support the conclusion that based on experience and all other information at their disposal, they did not perceive Hurricane Katrina to pose a serious threat.

Similarly, high numbers of hospital deaths under separate investigation in New Orleans appear to have resulted from complicating factors post-storm, such as flooding, loss of utilities, extreme temperatures, and general medical conditions that staff were not able to treat in the

deteriorating conditions (e.g., Gray and Hebert 2007). However, while reports are conflicting, there is no evidence that any of the hospitals in the greater metropolitan New Orleans area fully evacuated for Hurricane Katrina (ibid, LA DHH 2007b). Catastrophic hurricane plans for Louisiana (drafted during the Hurricane Pam exercise of 2004) indicated that hospitals had planned to shelter in place at reduced capacity for even the most severe hurricanes, but would have enough resources on hand, including generator power, to shelter patients in place for up to seven days. This was based on the estimated time search and rescue planners felt they could get to hospitals in flooded conditions to replenish their supplies (IEM 2004).

In both cases, as well as in cases where MSN residents decided to ride out the storm in their homes, levee breach or perhaps a delay in emergency response on some levels, may be argued as the primary reason plans for sheltering in place failed for this specific event. However, the increasing hurricane vulnerability to coastal Louisiana and New Orleans - including surge and wave stress on the levees during hurricanes with the potential for overtopping - had been discussed in academic research for years. Why didn't the science appear to weigh into evacuation decisions?

Scientific data had been presented years earlier on topics ranging from storm surge risk (e.g., Suhayda, van Heerden and others, various academic presentations 2003-2005) to the hurricane "funnel" created by the Mississippi River Gulf Outlet (Mashriqui 2004) to the potential filling of the New Orleans "bowl" from the "Big One" (e.g., "Drowning New Orleans," Scientific American 2001). However, except for a few articles or special features, most notably, in the Times Picayune (e.g. the 'Washing Away' series by Schleifstein/McQuaid) and documentaries (e.g. NOVA in 2004), the hurricane risk which researchers were discussing does not appear to have been adequately conveyed, or received by the MSN community.

Regardless of the eventual levee breaches, or other substantial problems faced by facility administrators or residents preventing them from evacuating (e.g., lack of transportation assets, a serious issue (DOT/DHS 2007, Dosa et al 2007, DHHS/OIG 2006, Bascetta/GAO 2006 and others), the scientific data and hurricane research does not appear to have influenced local MSN decision-makers, or their perceived level of threat from a hurricane, enough to counter the risks they had calculated or associated with evacuation.

In summary, there is evidence that local MSN decision-makers rely heavily on various information assets when contemplating hurricane evacuation vs. sheltering in place (Dosa et al 2007, Gray and Hebert 2007, Kirkpatrick and Bryan 2007, DHHS/OIG 2006, Nursing Home Administrators pers comm, Butcher pers comm 2006, LA DHH 2007c). However, there is little evidence to suggest that the latest hurricane research, science, or technologies, including storm surge models or GIS modeling, weigh in to MSN decision-making on the local or individual level.

Of note, numerous decision-makers have indicated that they receive "very little assistance in making decisions related to evacuation…" from emergency response agencies, and feel that in some respects, they are left "entirely on their own (Dosa et al 2007, Nursing Home Administrators pers comm 2007)."

CHAPTER 2 OBJECTIVES

The objectives of the study included four major research components. These were to:

1. Identify the risks associated with MSN evacuation vs. sheltering in place;

2. Determine current hurricane risks to coastal Louisiana MSN facilities and residences, and the threshold storm events which would prompt their evacuation. For this preliminary study, hurricane risks included mainly storm surge and wind;

3. Incorporate the latest hurricane research and models into a GIS environment; and

4. Explore ways to clearly communicate and visualize the current science to MSN decision-makers.

The key research question was: **Can any MSN patient shelter safely in coastal Louisiana for any level of hurricane?** Or, phrased differently: Are there any areas of relative safety in coastal Louisiana, south of interstates I-10 and I-12, where MSN sheltering in place would be a "low-risk" or conservative option for lower order storms?

Such a determination could be very useful towards MSN planning in coastal Louisiana given the health risks and costs to evacuate and operate alternate sheltering facilities. This would apply not only to the hundreds of patients from each hospital or nursing home, but to the many others in private residences and other MSN facilities. Research outcomes could potentially reduce health risks and human suffering of patients by identifying any sites that could safely shelter in coastal Louisiana and forego the risks and disruptions of hurricane evacuation.

2.1 Identify Risks: MSN Evacuation vs. Sheltering

The first objective of the study was to assess and compare the health risks of MSN patient evacuation vs. sheltering in place for hurricanes in coastal Louisiana. This was necessary to provide a greater understanding of the complexity of issues involved in both decisions, in

whether to go or stay. This prompted a secondary question as well, in why MSN patients did not evacuate the risk area as Hurricane Katrina approached New Orleans. A literature review commenced to identify the health risks faced by MSN patients and their caretakers during hurricane emergencies, as well as to understand their decision processes. Both were integral to answering the research question.

2.2 Determine Threshold Storm Events: Can Anyone Shelter Safely in Coastal Louisiana for Hurricanes?

A threshold storm event for this study was conceptualized as: **flood and wind levels unsafe for MSN patient sheltering in place, without substantial mitigation measures taking place, such that MSN patients would be recommended to evacuate.** Threshold events as determined by this study accounted only for hurricane storm surge and wind risks; they did not take into consideration other important information that MSN decision-makers would need to know, such as available personnel resources, transportation assets, supply issues, and patient vulnerability.

The second study objective was to determine threshold hurricane events that would trigger MSN evacuation in coastal Louisiana. This could allow for priority levels to be assigned to the evacuation of facilities, and indicate to decision-makers which structures would be most vulnerable during certain events. With added MSN GIS data, meeting this second objective could also provide tabulated census counts of facilities and patients for MSN planning and response.

2.3 Incorporate Hurricane Research and Models into a GIS

The third research objective was to review the state of hurricane research and technology, including current models in use and available data, and to integrate the best and most relevant into a GIS environment. Similar to the multidisciplinary research objectives of the New Orleans

Project GIS (discussed in more detail in the overview to chapter 3), by viewing all research, data and modeling layers in a GIS environment (e.g., the integration of storm surge models and wind hazard data with critical MSN location data), the larger expanse of hurricane risks might be discerned.

2.4 Explore Ways to Clearly Communicate and Visualize the Science to MSN Decision-Makers

Before making difficult medical/health decisions in any emergency, or implementing volumed, multi-tiered plans, the physical threat of an incoming hurricane must first be assessed. Thus, MSN facility administrators and the public require access to site-specific, updated hurricane risk information. However, they may not have (1) adequate computer resources or capabilities; (2) technical expertise; or (3) the latest information on where to find current technology and/or tools. Time or resource constraints may also prevent their access of physical hurricane risk models or research.

Once threshold storm events were determined and supported in a GIS, methods were sought to clearly communicate and share project outcomes with MSN decision-makers. Access to similar planning tools ahead of time can better prepare decision makers to view facility or residence-specific information; to be informed of what they can reasonably expect from hurricane surge and wind; and to use this information to review time schedules and hurricane emergency plans.

Solutions for providing GIS research tools to facility decision-makers at the local and individual level, as well as to regional, state and Federal partners, were the final objective explored. Particular focus was placed on decision tools that are accessible, understandable, practical, and do not require significant computer enhancements, technical expertise, or excessive investments in resources or time.

CHAPTER 3 LITERATURE REVIEW

A literature review was conducted to assess and compare the health risks of MSN patient evacuation vs. sheltering in place for hurricanes in coastal Louisiana.

MSN patient definitions and needs outlined in this research were introduced in Chapter 1, contributed mainly from internet presentations such as Bridges and Garcie 2006, "Providing Care to Special Needs Residents During Times of Disaster," and Lapolla 2003, "Finding Vulnerable and Medically Fragile Populations." Training and class materials related to disabilities and special needs in shelters, as presented at annual National Hurricane Conferences, likewise added to overviews of MSN population issues in earlier chapters. This specifically includes training hosted by the US Fire Administration (USFA) Emergency Management Institute (EMI) and Federal Emergency Management Agency (FEMA) 2003, entitled "Emergency Planning and Special Needs Populations," referenced throughout this manuscript.

Following the catastrophe of the 2005 hurricanes, an upsurge of studies and initiatives have focused on critical medical facilities and hurricane risk. Among these numerous sources, researchers at LSU and the LSU Health Sciences Center have been accumulating data on hurricane health impacts as part of a New Orleans pilot study which began in 2002. As determined from a review of historical Hurricanes Andrew (1992), Tropical Storm Allison (2001), and recent events, these findings are discussed in section 3.1 from the viewpoints of MSN evacuation and sheltering.

One of the most relevant questions in this research involves why MSN patients did not evacuate the risk area as Hurricane Katrina approached New Orleans. The current literature and survey data are consulted to gain further insight to this question, as well as to consider the decision processes faced by MSN decision-makers. Policy initiatives that might affect MSN

evacuation and sheltering decisions in Louisiana, as well as in other hurricane-prone states, are briefly discussed.

The many physical aspects of hurricanes in coastal Louisiana are outlined in section 3.2. Important hurricane facts that will affect MSN planning and decision-making are given added emphasis. An overview of Hurricanes Katrina, Rita, and historical hurricanes over the past century are presented as a backdrop to discover what likely and worst case hurricane scenarios can be reasonably expected to affect Louisiana in the coming decades.

Finally, an overview of current hurricane and health research, models, GIS technology and mapping is provided, highlighting the tools which were selected for the study and their limitations. Medical data privacy and online mapping considerations for MSN patients are also addressed.

3.1 Health Aspects of Hurricanes

Public health impacts of tropical storms and hurricanes are diverse; yet specific risks are encountered in the evacuation and sheltering in place of MSN patients.

Briefly, various hurricane public health impacts that fall outside of the risk categories of evacuation or sheltering may include clean up injuries such as falls, sprains, chainsaw lacerations and cuts; increased risk of exposure to tetanus from debris; animal and insect bites and stings (including from snakes, spiders, fire ants and bee stings, wild animals and domestic pets, introducing also an associated increased risk of rabies); and sunburn (Diaz and Hugh Jones 2003-07, van Heerden 2006a, CDC MMWRs 2006a-c).

Weeks after a flood, environmental health risks from hurricanes may additionally expose the public to toxic mold, polluted water or contaminated sediment (ibid, Pardue et al 2005). Anyone who has suffered a hurricane, whether sheltering in place or evacuating to an alternate

sheltering site, will have increased medical risk. Conditions may include exacerbated medical conditions such as heart attack; diabetic conditions; kidney problems and stroke, often caused by lack of medications or access to medical care; gastrointestinal disease; food poisoning from eating raw or spoiled foods; upper respiratory diseases such as viruses which are highly contagious in shelters; and risk of serious communicable disease (e.g. Tuberculosis) (ibid). Mental health conditions are common following hurricane experiences and may include psychological conditions such as depression, shock, substance abuse, stress-induced conditions, and feelings of loss or separation from family or pets, among many others (ibid).

Hurricane Katrina victims presented with some surprising conditions including wound infections (e.g. Vibrio), skin diseases and staph infections including MRSA; lice and scabies; and numerous cases of rash (ibid). Increased risk of violence or harm was also a health concern at some shelter locations, within and outside of the affected area, due to lack of security (ibid).

3.1.1 Risks of MSN Evacuation v. Sheltering in Place

One of the primary study objectives was to identify and compare the health risks associated with the hurricane evacuation of MSN patients vs. the risks of sheltering in place in a hazard area. Numerous sources are cited which support health aspects encountered after major hurricanes such as Katrina.

3.1.1.1 Hurricane Evacuation Risks

As learned from the New Orleans hurricane public health pilot study introduced at the beginning of this chapter, MSN patients and evacuees risk ***motor vehicle accidents*** and ***drownings*** from attempting to drive through flooded roadways of unknown depth (Diaz and Hugh Jones 2003-07) during evacuations. For example, motor vehicle accidents accounted for over half of all deaths from Hurricane Isabel in 2003, while two drownings occurred at an

underpass in New Orleans due to the 1995 floods (ibid). Causes of evacuation deaths during Hurricane Rita in Texas included ***heat exposure or heat-related deaths***, ***medical distress*** (e.g., lack of immediate access to medical care or medicines), and a bus fire which killed twenty-three nursing home patients (O'Hare 2005) when an unsecured oxygen tank was believed to have punctured and exploded. While specific details are difficult to ascertain, a certain number of elderly deaths can be expected to occur in transit during most hurricane evacuations (Kalis pers comm 2003).

Additionally, as introduced in section 1.3, evacuation risks may include ***dehydration, injury in transit, skin tears and pressure sores for the elderly; lack of appropriate levels of care in transit or at receiving facilities,*** and ***stress*** (Dosa et al 2007, Gray and Hebert 2007, Klein and Nagel 2007, Mutter and R'id 2007, DHHS/OIG 2006, Cutter 2006, Kuba et al 2004).

For example, some evacuating nursing homes experienced "host facilities [that] were unavailable or inadequately prepared" (US DHHS/OIG 2006, p. ii), had "substantial difficulty in transporting frail residents (Dosa et al 2007)," and found that "…placing residents in alternative shelters not designed for the care of elderly and disabled posed particular challenges" including "problems with supplies;" not having enough beds or appropriate beds; and not having rooms that locked to protect Alzheimer's patients from wandering (US DHHS/OIG 2006, p. 13), as well as inadequate staffing (Dosa et al 2007).

3.1.1.2 Risks in Sheltering in Place During Hurricanes

As introduced earlier in section 1.3, sheltering in place presents a separate set of risks in coastal Louisiana. These can be quite severe as hurricanes can rapidly intensify, shift in track, or cause a host of other unanticipated problems (Keim/SRCC 2007, NOAA 2007b-c). ***Tornadoes and extreme rainfall*** often accompany hurricanes (ibid), followed by ***downed trees and power***

lines which may block access routes and disrupt electrical utilities, water supply and communication. In coastal Louisiana, ***levee breaches or hazardous chemical releases may also result*** (van Heerden et al 2006, Pardue et al 2005). Low elevations and other coastal factors expose facilities to serious flooding, and few have been designed to withstand high winds (LSU HC 2007, Levitan pers comm 2007).

Storm surge risks are the primary risk to MSN patients sheltering in place, resulting in ***drowning; near drowning; hypothermia; and submersion*** from storm surge and freshwater flooding (Diaz and Hugh Jones 2003-07, van Heerden 2006a, CDC MMWRs 2006a-c). Meanwhile, wind hazards may cause ***injuries from fallen trees, unsafe structures and airborne debris;*** while additional storm exposures may include ***heat-related illness and death,*** as well as a laundry list of other health outcomes such as ***dehydration and lack of basic needs*** (e.g., food, water and shelter); ***burns***, often from fires set by candles, punctured gas lines, gas grills or similar fire hazards; ***electrocution*** from downed power lines; ***carbon monoxide poisonings*** from generators which are not properly ventilated; ***toxic exposures*** including exposures to chemicals which may cause ***skin conditions, chemical burns and rash***; and ***bacterial skin or wound infections*** from wading in floodwaters (ibid).

Mutter and R'id of the Earth Institute, Columbia University, New York (2007) have compiled information in a Hurricane Katrina Deceased-Victims List[3] which relays personal accounts of both pre-existing medical or mental health conditions and the surrounding circumstances of those closely associated with Katrina victims. Many are vivid accounts provided by witnesses and family members who also suffered days without basic needs awaiting rescue.

[3] http://www.katrinalist.columbia.edu/index.php

Of the many health exposures discussed, similar themes reappeared, particularly among elderly MSN residents: dehydration, ***medical complications, lack of medical access, complications of long-term illness,*** heat exposure, ***heart failure, oxygen-dependent individuals needing supplies***, and many others (ibid). Some sheltering in place were cancer sufferers or had liver disease, respiratory infection or had experienced falls. Some died on rooftops awaiting rescue or were stranded on the interstate (ibid).

Perhaps related to ***mental health aspects*** of disaster, some family members say their families had died "of broken hearts;" "stress;" "sadness;" or "worry;" from losing their homes and belongings, and seeing their neighborhoods destroyed (ibid).

Hospitals with patients sheltering in place, such as in New Orleans during Hurricane Katrina, encountered ***flooding; generator failures; loss of water pressure, communications and power***; and thus endured conditions of ***extreme heat; lack of critical supplies; and need for security*** (Gray and Hebert 2007. Kuba et al 2004). Flooding in a nearby VA hospitals and Tulane University Hospital were disrupted by shorted out elevators, requiring medical and support staff to carry bedridden, oxygen and IV medicated patients up and down stairwells or into boats, at times needing to be moved with "500-pound heart-pumps" as well as "bariatric[4] surgery patients weighing over 600 lbs (ibid, 290-292)." Notwithstanding patient and caretaker stress, the ***potential for injury and lack of adequate medical care*** become apparent.

While actual MSN injuries and storm conditions are difficult to summarize from the available data, certainly as indicated by the high number of hospital, nursing home and other likely MSN patients' deaths during Katrina (section 1.1), risks are understood to be much more severe for MSN patients sheltering in place in coastal Louisiana.

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[4] treatment for obesity, such as gastric bypass

3.1.2 Why Don't MSN Patients Leave the Risk Area?

Given recent extreme hurricane events, it is unclear why so many MSN patients remained in a risk area even as a Category 5 hurricane approached. The literature was again consulted to help shed light on this question.

Some of the best information supplied as to why MSN patients do not evacuate was obtained from hurricane shelter surveys conducted in Louisiana (LA DHH 2005a-b); and Houston, Texas by Brodie et al 2006 and Eisenman et al 2007, both from the *American Journal of Public Health;* as well as within CDC Morbidity and Mortality Weekly Reports (MMWRs).

For example, Houston shelter residents who had been evacuated from New Orleans after Hurricane Katrina were asked in the Brodie et al study (2006) the reasons they did not evacuate. Their answers primarily included, "lack of transportation" and "underestimation of the storm (ibid)." In addition, **12% listed "being physically unable to leave" or "having to care for someone who was physically unable to leave as the main reason they stayed behind** (ibid)," indicating medical issues may have been a substantial determining factor.

Additional evidence supports that difficulty acquiring transportation, lack of resources, underestimation of the storm and medical issues were major reasons MSN patients did not evacuate for Hurricane Katrina. Numerous other factors also contributed to the high numbers of MSN elderly sheltering in place.

3.1.2.1 Lack of Resources or Transportation

Many MSN patients may not evacuate hurricane risk areas due to a lack of resources or transportation. Certainly, nursing homes and hospitals reported serious difficulty in acquiring the appropriate type and number of transportation resources (e.g., ambulances) to evacuate Hurricane Katrina (US DHHS/OIG 2006). This is discussed further in section 3.1.3.2.

Economic hardship or lack of resources has also often been cited as a factor hindering evacuation (Beggs et al 2004, Cutter 2006). In one example, residents surveyed following Katrina indicated that they had not left the risk area because they did not have enough room in the car for everyone (Eisenman et al 2007). In another example, the loss of caregivers - who must evacuate with their own families - may make it difficult for MSN patients to evacuate on their own (Kirkpatrick and Bryan 2007).

Meanwhile, emergency medical personnel and managers have documented cases of MSN patients that were dropped off, or who came in on their own to hospitals, nursing home facilities, or special needs shelters shortly before hurricane landfall (Kosak pers comm. 2007, McConnaughey/AP 2007, Gray and Hebert 2007, Nursing Home Administrators pers comm 2007, Prats 2003). Many of these facilities are considered hurricane “refuges” by the general public (Gray and Hebert 2007, p. 285), such that individuals from the community are “admitted secondary to the storm for weather” e.g., “…Because hospitals are some of the strongest buildings in the city, doctors often have had fragile patients admitted when a hurricane approaches, rather than trying to have them evacuated (McConnaughey/AP 2007).”

Federal reports such as Bascetta/GAO 2006, which focused mainly on transportation issues associated with vulnerable populations, and the US Departments of Transportation (DOT) and Homeland Security (DHS) 2007 “Catastrophic Hurricane Evacuation Plan Evaluation,” both concede that evacuation travel can take much longer than expected, particularly in procuring transportation and loading medical patients. That evacuees may face daunting traffic and associated health risks is well supported by these sources and disaster researchers such as Susan Cutter (2006) who has worked extensively with vulnerable populations, transportation and evacuation issues.

“Shadow evacuation” is a term used to describe an evacuation plan or strategy that has been overwhelmed by evacuations from less-vulnerable areas, congesting the roadways to a near stand still (ibid). This has happened in recent storms such as Hugo in South Carolina and Hurricane Rita in Texas. In the latter, an estimated 2.7 million people evacuated the Houston/Galveston Region; yet the evacuation needs of the population were almost double that of the planning and accommodations that had been planned for (an estimated 1.2 million, according to Wells/M2MEDIA360 2006). The situation was described as follows:

> “The result was a massive jam of slow-moving traffic with routes choked by voluntary evacuees who impeded the progress of those attempting to leave the storm-surge zone under mandatory evacuation orders… Texas had recently received 470,000 evacuees from Louisiana… In some instances, the trips were painfully long, as shelters filled, and evacuation busses were diverted further inland only to be redirected again at their next destination (ibid, p.1)”

After communication issues, sheltering and transportation were the main areas recommended for improvement in the DHS and State of Louisiana Governor’s Office of Homeland Security (LA GOHSEP) “Hurricanes Katrina and Rita After-Action Report and Improvement Plan (2006a).” Action items slated for future follow-up were numerous, but as related to transportation problems included: the development of transportation databases; updated plans to ensure adequate transportation assets; transportation to move patients between shelters; and a better tracking system for evacuees - particularly if evacuated out-of-state (ibid).

According to the state report, operations during the 2005 hurricanes were also hindered by an inability to effectively credential support staff and supply vendors in Louisiana (ibid), which likely constrained rescue and effective medical response to a certain degree. The procurement of emergency generators to power shelters and to serve special needs populations was an additional recommendation of the report (ibid).

3.1.2.2 Fragile Health and Medical Issues

Not surprisingly, complications from medical issues are another major factor that prevent residents from evacuating during hurricanes. From the Eisenman survey (2007) of Hurricane Katrina evacuees in Houston, some residents indicated not being healthy enough to drive very far; that they were on medication that hindered their ability to drive; or expressed inability to make the trip.

Additional questions may be raised with the discharge of patients by hospitals before hurricane landfall (Gray and Hebert 2007, Kuba et al 2004); that this does not provide much time for planning and executing an evacuation on already congested roads, especially for those recovering from a medical stay or those who are elderly.

Mutter and R'id 2007 provide evidence of medical reasons prompting elderly MSN residents to shelter in place. One resident was "just out of the hospital and couldn't go to a shelter." Others had complications from surgery, poor eyesight, Dementia and Alzheimer's.

3.1.2.3 Underestimation of the Storm Threat

There is evidence that some MSN residents are not convinced of hurricane risks when they decide to shelter in place during hurricanes. As previously discussed, "underestimation of the storm" was one of the main reasons residents did not evacuate based on the Brodie et al survey (2006). Meanwhile, of over a hundred nursing home administrators in the coastal Louisiana parishes south of the interstates, only 19 facilities appear to have evacuated prior to Hurricane Katrina for an incoming Category 5 hurricane (LA DHH 2007b).

3.1.2.3 Confusion and Fear

Eisenman et al (2007) again add insights from the Hurricane Katrina evacuation perspective, such as residents who did not receive information from emergency management on

where they should go; getting mixed messages on whether they should go or stay; expressing fear of leaving their homes because of robbery or looting; or decided to shelter in place after hearing media reports of people getting injured in highway accidents and running out of gas. In other anecdotal evidence from Mutter and R'id (2007), some residents had just remodeled and were "afraid of looters" so they decided to ride out the hurricane.

Communication issues were a major problem cited in state after action reports (US DHS & LA GOHSEP 2006). Work by Edson et al (2007) includes, "A Systems Analysis of Special-Needs Population Evacuation during Catastrophic Events" demonstrating in many cases how much differently execution in the Hurricane events of 2005 differed from plans as designed.

3.1.2.4 Resignation, Stubbornness or Unexplainable Factors

In yet other cases, reasons that potential MSN patients such as the elderly refused to evacuate, as described by friends and family members, were difficult to comprehend. Their explanations varied from impressions of stubbornness, apathy, denial, an unwillingness to step outside of comfort levels, shock, or resignation (Mutter and R'id 2007, Gibson and Hayunga 2006, and other anecdotal evidence and accounts).

It has been suggested by the initial data that elderly populations were disproportionately affected by the Hurricane Katrina event, and that elderly have age-associated medical special needs as well as disabilities. In addition, a research report prepared by the American Association of Retired Persons (AARP) Public Policy Institute (PPI) by Gibson and Hayunga 2006, "We Can Do Better: Lessons Learned for Protecting Older Persons in Disasters" discovered that older residents who live independently or in larger households may generally find evacuation to be a hassle, a long trip and not suited to their needs (e.g., maneuvering an information point or rest

area). They also fear being an undue burden on their families (Gibson and Hayunga 2006), and for these and many other reason may decide to shelter in place (Mutter and R'id 2007).

Michael Weston, Director of Emergency Field Operations for the U.S. Administration on Aging perceives that the overwhelming inconvenience of the ordeal may cause elderly to rationalize staying through storms. In ensuring actionable plans for the evacuation of seniors, he advises:

> "Many older adults feel they are ready 'if it's their time to go.' One strategy is to remind them that if it is not "quite" their time; they could be in for several weeks of misery while waiting for help (Gibson and Hayunga 2006, p 65)."

Additionally, some elderly indicated they had "lived through Betsy in 1965 (Mutter and R'id 2007)." Others did not want to leave the homes their families had built "with their own hands (ibid);" Some simply said "I'm too old for this;" "It's in God's hands;" "You go on, we've lived our lives;" and "Whatever happens, we'll go together (ibid)." Many did not want to leave their husbands or families (ibid).

3.1.3 Factors Dominating MSN Decision-making

It has been determined that there are health risks to both evacuation and sheltering in place for MSN patients, and that MSN patients may remain in a risk area for reasons ranging from transportation availability to inconvenience. Questions necessary follow as to what decision processes MSN decision-makers apply when they weigh their hurricane health risks, and which are the over-riding factors that dominate their decisions to evacuate or shelter in place.

To answer this question, it is important to review briefly that, as discussed in section 1.5.1, MSN decision makers may include hospital CEOs, nursing home administrators, parent or sister facilities, facility owners, nurses, staff, maintenance personnel, and others (Dosa et al 2007, Gray and Hebert 2007, Kirkpatrick and Bryan 2007, DHHS/OIG 2006). The public living

in households or group residences and requiring varying levels of medical support and care are also decision-makers, as they must weigh the risks of evacuation and sheltering in place during hurricanes as well (Kirkpatrick and Bryan 2007, Fernandez et al 2002).

Additionally, it should be re-iterated that MSN facilities and residents may not have the capabilities to be in close communication with emergency management at all times. MSN decision-makers may evaluate their hurricane risk by other available sources (e.g., from past experience or the media, and other factors besides physical hurricane risks); will consider heavily the health risk to move a patient or loved one and available resources; and will determine which immediate actions they will take (Dosa et al 2007, Gray and Hebert 2007, Kirkpatrick and Bryan 2007, DHHS/OIG 2006). Thus, the decisions they make may be in direct conflict with the hurricane information and evacuation strategies of local emergency management and police.

Finally, it should again be noted that in most Gulf States including Louisiana, local emergency managers, officials and the Governor can issue voluntary and mandatory evacuations. However, there is currently no mechanism to enforce an evacuation of a nursing home, hospital, private facility or residence other than, in some cases, to impose sanctions or penalties for violations such as deficiencies or fines on a facility (LA DHH 2007c, Gray and Hebert 2007, Nursing Home Administrators pers comm 2007).

3.1.3.1 Hospitals Vulnerabilities in a Hurricane Emergency

Decision strategies of hospital administrators related to evacuation are based on factors which are unique to their facilities and patients. Hospital vulnerabilities in an emergency however are numerous and appear to weigh heavily into evacuation and sheltering decisions.

The most frequently cited recent articles related to hospitals and field hospitals for this study include Gray and Hebert 2007 "Hospitals in Hurricane Katrina: Challenges Facing

Custodial Institutions in a Disaster," from the *Journal of Health Care for the Poor and Underserved;* Klein and Nagel 2007 "Mass Medical Evacuation: Hurricane Katrina and Nursing Experiences at the New Orleans Airport;" and Deal et al, "Challenges and Opportunities of Nursing Care in Special-Needs Shelters," both from the Journal of *Disaster Management and Response*. Inside accounts are provided in these sources by medical professionals who experienced working with MSN individuals in a hurricane emergency, whether in formal or field hospital settings or in special needs shelters.

Of import to this study, there are indications that the hospitals that experienced high mortality during Katrina differed from most other hospitals in one major aspect: they had non-traditional medical units on site including hospice and "long-term-acute care" patients who may have been seriously ill (Gray and Hebert 2007. Kuba et al 2004). Therefore, the types of patients and their critical medical status may introduce the single largest vulnerability.

Custodial institutions such as hospitals will often discharge ambulatory and stable patients ahead of a storm in anticipation of a surge of new patients, including nursing home patients and people who will come in from the community (Gray and Hebert 2007). As already mentioned, from the community perspective, both nursing homes and hospitals may still be viewed as "refuges" and the place to take or drop of MSN patients and family before hurricane landfall (ibid, p. 285, Nursing Home Administrators pers comm 2007). This is particularly true if the facility has held up well through past storms (ibid). Hospitals in a risk area therefore run the risk of exceeding patient capacity even before hurricane landfall (see also, Appendix C).

However, the remaining hospital patients are generally not stable enough or able to be easily moved (ibid). Many hospital patients cannot be discharged prior to a storm and evacuated without significant planning and time, such as those "recovering from surgery or debilitated by

disease;" those "dependant on medical assistance to breathe… demented patients, newborn babies" and others, including hospital patients "requiring dialysis and those transferred from nursing homes (Gray and Hebert 2007, p. 285)."

Some detailed analyses of hurricane performance have been conducted on major Louisiana hospitals (e.g., Gregg 2006 on West Jefferson Hospital in "Development and Application of Methods for Evaluation of Hurricane Shelters"). However, most hospitals are not designed for emergency power (ibid), and in the case of Hurricane events like Katrina, were not otherwise prepared to accommodate the onslaught of patients that would soon be under their care, particularly as the emergency escalated, reinforcements and supplies were delayed, and conditions worsened. Thus, hospitals are inevitably 'set up' for serious hurricane health outcomes.

Dr. Ben deBoisblanc, a critical care expert at Charity Hospital described his experience during Hurricane Katrina,

> "At Charity Hospital…I and nearly 60 other staff doctors, nurses, and residents were stuck in a hospital without electricity, without water, without food, for five days with about 340 patients, 50 of them critically ill. We had no ability to use ventilators, so we had to squeeze ambu bags by hand to get air into their lungs. We had no monitoring equipment, no X-ray, no laboratory, no dialysis. Compounding all this, we were unable to have families at the bedside — or even available by phone — to participate in treatment decisions for the sickest patients. It was very, very difficult (Haber/AP 2006)."

3.1.3.2 Nursing Home Vulnerabilities in a Hurricane Emergency

An important Federal study of "Nursing Home Emergency Preparedness and Response during Recent Hurricanes" was conducted by the United States Department of Health and Human Services (US DHHS), Office of the Inspector General (OIG), August 2006. This study directly interviewed MSN facility administrators across the Gulf States related to numerous

hurricane events to better understand the vulnerabilities and decision strategies of evacuation and sheltering in place for coastal nursing homes.

Additional work on nursing home vulnerabilities in disaster cited frequently throughout this study are by Dosa et al (2007) “To Evacuate or Not to Evacuate: Lessons Learned from Louisiana Nursing Home Administrators Following Hurricanes Katrina and Rita,” *Journal of the American Medical Director’s Association.* The authors have emphasized numerous problems encountered in nursing home evacuation and sheltering (see also, section 1.3)

US DHHS/OIG (2006) results indicated that, of the Gulf State nursing homes surveyed,

> “All nursing home administrators reported that an evacuation can cause physical and mental stress on nursing home residents, and consequently is not necessarily the best course of action for residents during hurricanes. Administrators also reported that sometimes sheltering on place is the safer (and also less expensive) alternative, particularly in the case of hurricanes during which storms can quickly shift and reduce risk to residents and staff (US DHHS/OIG 2006, p. 8).”

Gulf State nursing home administrators and decision-makers expressed problems encountered during recent hurricanes, either having evacuated or sheltered in place. Major problems included being unable to secure adequate “space in other nursing homes to accommodate all residents (DHHS/OIG 2006, p. 10).” Many had prior contracts with transportation that fell through “days or hours” before evacuation when vehicles were needed by other facilities more likely to be directly affected by the hurricane (ibid). In some cases, “…multiple nursing homes contracted with the same companies, typically the company used for routine ambulance services (ibid, p. 10).”

Travelers were be exposed to high temperatures in traffic and depletion of supplies such as adequate water, while medical or “medication needs” complicated travel such as not being “readily available during transit” or “improperly packed and supervised (ibid, p. 10-11).” During some nursing home evacuations there was an identified need to “prevent residents from

inappropriately exchanging medications (ibid, p. 11)". Dosa et al (2007) identified even more problems ranging from difficulty in transporting frail residents to inadequate staffing.

Findings released on a Federal-state survey of nursing homes in coastal Louisiana in 2006 for issues such as staffing, emergency power and supplies were summarized in the press as "most…homes had neither an adequate way to move patients out of harm's way nor a suitable place to put them once they got there" (Shuler/Baton Rouge Advocate, Nov 2006). Later hurricane shelter suitability surveys and briefings however reported substantial progress in these areas (US DHHS/LSU HC 2007, LA DHH 2007b).

Nursing home vulnerabilities specific to Louisiana in hurricane emergencies were discussed in detail by Prats 2003, "Multiple Criteria Decision Making (MCDM) Application in Evaluating Nursing Home Emergency Preparedness Plans in Louisiana," as referenced throughout this study. As previously discussed, she identified major problems with topics ranging from moving critical care patients in an evacuation to accommodating nursing home patients in state shelters. Her study focused specifically on Louisiana nursing homes and their preparedness plans, outlining methods to resolve the multiple criteria that must be arranged and prioritized within a meaningful framework to make better decisions on all levels regarding nursing homes. Prats identified the need to resolve the many agency and organizational disputes, both laterally, horizontally ands inter-agency, which seemed to put nursing home evacuation plans at odds when agencies viewed their directives or goals as mutually exclusive.

3.1.3.3 Elderly Vulnerabilities in a Hurricane Emergency

Kuba et al (2004) "Elderly Populations in Disasters: Recounting Evacuation Processes from Two Skilled-Care Facilities in Central Florida, August 2004" and Fernandez et al (2002)

"Frail Elderly as Disaster Victims: Emergency Management Strategies" were some of the major sources for identifying evacuation risks to elderly throughout the current study.

In addition to the factors that may have hindered MSN elderly evacuations as discussed in section 3.1.2, elderly may have sensory impairments, mobility disabilities, and potential language or cultural barriers (USFA EMI 2003, p.1.9). The elderly are often "more susceptible to heat and cold, creating potential crisis situations when air conditioning and heat are not available;" often have "memory disorders, such as Alzheimer's or senility;" and may be at risk of "transfer trauma if they are forced to leave their homes (ibid)." Many studies have shown that dislocation without care can cause illness and even death in senior citizens (ibid)."

The elderly may experience dementia, delayed response syndrome (slow response in a crisis and poor understanding of impending danger), and fear of institutionalization (being transferred to a nursing home) when emergency responders attempt to assist them in a rescue situation (Missouri SEMA 2007).

According to a 2005 US Census Bureau survey, nearly half (46.6 percent) of the household population 65 years and over in Louisiana had some form of disability.[5]

Recent studies at LSU have shown that the longer an individual has lived in New Orleans, the less likely they are to leave (Beggs et al 2004). Although no clear relationship was supported, preliminary data suggests that the likelihood of evacuation declines with age (ibid). Brodie et al (2006) also present evidence that low-income, minority households with elderly or disabled residents are less likely to evacuate than other households.

Specific to the elderly, surveys also indicated older residents that had made it through Betsy and Camille weren't evacuating, or had mobility or medical disabilities such that their

[5] This includes household population only, excluding the population living in institutions and other group quarters such as nursing homes or hospice

families would not leave them behind (Beggs et al 2004, Mutter and R'id 2007, Callimachi/AP 2006 and others).

As previously discussed, reasons that the elderly refused to evacuate as described by friends and family members ranged from impressions of stubbornness, apathy, denial, an unwillingness to step outside of comfort levels, shock, and resignation (Mutter and R'id 2007).

As emphasized by Mayhorn 2005, *Natural Hazards Review* "Cognitive Aging and the Processing of Hazard Information and Disaster Warnings" and others, more study is needed to determine how MSN and elderly individuals process information and respond to hurricane threats.

Taken in combination with section 3.1.2.4, these various explanations finally begin to make sense of why so many MSN elderly appear to have remained in the risk area during Hurricane Katrina, and why so many did not evacuate.

3.1.3.4 Disabled and Other MSN Patient Vulnerabilities in a Hurricane Emergency

MSN disabled become most vulnerable in hurricane emergencies when evacuation and sheltering systems cannot accommodate the diversity of their needs. Deal et al 2006, in "Challenges and Opportunities of Nursing Care in Special-Needs Shelters," outline the care given to a wide spectrum of individuals including nursing home patients, people with mental retardation and long term physical disabilities, and those who had lost their homes (ibid). Major problems encountered included "unavailability of medications, treatment and ancillary supplies," and identifying patients, as well as privacy, confidentiality, and other management concerns (ibid, 102).

Medically fragile residents who depend on family members for care are subject to the resource and medical information limitations of that household in a hurricane emergency.

Critical medical decisions also appear often times to be made on an emotional level (e.g., family members will shelter in place to care for medically fragile loved ones). Among the examples of Hurricane Katrina and medically fragile patients who did not or could not evacuate, one story details a son who had decided to remain in New Orleans to care for his elderly mother. She had "broken her hip in 2000, was bedridden and had a feeding tube attached to her stomach. Because of her fragile health, her son thought it would be imprudent to move her when the city called for a mandatory evacuation, one day before the storm made landfall…(Callimachi, 2006)" This MSN patient was ultimately exposed to heat and dehydration and later died before rescuers or medical support could retrieve her from the Convention Center.

MSN patients, particularly the immuno-compromised, are almost certainly exposed to increased health risks in shelter environments (Diaz 2003-07). Hurricane sheltering in Louisiana includes extensive plans for state run Special Medical Needs Shelters (SMNS); shelters for state transported evacuees with critical transportation needs (CTNS); and parish run shelters, some of which are staffed by the American Red Cross (ARC); and faith-based shelters (LA GOHSEP, May 18, 2006). However, unlike nursing home or hospital care settings, shelter conditions are not always well-suited to the MSN patients they are designed to serve, and specialized medical care may not be available.

During Hurricane Katrina in New Orleans, State Epidemiologist Raoult Ratard, MD warned specifically of his concern for shelters due to their risk levels for infectious disease. He indicated, "The problem is not going to be from New Orleans, it's going to be from the shelters" where "contagious disease" risks are "considerable (Barclay 2005)." One of the other major problems he indicated were that shelter residents experienced a loss of their individual health

support systems (ibid). Many sheltering in place are thus destined to become additional MSN patients.

As previously discussed, MSN patients with chronic health conditions are highly vulnerable in hurricane emergencies when their access to medical care, equipment or medicines is disrupted. Some of the most common reasons for hospital admission immediately following Hurricane Katrina according to the CDC were "heart disease (26.6%), nondiarrheal gastrointestinal illness (12.3%), mental health conditions (6.7%) and heat-related illness (6.1%) (CDC MMWR 2006a)." Chronic diseases are being addressed more in the literature (Ford et al 2006, Mokdad et al 2005) as one of the main problems identified in follow-up care after hurricanes. Chronic conditions are common among MSN patients and the elderly as discussed throughout the current study.

In review, Houston shelter surveys conducted by Brodie et al 2006 identify that "…41% of all Houston shelter residents reported chronic health conditions such as heart disease, hypertension, diabetes, or asthma." CDC reports also indicate "…during Sept 1-22, chronic illness (e.g., diabetes, asthma, emphysema, and cardiovascular disease) was the most commonly reported category in evacuation centers (ECs)…(CDC MMWR 2006b)."

3.1.3.5 Louisiana Policy Initiatives Affecting Medical Special Needs

In Louisiana, hurricane emergencies are locally managed by parish emergency managers and their partners, including police, fire and EMS. Hurricanes are also centrally managed from the GOHSEP in the Emergency Operations Center (EOC), which houses many state, federal and military agency representatives (such as the Louisiana National Guard) during an actual emergency.

Of note, GOHSEP operates under the National Response Plan (NRP), with an Incident Command System (ICS) Structure (Blanco 2006) or National Incident Management System (NIMS)/ Incident Command System (ICS) Unified Command (US DHS & LA GOHSEP 2006a). The NRP will directly affect the management of MSN evacuation and sheltering whenever it is activated. Technically the NRP is always considered "in effect" but the level of coordination is "flexible and scalable" depending on the situation (US DHS 2006b, p. 1). The NRP and NIMS are considered "companion documents," in that NIMS provides a "template for incident management" at any level, while the ICS can accommodate multiple agency coordination when more than one have jurisdiction in an emergency event (ibid, p. 5).

All hurricane emergencies begin by being managed at the local level. When resources or capabilities become overwhelmed, local emergency managers and decision-makers have established protocols in the NRP which they will use to call upon the state and then Federal government as needed for reinforcements.

As evidenced during Hurricane Katrina, communication, coordination and timing are all crucial if the NRP is going to work effectively. Further, command and control issues (i.e., who is in charge, who has authority, who is responsible for making decisions, and any necessary legal information that would stall these actions), play a large role in an effective unified response to a disaster.

Arranged under the NRP, Louisiana state and other partner agencies are grouped as Emergency Support Functions (ESFs) at the state EOC. ESFs are defined as:

> "…the primary means through which the Federal government provides assistance to State, local, and tribal governments or to Federal departments and agencies conducting missions of primary Federal responsibility… ESFs were established …as an effective mechanism to group capabilities and resources into the functions that are most likely needed during actual or potential incidents where coordinated

> Federal response is required (e.g., Transportation, Firefighting, Public Health, etc.) (ibid, p.14)."

ESF 1 (Transportation) is responsible for transportation and evacuation. ESF 1 is supported by ESF 8 (Public Health and Medical Services). ESF 6 (Mass Care, Housing and Human Services) and ESF 8 work together to provide MSN sheltering in a hurricane.

The Louisiana Department of Health and Hospitals (LA DHH) is tasked, among many other responsibilities, to "establish criteria for evacuating healthcare facilities by identifying threats, developing plans and evaluating and validating plans (US DHS & LA GOHSEP 2006a, p. 2-26)." The LA DHH Bureau of Emergency Medical Services (BEMS) within the Office of Public Health (OPH) Center for Community Preparedness, Emergency Preparedness and Response is responsible for planning and coordinating "state-level pre-hospital medical response to disasters;" supporting "local response efforts by providing supplemental pre-hospital medical sources (e.g., contracted and mutual aid private and public EMS resources);" arranging "for evacuation of the special needs population, hospitals and nursing homes" and for the "movement of injured disaster victims to hospitals, SpNS and TMOSAs in areas/regions not impacted by the disaster (Blanco 2006, LA DHH Appendix 9, p. A-9)." As recently described by BEMS:

> "The primary concerns for BEMS during weather-related emergencies include the evacuation of acute and long-term care facilities threatened with flooding, emergency support to home health care patients and medical support to the medically fragile who are evacuated. In addition to these responsibilities, BEMS has been tasked with the deployment and maintenance of medical response equipment and supplies (ibid, A-9)."

Louisiana nursing homes are subject to the State of Louisiana Model Nursing Home Emergency Plan and quality measures reported to the Centers for Medicare & Medicaid (CMS) (Sadden et al 2005). Act 540 (2006) is a new initiative in Louisiana providing for promulgation

of rules and protocol for the evacuation or sheltering in place of nursing homes in the event of an oncoming hurricane.

For local governments in Louisiana working to evacuate MSN patients in a hurricane emergency, the Americans with Disabilities Act (ADA 1990) would be most relevant in implementing strategies to be put in place for individuals with disabilities. These would relate to notification and access to information; evacuation and emergency transportation; sheltering; and access to medical care, medications, mobility devices, and service animals while in transit or at shelters (DOJ CRD/DRS 2004). Title II of the ADA mainly concerns government entities, and prohibits discrimination against persons with disabilities; Title III affects more non-governmental entities providing public service (e.g., ensuring ADA accessible entrances, toilets and shelter areas); and Title IV deals with communications (ibid) such as telecommunication requirements (e.g., teletypewriters or TTY - devices used to communicate with the hearing impaired via telephone), FCC regulations on open and closed captioning, and the Emergency Alert System on TV and radio (USFA EMI 2003).

Presidential Executive Order 13347 (July 26, 2004) "Individuals with Disabilities in Emergency Preparedness" mandates that those with disabilities must be considered in emergency preparedness plans.

Looking more locally at Louisiana policy initiatives affecting MSN evacuation planning and decision-making, in New Orleans following Hurricane Katrina, the city is reviewing and implementing new strategies for city-wide evacuation. For example, Mayor Ray Nagin announced in May 2006 that neither the Superdome nor the Convention Center would be used as a 'refuge of last resort' in future storms. However, the Convention Center is planned be used as a staging area for buses to take critical transportation needs (CTN) residents from designated

pick up sites around the city to shelters outside the metro area (Schleifstein/Times-Picayune 2006).

Other changes and initiatives that may impact MSN patients include that "Elderly residents and those with medical problems will be taken to Union Station [Union Passenger Terminal] and put on Amtrak trains out of the city (ibid)." Additionally, "people living in FEMA trailers will be ordered to evacuate whenever a tropical storm with winds above 40 mph approaches the city" and "bused evacuees will be able to take their pets if in cages or containers (ibid)." Of note, special needs registration is being attempted with eligibility based on "having reliable transportation" and "… [if individuals] cannot afford fuel or hotel costs, or have medical, physical or psychological conditions that could prevent them from evacuating (ibid)."

3.1.3.6 MSN Initiatives in Other Hurricane-Prone States

Reviewing briefly MSN initiatives in other hurricane-prone states such as Florida, Texas and North Carolina, it is interesting to note that special needs evacuation lists have been required of many Florida counties for years, with officials updating the lists through networking and relationships with "aging and health care facilities (Olsen 2005)." Florida Statutes actually include:

> Registry of persons with special needs; whereby local emergency management agencies must: "…maintain a registry of persons with special needs, identify needs and plan for resource allocation to meet those needs… [and] …to assist the local emergency management agency in identifying such persons, home health agencies, hospices, nurse registries, home medical equipment providers, the Department of Children and Family Services, Department of Health, Agency for Health Care Administration, Department of Education, Agency for Persons with Disabilities, and Department of Elderly Affairs shall provide registration information to all of their special needs clients and to all persons with special needs who receive services. The registry will be updated annually (252.355)."

Florida residents are given the option for pre-authorized entry of search and rescue personnel following disasters. Additionally, emergency and disaster planning provisions provide assistance to persons with disabilities and include the:

> "…designation of an emergency coordinating officer, a procedure to contact special needs citizens, registry and dispatch, and essential support services to organizations before, during and after disasters (252.356)."

Florida is also forward-thinking in its adoption of strict building codes. Following Hurricane Andrew in 1992, Florida instituted some of the strongest building codes in the nation for its coastal parishes (Levitan pres comm 2007). Louisiana's statewide adoption of the International Building Codes is only now scheduled to take effect in 2007 (ibid).

In other policies, following Hurricane Rita, Governor Rick Perry issued Executive Order RP57 (March 2006) to improve mass evacuation in Texas including provisions for people with special needs. Some coastal cities such as Galveston have had voluntary special needs registries prior to Hurricane Rita. These listed residents requiring ambulance transport and in some cases prescription and medical equipment needs (Olsen 2005). Houston designated the city 3-1-1 help-line prior to Hurricane Rita to register anyone needing evacuation assistance (ibid). Currently, Texas is developing a statewide special-needs database entitled the "Transportation Assistance Registry" to be shared with local emergency management. Local Emergency Mangers will contact the individual, arrange for transportation to a pick up point, and the state will arrange for their further evacuation location (Wells/M2MEDIA360 2006). 2-1-1 call centers are also being established with individual categories of special medical needs ranging from 1 "minor and ambulatory" to 5 – "severe and requiring life support (ibid)." Some locals are also taking the initiative to develop their own databases for their areas (Olsen 2005). Louisiana is pursuing similar initiatives with coastal parish pick-up points.

Both Texas and Louisiana are developing tracking evacuation systems that may incorporate GIS. In Texas,

> "At the departure points, evacuees including their pets, will receive an RFID wristband with a barcode that links them with a record entered into a template by typing the information into a laptop computer or using magnetic card readers and bar code scanners to enter Texas ID cards, drivers' licenses and other forms of state identification (ibid)."

The intent is for real-time data upload and tracking of evacuees. GPS units are a future option being explored to track buses and expected supplies, as well as to geo-code evacuation routes to provide an overall "operational picture (ibid)."

Following Hurricane Floyd (1999), North Carolina has developed an innovative and alternative way to support MSN planning. Special Operations Response Teams (SORTs)[6] have been created to support what they term the "alternate medical care population." Their mission includes:

> "to meet the Special Medical Needs of those individuals who are either homebound or in assisted living facilities in times of disaster. This division will provide pre-disaster planning assistance, an emergency response team to coordinate disaster response, and the equipment, supplies, and personnel to establish a Special Medical Needs Shelter. This division works closely with the Medical and Logistics Divisions to provide the care required in an Alternate Medical Care Facility… The Division's goal is to provide support for the Alternate Medical Care population in order that they may remain in their current residence and when that is no longer feasible, to mobilize and maintain an Alternate Medical Care Facility (SORT 2007)."

NC SORT teams have established MOUs with area shelters including colleges and churches; have an emergency number which local residents may call; consist of multi-agency representatives on teams; have an available stockpile of supplies; and have even planned to provide childcare to SORT volunteers (ibid).

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6 http://www.sortteam.org/spneeds.html

3.2 Physical Aspects of Hurricanes

In determining actual hurricane risk to medical facilities such as hospitals, nursing homes and other MSN facilities or residences in coastal Louisiana, this study necessarily reviews the reality of 2005. Recent Hurricanes Katrina and Rita provide an example of how quickly storms can reach catastrophic strength in the Gulf of Mexico, and their potential for destruction. Physical aspects of hurricane storm surge and wind and their impact on critical infrastructure along the coast are detailed in the following section. The impacts of these storms can serve as a conservative, yet reasonable estimate of risks that an MSN facility could endure; but should also be kept in perspective and viewed against an historical back-drop.

3.2.1 2005 Hurricanes Katrina and Rita: Wind and Surge

Louisiana was hit with a ‘one-two punch’ to the coastal southeast and southwest, respectively, in a single year. Beginning on 29 August 2005 with Hurricane Katrina, which impacted much of the greater metropolitan area surrounding New Orleans, Hurricane Rita made Louisiana landfall approximately a month later on 24 September. Both storms had achieved maximum storm strengths of Category 5 on the Saffir-Simpson scale for Hurricanes (see Appendix A) while in the Gulf of Mexico. Storm winds and surge diminished slightly over some of Louisiana’s last remaining coastal defenses, now comprised mainly of slivered barrier islands and fragmented marsh (van Heerden 2007, Barras/USGS 2006, Guidroz et al 2006 and others). However, for those who sheltered in place to ride out the storm in coastal Louisiana, the maximum sustained winds realized were likely well over the recorded 87 mph clocked in before measurement instruments snapped for Katrina; and 120 mph for Hurricane Rita, with substantially higher wind gusts for both (Knabb et al 2006, Guidroz, et al 2006).

Meanwhile, both storms retained much of their Category–five storm surge potential (due to inertia, Levitan pers comm 2007) even though making landfall closer to Category 3 storm levels. Walls of storm surge pushed ashore by Hurricane Katrina were over 19 feet in some areas of east New Orleans, St. Bernard and Plaquemines Parishes in southeast Louisiana (although measurements were again sparse as equipment was damaged by the surge), and as much as 14-15 feet in areas of Cameron Parish for Rita (ibid).

Those who lived through these life-changing storms in Louisiana will recall that initial Katrina reports were encouraging. The Superdome, with separate areas having been used as a general population and special needs shelter for the storm, had only incurred minor damage to the roof. Most of the New Orleans Protection System[7] was reported to have initially held. But reports of the worst flooding had not yet come in. The true extent of flooding in the ninth ward and St. Bernard parish - which had literally been devastated – was realized soon after, followed by reports of unexplained rising water in residences and hospitals, where people had been sheltering in place in the city.

Katrina generated up to 20 feet of storm surge and waves (van Heerden et al 2006b), propagated by storm winds through Lake Borgne and funneled into New Orleans through a reach of the Mississippi River Gulf Outlet (MRGO), battering and disintegrating eastern levees and eventually sections of the Industrial Canal. The resultant breaches sent high velocity flows (ibid, Mashriqui 2006a) into neighborhoods in the early morning. Over 200 residents are estimated to have drowned in their homes (Boyd pers comm 2007). As the storm tracked north towards Mississippi, Katrina surge then poured into Lake Pontchartrain and into city canals such as 17th Street and London Avenue (van Heerden et al 2006b), snapping and bending the canal walls in

[7] A system of ringed Federal, state and local levees and canals that provide storm surge protection for the city and surrounding areas.

what numerous witnesses described as ‘sounding like explosions.’ Reports of rising water intensified as flood levels equalized. Nurses called in to radio stations reporting rising floodwaters at hospitals in the Central Business District; Levee breaches were suspected and then confirmed. Over 1,464 in Louisiana died, not counting the other as-yet unrecorded losses, such as the over 130 remaining Katrina missing, many who likely drowned but whose bodies were never recovered. From the available data, many were elderly residents who died in their homes (LA DHH 2006a; Boyd 2006).

Hurricane Rita soon after delivered a swath of hurricane surge as far inland as Lake Charles and New Iberia in Louisiana, and reflooded parts of New Orleans through as-yet unrepaired hurricane protection structures, with both far-reaching surge and rainfall. Although details are unclear, as many as a hundred deaths may be attributed to Hurricane Rita (ibid), many occurring as a result of the evacuation out of Houston prior to the storm, and many possibly elderly.

3.2.2 Louisiana Historical Hurricanes 1905-2005

Following Hurricanes Katrina and Rita, whose intensities and impacts were unprecedented in Louisiana, it is important to place this destruction in the context of previous hurricane events. Particularly when planning for future storms, the natural questions become, “What hurricanes can we expect next?” “What is likely, and what is worst case?” and, as some scientists have warned due to climate change and sea level rise, “Will hurricanes be more frequent and more intense?” or even, “Is this the age of ‘megastorms?’

Helping to shed light on some of these questions, the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) has made historical hurricane tracks available for US hurricanes dating as far back as the mid nineteenth century. The dataset

includes storm name, year, dates, track, central pressures, and wind speeds, and is now available in GIS shapefile format.[8] This introduces new options for querying and mapping selected storm data in a GIS. Storms striking Louisiana can be selected for time period, storm intensity and dates, with historical tracks that can be mapped.

However, it is important to note the main limitations that will affect analysis of the data. LSU climatologists note,

> "Major changes in the observation methods of tropical storms begin with land and ship observations from the beginning of [the] record in 1851. In the 1940s, military aircraft reconnaissance was first used to monitor hurricanes. Then in the late 1960's, satellite surveillance became a dominant observation method… (Keim and Robbins 2006, L21706)."

Chris Landsea of NOAA's Hurricane Research Division (2001) shares this opinion that it would be an "erroneous conclusion that major hurricanes became much more numerous in 1943 (p. 2871)" since that was the year planes actually started flying into hurricanes to obtain measurements. Prior to that, the quality of data obtained by US naval ships or buoys noting storm tracks and pressures by land and sea would have been closely proportional to the distance at which measurements could be taken (Romolo pers comm 2007), with actual intensities "likely to be drastically underestimated (Landsea 2001, p. 2871)."

For example, no Category 4 or 5 storms are recorded to have made landfall in Louisiana according to the dataset for the first half of the century, which is in stark contrast to the second half, where there are seven total. Therefore, any analysis of these data should take into account that methods of data collection have vastly improved since the first records, and that these data may have serious limitations prior to the past few decades. Landsea also hypothesizes a "consistent overestimation of… intensity during the mid-1940's through the late 1960's (ibid),"

[8] Atlantic basin storm tracks: http://maps.csc.noaa.gov/hurricanes/download.html

and that populations in some areas of coastal Louisiana may not have been sufficient for accurate record-keeping in the earlier part of the record (2005).

3.2.2.1 Increased Hurricane Activity Expected For Decades

On the other hand, it is valuable to capture climate cycles currently being debated in the literature when selecting a time scale over which to view the data. Of the many hypothesized climate factors or cycles which may have the potential to affect the frequency, intensity or path of a hurricane,[9] the Atlantic Multidecadal Oscillation (AMO) is particularly relevant to the next few decades.

Hugh Willoughby, hurricane researchers at Florida International University, and climate scientists such as Gray, Landsea, and others, support the theory that hurricane activity is cyclical, and that the recent hurricane activity (e.g., in 2004 - Florida was hit by four hurricanes in a single season - and 2005) is part of a "natural cycle of hurricane activity" (Coats/St. Petersburg Times 2005). Specifically, "there are multidecadal shifts of Atlantic major hurricanes…and a return of the active regime in recent years …the years since 1995 have marked a substantial shift to a higher frequency of major hurricanes (Landsea 2001, p. 2871)." Some climate scientists therefore predict another 10 to 20 years (Coats 2005) or more of increased hurricane activity.

3.2.2.2 Climate Change and Sea Level Rise May Worsen Hurricane Impacts

Alternately, there are numerous climate scientists (e.g., Webster, Knutson and Emmanuel, who study climate change impacts on hurricane frequency and intensity) who support the theory of more frequent or more intense hurricanes, on account of global warming and increasing sea surface temperatures. While to date, these scientists indicate only a gradual increase (on the order of 5%) over the next 100 years (Knutson 2004, Emmanuel 2004), not

[9] including the Bermuda High (Azores High) and El Niño Southern Oscillation (El Niño/La Niña); however these change seasonally or last only a few years. They are important climate factors however in determining hurricane track (the Bermuda High often acts as a steering current) and formation (El Niño tends to impede hurricanes).

impacting the cyclical likelihood of storm frequency or intensity by much; certainly, sea level rise could add to storm surge risk over the coming decades. Other potential impacts of climate change include increased precipitation (IPCC Climate Change 2001[10]), which could increase rainfall and flooding risks.

Despite the fact that data measurements may be less accurate during the early part of the century, it is relevant to try to look at as many historical Louisiana hurricanes as possible and to include at least a few AMO cycles. This helps to conceptualize if there are any similarities between past and current warming and cooling trends and if these could be projected to get an outlook of what to expect for upcoming Louisiana storm frequencies and intensities. Viewing a century or so of data (1905-2005, to include the recent season) provides a good baseline from which to view approximately four AMO cycles, as well as to see where Hurricanes Katrina and Rita rank in terms of intensities, from a historical perspective.

Working with NOAA CSC historical hurricane data, Appendix D provides a 'snapshot,' or visual understanding of the storms, reviewing over a century of recorded Louisiana hurricanes. Hurricane intensities were estimated ***at landfall in Louisiana*** and were ***generated from the GIS track data***. Therefore, the tables (Appendix D) will not be directly comparable to formal records of NOAA historical hurricane data. The tables were designed to provide a larger overview only, of landfalling hurricanes as they impacted the Louisiana coast.

Storms 1, 2 and 3 represent as many as three subsequent storms which may have made landfall in Louisiana in a given year. The maximum windspeed as storms approach landfall is represented in knots. The windspeeds applied in this analysis resulted from selecting shapefiles of historical tracks on the NOAA viewing tool[11] for storms within the Gulf of Mexico, and

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[10] http://www.grida.no/climate/ipcc_tar/
[11] http://maps.csc.noaa.gov/hurricanes/viewer.html

capturing approximately 58-72 hours of associated data in shapefiles as storms approached the coast. These few days and hours before a storm makes landfall on the Louisiana coast are most relevant to MSN planning for evacuation.

Data were exported to Microsoft Excel, and windspeeds were converted from knots to miles per hour (mph). Each storm event was then coded as tropical storm or Category hurricane level 1-5 (see also Appendix A: Saffir-Simpson Scale for Hurricanes, and the table legend). The approximate AMO cycle (C1=cold 1, 1905-1925; W1=warm 1, 1926-1969; C2=cold 2, 1970-1994; and W2=warm 2, 1995 to present) is also indicated (Goldenberg et al 2001) (Appendix D).

As discussed, data quality should be assumed to decrease dramatically the earlier the measurement. As will be shown, the earlier part of the Louisiana record (1905-1955) is noticeably absent of *any* storms over Category 3 strength in fifty years, in stark contrast to later records (1956-2005); which may indicate some of the major storms and intensities were not recorded, or able to be measured, prior to the late 1950's and the first-recorded Category 4 storm, Hurricane Audrey, 1957. Nonetheless, southeast regional climatologists such as Keim and Romolo (pers comm 2007) indicate that this is still an accurate representation of likely hurricane strikes in Louisiana and nationwide, in that lower order storms are much more frequent than higher order storms.

3.2.2.3 Tropical Storms and Hurricanes Strike Louisiana Every Few Years

Viewing the historical NOAA data in Appendix D, a few of the more obvious indications are that storms frequently make landfall in Louisiana, with the longest reprieve lasting only four years. It can generally be expected then that tropical storms and hurricanes will threaten the coast every few years.

3.2.2.4 Lower Order Storms Are the Most Frequent Storms Affecting Louisiana

Also from the data, although this would be expected, lower order storms such as tropical storms and Category 1 hurricanes are the most frequent storms to make landfall along the coast (Table 1). Only 2 hurricanes have been recorded to make landfall in Louisiana at or near Category 5 strength over the past Century (Ethel 1960, and Camille, 1969), and these happen to fall within the timeframe indicated by Landsea (2001) as potentially overestimated intensities.

It must again be noted that records and measurements of early hurricanes may not have been captured in recent years, and that there were likely major hurricanes striking Louisiana from 1905-1945 that were missed or underestimated in the records (Keim pers comm 2007).

Table 1. Total recorded hurricane strikes in Louisiana (1905-2005)

	Maximum Wind Speed (in knots)	Total
TS	<64	39
CAT1	64-82	13
CAT2	83-95	7
CAT3	96-113	5
CAT4	114-135	5
CAT5	>135	2
		71

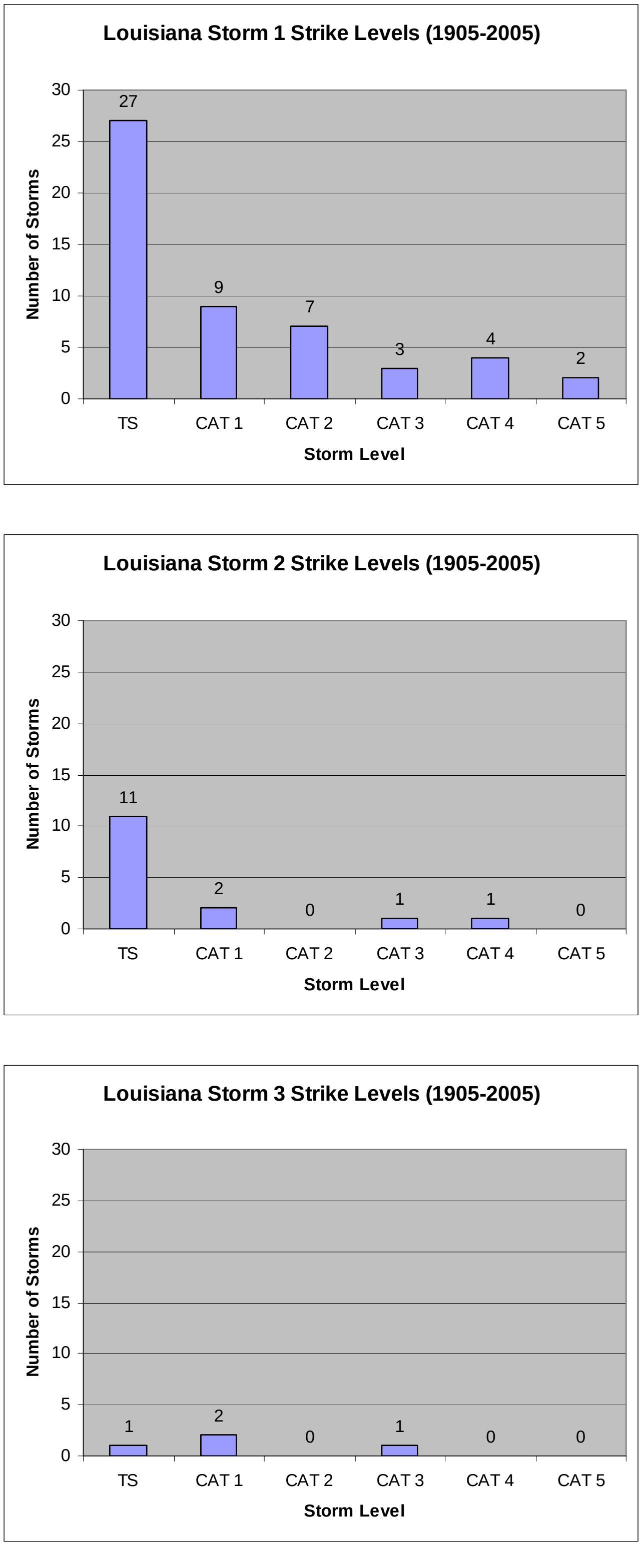
(NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html). The data are approximate for landfall intensities in Louisiana and are not directly comparable with formal historical hurricane records.

Table 2. Total hurricane strikes in Louisiana (1905-2005), First and Second Half of the Century

	Maximum Wind Speed (in knots)	Total	1905-1955 Totals	1956-2005 Totals
TS	<64	39	25	14
CAT1	64-82	13	5	8
CAT2	83-95	7	5	2
CAT3	96-113	5	2	3
CAT4	114-135	5	0	5
CAT5	>135	2	0	2
		71	37	34

(NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html). The data are approximate for landfall intensities in Louisiana and are not directly comparable with formal historical hurricane records.

Storm strike intensities broken down by first, second and third strikes (1905-2005) are also presented in figures 6a-c.



Figures 6a-c. Louisiana Hurricane Strike Intensities by first, second and third storms. NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html.

Supporting analysis of basic historical hurricane data for Louisiana in the SAS statistical program, descriptive statistics confirmed average maximum windspeeds for Louisiana hurricane storm strikes (1905-2005) ranging between 78.6 and 84.8 miles per hour (Figure 7).

Average Tropical Storm and Hurricane Windspeeds, 1905-2005 (SAS Boxplots)

```
Stem Leaf                     #          Boxplot
  19 0                        1             0
  18
  17
  16 1                        1             |
  15 05                       2             |
  14 44                       2             |
  13                                        |
  12 11                       2             |
  11 5                        1             |
  10 49                       2             |
   9 22288888                 8          +-----+
   8 11                       2          |     |
   7 555555                   6          *--+--*
   6 99                       2          |     |
   5 2228888888              10          |     |
   4 000006666666666         15          +-----+
     ----+----+----+----+
 Multiply Stem.Leaf by 10**+1
```

```
Stem Leaf                     #          Boxplot
  14 4                        1             0
  12 1                        1             |
  10                                        |
   8 16                       2          +-----+
   6 399                      3          |  +  |
   4 66662228                 8          *-----*
     ----+----+----+----+
 Multiply Stem.Leaf by 10**+1
```

```
Stem Leaf                     #          Boxplot
  11 5                        1             |
  10                                     +-----+
   9 2                        1          |     |
   8 1                        1          *--+--*
   7                                     |     |
   6                                     +-----+
   5 2                        1             |
     ----+----+----+----+
 Multiply Stem.Leaf by 10**+1
```

Figure 7. Boxplots of average maximum windspeeds at landfall indicate lower order storms.

One unknown that may present difficulty in grasping Louisiana's hurricane history is measuring the effect of Louisiana's wetland loss and loss of protective barrier islands over the past century. With over one million acres[12] of wetlands lost since the turn of the century (van Heerden 2006, 2003 and 1994), hydrologic science alone suggests storms are impacting Louisiana

[12] an area 1½ times that of Rhode Island (van Heerden 2007 pers comm.).

at greater intensity than before, in both wind speed and surge. Built into this are the damage to the coast following each major hurricane (van Heerden 2007, Barras 2006, Guidroz et al 2006, USGS 2006 and others). Seen from this perspective, the snapshot of increasing hurricane intensities at landfall near the end of the century may to some extent be reflecting not climate change, or not *only* climate change, but accelerating land loss which is gradually bringing hurricanes 'closer in' to the coast. That is, storms will make landfall at greater recorded intensities than they would have previously without dampened effects.

3.2.2.5 Second and Third Hurricane Strikes in a Single Year are Rare

From Appendix D, it can be approximated that two hurricane strikes in a single season have been recorded only 15 times out of 100 years of data, or 15 percent of the time; and three Louisiana hurricane strikes recorded 4 times out of 100 years or 4 percent of the time. 2002 was actually the first year this century where Louisiana was recorded to have been hit by four storms (Bertha, Hanna, Isidore and Lili). Out of the fifteen years when more than one hurricane struck the Louisiana coast, three (or 1/5) were recorded at Category 3 strength or higher (Elena in 1985 and Katrina and Rita in 2005). However, as noted, the storm strengths of earlier storms may have been underestimated. A quick reference of named Louisiana storms and dates is provided in Appendix E.

3.2.2.6 Tropical Storms and Minor Hurricanes are Over Twice as Likely to Hit the Louisiana Coast as a Major Hurricane

Statistical analyses to detect significant differences between years or cycles were run on maximum windspeeds at landfall in the SAS statistical program, to arrive at the most probable hurricane intensities which Louisiana may experience; but these ultimately prove inconclusive due to the uncertainty of the early data. The available data from the second half of the century (1955-2005), when records and measurements were improving, do however support that tropical

storms and minor hurricanes (Cat 1-2) were over twice as likely (24/34 at 71% strike rate) to hit the coast as a major hurricane (Cat 3-5, 10/34 at 29% strike rate) (Table 2).

Two additional historical analyses that may yield some value in MSN evacuation and shelter planning can be estimated from the NOAA data are (1) historical track directions and (2) coastal strike locations. Specifically, questions that can be posed include “Do most hurricanes hit Louisiana tracking northwest from the Gulf of Mexico, making this storm surge analysis the most preferred?” and “Are southeastern Louisiana and New Orleans any more likely to be hit by future hurricanes than the rest of Louisiana?”

Storm strike locations and track directions were generalized from the NOAA CSC historical hurricane track data for Louisiana (1905 – 2005) and categorized as storm strikes in (W)-Western Louisiana, (C)-Central Louisiana, and (E)-Eastern Louisiana. Storm track directions were categorized as approaching Louisiana from the Gulf of Mexico tracking East (E), Northeast (NE), North (N), Northwest (NW) and West (W) (figure 8). Results were calculated in Tables 3 and 4, and graphed in Figures 9a-c and 10a-c, broken down by first, second and third storm strikes (1905-2005).

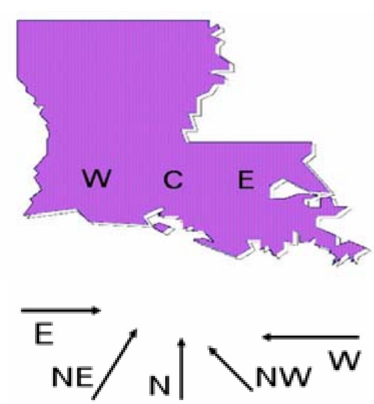
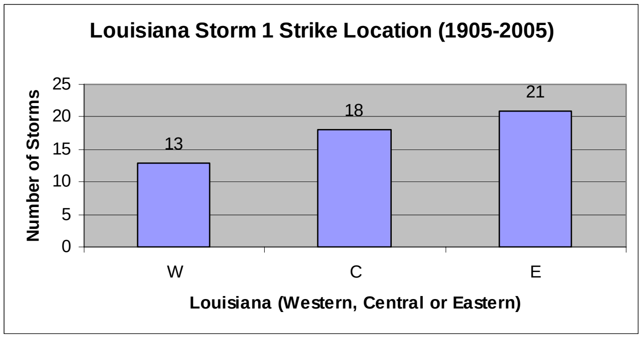
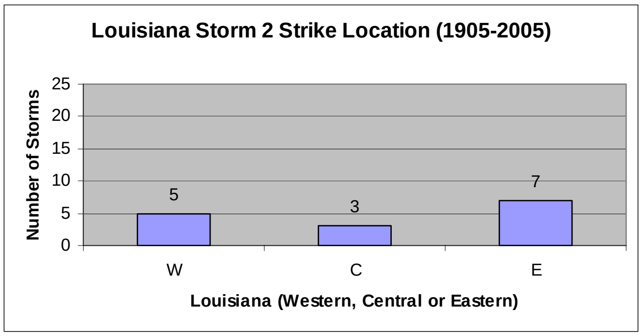
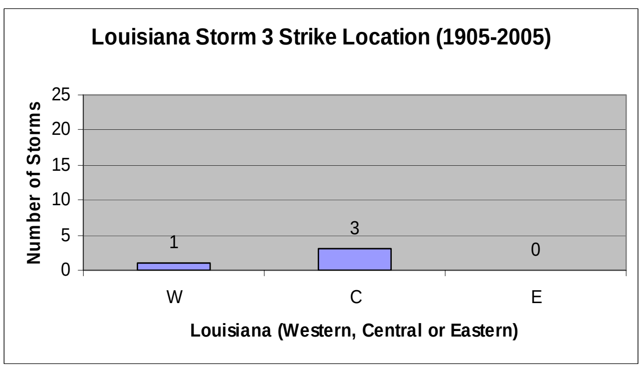


Figure 8. Storm strike locations and track directions analyzed.





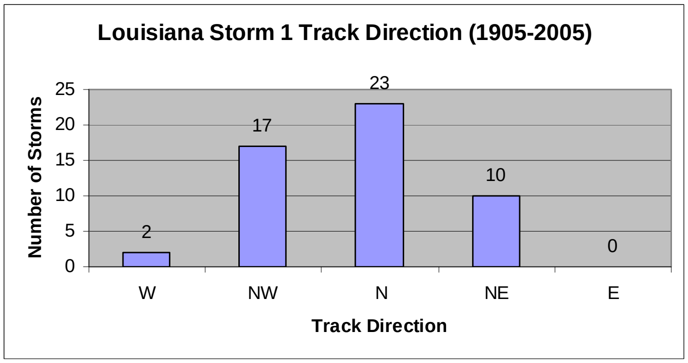


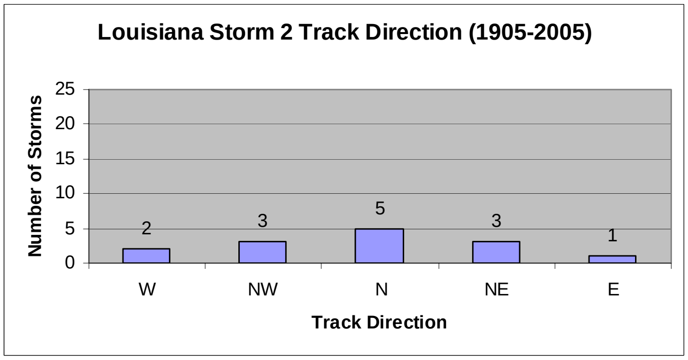
Figures 9a-c. Louisiana Hurricane Strike Locations
(first, second and third storms to hit the Louisiana coast, making landfall in either western, central or eastern Louisiana)
NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html.

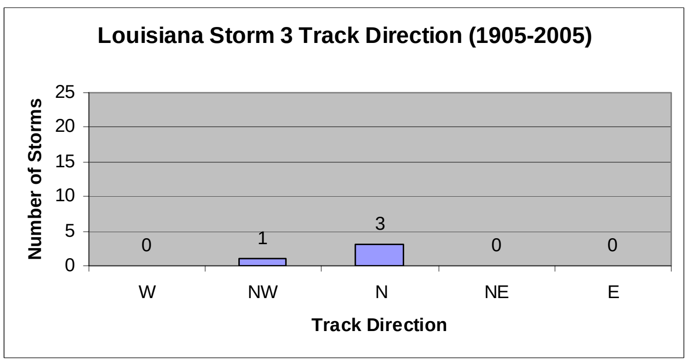
Table 3. Hurricane strike locations in Louisiana (1905-2005)

STORM 1		STORM 2		STORM 3		TOTALS
W	13	W	5	W	1	19
C	18	C	3	C	3	24
E	$\boxed{21}$	E	$\boxed{7}$	E	0	$\boxed{28}$
	52		15		4	71

(NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html)
The data are approximate for landfall intensities in Louisiana and are not directly comparable with formal historical hurricane records.







Figures 10a-c. Louisiana Hurricane track direction *(by first, second and third storms to hit the LA coast, tracking west, northwest, north, northeast, and east)*
NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html.

Table 4. Hurricane track directions in Louisiana (1905-2005)

STORM 1		STORM 2		STORM 3		TOTALS
W	2	W	2	W	0	4
NW	17	NW	4	NW	1	22
N	23	N	5	N	3	31
NE	10	NE	3	NE	0	13
E	0	E	1	E	0	1
	52		15		4	71

(NOAA CSC historical hurricane record: http://www.csc.noaa.gov/id/downloads.html)
The data are approximate for landfall intensities in Louisiana and are not directly comparable with formal historical hurricane records.

3.2.2.7 Hurricanes Most Often Track North and Northwest Towards the Louisiana Coast

In summary, over the century of data analyzed (1905 - 2005), the data seem to support the hypothesis that southeastern Louisiana and New Orleans may be *slightly* more prone to tropical storm and hurricane strikes than central or western Louisiana. The data support even more the indication that hurricanes tend to track north or northwest from the Gulf of Mexico towards Louisiana, followed by northeast; but rarely due west or east; supporting that hurricane surge models, if limited by time or effort, should be run for these tracks initially.

Although wind speeds were not measured with consistently high accuracy throughout the dataset, the most *likely* storm to strike Louisiana in any given year based on the best estimates of data, even if there are three or more storms in a given year, is still a tropical storm or weak Category 1. Historically, Hurricanes Katrina and Rita together striking the Louisiana coast as major hurricanes in a single year are a rare exception (Romolo pers comm 2007). MSN facilities should also then focus on lower order storm events which hit the Louisiana coast more frequently, as well as on the major storm events.

In regards to AMO cycles and hurricanes over the past century (Appendix D), Keim (pers comm 2007) explains that viewing only Louisiana strikes will not reveal much of a pattern on which to base future hurricane strike or intensity probabilities. However, mapping landfalls along the entire US coast, from the Gulf Coast through the Atlantic East Coast (Keim, journal article in press), does reveal "pockets" of increased hurricane landfalls and intensities over approximate 5-10 year intervals in specific localities of Florida, North Carolina, Texas, Louisiana and elsewhere. For the purpose of this study, it is important to note that the theory of cyclical hurricane activity is supported by indications in the overall data, and that Louisiana, as well as the rest of the US, could experience decades more of increased hurricane activity.

3.2.3 Hurricane Forward Track Speeds, Shifts in Track and Intensity in the Gulf of Mexico

According to scientists at NOAA's AOML Hurricane Research Division (HRD), the forward speed of a hurricane is "very latitude dependent" (Landsea 2007, online reference). Hurricanes also pick up speed traveling along steering currents (Keim, Romolo pers comm 2007). Approaching Louisiana from the Gulf of Mexico, the forward speed of hurricanes as taken from the HURDAT database, and averaged in 5 degree latitude bins (note: Latitudes in the Gulf of Mexico range between 20º to 30ºN) resulted in the following estimates (Landsea 2007, abridged):

Table 5: Average Hurricane Forward track speed in the Gulf of Mexico Approaching Louisiana

Forward speed of Atlantic hurricanes averaged by 5 degree latitude bins				
Latitude bin	**Speed**			**No. Cases**
	km/hr	knt	**mph**	
20°-25°N	17.7	9.5	**11.0**	6817
25°-30°N	20.1	10.9	**12.5**	5321

(Landsea 2007, http://www.aoml.noaa.gov/hrd/tcfaq/G17.html)

From the table, on average, **hurricanes approaching Louisiana from the Gulf of Mexico have been determined to track forward at speeds between 11-12.5 mph.** While extreme ranges of hurricane forward speeds have been recorded in the Gulf, they are rare, ranging on the slow end from practically stalled or "quasi-stationary" hurricanes, to hurricanes traveling faster than 15 mph, such as Hurricane Betsy which tracked forward at 22 mph (NOAA AOML 2007c).

Hurricane forward track speeds can be estimated in a GIS by mapping the NOAA CSC historical track shapefiles and using the distance tool to investigate how far a hurricane traveled in a certain time frame. For example, Hurricane Audrey can be calculated on the approach to Louisiana to have traveled approximately 566 miles from 0600Z on 6/25 to 1200Z on 6/27, or in 54 hours. This would estimate Audrey's average forward track speed at 10.48 mph. Hurricane Camille's track (with associated date and time measurements included within the shape file) can be similarly measured. Camille was measured to have traveled approximately 852 miles in 72 hours at an average forward track speed of 11.83 mph.

Hurricane track speeds of 11-12 mph appear a reasonable estimate for storms approaching Louisiana in the Gulf of Mexico for planning purposes dealing with MSN, and may be used to calculate "H-Hour," (when Tropical Storm Force Winds (TSFWs) will hit the Louisiana coast), or "L-Hour" (landfall) keeping in mind that in rare cases, storms can track forward faster.

In coastal Louisiana, hurricane forward speeds as they relate to MSN evacuation and sheltering are important for two main reasons: (1) To estimate how much time there is before TSFWs and rain bands are anticipated to hit Louisiana; and (2) To estimate the severity of expected storm surge and stress on levee systems. Hurricanes with significant forward speeds and size have a lot of momentum; they can produce substantial storm surge and maintain hurricane strength further inland (Romolo pers comm 2007). New Orleans is a unique case where a slower storm could be just as dangerous, since shifting winds and extended periods of wave action could deteriorate or cause overtopping of existing levee systems. Slower storms could also produce extreme rainfall conditions within the city (Hurricane Pam 2004).

Hurricanes may speed up if they travel with the tradewinds, catch a ride on steering currents or as they begin their northwest turn on the westerly currents towards the more northern latitudes (Romolo pers comm 2007) Hurricanes generally slow down over more shallow waters along the coast (ibid). However hurricane speeds can also be affected by “complex ocean and atmospheric interactions, including the presence or absence of other weather patterns… this complexity …makes it very difficult to predict the speed [and direction] of a hurricane (NOAA 1999, p. 2).”

3.2.3.1 Hurricane Size

NOAA experts provide the following dimensions for a typical hurricane: “about 300 miles wide although they can vary considerably in size;” with a “calm, clear area” in the eye “approximately 20-40 miles across;” and “an eyewall composed of dense clouds that contain the highest winds in the storm (ibid).” They also indicate that hurricane-force winds (HFW) “can extend outward to about 25 miles in a small hurricane and to more than 150 miles for a large one (ibid).” Meanwhile “tropical storm-force winds [TSFW] can stretch out as far as 300 miles from the eye of a large hurricane (ibid).” Hurricane Katrina was considered “exceptionally large” with TSFWs extending 200 nautical miles from the center, and HFWs 90 nautical miles from the center (Knabb et al 2006, p. 3).

Hurricane size and range of winds are important to keep in mind when modeling hurricane risk. Powell, NOAA HRD (2007b) indicates that overall storm size and the wind reach together affect a hurricane’s destructive potential, making size and reach of winds additional important factors to consider along with the Saffir-Simpson scale when estimating potential hurricane damage.

3.2.3.2 Hurricane Intensification

A variety of factors can intensify or degrade a hurricane, including sea surface temperatures (SSTs), upper level conditions, and low and high pressure systems (Keim pers comm 2007, Romolo pers comm 2007, Walker et al 2006, NOAA 1999). An historical analysis of hurricanes and their intensification before landfall in Louisiana will therefore only reveal part of the story. However, **in regard to the intensification of Louisiana hurricanes, the Loop Current in the Gulf of Mexico may play a significant role** (Keim pers comm 2007, Walker et al 2006). It has been observed that hurricanes are prone to rapid intensification over warm Gulf of Mexico waters, particularly in late summer (Robbins/SRCC 2004). 'Monster' hurricanes Katrina, Rita and Wilma in 2005 intensified rapidly to Category 5 hurricanes as they traveled over the warmest sections of the Loop Current in the Gulf of Mexico (Keim pers comm 2007, Walker et al 2006). As Dr. Nan Walker of the LSU Earth Scan Laboratory explains,

> "Hurricanes Katrina and Rita provided two vivid examples of how oceanic heat content can fuel rapid hurricane intensification. Both Katrina and Rita were relatively weak hurricanes (Category 2) until they moved over Loop Current waters in the Gulf of Mexico, where they rapidly became Category 5 monsters… The Loop Current is the Gulf of Mexico portion of an enormous moving mass of warm water, which enters the Gulf from the Caribbean Sea…(Walker et al 2006, p. 33)."

Warm waters of the Loop current can extend to several hundred meters (ibid), and with the appropriate upper level atmospheric conditions and the opportunity to 'vent,' hurricanes can rapidly intensify within hours (Keim pers comm 2007). For example, Hurricane Wilma went from a Category 1 to a Category 5 storm in approximately 24 hours off of Florida's coast; Katrina from a Category 3 to a 5 within 12 hours (ibid). The location of the Loop Current is not fixed; circulation patterns change within the Gulf, and small eddys can break apart from the Current and form separate but smaller pockets of warm water (ibid).

Satellite technology makes it possible to map SST data, but locating the Loop Current is difficult in late summer when most hurricanes form in the Gulf (Walker et al 2006); However, sea surface height (SSH) can be used to measure hot-spots (ibid) and attempt to map the location. Warm water at deep levels such as the Loop current can intensify storms, while cold pools or "cyclones" can slow storms down (Romolo pers comm 2007). Storms will also lose speed and strength fairly quickly over land (ibid, Kaplan and DeMaria 1995, Gregg 2006, see also: Krayer-Marshall curve). Beyond these observations, there is a wide a variation in factors that will cause a storm to intensify or weaken.

Historical Louisiana hurricanes vary widely in the degree of their intensification. Some recent benchmark storms in Louisiana are summarized in Table 6. Of importance for this study, MSN facility decision-makers in Louisiana are expected to "communicate their decisions to regional and state coordinators by approximately L-51 (51 hours to landfall) whether they will shelter in place, partially evacuate, or fully evacuate (LA DHH ex. 9)." **While most storms will degrade or at worst, intensify by 1 or 2 categories in the 48 hours before Louisiana landfall, Hurricane Audrey, 1957 is an unfortunate exception.** Reminiscent of the monster hurricanes of 2005, the NOAA CSC data indicate Audrey rapidly intensified from a Category 1 hurricane to a Category 4 storm in just under 48 hours, as she approached Louisiana from the Gulf of Mexico. If a storm like Audrey were to make landfall in Louisiana today, coastal parish MSN facilities choosing to shelter in place for a Category 1 (or 2) hurricane at L-48 could end up facing storm surge over 18 feet and the 131 to 155 mph winds of a Category 4 hurricane.

Table 6 estimates historical and recent hurricanes and their intensification or downgrade from about L-48, noting the ranges in rapid hurricane intensification as well as the potential for storms to degrade.

Table 6. Intensification or Downgrade to Landfall (Louisiana benchmark storms)

STORM	L-48	TRANS1	TRANS2	TRANS-3	L-HR	TREND	DATE RANGE	YEAR
*AUDREY	1	2			4	*INT-3	6/25-6/27	1957
HILDA	2	3	4		3	INT-1	10/1-10/3	1964
BETSY	3				4	INT-1	9/8-9/10	1965
EDITH	1				2	INT-1	9/14-9/16	1971
*CARMEN	1	2	3	4	3	*INT-2	9/5-9/7	1974
BOB	TD				1	INT-1	7/9-7/11	1979
DANNY	TD				1	INT-1	8/13-8/15	1985
*ELENA	1	(looped)			3	*INT-2	8/31-9/2	1985
ANDREW	4				4	SAME	8/24-8/26	1992
LILI	2	4			2	SAME	10/1-10/3	2002
IVAN	5	4			3	DEG-2	9/14-9/16	2004
*KATRINA	2	3	4	5	4	*INT-2	8/27-8/29	2005
RITA	5	4			3	DEG-2	9/22-9/24	2005

* Four storms have intensified by more than one category from 48 hours to landfall over the past few decades.
TRANS=transition, L-HR=landfall, INT=intensification, DEG=degraded.

The potential for rapid hurricane intensification is therefore a risk that must be built into any hurricane model; yet introduces a tremendous problem to MSN evacuation and sheltering strategies.

3.2.3.3 Rainfall Risk and Tornadoes Associated with Hurricanes

It is important to note that **regardless of where a storm makes landfall along the Gulf Coast, there will be some risk of extreme rainfall and the possibility of tornadoes.** Hammond, Louisiana experienced almost 12 inches of rain from Hurricane Andrew in 1992, while the hurricane caused two tornado deaths and numerous injuries across Louisiana (NOAA AOML 2007b). Similarly, New Orleans was seriously flooded by rainfall from a tropical storm (Allison) that made landfall in Houston in 2001 (ibid).

NOAA experts have often indicated that the "front right quadrant" of a hurricane is the most dangerous part of the path for storm surge and winds; but this is also where tornadoes are most likely to occur (NOAA 1999); Tornadoes also form within the storm rainbands (ibid). The more intense a hurricane, the greater the tornado risk, and tornadoes can still occur for days after landfall (ibid). Most tornadoes "occur within 150 miles of the coast (ibid, p 14)."

3.2.4 Forecast of Louisiana Hurricanes: Likely Storms vs. Worst Case

Although inherent problems exist with some of the historical hurricane data, there is value in becoming acquainted with the historical records and recent hurricane research for MSN planning.

In summary, Louisiana is likely to experience tropical storms and hurricanes every few years. Particularly it can be said that, while planning for unlikely or worst case events from Category 4 or 5 levels hurricanes is certainly necessary, planning for the more common, lower order storms (tropical storms and Category 1 hurricanes) that may threaten coastal Louisiana is highly relevant, based on likelihood and risk. Current study analyses support that tropical storms and Category 1 and 2 hurricanes will make landfall in Louisiana over twice as often as major hurricanes.

The worst case event for Louisiana MSN planning would be a tropical storm or minor hurricane that rapidly intensified within 48 hours over warm Gulf of Mexico waters. This scenario is not far-fetched and has happened historically with Hurricane Audrey (1957), and to a lesser extent with Hurricanes Carmen (1974), Elena (1985) and Katrina (2005). Today, Louisiana scientists may be able to map the Loop Current with satellite technology and be able to better predict the rapid intensification of approaching storms (Walker et al 2006), along with other meteorological factors.

Some climate scientists predict at least ten to twenty more years of increased hurricane activity in the US (Goldenberg et al 2001). Louisiana could see more hurricanes, and more intense hurricanes, in the coming years as part of a natural cycle (Landsea 2005). Hurricanes may also become more intense or frequent in the coming years due to global warming, but so far data support this will happen to only a small degree (Knutson 2004, Emmanuel 2004).

‘Megastorms,’ if understood to be Category 5 hurricanes, can and do form in the Gulf of Mexico, and may be explained by increased SSTs as well as other climate conditions; however, the presence of the Loop Current and increase in Gulf temperatures in summer are at the same time common phenomena. Therefore, megastorm formation is difficult to support solely with studies of global warming.

Hurricane forward tracking speeds in the Gulf of Mexico approaching Louisiana average approximately 10-12 miles per hour (Landsea 2007), but hurricane forward speed, size, wind reach, and the potential for extreme rainfall will all vary.

Storm surge and other models, if limited by time or cost constraints, might first be run for eastern Louisiana and model storms tracking north, northwest and then northeast. Hurricane intensification, extreme rainfall and threat of tornadoes should all be considered when evaluating a MSN facility or residence for hurricane risk.

In post-Katrina Louisiana, evacuation is not likely to even be a question (or should not be) for MSN facilities when a Category 4 or 5 hurricane threatens the coast. But what about other storms? Is a Category 2 storm at landfall potentially severe enough to prompt an evacuation of the hospitals in New Orleans, or the nursing homes in the 12 Louisiana coastal parishes?

Mayor Nagin of New Orleans stated in 2006 that he planned to order a mandatory evacuation for most hurricanes with Category 2 strength, at 30 to 36 hours out. (Schleifstein/The New Orleans Times-Picayune May 3, 2006). Nursing homes and hospitals are also strongly considering evacuation for lower level storms, but the criteria on what ultimately determines whether they should evacuate or shelter in place remain in question (US DHS and LA GOHSEP 2006). Based on the historical hurricane data and current research reviewed, such questions

support the need for analyses of minor storms, a more in-depth investigation into threshold events for coastal Louisiana MSN facilities, and the development of tools such as GIS maps that can provide better analysis tools to decision-makers.

3.3 State of the Technology: Hurricane Modeling and GIS

Hurricane models are becoming increasingly available for integration with Geographic Information Systems (GIS). Geographic databases and mapping tools allow multiple levels of information, including critical facility locations, models, and data crucial to an emergency medical response to be viewed together as layers and analyzed in a digital format. Data is presented via electronic maps, which provide a more visual, geographic presentation to decision-makers. Highly sophisticated models/scripts, spatial analyses and queries can be run on the various levels of data in a GIS, which can be output into detailed reports or new maps.

This section highlights the hurricane models selected for incorporation into a GIS in the current study, and discusses a few other commonly used and available models with their program limitations. Medical data privacy and online mapping considerations for MSN patients are also addressed.

3.3.1 A Review of Available Models and Data

A number of Federal operational models and online tools are being developed for the evaluation of hurricane risk from storm surge and wind. NOAA SLOSH and FEMA HAZUS were two of the major models employed in the current study that can be integrated into a GIS.

3.3.1.1 NOAA SLOSH

As discussed previously, storm surge is a major threat to coastal Louisiana during hurricanes, and thus one of the most important hurricane risks to accurately model. The NOAA **Sea Lake and Overland Surges from Hurricanes (SLOSH)** model is a storm surge prediction

tool developed by Jelesnianski and Taylor at the National Weather Service (FEMA/USACE 2007). SLOSH can be used to “evaluate storm surge threat from different categories of hurricanes striking from various directions (NOAA 1999).” Version 1.43 of the SLOSH model was made available on CD (May 9, 2007) and includes recently updated storm surge data analyses for post-Katrina New Orleans. Model options include Maximum Envelope of Water (MEOW, figure 11a) and Maximum of Maximum (MOM, figure 11b), at varying tides and forward track speeds (5, 10 or 15 mph).

Discussions with the National Weather Service in Slidell support use of the SLOSH MOMs as the better tool (vs. the MEOW) for planning, since the MOMS are a “consensus” model with flood levels refined from hundreds of historical and hypothetical storms (SEHTF 2007).

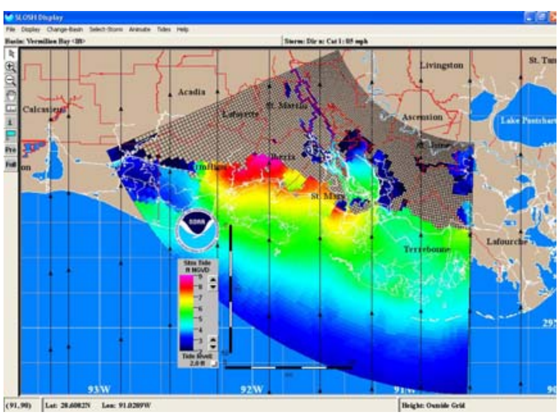


Figure 11a. SLOSH Meow Cat 1, 5 mph (Vermilion Bay Basin) (SLOSH 2007)

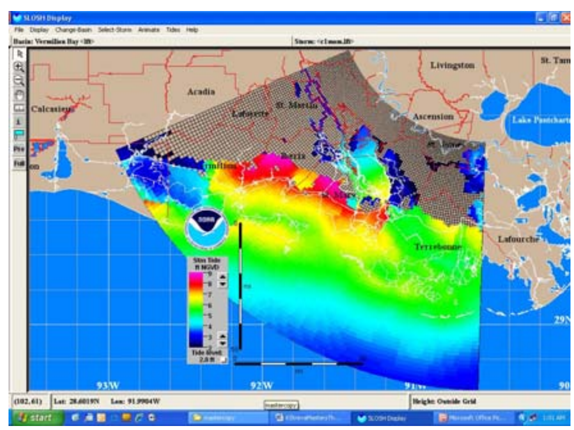


Figure 11b. SLOSH MOM Cat 1 (Vermilion Bay Basin) (SLOSH 2007)

Additionally, according to the NWS, single track SLOSH models as well as many other single track models, have so far not produced solid results (ibid). Change in track and rapid intensification also make the use of single track models and MEOWs less desirable to the MOMs in Louisiana for hurricane planning (ibid). American Red Cross (ARC) 4996 Hurricane Shelter

Standards (revised Jan 2002) for example encourage SLOSH as a Storm Tide Atlas and the use of MOMs.

"MOM" values will generally indicate the worst-case possible flooding for the category storm selected, taken from all directions, selected for mean or high tide. Conservatively however, this analysis may build in some needed caution, since as discussed in section 3.2.3.2, hurricanes have been known to undergo rapid intensification in a matter of hours.

There are a number of SLOSH limitations which are briefly listed here. First, limitations to SLOSH model outputs include that they are generated in the National Geodetic Vertical Datum of 1929 (NGVD29) feet (ft) which require a conversion factor to compare with the latest Light Detection and Ranging (LIDAR) values[13] or recent Louisiana elevation surveys in North American Vertical Datum of 1988 (NAVD88) ft. A rough conversion that accounts for uneven subsidence rates across Louisiana can be applied through the National Geodetic Survey CORPSCON/VERTCON online orthometric height conversion tool,[14] if comparisons are needed. Most conversions in Louisiana result in a difference of less than 0.5 feet.

A second limitation is SLOSH accuracy, within +/- 20% of peak storm surge. For example, a model output result of 10 feet would likely be observed in actual conditions within the range of 8-12 feet (SLOSH 2007).

Third, SLOSH predicted surge levels do not account for additional rainfall, river flow or wind driven waves, or levee failures. Only flooding due to overtopping of levee systems is considered (ibid). It is important to note that storm track/direction is an important factor in surge generation, and may mean the difference between serious vs. minor flooding (ibid). SLOSH assumes all barriers hold; and is not yet capable of modeling breach (SEHTF 2007).

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[13] LIDAR (2003) values, while a valuable dataset in Louisiana for research applications, have been shown to be as much as 1-3 feet off in some locations when compared to corrected elevation survey methods.
[14] http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl

NOAA requires and has requested updated levee heights and status from the US Army Corps of Engineers (USACE) to update surge models for the New Orleans Hurricane Protection System (HPS) for post-Katrina (ibid). While the best available data is understood to have been incorporated into the SLOSH model, actual levee heights and status both before and after the 2005 hurricanes in SLOSH may still retain slight inaccuracies, unless based on current field measurements employing updated elevation survey methods (van Heerden pers comm. 2007). This has been acknowledged by the model developers but the possibility of error should be kept in mind also by emergency planners.

Fourth, SLOSH developers note:

> "The accuracy of the SLOSH model depends heavily on the ability to accurately model the topographic and bathymetric features of the basin... Inaccuracies in modeling these features will contribute directly to errors in the modeling of storm surge. …The major barriers to storm surge… include natural ridges along many of the rivers and bayous and man-made features such as, levees, floodwalls, highways, and railroad embankments. The bathymetry of the coastline and the areas bays, lakes, rivers, canals, and bayous are also of importance in accurately modeling hurricane surge. Data was collected to establish the heights of both Federal and non-Federal levees and floodwalls, and to establish the existence of any gaps or other information that might affect the integrity of a barrier to hurricane surge. Other barrier heights were obtained from existing profiles or actual surveys of features critical to the limits of inundation. The bathymetry of the coastline and other bodies of water within the study area was obtained using hydrographic surveys, bathymetric maps, and U.S.G.S. quadrangle maps. Input to the model also included average ground elevations for each grid square within the basin (FEMA and USACE Comprehensive Hurricane Data Preparedness Study, online reference[15])"

Additionally, SLOSH:

> "operates on a grid having a relatively large size. Cell size varies over the grid, but a typical size might be about 1 mile by 1 mile. The model uses an average elevation for each cell, so some locations may be at 10 feet, but across the road, there might be another facility with an elevation of 6 feet. That one would flood, while [other] stays dry (Shaffer 2007, personal e-mail communication)."

[15] http://chps.sam.usace.army.mil/USHESdata/SLOSH/Sloshmainframe.htm)

The large grid may cause confusion in areas surrounding the Mississippi River or Lake Pontchartrain, where represented river or lake levels may spill over to areas that are actually leveed/may actually remain dry (ibid). This must be kept in mind when visually determining if facilities fall within a storm surge risk area.

Of great import to this study, there is some disagreement among surge modeling researchers whether SLOSH MOM's accurately calculate or portray overland storm surge flooding that extends beyond the shoreline. However, SLOSH applications can be mapped more precisely “using a fine-resolution elevation database, such as the USGS's 30 m by 30 m (or 10 m by 10 m) Digital Elevation Model (DEM) (ibid)” alleviating some of this concern. The current study therefore applies a LSU Hurricane Center project dataset created by S. Ahmet Binselam (2007 refinements) to tally and verify project results, discussed more in sections 4.3 and 5.2.3.

Final limitations of the current SLOSH model include that no corrections have been incorporated for western Louisiana on account of Hurricane Rita. It is possible that storm surge risks have increased to some extent due to damage to the wetlands and other land features caused by the storm along the western coast (see also, sections 1.4 and 3.2.2.4). Also, mapping SLOSH shapefiles in a GIS is a relatively new feature which has some expected ‘bugs,’ such as problems applying or viewing symbology or layer files (.lyr) when mapping storm surge risks in New Orleans (e.g., shapefiles may not denote flooding in the city when levees are actually overtopped).

Of note, Pedro (2006), in her thesis “Delineating Hurricane-Vulnerable Populations in Orleans Parish, Louisiana” reviewed SLOSH storm surge modeling in a GIS when she mapped hurricane risk factors at the census block level. Pedro raises concerns about imprecise flood values predicted in SLOSH surge estimates for use in mitigation planning (p. 23). Higher

resolution Advanced Circulation Model for Ocean Hydrodynamics (ADCIRC) storm surge models developed specifically for southeast Louisiana were successfully used in Pedro's methodology.

ADCIRC outputs were highly preferred in the current analysis as well, but present limitations for the current study. ADCIRC has been applied as an experimental model in Louisiana with successful results, used most notably in pre-Katrina evacuation planning and evaluations such as the Team Louisiana forensic levee study (van Heerden et al 2006b).

However, ADCIRC is a single track model and comparatively new. Results as discussed are not yet widely proven in the literature or widely accepted. Additionally, unless a labor and time-intensive suite of hurricane tracks are run, ADCIRC lacks the capacity to produce worst case, consensus model approximations using many historical and hypothetical storms to determine surge risk comparable to SLOSH. Although overland surge flooding extent may be better approximated by ADCIRC (van Heerden and Mashriqui pers comm 2007), outputs are nonetheless track-specific, and in such cases will not be as useful as SLOSH MOMs when attempting to incorporate risk factors for worst case scenarios such as hurricane shift in track and intensification. As an added note, SLOSH is considered an operational (vs. experimental) model which makes it more desirable for use in decision-making. ADCIRC is nonetheless a desirable supplemental model for use in additional MSN risk analysis, and is discussed in section 6.2.1 in more detail as a future direction of storm surge modeling.

Additionally with SLOSH, Meduri's thesis (May 2004) looked specifically at developing a methodology for delineating hurricane evacuation zones modeling different storm surge scenarios. He explored methods to incorporate storm surge data with census level data, population land use data and zip code information for ease of identification by evacuees.

3.3.1.2 FEMA HAZUS

FEMA HAZUS[16] (HAZUS MH ER2 (2007) and earlier versions) is software designed to help decision makers and planners assess their risk and estimate potential losses from disasters such as floods and hurricanes. Newer releases with added functionality are making it possible to perform detailed risk analyses either separately or within a GIS environment. Current capabilities include physical damage modeling to critical facilities, economic losses, and social impacts, including "estimates of shelter requirements, displaced households, and exposed population … (FEMA HAZUS website[16])."

The wind field model and damage estimate capability (e.g., moderate, severe) are a strong feature of HAZUS which can be exported as shapefiles into a GIS and be used for more detailed emergency planning analyses (Figure 12).

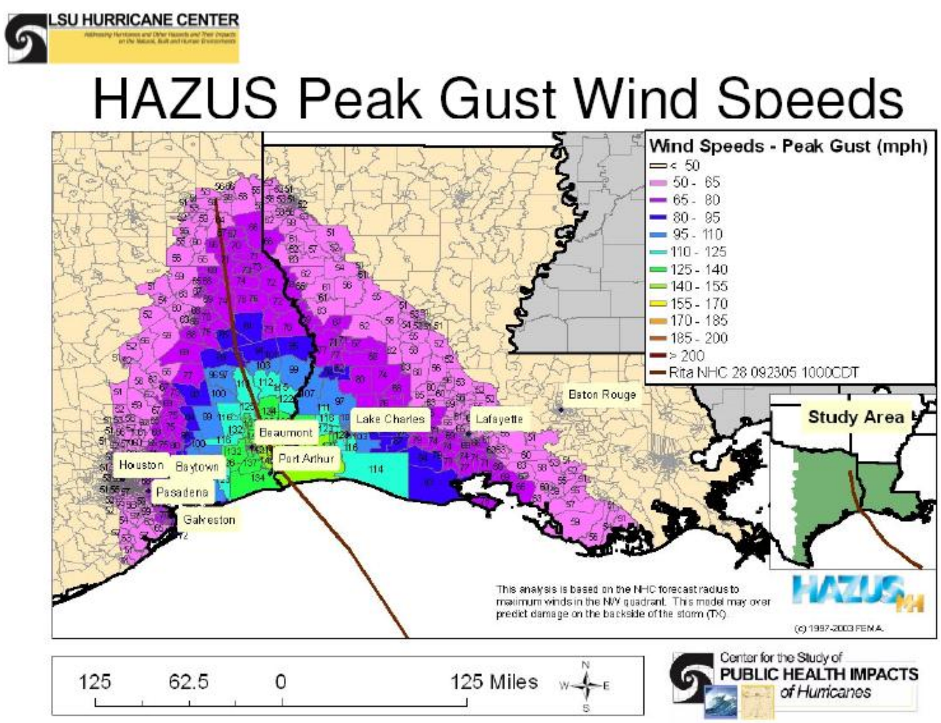

Figure 12. Hazus peak gusts for Hurricane Rita generated by Carol Friedland using FEMA Hazus MH (LSU Hurricane Center 2005).

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[16] http://www.fema.gov/plan/prevent/hazus/

The wind field model can calculate surface level wind fields for both historical and user-defined storms (Hill/Friedland 2004). Methods of incorporating HAZUS wind field data into a GIS to support the calculation of wind fields for this study are detailed in section 4.4.

Limitations to HAZUS first include that wind shapefiles must be generated as single runs and may require additional input information (Friedland pers comm 2007). For the same reasons discussed for NOAA SLOSH, 'consensus model' runs would be the preferred wind modeling application for hurricane planning, to account for such factors as variations in hurricane size (and thus variations in wind fields and reach), as well as to build in tolerance for unforeseen changes in hurricane intensity and track. However again, unless a labor and time-intensive suite of hurricane tracks are run, HAZUS lacks the capacity to produce worst case, consensus model approximations for wind using many historical and hypothetical storms, etc. Such a feature for wind is as yet unavailable within the SLOSH program and cannot be mapped.

Second, HAZUS riverine flooding programs are complex and require technical expertise yet may be used to effectively model flood hazards for local areas of interest; Coastal flood models are much more complex and require additional input parameters (ibid). Some additional limitations to HAZUS in Louisiana at present include the inability to model flooding - whether storm surge, rainfall or levee breach flooding - in New Orleans[17] including difficulty incorporating new releases of the latest surge modeling updates (e.g., post-Katrina SLOSH).

Third, overall, there are computer and technical issues which must be overcome in the near future for installing, using the software, and obtaining technical support. While access to the software is not difficult (the CD is made available upon request), technical expertise and time requirements may be the most prohibitive aspects to MSN planners and decision-makers.

[17] a feature currently being addressed by modelers such as John Pine at LSU, with a flood grid in GIS

For the purpose of this study, HAZUS wind fields mapped from Hurricanes Katrina and Rita (Friedland 2007) are mapped in GIS shapefile format to explore wind field calculation methods (section 4.4). HAZUS is further explored as a future direction to estimate maximum hurricane winds for lower order storms; and potentially to determine decreased risk zones for MSN facilities to shelter in place for storms with predicted landfall strike probabilities east or west of Louisiana at L-48 (forty-eight hours to landfall) (section 6.2.2).

Additional hurricane modeling tools are currently available and continually being improved upon for hurricane planning and risk determination. While they were not utilized in the current study, they are briefly discussed here for reference.

3.3.1.3 NOAA Coastal Risk Atlas

The **NOAA Coastal Risk Atlas**[18] is an online tool which provides access to highly detailed vulnerability assessment maps and tools (VATs). For coastal Louisiana, viewers have access to flood zone information, surge and wind envelopes, and many other data layers such as critical facilities, storm tracks, evacuation routes, and environmental and demographic vulnerabilities (Coastal Risk Atlas website,[18] Figure 13).

Image loading and map generation are fast, with coordinates displayed in both decimal degrees and Degrees Minutes Seconds (ddmmss).

However, the mapping is in some ways unclear; for example, the flood and wind risk color codes and what these actually mean to planners. Although there is a tutorial and links to surge information, the site is in still in development and missing some information and links for Louisiana parishes. It is hoped the site may incorporate more GIS functionality as it is further developed, including the ability to download files for individual GIS use.

[18] http://www.ncddc.noaa.gov/website/CRA_Louisiana/viewer.htm

The Coastal Risk Atlas is nonetheless a landmark in the type of tool that may be most useful in emergency planning for MSN at the local level. Only minor enhancements would be needed to integrate it with GIS and modeling projects. Expanding the atlas to include more information and legend detail would make it more useful to local MSN decision-makers.

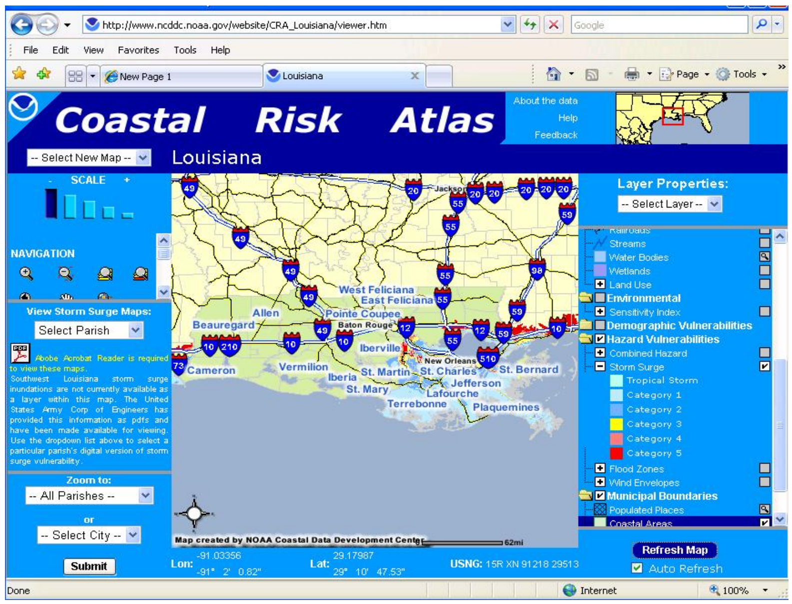

Figure 13. The NOAA Coastal Risk Atlas Vulnerability Mapping tool for Louisiana (NOAA CSC 2007)

3.3.1.4 HURREVAC

HURREVAC is a program used by emergency managers to plan and manage evacuation operations and anticipate hurricane effects of surge and wind (Figure 14). HURREVAC can incorporate data from local hurricane evacuation studies with National Hurricane Center (NHC) advisory and landfall probability data (i.e., error cones) for approaching hurricanes allowing emergency managers to manage the more detailed aspects of an evacuation (FEMA and USACE Comprehensive Hurricane Data Preparedness Study Web Site[19]).

[19] http://chps.sam.usace.army.mil/USHESdata/SLOSH/Sloshmainframe.htm

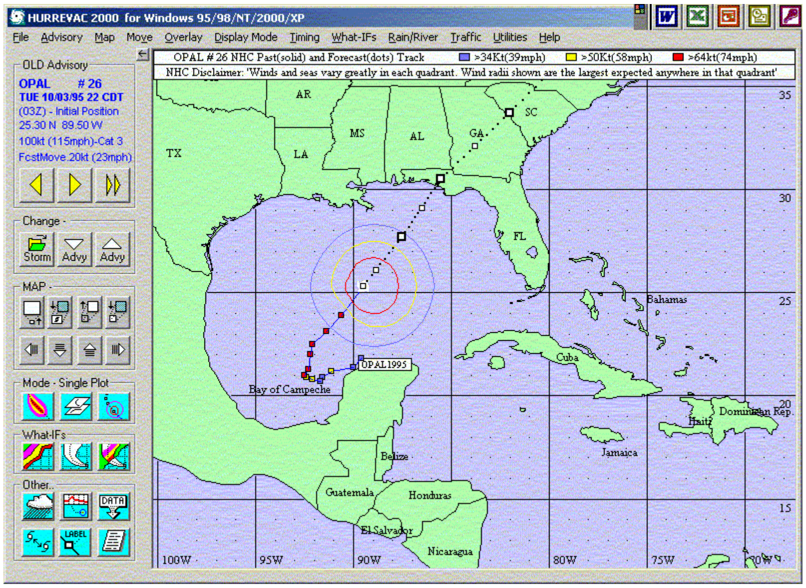

Figure 14. Hurrevac sample screen (FEMA/USACE 2007)

HURREVAC is equipped with a timeline for decision-making and other features such as state-specific data, estimated approach of hurricane force winds and range of winds (figure 14), and estimated travel times (e.g. estimated distance and time to move between a facility and a shelter); Storm surge information may potentially be integrated with HURREVAC as an added feature (ibid).

However, the program is not widely available to local medical facilities, researchers or the public, and is currently considered “restricted-use” or for official use only.

3.3.1.5 GIS Data Servers and Imagery Mappers

GIS data servers and imagery mappers are rapidly expanding ways to incorporate facility-specific GIS data layers with high resolution imagery. Imagery mappers such as NGA Earth[20], NASA World Wind,[21] Google Earth,[22] Microsoft Virtual Earth[23] [providing access to high

[20] http://www.hurricaneimagery.org/
[21] http://worldwind.arc.nasa.gov/
[22] http://earth.google.com/
[23] http://www.microsoft.com/virtualearth/default.mspx

quality local imagery and aerial photography through extensions such as Live Local[24]] and others are developing at a rapid pace. Most recently, the Louisiana GOHSEP has developed Virtual Louisiana, with access currently available to government officials upon request.

Google Earth Pro (the commercial version) was used in aspects of the Hurricane Katrina emergency mapping response to provide emergency managers with access to images of the flood extent in the city of New Orleans. The New Orleans GIS database (LSU HPHC 2007) was utilized extensively following Katrina, effectively transformed from an Arc-IMS for hurricane research into a GIS data server for emergency response mapping. GIS software from ESRI (discussed more in detail in section 4.2), GeoMedia, Intergraph and others are increasingly able to incorporate hurricane modeling outputs with facility and region-specific data via online servers. Meanwhile, imagery mappers such as NASA World Wind can incorporate various "add-ons," most often developed by individuals (e.g., via scripts and code); but sometimes require fixes, have limitations in GIS data processing abilities, or do not operate as intended.

NOAA's Coastal Risk Atlas (Section 3.3.1.3), as well as other mapping websites with hurricane information (e.g., made available by ESRI ArcServer, the LSU HPHC, or Louisiana State Agencies such as GOHSEP, the Department of Transportation and Development (LA DOTD)[25] and Louisiana Geographic Information Center (LAGIC)[26]) may be some of the most applicable tools for local level facility managers and planners to assess hurricane risks to their facilities, particularly where hurricane data is incorporated, detailed and up to date.

A feature that is mainly still in development includes download capability and ways to incorporate or modify site-specific information from these servers and imagery mappers. At the same time, the sites may be difficult to use or understand when planning for a specific storm,

[24] http://maps.live.com/
[25] http://dotdgis.dotd.louisiana.gov/website/
[26] http://lagic.lsu.edu/hurricanes/

may not incorporate all necessary or updated data, or explain the data layers and their symbology. Similar sites that have been developed to provide online mapping, but without efficient storage or knowledge of how to transfer the information quickly, often frustrate and limit the public. Unless maps can be generated within a few seconds, online maps will cause frustration and are not likely to be used.

3.3.2 GIS Mapping for Hurricane and Public Health

Diverse state initiatives are currently underway to incorporate public health with emergency response and planning for hurricanes in a GIS. A number of newsletters including CDC Public Health and GIS News and Information[27] and ESRI Healthy GIS[28] detail the wide-ranging advances being made in public health geoinformatics, GIS for epidemiological studies, and hurricane studies which vary by state and state emergency agency.

For example, The Division of Environmental Health (within Florida's Department of Health) recently placed online downloadable GIS data and a dynamic mapping tool to access vulnerability data such as Mobile Home Parks, Group Homes, etc. (Healthy GIS, Summer 2006).

The Center for Pre-hospital Care Education and Research at Loma Linda University Medical Center is using GIS to bridge Emergency Medical Services (EMS) and other emergency resources including hospitals, medical helicopters, ambulances and rescue vehicles among regional response agencies (Healthy GIS Winter 2007).

Meanwhile, on the Federal level, the US DHS is exploring enterprise GIS for its disaster planning (ArcNews, Winter 2006/2007); Updates to public health data are newly available through the Health Resources and Services Administration (HRSA) (Public Health GIS News

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[27] http://www.cdc.gov/nchs/about/otheract/gis/gis_publichealthinfo.htm
[28] http://www.esri.com/industries/health/news-community/healthy_gis.html

and Information, March 2006, No. 69); and mobile GIS is being explored outside of the US for disaster planning in El Salvador for use in relief efforts (ArcUser Jan-Mar 2007).

As discussed, at LSU, a project has been underway since 2002 to integrate physical hurricane research and modeling outputs (e.g., data layers for transportation, evacuation, meteorology, wind and surge, etc.) into a GIS to determine public health impacts of a hurricane strike in New Orleans (LSU HPHC 2007).

A number of articles from the perspectives of GIS and health are briefly mentioned as applicable to the current study. These are introduced from the *International Journal of Health Geographics*. For example, GIS has been used by Bell and Dallas (2007) to simulate and model vulnerability of urban health care systems to nuclear attack. They attempt to identify inoperable hospitals and trauma centers relevant to weapons of mass destruction and mass casualty events at varying scales. Moss et al 2006 have applied GIS to map functional disability among older American Indians and Alaska natives from 2000 census data. Of particular relevance, they indicate that the GIS mapping techniques used helped "visualize those who might otherwise be 'lost' from the data" and help to plan for the better placement of services (ibid). Mobley et al 2006 perform spatial analysis in GIS to study elderly access to primary care, to support the ongoing debate related to physician shortages.

3.3.2.1 Protecting Medical Data Privacy in Maps

One important aspect to consider when mapping public health data at detailed levels is that "…most health and social service data at the client or case level is strictly confidential (ESRI 1999, p. 6)." However, "GIS can help aggregate and display this data accurately to the census tract, county or region level (ibid, p. 6)."

Privacy concerns must be considered when retrieving and mapping data that could potentially reveal the identity of a person or their medical information. To prevent data from being extracted on individuals, personal identities can be further aggregated beyond the county level (Laymon 1999) such as by census tract block group, neighborhood or zip code. For zip codes with populations less than 20,000, first three zip code numbers should be used only (Tsui and Curtis 2007). Other ways to de-identify data include destroying identifiers and all elements of dates except year (ibid).

Privacy issues related to GIS mapping of medical and public health data are becoming a major issue. Generally, GIS and public health mapping are governed by the Federal Health Insurance Portability and Accountability Act (HIPPA, 1996), Freedom of Information Acts (FOIA, 1983) and may also vary by individual state (public records acts) and agencies as governed by state law (ibid). Requirements to protect critical infrastructure data may also apply in some circumstances (ibid). Additional information on protecting privacy in GIS maps is available from the National Cancer Institute website,[29] Curtis et al 2006, and Onsrud et al 2004.

3.3.2.2 Mapping Considerations for MSN Decision-Makers and the Public

There is an additional mapping note which hurricane researchers, academics and modelers should consider when they attempt to transfer the latest technology and research products to emergency management, facility managers, decision-makers and the public. Unless addressed, resultant maps may be unclear and will unavoidably reflect a difference in expertise, priorities, urgency, responsibilities, jargon (especially acronyms), management styles, and ways of doing business, among others.

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[29] http://gis.cancer.gov/resources/regulations.html

For example, in 2002, experimental storm surge models in development at the time[30] were used to brief to Governor Mike Foster as Hurricane Lili approached Louisiana. The Governor, similar to most emergency managers and decision-makers, had little patience for a time-series model of estimated surge flooding that presented flood levels in meters (versus feet)[31] and times in Universal Coordinated Time (UCT) or Zulu[32]. He immediately asked for depths in feet, and times to be represented in Central Standard Time (CST) for Louisiana; a reasonable request, but which had escaped the focus of the modelers as they attempted a very high resolution flood animation (Westerink et al 2004). Similarly, emergency managers (particularly the military, on critical missions) understandably prefer one to two sentence explanations of what model outputs or GIS maps actually mean in an emergency.

Thus, hurricane researchers and modelers should consider abridged notes or explanations on map legends to clearly explain model outputs and maps. Maps should also spell out acronyms and be designed to suit the perspective of the user. In the case of MSN patients or planning, further study is needed to explore methods of effectively communicating and visualizing risk (see also, section 5.2.5). Optimally, emergency managers and researchers should meet long before hurricane season to discuss research products in development, their assumptions and limitations. In the example of the New Orleans pilot study (HPHC 2007), annual advisory board meetings of Federal, state and local partners with academia worked well to provide a common forum.

There are many new tools in development which MSN planners and decision-makers can choose from to incorporate hurricane risk modeling with some level of local and regional mapping information. However, the challenge remains to choose the best tools and build the

[30] through the LSU Hurricane Public Health Center New Orleans Pilot Study
[31] 1 meter = approximately 3.28 feet
[32] Central Standard Time (CST) = UCT or Zulu (or Greenwich Mean Time, GMT) minus 6 hours

most useful system for individual information needs. Current geographic approaches have varying strengths and weaknesses, and are constantly improving. However, the latest updated and site-specific hurricane data should be available, understandable, and not allow the information to be “lost in translation (see also, section 1.5).” This study has a particular focus on ensuring that the technology and science are accessible to MSN decision-makers in an emergency and presented in an understandable, practical way.

3.3.2.3 Section 508 Online Mapping Considerations

One final mapping consideration for hurricane and health GIS includes Section 508 online mapping requirements. Since 1998, Congress has required Federal agencies to ensure that their electronic information is accessible to people with disabilities. Section 508 promotes accessible information technologies across the internet for online applications for the disabled such as the visually impaired (1194.22). Features such as “Alt Text” web text on web pages and similar features specific to GIS mapping can be added or built into online map resources. Later release versions of ESRI ArcReader are Section 508 compliant with minor issues (ESRI 2007). Section 508 considerations will need to be addressed for any GIS planning tool designed for use by MSN facilities and the public.

CHAPTER 4 RESEARCH METHODS

As outlined in Chapter 2 (Objectives), a literature review (Chapter 3) was conducted to identify health risks associated with evacuation vs. sheltering in place for coastal Louisiana MSN patients. Additionally, insights were sought on the decision processes of MSN patients and why, as evidenced from Hurricane Katrina, many decided not to evacuate a hurricane risk area (section 1.3). A summary of these findings was provided in sections 3.1.1 through 3.1.3.

Building upon this data, further objectives were to determine threshold storm events affecting MSN populations in coastal Louisiana to answer the research question: Can any MSN patient shelter safely in coastal Louisiana for any level of hurricane? Current hurricane risks (section 1.4) and physical aspects of hurricanes (section 3.2) to coastal Louisiana MSN facilities and residences revealed some crucial factors to consider when researching this question.

Referencing the latest hurricane research and project findings, selected hurricane models (section 3.3.1) were incorporated into a GIS. Critical MSN locations such as hospitals and nursing homes were mapped with recent patient census counts, as well as other MSN data related to emergency medical response. This chapter describes study research methods in more detail.

4.1 Determining Threshold Hurricane Events Affecting MSN Evacuation and Sheltering

For this study, a threshold hurricane event was generally defined as the storm level and/or storm condition that would place coastal Louisiana MSN facilities or critical transportation, evacuation or sheltering sites in jeopardy of flooding or wind damage above what the facilities would likely be able to sustain. From section 2.2, threshold storms were conceptualized as flood and wind levels unsafe for MSN patient sheltering in place, without substantial mitigation measures taking place, such that MSN patients would be recommended to evacuate.

Twenty-six coastal Louisiana parishes (listed in Appendix B) were selected for the study based on the elevation vulnerability of those parishes that had some portion of land south of interstates I-10 and I-12 in Louisiana. As discussed in section 1.4 (see also, Figure 5) these parishes may have elevations which drop off drastically south of the interstates, exposing them to higher storm surge vulnerabilities. The selection of these coastal parishes is also supported by the hurricane research which substantiates higher wind risk directly off the Louisiana coast (Robbins 2004, Kaplan and DeMaria 1995).

Based again on project findings (sections 1.4 and 3.2), Category 1-3 level storms (see also, Appendix A) were chosen for analysis in this study in an attempt to determine threshold events that will impact coastal Louisiana MSN facilities. First, it has been determined that it is highly relevant to model lower order storms which commonly make landfall in Louisiana. Second, since tropical storms are less likely to cause severe storm surge flooding (or substantial wind damage), and Category 4 hurricanes are likely to trigger a substantial medical evacuation, the storms that fall within this range were selected for a more in-depth review. Third, there is greater uncertainty as to how these storm levels would impact specific MSN facilities and plans to evacuate or shelter-in-place. The selection of Cat 1-3 storms for modeling was determined the most effective approach to begin differentiating coastal MSN facilities south of the interstates according to storm surge, wind and other hurricane risks.

A review of historical Louisiana hurricane data and related research (section 3.2) has indicated three major directions in which to proceed with SLOSH storm surge modeling for the Louisiana coast. First, due to the planning objective of the study, and to consider the risk of rapid hurricane intensification, other coastal factors, and the serious implications for MSN patients, SLOSH MOMs were selected to be modeled to provide the most conservative analysis

(see also, section 3.3.1.1). Conservative modeling approaches are favored by Dr. S. Hassan Mashriqui, PE of LSU (2007) based on his experience with storm surge modeling uncertainties. Particularly, while he indicates that both SLOSH and ADCIRC storm surge models currently tend to overpredict surge values, he advises that error should always be on the side of caution for hurricane evacuation strategies due to the unpredictable nature of hurricanes and potential for rapid intensification and shift in track; potential error in the models (potentially in modeling waves and accurate barrier heights); the critical nature of MSN patients and risks to human life; and considering dramatic recent changes to the coast (ibid).

In a second direction for storm surge modeling as supported by project findings in section 3.2.2.7, hurricane flood risks were reviewed for north (N) tracks (where applicable) as they approached the Louisiana coast.

Finally, as discussed in SLOSH limitations (again, section 3.3.1.1) data layers which extended surge flood risks further inland from the shoreline based on LIDAR data (herein referred to as "LIDAR-extrapolated" SLOSH MOM datasets or GIS layers - Binselam 2007/LSU Hurricane Center) were also incorporated into the study in an attempt to tally and verify project results from SLOSH version 1.43 shapefiles.

As will be discussed, Critical MSN data layers were collected and imported into a GIS and viewed with SLOSH MOM storm surge outputs for Cat 1-3 hurricanes. HAZUS shapefiles were originally explored in a GIS for the determination of winds that could impact MSN facilities under Cat 1-3 storm conditions; but overriding wind calculation factors (section 4.4) were utilized to generate final wind effects results. Given all project findings and methods, threshold events impacting MSN facilities in coastal Louisiana were determined for MSN facilities with results presented in Chapter 5.

4.2 Data Collection and Incorporation into a GIS

MSN facilities for this study included Louisiana:

1. Hospitals (with hurricane season 2007 census estimates)

2. Nursing homes (with hurricane season 2007 census estimates)

3. Additional MSN facilities such as:

    a) hospice – places where end of life care is provided to the terminally ill. This can be an inpatient setting or a patient's residence

    b) adult day care (ADC) – facilities where there are 10 or more functionally-impaired adults throughout the day

    c) adult hospital day care (AHDC) – facilities that provides direct professional medical supervision and/or personal care supervision to the physically and/or mentally impaired

    d) adult residential settings - 24 hour residences that provide personal assistance, lodging and meals for compensation to at least 2 adults

    e) early infant intervention (EINF) – facilities that provide care, supervision, treatment, and therapy to children who are developmentally delayed and may have a serious disabling condition

    f) intermediate care facilities for persons with mental retardation (ICF/MR); also Intermediate Care facilities for persons with Developmental Disabilities, (ICF/DD) – facilities which provide health or rehabilitation services to individuals with mental retardation or related conditions

    g) respite care – facilities that provide temporary care and supervision of a person with a disability or infirm elderly

h) traumatic brain injury facilities – facilities that provide rehabilitative treatment, personal assistance and supervision to adults who suffer from brain injury in an inpatient, outpatient, or apartment living setting

4. Critical MSN transportation, evacuation or sheltering locations such as:

   a) Temporary Medical Operations Staging Areas (T-MOSAs)

   b) Medical Special Needs Shelters (MSNS)

   c) Medical Special Needs Medical Marshalling Points (MMPs) – train stations (MMP-Ts) and airfields (MMP-As) where MSN patients are planned to be triaged for further care and transported on trains to MSNS, other MMPs or TMOSAs

   d) Coastal Parish Pick-up Points (CPPP) - pick-up points in the coastal parishes for individuals needing assistance with further transportation to a shelter

   e) Critical Transportation Needs Shelters (CTNS) – new shelters designated for those who don't have transportation or a place to stay during the storm

   f) Information points - stations along the hurricane evacuation route where evacuees can obtain important information on evacuation and sheltering

Data sources for each of the critical MSN locations are listed separately in section 4.2.1.

Additional MSN facilities and residences which were not mapped included facilities which house the blind, deaf, or mentally ill. These datasets were not available for Louisiana at the time of the study. Other large MSN population groups that could not be mapped included parish or zip code level counts of elderly, disabled and those with chronic conditions living in households. While data (US Census Bureau 2000) is available on elderly and disabled in Louisiana, these populations are expected to have changed significantly in 2005 following

Hurricanes Katrina and Rita. 2005 population estimates (US Census Bureau 2006a) and Health & Population Surveys (US Census Bureau 2006b) are available for some coastal Louisiana parishes with information on elderly in households and health indicators such as diabetes, high blood pressure, heart disease and mental illness. However the current mapping study excluded these maps since a complete dataset for all 26 coastal parishes is not available, but would be necessary to compare statistics, determine areas of higher vulnerability and distinguish priority areas. The data will be an important addition for future study when census totals are complete.

Critical MSN data sets were collected and geo-coded for incorporation into ESRI ArcGIS 9.2. Data sources and the geocoding method used are next outlined.

4.2.1 MSN Location Data

Louisiana hospital and nursing home locations were compiled from various sources, including from the FEMA Geospatial Intelligence Unit CD, provided by the US DHHS; Louisiana state databases, and other online sources. Lists were converted into Microsoft Excel spreadsheets, where coordinate information was converted into decimal degrees (longitude and latitude); or a search was conducted using NASA World Wind 1.4 (Figure 15) to locate coordinate data. In some cases, addresses were geo-coded using merged tiger road files (2004).

DHH Regions were created and color-coded from Louisiana parish shapefiles. Cities, places, roads (including interstates I-10 and I-12) and the Mississippi River were added to the GIS. Data on licensed beds, operational beds, current census counts, status (open or closed), and previous facility names were added to the excel lists from the DHH Health Standards website. The excel files were converted to database (dbf IV) files and added to the map as x,y data.

Similar methods were used to map identified Temporary Medical Operations Staging Areas (T-MOSAs), and Medical Marshalling Points (MMPs) which include airfields, Amtrak Union Passenger Terminal and the New Orleans Convention Center.

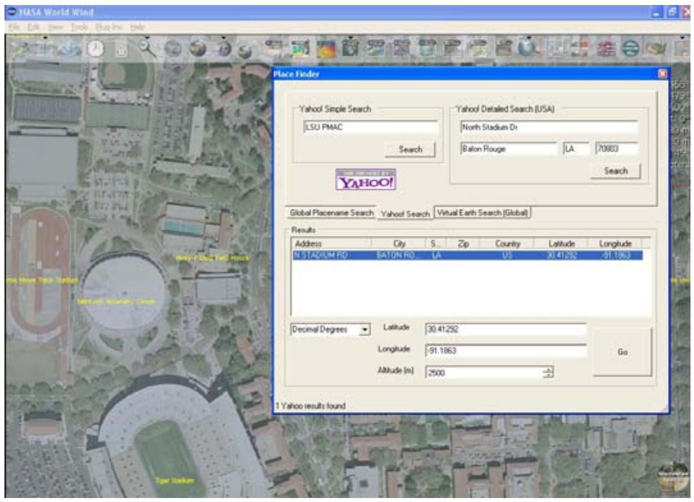


Figure 15. NASA World Wind 1.4 with Yahoo! search feature.

Data sources included appendices provided by state agencies to the US DHS in 2006 (Blanco/DHH Ex. 9). Data sources for additional MSN sites including hospice, adult day care, adult hospital day care, adult residential settings, early infant intervention, intermediate care facilities for persons with developmental disabilities, respite care, and traumatic brain injury were selected from LA DHH and LA DSS datatsets, Louisiana GIS Digital Map (May 2007).

4.2.2 Critical MSN Evacuation and Transportation Data

Not surprisingly, many nursing home administrators view transportation as the most pressing need for community collaboration during disasters (US DHHS/OIG 2006, p. 19). Current city and state plans now outline strategies to pick up MSN patients, residents and those with limited mobility in their homes, and to bring them to collection points where they will be transferred via coach to designated shelters (Gordon/Times Picayune 2007). Some of the critical points that were therefore mapped included DOTD Coastal Parish Pick-up Points (CPPPs),

information points (LA Stormwatch, http://batonrouge.lastormwatch.com), and identified Critical Transportation Needs Shelters (CTNS) (Blanco/DOTD Ex. 2).

One additional critical data layer that the state is working to obtain relates to transportation assets such as ambulance service providers and EMS (Yennie pers comm 2006). Another data layer that is needed but not available in shapefile format (currently under update) relates to tiered evacuation strategies and contraflow (Figure 16). Unfortunately these data layers were not accessible at the time of the study and could not be incorporated into the GIS mapping and modeling.

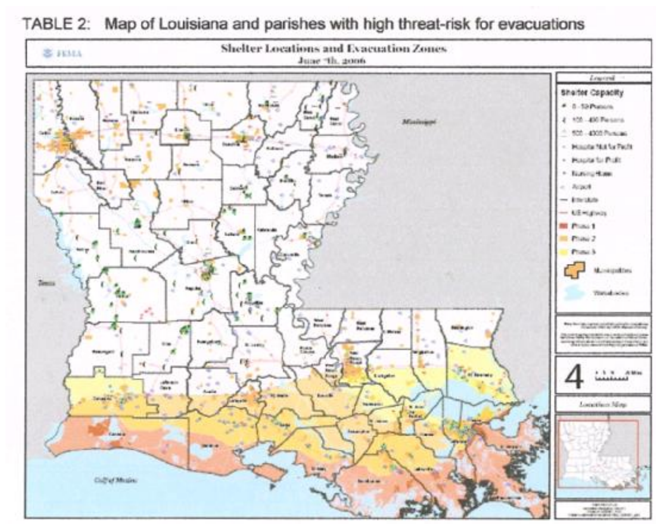
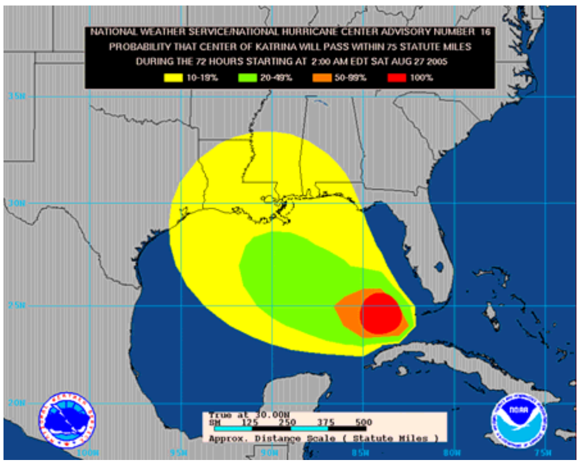


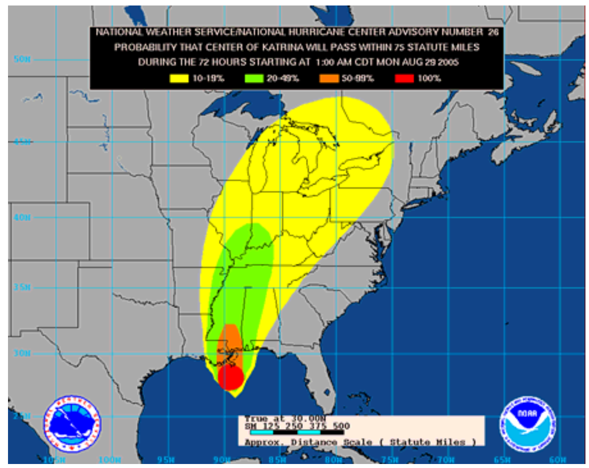
Figure 16. FEMA map with shelter locations (not made public) and capacities, overlaid with Louisiana's Tier 1-3 evacuation zones to determine high threat-risks for evacuation (Blanco/DHS 2006).

A pivotal transportation consideration warrants review before proceeding with the methods discussion. As discussed in section 3.2, hurricanes vary in size, speed, intensity and temporal/spatial decay, and may generate very individualized wind fields and reaches. Medical special needs patients are among the first to be evacuated for a hurricane emergency; or certainly should be; well before the onset of tropical storm force winds, rainfall, or congested roadways.

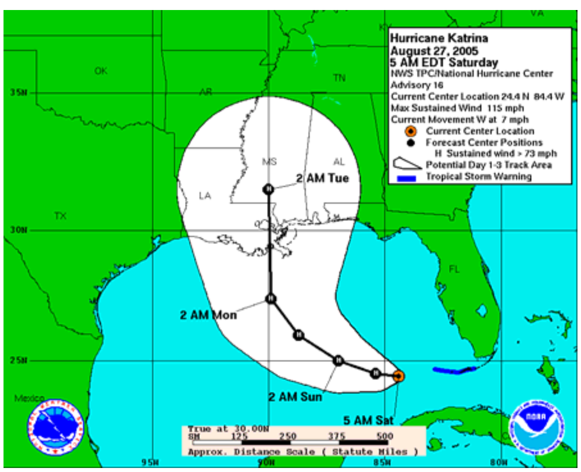
Ideally, decisions to evacuate will occur no later than 48 hours to hurricane landfall (L-48). National Hurricane Center storm prediction technologies and capabilities are constantly improving and becoming increasingly accurate; most recently a five-day forecast track model has been released, although it is much less certain than the 3-day (NOAA 2007). So, what level of information and warning do local facility decision-makers have in advisories at L-48?



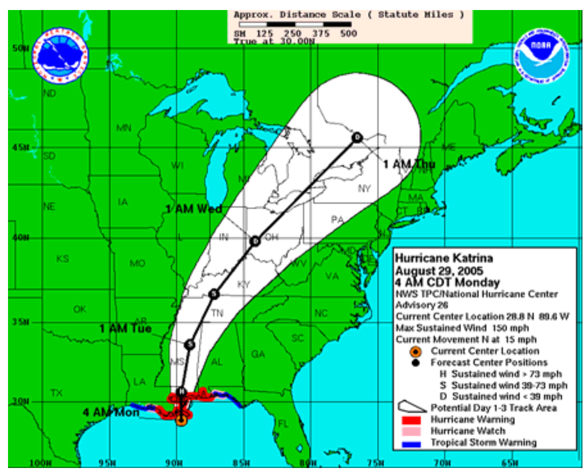
(17a) Katrina strike probabilities, approximately 48-hours to landfall



(17b) Katrina approximate landfall



(17c) Katrina warning/watch projection cone, approximately 48-hours to landfall (Cat 2-3)



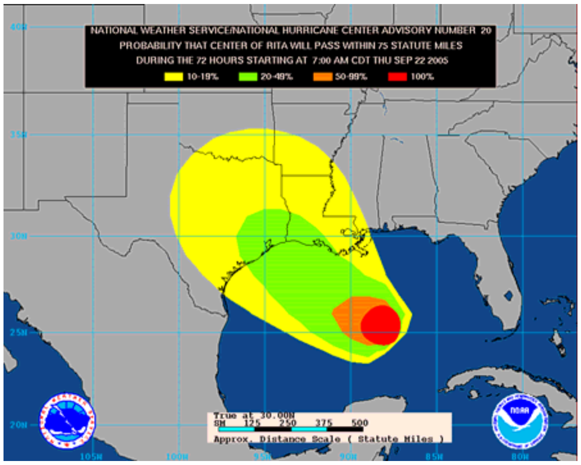
(17d) Katrina approximate landfall (Cat 3)

Figures 17a-d. Hurricane Katrina strike probabilities and 3-day warning/watch at approximately 48 hours and landfall *(NOAA National Hurricane Center, National Weather Service)*

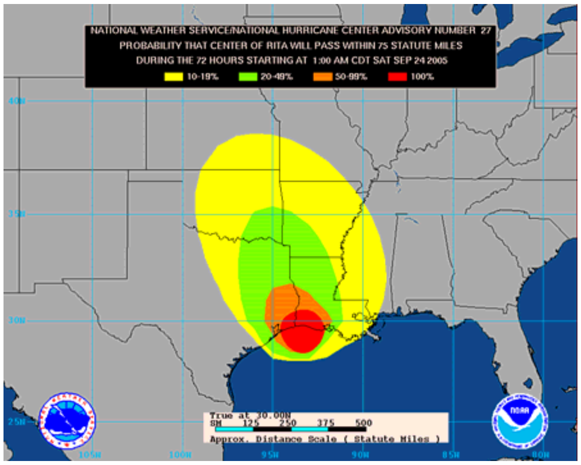
Even considering storms that are initially set to strike the Florida panhandle or Mississippi, with a lower possibility of striking Louisiana (Katrina in 2005, figures 17a-d); OR

storms that are heading for Texas with a lower probability of striking Louisiana (Rita in 2005, figures 18a-d); **all or most of Louisiana is still likely to be shown within the strike probability zone and the projection cones at L-48 hours!**

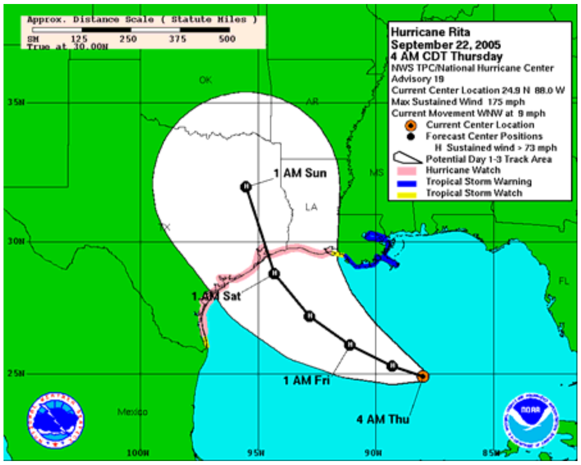
Other storms may be directly headed for Louisiana at L-48... Either way, this demonstrates the level of uncertainty as to the actual landfall the storm will make, as well as to intensity, surge and winds at landfall, at the time MSN decisions must ultimately be made.



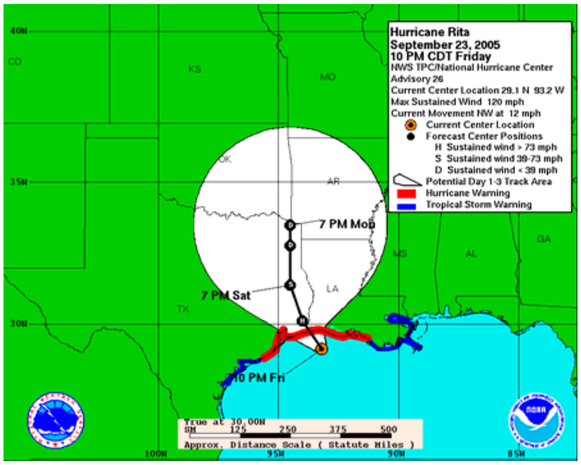
(18a) Rita strike probabilities, approximately 48-hours to landfall



(18b) Rita approximate landfall



(18c) Rita warning/watch projection cone, approximately 48-hours to landfall (Cat 5)



(18d) Rita approximate landfall (cat 3)

Figure 18a-d. Hurricane Rita strike probabilities and 3-day warning/watch at approximately 48 hours and then landfall *(NOAA National Hurricane Center, National Weather Service)*

4.2.3 Critical MSN Shelter Data

Medical Special Needs Shelters (MSNS) were mapped with capacity information. General population shelter data was not incorporated or mapped in this study since the data is not made public. While there are hundreds of shelter sites across the state, community resources in place for other citizens may not be available to nursing home residents (Prats 2003) or to other MSN patients. Louisiana is among the Gulf States that "discourage or restrict nursing homes from using State special needs shelters as evacuation sites… (ibid, US DHHS/OIG 2006, p. 19)." General population shelter locations are not released to the public until the site is deemed safe and able to be used; there is a "delicate balance" that must be achieved when deciding which shelters to open, when and where, because often soon after an announcement, the public will arrive (Downey pers comm 2007). However, there will be a benefit to analyzing shelters with hurricane risk data in future work since "…surge models could be used to help coastal parishes decide whether or not to open, and better weigh the risk vs. the benefit (ibid)."

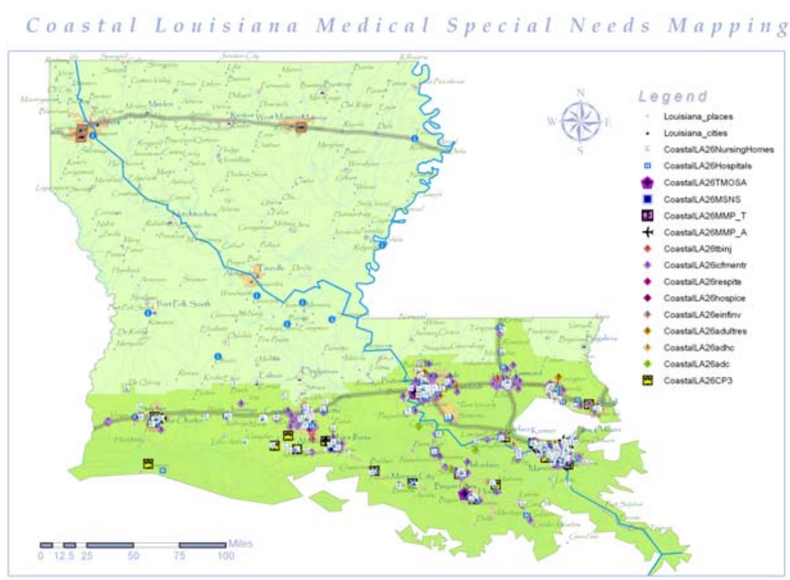
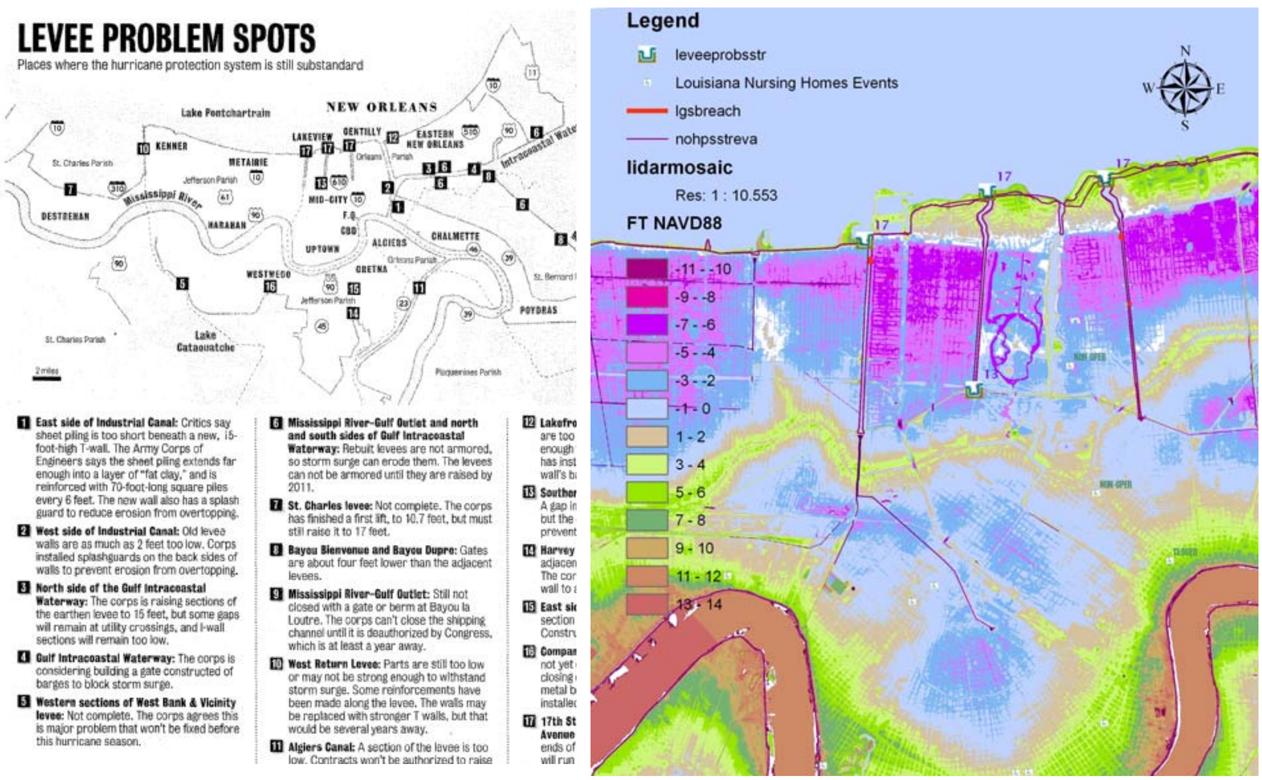


Figure 19. Critical medical sites and MSN locations for the project study *(ESRI ArcGIS 9.2, Data sources are listed in section 4.2.1).*

The final project map for this study as mapped in ESRI ArcGIS 9.2 by LA DHH Region is shown in Figure 19. It can also be viewed with LIDAR elevation data and imagery.

4.2.4 Special Considerations: Levee Breach and Status, Katrina Maximum Flood Depths

Two years after Hurricane Katrina and the levee breaches, independent critics and Corps officials agree that in New Orleans, regarding the Hurricane Protection System (HPS) there is "…an incomplete levee system that could fail on its eastern and southern borders – even during smaller hurricanes" (Schleifstein/The New Orleans Times-Picayune May 9, 2007, Figure 20a).



Figures 20a-b: Levee breach locations and current problem spots viewed with LIDAR elevation contours and nursing home status (non-operational and closed facilities), based on overview data from the New Orleans Times Picayune (Schleifstein 2007). (*ESRI ArcGIS 9.2, with GIS data from Yang, Peele, and Binselam).*

As of hurricane season 2007 "…even a strong Category 2 hurricane entering the Intracoastal Waterway from Lake Borgne could overtop levees…(ibid)." Levee problem spots circle the city of New Orleans on both the East and West Bank, with sections that remain to be

rebuilt or are incomplete; remain unarmored; are too low; have gates that are lower than adjoining levee walls; have sheet piling that is insufficient, or gaps at utility and other crossings (ibid). To account for this added hurricane risk, a Light Detection and Ranging (LIDAR) mosaic providing elevation depth in ft NAVD88 (Binselam 2006) was incorporated with data layers such as the New Orleans HPS (USACE, Yang 2004) and Katrina levee breach shapefiles (Peele/LGS, Cunningham and Braud) to be viewed in a GIS environment (Figure 20b).

The LIDAR data was classified and a symbology was developed to represent elevation values in New Orleans (feet NAVD88). Levee breaches were represented as red on a new HPS shapefile that incorporated the full HPS including the Arpent levee (ibid) and West Bank levees (USACE). A separate data layer was developed to point out levee problem spots to be viewed with MSN locations (Figure 21).

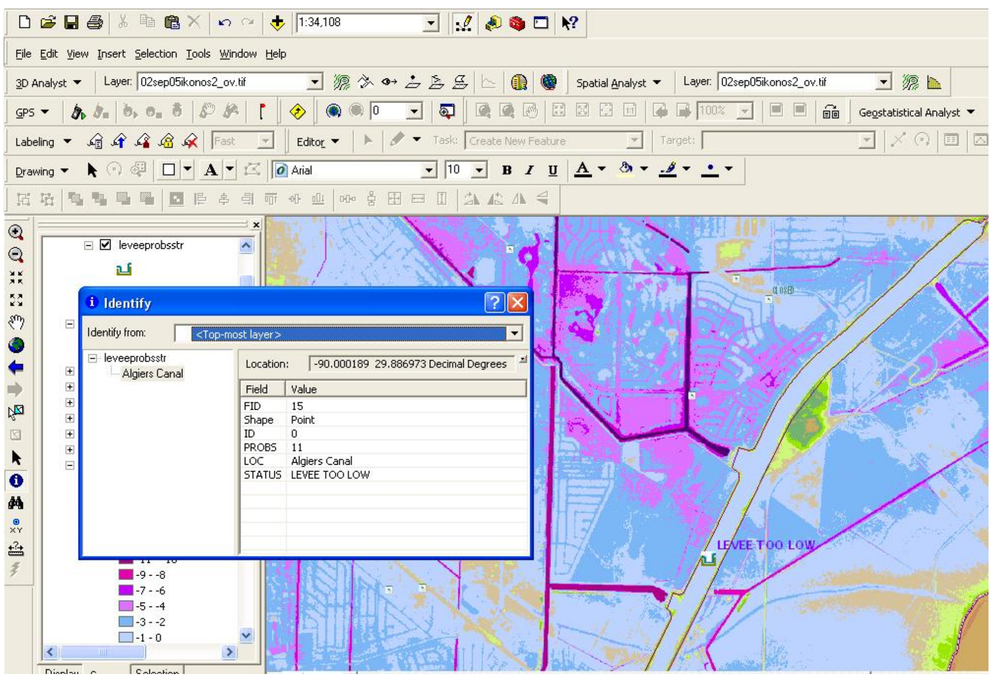


Figure 21. Levee problem notes and LIDAR for adjacent MSN facilities (zoomed data) and info tool. ESRI ArcGIS 9.2.

Potential flood depths in New Orleans from another levee breach may be estimated by maximum water depths as mapped by Cunningham and Braud with a flood mask (post-Katrina 2006, figure 22). Low and high (e.g. Metairie Ridge, natural Mississippi River levee) features become evident with the LIDAR and flood mask data. Maximum water depth data can also be viewed with critical MSN point data in ArcGIS to determine how deep floodwaters actually reached at some MSN facilities. Data is available for the New Orleans, New Orleans East and St. Bernard polders (ibid).

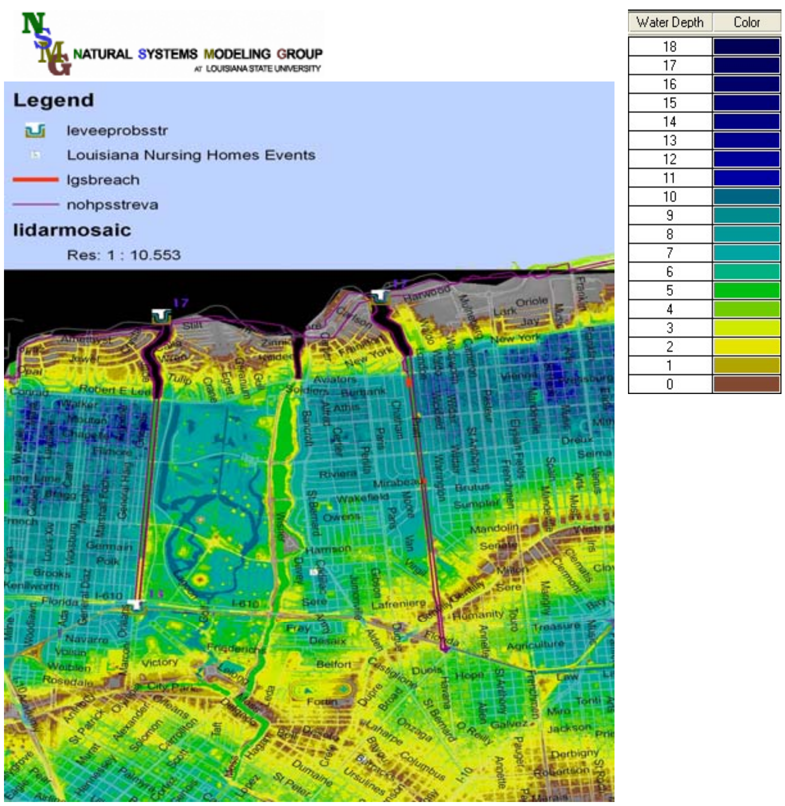


Figure 22. Maximum Water Depths Flood mask. Depths are in feet NAVD88 *(Cunningham and Braud 2006).*

Unfortunately, one additional data layer that was not available for this study was the shapefile for FEMA trailers located throughout coastal Louisiana, which may become threatened at approximately 50-74 mph or TSFW winds (SEHTF 2007). While FEMA trailer residents are

expected to evacuate very early, they could unwarily become MSN patients in unsuccessful evacuation or other unforeseen circumstances or hazards.

Hurricane tracks from the NOAA CSC shapefiles were also added to the final GIS with time fields estimating 'hours until landfall' (L-HR) added for added 'time-series' analysis.

4.3 Integration of Storm Surge Flood Layers into GIS

As explained earlier by Will Shaffer of NOAA, a generated SLOSH surge value of 10 feet would be estimated to flood a facility at 8 ft but not at 12 ft within a grid cell. Therefore, an important consideration when evaluating storm surge risk for any facility with SLOSH modeling is the facility first floor elevation. However, these data were not generally available for the current study. To support surge risk determination in this study where elevation is unclear, LIDAR data (LOSCO, LSU and LOSRADP 2007, LGS/Binselam 2006) was applied to provide a rough estimation of facility elevation. Based on 2007 elevation surveys employing recent techniques for accurate elevation measurement, LIDAR is generally only accurate to within 1-3 feet (Cunningham et al 2003). However, it can still be used to provide an estimate of elevation in the current analysis.

As discussed in section 3.3.1.1, NOAA developers have recently added a shapefile feature to SLOSH outputs, so that they can be viewed in a GIS. Entire basin files can be imported into ArcGIS as shapefiles and classified at corresponding storm levels for the MOM (Cat 1- 5). Shapefiles were imported and color coded to match SLOSH outputs as they appear on the CD program then clipped along the Louisiana coast. SLOSH outputs were then viewed at selected storm levels in a GIS with other critical data layers. Hospital and nursing home census estimates were labeled and viewed with labeled surge flooding estimates in SLOSH (figure 23).

Additional MSN facilities and critical locations were also evaluated, with results summarized in Chapter 5.

SLOSH MOM values were calculated from input shapefiles (SLOSH version 1.43) across the Louisiana coast for all storms. As discussed in section 3.3.1.1, conservative surge MOMs will show flooding as if the storm makes landfall at every point, from every direction, worst case. MSN facilities were manually counted, with additional verification applying clipped SLOSH shapefiles (see also section 5.3), to tally facilities receiving at least 1 foot of storm surge.

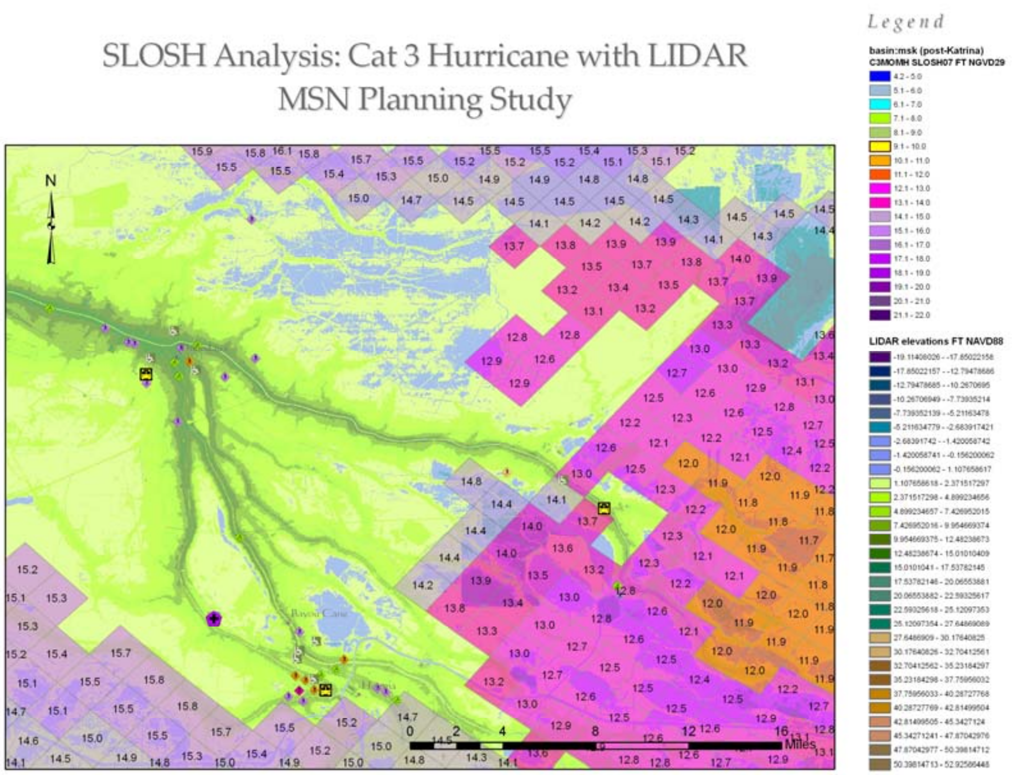


Figure 23. MSN facilities at serious storm surge risk from a CAT 3 hurricane are evaluated and summarized (Chapter 5, Results). *(SLOSH 2007, shown with LIDAR 2006, and MSN data layers).* Note facilities falling just outside of SLOSH grid cells.

Mapping worst case storm surge flooding via SLOSH MOMs may be desirable in one respect, since MSN facilities are the first to evacuate and begin transport of patients as far as 48-72 hours out prior to hurricane landfall (L-HR). As discussed, although there are increasingly

accurate track predictions available from the NHC, facility decision-makers still cannot be certain where the storm will actually make landfall while the storm is still so far away, OR if the storm will intensify. To err on the side of caution, many will necessarily consider evacuation.

However, it should be noted that in actuality, when a storm makes landfall along the Louisiana coast (approximately 300 miles across), most hurricanes – even Katrina and Rita – will only produce surge flooding along a portion, not all, of the coastline (Figures 30a-b). Some MSN patients and residents may therefore evacuate needlessly. As much as the prediction and modeling technologies have improved, this is difficult to avoid without accepting serious risk.

Due to the limitations discussed in section 3.3.1.1, a partial re-analysis was conducted for this study with LIDAR-extrapolated SLOSH MOM shapefiles provided by Binselam 2007 (Figure 24) in an attempt to verify tally counts and incorporate any MSN critical points which may have fallen outside of the SLOSH 2007 shapefile extent.

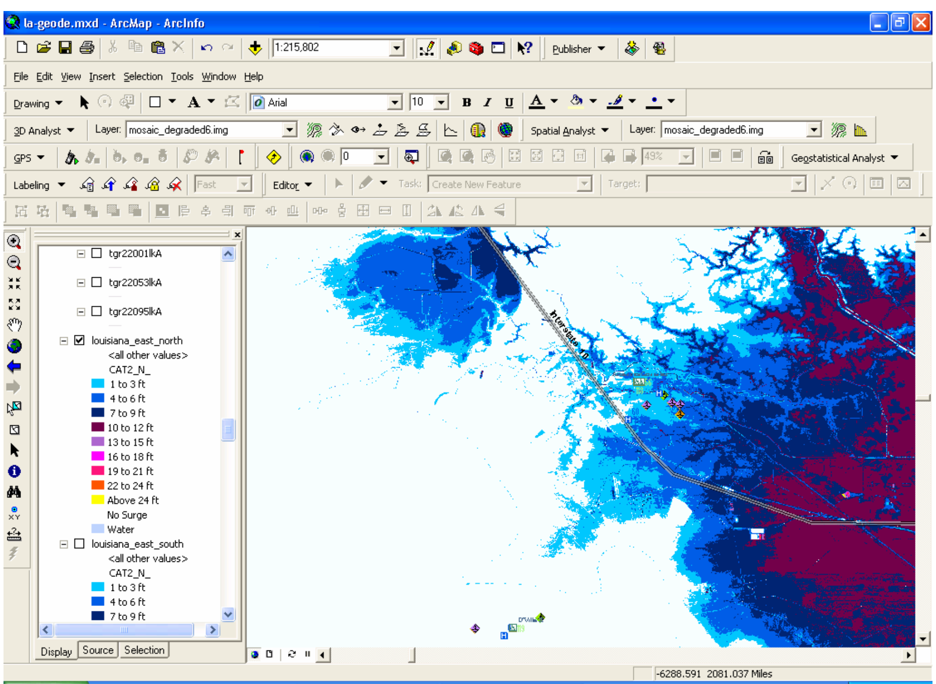


Figure 24. MSN facilities at serious storm surge risk from a CAT 2 hurricane (Chapter 5, Results) *(Binselam 2007, extrapolated from SLOSH 2006 with LIDAR, with critical MSN data layers, ESRI ArcGIS 9.2)*

There were two major limitations with the dataset. First, analysis was only possible for Cat 2 and 3 storms, based on the original purpose of the dataset. Therefore, Cat 1 results could not be re-analyzed with the LIDAR-extrapolated SLOSH data. Second, other than the extrapolation of LIDAR, the re-analysis differed from the original SLOSH analysis in two respects: (1) north tracks only were analyzed, rather than all directions; and (2) pre-Katrina SLOSH data (2006) was used as the baseline (converted to the LIDAR NAVD88). The supplementary tally with LIDAR-extrapolated SLOSH contours was a highly valued dataset for its value in gleaning MSN facilities that may have been missed in the original SLOSH analysis. Overall results and observations are discussed in Chapter 5.

4.4 Calculation of Wind Fields

A number of aspects of hurricane wind must first be understood to make adequate use of wind models for the calculation of wind fields. First, wind fields over land cannot be represented using simply Saffir-Simpson hurricane categories (Appendix A), which are wind speeds over water; but require a conversion method to represent wind speeds over land (Friedland pers comm 2007, Gregg 2006, Easley 2003, Vickery et al 2000). Further, wind speeds are averaged over one minute in the Saffir-Simpson scale, while a 3-second gust is used in the design and evaluation of building performance (Friedland pers comm 2007). Therefore, a series of conversions are necessary to translate estimated Saffir-Simpson windspeeds at landfall into peak gusts, which structural engineers will use to determine the level of damage a facility such that an MSN nursing home will likely sustain (ibid).

Second, wind speeds will dissipate shortly after landfall, and at varying rates, based on the storm size, forward tracking speed and other factors (Kaplan and DeMaria 1995, Robbins 2004). Therefore, wind impacts will not be as severe the further a storm moves inland.

Lastly, a very important facet of wind that is not largely known to the public in general is that the pressure exerted by winds on a structure in a hurricane does not increase proportionally to velocity, or windspeed. Aerodynamic equations reveal that wind force is proportional to the *square* of the velocity,

$$F_w = \frac{1}{2}\,\rho C_f A V^2$$

where F_w = the force of the wind on a surface

ρ = the density of the air

C_f = force coefficients (drag, lift, etc.)

V = wind velocity (3-second gust at 33')

A = projected area normal to wind

such that, **as windspeeds increase, the wind *force* increases four-fold!** (ASCE 2005, Friedland pers comm 2007, English pers comm 2007). Therefore, a jump by one hurricane category (Appendix A) translates to much more damage structurally than generally perceived.

The FEMA HAZUS wind data from 2005 turned out to be a fitting dataset for review in a GIS to gain a greater understanding of the wind levels and associated damage that may be realized along the coast from a major hurricane (Figure 25).

Particularly, since both Hurricanes Katrina and Rita made landfall as approximate Category 3 storms, HAZUS analysis and shapefiles (Friedland 2007) demonstrate the impacts of estimated peak gusts over land and estimated percent of damage at the upper level intensity desired for this study (as Cat 1- 3 storms were analyzed). Additionally, the hurricanes struck alternate end of the state, demonstrating both the limiting extent of wind effects and surge (see also section 6.2.1).

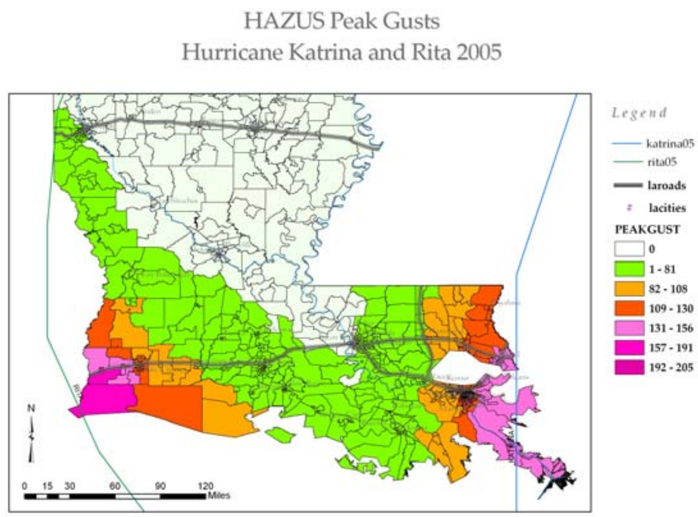


Figure 25. Peak gusts over land, Hurricanes Katrina and Rita (2005). *HAZUS shapefiles provided by Friedland 2007. Katrina Data provided by ARA/FEMA directly after the storm. Rita data from NHC Advisory #28.*

As determined from the mapped 2005 data for HAZUS peak gusts (Figure 25), associated damage estimates for Hurricanes Katrina and Rita were also calculated and mapped (Figure 26).

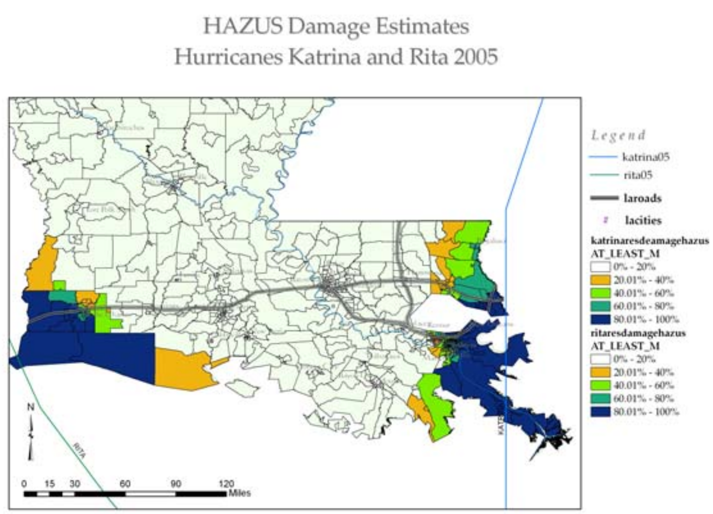


Figure 26. Damage estimates (at least moderate damage) from Hurricanes Katrina and Rita, 2005. (*HAZUS shapefiles provided by Friedland 2007. Both figures mapped in ESRI ArcGIS 9.2).*

Damage estimates approximated the percent range of residential structures that may have been impacted by 'at least moderate damage' but potentially severe damage from winds (Figure 26). As supported by the mapped findings, this study determined that all Louisiana coastal MSN facilities and residences south of the interstates are likely to be impacted by the peak wind gusts of hurricane force winds for each hurricane category. Peak gusts (3-sec) on buildings, as converted from Saffir-Simpson maximum sustained wind values over water (1-min) revealed upper gusts of 108, 130 and 156 mph for Category 1, 2 and 3 hurricanes respectively, as hurricanes approach land (Figure 25 and Table 7).

Table 7. Peak Gust Wind Speeds and Estimated Range of Damage for Saffir-Simpson Hurricane Categories (based on 2005 HAZUS Data and modified from Vickery et al 2000)

Saffir-Simpson Category	Max Sustained Wind Over Water (mph) (1 minute)	PEAK GUST 3-second Max Gust Speed Over Water (mph)	PEAK GUST 3-second Max Gust over Open Terrain at Landfall (mph) (z_0=.1 ft)	Range of Percent of 'at least moderate damage' to MSN facilities and residences based on 2005 data analysis in HAZUS
1	74-94	91-116	82-108	0-60%
2	94-110	116-140	108-130	20%-100%
3	110-130	140-165	130-156	80-100%
4	*130-155*	*165-195*	*156-191*	*(not evaluated)*
5	*>155*	*>195*	*>191*	*(not evaluated)*

Determinations were that between zero to sixty percent of coastal Louisiana MSN structures would experience at least moderate damage from Category 1 peak gusts over land; between twenty to one hundred percent of MSN structures would experience at least moderate damage from Category 2 peak gusts over land; and eighty to one hundred percent of MSN structures would experience at least moderate damage from Category 3 peak gusts over land, with a higher potential for severe damage!

“At least moderate damage” in HAZUS is defined as “major roof cover damage, moderate window breakage, minor roof sheathing failure, and some resulting damage to interior of building from water.” Severe damage extends to “major window damage, or roof sheathing loss, major roof cover loss, extensive damage to interior from water (HAZUS technical manual, Damage States for Residential Construction Classes).” Thus, even at Category 1 storm levels, up to sixty percent of coastal Louisiana structures (including MSN) in the study would be expected to sustain damage that could harm MSN patients by ‘at least moderate’ damage levels, unless sheltering in a recently designed or mitigated facility such as a multi-story hospital.

Following a review of the 2005 wind data, it was determined that hurricane characteristics and the baseline wind equations that go into the HAZUS determinations, as well as NOAA NHC HRD surface wind products (Figures 33a-c, section 6.2.2), could be applied in the current study. These provide a conservative methodology in GIS to determine added wind risk from hurricanes at the Category 1-3 level. The methodology was further developed along the following basis: The distance from the Louisiana coast to interstates I-10 and I-12 was estimated in a GIS to range between 25 and 100 miles. As discussed in section 3.1.3.1, hurricane-force winds (HFWs) “can extend outward [from the eye] to about 25 miles in a small hurricane and to more than 150 miles for a large one (NOAA 1999, p.2) (Figure 27).”

Regardless of hurricane size, it is assumed for this study that the HFWs that extend outward from the hurricane eyewall (1) will make landfall well before the eyewall and (2) will not likely dissipate until the hurricane hits, i.e., approaches the shallow waters of the coast and then traverses land (Friedland pers comm 2007). Thus, in this case, **the current study assumes that the maximum or peak wind gust over terrain will be realized on MSN residences and facilities for each Category hurricane at least as far inland as the interstates.**

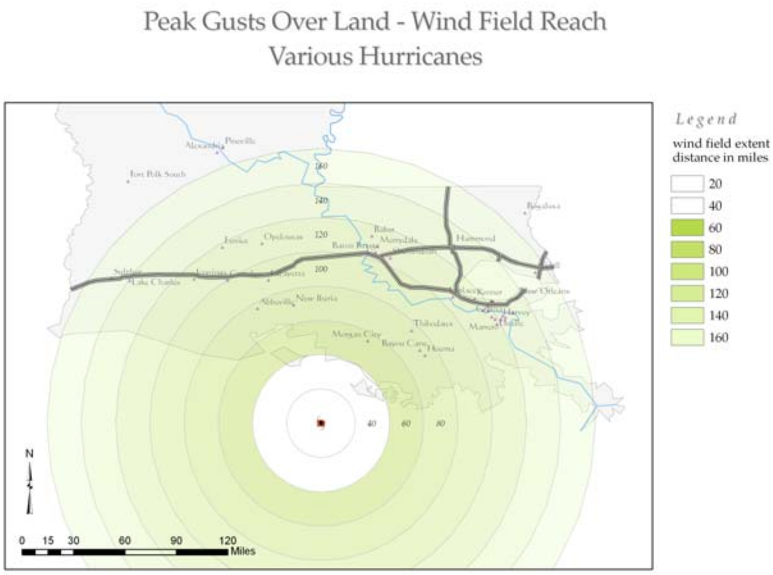


Figure 27. 20 mile wind buffers simulate hurricane force winds extending as far inland as the interstates as various hurricanes approach landfall (NOAA 1999) *ESRI ArcGIS 9.2*

4.5 Sharing Hurricane Research and Modeling Tools in GIS

Methods were also explored to present hurricane research and models with facility-specific data, MSN locations and other critical data for local facility managers and other planners to access and use. Further study and one-on-one discussions are needed on this topic to identify effective methods of communicating and visualizing risk data to MSN populations, perhaps with GIS. However, some preliminary identified strategies could include preparing data layers on CD and supplying these; or providing the data layers online for download, with options for downloadable GIS readers. The intention would be to make as much of the data available, able to be managed locally by users, and freely available and read by GIS readers; yet still preserve the ability of local users to view and manipulate input tables of data as well as add their own data. The following formats were tested for this application with methods briefly reviewed here.

- Arc Explorer (Arc Explorer map files -.axl)

Versions of Arc Explorer are freely available for download. Selected project shapefiles were imported into ArcExplorer 9.2 and maps were saved as .axl files. Basic shapefiles were loaded and saved as maps for viewing, but with little ability to edit or manage the files, view multiple layers, or add symbology. Limitations included low quality of data viewing and difficulty in modifying or adding files. The software can also be slow and tedious when it first opens and present problems with graphics or computer requirements.

- GIS Data Servers and Imagery Mappers

GIS data server and mappers were also explored as a means of sharing project outcomes with the MSN public. In some cases, individual shapefiles can be added as layers over many types of imagery, and can be viewed in detail from many perspectives. There are also some powerful search tools for address searching and obtaining coordinates through features such as Yahoo! search and integrated Microsoft Virtual Earth. However, while the imagery and search tools are often impressive, the ability to view, manage, edit or add multiple files is still being developed and is not currently suited to the current task.

- Arc Reader (Arc Publisher Map Files -.pmf)

Map files (.pmf) were another option explored. These can be created within ArcGIS through an extension of ArcPublisher. All of the project data layers were able to be loaded into a user-friendy interface for viewing, with options for adding data and allowing some data management. The ArcGIS symbologies are maintained in map files making this a good way to share data, view multiple files, and integrate site-specific data. More however is needed for local users to be able to view and edit tables, arrange layers, edit symbologies to some extent once they have been created, and integrate and manage the data into their own files.

CHAPTER 5 RESULTS

5.1 Result Tables

The following tables present the results of the hurricane storm surge modeling in a GIS. Result summaries follow the tables (in sections 5.2.1 and 5.2.2) indicating final determinations of threshold storm events that would impact MSN evacuation and sheltering planning.

SLOSH 2007 storm surge modeling results for MSN facilities impacted by Category 1, 2 and 3 storms are presented in tables 8-10, respectively. Any facility impacted by at least one foot of floodwater was tallied in the table. Hospitals and nursing homes, which had census counts available for hurricane season 2007, also include patient tallies. Although "available beds" and "capacity" information was also available for some of the other MSN sites within the data, these were not included in total patient counts since they were not actual census counts.

One important note for final result table 10 is that even though **SLOSH models predict levee overtopping and severe flooding within New Orleans at Category 3 MOM levels,** table 10 has been tabulated ***excluding the MSN facilities within Orleans and Jefferson parishes and the HPS. This helps to demonstrate the initial tallies, should the HPS hold for some Category 3 storms. Additional facilities impacted by levee overtopping or failure or during a New Orleans city-wide evacuation are then discussed in section 5.2.4 under "New Orleans Levee Breach and Flood Inundation Scenarios."

MSN facility cities are listed in place of names or other unique facility identifiers to explore the results without directly identifying MSN sites by name.[33] Estimated storm surge risks to MSN critical medical evacuation, transportation and sheltering sites follow in table 11. Again, the **Category 3 analysis in Table 11 has been tabulated excluding the Orleans and Jefferson**

[33] For planning or emergency purposes, or for further analysis, the GIS shapefiles contain identifying markers and additional information.

Parish MSN sites within the HPS, to demonstrate the added numbers in a New Orleans evacuation. Section 5.2.4 discusses a levee overtopping or city-wide breach scenario, and additional medical evacuation, transportation and sheltering sites that would be affected.

Re-analysis results with LIDAR-Extrapolated SLOSH data (Binselam 2007) follow in section 5.2.3, followed by a discussion of New Orleans levee and flood inundation scenarios in section 5.2.4. The selected methods for clear communication and visualization of project MSN data is briefly presented in section 5.2.5, followed by a discussion of GIS limitations.

5.2 Threshold Storm Events Impacting MSN Evacuation

Assuming (1) The New Orleans HPS (East and West Bank) remains intact and all pumps are operational; (2) Excluding potential increased surge risk from Hurricane Rita (2005) that has not been incorporated into the current SLOSH version; and (3) without considering sheltering above the first floor of any multi-level structures or mitigation (these may be subtracted from the totals if facilities are adequately designed and prepared to shelter in place), the result tables were summarized as follows.

5.2.1 Summarizing MSN Point Data for Storm Surge Risk

Preliminary SLOSH (2007) analyses of the available data indicate that:

Category 1 hurricane surge impacts would impact an estimated 22 coastal Louisiana MSN facilities seriously enough to warrant an evacuation of those facilities, including:

7 hospitals with 179 patients, and;

3 nursing homes with 305 patients, respectively;

484 total patients in the 26 coastal parishes would therefore be estimated to require transport and evacuation to alternate facilities or shelters (Table 8).

Table 8. Estimated number of evacuating facilities and/or patients as a result of updated SLOSH storm surge modeling for Category 1 hurricanes[34]. Threshold storm event: TROPICAL STORM IN THE GULF OF MEXICO AT L-48

CITY	HOSPITALS	HOSP_PATIENTS	NURS HOMES	NH_PATIENTS	HOSPICE	ADC	AHDC	ADULTRES	EINF	ICF/MR/DD	RESPITE	TBIJ
BERWICK						1						
BOUTTE						1				1		
CAMERON	1	10										
CUT-OFF	1	35										
DELCAMBRE										1		
ERATH						1						
FRANKLIN	1	8	1	123						1		
GARYVILLE										1		
LAPLACE	1	51								1		
LULING	1	35										
MORGAN CITY	1	40	1	70				1				
PATTERSON										1		
RACELAND	1	0										
RIVERBEND			1	112								
SLIDELL						1	1					
TOTALS	**7**	**179**	**3**	**305**	**0**	**4**	**1**	**1**	**0**	**6**	**0**	**0**

TOTAL EVAC FACILTIES - STORM SURGE RISK	**22**
TOTAL EVAC PATIENTS* - STORM SURGE RISK	**484**

***This number is likely an underestimate since census counts are not available for all MSN facilities**

[34] Assumes New Orleans HPS (East and West Bank) intact and all pumps operational; does not account for increased surge risk from Hurricane Rita (2005); does not consider sheltering above the first floor of the facility in multi-level structures or further mitigation.

Table 9. Estimated number of evacuating facilities and/or patients as a result of updated SLOSH storm surge modeling for Category 2 hurricanes[35]. Threshold storm event: TROPICAL STORM IN THE GULF OF MEXICO AT L-48

CITY	HOSPITALS	HOSP_PATIENTS	NURS HOMES	NH_PATIENTS	HOSPICE	ADC	AHDC	ADULTRES	EINF	ICF/MR/DD	RESPITE	TBIJ
ABBEVILLE	2	52	2	154				2		1		
BELLE CHASE			1	112						3		
BERWICK						1						
BOUTTE						1				1		
CAMERON	1	10										
CHACKBAY										1		
CUT-OFF	1	25	1	106		1				1		
DELCAMBRE										1		
DESTREHAN			*1*	*132*						1		
ERATH			1	105		1						
FRANKLIN	1	8	1	123						1		
GALLIANO										1		
GARYVILLE										1		
GONZALES	2	60	1	174		1		1		3		
GRAY						1						
GRETNA	1	22	1	65		6		1		5		
GUEYDAN			1	66								
HARVEY			2	185						6		
HOUMA	3	261	5	381		3		4		5	1	
JEANERETTE			1	99								
KAPLAN			1	109								
LAKE CHARLES										1		
LAPLACE	2	51	1	99				1		2		
LOCKPORT										1		
LOCKPORT						1						
LULING	1	33	2	91								
LUTCHER	2	11	1	92		1						
MANDEVILLE										1		
MARRERO	*2*	*288*	3	285				1				

35 Assumes New Orleans HPS (East and West Bank) intact and all pumps operational; does not account for increased surge risk from Hurricane Rita (2005); does not consider sheltering above the first floor of the facility in multi-level structures or further mitigation.

Table 9 cont'd.

CITY	HOSPITALS	HOSP_PATIENTS	NURS HOMES	NH_PATIENTS	HOSPICE	ADC	AHDC	ADULTRES	EINF	ICF/MR/DD	RESPITE	TBIJ
MORGAN CITY	1	40	1	70				1				
NEW IBERIA	2	83	2	196		2				6		
NEW ORLEANS			5	408				2		6		
NORCO							1					
PATTERSON			1	126						1		
RACELAND	1	0	1	87		1	1			1		
RIVERBEND			1	112								
SLIDELL						1	1			1	1	
THIBODEAUX	1	107	1	136		3				8		
VACHERIE						1						
VIOLET										1		
WESTWEGO						1						
TOTALS	**23**	**1051**	**38**	**3513**	**0**	**26**	**3**	**13**	**0**	**60**	**2**	**0**

note: italics represent a borderline decision for a facility which could potentially shelter in place given the right circumstances or more review.

TOTAL EVAC FACILTIES - STORM SURGE RISK	**165**
TOTAL EVAC PATIENTS* - STORM SURGE RISK	**4564**

***this number is likely an underestimate since census counts are not available for all MSN facilities**

Table 10. Estimated number of evacuating facilities and/or patients as a result of updated SLOSH storm surge modeling, Category 3 hurricanes ***see also IMPORTANT NOTE.[36] Threshold storm event: TROPICAL STORM IN THE GULF OF MEXICO AT L-48

CITY	HOSPITALS	HOSP_PATIENTS	NURS HOMES	NH_PATIENTS	HOSPICE	ADC	AHDC	ADULTRES	EINF	ICF/MR/DD	RESPITE	TBIJ
ABBEVILLE	2	52	2	154				2		1		
ARABI										1		
BELLE CHASE			1	112						3		
BERWICK						1						
BOUTTE						1				1		
CAMERON	1	10										
CHACKBAY										1		
CHALMETTE							1					
CUT-OFF	1	25	1	106		1				1		
DELCAMBRE										1		
DESTREHAN			1	132						1		
ERATH			1	105		1						
FRANKLIN	1	8	1	123						1		
GALLIANO										1		
GARYVILLE										1		
GONZALES	2	60	1	174		1		1		3		
GRAY						1						
GRETNA	1	22	1	65		6		1		5		
GUEYDAN			1	66								
HARVEY			2	185						6		
HOUMA	3	261	5	381		3		4		5	1	
JEANERETTE			1	99								
KAPLAN	1	19	2	217								
KENNER	1	109	2	256				2		20		
LACOMBE			1	87								
LAKE CHARLES										1		
LAPLACE	2	51	1	99		1		1		2		

[36] Assumes New Orleans HPS (East and West Bank) intact and all pumps operational; does not account for increased surge risk from Hurricane Rita (2005); does not consider sheltering above the first floor of the facility in multi-level structures or further mitigation. **NOTE: DOES NOT INCLUDE NEW ORLEANS MSN EVACUATION NUMBERS; TALLYS PATIENTS AS IF THE NEW ORLEANS HPS HOLDS FOR A CAT 3 HURRICANE**

Table 10 cont'd.

CITY	HOSPITALS	HOSP_PATIENTS	NURS HOMES	NH_PATIENTS	HOSPICE	ADC	AHDC	ADULTRES	EINF	ICF/MR/DD	RESPITE	TBIJ
LOCKPORT						1				1		
LULING	1	33	2	91								
LUTCHER	2	11	1	92		1						
MANDEVILLE										1		
MARRERO	2	288	3	285				1				
METAIRIE			1	90				3				
MORGAN CITY	1	40	1	70				1				
NAPOLEONVILLE			1	108		1				1		
NEW IBERIA	3	170	4	387		2		2		9		
NEW ORLEANS	2	12	9	627	1	1	1	2		6		
NORCO							1					
PATTERSON			1	126						1		
PLAQUEMINE	1	80	1	216		1				1		
RACELAND	1	0	1	87		1	1			1		
RIVERBEND			1	112								
SLIDELL	2	127	3	168		2	1	1		2	1	
ST MARTINVILLE										1		
SULPHUR	2	104	1	102		1				5		
THIBODEAUX	1	107	1	211		3		1		8		
VACHERIE						1						
VINTON						1				6		
VIOLET										1		
WESTWEGO						1						
WHITE CASTLE						1						
TOTALS	**33**	**1589**	**55**	**5133**	**1**	**34**	**5**	**22**	**0**	**99**	**2**	**0**

note: italics represent a borderline decision for a facility which could potential shelter in place given the right circumstances or more review.

TOTAL EVAC FACILTIES - STORM SURGE RISK[36] **251**

TOTAL EVAC PATIENTS - STORM SURGE RISK[36] **6722**

***this number is likely an underestimate since census counts are not available for all MSN facilities**

Table 11. Critical Medical Sites Surge Risk from Category 1, 2 and 3 hurricanes based on 2007 SLOSH, ***see also IMPORTANT NOTE.[37]

1=flood	MSN TES CAT1 (Threshold event: T. Storm at L-48)					MSN TES CAT2 (Threshold event: T. Storm at L-48)					MSN TES CAT3 (Threshold event:T. Storm at L-48)				
0=dry	T-MOSAs	MSNS	MMPs	CPPP	CTNS	T-MOSAs	MSNS	MMPs	CPPP	CTNS	T-MOSAs	MSNS	MMPs	CPPP	CTNS
Abbeville				0					1					1	
Alexandria_CT		0					0					0			
Alexandria_EAP		0					0					0			
Alexandria_LSU		0					0					0			
Baton Rouge_FH	0					0					0				
Baton Rouge_PMAC		0					0					0			
Belle Chase_AUD				0					0					1	
Belle Chase_NAS			0					0					1		
Bossier City		0					0					0			
Chalmette				0					1					1	
Franklin				1					1					1	
Grand Lake				1					1					1	
Hackberry				1					1					1	
Hammond		0					0					0			
Houma				0					1					1	
Jefferson				0					0					1	
Kenner			0					0					1		
Lafayette	0	0				0	0				0	0			
Lake Charles		0	0	0			0	0	0			0	0	1	
LaRose				0					0					1	
Maurice				0					0					0	
Monroe_SF					0					0					0
Monroe_UL		0					0					0			
Morgan City				0					0					0	
Napoleonville		0					0					1			
New Iberia			0	0				0	0				0	0	
New Orleans_EMCC				0					0					0	

[37] Assumes New Orleans HPS (East and West Bank) intact and all pumps operational; does not account for increased surge risk from Hurricane Rita (2005); does not consider sheltering above the first floor of the facility in multi-level structures or further mitigation. MSN TES = medical special needs critical transportation evacuation and sheltering sites. **NOTE: CAT 3 ANALYSIS DOES NOT INCLUDE NEW ORLEANS MSN EVACUATION NUMBERS; TALLYS PATIENTS AS IF THE NEW ORLEANS HPS COULD WITHSTAND A CAT 3 HURRICANE**

Table 11. cont'd.

1=flood	MSN TES CAT1 (Threshold event: T. Storm at L-48)					MSN TES CAT2 (Threshold event: T. Storm at L-48)					MSN TES CAT3 (Threshold event: T. Storm at L-48)				
0=dry	T-MOSAs	MSNS	MMPs	CPPP	CTNS	T-MOSAs	MSNS	MMPs	CPPP	CTNS	T-MOSAs	MSNS	MMPs	CPPP	CTNS
New Orleans_LAKFR			0					0					1		
New Orleans_UPT				0					0					0	
Raceland				0					1					1	
Shreveport_HC					0					0					0
Shreveport_SC					0					0					0
Slidell				0					0					0	
Thibodaux	0	0		0		1	1		1		1	1		1	
Westwego				1					1					1	
TOTAL FLOODED[37]	**0**	**0**	**0**	**4**	**0**	**1**	**1**	**0**	**9**	**0**	**1**	**2**	**3**	**13**	**0**

Category 2 hurricane surge impacts would impact an estimated 165 coastal Louisiana MSN facilities seriously enough to warrant an evacuation of those facilities, including:

23 hospitals with 1,051 patients, and;

38 nursing homes with 3,513 patients, respectively;

4,564 total patients in the 26 coastal parishes would be estimated to require transport and evacuation to alternate facilities or shelters (Table 9).

Category 3 hurricane surge impacts, *not including the MSN facilities within the New Orleans HPS*, would impact an estimated 251 coastal Louisiana MSN facilities seriously enough to warrant an evacuation of those facilities, including:

33 hospitals with 1,589 patients, and;

55 nursing homes with 5,133 patients, respectively;

6,722 total patients in the 26 coastal parishes would be estimated to require transport and evacuation to alternate facilities or shelters (Table 10).

It should be noted that patient counts will be more seriously underestimated with each subsequent event, since census numbers were not available for all MSN facilities. Additional rainfall risks, not calculated in the current study, should also be considered. Additional facilities at risk due to wind, levee breach, and additional considerations are presented in sections 5.2.2 – 5.2.4).

Regardless of the initial storm surge risks and tallies as presented in the result tables, **the current study has determined the threshold storm event for all MSN facilities to be a tropical storm approaching the Louisiana coast at L-48**. This is based on factors including the potential for rapid hurricane intensification (section 3.2.3) and shift in track; additional wind impacts to the coast (section 4.4); and the time constraints on MSN evacuation decisions.

5.2.2 Storm Surge Events Affecting Critical Medical Evacuation, Transportation and Sheltering Sites

According to MSN evacuation plans, by L-53 (or 53 hours to hurricane landfall) National Guard and other pre-contracted assets will begin assembling at airfields, with other medical teams ready to receive patients at designated Medical Marshalling Points (MMPs). By L-51, hospital decision makers are supposed to communicate their decisions to either: shelter in place, partially evacuate, or completely evacuate. From preliminary plans, the first load of MSN patients are set to depart from airfields at L-48 (LA DHH ex 9). Medical response will need to be very coordinated and stay within schedule to avoid hurricane risks to patients from early surge and wind effects. Table 11 summarizes surge risk evaluation of critical medical and related sites for Cat 1-3 storms. As discussed, *the Category 3 analysis in Table 11 has been tabulated excluding the Orleans and Jefferson Parish MSN sites within the HPS, to demonstrate the added numbers in a New Orleans evacuation.*

Observations from the final results include:

- Coastal Parish Pick-up Points (CPPPs) should be evacuated promptly. Four, nine and thirteen CPPPs would need to be fully evacuated at Cat 1, 2 and 3 levels, respectively, to avoid storm surge risks.
- At Category 3 hurricane levels, 3 MMPs are at risk of surge flooding. These sites would need to be evacuated before storm landfall, and may not be useable under some storm conditions.
- 2 Medical Special Needs Shelters (MSNS) are in surge risk areas, one at Cat 2 levels and one at Cat 3. These shelter sites require further investigation for storm safety.
- 1 T-MOSA may experience surge flooding by Cat 2 levels. This site will not be useable for some storms.

- CTNS shelters are located in northern Louisiana and indicated no surge risks.

As discussed in section 4.4, considering the balance of MSN facilities in twenty-six coastal parishes with some portion south of the interstates, **all three Categories of HFW (1-3) have the potential to exceed over half of MSN structures sustaining at least moderate damage.** This will most directly impact the facilities in the hurricane path; but the hurricane path cannot be predicted at L-48 to MSN decision makers. So, the remaining facilities south of the interstate should therefore be considered for additional evacuation based on wind damage risks, with increasing urgency for Category 2 and 3 hurricanes, unless mitigation or previous storm history have demonstrated the structure can withstand HFWs. The possibility of tornadoes should also be considered.

Total facilities impacted for each Category storm of wind ***can include up to the full balance of facilities in the 26 coastal parishes with some portion south of the interstate.*** Specifically, the balance of:

135 additional coastal Louisiana hospitals with 2007 census estimates of 6,694;

153 additional coastal Louisiana nursing homes with 2007 census estimates of 13,831;

and an estimated 523 MSN facilities, including the coastal cities of New Orleans, East Baton Rouge, Lafayette and Lake Charles.

Although MSN facilities located in high storm surge risk areas along the coast would generally be a higher evacuation priority, the 2005 data suggests that even Category 1 winds can cause moderate damage to MSN facilities, potentially injuring patients who are sheltering in place. The results of this study thus indicate that MSN facilities sheltering in place anywhere in coastal Louisiana may face storm surge and/or wind risks. Since hurricane track and intensity cannot be certain at 48 hours to landfall, the safety of sheltering in place will remain uncertain.

Table 12. Project Tallies of Storm Surge Impacts to Coastal Louisiana MSN Facilities

	Hospitals	Hospital Patients	Nursing Homes	Nursing Home Patients	Other MSN facilities	Total Site Count	Total Est. Patients (Hospital and NH)
CAT 1	7	179	3	305	12	22	484
CAT 2	23	1051	38	3513	104	165	4564
CAT 3 ***– HPS holds***	33	1589	55	5133	163	251	6722
CAT 3 ***– HPS overtop or breach, east bank***	56	3,020	73	6415	263	392	9435
CAT 3 ***– HPS overtop or breach, west bank***	37	1908	69	7571	203	309	9479

Refer to Appendix B for a listing of the study set of 26 coastal Louisiana parishes.
SLOSH 2007 shapefiles were applied in this analysis. See also, tables 8-11.
Critical Medical Sites (e.g., TMOSA, MSNS, etc) are not included in the above table.

5.2.3 Re-analysis Results with LIDAR-Extrapolated SLOSH Data

A new dataset created by Binselam (2007) from the 2006 SLOSH data was applied in the study to verify the initial manual/visual counts of MSN facilities. In a GIS, these demonstrated that a more precise analysis of MSN locations may be possible in the future, throughout the study set (26 coastal LA parishes, see also Appendix B listing). For example, the LIDAR-extrapolated SLOSH data in some cases helped to visualize additional MSN facilities that may flood at Category 2 storm surge levels. These would not have been included in the first tally (Figure 28). However, in other cases, the detail of the new datatset also results in the exclusion of some facilities. Both SLOSH shapefiles and the LIDAR-extrapolated dataset introduce problems when attempting to “clip” layers by MSN facility locations in a GIS (e.g., the large grid cell size of SLOSH shapefiles tend to over-count facilities, such as in the New Orleans

“bowl;” while clips of the high-resolution LIDAR-extrapolated SLOSH dataset so far have a tendency to undercount, even though previously unidentified facilities may be added in).

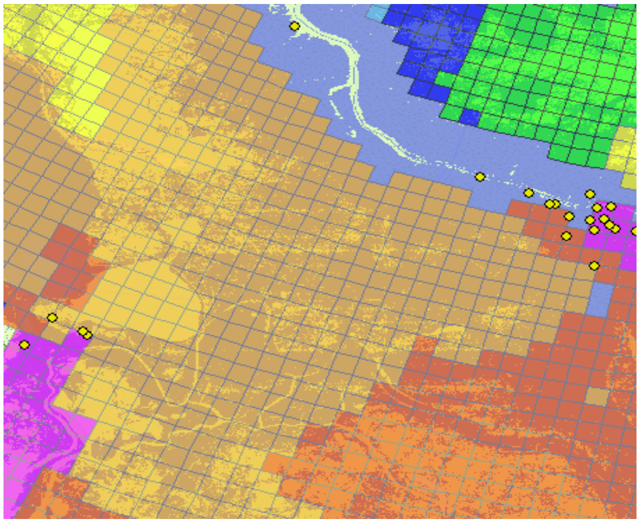


Figure 28. New LIDAR-extrapolated SLOSH data (shown in light blue above, Binselam 2007) help to visualize the surge flooding risk to additional MSN facilities (yellow points). SLOSH 2007 grid cells are color-coded above.

Further work is needed on both datasets to refine their use, particularly to tally with GIS clip features or Model Builder, rather than to have to count manually/visually. While the second method of analysis (with LIDAR-extrapolated SLOSH data) was demonstrated, final study results are not significantly altered, in that the threshold event for all MSN facility evacuations remains a tropical storm in the Gulf. Initial tallies still demonstrate conservative counts of facilities at risk for storm surge at Cat 1-3 hurricane levels along the coast. It is unclear to what degree additional analysis with the final version of the datasets (Binselam 2007) will affect future counts; although the concept can be applied in further detailed study.

Storm surge re-analysis alone is not likely to change future outcomes. Combined surge and wind effects; the uncertainties of hurricane track and intensification; and the timeline for decision-making, taken together, place all coastal Louisiana MSN facilities at risk.

Determination of the extent of risk zones, and differentiating or prioritizing individual facility risk falls outside of the scope of the current project, but remains an important future objective. It is hoped the current methods and findings will help to support future studies.

5.2.4 New Orleans Levee Breach and Flood Inundation Scenarios

As discussed, although SLOSH 2007 MOMs and other storm surge models currently indicate levee overtopping from a Category 3 hurricane, Tables 10 and 11 first tabulate results assuming that the Orleans and Jefferson Parish HPS levees have been fortified to Category 3 levels and will hold. These results allow for the comparison of the estimated MSN evacuation numbers without evacuating the area within the HPS.

As discussed in section 3.3.1.1, for Cat 1 and 2 hurricanes, SLOSH assumes all barriers hold, and all levees are completed and built at specified heights. Although repairs and reinforcements are ongoing, unfortunately, as presented in section 4.2.4, levee problems have been identified at over seventeen locations along the current HPS as of hurricane season 2007.

Prior to Hurricanes Katrina and Rita in 2005, ADCIRC storm surge simulations had also demonstrated that a Category 3 hurricane striking west of New Orleans could fully inundate the New Orleans East and West Bank (Figure 29, Hurricane Pam catastrophic hurricane scenario). Post-Katrina ADCIRC hindcasts demonstrate levee overtopping in New Orleans for a similar storm even if the levees had held, although depths are limited to about 4 ft (van Heerden 2007). ADCIRC experimental storm surge runs based on NHC Advisories 18, 22 and 25 for Hurricane Katrina all predicted overtopping of the New Orleans HPS from the west and east; (http://hurricane.lsu.edu/floodprediction/) particularly from the Mississippi River Gulf Outlet (MRGO) "funnel;" and scientists still consider the MRGO the number one threat to New Orleans from hurricane storm surge (ibid, Mashriqui 2006).

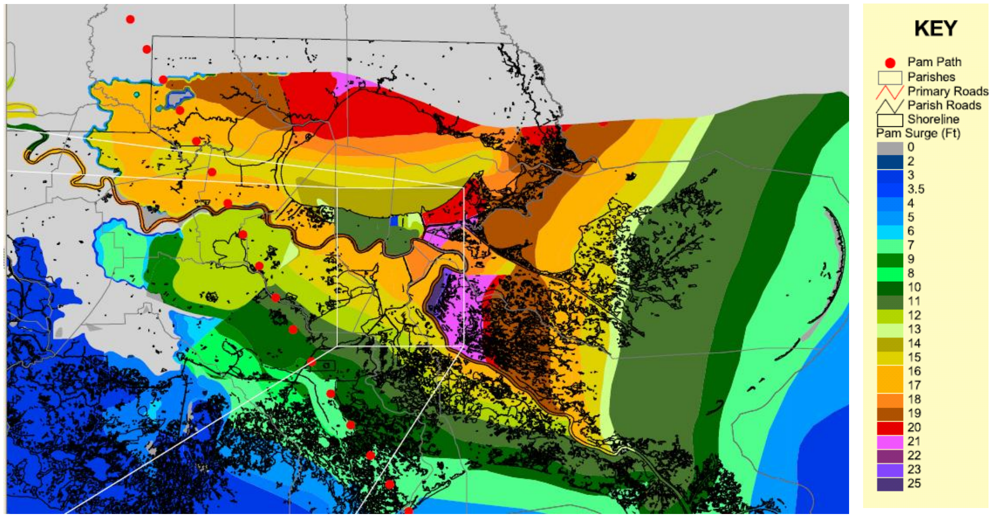


Figure 29. ADCIRC Surge Maximum Elevations mapped for the Hurricane Pam catastrophic hurricane scenario (FEMA/GOHSEP/Binselam July 2004). Models demonstrate that a Category 3 Hurricane can inundate New Orleans. http://hurricane.lsu.edu/floodprediction/PAM_Exercise04/

In contrast to the SLOSH model MOMs, some LSU scientists and modelers anticipate levee overtopping in New Orleans at Category 2 hurricane levels for certain storms, based on ADCIRC modeling. Specifically, "a slow-moving Category 2 hurricane or above striking west of the airport" could cause overtopping along the MRGO and flooding in New Orleans from the east (van Heerden pers comm 2007). According to lead investigator Ivor van Heerden for the state forensic levee investigation, the MRGO levees are "highly erodable," "still made of sand," "remain unarmored," and "will blow out again (ibid)." The New Orleans West Bank could flood from slow Category 2 hurricanes and above striking anywhere between the Mississippi River and Morgan City (ibid). Likewise, storms striking to the east of New Orleans on a path similar to Katrina could cause overtopping by Category 2 storm levels (ibid).

Although gates have been installed along Lake Pontchartrain at the canals, the pumping capacity remains in question and I-walls still in place and stressed by Hurricane Katrina surge will not likely withstand more than 6 feet of surge in their current state before collapse (ibid).

In summary, as demonstrated by SLOSH MOMs, the Hurricane Pam scenario (2004), and based on other research data, strong Category 3 hurricanes and potentially lesser storms could still inundate most of New Orleans, east and west banks, at present levee heights.

Specific counts for MSN facilities which could be additionally impacted by a New Orleans levee breach or flood inundation scenarios, based on the GIS mapping tool, include an estimated twenty-three more hospitals in New Orleans, although nine may be closed. The remaining twelve house as many as 1,431 additional patients according to the 2007 census data. Two hospitals have over 100 patients each, one with over 200 and two others have over 300 patients each. An estimated eighteen more nursing homes with 1,282 patients could also be affected in New Orleans, although four are closed.

Expected flood depths at the hospitals and nursing homes can be modeled for various scenarios with more detail from the Katrina flood mask data (Cunningham and Braud 2006). Levee problems have also been viewed in a GIS for proximity to their location. Over one hundred other MSN facilities are located within New Orleans (east bank) which could be additionally impacted by levee breach or flood inundation, as well as six critical MSN locations: two MMP-As (airfields), three CPPPs and the MMP-T (Amtrak Union Passenger Terminal).

MSN individuals in residences are not included in this count, but elderly counts may be estimated with the census data; e.g., as of 2006 there were an estimated 21,032 elderly (over 65) in Orleans Parish (US Census 2006b). SLOSH 2007 and other storm surge models support that potentially all of these additional MSN patients would be exposed to serious flooding from levee overtopping from a Category 3 Hurricane.

Flooding of the New Orleans west bank could impact four additional hospitals (although one may be closed) with an estimated 319 patients; including one hospital that has over 200

patients. An estimated fourteen additional nursing homes (although 2 are closed) could be impacted by levee breach, surge or flood inundation, with approximately 1,156 patients. Of these, nine nursing homes have approximately one hundred patients each. Over forty other MSN locations could be impacted, and three critical MSN locations: two CPPPs and an MMP-A. Jefferson Parish also has three times the estimated elderly population as New Orleans, at 66,265 individuals (US Census Bureau 2006b). Table 12 summarizes all of these scenarios and counts.

5.2.5 Clear Communication and Visualization of the Data

It has been discussed that MSN decision-makers are not always emergency managers or state officials, but can range from the nursing home administrator, to the elderly or disabled MSN patient sheltering in their residence. What has become apparent is that while these MSN facility decision-makers often look to emergency management for guidance, they essentially make their own determinations of risk, and whether they will evacuate or shelter in place.

Given that MSN facility mangers and residents remain very independent in their desire to assess and determine their own risks, it is important to: (1) acknowledge that they are indeed local decision-makers, whether or not this works within the framework of local emergency plans that are in place, (2) ensure that they have access to crucial information and decision tools capable of conveying hurricane risk, and (3) ensure that the information provided to them is clear - particularly emergency instructions or contact numbers – as well as expectations or requirements. It is also crucial that indications of the seriousness of the threat and instructions be clearly conveyed (Eisenman et al 2007).

Publisher map files were determined to be the best initial method of sharing critical hurricane risk data with MSN communities (Figure 30). Most relevant would be that LIDAR-extrapolated SLOSH data, as it becomes more refined, could be shared via Arc Reader, a freely

available and easily accessible GIS reader. However, further study is still needed, as well as more interaction with MSN communities, to determine additional methods of risk communication and visualization.

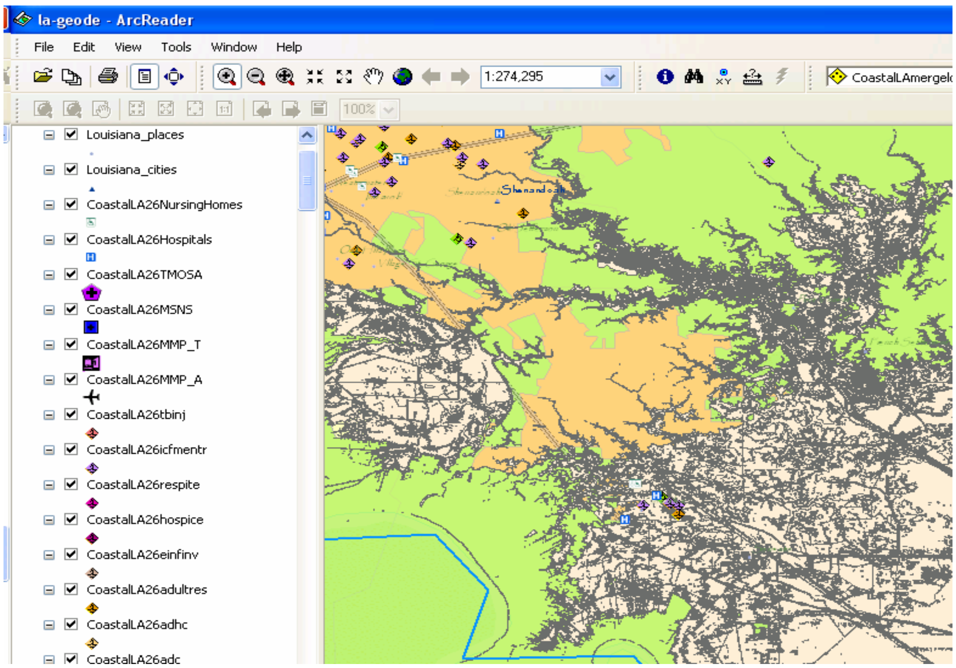


Figure 30. Critical MSN sites can be viewed with Category 2 storm surge risk layers (Binselam 2007) in ArcReader as an ArcPublisher (.pmf) map file. Hurricane risk layers may be shared in this type of free GIS format.

While not currently suited to the task, online methods such as GIS data and imagery servers (see also section 3.3.1.5) are also being quickly developed to provide detailed data and risk analysis tools to local, state and Federal emergency planners and officials.

5.3 GIS Data and Analysis: Limitations

The current study was limited to manual and visual interpretation of flood and wind risks in a GIS environment, with counts of affected facilities and patients calculated in result tables. Counts were thus subject to human error, where facilities may have been missed in original counts, counted twice, etc. Although a model was successfully built for this project to clip SLOSH for MSN facilities and verify counts, the counts were far overestimated, since SLOSH

resolution 1 mi by 1 mi grid cells often ‘spill over’ from rivers or other water features (see also section 3.3.1.1) and include many more MSN sites than are actually at risk. Thus, urban areas, levees and canals had to be scrutinized for flood interpretation. As discussed in section 6.2.4, models and scripts will be further explored as a future direction to eliminate tedious tallying and provide immediate counts for MSN GIS applications, including applying the LIDAR-extrapolated datasets when completed (Binselam 2007).

Additionally, as mentioned, multi-level structures such as hospitals were still included in surge risk determinations as recommended to evacuate. Some hospitals and other multi-level structures may be adequately equipped to shelter in place on upper floors, based on hurricane assessments. The location of the generator would also be an important consideration for future work, but could not be included in the scope of the current study.

Finally, mitigation measures are important. Mitigation projects have been explored and implemented at many facilities, but these could not be considered in the current study. This does however add support to the value of supplying facility-specific hurricane risk data to MSN decision-makers on the local and individual level. This would allow them to evaluate their facilities for potential mitigation measures, as well as to revisit their physical hurricane risks against implemented measures, and update hurricane emergency plans.

CHAPTER 6 CONCLUSIONS

6.1 Hurricane Modeling in GIS: Threshold Events for MSN Facilities - Can Anyone Shelter Safely in Coastal Louisiana for Hurricanes?

Coastal Louisiana MSN facilities and residences vary on some level regarding individual risk from storm surge, wind and other hurricane threats. They also vary widely by decision-strategies; both by decision criteria, and dominating factors that will ultimately prompt evacuation or support sheltering in place.

However, what coastal Louisiana MSN facilities, residences and their patients share in common, based on the research evidence and outcomes of this study, is that ALL are exposed to serious flood and/or wind risks from hurricanes, and ALL will be exposed to less risk if they successfully evacuate a risk area well ahead of an approaching storm.

The literature has supported that MSN patients everywhere are likely to share common risks to their health, regardless of setting, when hurricanes threaten, as both evacuation and sheltering in place carry risks. However, **coastal Louisiana MSN sites are set apart in that they face severe threats from hurricanes when they shelter in place**; they are perhaps among the most at-risk sites nationwide, given all compounding factors reviewed in this manuscript. The devastating impacts of Hurricane Katrina in Louisiana support the urgency of conveying such findings to MSN decision-makers well before each hurricane season.

While Category 3 hurricanes appear at first glance to be a threshold event for MSN facilities along the Louisiana coast as a whole (based solely on storm surge risk), this study has determined that a tropical storm in the Gulf of Mexico at 48-hours to landfall is the actual threshold storm event which should trigger MSN patient evacuation.

Most concerning is that at 48 hours to hurricane landfall, the location where storms will make landfall across the Louisiana coast, and whether storms will undergo rapid intensification is unclear. Yet MSN decision-makers will need to decide whether they will evacuate or shelter in place by this time, or prior to this 48-hour window. The severity of storm surge risks; wind risks; the time needed to successfully evacuate; and additional added risks specific to coastal Louisiana as reviewed in this study together warrant the evacuation of MSN patients, regardless of cost, accepting (albeit, with the goal of greatly reducing) evacuation risks, for most storms.

6.2 Future Directions

The following examples briefly highlight some additional future directions which could help to further and improve upon this research.

6.2.1 Storm Surge Modeling in GIS

Modeling specific hurricane tracks and intensities for planning will be increasingly valuable as prediction technology, satellite technology and ocean monitoring evolve and improve. For example, the ADCIRC model[38] previously discussed is a very high resolution storm surge prediction tool (Figure 31) with versions that were developed specifically for southeast Louisiana flooding, http://www.hurricane.lsu.edu/floodprediction/.

As discussed, state and local emergency officials usually count down to hurricane landfall or "L-hour" (e.g., LA DHH), or to "H-hour" - the onset of tropical storm force winds (TSFW) on the coast (SEHTF 2007). The LSU experimental ADCIRC model has been run on subsequent updated advisories released by the NHC to support operational response, just as with SLOSH actual track model runs by NOAA, as hurricanes approach. It can also be run on

[38] developed by Luettich, Westerink, Kolar and Dawson in partnership with numerous federal and academic partners (ADCIRC Development Group webpage, http://www.nd.edu/~adcirc/index.htm).

hypothetical tracks and intensities for planning, to support training exercises, and to explore and identify threshold events that would overtop levees or flood certain areas.

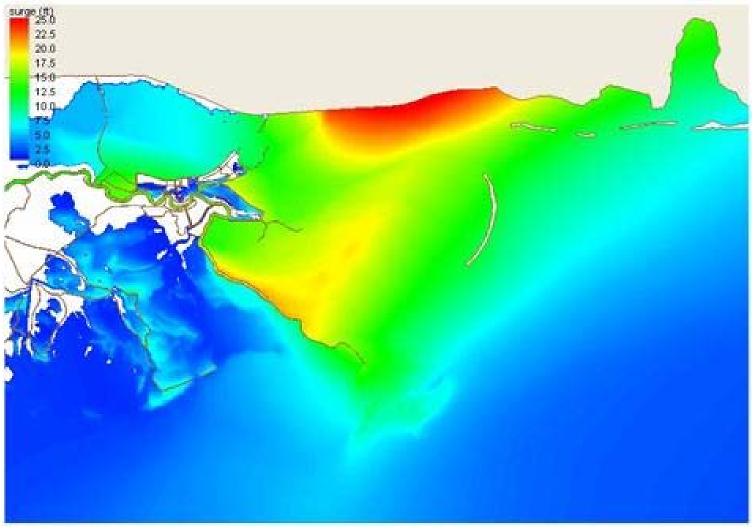


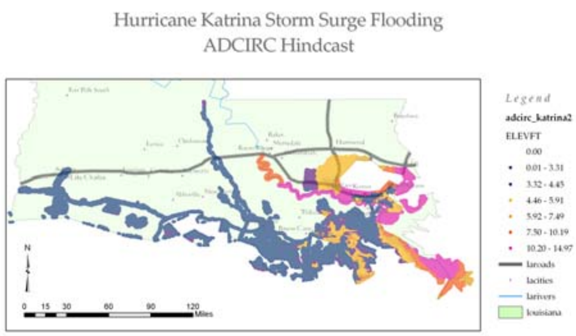
Figure 31. High resolution ADCIRC hindcast of Hurricane Katrina (surge elevations in ft). *LSU HPHC 2005.*

Briefly, ADCIRC has proven to be a reliable surge estimation model in recent storm events, such as Isidore, Lili, and Ivan, but most notably prior to Hurricane Katrina, as well as in current studies (van Heerden et al 2006). However, the process to submit the model is complex and time intensive, even with direct access to supercomputing resources.[39] Improvements are continuously being made to the model, which has recently quadrupled in nodes (increasing resolution even more and enhancing other aspects of the model physics). However, refinements introduce new complexities and time constraints to running the model operationally.

ADCIRC outputs, which provide latitude, longitude and predicted elevation values, can now be imported into a GIS for analysis. Model outputs (at 340,000 nodes) were provided by

[39] ADCIRC has been run at LSU on the "Supermike" supercomputer for past storms in collaboration with the LSU CCT.

Dr. S. Hassan Mashriqui, PE, through the HPHC in a text file (x,y point data) for this study, to demonstrate future directions in hurricane GIS modeling (Figures 31a-b).



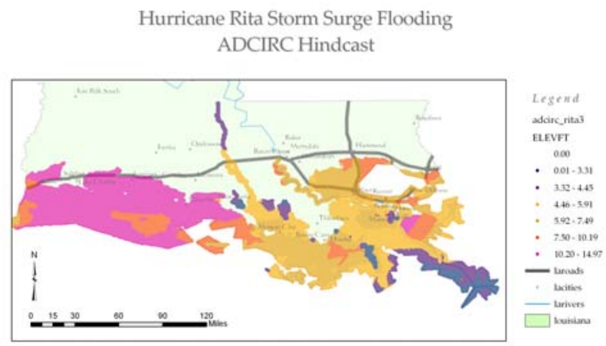


Figure 31a. ADCIRC surge hindcast for Katrina *(provided by HPHC/Mashriqui 2007). ESRI ArcGIS 9.2.*

Figure 31b. ADCIRC surge hindcast for Rita *(provided by HPHC/Mashriqui 2007). ESRI ArcGIS 9.2.*

In future research, hypothetical storms in ADCIRC or other high resolution models for the Louisiana coast can be run for Cat 1, 2 and 3 storm intensities based on past historical tracks (Figure 32) tracking N or NW and striking Western, Central or Eastern Louisiana. For example, NOAA CSC shapefiles of past storms including Audrey and Rita (western LA); Andrew and Betsy (central LA); and Katrina and Camille (eastern LA) can be altered to increase central pressures along tracking points to produce hypothetical storms hitting Louisiana on identical tracks but at varying intensities.

This method could be used to further refine analyses for MSN patient evacuation and sheltering decisions for both surge and wind fields (which are another ADCIRC output), and be viewed with SLOSH outputs in a GIS. Potentially, this analysis could offer finer resolution and insight for planning, to identify more precisely the priority evacuation sites for some storms based on storm surge risk. However, the analysis would necessarily incorporate added risk to MSN evacuation (since track and intensity at landfall are unknown at L-48), would be much more dependant on prediction and other technologies, and is still a single track model. Likely

there would be few storm events before the analysis would begin to incorporate increasing levels of risk.

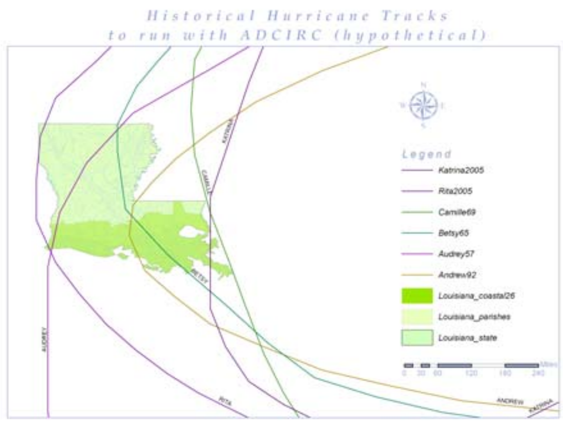


Figure 32. Historical hurricane tracks which can be edited for central pressure, to modify storm strength and run as hypothetical storms in ADCIRC *(NOAA CSC historical hurricane tracks in ERSI ArcGIS).*

6.2.2 Hurricane Wind Modeling

Similar to future directions in ADCIRC, specifically defined tracks (as in Figure 32) with input wind fields for Category 1, 2 and 3 hurricanes could be generated and run within the HAZUS model (Figures 12, 25-26), to estimate wind and damage levels to structures in Louisiana for reference or future study. Coastal Louisiana MSN facilities that may opt to shelter in place perhaps outside of risk zones for storm surge could be more specifically evaluated with this data for planning purposes. Such analysis could also be valuable for future planning of storms where there is (1) high confidence of a landfall probability and (2) low potential for rapid intensification or other risks (such as rainfall and tornadic activity). Likewise, such an analysis could demonstrate a methodology for determining priority and risk zones if medical evacuation resources become limited, or if unforeseen problems arise in evacuating patients.

As prediction technologies improve, and as difficult decisions are made regarding the balance of risk and cost between MSN evacuation and sheltering, such analyses will become more important. They could also hold value operationally.

In addition to applying FEMA HAZUS as a potential future direction in wind field estimation, the NOAA NHC Hurricane Research Division (HRD) has started to release experimental surface wind field products in shapefiles, beginning with Hurricane Ivan in 2004 (Figures 33a-c). The products are currently for research use only.

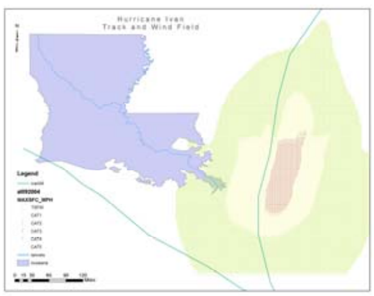


Figure 33a. Ivan (2004)
Surface Wind field and track
(NHC HRD) ESRI ArcGIS 9.2

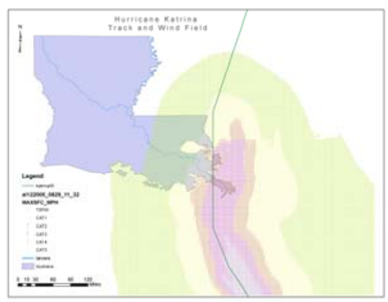


Figure 33b. Katina (2005)
Surface Wind field and track
(NHC HRD)ESRI ArcGIS 9.2

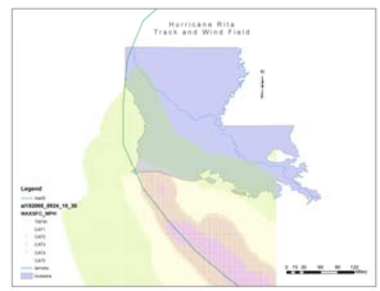


Figure 33c. Rita (2005)
Surface Wind field and track
(NHC HRD) ESRI ArcGIS 9.2

These can be edited for hurricane symbology and imported into a GIS to be viewed with hurricane tracks, SLOSH models, MSN facilities, and other data layers. Similar to HAZUS, the surface wind fields are generated as part of the H*Wind experimental product in near-real time, combining surface weather observations from “ships, buoys, coastal platforms, surface aviation reports, [and] reconnaissance aircraft data adjusted to the surface” (NOAA AOML 2007d).

Future directions may include a way to more accurately model hypothetical Cat 1 – 3 hurricane tracks and wind intensities with HRD surface wind analysis layers to potentially demonstrate ‘windows of opportunity’ that would exist for MSN residents to shelter in place; although as discussed, this would be hard to apply at L-48, unless under special considerations or circumstances (e.g., a determined very low risk event). The same limitations would apply to

using such a wind representation in a GIS for local planning; both in maintaining focus on surge and hurricane risk factors even before wind; and accurately explaining and representing data.

6.2.3 Incorporating MSN Data into 3D Image Viewers

3-dimensional imagery interfaces are hoped to be explored in future directions as well.

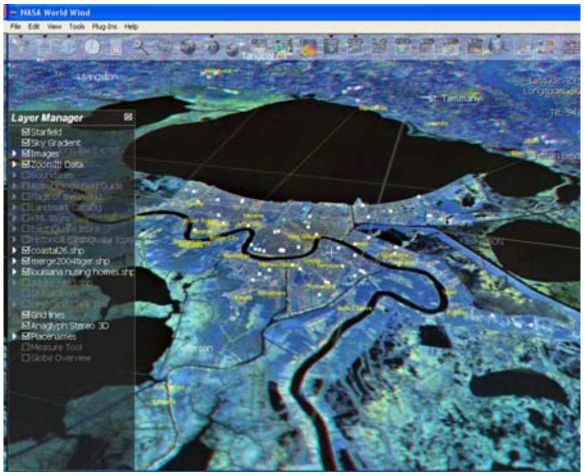


Figure 34a. NASA World Wind ver. 1.4 imported shapefiles for Louisiana parishes, Tiger Roads (2004) and nursing homes over impressive New Orleans imagery.

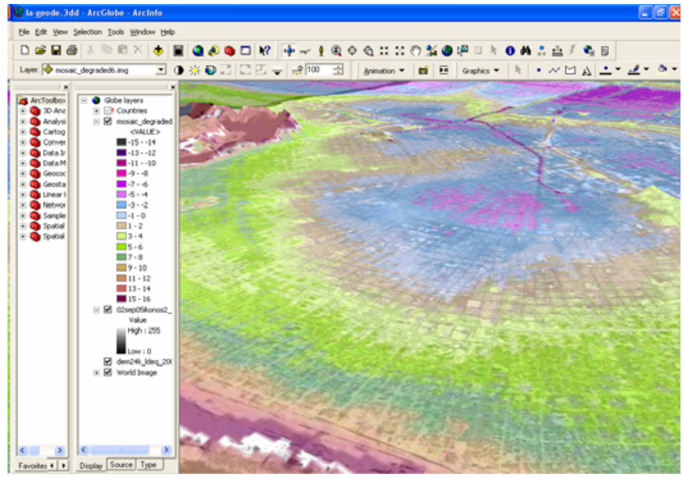


Figure 34b. 3D LIDAR data overlay with imagery in ESRI ArcGlobe *(Louisiana GIS Digital Map 2007, geo-referenced Ikonos Imagery/Braud 2005)*

It is hoped that detailed MSN project data can soon be incorporated with imagery mappers such as NASA World Wind version 1.4 (Figure 34a) or Virtual Louisiana, or 3D Image viewers such as ESRI ArcGlobe (Figure 34b).

6.2.4 Models and Scripts for Data Tabulation and Reporting

Future directions of this research additionally include building more elaborate models or writing scripts that will quickly tabulate MSN facility or census counts. As discussed in results section 5.3, both SLOSH shapefiles and LIDAR-extrapolated datasets (Binselam 2007) are currently too imprecise to make accurate and quick counts clipped by MSN site. Another feature of model builder and scripting includes the output of results into not only tables, but reports, as well as creating new feature datasets for facilities impacted at each storm level.

6.2.5 Enterprise GIS for Medical Planning and Response

The future of GIS mapping of medical data for response is likely to develop out of a greater framework of databases in Enterprise GIS. In one of the paramount examples, GIS experts at the Louisiana State Department of Social Services (DSS) have been implementing "TINA-GIS" since Hurricane Katrina struck in 2005 (McKeefry 2006, Lemoine pers comm 2006). TINA-GIS was developed as an anti-fraud system, using WebFOCUS - business intelligence (BI) software from Information Builders - along with GIS technology. However, it has since been developed to provide 'Disaster Business Intelligence and GIS' to numerous Federal and state agencies, including interdepartmentally (ibid).

Through this award-winning system, Louisiana DSS can extract, transform and load or 'ETL' mainframe data, query and create graphs and reports, run spatial analysis, and "interpret complex relationships that might otherwise be difficult to detect (ibid)." Similar systems could provide invaluable information to state and local health officials and decision-makers and be applied towards MSN planning. Data can be queried and mapped, gathering information from databases across the state in seconds. Data can also be further analyzed, added to reports, or mapped. A similar application would be pivotal in medical response and mapping.

There is an increasing level of GIS coordination and collaboration among Louisiana State agencies. Examples include the Louisiana GIS Council and expanding GIS capabilities centralized at the Louisiana GOHSEP. Critical response capabilities of GIS were tested during Hurricane Katrina in everything from search and rescue emergency GIS mapping to GIS maps for future recovery. However, medical GIS data can be used for many of the same emergencies, including hurricanes/flood; technological disasters; pandemic flu planning; and bioterror events/terrorism.

Each has critical datasets, and some that could apply to all. For example, hospital surge capacity is a critical dataset which can be used in many levels of planning and response.

Data integration in an enterprise GIS system will allow for increased interaction and access to critical data among agencies. Data management, querying, reporting and mapping database information, creating and sharing data layers, epidemiologic study support, and patient or evacuee tracking are just a few examples of the "multimedia functionality" (ESRI 1999).

6.3 Refining the Science to Reduce MSN Evacuation in Coastal Louisiana

As hurricane prediction technologies improve, including methods for tracking not only the predicted landfall of a storm, but intensity, rainfall and other risks, there may be increased opportunity for hurricane research and models to be implemented towards more precise MSN planning for evacuation and sheltering. While the current study has concluded a tropical storm in the Gulf of Mexico to be the trigger for coastal Louisiana MSN facility evacuation, many may find this outcome excessively conservative or unrealistic. However, until the science further improves, refinements to planning that would allow facilities to shelter safely in place for hurricanes are difficult to support without accepting serious risk.

van Heerden and Bryan (2006a), in discussing the National Hurricane Center hurricane "projection cone" indicate "…the best our science can ever achieve will be an error of 30 miles at one day (p. 48)." This will likely always result then in at least a sixty mile error possibility at 48 hours to landfall, the difference between a hurricane strike in Lafayette versus Baton Rouge versus New Orleans, Louisiana.

Meanwhile, Hurricane Audrey in 1957, which intensified from a Category 1 to a Category 4 Hurricane before making landfall on the Louisiana coast, may be an exception historically, representing only a small percent of storms that intensified this dramatically

before landfall. Yet, hurricane intensification is not only based on warm Gulf waters or the presence of the Loop current, but also on climate conditions such as upper level winds. Climate will vary every season. Therefore, any hurricane, given the right conditions, could intensify as Audrey, and cause devastating impacts on MSN facilities.

Nonetheless, in the future, with combined improvements in coastal restoration, the implementation of mitigation measures, and advancements in technology, hurricane research, modeling and methods, more MSN individuals in coastal Louisiana may be able to shelter safely in place. It is hoped the current project conclusions will prompt further investigation and action, exploring future possibilities of MSN sheltering in place.

As an example, with increasingly better science, risk and evacuation priorities might be assigned to longitudinal zones based on increasing proximity to, and surge and wind impacts from, actual storm landfall; while assigning less risk and decreasing the evacuation priority of longitudinal zones further from actual landfall. In the interim, assessment of risk by applying hurricane modeling and GIS methods may help to prioritize MSN and medical evacuation for individuals and local decision-makers. Planning is also supported by overall risk zones or regions (either state health regions, or western, central and eastern coastal regions, etc) which can help to effectively manage increasingly complex public health threats.

In another example, according to Lapolla (2003), evacuation and shelter strategies are not so limited, but may include different phases or levels such as "sheltering in place without moving from a facility; sheltering in place vertically (moving up); evacuating just outside of the facility; evacuating to a nearby, like facility; evacuating to a distant facility; or evacuating to a shelter facility." These may become another area for study in reducing MSN evacuation.

Other options open to MSN individuals and facilities include hurricane mitigation strategies, further assessment of their facilities, designing and building for hurricanes, and holding training for MSN decision-makers.

Due to transportation agency and university research collaborations, hurricane evacuations are becoming increasingly efficient and successful. Estimates are that the Hurricane Katrina evacuation time of New Orleans was “cut nearly in half, exceeding even the most optimistic prior projections by at least 40%; that is, an anticipated 72 hour evacuation was able to be executed in 28-36 hours (Wolshon/HPHC Report, January 2006).”

Meanwhile, across the board, MSN decision-makers note that early evacuation works. For example, home health patients and agencies that left 72 hours before projected hurricane landfall for Katrina “avoided long waits,” “experienced less stress,” and “easily found… shelter space for their patients (Kirkpatrick and Bryan, 2007, p. 309).” Nursing homes that left early reported having plenty of water and supplies, and even being able to open the windows on the school buses they were using on account of the pleasant weather (Nursing Home Administrators pers comm 2007). Patients experienced minimal stress, even approaching the trip as a welcome break or ‘field trip (ibid).’ Evacuating every time, and evacuating early, one coastal Louisiana nursing home demonstrates a culture of preparedness and practice which makes it possible to envision MSN evacuation without traffic, without serious accidents or injuries, and the safeguarding of patients against daunting hurricane risks.

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US Department of Health and Human Services (US DHHS) Hospital and Nursing Home Database, provided by FEMA's Geospatial Intelligence Unit (GIU)

GIS Software

ESRI ArcView 3.3

ESRI ArcGIS 9.2

ESRI ArcExplorer 9.2

ESRI ArcPublisher (extension)

ESRI ArcReader

Hurricane Models

Jelesnianski, C., Chen, J. Shaffer, W. and Taylor. A. D. NOAA Sea Lake and Overland Surge from Hurricane (SLOSH) Storm Surge CD. May 9, 2007.

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APPENDIX A: THE SAFFIR-SIMPSON SCALE FOR HURRICANES

Saffir-Simpson Scale
for Hurricanes

Category	Wind speeds (mph)	Approximate wind speeds in knots	Storm Surge	Damage level	Anticipated effects
1	**74-95**	**64-82**	**4-5 ft**	**minimal**	**Damage to unanchored mobile homes, shrubbery, & trees; some coastal road flooding; minor pier damage**
2	**96-110**	**83-95**	**6-8 ft**	**moderate**	**Some roofing material, door, and window damage to buildings; considerable damage to vegetation, mobile homes, and piers; Coastal and low-lying escape routes flood 2-4 hours before arrival of center; Small craft in unprotected anchorages break moorings.**
3	**111-130**	**96-113**	**9-12 ft**	**extensive**	**Some structural damage to small residences and utility buildings; minor amount of curtainwall failures; Mobile homes destroyed; Coastal flooding destroys smaller structures; larger structures damaged by floating debris; Terrain <5 feet ASL may be flooded inland 8 miles or more.**
4	**131-155**	**114-135**	**13-18 ft**	**extreme**	**More extensive curtainwall failures with some complete roof structure failure on small residences; Major beach erosion; Major damage to lower floors of structures near the shore; Terrain <10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.**
5	**>155**	**>135**	**> 18 ft**	**catastrophic**	**Complete roof failure on many residences and industrial buildings; Some complete building failures with small utility buildings blown over or away; Major damage to lower floors of all structures located <15 feet ASL and within 500 yards of the shoreline; Massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline may be required.**

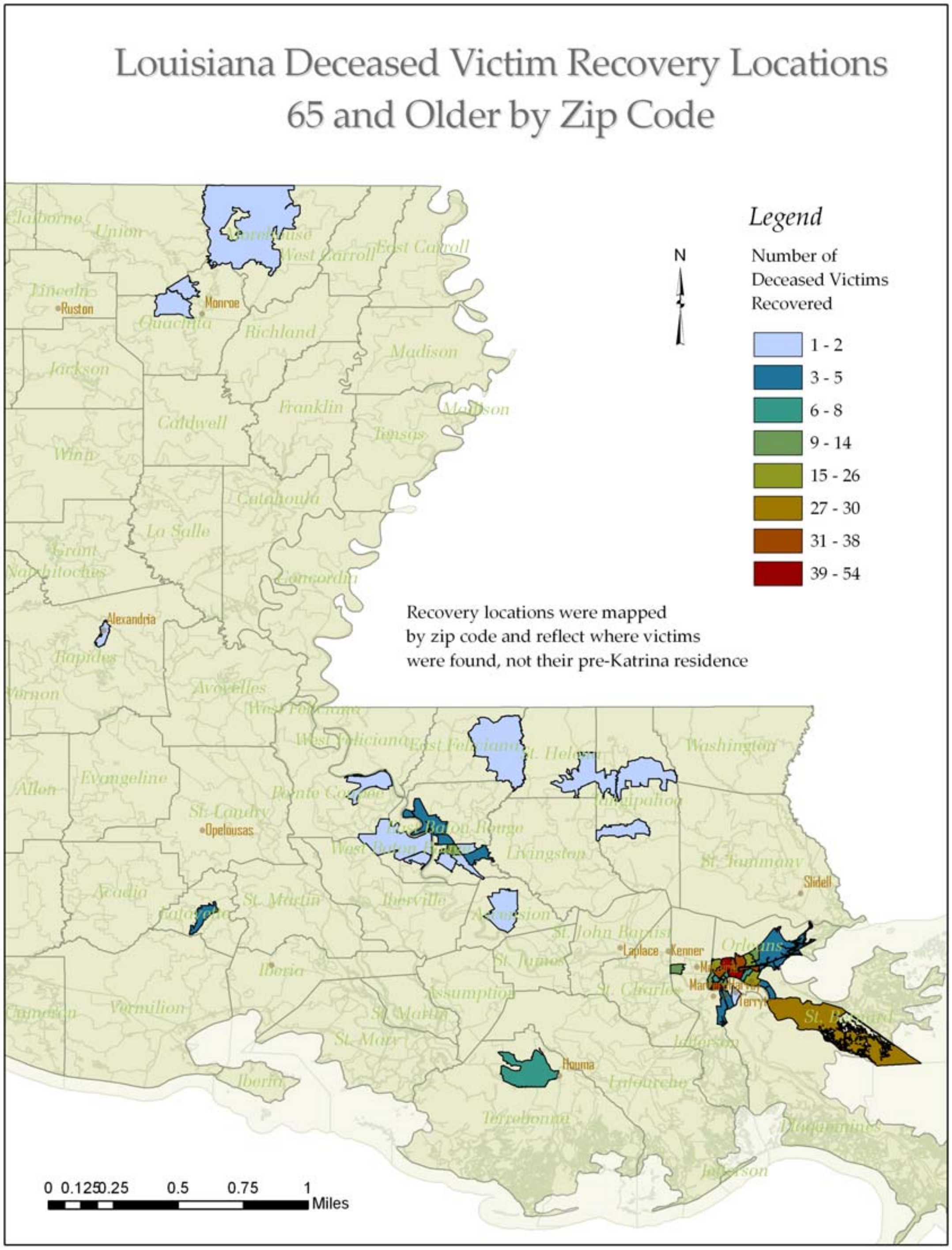
From the LSU Hurricane Center website: www.hurricane.lsu.edu

APPENDIX B: STUDY SET: 26 COASTAL LOUISIANA PARISHES

Louisiana Parishes included in the results of this study, with some or all portions of the parish south of interstates I-10 and I-12.

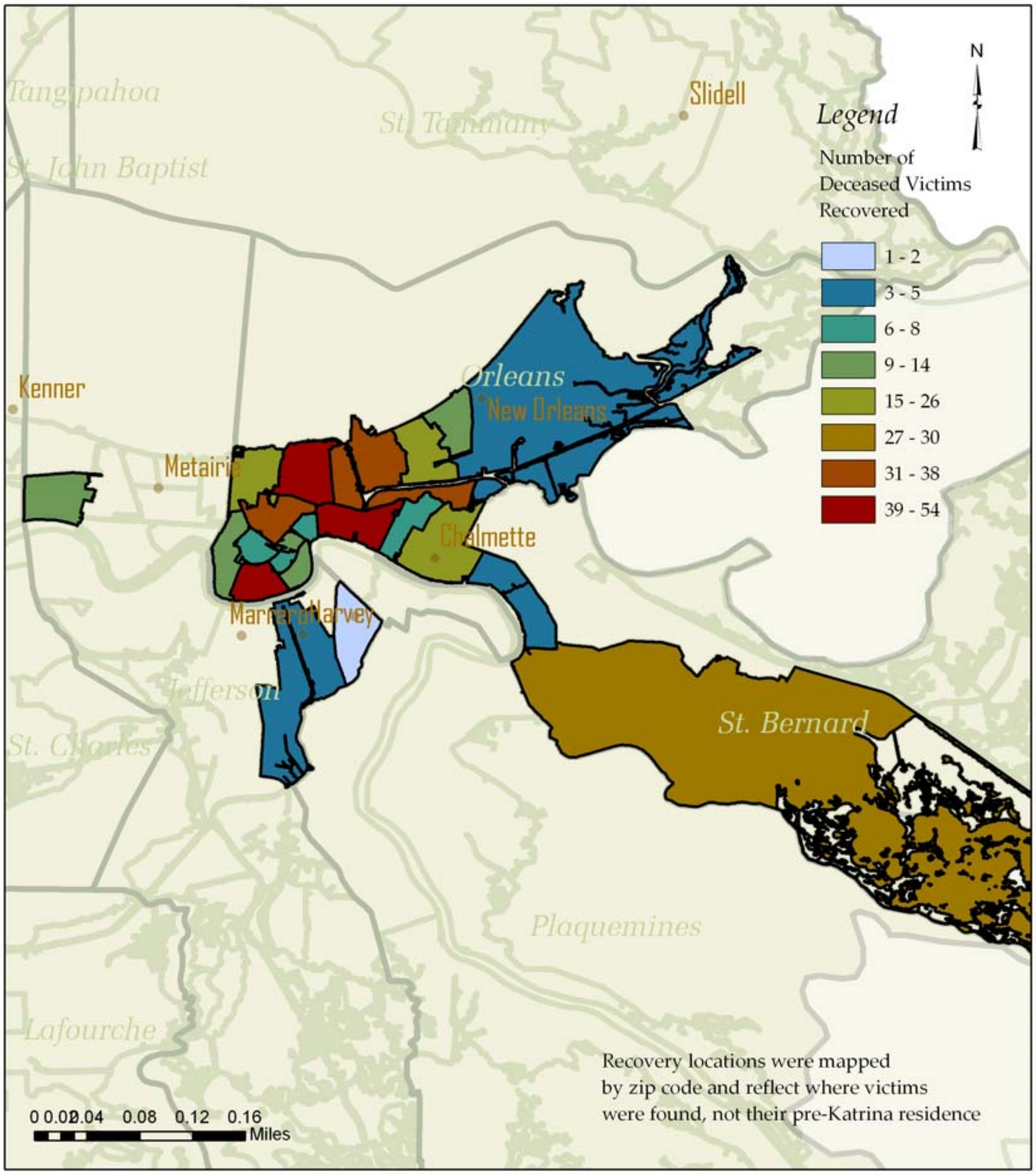
Louisiana Parish
Acadia
Ascension
Assumption
Calcasieu
Cameron
East Baton Rouge
Iberia
Iberville
Jefferson
Jefferson Davis
Lafayette
LaFourche
Livingston
Orleans
Plaquemines
St. Bernard
St. Charles
St. James
St. John the Baptist
St. Martin
St. Mary
St. Tammany
Tangipahoa
Terrebonne
Vermilion
West Baton Rouge

APPENDIX C: MAPS OF ELDERLY EXPOSURES DURING HURRICANE KATRINA

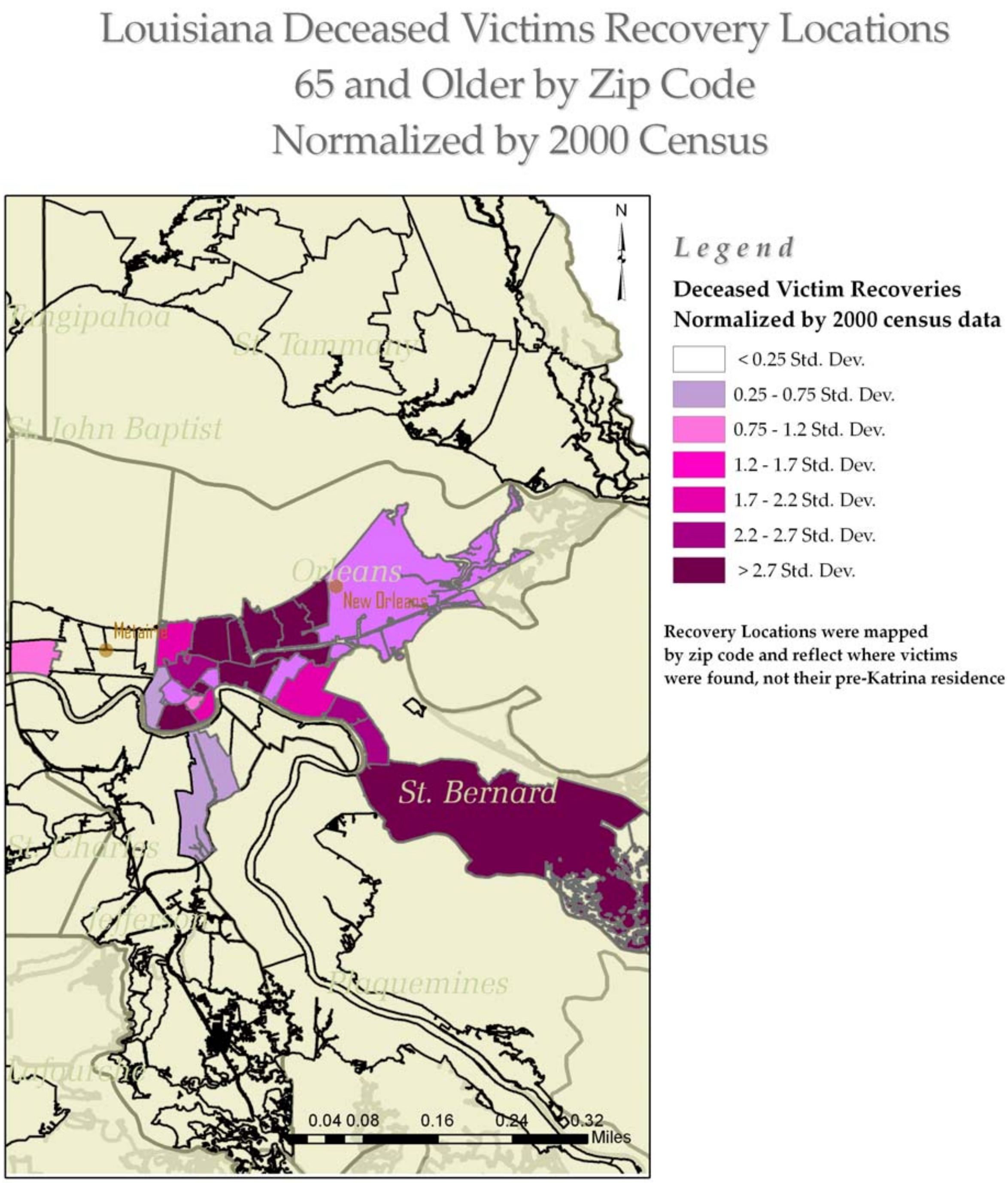


Elderly deceased recovery locations mapped by zip code across Louisiana, from available data (State Medical Examiner, LA DHH 2006c). ESRI ArcGIS 9.2, Tiger Zip Codes 2004.

Louisiana Deceased Victim Recovery Locations 65 and Older by Zip Code (New Orleans inset)

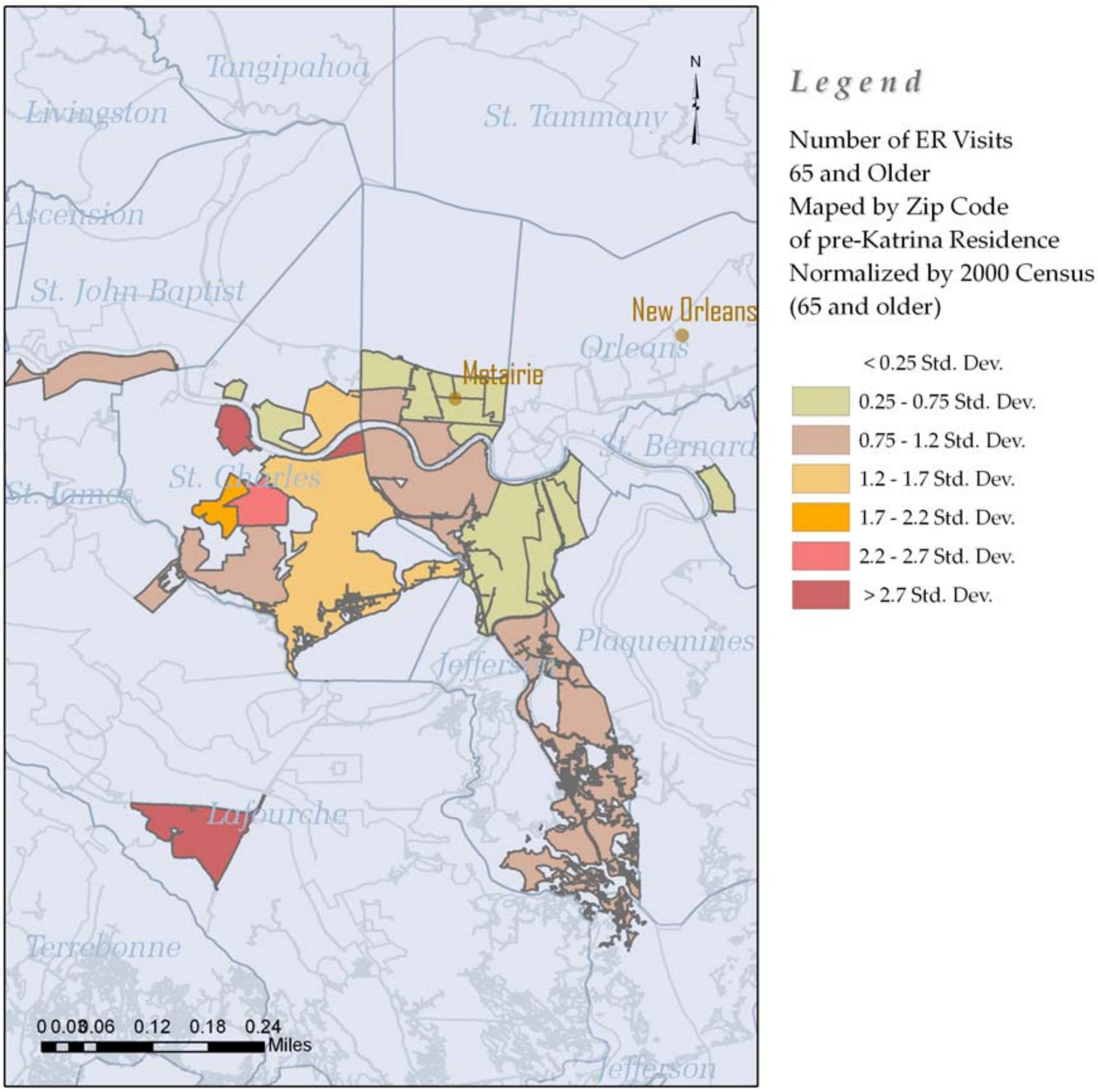


Elderly deceased recovery locations, New Orleans Area (Inset) mapped by zip code from available data (State Medical Examiner, LA DHH 2006c). ESRI ArcGIS 9.2, Tiger Zip Codes 2004.



Elderly deceased recovery locations, New Orleans Area (Inset) mapped by zip code from available data (State Medical Examiner, LA DHH 2006c) and normalized by 2000 census data for the 65 and older population. ESRI ArcGIS 9.2, Tiger Zip Codes 2004.

Emergency Room Visits 65 and Older in Louisiana from Hurricane Katrina



ER Surveillance mapping of visits by elderly surrounding Hurricane Katrina landfall demonstrate areas where hospitals remained open in Jefferson and St. Charles Parishes, as well as how hospitals were likely at or over capacity receiving patients from the surrounding areas. Very few elderly patients were seen from the severely impacted parishes of Orleans and St. Bernard for example, indicating they were likely transported further distance for emergency medical care (State Epidemiologist, LA DHH 2006c). ESRI ArcGIS 9.2, Tiger Zip Codes 2004.

APPENDIX D: LOUISIANA HURRICANE INTENSITIES AT LANDFALL, 1905-2005

Louisiana Hurricane Strikes over the Last Century (1905-1955) by Maximum Windspeed at Landfall[40]

		STORM 1				STORM 2				STORM 3				
YEAR	AMO	ST1Wmx	STW1mn	S1dir	S1loc	ST2Wmx	STW2mn	S2dir	S2loc	ST3Wmx	STW3mn	S3dir	S3loc	stormT
1905	C1	45	35	N	W	45	35	NE	C					2
1906	C1													0
1907	C1	40	40	NW	E									1
1908	C1	50	35	NW	C									1
1909	C1	105	75	N	C									1
1910	C1													0
1911	C1	40	35	W	E									1
1912	C1	60	50	NE	C									1
1913	C1													0
1914	C1	35	35	W	E									1
1915	C1	85	60	N	E									1
1916	C1	105	105	NW	E									1
1917	C1													0
1918	C1	85	40	NW	W									1
1919	C1													0
1920	C1	90	45	NW	C									1
1921	C1													0
1922	C1													0
1923	C1	85	40	N	C									1
1924	C1													0
1925	C1													0
1926	W1	85	35	N	C	60	35	W	E					2
1927	W1													0
1928	W1													0
1929	W1													0
1930	W1													0
1931	W1	50	35	N	C									1
1932	W1	35	35	NE	C	40	40	NE	C					2
1933	W1													0
1934	W1	65	55	N	C									1
1935	W1													0
1936	W1	40	40	NE	E									1
1937	W1	35	35	N	C									1
1938	W1	65	35	NW	W									1
1939	W1	40	35	NE	E									1
1940	W1	70	65	NW	W	40	35	E	W					2
1941	W1	40	35	NE	W	45	45	NW	W					2
1942	W1													0
1943	W1	35	35	NE	W									1
1944	W1	40	35	NE	E									1
1945	W1													0
1946	W1	35	35	NW	W									0
1947	W1	80	35	NW	E									1
1948	W1	65	50	NE	E									1
1949	W1	40	40	N	E	50	40	N	W					2
1950	W1													0
1951	W1													0
1952	W1													0
1953	W1													0
1954	W1	40	35	NW	W									1
1955	W1	60	35	NW	E	40	40	NW	E					2

	Wmknots
TS	<64
CAT1	64-82
CAT2	83-95
CAT3	96-113
CAT4	114-135
CAT5	>135

Hurricane strikes in Louisiana in the first part of the past century (1905-1955). Data was mainly from ship and buoy measurements prior to 1943 when planes began flying in to hurricanes to take measurements (Landsea 2001). Note the absence of intense hurricanes (Category 3 or above).

[40] Table Legend: YEAR=year of hurricane landfall. AMO=Atlantic Multidecadal Oscillation, first or second warm or cool phase. ST1Wmx=first storm strike, maximum windspeed in knots, STW1mn=first storm strike, minimum windspeed in knots, S1dir=direction of first storm strike, tracking north, northwest, northeast, east or west. S1loc=first storm strike, west, central or east Louisiana, ST2Wmx, STW2mn, S2dir, S2loc, ST3Wmx, STW3mn, S3dir, S3loc = similar data for second and third storm strikes in Louisiana. stormT=total number of storms to strike Louisiana that year. **All data were taken from the NOAA CSC historical track data in a GIS and are approximate. Data are provided for a general overview of storm strikes in Louisiana and their approximate intensity AT LANDFALL.**

Louisiana Hurricane Strikes over the Last Century (1956-2005) by Maximum Windspeed at Landfall[41]

		STORM 1				STORM 2				STORM 3				
YEAR	AMO	ST1Wmx	STW1mn	S1dir	S1loc	ST2Wmx	STW2mn	S2dir	S2loc	ST3Wmx	STW3mn	S3dir	S3loc	stormT
1956	W1	50	35	N	C	75	75	NE	E					2
1957	W1	125	45	N	W	60	60	NW	W	45	45	N	C	3
1958	W1													0
1959	W1	40	40	N	C									1
1960	W1	140	60	N	E									1
1961	W1													0
1962	W1													0
1963	W1													0
1964	W1	100	60	N	C									1
1965	W1	135	35	NW	E									1
1966	W1													0
1967	W1													0
1968	W1													0
1969	W1	165	100	N	E									1
1970	C2													0
1971	C2	85	60	NW	W									1
1972	C2													0
1973	C2													0
1974	C2	130	45	NW	C									1
1975	C2													0
1976	C2													0
1977	C2	65	50	N	C									1
1978	C2	50	40	N	W									1
1979	C2	65	40	NE	E	45	40	N	W					2
1980	C2													0
1981	C2													0
1982	C2	50	40	N	W									1
1983	C2													0
1984	C2													0
1985	C2	80	40	N	W	105	45	W	E	70	55	N	C	3
1986	C2													0
1987	C2													0
1988	C2	45	35	NW	E	70	60	NW	E					2
1989	C2													0
1990	C2													0
1991	C2													0
1992	C2	125	50	NW	C									1
1993	C2													0
1994	C2													0
1995	W2													0
1996	W2													0
1997	W2	70	55	NE	E									1
1998	W2	95	90	NW	E	40	35	N	C					2
1999	W2													0
2000	W2													0
2001	W2													0
2002	W2	50	50	N	E	55	55	N	E	80	40	N	C	4
2003	W2	50	45	N	C									1
2004	W2	40	40	N	C									1
2005	W2	65	50	N	E	125	80	N	E	99	35	NW	W	3

	Wmknots
TS	<64
CAT1	64-82
CAT2	83-95
CAT3	96-113
CAT4	114-135
CAT5	>135

Hurricane strikes in Louisiana in the second part of the past century (1956-2005). Satellite measurements added increased accuracy to the record in the late 1960's (Landsea 2001, Keim and Robbins, 2006). However, between approximately 1945-1970, intensities may have been overestimated (Landsea 2001).

[41] Table Legend: YEAR=year of hurricane landfall. AMO=Atlantic Multidecadal Oscillation, first or second warm or cool phase. ST1Wmx=first storm strike, maximum windspeed in knots, STW1mn=first storm strike, minimum windspeed in knots, S1dir=direction of first storm strike, tracking north, northwest, northeast, east or west. S1loc=first storm strike, west, central or east Louisiana, ST2Wmx, STW2mn, S2dir, S2loc, ST3Wmx, STW3mn, S3dir, S3loc = similar data for second and third storm strikes in Louisiana. stormT=total number of storms to strike Louisiana that year. **All data were taken from the NOAA CSC historical track data in a GIS and are approximate. Data are provided for a general overview of storm strikes in Louisiana and their approximate intensity AT LANDFALL.**

APPENDIX E: LOUISIANA NAMED STORMS, 1905-2005

(Quick Reference: Names and Dates, NOAA CSC)

YEAR	MONTH	DAY	NAME
1954	7	29	BARBARA
1955	8	2	BRENDA
1957	6	28	AUDREY
1957	9	18	ESTHER
1959	5	31	ARLENE
1964	10	4	HILDA
1965	9	11	BETSY
1971	9	16	EDITH
1971	9	6	FERN
1974	9	8	CARMEN
1977	9	6	BABE
1978	8	29	DEBRA
1979	7	11	BOB
1982	9	12	CHRIS
1985	8	16	DANNY
1985	9	3	ELENA
1985	10	30	JUAN
1988	8	10	BERYL
1988	9	11	FLORENCE
1992	8	26	ANDREW
1998	9	20	HERMINE
2001	6	11	ALLISON
2002	8	7	BERTHA
2002	9	26	ISIDORE
2002	10	4	LILI
2003	7	1	BILL
2004	10	10	MATTHEW
2005	7	6	CINDY
2005	8	29	KATRINA
2005	9	25	RITA

VITA

Kathryn Emily (Friedman) Streva is a native of upstate New York. She studied environmental science at the State University of New York (SUNY) at Binghamton, from 1990-1992, and received her Bachelor of Science degree in environmental biology from Saint Francis University, Loretto, Pennsylvania, in 1995.

Following some preliminary coursework in water resources engineering at Johns Hopkins Whiting School of Engineering (Baltimore, Maryland, 1997 and 2001), Kate changed her major and was accepted into the Master of Natural Sciences Program at LSU in 2003. She is majoring in physical geography/GIS with a minor in pathobiological sciences. Her current research interests include the application of geographic methods in support of public health and epidemiologic studies.

Kate has worked as an LSU Research Associate since 2002 with the LSU Hurricane Center and Hurricane Public Health Center, focusing on a New Orleans pilot study related to hurricane public health vulnerability.

She was married in 2001 to John Streva of Morgan City, Louisiana, and they have a son, Edan Joseph. Her hobbies and interests in Baton Rouge include horseback riding, aikido, philosophy, anthropology, and religious studies. Kate has been involved with Capital Area CASA since 2003.