




Observations on the Behavior of Storm Surge, Waves and Flooding on the Mississippi Coast, Hurricane Katrina, 2005: A Protocol Study

Developed by FEMA, Mitigation Division
Hazards & Performance Analysis Group

FEMA-DR-1604-MS - Jackson - AFO

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On the Cover

Top Left:
A neighbor comforts Sam Miller as the 10-year-old sees the devastation of his home in Pascagoula.
Photo by William Colgin, The Associated Press

Top Center:
Jonathan Harvey rescuing his dog Cuddles from his flooded Gulfport home.
Photo by John Bazemore, The Associated Press

Center:
Rescue personnel head out to rescue a family from Hurricane Katrina floodwaters in Pascagoula.
Photo by Michael Spooneybarger, The Associated Press

Top Right:
Surge entering the lower floor of a hotel in Gulfport.
Photo by Mike Theiss, The Ultimate Chase

Bottom Left:
A car is inundated by Hurricane Katrina's massive storm surge.
Photo by Mike Theiss, The Ultimate Chase

Bottom Right:
Samuel Honnald of the Rescue Society of Tulsa searches Waveland with his air-scenting dogs Phobos and Tromos.
Photo by Jonathan Newton, The Washington Post

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FEMA Mitigation Division, Hazards and Performance Analysis Group
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August 29, 2005

6:08 a.m., Twilight.
6:10 a.m., Hurricane Katrina makes landfall
at the mouth of the Mississippi River.
6:33 a.m., Sunrise.

An 81-year old woman and a friend sit in her attic in Bay St. Louis, axes in hand, ready to chop the roof if necessary. She later reports methodically that mortality from Hurricane Katrina would have been much higher if people were forced to escape their flooding houses in the dark, not being able to see obstacles and debris, not being able to find a place of safety to hang on to. In hindsight, she is thankful that the sunlight came.

Purpose and Background

The purpose of this protocol study was to gather observations from local people on the Mississippi Coast[1] regarding the way Hurricane Katrina's surge came ashore on August 29, 2005. This approach of collecting verbal accounts and real-time photography, if developed into an established protocol, could be used to inform modelers and researchers, and possibly increase accuracy of surge, wave and flood models and maps. Local information may be particularly useful where a computer model may not perform accurately because of the inherent variability of a hurricane and because of complex bathymetric and topographic areas along the path of the hurricane.

Local Knowledge

For the most part, Western science in the past decades has not recognized the local knowledge of indigenous and long-time residents as providing valid contributions to the realm of science. Most often this local source of information has been ignored or dismissed because it is acquired in ways other than quantitative cause-and-effect hypothesis-testing.

Now, however, these peoples' stories of natural phenomena on the land and water are being sought out as a source of important information. Most commonly indigenous knowledge is being gathered and reported by the scientific community regarding wildlife populations and behavior. In the arctic, knowledge held by indigenous people, particularly elders and hunters, is an important source of information in the study of climate change, especially in relation to ice and snow behavior and wind and sea conditions over time.

Western science is also recognizing the value of not only indigenous peoples, but local people who have lived in an area for a long time and have worked on the land or water, such as fishermen, seaside dwellers, boatmen, mail carriers, weather forecasters, photographers and lodge owners. Kovacs et al. (2004), as an example, used an established methodology to design and analyze the results of interviews with fishermen in four Mexican villages regarding the effects of a hurricane on coastal mangrove forests. The results of the interviews coincided with scientific field transects in which over 1,000 individual trees were examined.

Puzzle and debate remains regarding the integration of traditional or local knowledge with quantitative results from scientific field methods or modeling. Mackinson (2001) and Kovacs et al. (2004) present methods for an integration of these different types of knowledge and support the idea of local knowledge woven with the scientific process.

Moller et al. (2004) suggests that the two fields may have to work in greater collaboration in the future as conventional scientific approaches alone may not be able to answer questions in a world of increasing complexity. With some contrast, Gilchrist et al. (2005), are cautious about local or traditional knowledge as a primary source of information.

The limitations of Western scientific field research and the sources of inherent error are discussed by Brook and McLachlan (2005); they suggest that a better approach is to recognize the prob-

[1]The total coastline of Mississippi, including the connecting coasts of inlets, bayous and bays is 128 miles. A line drawn east-to-west directly across the Mississippi coast measures 74 miles.

lems and errors in both the scientific method and in local knowledge to best answer ecological questions.

The National Marine Fisheries Service (NMFS) has developed a National Cooperative Research Program among federal fishery scientists, fishermen and the fishing industry. The program was established to collect basic fisheries information, with the goal of improved fisheries management. There are many benefits for the agency, fishermen and industry including: improved research design and at-sea surveys with the input of fishermen's local knowledge; increased knowledge of the scientific process gained by fishermen, industry and the public; improved credibility of fisheries data used in management decisions; and cost savings to the government in collecting more and better data through cooperation among people with different types of knowledge.

Variability and Complexity of Natural Systems

There is great variability within a hurricane just as in any natural system. Near the eye and to the outer edges of a hurricane, winds are weaker. The height of the surge varies, as does the wave height and the amount of precipitation that falls, both spatially and temporally. Frequently tornadoes spin off from a hurricane resulting in extreme winds in a narrow path within the hurricane's much wider path.

In addition to natural variations within a hurricane, the physical features of water bodies and the topography of the land affect how a hurricane comes ashore. For example: the slope of the beach, the depth of offshore waters, the shape and behavior of coastal water bodies (bay, rivermouth, bayou, open ocean), the degree of relief of the land at landfall, the angle at which a hurricane strikes relative to the shoreline, and the nearness of the hurricane's eye to a community are all factors that affect how a hurricane manifests its power on land and the way surge and waves move on to and across the landscape.

Scientists and mathematicians have long been investigating and modeling the concept of complexity, variability and patchiness in natural systems. The simultaneous operation of mechanisms at different spatial and temporal scales presents a natural system that is not completely ordered, yet at the same time is not chaotic or disordered. Over decades, researchers have questioned and debated the degree of stability in a complex system (Pimm, 1984).

Levin (1992), discussed the question of patterns and scale in ecological systems, emphasizing the importance of understanding the basic mechanisms that underlie the system:

> "…Systems generally show characteristic variability on a range of spatial, temporal, and organizational scales. The observer imposes a perceptual bias, a filter through which the system is viewed…the key to prediction and understanding lies in the elucidation of mechanisms underlying observed patterns."

Although much of the ecological complexity theory has been developed within the framework of populations, communities and ecosystems, some of these same principles may be considered in thinking about hurricanes. In a hurricane, for example, there is a network of mechanisms - wind speed and direction, barometric pressure, sea temperature, seafloor bathymetry, type of nearby and landfall land masses - that operate at different scales to form an ordered, but not reliably predictable, phenomenon.

Methods

This protocol study is based on an inductive approach of gathering information from various sources and then identifying trends. Information was collected on the Katrina surge through conversations, news articles and photographs. This information was compiled and reviewed for insights might that not be apparent through large scale physical science research or computer modeling.

Using USGS topographic maps and NOAA bathymetric charts areas were identified where the nearshore seafloor and the coastland formed complexities (Appendix A) in which surge movement might not have been predictable. Post-Katrina aerial imagery was examined in these complex areas for general patterns of building and infrastructure destruction. With these sources of information, areas were selected (Figure 1) to focus this protocol effort for conversations with people who witnessed the hurricane or returned to their property within a day. Given limited time for this protocol study, not all the complex areas that were identified could be visited.

Conversations with Local People

Conversations were held with hurricane victims at ten locations (Figure 2; Appendix B). Of particular interest were people who stayed on the coast through the hurricane had lived in the local area long enough to have observed and have knowledge of the behavior of the sea, bayous and rivers over time.

Conversations were intended to be open-ended with the hurricane victim telling their story and the scientist only occasionally moving the conversation with a question or comment to hear the person's more detailed account of the aspects of the surge, waves and flooding in their immediate area.

The location of the site the victim was discussing was noted on a topographic map. Names were not asked, however if the person offered their name, it was recorded. If age was offered, that was recorded. If not, the age of the victim was estimated or at least the length of time the victim had lived in that house was asked for consideration of flood frequency. The elevation of the site was asked; if the person did not know, elevation was estimated from NOAA 2-ft contours of the Mississippi Coast (NOAA, 2006).

During the course of the conversation, the scientist listened, and occasionally asked in layman's terms, for information related to the following hydrologic and oceanographic topics:

- Source of floodwaters
- Timing of water – how fast it rose, how long it stayed, how it retreated
- Height to which the water rose
- Velocity of water inside and outside of the building
- Wave behavior
- Directionality of water
- Channeling or "trapping" of water in the nearby landscape
- Debris – size, type, how it moved in the floodwaters
- Sand/Sediment deposition in house, neighborhood
- Erosion near structure, in nearby area

- Location of displaced cars, house, boat, pets
- Effects of local topography (e.g. hills) or bathymetry (e.g. narrowing bayou)
- The sounds of the water

Simplified computer-generated maps depicting the main features in the local area including the Gulf, bayous, rivers, major highways and train tracks were provided for the people to draw on if they were inclined. They were encouraged to mark the direction from which the water came and how it moved across the landscape.

Field Notes Transcription and Datasheets

Upon returning to the office, fieldnotes were entered into the computer in a rough transcript; from the field notes and transcript, pertinent information was drawn out and put into a conversation datasheet (Appendix B).

Biloxi SunHerald Community Articles

Given that this protocol study was short-term and only a small sampling of conversations could be collected, a series of 30 articles about 30 Katrina-affected communities written by Biloxi SunHerald reporters shortly after the hurricane was examined for surge and flood information. People who were interviewed about their house or church often commented on the specific height of the water and the speed at which it came in. Pertinent numbers and comments in the articles were compiled into a table with headings similar to the topics of conversation used in the protocol (Figure 3, Appendix C).

Photographs of Hurricane Katrina Surge

A search was made on the worldwide web for photographs of the storm surge at the height of Hurricane Katrina (Figure 4, Appendix D). Though none of the local people interviewed in this study had photographs of the ongoing surge, professional and amateur photographers on the coast during the hurricane captured real-time images. These photos were gathered to add another dimension to understanding the real-time behavior of Katrina's surge and waves on the Mississippi Coast.

High Water Mark Field Data

Hurricane Katrina high water marks were flagged and surveyed along the 128-mile Mississippi Coast[1] by the Federal Emergency Management Agency (FEMA) in conjunction with URS (2006) (Appendix E). (Other research groups, such as USGS, ACOE and NOAA also collected Hurricane Katrina water level data.) Several circumstances limited the extent and quality of high water data collection in Mississippi during and after Katrina including: coastal water level gages[2] failed and stopped recording data; FEMA-URS flagging and survey crews were not able to get into the field (due to debris piles littering the roads) until between 12 and 23 days after the storm; the surge obliterated structures that might have otherwise showed high water marks; many flood marks had perished within days after the hurricane; the separation of surge, wave action and riverine high water marks in the field can be difficult task; and the interaction among these complex flood factors can be difficult to define.

[2]For further information about water level gages located on the Mississippi Coast, see websites for NOAA (www.noaa.gov) and USGS (www.usgs.gov).

Figure 1: Map of Complex Bathymetric–Topographic Areas on Mississippi Coast

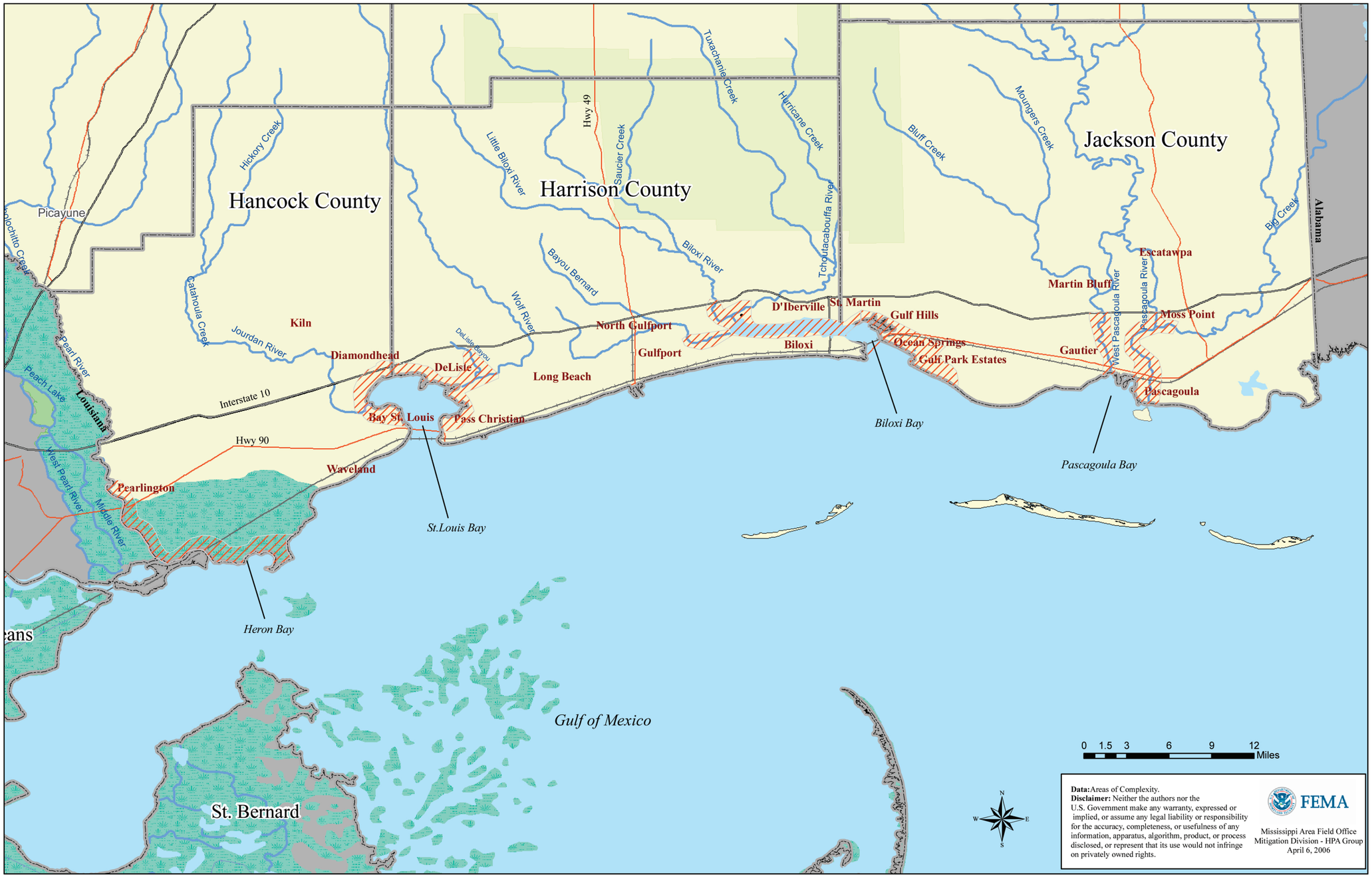


Figure 2: Map of Sites of Conversations on the Mississippi Gulf Coast

Figure 3: Map of Locations of SunHerald Community Reports

Figure 4: Map of Locations of Hurricane Katrina Storm Surge Photographs

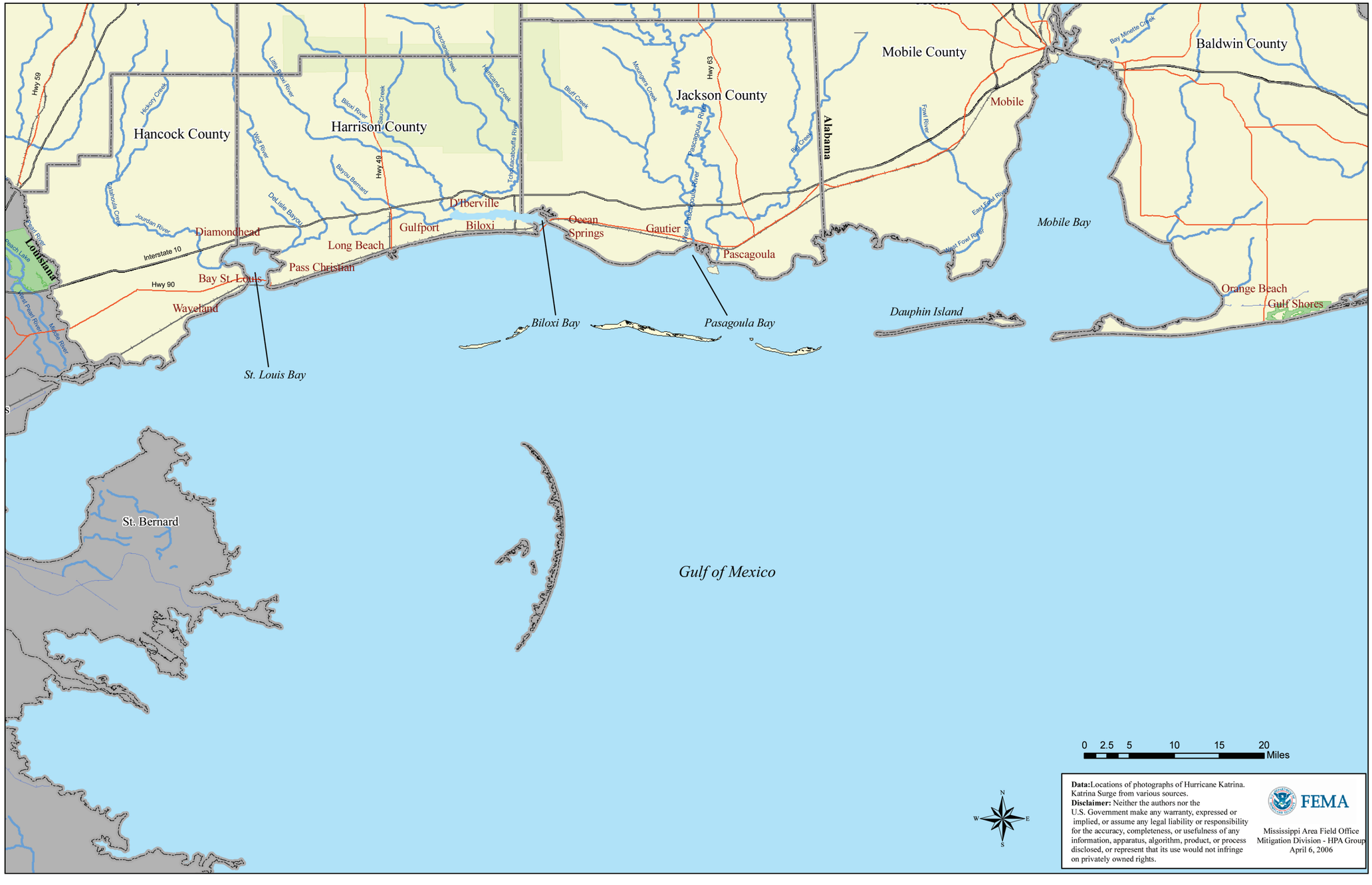
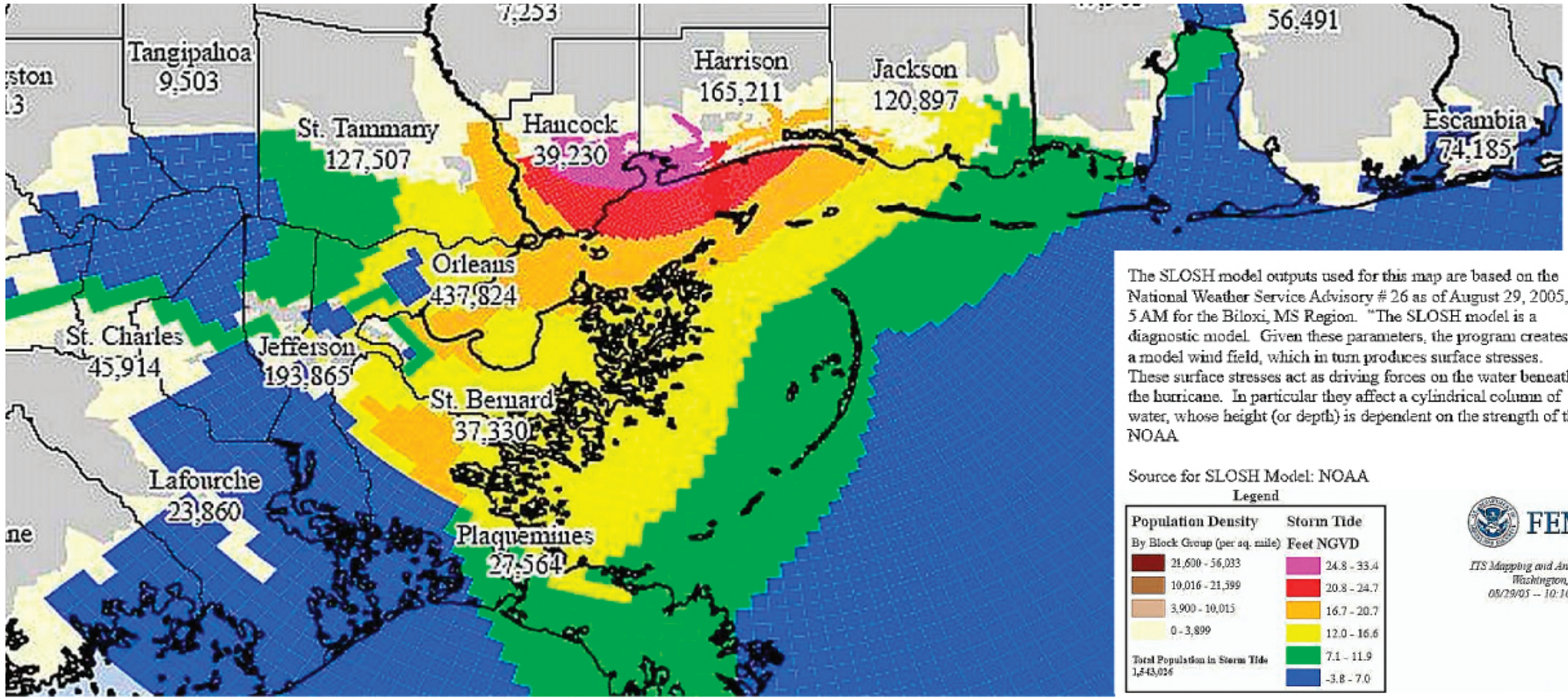


Figure 5: SLOSH Model Results, Gulf Coast, August 29, 2005



Results

Local People: Conversations and Observations

Conversations with hurricane victims (Figure 2) often provided quantitative information regarding the surge and flooding (Appendix B). Not all hydrologic topics of interest, however, were addressed by all people contacted. The most common surge-related topics reported by local people are summarized in Table 1.

SunHerald reporters interviewed hurricane victims in 30 Mississippi coastal communities shortly after the hurricane (Figure 3). These people's comments contained quantitative information and insight on the behavior of the surge and flooding in their communities. A table summarizing these results is in Appendix C. In addition, documentation written by a professional storm-chaser who witnessed the hurricane come ashore at Gulfport Beach (Ultimate Chase, 2006) was examined for surge and wave information.

Table 1: Surge–related Topics Most Often Reported by Local People

Depth of water in their home
Depth of water on their property
Comparison of flooding in Hurricane Camille vs. Hurricane Katrina
Time it took for surge to rise
Time of day the surge arrived
Time it took the surge to leave
Total time for the surge to rise and then leave their home
The direction the floodwaters came from
The source of the floodwaters (Gulf, bay, bayou, river, etc)
Description of sediment carried in on the surge
How the surge worked to damage or destroy their home
Buoyancy as related to cars, sheds and household goods
Boats that were transported on the surge
History of flooding on their property
Debris moving on the surge
The sound of the water

Following is a summary by category of peoples' comments related to the surge, waves and flooding associated with Hurricane Katrina.

Timing and Height of Floodwaters

Conversations with Local People: Record #s from Appendix B

People reported that the surge began on the morning of August 29, 2005. There were variations in the timing of the surge's arrival – for example, just after daybreak in Bay St. Louis (record #2) until 9 a.m. on Back Bay Biloxi (#5). A rescue worker in Gulfport noted that many household wall-clocks in the area stopped at 10:38 a.m. (#9).

Everyone who witnessed the surge remarked how quickly it came in, and more so, how fast the water retreated. The total time for the surge flooding to come in and then to retreat was reported to be between 1 and 3 hours. In one case, a person on the Biloxi Gulf shore reported that the surge retreated from her house in 20 minutes (#3).

Rescuers evacuate children and an elderly woman in Gulfport
Photo by John Bazemore, The Associated Press

Even after most of the surge water rapidly retreated, there was still elevated standing water in most areas, some more than others. A marine rescue worker who operated a boat in the Gulfport area reported that on 3 p.m. on August 29th, he was "still pulling people off roofs in Gulfport Estates" (#9). A person living at just 5 ft above sea level reported that the water in his bayou in the 3-Rivers area of the Back Bay of Biloxi remained elevated to the level of his property (5 ft above sea level) for the entire next day, August 30 (#10). Similarly, the rescue worker reported that the water had dropped to "4 to 6 ft above sea level on August 30th."

Based on people's observations during the hurricane or shortly after upon their return home, the stillwater surge height was between 19 ft and to 31 ft. The greatest flood height reported in any conversation was on a property in Bay St. Louis where the ground elevation is 28 ft and the property received surge 3 ft deep; the water lapped at the underneath of her elevated home (#1). The greatest absolute height of water above ground level reported in a conversation was by a homeowner in Eagle Point at the mouth of the Biloxi River with his property at 5 ft above sea level, he was inundated by 21½ ft of water (#10).

In the Back Bay of Biloxi at the mouth of the Biloxi River, there was a difference of nearly 3 ft between a measurable local knowledge report of 21.50 ft and of a nearby surveyed high water mark of 18.58 ft. Similarly, an exact local knowledge report from Bay St. Louis showed surge at 31 ft whereas nearby surveyed high water marks ranged from 22 to 26 ft.

There were surveyed high water marks (URS, 2006) and local people's reports that indicate the

surge inside Biloxi Bay in places was as high as some of the surveyed surge heights directly on the Gulf shoreline that received the first impact of the Gulf surge (Appendix E).

The NOAA SLOSH[3] model predicted lower surge levels in the Back Bay of Biloxi than actual reports of local people (Figure 5).

SunHerald and Storm Chaser Reports: Record #s from Appendix C

By noon on Monday, August 29th people were escaping floodwaters by going to the second floor of the Safe Harbor United Methodist Church in Escatawpa (#38). As people arrived by boat, they tied their boats off to the second floor landing, indicating that at mid-day on Monday, the water in that area of Escatawpa was still very deep.

In Gulfport, a person who stayed through the storm reported that water from Bayou Bernard "started rushing in houses about 8 a.m. on Monday, August 29th" (#21). Another family in Gulfport reported that they heard the surge from the Gulf arriving in the early morning "like the sound of a rumbling train" (#14).

Many people reported the exact height of the water on their property or in their house in relation to the ground elevation. Some reported water height in relation to piers, roads or bridges, as did the person who reported that the Biloxi River was flowing 6 feet over the Biloxi River Bridge at Interstate 10 (#26).

Theiss (Ultimate Chase, 2006) reported that by daybreak the surge was ashore at Gulfport Beach and perpendicularly crossing Highway 90, which is approximately 12 ft above sea level at that point. Twilight occurred that morning at 6:08 a.m., sunrise at 6:33 a.m. (Sunrise-Sunset, 2006). Two hours after daybreak he reported that the surge inside the Gulfport Beach Holiday Inn (elevation 16 feet, 250 yards from the Gulf shore) was two feet and there were waves on top of that depth. One of the most remarkable observations, he notes, "wasn't how fast the surge came up but how fast it subsided. It was like someone pulled the plug and instantly drained all the water."

Source and Directionality of Floodwaters

Conversations: Record #s from Appendix B

People who witnessed the storm had a sense of where the water came from, both the direction and the source - whether from the Gulf directly or secondarily flowing from bays, bayous, rivers or canals. A man two blocks south of the Back Bay of Biloxi near Interstate 110 reported that the water "came from both directions" meaning the Gulf surge from the southeast and the surge that came in from the back bay (#5). He watched the water coming down his street from the north and south, meeting on his block. He and his neighbors were able to identify another source – Keegan Bayou – by the coloration and smell of that water coming from a few blocks west because the sewage treatment plant discharges its waste into Keegan's bayou.

[3]SLOSH (Sea, Lake and Overland Surges from Hurricanes) is a computerized model run by the National Hurricane Center (NHC) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes by taking into account pressure, size, forward speed, track and winds. (www.nhc.noaa.gov/HAW2/english/surge/slosh.shtml)

A long-time Bay St. Louis resident, who witnessed the flood from the attic reported succinctly that the surge "came from the north, from the bayou" (#2).

A person in the 3-Rivers area was able to describe the source and direction of the local surge by the way his house was destroyed and where he found a few pieces of his furniture and his refrigerator. He reported the water and wind came from the southwest and that the furniture and refrigerator were hundreds of feet northeast of where his house had stood (#10)

People observed that certain streets and highways acted as conveyances for the surge. A woman whose home is approximately 1,400 ft inland from the Gulf on Briarfield Street (which runs perpendicular to the coastline), watched the early surge waters traveling northwards on Briarfield Street to her house, "just coming right up the road" (#3).

A boat that was displaced by the surge

The operator of a boat salvage company, after having salvaged over 1,200 boats along the Mississippi coast, had a sense of the directions and distances that boats traveled with the surge (and wind) from the many Gulf Coast communities in which he had worked (#9). In addition to boats being forced inland by the surge, up to sixteen boats were carried by the retreating surge from Gulfport to Cat Island where they stranded, nearly seven miles offshore (#9).

A boat ended up in the yard of a woman who lives near DeLisle. She did not recognize the boat but felt that it came from Bayou DeLisle "about a mile southeast of here" (#8). The salvage operator later independently confirmed that many boats from the Wolf River- Bayou DeLisle headed north with the surge, commonly for a mile.

A couple who were life-long residents on the Back Bay of Biloxi (near Keegan's Bayou) reported that the hurricane filled their previously empty swimming pool with "back bay water" and "about 50 shrimp and some small blue crabs" (#6).

SunHerald and Storm Chaser Reports: Record #s from Appendix C

An Ocean Springs resident reported the water came from the north from Simmons Bayou (#27). A resident in Pass Christian noted that the water came directly from the Gulf and from the nearby bayou (#6). In Gulfport a resident identified Bayou Bernard as the source of floodwaters (#22, 23). Bayou Castille was reported as the source of flooding for many homes in Gautier in the Hickory Hill area (#32).

A long-time Escatawpa resident noted that roadbeds and highways in the area acted as conveyances to funnel surge waters (that had overtopped from the Escatawpa River) into the community, sometimes even "trapping" the water and causing further flooding. (#38).

Force of Surge and Waves

Conversations: Record #s from Appendix B

The hydrodynamic forces (waves, surge retreat, currents, channeling, etc.) associated with Katrina were often commented on by people who witnessed the hurricane.

Every person who remained through the storm reported the same observation: the surge coming in was fast but the retreating surge was even faster. In two cases, the retreat was reported to be 20-30 minutes (#5, 3) by people who were standing in the surge water in their homes in different areas of Biloxi, one near the Gulf shorefront and the other on the Back Bay. The man who reported the surge retreat as less than 30 minutes, noted that though the incoming water was moving fast, it had no waves or other texture on its surface (flat water), however "there were ripples on the going-out water" (#5), evidence of a higher velocity.

A velocity of 40 mph for the retreating water was reported by a man who runs a marine rescue and salvage company and who is also a recreational river runner (#9). He was operating a rescue boat in the Gulfport area while the surge was at its height and as it retreated. He commented: "When the water retreated, if a house was not already knocked down, it collapsed with the exiting water."

An employee of the Imperial Palace in Biloxi who stayed in the hotel through the hurricane reported that the surge entered the ground floor (hotel reception, lobby and offices) quickly. As it rose, she and a few other people climbed up the interior stairwell because, at that point, they had no way to get away from the surge but to go up. Ultimately the water rose 30 ft in the building. After the water retreated rapidly towards Biloxi Bay, they returned to the ground floor to find the bottom floor entirely washed away except for the girders holding up the building. There were no interior or exterior walls, doors, furniture, file cabinets, computer or lobby desk (personal communication, Payne, November 30, 2005).

Several casino barges were ripped from their moorings. This one came to rest across Highway 90, several hundred feet from the water.

A man evacuated from the 3-Rivers area and returned to find his elevated house destroyed (elevated on 17 ft concrete piers). He surmised from the remnants of his house, including the elevated north wall that remained standing, that surge with waves on top swept through from the south, basically scouring all the contents out of his house (#10).

A couple in Biloxi near the Back Bay reported that part of the roof blew off their house (which had several additions at different elevations) and then the rest of the roof areas were damaged or destroyed. The surge came in after that and finished destroying the house (#6).

A one-story, slab-on-grade brick house located two blocks south of the Back Bay of Biloxi, was inundated with 4 ft of water. (#4) The owner felt that his house was so "tight" (brick construction, relatively new at 6 years old, tightly fitted windows and doors, tight plywood storm window-shutters) that the floodwater could not get in as quickly as in his neighbor's house, only 20 ft away which flooded with 8 ft of water. The neighbor's house, elevated on single concrete-block piers less than 1 ft high, was an old, poorly maintained, wooden-clapboard house with loosely-fitted doors and tall, low windows that had not been shuttered for the hurricane. Because the water came and left this area in one hour, he felt there was not much time for standing-water to seep into his tightly constructed house. It was also helpful that the surge was reported to have no waves and was carrying little debris at that point (#5).

A house in Bay St. Louis, approximately 1,900 ft from the Gulf, was primarily protected from the surge by its 28 ft elevation, one of the highest areas in the Gulf region (#1). Other factors, however, played a role in preventing the 3 ft of surge on her property from doing further damage. An undeveloped, dense woodland lot sits just east of the house and a sturdy wooden fence runs along the east side of the house; both of these elements may have knocked down waves and baffled the surge and debris. Also, she reported that the cemetery (elevation of 24 ft with a 2 ft cement wall) at the south foot of her street may have contributed to slowing surge waters before it came into her block of neighborhood.

It was not uncommon that boats were recovered after the hurricane a mile or more from their original places (#9). A few boats were documented to have moved with the surge and wind as far as 4-5 miles across the mainland. Many boats were damaged when they were carried into wooded areas where they landed when the water retreated. A 25-ft-long boat ended up perched 11-ft high in a tree in Gulfport. Surge and waves flooded a boat that was stored in dry dock over 30 ft high on Bernard Bayou, 2 miles north of the Gulf coast; though the boat remained in its bay and appeared intact, the boat was flooded with saltwater (#9).

At Eagle Point in the 3-Rivers area, a resident thought that the boats transported inland appear to have "dropped suddenly" with the high velocity retreat waters (as indicated by the angle and manner the boats set down); they were not gently set down as might happen on a more slowly retreating water. He also thought that as the surge retreated, the strong south wind was "working against" the boats to prevent the boats from riding the surge back to the sea (#10).

Large rolls of industrial paper and other debris strewn about with shipping containers an a barge

A barge broke loose from the port at Gulfport loaded with huge spindles of brown paper product. It was forced inland on the surge and landed on top of an apartment building, killing the people who were harbored inside (#9).

SunHerald and Storm Chaser Reports: Report #s from Appendix C

Wave action was observed from the Gulf shore by Theiss (Ultimate Chase, 2006). He wrote: "They were extremely long, two-to-three foot tall waves that didn't crash but just moved in - the classic storm surge…I remember going to the second floor [of the Gulfport Beach Holiday Inn] during the peak of the hurricane and noticing waves crashing against the windows of the second floor" (#11). A resident of Escatawpa took specific notice of the power of the waves: "It was the waves on top of the 9 feet that tore up everything…There were big waves rolling over" (#36).

Many people commented on the power of the surge, how it washed away house siding, walls and entire houses (#24,) and picked up debris and "cleaned out" miles of Pascagoula River marshlands (#33). Other people described first floors that were swept clean of everything (furniture, fixtures, appliances, etc), however, the building pilings remained standing (#10, 30).

On Vacation Lane in Waveland, "nearly every house and St. Clare Catholic Church were destroyed by surge up to the railroad tracks" (#4).

Buoyancy, Debris and Sediment

Conversations: Report #s from Appendix B

Vehicles that people left on their properties during the hurricane were destroyed by flooding and sediment deposition (#1,3,4,5,6,8). Most of these cars stayed in place in a garage or carport but were knocked around by the rising floodwaters. One woman noted that her car was transported northwards but was stopped against her neighbor's house (#3). A man on the Back Bay of Biloxi watched from his house as his car flooded slowly enough that it did not become buoyant; it remained in place but water rose over the roof of the car (#5).

Two people reported large storage sheds transported by the surge and wind. One man watched his shed transported from his backyard on the retreating surge and it finally settled in the street nearby (#5). A shed landed in the yard of a woman near Bayou DeLisle having traveled from a property south of hers. Though the shed remained intact as it traveled in 7 feet of surge floodwater, it destroyed her cement yard ornaments and settled on top of her cement flower planters (#8).

People whose homes were inundated but not destroyed talked about furniture and other large household contents being "washed around" inside the house (#8). A woman who stayed in the attic during the hurricane as the water rose, reported listening to the water entering the main floor, "swirling around", and things falling and breaking (#2). Two people whose homes were destroyed reported specific items that stayed in place even though the house essentially fell apart around these items: A woman in Biloxi reported that though her house was de-

Sediment deposition and furniture displacement. The Inn at Dauphin Island
Photo by al.com

stroyed and contents displaced, her set of iron skillets "stayed put"; similarly a man's heavy tool boxes remained in place though all the other house contents were washed out of his elevated house (#10).

Sediment transport and deposition was a destructive force. People talked repeatedly about the extreme damages and mess the mud left behind in houses, cars and boats.

People in the area of Keegan Slough in Biloxi suffered the deposition of sewage-laced sediment in their homes. (Keegan Slough is the wastewater treatment plant's sewage discharge waterbody.) The sewage-sediment mix that arrived at a man's house (#5) was distinguished from other water sources because of its color and smell. What was left behind after the surge retreated was "black slime so bad"; it was ¼" deep after it dried on the oak floors of his house. Removing it was a slow scraping process as it had adhered quickly to the wood. A neighbor of his, whose house was slab-on-grade, had a "half-foot of mud" inside the house when he returned the day after the storm (#4).

In another area of Biloxi, near the Gulf shore, a woman reported that the water was "awful, very smelly" (#3). When the surge retreated it left a smelly "black slime" on the floors and walls. She worked to remove this with bleach shortly after the hurricane. She also remarked that there was small debris (pine needles, twigs) that came up through the toilet as the surge was rising in her house.

The owner of a boat salvage company reported that sunken boats were laden with sediment (#9). The sediment was "dark, slimy, slick" and when it dried, it cracked and got a rough texture. The sediment was the same dark slime wherever they worked (except in nearshore areas where they also found sand). He said that it was "very difficult and messy stuff to work around" as they raised boats.

Because he and his crews were immersed for long periods while diving and retrieving boats over several months, he had many observations. He stated that the water quality was very unsafe immediately after the hurricane and for a long time afterwards. Specifically he noted that: the brass on his dive equipment tarnished to black immediately upon immersion in the seawater; his galvanized equipment corroded; he and others developed rashes and skin lesions. He thought the surface water quality actually worsened 2 to 3 days after the storm because contaminants had soaked into the ground, migrated into the groundwater, and then a few days later, the groundwater transported contaminants into the surface waters (rivers, bayous, lakes, nearshore).

Debris loosed into the surge was not only a terribly destructive force to buildings, but was also a deadly threat to the people who were forced to swim out of their houses. In the small community of Eagle Point in the 3-Rivers area, where 26 people died, survivors who were forced to swim reported encountering ubiquitous debris in the water - building materials, boats, tree branches and wires– as they tried to swim to a place of safety (#10).

SunHerald and Storm Chaser Reports: Report #s from Appendix C

Because the surge was so high, buoyancy played a major role in building damage and in the pro-

Shipping containers that were washed ashore during landfall

duction of debris which then caused damage or destruction to other buildings. A resident in Waveland reported simply, "Some houses floated off their foundations" (#3). In Gulfport Beach, when the surge was still only 2 feet deep, a buoyant car riding on the surge and waves crashed through the glass doors of a hotel lobby (Records #3, 9) effectively adding destructive debris to the power of the surge and waves themselves.

A resident of DeLisle Bayou in the Wolf River area, whose neighborhood experienced extreme floods, said: "When the water rose and debris knocked out the south wall, the other walls began to separate" (#5). In Gulfport[4], shipping containers from the port became buoyant in the surge and acted as debris causing catastrophic destruction inland. Theiss (Ultimate Chase, 2006) reported that the shipping containers were "completely plowing down everything in their path for about a quarter mile…It didn't matter if a structure was wood or concrete, if it was downstream from these shipping containers and on the immediate coast, it was gone…We were standing where a Days Inn used to be and it was simply gone. Nothing left but foundation" (#16).

In Gulfport, a moving company's trucking containers were transported by surge, coming to rest on Interstate 10 just east of the intersection with Highway 49 (#19).

Flood Frequency:

Conversations: Record #s from Appendix

People who experienced Hurricane Camille (in 1969) and Hurricane Katrina always compared the storms and described how the two hurricanes affected them. Several people reported no flooding damage at their houses in Camille but their houses had extreme flooding or were destroyed during Katrina (#8,7,6,5,1). Three of these people were life-long Mississippians between 78 and 82 years-old: all three reported that they had never experienced any remarkable flooding on their properties before Katrina. A man whose house had been in his family for 5 generations (over 100 years) reported that floodwaters had "never come over the street curb in 100 years," yet in Katrina there was 6½ feet of surge water in his yard and 3½ feet in his elevated house (#5).

SunHerald and Storm Chaser Records: Record #s from Appendix C

Longtime residents or people with century-old houses provided information that indicated flood frequency in their specific area. Although the effect of destructive debris cannot be separated from the effects of the power of the water alone, their remarks provide some insight. In Gulfport a resident reported that his 100-year old house began to "rip apart" as Katrina's surge arrived and

[4]Gulfport, ranked as the 3rd busiest container port on the Gulf of Mexico, has nearly 6,000 feet of berthing space and averages over 2.4 million tons of cargo a year. In 2003, the Port of Gulfport handled nearly 200,000 containers (www.shipmspa.com)

was eventually destroyed by the surge in combination with moving debris (#15).

An 80-year old woman in Escatawpa, who survived Katrina in a boat in her garage as the water nearly rose to the ceiling, said, "This property is my grandfather's and it never had water come up in it" (#35). A 79-year old man in the Turkey Creek watershed near Gulfport stated that "I've lived here all my life, and I never saw water like this in my life. It was just like a big lake over there" (#18). A resident in Gautier reported that in 18 years of living on a Pascagoula River bluff property, three hurricanes had "torn up" her backyard (#33).

Photographs of Hurricane Katrina Surge

A compilation of 41 photographs from various sources (Appendix D) taken at the height of Hurricane Katrina provides information regarding surge and wave behavior, the type and behavior of debris in the surge, buoyancy effects, and sediment-sand washover after the surge retreated.

The advance and retreat of breaking waves crossing Highway 90 as Katrina's surge began to arrive
Photo by Mike Theiss, The Ultimate Chase

Surge Behavior:
Record #s from Appendix D-1

Photographs of storm surge behavior demonstrate characteristics such as the wave action and height (e.g. photos 1:3, 10, 13, 19); wave series (1:1, 4, 8, 14, 15, 16); wave advance and retreat (1:7, 11); water depth and pressure (1:6) water velocity (1:3, 15, 21); and the fast river-like hydraulics of the surge and waves (e.g. eddies, whitewater, rooster-tails) (1:2, 10, 15, 20).

Several of the surge behavior photos (1:5, 10, 11, 12) are clipped from video footage produced by Ultimate Chase, a commercial storm-chase business (Ultimate Chase, 2006). Videos of the surge inside a building provides additional insight to surge and wave behavior. In a clip of the surge entering and retreating a hotel doorway in Gulfport Beach, the velocity appears to be between 6 to 8 ft/second as it approaches the stairwell. The photographer remarks at that point that the water "gets sucked out and comes right back in". The water is capped with large standing waves that break against the doorway and interior walls. The photographer also films the surge as it enters the hotel lobby through a set of glass double-doors, pushing the doors open and carrying into the lobby a still-buoyant car. The water level in the lobby rises quickly.

Many long swaths of nearshore homes were totally swept away by the force of the hurricane's surge and waves (1:22). Surge in backwater areas, such as protected bayous, may have risen as high or higher than those on the Gulf coastline, but at least in some locations, with less force and wave action (1:21).

Debris Type and Movement:

Record #s from Appendix D-2

Debris ranged from huge floating casinos to entire houses (photos 2:2, 3, 4, 6) to shipping containers (2:9), fuel storage tanks (2:5), vehicles (2:1, 7) and ubiquitous, relatively small building debris (2:1, 8, 10). Shipping containers from the Mississippi State Port in Gulfport[4] washed in on the surge (2:9). Empty 40x8-ft containers can weigh between 7,000 and 9,000 pounds. These empty containers sheared a pathway and settled many blocks inland.

Debris carried by the surge at Biloxi City Hall
The SunHerald

Similarly, an industrial-sized Chevron fuel tank was loosed during the hurricane and moved with the floodwaters, finally settling in the westbound lanes of Interstate #10 in Diamondhead (2:5). A barge at the port that became loose carried industrial rolls of brown paper product, approximately 3 ft in diameter and 6 feet tall. Although these rolls were extremely heavy, they traveled with the surge and were strewn several blocks inland (2:9)

Debris battered and weakened structures as it was pushed along by the surge velocity and waves (2:1). Structures that might have otherwise survived the surge height and waves collapsed because of the weakening or total destruction caused by battering debris (2:9, 10) on both the in-coming and retreating waters.

Buoyancy:

Record #s from Appendix D-3

Many buildings were moved off their foundations or pilings by buoyancy forces acting vertically. In many cases these houses stayed somewhat intact but moved with the surge and waves away from their foundation sites and dropped elsewhere (3:2, 5). In cases, these floating buildings themselves acted as destructive debris (2:2,3,4,6).

Two houses that became buoyant, crashed into each other and came to rest against a tree several yards from their foundations in Pass Christian

Cars and other vehicles were transported by Hurricane Katrina's surge and waves (photos 3:1, 2) and in many cases acted as destructive debris (3:3, 4).

Sediment deposition at the shoreline

Washover:

Record #s from Appendix D-4

Katrina's surge carried with it a great load of sand and sediment. When the water velocity slowed to less than 3 ft/sec most sediment types were deposited. Thick depositions in houses and upon roads were common (photos 4:1,3,4) along the Gulf coast. Even if a building structurally survived the forces of the surge and wave action, it still might have been destroyed by the sand-sediment deposited by floodwaters inside the house (4:3).

Sand deposited by the surge on to roadbeds formed drifts in the strong winds, requiring expensive cleanups. Damage was also caused to houses by wind-transported sand (4:2, 4).

Discussion

Variability and Complexity

Beyond the inherent complexity of a hurricane is the complexity of its interface with varying nearshore bathymetry and topography of the land it strikes. There is also variability and patchiness within any hurricane so that the land and structures it strikes can be affected differently. All these factors interacting make predictions before landfall and modeling in hindsight a challenging task.

The intricate back bays, bayous and coastal rivers along the Mississippi coastline present varying landscapes which the surge traveled across. In places there are relatively abrupt changes in elevation in a short distance (e.g. the north-south transect of Biloxi peninsula to the Back Bay of Biloxi to the mainland) and there are long relatively flat sections of Gulf shoreline, (e.g. between Pass Christian and Long Beach) (Appendix A, Transects 1-7).

When the Gulf surge entered Biloxi Bay, the water drove into a narrowing bay 11 miles long. A sinuous natural channel runs approximately 10 miles from the mouth of the Biloxi River at the far west end of the bay to the bay mouth at the east end. The channel is up to a mile wide along its course and 8 to 31 ft deep (at mean lower low water); the surrounding shelf waters are 1 to 4 ft deep. This change in bathymetry can be seen on the Biloxi peninsula-to-bay transect #2 (Appendix A) where the channel at that point is 17 ft deep.

In addition to the deep-channel to shallow-shelf bathymetry, the Back Bay of Biloxi is constricted in areas by several islands that, effectively, narrow the bay and could increase the velocity of the water or cause greater lateral flooding (Appendix A, Transects 4-6). The rate at which the huge surge equilibrated across a complex landscape, such as in the Back Bay constricted areas, could be difficult to capture in a computer model of the coast.

The surge that moved through the Back Bay of Biloxi hit the 3-Rivers area and continued up the many river channels and across the connected marshlands. (According to a man from Eagle Point, people who witnessed the hurricane in the Eagle Point area reported that the velocity of the exiting water from the Biloxi River-3 Rivers area was very fast and extremely destructive).

The interface of complex land topography and shallow bathymetry channeled the surge in some back bay areas of St Louis Bay. After the surge forced through the narrows of St. Louis Bay, it reached extreme shoal areas leading up to the low flatlands of the Wolf River and DeLisle Bayou in eastern St. Louis Bay and to the Jourdan River and associated bayous in western St. Louis Bay (Appendix A, Transect 1).

NOAA's predictive storm surge model, SLOSH (based on pressure, size, forward speed, track and winds) that was run at 5 a.m. on the morning of Katrina's landfall (Figure 5), underestimated surge levels compared to the reports of people in some areas of the Back Bay of Biloxi. This discrepancy between the model and locals' real-time reports may be attributed to the geographic and bathymetric complexities of the bay.

Local Knowledge

Through this local knowledge study it was learned that people who witnessed the storm provided some detailed hydrological and oceanographic information, often describing it in a numerical form or in a descriptive form that could be measured on the ground or on a map. In several cases, people discussed their observations in relation to the USGS topographic map or NOAA chart provided to them, sometimes sketching wind and water direction on the maps.

Those people who evacuated their property and returned shortly after the storm were still able to provide specific information about the surge behavior (e.g. depth of water, direction of surge travel, likely source of floodwaters, debris and sediment transport, buoyancy) from making observations and measurements at their house upon return.

In most every case, local people's descriptions validated each other's information, even when reported from different areas of the coast. This was the case with Kovacs et al. (2004) who controlled for this in their study and with Mackinson (2001).

The information most often provided by people who stayed through Hurricane Katrina was the depth of water on their property and in their house. Several people had actually measured the depth after retreat but in some cases a person had a mark in their house that they referred to for maximum depth.

Commonly, people reported the remarkably short time the surge took to come in but more so the shorter time and the speed with which the surge left. People often noted the time at which the surge began to arrive at their property or the time of day in relation to daybreak. They also reported the total time the surge took to rise and retreat in their homes. It was noted by some people that the sea level was still elevated by up to six feet the day after the hurricane.

The time of day the surge arrived in different areas varied and provides interesting insight to the water's direction and movement. While a witness watched the surge begin to come up over Highway 90 in Gulfport Beach "at daybreak," a woman in Bay St Louis reported that it was "just after daybreak" as the water began to rise. (Twilight occurred that morning at 6:08, sunrise at 6:33 a.m.). But it was not until 8 a.m. to 9 a.m. that two people in different areas of the Back Bay of Biloxi reported the water rising onto their properties. Based on the reports of local people covered in this study, it appears that the beginning of the surge's arrival on the Gulf shoreline to the surge's arrival in back bay pockets and bayous was between 6 a.m. and 9 a.m.[5]

People reported that the surge traveled in many directions to reach their communities inside the larger bays (e.g. St. Louis Bay, Back Bay of Biloxi), along the rivers (e.g. Biloxi River, Wolf River, Jourdan River, Pascagoula River) and along bayous feeding into the bays and rivers (Simmons Bayou, Bayou Bernard, Keegan's Bayou, DeLisle Bayou). They often described the specific direction and source of their floodwaters, understanding the local travel routes for waters into bays, rivers, canals and bayous. Even if there were bayous in several directions from their homes,

[5]Katrina officially made its first landfall at the mouth of the Mississippi River on August 29th at 6:10 a.m. Central Time and its second landfall at the Mississippi-Louisiana border at 10:00 a.m. Central Time (http://hurricanes.noaa.gov/)

people commonly were able to name the bayou that flooded them, how that related to the surge in the Gulf, and the travel route and travel time for the surge to get to their location.

For the most part, the local knowledge information followed the same trend of high water marks that were flagged by URS-FEMA (2006) between 12 to 23 days after the hurricane. There were, however, some noticeable differences. For example, in the complex bathymetric area where the Biloxi River enters the Back Bay of Biloxi, there was a difference of nearly 3 ft between a measurable local knowledge stillwater report of 21.50 ft and a nearby surveyed stillwater mark of 18.58 ft. Similarly, a measurable local knowledge report from Bay St. Louis showed stillwater surge at 31 ft whereas nearby surveyed stillwater surge marks ranged from 22 to 26 ft.

Inside St. Louis Bay, some of the URS-FEMA surveyed high water marks (Appendix E) were similar to those reported by a person on DeLisle Bayou. Interestingly, some of the surveyed high water marks and this person's report from far up the bay were as high or nearly as high as the marks surveyed along the Gulf shoreline directly south, where the surge first hit land. This suggests that in places, the back bay surge levels were as high as coast surge levels.

Particularly challenging for the URS-FEMA high water mark flaggers was to determine wave height and wave run-up nearly two weeks after the hurricane, and to separate these elements out from the stillwater surge to derive numbers that accurately reflected what occurred on August 29th, 2005. Because of some of these field data limitations, data analysts developing surge inundation and surge height maps later found it necessary to exclude high water marks that did not match the trend of the elevations or that had poor quality or a low confidence.

Observations related to buoyancy were common. People described houses that "just floated away" and sheds that were transported. Commonly people commented on their furniture, how it was turned over and moved, "washed around," while the house was flooding, how it floated or did not, and where it was transported. There were so many boats on the coast that were loosed and set adrift in the hurricane that boat movement was frequently mentioned. Boats were also subjects of curiosity because they sometimes were caught up unusual obstacles or were dropped down in remarkable locations as the surge retreated.

Buoyant car crashing into hotel lobby

Car buoyancy and transport was reported by many people. Though vehicles vary in buoyancy as a function of their volumes, the surge and wave forces were so great that the relatively small differences in vehicle volume was not the limiting factor if a vehicle was transported in Katrina.

More important was the rate of the vehicle flooding and the location of the vehicle: if a vehicle was inundated slowly enough before the surge and waves acted to transport it, it likely stayed in place; if a vehicle was in a

protected place, like a carport on the leeward side of a house, it might have stayed in place even if it became buoyant; if a vehicle was struck by the surge before it had time to become weighted with water, it became buoyant and was carried a distance by the surge until it ran up against an obstacle and was flooded and sank or was crushed in place.

Most people described in detail or referred to the "mud" or "slime" that was carried into their homes, cars, boats and deposited on their properties. The color, smell, slickness, how it settled, adhered and dried, and the difficulty in removing it were the common descriptors. Only one person, a salvage diver, discussed in detail the quality and likely toxicity of the floodwaters and sediments.

Beyond the rising depth of the surge, wave run-up against buildings was a destructive force observed by people. Wave action inside buildings damaged wall boards and ceiling panels. In this study, however, only a few people talked specifically and in detail about wave behavior. This lack of reporting on waves might have been because waves were not noticeable in their neighborhood or the people were more focused on the overwhelming level of the rising surge; waves were just one more factor in an already dramatic scene.

People reported that houses were destroyed not only by the surge and waves that struck horizontally against the walls, but also by the vertical forces of the surge that lifted the house off its piers and sent it adrift. In cases these houses themselves became debris that caused damage to structures downsteam of the movement of the surge.

Building damaged by a loosed casino barge

Debris loosed in Hurricane Katrina varied greatly in size, weight, material, floatability and surface area for "sailing." Huge debris, such as shipping containers, barges and large vehicles, sheared entire structures down. Some houses that were above the level of the surge were destroyed when debris became entrapped and transferred the surge and wave loads from the debris to the house or when the debris simply knocked down supporting piers. Several people described how debris weakened their house by knocking out one part, and subsequently the house began to fall apart entirely.

Some people's reports indicated that their houses seemed to be better "flood-proofed" than their neighbors' houses. Some of these flood-proofing factors included: "tightness" of building construction, building materials, height of windows above ground level, maintenance on the build-

ing, presence of hurricane shutters, and the length of time floodwater surrounded the house. People who stayed through the storm or returned shortly afterwards mentioned the importance of being able to begin immediate clean-up of their home.

Sand and sediment deposited by overwash caused extensive damage to buildings. In some cases, people reported that their houses were flooded by only a few feet of water but they still suffered costly damage as a result of the depositions inside the house.

The surge was such a major flood event that precipitation, though substantial in areas, was rarely mentioned by local people. Rainfall as much as 12 to 17 inches fell between August 24th and 30th along the path of the hurricane and to the east of the path (Figure 6). Only three people, however, talked specifically about rainfall and then as it related to how it entered their homes during the storm, such as the chimney or through a section of damaged roof.

The river stage on the Biloxi River at Wortham (19 miles upstream of the Back Bay of Biloxi) rose during the afternoon and night of August 29th from 1.46 ft (52 cfs) to finally peak at 25.34 ft (7,810 cfs) in the early morning hours of August 30th (USGS Provisional data, Mississippi District, Figure 7); the stage fell over the next four days. Similarly, the Wolf River at Landon (17 miles upstream of St. Louis Bay) rose from 5 ft to nearly 27 ft on August 29th, peaking in the early evening around 7 p.m. before beginning a slow fall over the next six days (Figure 8). Although precipitation and isolated levee breaks likely contributed to the flood peaks measured in these drainages, the surge traveling upstream appears to have been a primary flooding force, even this far upriver (NOAA, NCDC preliminary report, 2005).

A man at Eagle Point at the mouth of the Biloxi River who was back on his shorefront property the day after the hurricane reported that the sea level remained elevated 5 ft that day and slowly dropped; his report would coincide with the stage falling at the Biloxi River upstream gage over the four days following the hurricane. Because the mouth of the river is so broad and the surrounding marshlands so vast and flat, the area likely tamped the height of the exiting surge and precipitation from upstream.

People who had been in the same house for decades described in detail the flooding, if any, that occurred on their property during Hurricane Camille and compared that to Katrina's extreme flooding at that same property. In some cases, the house had been in the family for generations and the person was able to report a century of flood history handed down through the family.

Photographs and video footage taken during the height of the surge provide insight about surge and waves that would otherwise be difficult to gain if one was only able to see conditions after the surge receded. Some of the site-specific information that can be observed from these real-time images includes: velocity of the surge in open areas and restricted spaces; wave height on top of the surge; wave behavior in open areas and inside buildings; period between waves; the direction from which the surge arrived; the rate of surge retreat; the surge as a buoyant force on vehicles and houses; behavior of large debris as it traveled on the surge; the force of the waves and surge against a buildings; and how a structure ultimately fell apart.

In addition to observing the surge working its forces against structures, photographs and video show how the landscape and man-made obstacles constrict and force the surge to move, how waves are knocked down and water movement baffled by woodlands and rolling topography.

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The concept of what is "objective" and "subjective" information is debatable. Typically the scientific method used by scientists is considered objective and information gathered outside of that method is considered subjective. There are, however, scientists and communications experts who are discussing this divide, questioning if this separation is indeed so clear (Mackinson, 2001; Ludwig, 2001; Weber and Word, 2001).

In the case of this protocol study on observations of Katrina's surge, one must weigh the "subjectivity" of Mississippians who stood in rising surge and reported the maximum depth by pointing to a place on their body or house against the "objectivity" of out-of-state fieldworkers who flagged high water marks in complex landscapes beginning 12 days after Katrina had passed.

Recognition and acceptance of local knowledge as a valid information source is only one of the limitations in using local knowledge. It is challenging to incorporate local knowledge into the science and management structures that government and most organizations typically work within to make decisions and public policy. Some researchers have demonstrated success in rigorously bringing the two forms of knowledge together for use in research and decision making (such as Mackinson, 2001, in the management of a Canadian fishery and Kovacs et al., 2004, in studying hurricane effects on coastal mangrove forests).

As Levin (1992) notes, "The key to prediction and understanding lies in the elucidation of mechanisms underlying observed patterns." That elucidation for a hurricane can come from many sources – scientists, modelers, remote sensing instrumentation developed by engineers, and local witnesses to the surge event. Every person has a template of knowledge through which they observe the complexity and variability in an event such as Katrina. Levin writes, "The observer imposes a perceptual bias, a filter through which the system is viewed."

Figure 6: Map of Observed Precipitation, Hurricane Katrina August 24–30, 2005

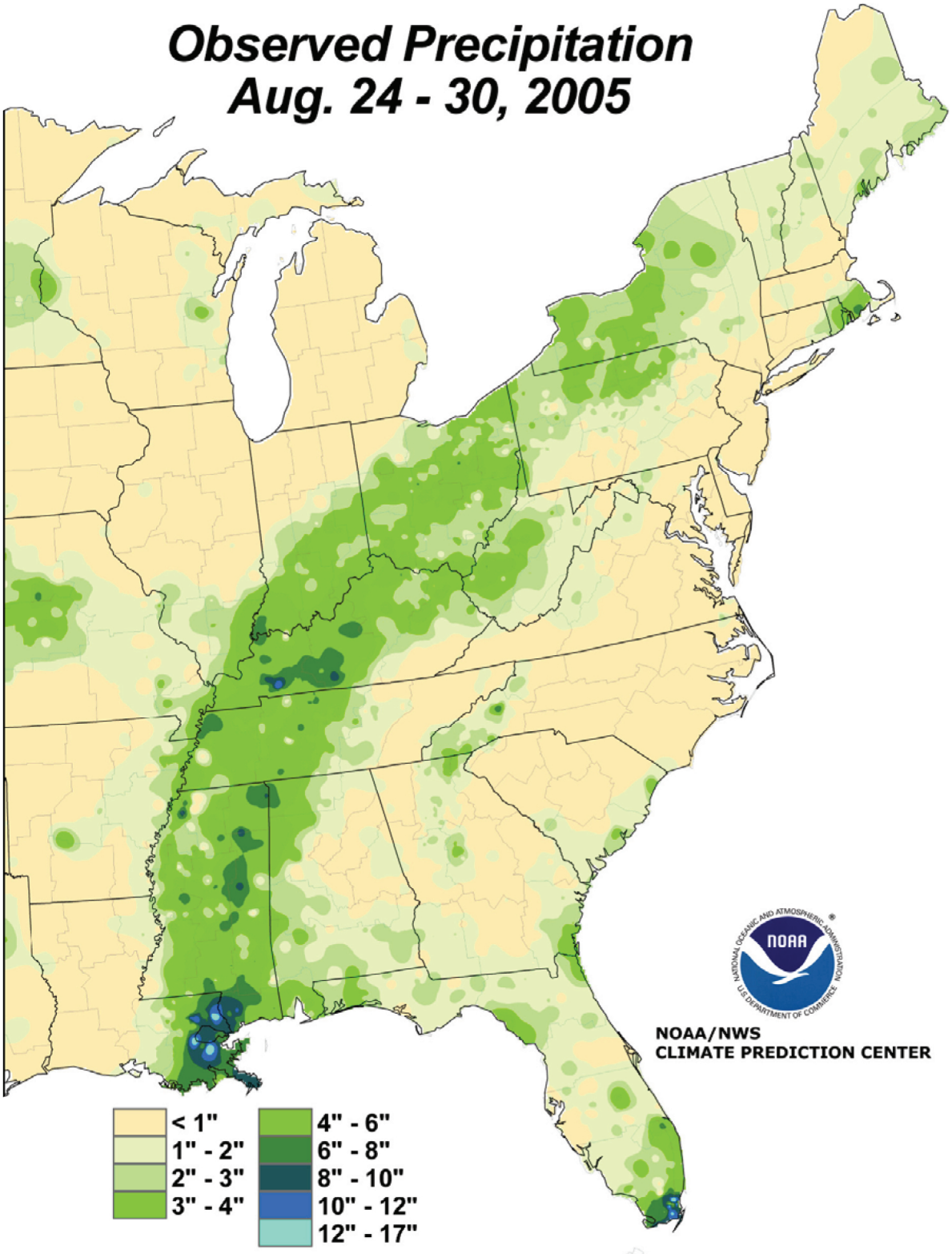


Figure 7: Hydrograph and Map of Biloxi River at Wortham, August–September, 2005

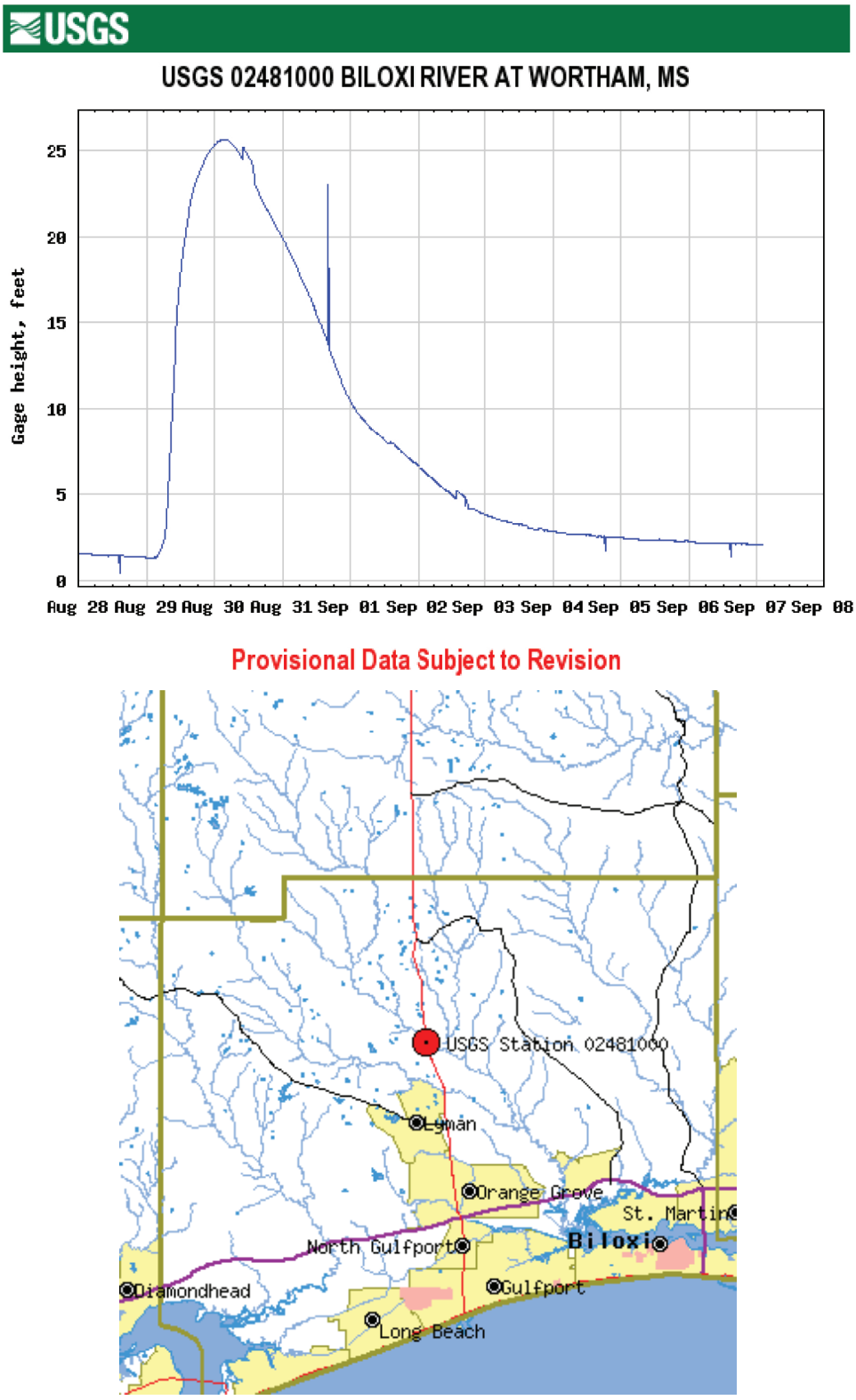
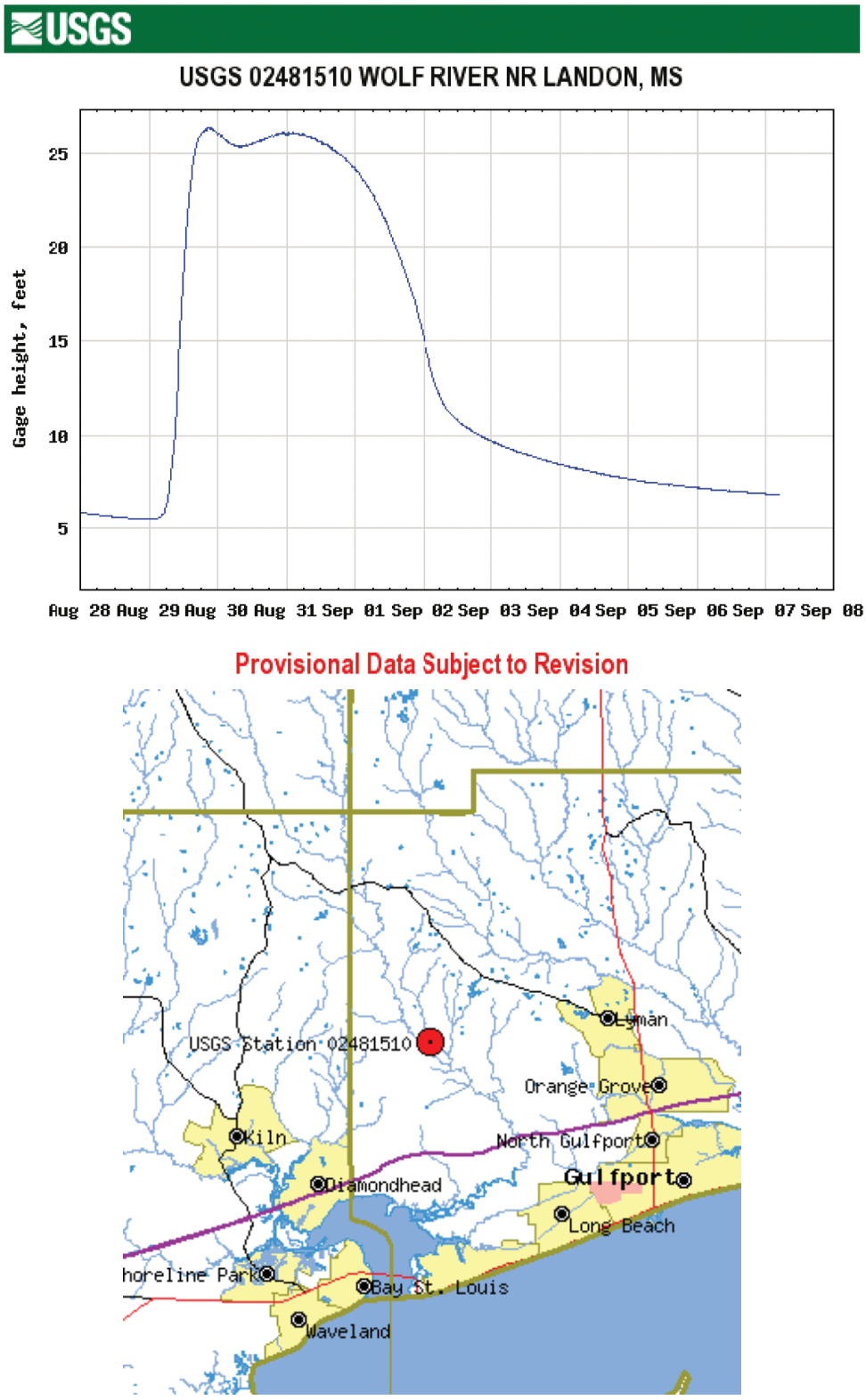


Figure 8: Hydrograph and Map of Wolf River at Landon, August–September, 2005



Conclusions

- The behavior of Hurricane Katrina's surge variable along the Mississippi Coast due to many factors including: nearshore bathymetry; the shape of bays; orientation of the water body to the oncoming surge; presence of islands and narrows; and coastal topography and gradient. In intricate bathymetric-topographic areas, it was not just the surge working on the landscape but also the landscape working back on the surge to constrict and direct its powerful flow inland.

- This protocol study showed that people who witnessed the storm and people who returned home shortly after the storm provided hydrological and oceanographic information, often described in numerical form or in a descriptive form that could be measured on the ground or on a map.

- The surge information most often provided by people who stayed through Hurricane Katrina was: the depth of water on their property and in their house; the time it took the surge to rise and recede; the time of day the events occurred; how Katrina floodwaters compared to Camille's; the direction the surge came from; the source of the floodwaters; the debris riding on the surge; and how the surge worked to destroy their house.

- Based on reports of local people in this study, the surge began to arrive on the Gulf shoreline as early as 6 a.m. and arrived in pockets and bayous of the Back Bay of Biloxi as late as 9 a.m.

- It was consistently noted by people who witnessed the surge that it came in quickly, but more so, how quickly the surge retreated; nearly everyone expressed surprise over the velocity of the water's retreat.

- Besides damage caused by the surge, some people specifically reported that waves on top of the surge caused structural damage. Some people reported that wind weakened structures before the surge arrived, and then the surge caused further damage or destruction. One witness noted that if a building was not fully destroyed when the surge came in, it was likely destroyed as the surge retreated.

- In addition to the critical factors of elevation, waves, surge, debris transport and wind, there were other factors that were reported to determine a structure's fate. Some of these factors included; quality of the construction; quality of the building materials; "tightness" of the construction; level of maintenance; effects of nearby stands of trees and other obstacles that baffled water and trapped debris; and location in relation to bayous and river mouths.

- It was reported by some witnesses that roads and highways served as a conveyance for the surge to come inland, particularly when the road ran perpendicular to the direction of the surge, as is the case for many of the coastal-town roads that run south to the beachfront.

- Rainfall as much as 12 to 17 inches fell between August 24th and 30th along the path of the

hurricane and to the east of the path. The surge was such a major flood event, however, that precipitation was rarely mentioned by people on the coast who contributed information to this study.

- In most every case, local people's descriptions validated each other's information, even when reported from different areas of the coast.

- Photographs and video footage taken by people during the height of Katrina's surge, provided insight that would be difficult to gain if one was only able to see conditions after the hurricane passed and the surge receded. A concerted effort to collect and catalog photographs and videos taken by local people during a hurricane would provide a valuable source of information for scientists and engineers.

- Collection of information from local people after a hurricane or flood event could be further developed to include GPS to document the directionality of vehicles and boats transported by floodwaters to provide GIS maps showing general directionality of floodwaters over a large region.

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- For the most part, the local knowledge information followed the trends of high water marks that were flagged and surveyed between 12 to 23 days after the hurricane. There were, however, some noticeable differences. For example, in the complex bathymetric area where the Biloxi River enters the Back Bay of Biloxi, there was a difference of nearly 3 ft between a measurable local knowledge stillwater report of 21.50 ft and a nearby surveyed stillwater mark of 18.58 ft. Similarly, a measurable local knowledge report from Bay St. Louis showed stillwater surge at 31 ft whereas nearby surveyed stillwater surge marks ranged from 22 to 26 ft.

- The collection of flagged and surveyed high water marks on the ground after a huge surge like Katrina presents challenges: the area affected was so large; access for the first few weeks was limited; high water mark data can perish quickly; it is often difficult to separate stillwater surge from wave height and wave run-up; and under these conditions, each survey point can take up to 2-3 hours. Although there may be great survey precision at each site, the accuracy may be compromised by these limiting factors.

- The NOAA SLOSH model run on August 29th at 5 a.m., just before landfall, predicted lower surge levels than actual reports from local people living in pockets and bayous of the Back Bay of Biloxi.

- Computer modeling is an important and needed approach to understand the overall behavior of a large natural phenomenon such as Hurricane Katrina in Mississippi. In the process, modelers necessarily make subjective decisions based on professional judgment and knowledge and apply statistical methods which require decisions about dropping points, smoothing data to fit and determining acceptable confidence intervals.

- The systematic collection of local knowledge using an established method and searchable database could complement surveyed high water marks, data from real-time instruments, aerial imagery and calibration of numerical modeling. Together this information could facilitate the accuracy of mapping surge and wave heights and extent of inundation.

- A challenge remains to develop a method to dove-tail local knowledge from a disaster, such as the Hurricane Katrina surge, into the scientific structures that technical organizations typically work within.

Recommendations

FEMA strives for improved accuracy in flood evaluation and mapping, particularly in the following areas: modeling of surge and wave behavior, field collection of high water marks and development of base flood elevations maps immediately after a flood disaster.

Local knowledge, as described in this study, could be used to assist in the improvement of evaluation and mapping methods and calibration of models. With inclusion of systematically collected local knowledge, a greater public acceptance and buy-in to the agency's technical products could occur.

Given the goal of improved accuracy in flood evaluation and mapping, the following recommendations are made in light of this study:

1. Refine the methods used in this local knowledge protocol (including a searchable database) for an expanded local knowledge study of the Katrina surge and for use in future surge events.

2. Field test the refined methods with a larger pool of people interviewed on the Mississippi coast and specifically those in coastal areas where it has been identified that mapping and modeling may be inherently weak because of bathymetric-topographic complexity.

3. Determine how systematically-collected local knowledge data can be dove-tailed with science and engineering data to be effectively used in coastal flood studies, mapping and modeling.

4. If this local knowledge protocol proves effective in improving accuracy of surge, wave and flood modeling and mapping for hurricanes, develop spin-off protocols in the future using specific concepts and questions for use in other natural disasters where witnesses' information would be useful in calibrating and improving accuracy of concurrent science and engineering studies and models.

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Glossary

Bayou: Low gradient, slow moving stream, most often lined by lowlands of expansive marshes and swamps

Channeling: The movement of floodwaters into a man-made feature, such as a roadway or corridors among houses, which can often cause acceleration of the water because of constriction and smoother surfaces

Debris: The remains of things set adrift after being destroyed or detached by wind and water. Debris loosed in a hurricane can vary greatly – by size, weight, material, floatability and surface area for "sailing".

Hydrostatic Forces: The forces of rising or slow waters against a solid body

Hydrodynamic Forces: The forces acting on solid bodies immersed in moving fluids

Overwash: The part of the surge water that runs over the crest of a berm or structure and does not flow directly back to the ocean or lake; the effect of waves overtopping a coastal feature or structure, often carrying sediment landwards which is then lost to the beach system; a process in which waves penetrate inland of the beach; particularly common on low barriers (ACOE Coastal and Hydraulics Laboratory, 2006)

Stillwater Surge Elevation: The elevation that the surface of the water would assume if all wave action were absent

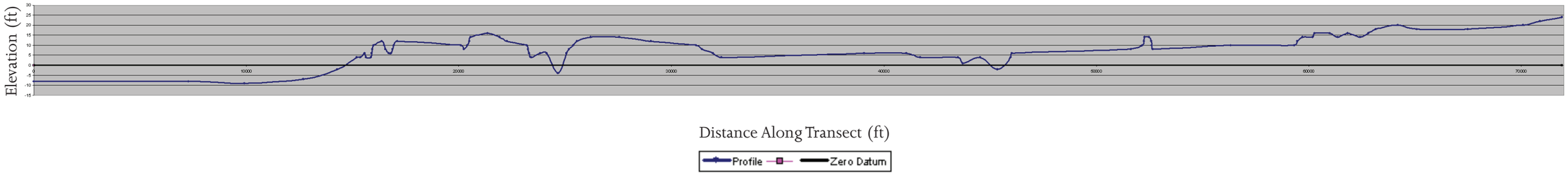
Surge: Water that is pushed toward the shore by the force of winds swirling around a storm; this advancing surge combines with the normal tides to create the hurricane storm tide, which can increase a mean water level by 15 feet or more. In addition, wind-caused waves are superimposed on the storm tide. Water level can rise even higher if the surge coincides with normal high tides. (www.noaa.gov)

Surge Retreat (or backrush): Seaward return of the surge water following the uprush of the surge on to shore

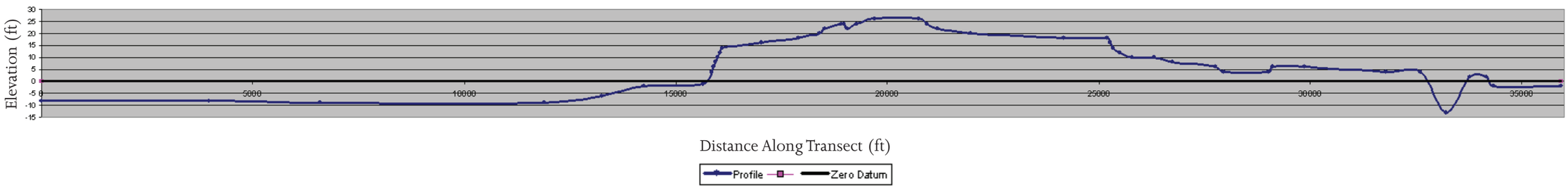
Washover: Sediment deposited inland of a beach by overwash processes (ACOE Coastal and Hydraulics Laboratory, 2006)

Appendix A
Bathymetric-Topographic Transects

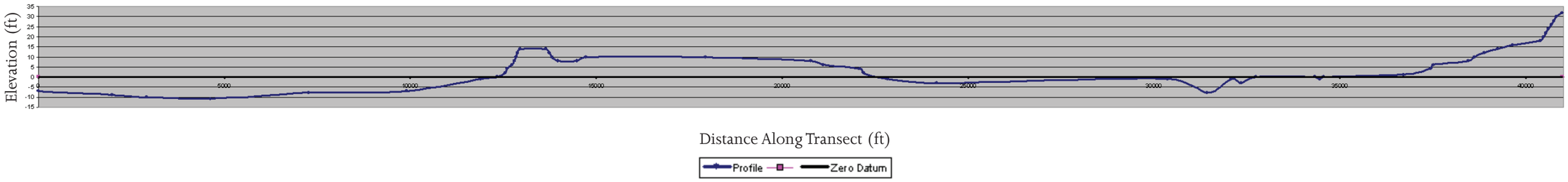
Transect 1: Waveland, MS



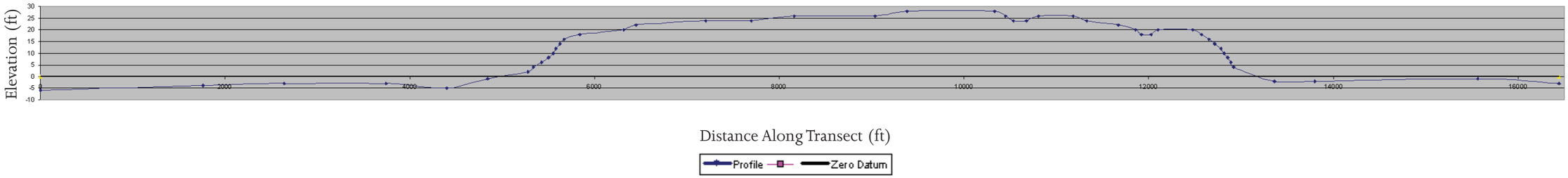
Transect 2: Bay St. Louis, MS



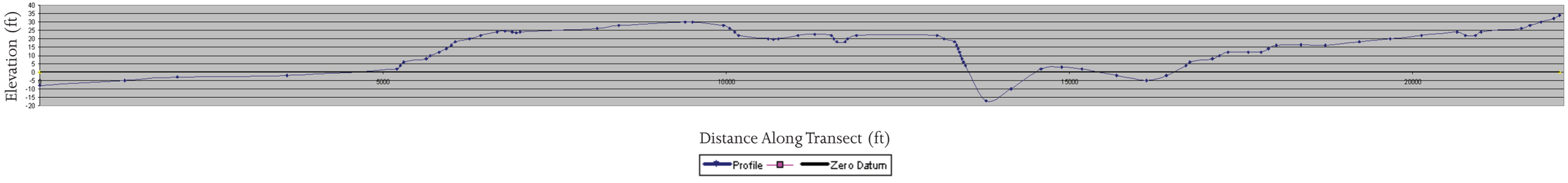
Transect 3: Pass Christian, MS



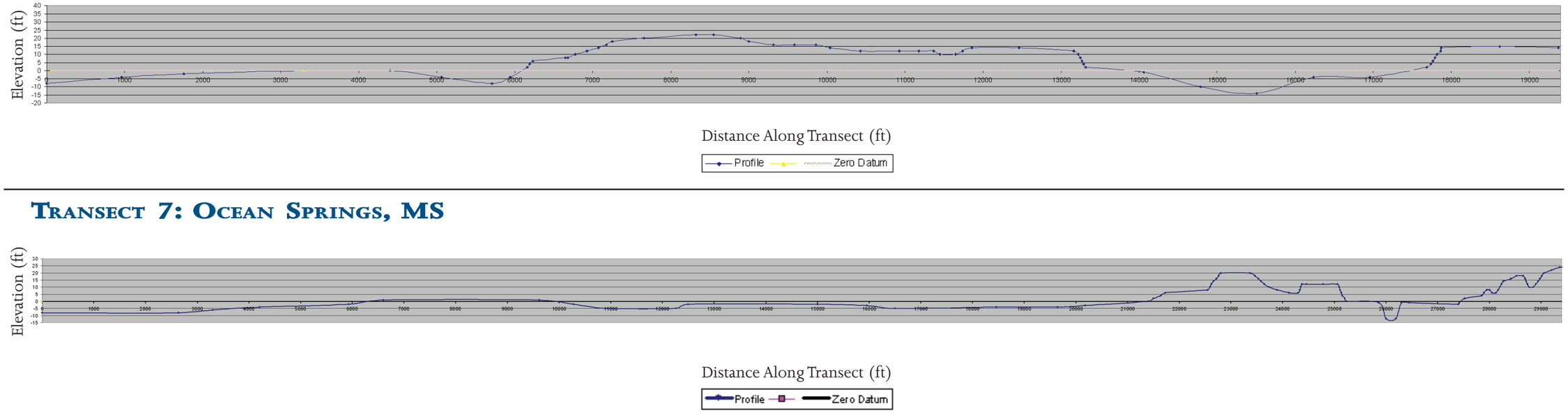
Transect 4: West Back Bay of Biloxi, MS



Transect 5: Central Back Bay of Biloxi, MS



Transect 6: East Back Bay of Biloxi, MS

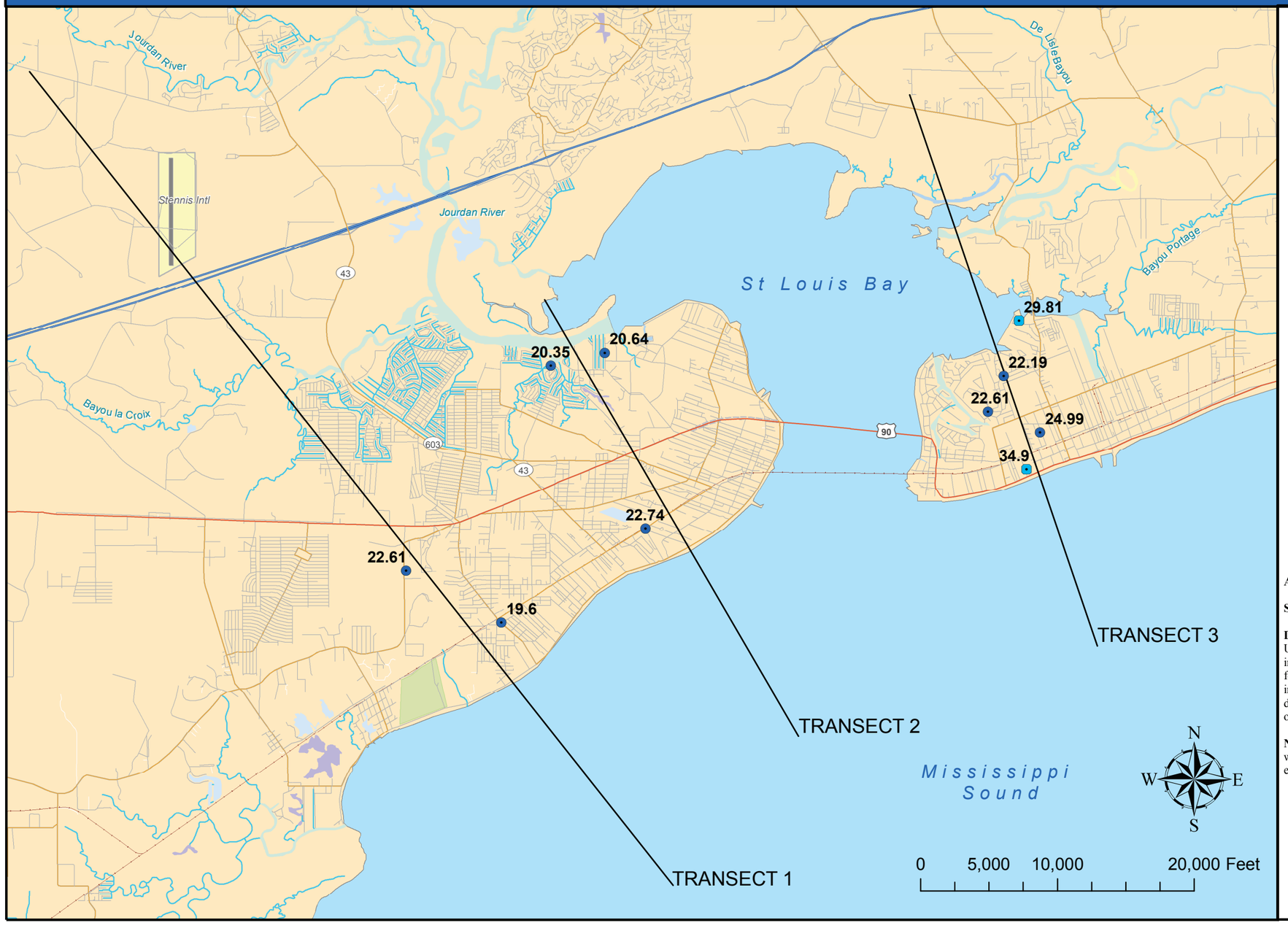


Transect 7: Ocean Springs, MS

Bathymetric-Topographic Transects

Seven transects of Mississippi coastal areas were produced in Excel software using data from NOAA 2-ft land contour maps (http://ekman.csc.noaa.gov/TCM/) and NOAA bathymetric chart data (Chart #s 11372, 11374). Transects were made in the scatter chart by graphing horizontal distance of the transect on the x-axis and nearshore depth and on-shore elevation (above sea level) on the y-axis. ArcGIS was used to obtain the values for the horizontal points along the transects which were plotted on the y-axis.

APPENDIX A: BATHYMETRIC-TOPOGRAPHIC-TRANSECTS (1-3)



Legend

Transects

High Water Marks

- Wave Runup (ft)
- Surge Height (ft)
- Wave Height (ft)

Appendix A: Bathymetric-Topographic-Transects

Source: High Water Marks taken from URS, 2006.

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Notes: High Water Marks shown on maps are located within 2,500 ft of Transects. High Water Marks represent elevation NAVD 1988

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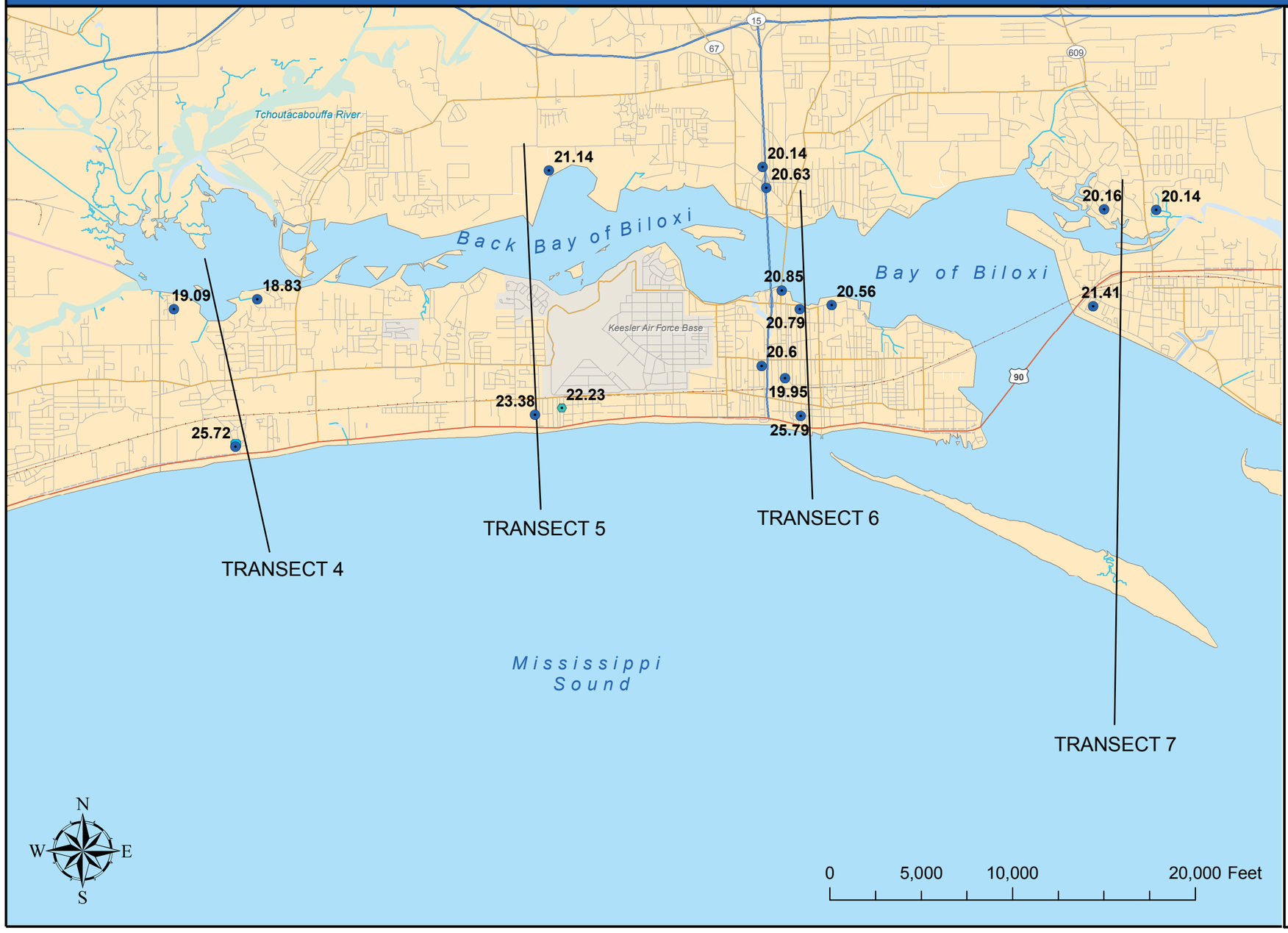
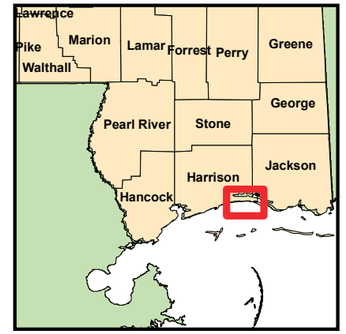
APPENDIX A: BATHYMETRIC-TOPOGRAPHIC-TRANSECTS (4-7)





Legend

Transects

High Water Marks

- Wave Runup (ft)
- Surge Height (ft)
- Wave Height (ft)

APPENDIX A: Bathymetric-Topographic-Transects

Source: High Water Marks taken from URS, 2006.

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Notes: High Water Marks shown on maps are located within 2,500 ft of Transects. High Water Marks represent elevation NAVD 1988

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Appendix B
Hurricane Katrina Conversations: Summary Sheets

CONVERSATION 1 — JANUARY 25, 2006

Coastal Town/Area:
Bay St. Louis

Neighborhood or Street:
St John's Street

Conversation With:
81-year old woman who lived in the same house, approximately 1,900 ft from the Gulf, since the 1950s; she rode out Camille at that house but evacuated for Katrina, returning home that night (August 29) by walking 2 miles.

Elevation of Ground Above Sea Level:
28 ft (estimated elevation from NOAA 2-ft contour map)

Type of House and Elevation of House:
3-ft-elevated, one-story wood house with tin roof

Height of Flood Water:
3 ft in the yard, surge waters lapping up against lowest member of elevated house; total depth of flood water on property 31 ft

Source and Movement of Flood Water:
Surge from Gulf. The wind and the surge came in from the south-east. She determines this from the location of the damage to her roof and fence; the one plywood window covering torn from her house on the southeast corner; and the large trees that snapped on the south-east corner of the wooded corner to the west of her property. A heavily wooded lot sits just east of the house and a wooden fence runs along the east side of the house; both of these elements may have baffled the surge waters, slowing it down and breaking the directionality. The fence remained standing except for a few of the vertical boards missing. A small stand of large pines were just west of her house, the ones exposed to Katrina winds coming from the southeast, snapped in half and the broken halves hung westward.

A cemetery (elevation of 24 ft with a 2 ft wall surrounding it) at the south foot of St. John's Street may have also contributed to baffling the surge before it came into her block of neighborhood.

Timing of Flooding:
(no information specifically for this property; person was not present at her house during surge although she reports the timing in the house she stayed in during the storm (Conversation #2); walked back to her house on the evening of August 29, the same day the hurricane had hit early that morning).

Waves:
(no information)

Debris and Sediment/Sand Transport:

(no information)

Wind/Water Interface:

Wind tore tin roof in places; wind-driven rain entered house in these places causing minor damage.

Damage to Structure:

Surge beneath her 3-ft elevated home (built in the early 1950s) lapped at boards below but did not rise into the house. She believes her house did well because of the land elevation of 28 feet and being raised another 3 feet. Also, the house was designed and built by her late husband in the 1950s with very sturdy timbers in anticipation of hurricanes. About ten years ago she had the shingle roof replaced with a tin roof. During Katrina she had some roof damage that allowed rain to enter, primarily through the kitchen in the southeast corner of the house – enough to run from the higher-elevation kitchen floor to all other rooms in the house.

Damage or Movement of Car or Other Vehicles:

Her car, parked on the west side of the house in the lee in an open carport, was inundated 3 ft but was not transported by flotation. The damage to her car was from the 3 feet of water and loads of sediment deposited in her car.

Comments on Rescue or Survival:

This person evacuated her home to stay with a friend in that person's home about 2 miles away in Bay St. Louis. Those surge experiences at her friend's property are reported in Conversation #2.

Comments on Rebuilding:

She will have the roof and the rain-damaged interior walls repaired. She will continue living in her house as it is one of the highest areas of land in the region and she feels confident her house is well-built to withstand hurricanes.

Summary:

In summary, it appears the surge at her house on St. John's Street, about 1,900 ft from the waterfront, had slowed due elevation increase and perhaps slowed or diverted by the woods and fence and perhaps even the large cemetery at the foot of St. John's Street.

Conversation 2 — January 25, 2006

Coastal Town/Area:
Bay St. Louis

Neighborhood or Street:
8th Street

Conversation With:
81-year old woman who evacuated her Bay St. Louis house to go to a friend's house in an area west of her in Bay St. Louis.

Elevation of Ground Above Sea Level:
18-20 feet (elevation estimated from NOAA 2-ft topographic maps)

Type of House and Elevation of House:
Raised a few feet (estimated 4 ft).

Height of Flood Water:
Water rose 4 feet in the elevated house (unknown exactly how high the house is elevated); total floodwaters on property estimated at 26-28 ft.

Source and Movement of Flood Water:
As the water rose 4 ft in the living room, they could hear the water swirling and things falling and breaking, most likely from buoyancy, however, from her description it sounded as if there was some velocity – enough that it turned furniture over quickly. The "going-out" water was just as bad – caused flooding and damage. Louise reported precisely that the floodwaters at this house "came from the bayou to the north." She also summarized the source of flooding in the area by saying that Hancock county flooded "from a combination of the bayous, rivers and surge."

Timing of Flooding:
It was just daybreak as the water rose. The water rose in the house over "about an hour."

Waves:
(no information)

Debris and Sediment/Sand Transport:
(no information)

Wind/Water Interface:
(no information)

Damage to Structure:
(no information)

Damage or Movement of Car or Other Vehicles:

(no information)

Comments on Rescue or Survival:

They retreated to the attic where they had life vests stored; they donned vests and had a roof vent they could have escaped from if necessary. Her friend's boat had been situated nearby the escape vent if they needed to leave the attic. The next-door neighbors ended up taking the boat because they were forced to escape from their attic because their slab-on-grade house was flooding. It was daylight while they were in the attic and when the neighbors resorted to the boat; otherwise, Louise emphasized, more people would have drowned as they escaped into the swirl of the surge; they wouldn't be able to see to find boats or trees to hang on or to avoid obstacles.

Comments on Rebuilding:

(no information)

Summary:

She said Katrina had been a Category 5 storm before landfall and the coast was experiencing the other edges of that Category 5 storm before the hurricane made landfall as a Category 3. The Katrina mortality would have been much higher if people were forced to escape flooding houses in the dark; not being able to see obstacles and debris and not being able to find a place to safely hang on to would have caused many more people to drown than did.

CONVERSATION 3 — FEBRUARY 9, 2006

Coastal Town/Area:
Biloxi

Neighborhood or Street:
Briarfield Street

Conversation With:
Woman who stayed through the hurricane (with her many pets) in her slab-on-grade, one-story rental house, approximately 1,400 ft from the Gulf coast.

Elevation of Ground Above Sea Level:
21 ft (estimated elevation from NOAA 2-ft contour map).

Type of House and Elevation of House:
One-story slab-on-grade; 1 ft

Height of Flood Water:
4½ ft in house; total flood height on property 26½.

Source and Movement of Flood Water:
The water first came in through the door jambs, slowly at first. Then it began to rise through the floors throughout the house. ("Like The Shining movie"). It then began coming up through the toilet, full of "pine needles and sticks and things." "A lot of rainwater came in through the chimney," adding to the flooding in the house. Her doors and windows did not break or fail with the surge (she had some window coverage). She was able to see out a window and noted that the surge "was just coming right up the road."

Timing of Flooding:
She reported that the water took "3 hours to come in and out;" that the "leaving" part only took about 20 minutes. Her house is situated perpendicular to the direction of the surge so it was hit directly on the narrower south side.

Waves:
Small debris (pine needles, twigs, came up through the toilet).

Debris and Sediment/Sand Transport:
(no information)

Wind/Water Interface:
(no information)

Damage to Structure:
The water was "awful, very smelly." When it retreated it left a smelly "black slime" on the floors and walls. She removed this with bleach shortly after the hurricane. Walls were soaked.

Damage or Movement of Car or Other Vehicles:

Vehicle in the lee of house was pushed up against the next house to the north, about 30 feet away. Vehicle totaled due to inundation.

Comments on Rescue or Survival:

She piled furniture up as the water rose so that she could put her 4 dogs and 8 cats up above the floodwater. "It's the first time in my life when all the animals obeyed."

Comments on Rebuilding:

She is still staying in the house though she has no water connection and no heat (on this day, Feb. 9, 2006). Her belongings remain in the front yard while she dries things out in the house. She doesn't know what her landlord (who lives next door) will decide about the house.

Summary:

Briarfield Street was a conveyance for the surge to travel from the sea north to her house. Surge came in, up the street for about 2½ hours, yet left very rapidly. (This length of time and the rate of rise and fall differs substantially around areas of Biloxi). Along with surge, she noted specifically the effects of the extreme rainfall.

Conversation 4 — February 16, 2006

Coastal Town/Area:
Biloxi

Neighborhood or Street:
Fayard Street

Conversation With:
A homeowner who evacuated and returned to find his one-story brick house had flooded but was structurally sound.

Elevation of Ground Above Sea Level:
14 ft (elevation estimated from NOAA 2-ft contour map)

Type of House and Elevation of House:
One-story brick slab on grade; 1 ft

Height of Flood Water:
4 ft in house; total depth of floodwaters inside house 19 ft.

Source and Movement of Flood Water:
No information from owner but neighbors who stayed through the hurricane said water came from Gulf, Bay and nearby bayou.

Timing of Flooding:
no information from owner but neighbors staying through the hurricane said the water came in the morning around 9 a.m.

Waves:
(no information)

Debris and Sediment/Sand Transport:
There was a "half-foot of mud" inside the house when he returned.

Wind/Water Interface:
(no information)

Damage to Structure:
He felt that his house was so "tight" (brick, relatively new at 6 years old, good fitting windows and doors, tight plywood storm window-covers) that the flood water could not get in as quickly as in his neighbor's house, 20 ft away. His neighbor's house, elevated with single concrete block piers (less than 1 ft high), flooded with 8 ft of water. It was an old, wooden clapboard house with loosely-fitted doors and windows and the windows had not been storm-shuttered for the hurricane. Additionally, it is possible that because the water rose in just 30 minutes before it began to leave his neighborhood (as reported in LEK #5), there wasn't much time for standing water to seep into his more tightly constructed house; this

appeared to be a case of a coincidental (though not intentional) flood-proofing.

Damage or Movement of Car or Other Vehicles:

His pick-up truck stayed in place on his property, though "water went to the top of the driver's seat."

Comments on Rescue or Survival:

He evacuated and returned safely.

Comments on Rebuilding:

With the help of volunteer groups immediately after the storm, his flooded wall board was removed, replaced and painted. He was preparing to move back in.

Summary:

In addition to his elevation of 14 ft, he felt that the construction materials (brick), the relative newness of the house (6 yrs), the "tightness" of all his doors and windows, and his tightly fitted plywood storm shutters protected his property from worse damage, especially in light of his neighbor's house. He also noted that wind patterns have changed since the Imperial Palace was built two blocks north of him. The wind coming from the south during hurricanes, hits the large surface area of the building, causing eddies that travel southward into their neighborhood, tearing up roofs and trees.

CONVERSATION 5 — FEBRUARY 16, 2006

Coastal Town/Area:
Biloxi

Neighborhood or Street:
Fayard Street

Conversation With:
A man who is the 5th generation in the house which he now owns; three of his neighbors joined in conversation.

Elevation of Ground Above Sea Level:
14 ft. (estimated from 2-ft NOAA contour map).

Type of House and Elevation of House:
3-foot elevation; 100+year-old wooden, 2-story house (heart of pine timbers, cypress walls, oak floors).

Height of Flood Water:
Received 3 ½ ft of water inside house; total flood depth 20½ ft.

Source and Movement of Flood Water:
Water came both ways – from the Gulf (south) and from the north (Bay of Biloxi); also from the west (Keegan's Bayou). The north and south entering waters met in front of his house on Fayard Street.

Timing of Flooding:
It took only a half an hour for the water to rise fully in his house between 9 and 10 a.m.; the water was faster going out than the water coming in. The total flood in and out took only about an hour.

Waves:
No waves with water movement. But he saw "ripples on the going-out water."

Flood Frequency:
His family had lived in this house for 100 years and there was never water on their property in 5 generations; there had been some water in the street before but never over the curb and up on the property.

Debris and Sediment/Sand Transport:
Keegan Slough to the west is the area's sewage discharge waterbody. The bayou is shallow and "full of sewage". Sewage came into the house; easy to determine from other water sources. What was left behind after the water receded was "slime so bad" - black sediment, ¼" deep after it dried on the floors of his house. It "dried and cracked like the desert."

Wind/Water Interface:

(no information)

Damage to Structure:

Flood waters left dried sewage on floor and mold began to grow on walls. He lost 2 sheets of tin from his roof on the southeast corner. His backyard shed moved with buoyancy and ended up in the street.

Damage or Movement of Car or Other Vehicles:

His vehicle filled slowly enough that it stayed in place and was destroyed in place; it did not float away.

Comments on Rescue or Survival:

The owner stayed through the storm in his house. He had "no fear through the whole thing" because he was too busy working in the house and the yard throughout the storm. Before the storm he filled his bathtub with clean water for later use. The sewage-laced floodwaters overtopped the bathtub, mixing with the clean water and continued to rise with the flood waters.

Comments on Rebuilding:

He worked throughout the storm to prevent damage and then worked "nearly around the clock" after the hurricane cleaning up inside and outside the house, scraping all the floors to remove dried sewage and bleaching the walls to remove and prevent mold. He said the immediate work prevented the house from having extensive sewage and mold damage.

Summary:

The solid structure and materials (heart-of-pine, cypress, oak) of this old house stood well in the hurricane winds.

The surge water came in from three directions (south, north and west); the floodwater arrived and left approximately within an hour. There were no waves observed at this property, only "ripples" on the surface of the retreating water.

The owner and his neighbors had a sense that the flood waters came from different directions and different timings from the Gulf, Biloxi Bay and Keegan Bayou but did not have a sense whether Biloxi River (mouth in west Biloxi Bay) contributed any to the floodwaters at their location.

The owner noted that localized wind patterns changed when the Imperial Palace was built on Biloxi Bay two blocks north. The tall hotel with a huge surface area interferes with wind coming from the south (as in the case of most hurricanes) and generates eddies around the hotel; this wind-eddying effect then moves in their neighborhood, causing roof and tree damage which he feels is different from the ways the winds moved through the neighbor hood before the hotel was built.

CONVERSATION 6 — FEBRUARY 16, 2006

Coastal Town/Area:
Biloxi

Neighborhood or Street:
Anglada Street, 2 blocks south of Biloxi Bay waterfront

Conversation With:
A couple who evacuated and returned to find their house was destroyed from wind and surge; born and raised in the neighborhood.

Elevation of Ground Above Sea Level:
14 ft (estimated from NOAA 2-ft contour map).

Type of House and Elevation of House:
Wood house with several additions ("add-ons") that had different levels and different designs.

Height of Flood Water:
6-7 ft on property (based on observation of neighbor who stayed through the storm); total flood depth 20-21 ft.

Source and Movement of Flood Water:
He felt that the water came into the neighborhood from 4 directions: south from the Gulf; north from Bay of Biloxi; west from Keegan's Bayou; and east from Augusta Bay.

He felt that the mean high tide plus the wind in the bayou and bay was just "pushing, pushing" for 6-7 hours causing the extreme flood conditions in their area.

He felt Keegan's Bayou, being so shallow, was affected by the hurricane winds which blew from the southeast and pushed the water to the right side (canoe-right) of the bayou, thus causing the right bank houses to flood and not the left bank houses as much.

Timing of Flooding:
between 9 a.m. and 10 a.m. (as reported by the neighbor who stayed through the storm)

Waves:
"Ripples" on the surge water surface (as reported by the next-door neighbor who stayed through the storm).

Debris and Sediment/Sand Transport:
Their swimming pool was full of "back bay water" and about 50 shrimp and some small blue crabs.

Wind/Water Interface:
He felt Keegan's Bayou, being so shallow, was very affected by the hurricane winds which blew from the southeast and pushed the water to the right side (canoe-right) of the bayou,

thus causing the right bank houses to flood and not the left bank houses as much.

Damage to Structure:

The roof blew off one part of the house and then the rest of the roof areas were damaged or destroyed. (This was observed and reported by a neighbor who stayed through the storm). The surge came in after that and finished destroying the house. (They had a "party room" they had built on to the main house with materials, flooring and furniture from a local place that went out of business. All was lost in the storm.

Damage or Movement of Car or Other Vehicles:

Several antique cars damaged or destroyed but remained in place in storage garage on property.

Comments on Rescue or Survival:

They evacuated and returned safely.

Comments on Rebuilding:

They are planning on rebuilding but had not started yet.

Summary:

These people were long-time residents, having grown up in the neighborhood and now in their 60's. Their house survived Camille. Though they did not stay through Katrina, they were astute about water and wind conditions in the area from years living there, including playing (and observing conditions) at Biloxi Bay as children.

They felt that flood waters came from several directions (Gulf, Bay of Biloxi, Keegan's Bayou and Augusta Bay) and that the winds had an effect on how the water locally piled up in the Bay and bayou.

CONVERSATION 7 — DECEMBER 2, 2005

Coastal Town/Area:
Biloxi

Neighborhood or Street:
Anglada Street

Conversation With:
A man and his family who evacuated and returned to find their house standing but with floodwater still inside.

Elevation of Ground Above Sea Level:
14 ft (estimated from NOAA 2-ft contour map).

Type of House and Elevation of House:
The house (cottage-style) was built in the 1930's (estimated by the conversation and the structure) with peaked tin roof; elevated 3-feet by sturdy foundation blocks.

Height of Flood Water:
The man reported that water had been to the top of his neighbor's slab-on-grade, flat-roofed house (estimated height 10 ft). According to this account, the floodwaters may have reached 24 feet at this location.

Source and Movement of Flood Water:
Because the owners were not at their house during the storm, they did not know from which direction the water came.

Timing of Flooding:
The family evacuated their house, going inland 2 miles to stay at relatives. (The relatives' house had only minor wind damage.) They returned to their house the next day to find it standing but when they opened the door, water flowed out.

Waves:
(no information)

Debris and Sediment/Sand Transport:
(no information)

Wind/Water Interface:
(no information)

Damage to Structure:
Wallboards, ceiling panels damaged; windows broken; holes punctured through south side of clapboard sheathing. The surge water had moved all the contents up against the north side of the small house; the water had approached the ceiling.

Damage or Movement of Car or Other Vehicles:

(no information)

Comments on Rescue or Survival:

They left their dog behind in the yard and returned to find the dog back in the yard but extremely traumatized where they could no longer touch him, only leave food for him. The man guesses the dog was swimming in the surge, and perhaps climbed up and sat on the neighbor's flat roof until the water receded and he returned to the yard.

Comments on Rebuilding:

The family did not know how they would be able to afford the interior rebuilding that was needed; they were in a waiting pattern, wanting to repair and keep their house.

Summary:

Water likely reached this site from both the Gulf and the Bay based on other reports from this neighborhood; the Gulf water would have flowed around undulating terrain to reach this site. Two blocks to the north, the Imperial Palace Hotel ground floor was gutted and water rose into the second level (personal communication with desk clerk who stayed through the hurricane at the hotel).

Local topography in this back bay neighborhood between Reynoir and Couevas streets varies a lot in elevation and there were significant flooding differences in pockets throughout the neighborhood.

CONVERSATION 8 — MARCH 15, 2006

Coastal Town/Area:
DeLisle near Bayou DeLisle and Wolf River

Neighborhood or Street:
Lechene Drive

Conversation With:
82 yr-old woman (and her invalid husband) who evacuated; their house was about ½ mile from Bayou DeLisle; the house went through Hurricane Camille with "no water at all" but was destroyed by flooding in Katrina.

Elevation of Ground Above Sea Level:
16 ft (estimated from NOAA 2-ft contour map); 14 ft on east end of large property.

Type of House and Elevation of House:
1-ft elevated house, one-story, located outside of the base flood zone on county maps.

Height of Flood Water:
7 ft of floodwaters; 6 ft inside the house; total flood water including ground elevation 22-23 ft.

Source and Movement of Flood Water:
A boat that she did not recognize ended up in her yard after the hurricane. She felt that the boat came from Bayou DeLisle "about a mile south east of here". Wolf River and Delisle Bayou are just south (extending one mile across) and east (one and a half mile in breadth) of her neighborhood.

Timing of Flooding:
(no information)

Waves:
(no information)

Debris and Sediment/Sand Transport:
Her neighbor's shed (across the street to the southwest) was transported on to her property by surge and wind, causing damage (knocking down a big cement birdbath and settling on top of cement flower boxes). The cement birdbath ended up south, in a ditch, the opposite direction from which the shed had traveled.

Wind/Water Interface:
Winds and surge from the south worked together across the flat, open landscape to transport debris onto their property.

Damage to Structure:
During Katrina, she evacuated; she returned to find her house and separate-garage still standing but flooded and essentially destroyed; things in the house had moved, "washed around"

– a big television unit had moved. The yard was torn up (large oak and magnolia trees downed), patio destroyed, and the long chain-link fence and chain-link gate surrounding the large rectangular property were knocked down.

Damage or Movement of Car or Other Vehicles:

Their car (Lincoln Continental), which they left behind in the garage, was pushed by the floodwaters up against the wall and into the water heater. The garage remained standing but the car was totaled from 7 ft of flooding in the garage.

Comments on Rescue or Survival:

(They had evacuated and returned safely.)

Comments on Rebuilding:

They have already replaced their house with a modular home that is elevated by concrete block footings stacked 6 blocks high (about 4 feet to lowest member of the house), for a total of 20 ft of elevation. Her husband is in a wheelchair and the elevation of the house raised a problem. They had to build two long ramps for access to the house. Even though it was extra cost and extra trouble getting up and down the ramps, she seemed to feel that not raising the house was not an option after experiencing what they did in Katrina.

She was amused by the idea that the county says she is not in the flood zone. (The east end of her large property, which is 2 ft lower, is considered part of the flood zone.) She built higher based on her experiences; she does not trust the county flood maps. The FEMA Advisory Base Flood Elevation maps (November, 2005 version) for her property is 16 ft. A nearby high-water mark (#KMSC-02-25) taken by URS (2006) on September 16, 2005 was 24.6 ft (7.1 ft of flooding above ground elevation). Her rebuilding at 20 ft is 4 ft higher than the FEMA advisory elevations.

Summary:

The house had "no water at all" during Hurricane Camille in 1969, their property received 7 ft with Katrina (6 ft in the house). She felt the existing county flood maps were very inadequate, given what Katrina wrought and they built over 4 ft elevation.

CONVERSATION 9 — MARCH 15, 2006

Location of Conversation:

Bayou Acadian-Wolf River, north of Pass Christian

Conversation With:

A man who is a rescue and boat salvage worker with a company out of Gulfport; he and his crews were recovering a boat from the canal on Midway Drive.

He stayed through Hurricane Katrina in the Gulfport area. During the height of the hurricane he and his crews worked in the Gulfport-Biloxi area rescuing people from rooftops by boat and also recovering bodies.

Since the hurricane occurred, John and his crews have retrieved 1200 boats that were sunk, stranded or inundated along the Mississippi Coast. He is observant of flows, velocity, depths and water behavior and patterns because of his work and also because he is a recreational river-runner and has a sense from that perspective.

Source and Movement of Flood Water:

The water coming in was fast but the water going out was much faster. He estimated that some of the water going out reached very high velocities of 40 mph or more (based on his experience of river running). When the water retreated, if a house was not already knocked down, it collapsed with the exiting water (velocity).

Timing of Flooding:

On August 29th at 3 p.m. he was "pulling people off roofs" in Gulfport Estates.

Clocks on several walls in Gulfport that he observed were stopped (flooded) on Monday August 29th at 10:38 a.m.; by 11:30 a.m. that day (less than an hour later) the rushing water was gone except for standing water which remained in the Gulfport area at 4-6 ft above msl until the next day, August 30. Overall the water remained elevated for 36 hours.

He noted that a friend of his, a scientist who stayed at the Gulf Coast Research Laboratory in Ocean Springs (directly on the coastline) told him that the storm was "beating the lab for 10-14 hours."

Sediment/Sand Transport:

When they salvaged sunken boats the boats were laden with sediment; it was similar sediment wherever they went (unless it was coastal sandy area nearshore and there they found sand inside). The sediment was "dark, slimy, slick" and when it dried, it cracked and got a rough texture (he showed an example). He reported that was "very difficult and messy stuff to work around" as they raised boats.

Debris, Movement of Boats:

Boats were transported all over the coast and landed/settled in all sorts of places. They recovered boats from: the tops of roofs (a common salvage operation); yards and marshes; the bottom of canals, bayous and lakes (recovered boats from maximum depth of 25 ft); forested

areas where they climbed through woods and understory with chainsaws, then used a Bobcat to pull the boats out. They recovered a 25-ft boat in Gulfport that was sitting 11-feet high in a tree (no ground elevation given).

At Riverbend Marina on Bernard Bayou, feeding into Back Bay of Biloxi (2 miles north of the Gulf coast) they salvaged a boat that was in the 3rd tier of a dry dock storage. The owner thought it was not damaged as it was still in the storage bay and appeared intact – but when they brought it down from the dry dock it was full of water. (John estimated the surge to be 28-32 ft at this point, using the dry dock as reference).

It was not uncommon that the recovered boats traveled a mile from its origin, forced by the surge and wind. But a few boats traveled as far as 4 -5 miles from their origin. Some got caught up on barbed-wire (he gave a specific example) or some other hindrance and these boats stopped traveling perhaps sooner than they might have.

A barge full of paper product (huge brown rolls strewn around Gulfport after the hurricane; photo 2-9) broke loose and was pushed inland; the barge landed on an apartment building, killing the people inside. John and crew retrieved the barge and helped locate the bodies.

On Cat Island offshore, they salvaged 14-16 boats that went up "high and dry" on the outbound surge waters from the mainland.

Comments on Rescue and Salvage:

John talked a lot about water quality. Since he was immersed in the foul water diving and retrieving boats, he had a lot of observations. He said it was "not true" when EPA reported that the waters were safe. Specifically he noted that: the brass on his equipment tarnished to black immediately in the seawater; his galvanized equipment corroded; he and others developed rashes and skin lesions; and 2-3 days after the storm, the water quality actually got worse – he believes it was that contaminants had soaked through the ground, went into groundwater and then a few days later, groundwater transported it into surface waters (rivers, bayous, lakes, nearshore) where they were working.

Summary:

John and his crews' observations are extensive given they have worked steadily on rescue and then salvage since August 29th, 2005. Having recovered 1200 boats and spoken to many of the boat owners, they have a great amount of information regarding how the surge and wind moved boats both on the coast and on inlands waters.

CONVERSATION 10 — MARCH 15, 2006

Coastal Town/Area:
3-Rivers Area, west of D'Iberville

Neighborhood or Street:
Eagle Point at mouth of Biloxi River

Conversation With:
61-year old man who owned a house facing out on the bayou on Eagle Point; he evacuated but his house was destroyed.

Elevation of Ground Above Sea Level:
5 ft (estimated from NOAA 2-ft contour map).

Type of House and Elevation of House:
He had a house elevated on concrete supports. The bottom horizontal member of the house was at 18½ ft (above msl).

Height of Flood Water:
The bottom horizontal member of the house was at 18½ ft (above msl). He received 3 ft of water in the elevated living floor for a total of 21½ ft surge height at his location.

Source and Movement of Flood Water:
Water came in from the southwest, moving to the northeast (from Back Bay of Biloxi). He found his refrigerator and sofa a few hundred yards northeast of his home in the woods.

Timing of Flooding:
His neighbors who stayed in their house reported that the water came in fast and went out fast. The water going out was faster. When he returned at 5:30 p.m. on August 29th, he found the water had almost entirely receded from his property but it still remained "about 5 ft above sea level" (he said this pointing to where his small dock had been).

Waves:
He surmises that the major (and final) destruction of his elevated house was due to the wave action from the south moving through the elevated living floor and the out-going flood waters.

Debris and Sediment/Sand Transport:
Boats from the neighborhood were transported all over. He felt that the boats that came inland on the point were dropped suddenly from the fast outgoing water (as indicated by the angle and manner the boats put down), but also from the strong wind from the south "working against them" to let them go back out. By walking around immediately after the hurricane, he feels that boats were pushed on the surge and wind up and over the sagging powerlines to land inside the point.

Damage to Structure:

The bottom ground level was washed out completely (washer-dryer, etc) and the 3 feet of water (and waves on top) scoured the inside of the living floor at 18½ ft and washed out the walls on south side of the house. He lost everything he left in the garage level area and nearly everything he had stored upstairs. Although heavy power tools did not wash away from the upper level, they were inundated with water and mud.

Damage or Movement of Car or Other Vehicles:

He made several trips to take his vehicles (two cars and two motorcycles) when he evacuated so none were exposed to the hurricane at Eagle Point.

Comments on Rescue or Survival:

He evacuated but then returned within 24 hours to the stunning sight of Eagle Point community leveled in places and extreme damage to those structures that survived.

Although he did not stay through the storm, a few nearby neighbors did and gave him their accounts. Several neighbors who stayed and survived reported swimming from houses and surviving despite terrible debris in the water (building materials, boats, tree branches, wires, etc) and how fast the water and debris were moving. Also, there was the danger of downed potentially live power lines and electrical wires.

The small community was extremely hard hit. 26 people died, several of them on Eagle Point proper (for which the community is named), a sand spit reaching in to the Biloxi River mouth. This string of about 6 houses was washed away. When we visited this site, there was no sign of debris in the large marsh area behind the former houses nor in the river itself. (It wasn't demolition clean-up; it appeared that the surge had carried all the building materials away).

Comments on Rebuilding:

He is planning on rebuilding on the same site but this time with poured, reinforced concrete and at least one foot higher for a lower member elevation of 19½ ft. The FEMA Advisory Base Flood Elevation for this location is 20 ft (November 2005 draft version).

Summary:

The water came in from the Back Bay of Biloxi Bay going up the river channels. The retreating water was even faster (as most people have reported all over the coast) but likely even more so due to the restriction of the river channels. The Biloxi River at Wortham (19 miles upstream) peaked the early hours of the next day (August 30) and likely did not cause much additional rise in standing waters when it reached the community of Eagle Point because, by then, as the surge had nearly fully retreated. The man reported that he did not notice a rise of any significance in bayou water on the 30th or later; if it had increased enough to be over 5 ft, it would have been on his property and he would have noticed.

Appendix C
Records from SunHerald Community Reports

#	Coastal Town/ Area	Neighborhood	Elevation of Site (ft)	Height of Flood Water (ft)	Source of Flood Water	Flood Frequency	Timing of the Flood Waters	Forces, Influences, Complexities, Wind-Water Interface, etc.	Additional Comments by Local People about Rescue from Flooding and Rebuilding	News Source, Date
1	Kiln	Hancock County Emergency Operations Center (EOC): 5370 Kiln DeLisle Rd.; Aug. 29, 2005; 12:01 p.m.	30 ft	1 ft in the EOC	Surge from the Gulf into St. Louis Bay and Jourdan River					SunHerald, Biloxi, real-time posting to website
2	Diamondhead	The Oaks subdivision; Fox Trot Drive		5 ft of water in the house	Surge from the Gulf into St. Louis Bay and bayous			Most residents of The Oaks were flooded by 5 to 15 feet of floodwater from the surge from the Gulf that hit Diamondhead. "Most of the homes in The Oaks in Diamondhead are still standing. Other homes had trees fall through them. Some [residents] stayed for the storm, while others fled north and west. Many that stayed were forced onto their roofs until the waters receded." (Biloxi SunHerald text)		SunHerald, Biloxi, Nov. 23, 2005 (A. Lee)
3	Waveland	Middle Town, Herlihy Street; north of the CSX railroad.		Floodwaters 6-12 ft; most of the houses had water up to the roof.	Surge from the Gulf			"Some houses floated off their foundations." (Biloxi SunHerald text)		SunHerald, Biloxi, Nov. 27, 2005 (K. Bergeron)
4	Waveland	Vacation Lane		Nearly every house and St. Clare Catholic Church were destroyed by surge up to the railroad tracks.	Surge from the Gulf			"Just before the railroad tracks, the land rises a bit, almost insignificantly. But here are the only walls still standing on Vacation Lane." (Biloxi SunHerald text).		SunHerald, Biloxi, Nov. 6, 2005 (M. Keller)
5	Delisle	DeLisle Bayou		35 ft of water in neighborhood	Surge moving up St. Louis Bay, Wolf River and DeLisle Bayou			"When the water rose and debris knocked out the south wall, the other walls began to separate. "(Biloxi SunHerald text)	"J.C. Necaise figured his house, built on pilings 20 feet above sea level, would withstand Katrina just fine...The Necaises swam to an oak tree, but Horace Necaise either never made it or could not hang on." (Biloxi SunHerald text)	SunHerald, Biloxi, Nov. 16, 2005 (A. Lee)
6	Pass Christian	328 Menge Avenue; nearly a half mile from the beach		10 ft entered house	Bayou waters and surge from the Gulf			"Nearly every home on Menge Avenue was flooded in some way, be it with bayou water or seawater. Very few homes were knocked down, even near the beach, but several houses were lifted off their foundations and deposited in neighboring yards." (Biloxi SunHerald summary text)	No one is leaving Vacation Lane. (Charles Dubuisson)	SunHerald, Biloxi, Nov. 9, 2005 (J. Norman)
7	Long Beach	Royal Drive		Wind-driven rain into houses.				"Several residents reported hearing tornadoes in the early morning hours of Aug. 29, and the roofs with chunks missing attest to that...Though there was no flooding, tornadoes wreaked havoc on several homes on Royal Drive, causing the contents of many to get soaked. Trees were downed all over." (Biloxi SunHerald text)		SunHerald, Biloxi, Nov. 26, 2005 (J. Norman)
8	Gulfport Beach	Gulfport Beach Holiday Inn, 250 yards from the Gulf	16 ft	Surge crossing U.S. 90 at day- break (approximately 12 ft elevation)	Surge from the Gulf, plus breaking waves		By daybreak, the storm surge was coming over Highway 90 and up to the hotel.			M. Theiss, Katrina Chase Account; Ultimatechase.com

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9	Gulfport Beach	Gulfport Beach Holiday Inn, 250 yards from the Gulf	16 ft	Surge inside the hotel was at 2ft (and waves) 2 hours after daybreak.	Surge from the Gulf, plus breaking waves		2 hours after daybreak, the surge came crashing in to the hotel lobby, carrying a car on the surge waves; extremely difficult to walk.	Waves from the Gulf: "They were extremely long, two-to-three foot tall waves that didn't crash, but just moved in - the classic storm surge. With every surge, the would bang objects into my lower legs, threatening to knock me off my feet." Buoyancy effects: Car crashing into lobby and lobby furniture floating in two feet of surge in hotel, two hours after daybreak. (M. Theiss, Ultimate Chase)		M. Theiss, Katrina Chase Account; Ultimat-echase.com
10	Gulfport Beach	Gulfport Beach Holiday Inn, 250 yards from the Gulf	16 ft	Water inside hotel at height of storm was 12 ft (plus waves) and reached the 2nd story. Total estimated surge: 28 feet (plus waves)	Surge from the Gulf, plus breaking waves		"One of the most memorable parts… wasn't how fast the surge came up but how fast it subsided. It was like someone pulled the plug and instantly drained all the water." (M. Theiss, Ultimate Chase)		"When the surge subsided and the winds died down, we quickly went down to the lobby, only to find the entire first floor completely gutted. Exterior walls were gone, interior walls were gone, doors, sinks, bathtubs, front desk- gone. All that was left were the concrete pilings that kept the hotel standing." (M. Theiss, Ultimate Chase)	M. Theiss, Katrina Chase Account; Ultimat-echase.com
11	Gulfport Beach	Gulfport Beach Holiday Inn, 250 yards from the Gulf	16 ft	2nd floor flooded." I estimate the peak surge reached 12 feet into this hotel with 1-2 foot waves on top." (M. Theiss, Ultimate Chase)	Surge from the Gulf, plus breaking waves			"I remember going to the second floor during the peak of the Hurricane and noticing waves crashing against the windows of the second floor." "Water was surging in through the air conditioning units and filling the second floor." (M. Theiss, Ultimate Chase)		M. Theiss, Katrina Chase Account; Ultimat-echase.com
12	Gulfport	Second Street: August 29, 2005; 10:22 a.m.		5 ft reported in one house					A University of Mississippi student in Oxford (northern MS) reported this Gulfport storm information; she received the information by cell phone from her parents who were escaping the surge in their Gulfport attic.	SunHerald, Biloxi, real-time posting to website
13	Gulfport	Second Street: August 29, 2005; 10:18 a.m.		People on Second Street are calling to be evacuated from their attics.						SunHerald, Biloxi, real-time posting to website
14	Gulfport	1514 18th Avenue, just south of the CSX railroad tracks, off Second Street; the early morning of Aug. 29, 2005		The house at 1514 18th Ave. was eventually destroyed by surge and moving debris.	Surge from the Gulf	Petro's house was over 100 years old; as Katrina surge came in the house began to rip apart and was eventually destroyed.	In the early morning hours, the Petro family heard the water arriving, like the sound of a rumbling train.			SunHerald, Biloxi, Aug. 30, 2005 (D. Hammock)

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15	Gulfport	Downtown and north of U.S. 90; Aug. 29, 2005; 8:56 a.m.		Waves breaking north of U.S. 90 in Gulfport. Water in downtown library and business district. (reported by Fire Chief)	Surge from the Gulf	Petro's house was over 100 years old; as Katrina surge came in the house began to rip apart and was eventually destroyed.		A tornado was reported in North Gulfport to Gulfport Fire Chief.		SunHerald, Biloxi, real-time posting to website
16	Gulfport Beach	Days Inn		Days Inn was destroyed; only slab remained. Likely destroyed by containers carried on the surge from port downstream.	Surge from the Gulf, plus breaking waves			The destruction was even more catastrophic just about half a mile west of the Gulfport Beach Holiday Inn (see #32-34). "...Gulfport had hundreds of shipping containers that came into the port with the surge, completely plowing down everything in their path for about a quarter mile inland. Where we rode out the hurricane [at the Holiday Inn], the live oak tress were still standing, but just half a mile to our west, even the live oaks were gone. It didn't matter if a structure was wood or concrete, if it was downstream from these shipping containers and on the immediate coast, it was gone...We were standing where a Days Inn used to be and it was simply gone. Nothing left but foundation." (M. Theiss, Ultimate Chase)		M. Theiss, Katrina Chase Account; Ultimatechase.com
17	Gulfport	Intersection of I-10 and U.S. 49; August 28, 2005; 11:58 a.m.			Surge into Back Bay of Biloxi and Bernard Bayou			There were also reports of containers [trucking-shipping] from the Fayard moving company littering the interstate just east of the I-10/U.S. 49 junction in Gulfport.		SunHerald, Biloxi, real-time posting to website
18	Gulfport Area (also see #19)	Turkey Creek, just north of the airport		Most homes were substantially flooded in this community.	Turkey Creek flooded with surge	"I've lived here all my life, and I never saw water like this in my life. It was just like a big lake over there." (Albert Theodore, 79 yrs-old)		"Most homes in Turkey Creek [near Gulfport] were flooded by Hurricane Katrina. Others suffered damage from wind and water." (text summary from Biloxi SunHerald)		SunHerald, Biloxi, Nov. 1, 2005 (G. Pender)
19	Gulfport Area (also see #18)	Turkey Creek, just north of the airport; Mt. Pleasant United Methodist Church on Rippy Road		No flooding occurred in the church				"Most homes in Turkey Creek [near Gulfport] were flooded by Hurricane Katrina. Others suffered damage from wind and water." (text summary from Biloxi SunHerald)	"I think most folks will rebuild. I'm confident." (Bernice Jackson, 78 years old)	SunHerald, Biloxi, Nov. 1, 2005 (G. Pender)
20	Gulfport	Fire station, Kelly Avenue, just east of downtown Gulfport, north of the CSX railroad; Aug. 29, 10:18 a.m.					Taking on water as of 10:18 a.m.			SunHerald, Biloxi, real-time posting to website

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21	Gulfport	Bayou Circle		Up to 22 ft into the neighborhood	Bayou Bernard		"Water started rushing in houses about 8 a.m. on Monday, Aug. 29. It stayed long enough to do its damage and was gone by the next day." (Biloxi SunHerald text)	"Scores of houses in Bayou View were damaged by flood water, especially those on Bayou Circle which received as much as 8 feet of water from Bayou Bernard. Many homes also had substantial roof damage." (Biloxi Sun-Herald summary text)		SunHerald, Biloxi, Nov. 11, 2005 (T. Dash)
22	Gulfport	116 Bayou Circle		8 ft of water in house	Bayou Bernard				" I didn't think it would be above Camille's standards." (Boyd Benefield, Bayou Circle resident who built his home in 1955) (Biloxi SunHerald text)	SunHerald, Biloxi, Nov. 11, 2005 (T. Dash)
23	Gulfport	101 Bayou Circle		5 ft of water in the house	Bayou Bernard					SunHerald, Biloxi, Nov. 11, 2005 (T. Dash)
24	D'Iberville	Forest Cove Subdivision, Locust Drive, near Back Bay		25-30 ft flooded Locust Street; one house on Locust was at 24 ft and flooded with 4 ft of water.	Surge into Back Bay of Biloxi and bayous			The water washed siding and walls off houses that weren't knocked from their foundations. The studs from the Williams' house are still standing under the damaged roof.	" Like most of their neighbors, the Williamses had no flood insurance because their property is not in a flood zone. Some residents, including Williams, have decided to rebuild anyway... [he] plans to rebuild at his current elevation, which is 12 feet above sea level. What are the chances of something like this happening in another 10 years? he asked. Life's a gamble." (Biloxi SunHerald summary text)	SunHerald, Biloxi, Nov. 11, 2005 (M. Scallan)
25	D'Iberville	Automall Parkway, Suburban Lodge, August 29, 2005; 10:25 a.m.		5.5 ft reported	Surge from Gulf into Back Bay of Biloxi					SunHerald, Biloxi, real-time posting to website
26	Biloxi River	Interstate 10, Harrison County, about 7 miles west of D'Iberville; Aug. 28, 2005; 11:58 a.m.		The river was flowing at an estimated 6 ft over the bridge.	Surge from Gulf into Back Bay of Biloxi and Biloxi River					SunHerald, Biloxi, real-time posting to website
27	Ocean Springs	Gulf Park Estates, 1900 Beach View Drive	22 ft (at Galle house)	1 ft in the house	Water came from north, Simmons Bayou			"My son was building a new house across the street [in Gulf Park Estates] and had 3 feet of water. Some neighbors to the south just had a foot, and some to the north had as much as 7 feet." (Debbie Galle, Gulf Park Estates resident)		SunHerald, Biloxi, Nov. 30, 2005 (G. Holland)
28	Ocean Springs	Gulf Park Estates, Simmons Bayou		marina and condos destroyed	Simmons Bayou					SunHerald, Biloxi, Nov. 30, 2005 (G. Holland)
29	Gulf Hills, north of Ocean Springs	Arbor Circle			Surge into Biloxi Bay and Old Fort Bayou			"The hurricane's surge washed through the bottom floor of the Bowen home [on Arbor Circle], leaving nothing behind but lawn furniture and china." (Biloxi SunHerald text)	"Bowen said he and his family feel lucky because his practice is OK and they can rebuild stronger. That's just the sacrifice you make when you live where you want to be, said Bowen, who moved to the home four weeks before the storm. We're going to rebuild, and we're in good spirits." (Biloxi SunHerald text)	SunHerald, Biloxi, Nov. 22, 2005 (Q. Collins)

#	Coastal Town/ Area	Neighborhood	Elevation of Site (ft)	Height of Flood Water (ft)	Source of Flood Water	Flood Frequency	Timing of the Flood Waters	Forces, Influences, Complexities, Wind-Water Interface, etc.	Additional Comments by Local People about Rescue from Flooding and Rebuilding	News Source, Date
30	Ocean Springs	Simmons Bayou Road		7 ft in house of T. Ray Lynn	Water came from north, Simmons Bayou				T. Ray Lynn is rebuilding at the same site on Simmons Bayou Road	SunHerald, Biloxi, Nov. 30, 2005 (G. Holland)
31	Gautier	Seacliff neighborhood, Park Drive		7 houses out of 11 were destroyed	Surge from the Gulf			"Residents are using the eyewitness accounts of two people who stayed during the storm, who say tornados ripped up Park Drive before the storm surge hit." (Biloxi SunHerald summary text)		SunHerald, Biloxi, Nov. 13, 2005 (D. Hammack)
32	Gautier	Hickory Hill, west side		6 ft above the pier; resident got 4 ft in her home. Houses on stilts got floodwaters.	Bayou Castille			"Dozens of homes to the west of the course flooded and homes to the east had scattered roof and tree damage." (Biloxi SunHerald text)		SunHerald, Biloxi, Nov. 20, 2005 (K.Nelson)
33	Gautier	Hickory Hill, east side, Powell's Point Drive, Clark's house)			Surge from the Gulf, moving up Pascagoula River	"In their 18 years of living on the bluff, three hurricanes have torn up the backyard." (Biloxi SunHerald text)		"When the storm surge came up the Pascagoula River system, it cleaned out miles of marshland and deposited the debris along the banks [of the Pascagoula River] ...in the Hickory Hill area." (Biloxi SunHerald text)	"Though the view is breathtaking, she said, she's tired of replanting bushes and losing trees. She's ready to move from the exclusive neighborhood along Powell's Point Drive." (Biloxi SunHerald text)	SunHerald, Biloxi, Nov. 20, 2005 (K.Nelson)
34	Moss Point	Magnolia Drive, Magnolia Junior High School		4 feet of water flooded the school's halls and classrooms.				"Residents reported severe wind damage to roofs, doors and windows [along Magnolia Drive, Moss Point]. Four to more than 6 feet of water flooded many low-lying homes." (Biloxi SunHerald text summary)		SunHerald, Biloxi, Nov. 2, 2005 (Q. Collins)
35	Escatawpa	Dutch Bayou		Beckham and grandchildren stayed in a boat in her garage; the boat floated; she was able to touch the garage ceiling		"I am 80 years old. This property was my grandfather's and it never had water come up in it." (Virginia Beckham)			Virginia Beckham is rebuilding on the same location.	SunHerald, Biloxi, Nov. 10, 2005 (K. Nelson)
36	Escatawpa	Leslie Lane		9 ft into house of Cecil Leslie				"It was the waves on top of the 9 feet that tore up everything. You've seen the beach when it's real rough? There were big waves rolling over." (Cecil Leslie)	Cecil Linwood is rebuilding on the same location	SunHerald, Biloxi, Nov. 10, 2005 (K. Nelson)
37	Moss Point	Magnolia Drive		More than 6 ft flooded house at 3600 Magnolia.				"Residents reported severe wind damage to roofs, doors and windows [along Magnolia Drive, Moss Point]. Four to more than 6 feet of water flooded many low-lying homes." (Biloxi SunHerald text summary)	"That storm tore this town up. " (Sherman Johnson, bricklayer working in Moss Point)	SunHerald, Biloxi, Nov. 2, 2005 (Q. Collins)

#	Coastal Town/ Area	Neighborhood	Elevation of Site (ft)	Height of Flood Water (ft)	Source of Flood Water	Flood Frequency	Timing of the Flood Waters	Forces, Influences, Complexities, Wind-Water Interface, etc.	Additional Comments by Local People about Rescue from Flooding and Rebuilding	News Source, Date
38	Escatawpa	Between Jamestown and Dutch Bayou; between Miss. #613 ad Miss. #63, with I-10 to the north; Safe Harbor United Methodist Church		4 to 9 ft in the houses in the community			By noon on Monday Aug. 29th, there were 50 people on the 2nd floor of the Safe Harbor United Methodist Church; people were tying their boats off to the 2nd floor landing. (observed by Linwood Grierson, longtime resident)	The north-south highways acted as a funnel; when the tidal surge pushed the Escatawpa River out of its banks, the roadbeds, like levees, channeled the water directly into the lower Escatawpa community and trapped it. (observation by Linwood Grierson, longtime resident). // "The storm surge from the Escatawpa and Pascagoula rivers hit this area north of Moss Point from both sides, the south and the west. Water flooded Escatawpa almost to the city limits at Saracennia Road, hitting homes, as well as businesses, including the hotels along Interstate 10. Escatawpa as a community extends beyond Moss Point north along the Pascagoula River, where homes flooded west of Mississippi 613." (text summary from SunHerald).	"There were five dogs and three or four other animals up there with us [in the 2nd floor of the Safe Harbor Methodist Church]."(Linwood Grierson, longtime resident).	SunHerald, Biloxi, Nov. 10, 2005 (K. Nelson)
39	Pascagoula	Cleveland Avenue		4 ft of water swept through the neighborhood	Surge from Gulf			"Homes on Cleveland Avenue were flooded with 3 to 4 feet of water. Some roofs were blown off; most families lost practically everything in their homes." (Biloxi SunHerald text) (Biloxi SunHerald text)	"Most of that area is not in the flood zone so I wouldn't see a lot of problems building back on Cleveland Avenue," said City Building Inspector Steve Mitchell. "We would like to see homeowners rebuild." (Biloxi SunHerald text)	SunHerald, Biloxi, Nov. 29, 2005 (G. Holland)

Appendix D
Photographs of Hurricane Katrina Storm Surge

APPENDIX D–1
Surge Behavior

Photo 1-1 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-2 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-3 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-4 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-5 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-6 Disney Enterprises, Inc., http://abcnews.go.com
Photo 1-7 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-8 PeenieWallie, www.peeniewallie.com
Photo 1-9 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-10 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-11 Ultimate Chase, Inc., www.ultimatechase.com
Photo 1-12 Buzznet, Inc., http://sunherald.buzznet.com
Photo 1-13 al.com, LLC, www.al.com
Photo 1-14 al.com, LLC, www.al.com
Photo 1-15 al.com, LLC, www.al.com
Photo 1-16 al.com, LLC, www.al.com
Photo 1-17 Buzznet, Inc., http://sunherald.buzznet.com
Photo 1-18 Buzznet, Inc., http://sunherald.buzznet.com
Photo 1-19 al.com, LLC, www.al.com
Photo 1-20 al.com, LLC, www.al.com
Photo 1-21 al.com, LLC, www.al.com
Photo 1-22 Knight Ridder, Inc., www.sunherald.com

Photo 1-1

Wave series on top of surge, coming ashore in Gulfport, MS.

Photo 1-2

Wave on top of surge, showing hydraulics of water, Gulfport, MS.

Photo 1-3

Wave crest and wind effects on surge ashore in Gulfport, MS.

Photo 1-4

Surge and waves covering Route 90, Gulfport, MS.

Photo 1-5

Close-up of wave traveling on surge, Gulfport, MS.

Photo 1-6

Surge depth and pressures causes car trunks to pop open, Gulfport, MS.

Photo 1-7

Surge on highway in Gulfport, MS.

Photo 1-8

Waves crash against boat washed on to Highway 90, Gulfport, MS.

Photo 1-9

Surge and waves as observed in Gulfport, MS.

Photo 1-10

Surge and waves entering hotel door in Gulfport, MS.

Photo 1-11

Surge advances and retreats at high velocity through hotel doorways, Gulfport, MS.

Photo 1-12

Surge and waves pass through Eagle Point near Ocean Springs. MS.

Photo 1-13

Vehicles battered by surge and waves.

Photo 1-14

Fire and rescue personnel in surge and waves near Interstate-10, Pascagoula, MS.

Photo 1-15

Fire and rescue personnel in surge and waves near Interstate-10, Pascagoula, MS.

Photo 1-16

Surge with wind-crested waves, Water Street, Mobile, AL.

Photo 1-17

Peak surge flooding on Reynoir Street, Biloxi, MS.

Photo 1-18

Peak surge flooding on Reynoir Street, Biloxi, MS.

Photo 1-19

Surge and wave action at Fairhope Pier and Yardarm Restaurant, Mobile Bay, AL.

Photo 1-20

Surge and wave action at Fairhope Pier and Yardarm Restaurant, Mobile Bay, AL.

Photo 1-21

A couple watches floodwaters rise outside their home, Mobile, AL.

Photo 1-22

Effects of surge and waves at Belle Fountain Beach, near Ocean Springs, MS.

APPENDIX D–2
Debris Type and Movement

Photo 2-1	Knight Ridder, Inc., www.sunherald.com
Photo 2-2	al.com, LLC, www.al.com
Photo 2-3	al.com, LLC, www.al.com
Photo 2-4	al.com, LLC, www.al.com
Photo 2-5	al.com, LLC, www.al.com
Photo 2-6	al.com, LLC, www.al.com
Photo 2-7	al.com, LLC, www.al.com
Photo 2-8	Knight Ridder, Inc., www.sunherald.com
Photo 2-9	Knight Ridder, Inc., www.sunherald.com
Photo 2-10	Knight Ridder, Inc., www.sunherald.com

Photo 2-1

Debris in surge, outside Biloxi City Hall, Biloxi, MS.

Photo 2-2

House lifted by buoyant forces, swept towards Interstate-10 bridge, Mobile Bay, AL.

Photo 2-3

House lifted by buoyant forces, swept towards Interstate-10 bridge, Mobile Bay, AL.

Photo 2-4

House lifted by buoyant forces, swept into Interstate-10 bridge, Mobile Bay, AL

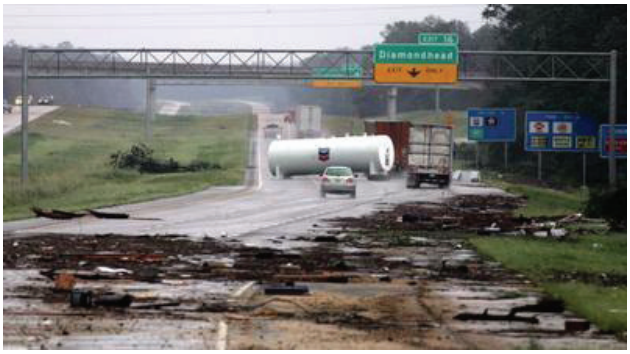


Photo 2-5

Commercial fuel tank transported on the surge on to Interstate 10, Diamondhead, MS.

Photo 2-6

Destroyed house transported by surge, crashed into nearby house, Dauphin Island, AL.

Photo 2-7

A truck overturned and transported by the surge, Mobile, AL.

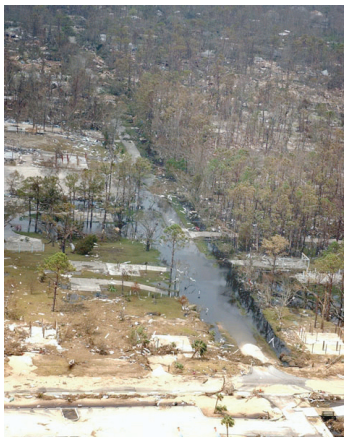


Photo 2-8

Standing water from surge remaining on Coleman Avenue, Waveland, MS.

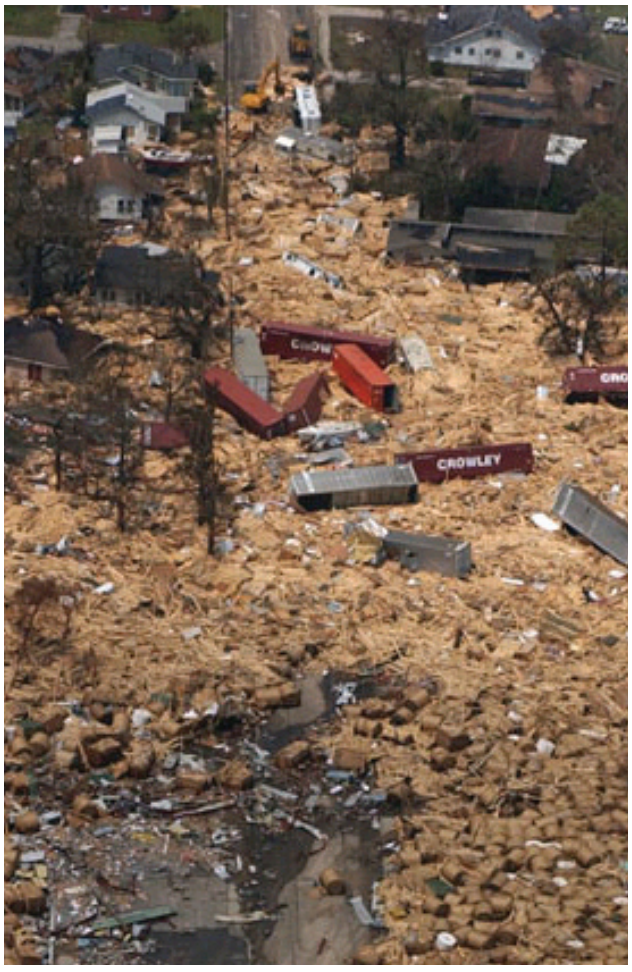


Photo 2-9

Debris, including shipping containers, transported by the surge, Gulfport, MS.

Photo 2-10

Debris and destroyed houses, Waveland, MS.

APPENDIX D–3
Buoyancy

Photo 3-1 Ultimate Chase, Inc., www.ultimatechase.com
Photo 3-2 Knight Ridder, Inc., www.sunherald.com
Photo 3-3 Ultimate Chase, Inc., www.ultimatechase.com
Photo 3-4 Ultimate Chase, Inc., www.ultimatechase.com
Photo 3-5 al.com, LLC, www.al.com

Photo 3-1

Surge and waves float and transport a car, Gulfport, MS.

Photo 3-2

Vehicles and other debris washes down Lamese Street, Biloxi, MS.

Photo 3-3

Surge and waves carry a vehicle towards a hotel lobby, Gulfport, MS.

Photo 3-4

Car transported by surge enters a hotel lobby (its lights shorted on), Gulfport, MS.

Photo 3-5

House that floated off its foundation ends up in a street, Pascagoula, MS.

Appendix D–4
Washover

Photo 4-1 Knight Ridder, Inc., www.sunherald.com
Photo 4-2 al.com, LLC, www.al.com
Photo 4-3 al.com, LLC, www.al.com
Photo 4-4 al.com, LLC, www.al.com

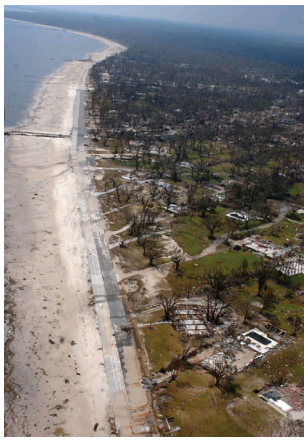


Photo 4-1

Sand washover deposited by the surge in Waveland, MS.

Photo 4-2

Water and wind-carried sand deposited on Dauphin Island, AL.

Photo 4-3

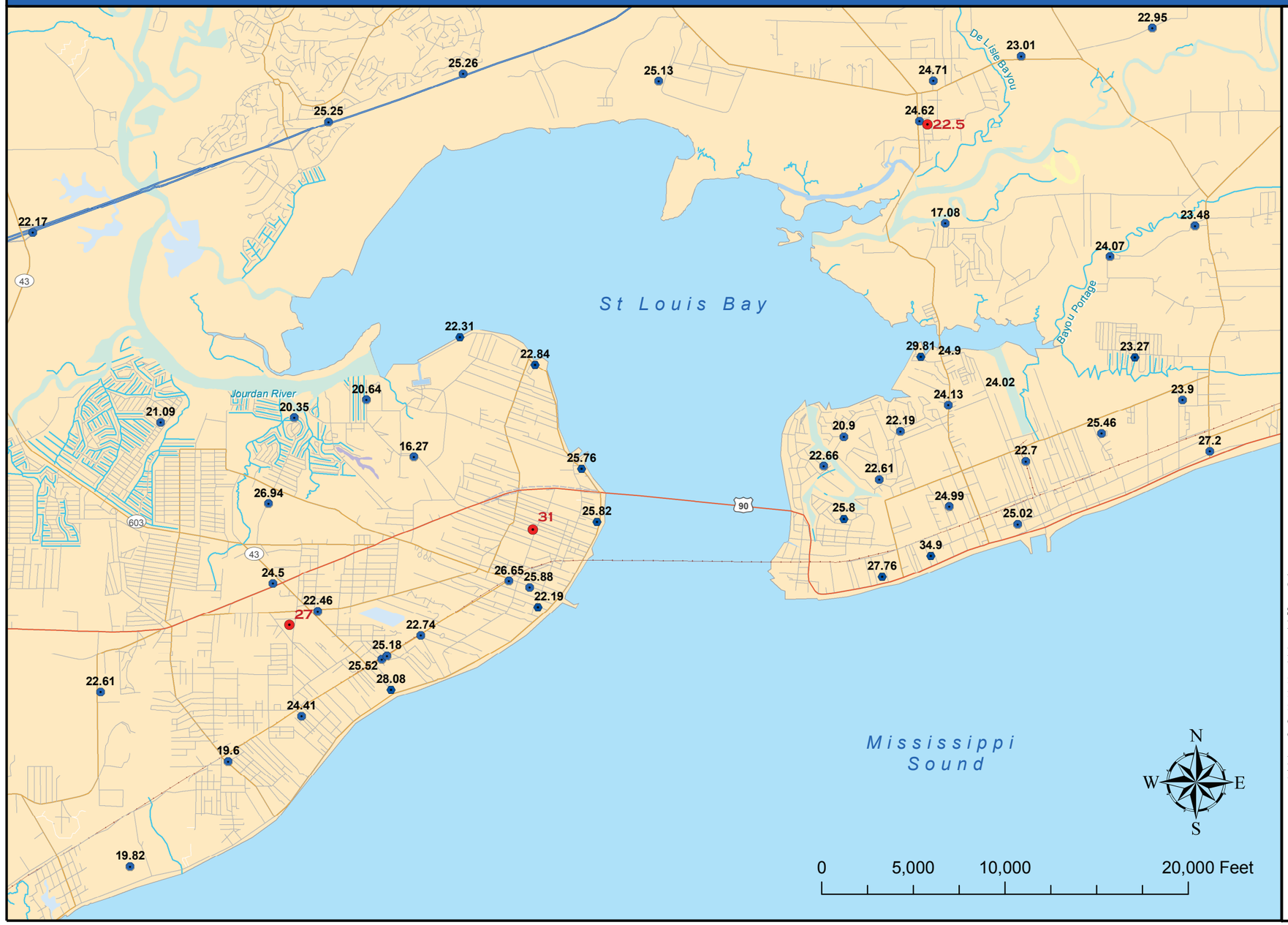
Sand deposited in ground floor of a hotel on Dauphin Island, AL.

Photo 4-4

Sand deposition on the road between Gulf Shores and Orange Beach, AL.

Appendix E
High Water Marks on the Mississippi Coast

APPENDIX E: ST LOUIS BAY HIGH WATER MARKS, MAP 1



Legend

- Elevations from Conversations (ft)

High Water Marks

- Wave Runup (ft)
- Surge Height (ft)
- Wave Height (ft)

APPENDIX E: High Water Marks, Mississippi Coast, 2005

Source: High Water Marks taken from URS, 2006. Elevations from conversations taken from Deschu, 2006.

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Notes: High Water Marks represent elevation NAVD 1988

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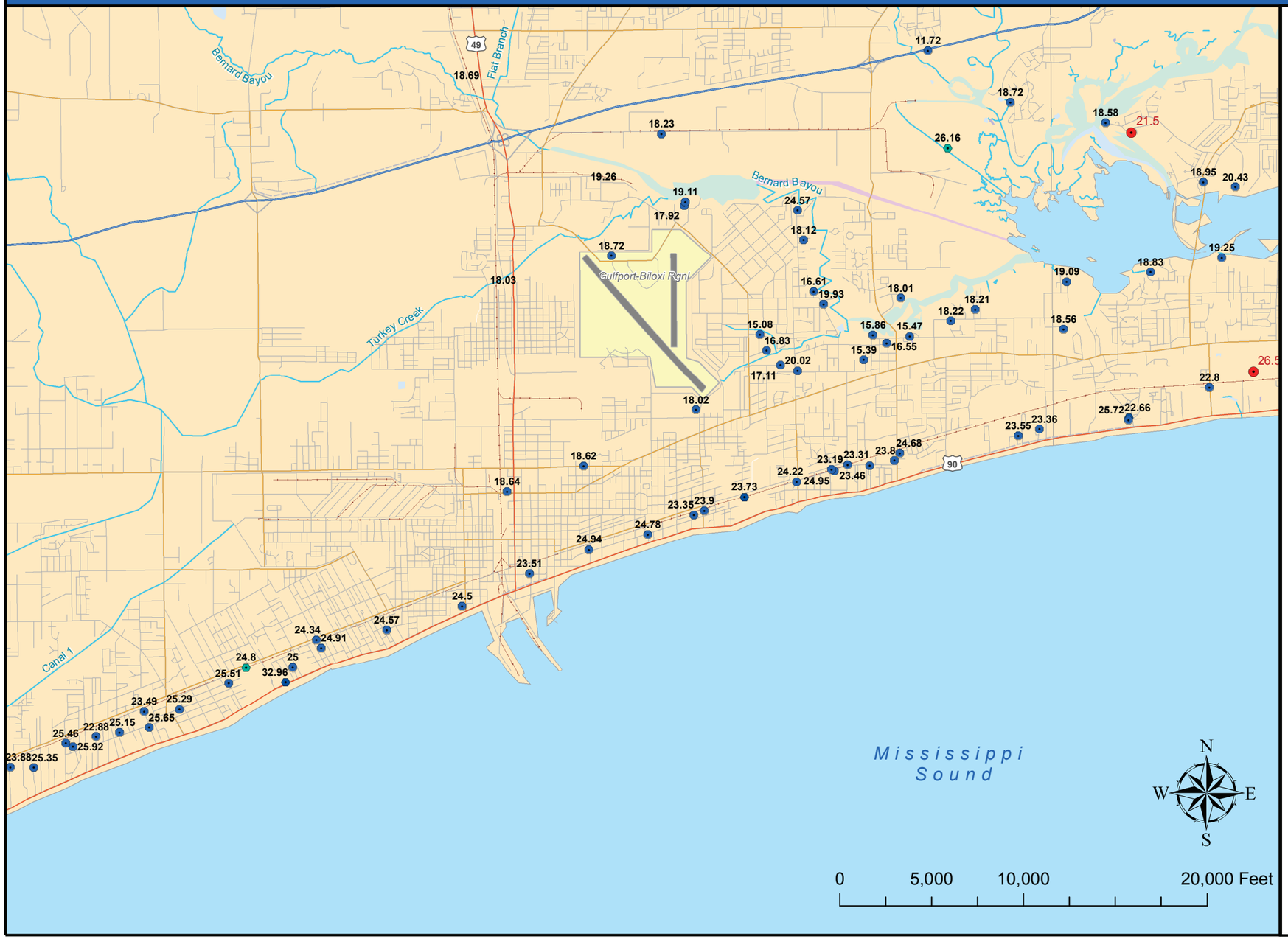
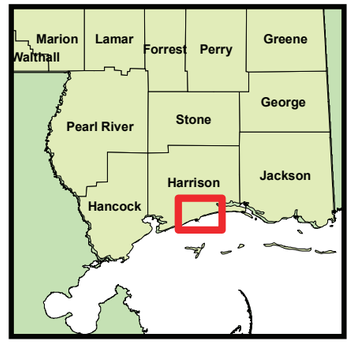
APPENDIX E: BILOXI RIVER & BERNARD BAYOU, MAP 2





Legend

- Elevations from Conversations (ft)

High Water Marks

- Wave Runup (ft)
- Surge Hieght (ft)
- Wave Hieght (ft)

APPENDIX E: High Water Marks, Mississippi Coast, 2005

Source: High Water Marks taken from URS, 2006. Elevations from conversations taken from Deschu, 2006.

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Notes: High Water Marks represent elevation NAVD 1988.

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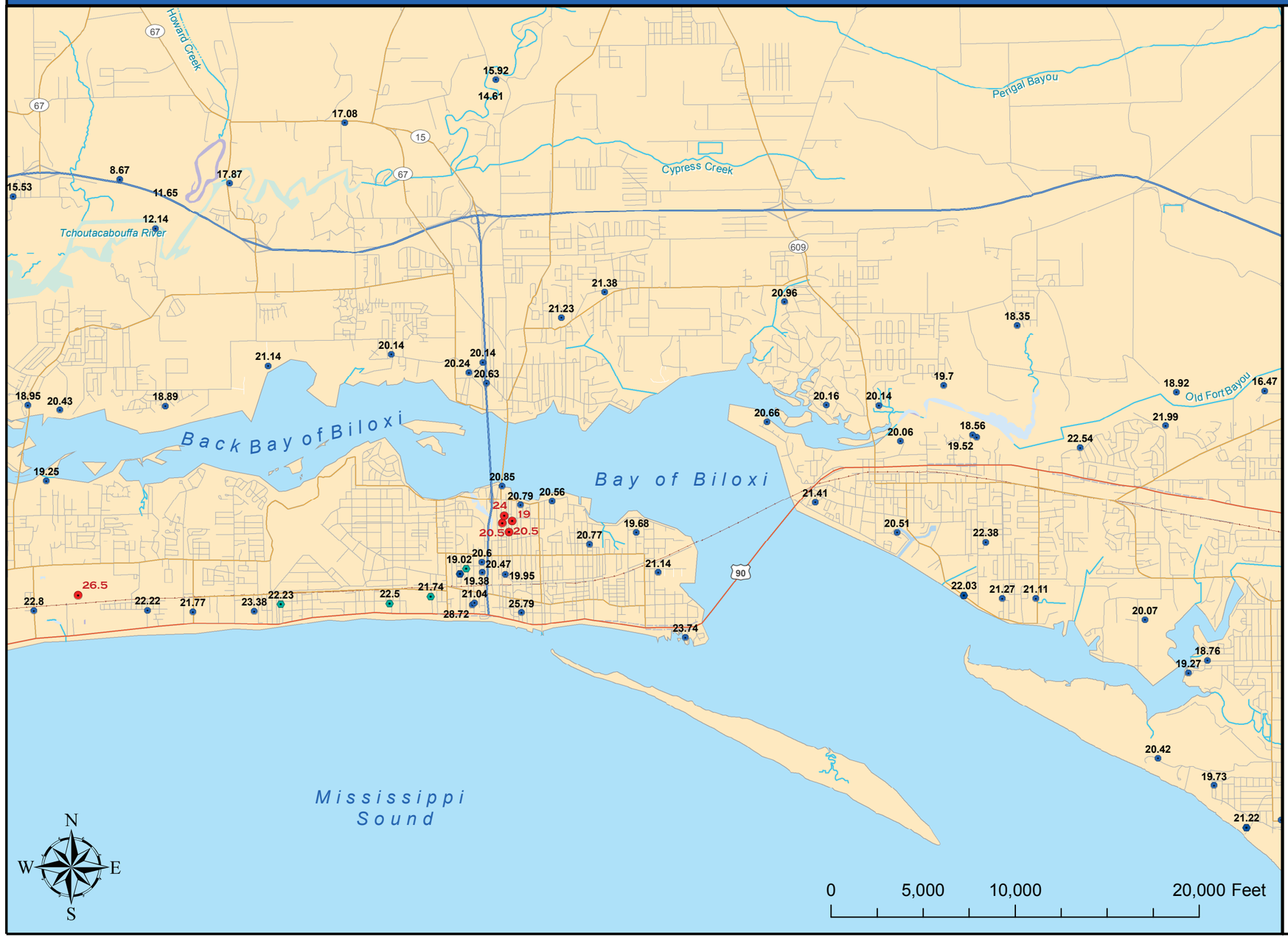
APPENDIX E: BAY OF BILOXI HIGH WATER MARKS, MAP 3



Legend

- Elevations from Conversations (ft)

High Water Marks

- Wave Runup (ft)
- Surge Height (ft)
- Wave Height (ft)

APPENDIX E: High Water Marks, Mississippi Coast, 2005

Source: High Water Marks taken from URS, 2006. Elevations from conversations taken from Deschu, 2006.

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Notes: High Water Marks represent elevation NAVD 1988

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