

SSPEED Center Phase I Report

*Learning the Lessons of Hurricane Ike:
Preparing for the Next Big One*

NOVEMBER 2011



ABOUT THE SSPEED CENTER

The Need For SSPEED

In the aftermath of Hurricanes Katrina and Rita it was obvious that there needed to be a technical discussion about the damage that hurricanes can cause along the Gulf Coast. The Severe Storm Prediction, Education and Evacuation from Disasters (SSPEED) Center was established in 2007 as a university based research and education organization.

Led by Rice University, the SSPEED Center organizes leading universities, researchers, emergency managers, and private and public entities to advance research that supports the creation and dissemination of knowledge to better address severe storms and their impact on the Gulf Coast.

Houston Endowment

The SSPEED Center is most grateful to the Houston Endowment which has made this research possible. In April 2011, the Houston Endowment awarded the SSPEED Center a three-year grant. This is a follow-up to the earlier two year grant funded in 2009, based on the needs immediately following Hurricane Ike.

With this new grant, the Center is able to offer educational outreach seminars to local area high school students, training and conferences for government officials and emergency managers and planners, and is able to continue the next phase of research with our collaborative team of over fifteen institutions. The figure below shows the general region in which SSPEED research projects are being developed.

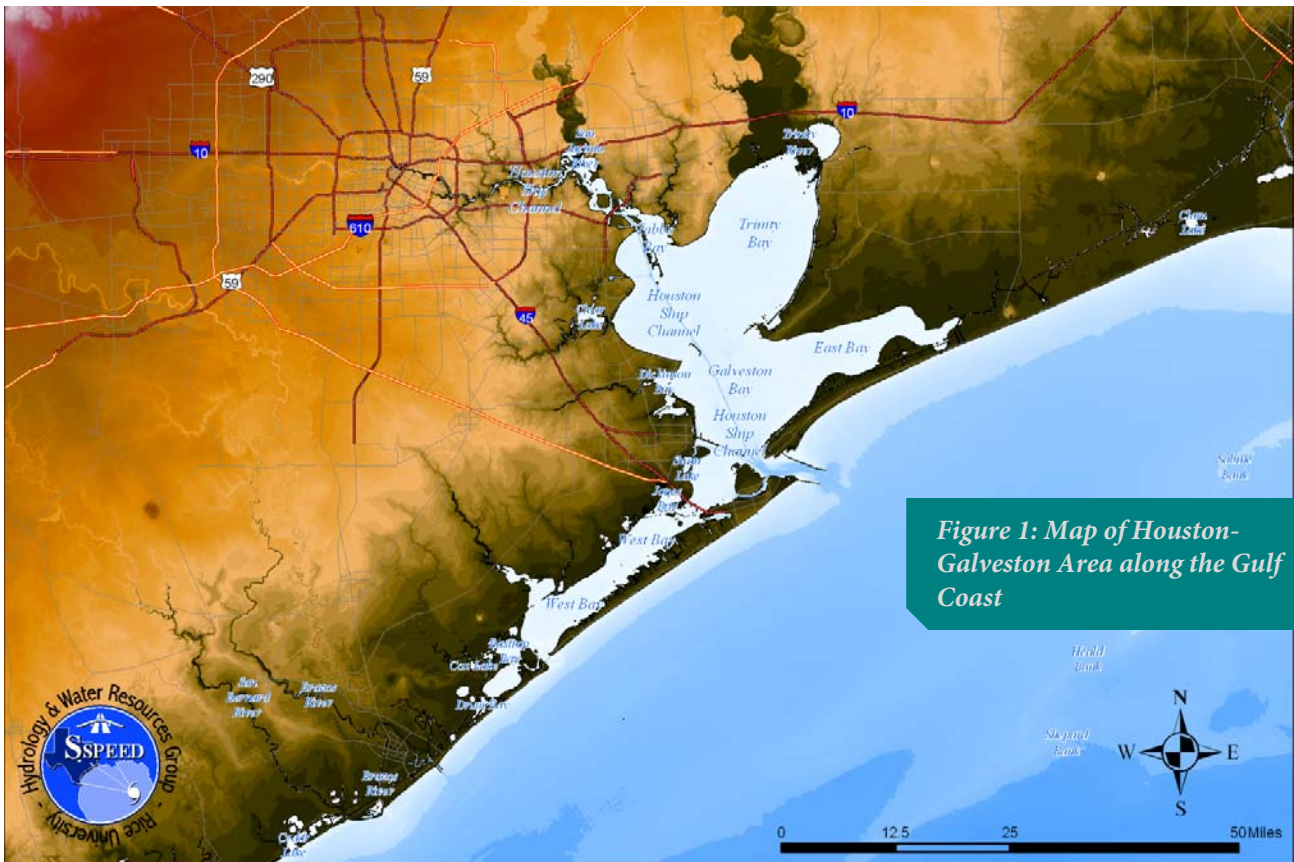


Figure 1: Map of Houston-Galveston Area along the Gulf Coast

On September 13, 2008 Hurricane Ike made landfall at Galveston Island, Texas. Hurricane Ike was a significant wind and surge event, knocking down power lines and flooding entire communities. The devastation to the Houston/Galveston region caused in excess of \$24 billion in damages and dozens of deaths. However, research conducted at the SSPEED Center has shown that had Ike made landfall 30-50 miles further down the coast, the situation would have been much worse and the damages catastrophic. Ike would have inundated much of the coastline in more than 20 feet of surge, including the barrier islands, the communities along West Galveston Bayshore and the Houston Ship Channel.

In the wake of Hurricane Ike, the Houston Endowment funded the SSPEED Center to identify the lessons learned from the storm and evaluate Houston's preparedness. The conclusions from Phase I of the Center's research can be found in the book *Lessons from Hurricane Ike* (to be published by A&M Press, 2012). In 2011, the Houston Endowment funded the SSPEED Center with an additional three-year grant to continue researching the impacts of hurricane events in the Houston/Galveston region. The SSPEED Center has also begun to propose mitigation strategies for the region.

Hurricane Ike served to highlight the vulnerability of this region to severe storms, but Ike also followed an eerily similar path to the Galveston Hurricane of 1900, indicating that the event was not unprecedented. Often, the delay between events causes citizens to forget how vulnerable a region is. Much like after Tropical Storm Allison and Hurricanes Rita and Katrina, public awareness about the damage inflicted by large storms near Texas peaked and then tapered off a few years later. Over time this forgetfulness manifests itself in a sort of apathy towards large events. Severe storms along the Upper Texas Coast are inevitable and it is not unlikely that a hurricane even bigger and more devastating than Hurricane Ike will make landfall. The SSPEED Center aims to prepare the region by increasing public awareness and proposing small and large scale mitigation strategies.

As discussed in the previous report "Learning the Lessons of Hurricane Ike" (May 2010), the SSPEED Center has opted to take a "zone specific solution" approach to its mitigation strategies. Researchers have identified four zones on which the majority of the focus will be placed: the Houston Ship Channel, West Bayshore, Low-lying Coastal Areas, and Galveston Island. The following discussion introduces the organization and primary focus areas of the SSPEED Center for research, Phase II.

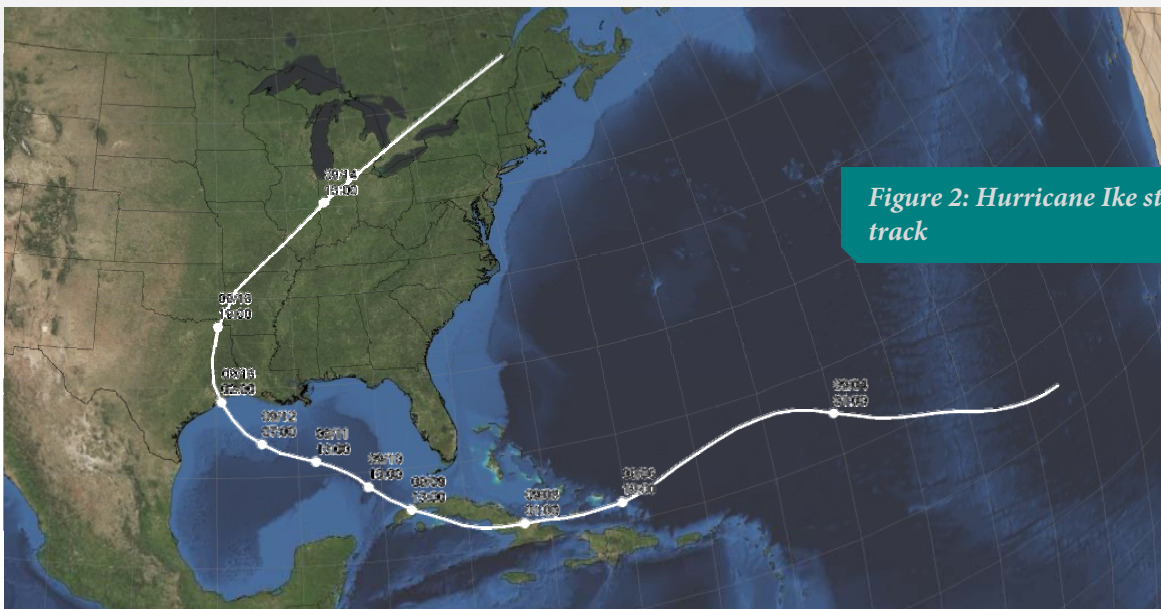


Figure 2: Hurricane Ike storm track

HOUSTON SHIP CHANNEL

The Houston Ship Channel is home to the nation's largest petrochemical complex and some of its most critical industrial facilities. However, many of the facilities are only protected to 14-16 feet above mean sea level and in the event of a large hurricane the damage to the region, as well as the national economy could be catastrophic. Facilities along the channel could be shut down for months and the environmental damage caused by chemical spills would be unprecedented. The SSPEED Center has identified two critical projects to be developed in the Houston Ship Channel:

1. Evaluation of a Gate and Levee Structure across the mouth of the Channel near Hartman Bridge
2. An Infrastructure Database and Damage Model

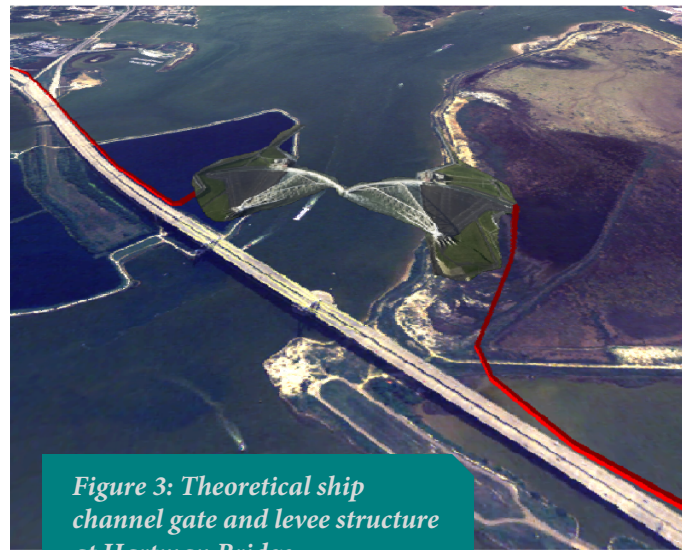


Figure 3: Theoretical ship channel gate and levee structure at Hartman Bridge.

Gate Structure

The SSPEED Center is currently examining the possibility of protecting the Ship Channel from storm surge by placing a moveable gate structure across the lower San Jacinto River in the vicinity of the Hartman Bridge (see Figure 4). This gate structure would prevent the upstream propagation of a storm surge from Galveston Bay and theoretically protect this critically important area by isolating it from the surge hazard. A consequence of closing this gate would be eliminating the outfall for the entire San Jacinto and HSC watersheds and their tributaries (a combined 5,200 square miles), so careful consideration of the structure and its likely operating characteristics is warranted.

Before such a structure is seriously considered, there must be some basic understanding of the minimum gate and levee dimensions, how the gate would be operated, what level of flood protection it could provide, how long the gate could stay closed without causing collateral flooding, and what happens hydraulically when the gate re-opens. These are not trivial questions. Finding the answers will be complicated by the fact that the processes involved

are highly dynamic, so understanding the timing of events is just as critical as understanding the events themselves.

The SSPEED Center is developing, calibrating and analyzing a dynamic HEC-RAS hydraulic model of the San Jacinto and HSC channels to provide preliminary guidance in evaluating this proposed levee and gate structure. This model will incorporate a dynamic storm surge boundary condition developed by the SSPEED ADCIRC modelers and take flow hydrographs from the latest hydrologic models of the watersheds. The model will incorporate LiDAR topographic data and will provide a fully dynamic analysis showing the state of all components throughout the analysis period (see Figure 5). It is expected this model will provide a preliminary screening tool to help SSPEED engineers and researchers assess the effectiveness, refine the preliminary design and communicate operational characteristics of this proposed flood control structure. This solution has a better chance of implementation in a reasonable time frame as opposed to the Ike Dike suggested earlier.

**HOUSTON SHIP CHANNEL
HYDRAULIC ANALYSIS**
SSPEED Center at Rice University

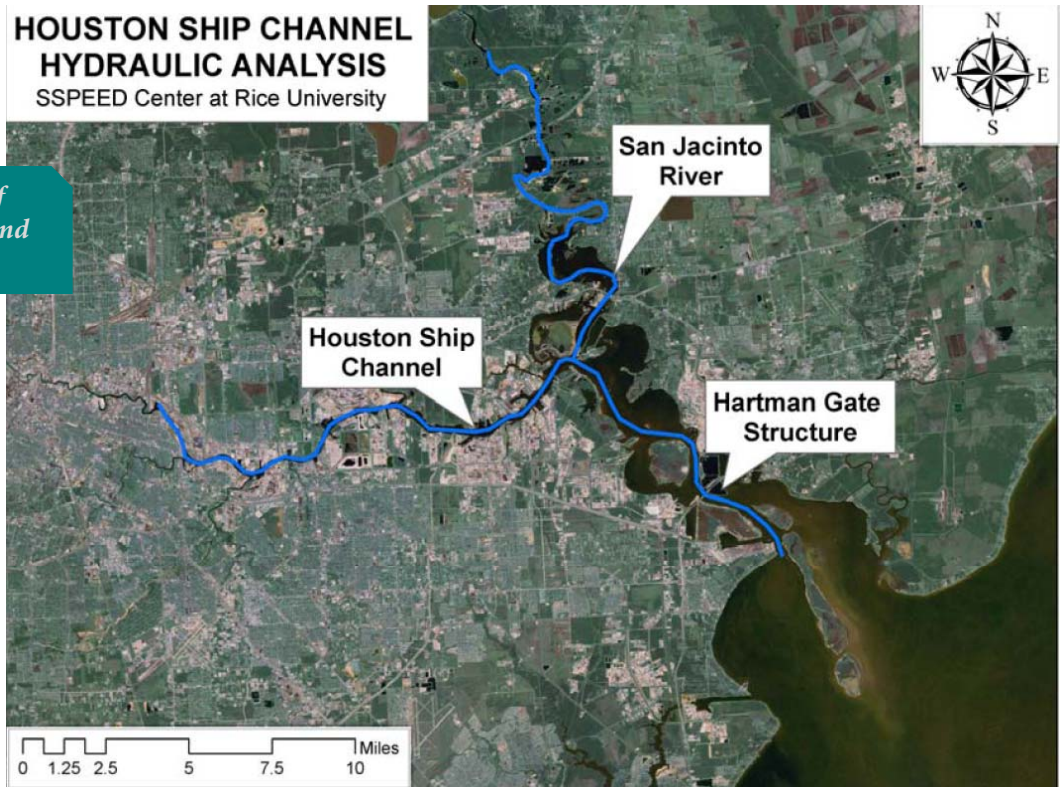
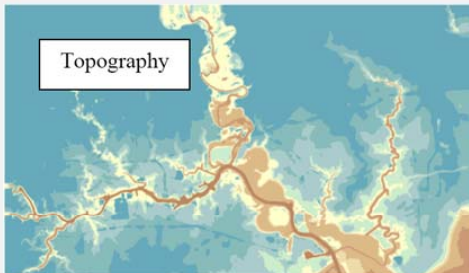
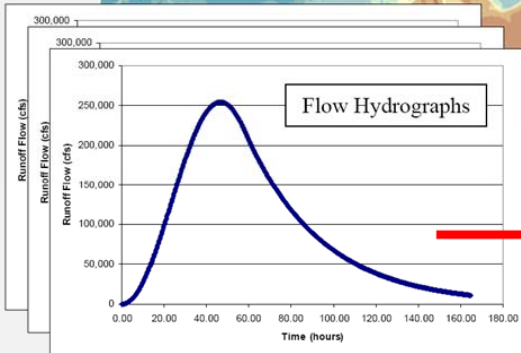


Figure 4: Vicinity map of Houston Ship Channel and San Jacinto River.



Topography



Flow Hydrographs

Channel Geometry

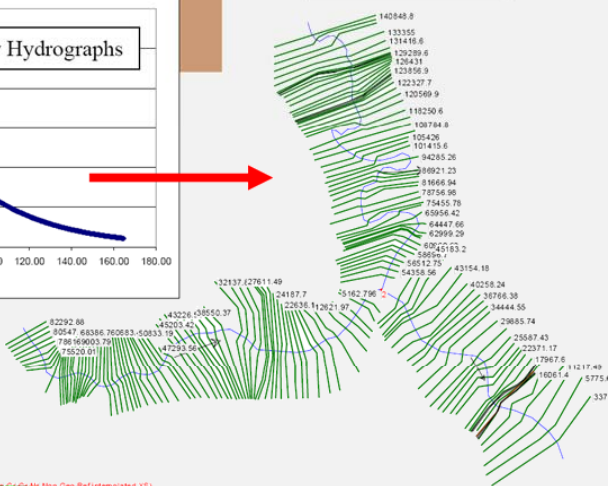


Figure 5: Inputs to the unsteady HEC-RAS Model.

Infrastructure Database and Damage Model



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ADCIRC modeling has indicated that storm surge in the Houston Ship Channel (HSC) could easily exceed 20 feet during a hurricane, inundating much of the infrastructure in the Channel. These results have highlighted the need for a detailed infrastructure database and damage model that will allow for the assessment of impacts on the Houston Ship Channel, as well as direct mitigation proposals for this zone.

The SSPEED Center has developed a spatially refined geodatabase that contains information about the industries, hazardous waste facilities and other critical infrastructure located along the HSC. In combination with results obtained from ADCIRC modeling for various hurricanes, this data can be used to analyze pre- and post-impacts on such facilities. In Figure 6, storage tanks are shown inundated by storm surge from a hurricane assumed to occur 30 miles to the west with winds 145 mph (Super Ike). In the next phase, the Center will begin to assess the probable economic and environmental damage to the region for any hurricane scenario.

During Phase I, the SSPEED Center began analysis of bay area bridges, compiling detailed information on 155 bridges over water in the bay area, which includes Galveston Island, Bolivar Peninsula and every bridge within approximately 1 mile of the Houston Ship Channel. This database is important to understanding coastal roadway infrastructure and measuring the risk to the system during hurricane events. Using the database and results provided from the ADCIRC Model, the probability of failure for each bridge due to deck uplift was evaluated. During Phase II, the research will be expanded to include other failure modes of bridges, such as scour.

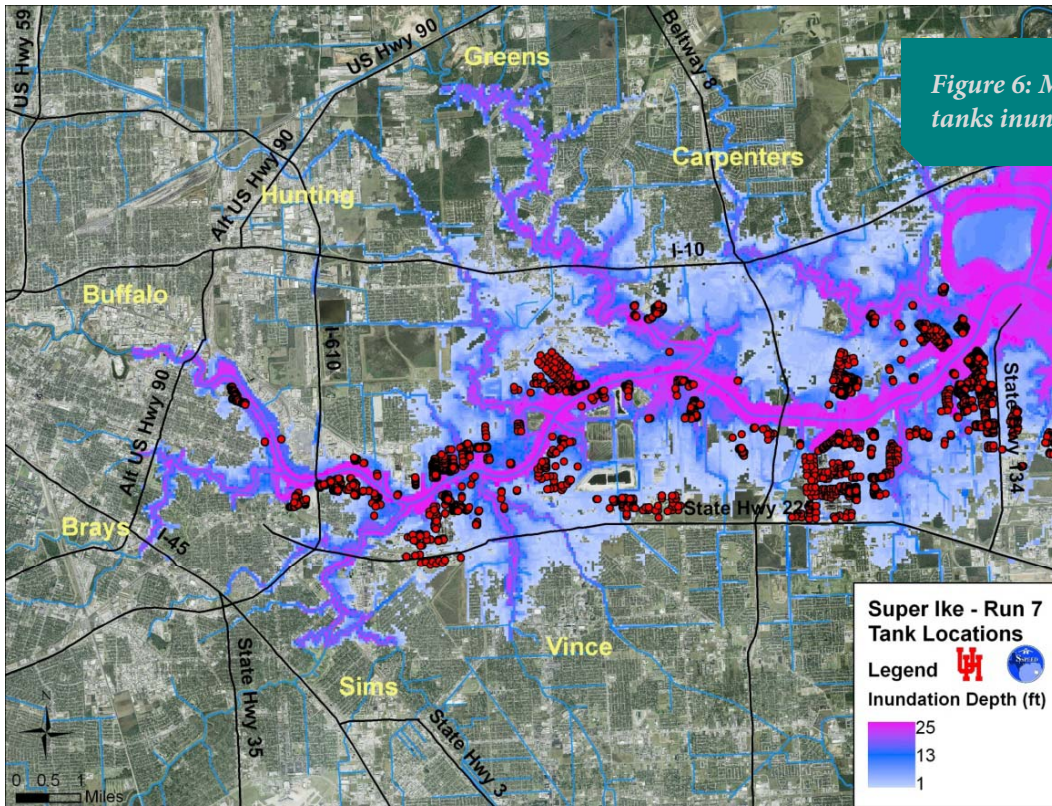
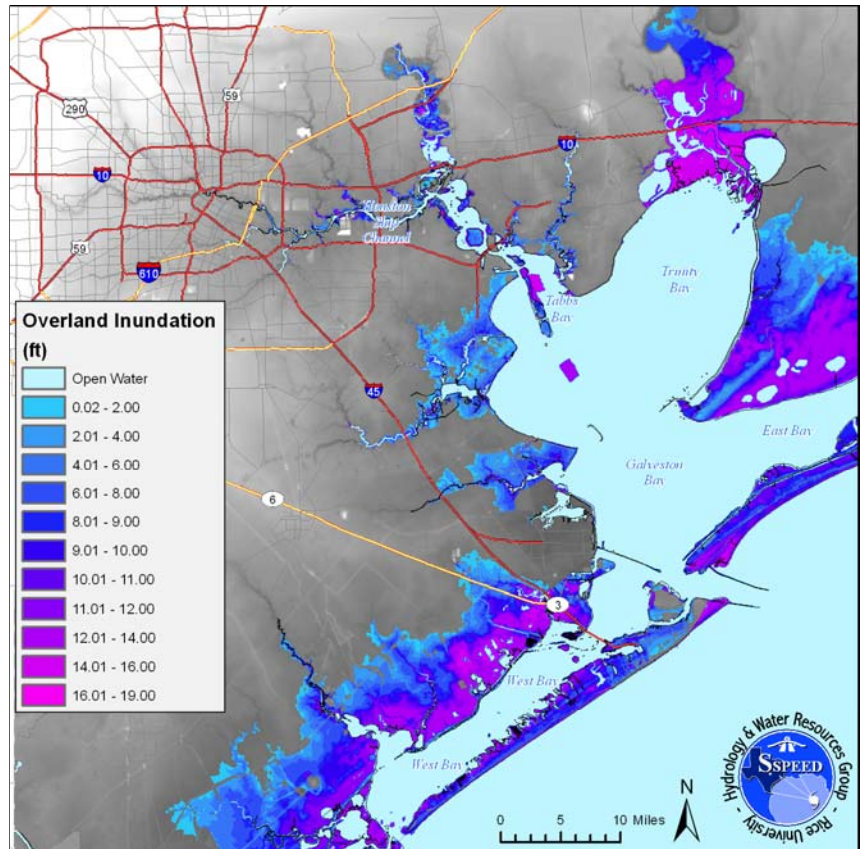


Figure 6: Map showing storage tanks inundated by Super Ike.

Figure 7: Storm surge in Galveston Bay, had Hurricane Ike made landfall approximately 30 miles further west.

Additionally, more emphasis will be placed on utilizing the regional risk assessment to assist decision makers on retrofit options and emergency managers on feasible post event re-entry routes into affected areas. This includes the main routes into the energy corridor of the Houston Ship Channel. The information will contribute to mitigation proposals in the other zone strategies to be discussed in subsequent sections. Such an assessment will result in recommended risk mitigation actions and emergency response support.



WEST BAYSHORE

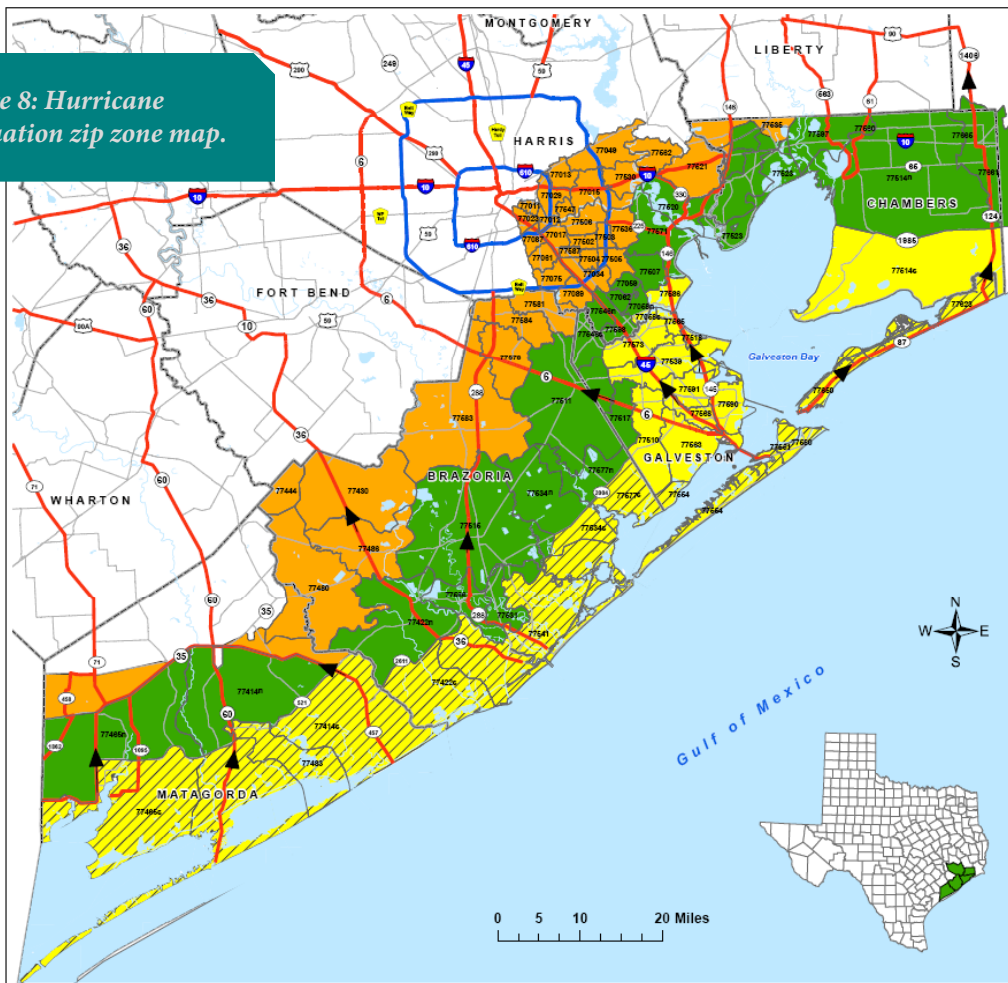
Currently, 1.5 million people live in the hurricane evacuation zones illustrated in Figure 8 amounting to approximately 20% of the total population of Harris County. According to H-GAC projections, by 2035 the population of the 4 coastal zones will increase by 0.812 million reaching 2.382 million, exacerbating an already existing problem. The Houston/Galveston Area Council (2007) estimates that 1 million people can be effectively moved out of this area in 36 hours, however, given current infrastructure, evacuating approximately 2 million people in advance of a hurricane is likely to be impossible.

The SSPEED Center has identified the area west of Galveston Bay as an important zone in which to focus its research efforts. The majority of this area is

located in Zip Zone A, one of the first zones to evacuate during a severe storm event. Much of the projected population growth is likely to be in this area, placing people, communities and critical facilities in danger of flooding. Some protection is necessary, but risk awareness is key. Given a large storm, upwards of 2 million people could be seriously impacted by flooding. The SSPEED Center has identified a series of projects that will raise awareness and help protect vulnerable communities:

1. Risk Disclosure
2. Clear Creek Flood Alert System and Infrastructure Risk Modeling
3. Surge Barrier

Figure 8: Hurricane evacuation zip zone map.



Brazoria, Chambers, Galveston, Harris and Matagorda Hurricane Evacuation Zip-Zones Coastal, A, B, C

Zip-Zone Coastal				
77414s	77483	77550	77577s	77660
77422s	77534s	77551	77617	
77465s	77541	77554	77623	
Zip-Zone A				
77055s	77518	77525	77558	
77510	77539	77568	77590	
77514s	77563	77573	77591	
Zip-Zone B				
77056m	77207	77222	77260	77661
77059	77511	77523	77596	77665
77062	77514n	77531	77571	
77414n	77515	77534n	77577n	
77422n	77517	77546n	77607	
77426m	77520	77545s	77608	
Zip-Zone C				
77011	77034	77444	77505	77562
77012	77049	77483	77506	77578
77013	77061	77480	77621	77581
77015	77075	77488	77630	77583
77017	77087	77502	77635	77584
77023	77089	77503	77638	77587
77029	77430	77504	77547	

Route Designation

- Evacuation Corridors (Red line with arrow)
- Evacuation Connections (Blue line)
- Other Roads (Grey line)
- County Boundary (Dashed line)

Risk Disclosure

Shortly after Hurricane Ike, Precinct 2 erected markers indicating probable height of storm surge given hurricane category for the Clear Lake area. Immediately, local real estate agents and homeowners demanded that they be removed, fearing the effect that this information could have on home values. The markers indicated that during a Category 5 hurricane, surge could easily exceed 12-15 feet, completely inundating the first floor of most homes. Despite the uproar caused by the markers, their purpose was justified. Public awareness about vulnerability must be increased.

Most Houstonians do not view Houston as a coastal city and current FEMA floodplain maps do not incorporate storm surge in the West Bayshore area. Prospective home buyers and current home owners are caught unaware when big storms make landfall. The SSPEED Center is examining the causes and consequences of

development in coastal watersheds including how land use change and development patterns drive populations to expose themselves to natural hazards, such as hurricanes.

The SSPEED Center has proposed working with local governments and other emergency managers to develop standards for buildings and real-estate that would disclose information about vulnerability to storm surge and flooding without condemning development in these areas. In order to facilitate construction, enhanced building codes must be developed and appropriate base flood elevations must be defined and enforced. At the same time, infrastructure should be hardened to withstand the ravages of severe weather events wherever it is constructed, whether the areas exposed to simple rainwater flooding and high winds or areas exposed to serious storm surge and wave action.



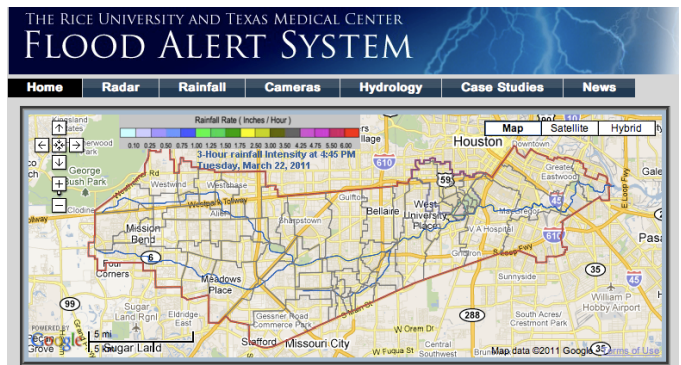
Storm surge inundated much of Kemah. Many residences and businesses were completely demolished during Hurricane Ike.

Highway 146, a main evacuation route, was littered with major debris created from storm surge in Galveston Bay.



Flood Alert System

Cities in West Bayshore are at risk of flooding, even during small events. The flat topography exacerbates street flooding, often overwhelming stormwater systems and resulting in overland flow into surrounding gullies and bayous. The SSPEED Center is currently developing a Flood Alert System (FAS) for Clear Creek which would advise residents of potential flood stage in the area. The model would function in real-time, interpreting radar rainfall data and predicting the rise and fall of the hydrograph in Clear Creek. This technologically has been successfully implemented in the Texas Medical Center and the City of Sugarland and is used by emergency managers and planners to determine how and when to protect critical facilities and communities.



Such a system has not yet been implemented in a coastal area and the Clear Lake FAS system will be the first such system to incorporate storm surge. Although most residents will be evacuated well in advance of the onset of surge, the system can be used by emergency managers to aid with the recovery and re-entry process. The bay area bridge analysis, discussed in previous sections, will help emergency managers predict which bridges may be damaged, allowing reconnaissance teams to approach these high risk bridges first after a storm, speeding the recovery and re-entry process. The system will provide a forum for which emergency managers can communicate with residents, increasing awareness about flood events, but also aiding post-event recovery. A system of this type will be particularly useful to this area as population continues to grow.

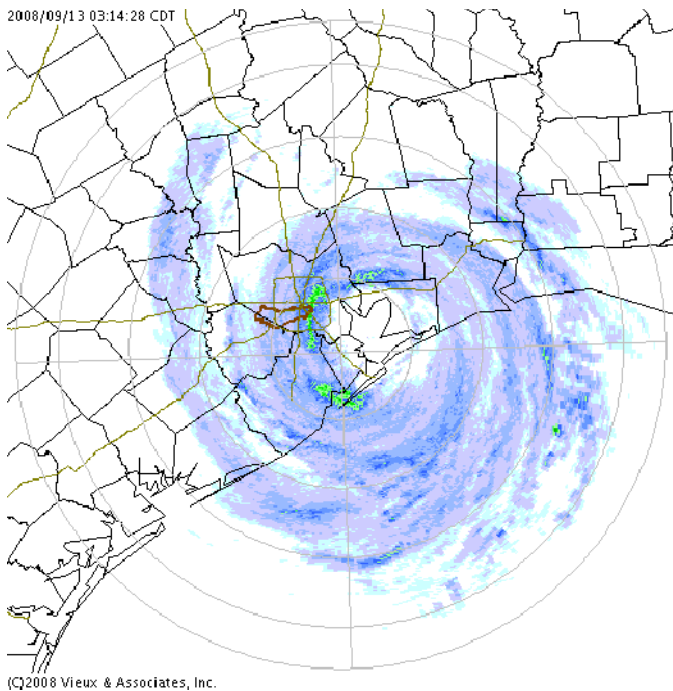


Figure 9: Radar image as Hurricane Ike makes landfall at Galveston, Texas.



Surge Barrier

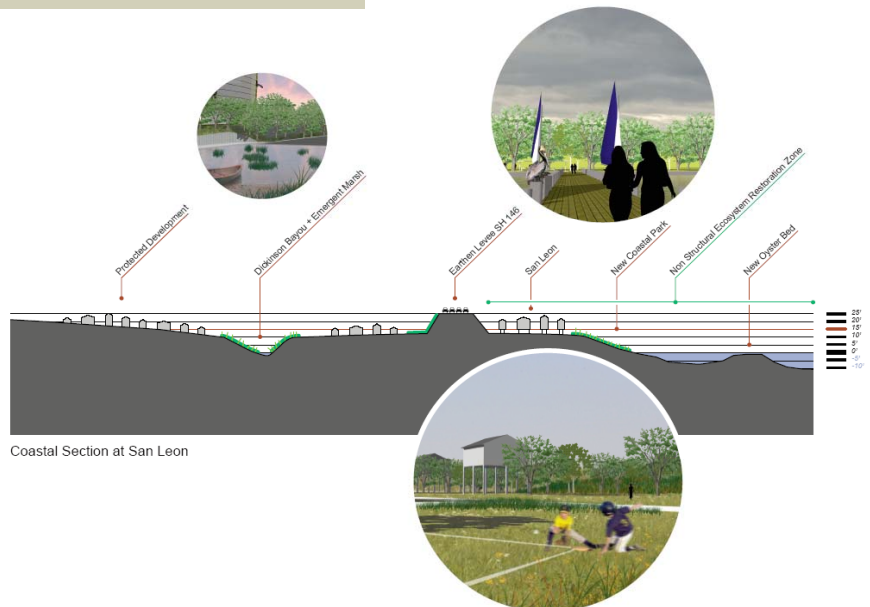
The SSPEED Center has identified areas below 5 feet elevation as high risk and those below 25 feet as moderate risk to storm surge inundation. Most of the communities in West Bayshore lie below 25 feet msl. Given the size of the affected population in this area, the SSPEED Center is proposing that it be protected by a structural levee system. The Center has examined a series of possible levee alignments, including pocket levees built by large land-owners, a bay front levee, a levee along SH-146 and various hybrids of these alternatives.

Preliminary research results indicate that the most

feasible structure will be a levee along SH-146 accompanied by pocket levees, built by private landowners. The levee would connect natural 25 foot elevations near the Houston Ship Channel and the Texas City Dike, effectively protecting the properties and critical facilities and infrastructure west of SH-146. However, moveable barriers would need to be placed at Clear Lake and highway underpasses. Furthermore, this proposal leaves waterfront properties and communities east of SH-146 vulnerable; however, it maintains the possibility of waterfront recreation and other environmental and natural coastal features.



The SSPEED Center has proposed a levee structure aligned along SH-146 to protect West Bayshore. The adjacent schematics display the integration of the levee structure in communities along the coastline.



GALVESTON ISLAND

Galveston Island is extremely vulnerable to severe storms. In the event of a hurricane, it can become completely inaccessible from the mainland and inundated by storm surge. The utter destruction caused by the Galveston Hurricane of 1900 prompted the construction of a 17 foot high seawall along the gulf-side of the island. During 2008, the seawall provided protection against Ike's powerful waves; however, as Galveston Bay responded to surge, floodwaters crept up through downtown, flooding homes and businesses from the bay-side of the island. After Hurricane Ike, many Galveston residents did not return. Much of the island is still

recovering and many homes and businesses are still under repair.

The SSPEED Center has determined that the businesses in downtown Galveston, as well as UTMB, should be protected by a bay-side levee. Researchers at the center are analyzing possible levee alignments including different configurations along the north side of downtown, inclusion of a levee and gate connecting Galveston and Pelican Islands, and a separate Pelican Island alternative. The figures below shows two possible levee alignments proposed by the center.

Figure 10: Bayside levee alignment protecting Galveston.



Figure 11: Bayside levee alignment protecting Galveston and Pelican Island.



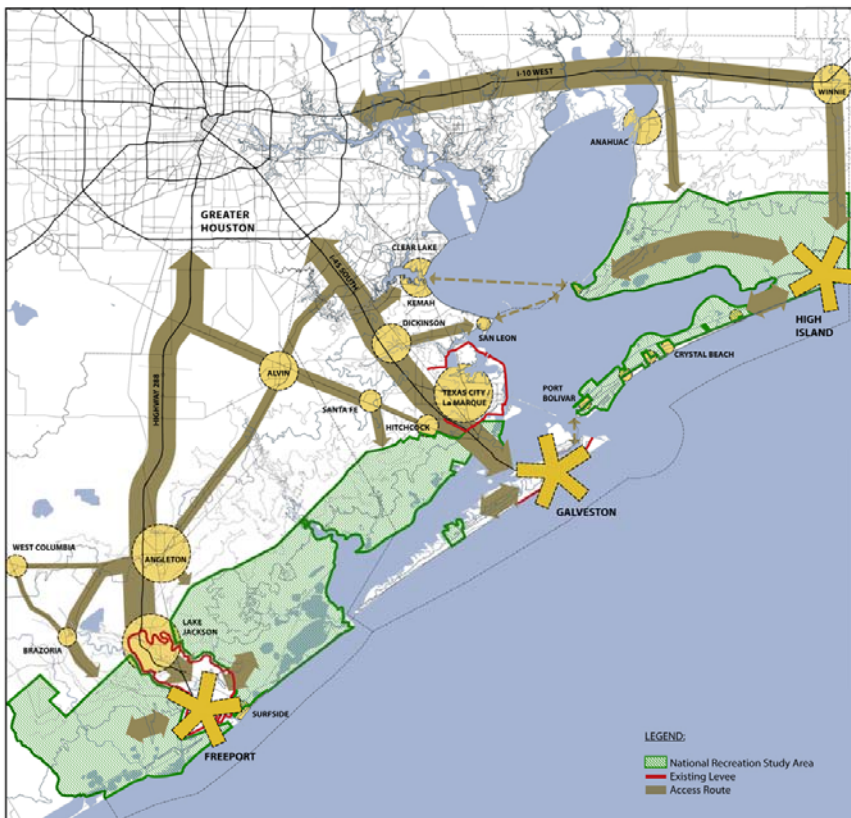
COASTAL RECREATIONAL AREA

In the wake of Hurricane Ike, researchers at the SSPEED Center were struck with the surge mitigation potential that the low-lying coastal areas are capable of providing to the region. The researchers began to discuss innovative ways to recognize those flood abatement characteristics of the coastal marshes. A concept that emerged involved rethinking and perhaps redefining the coastal economy to capitalize on the recreational and economic value of these low-lying lands. The initial study area covers about 450,000 acres of tidal marshland, brackish wetlands and coastal prairie and about 150,000 acres of bay and estuarine area.

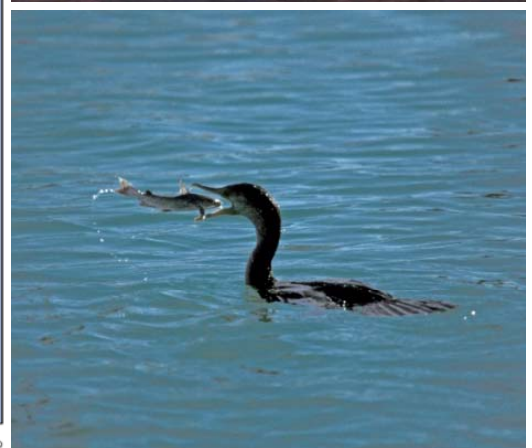
A survey of this area revealed that some of the best bird-watching and coastal kayaking in the United States exists within the low-lying areas of the Upper Texas Coast. Four of the top nine Christmas bird counts in the United States exist in the mid to upper Texas coast along with world famous sites such as High Island and Bolivar Flats for spring and fall

migrations. What is lacking is an institutional and governmental framework to organize the latent economic potential of these low-lying areas. As such, the SSPEED Center is proposing to create a recreational area of such importance that it would be worthy of national recognition.

This non-structural flood control concept would be formed by a partnership agreement among willing partners. Preliminary discussions have indicated that local governments, some state agencies, some federal agencies and numerous non-governmental organizations would be willing to join together voluntarily to form such a recreation partnership. Such a partnership would promote economic development in the region. Outdoor recreation is one of the largest retail sectors in the United States. The recreation and economic development area would provide a model for future creative non-structural flood control.



Houston-Galveston Region - National Recreation Study Area + Surrounding Communities



CONCLUSION

In the wake of Hurricane Ike, the SSPEED Center was funded by the Houston Endowment to address lessons learned and steps to the future. The conclusions from Phase I of this research can be found in *Lessons from Hurricane Ike* (Texas A&M Press, forthcoming 2012). Hurricane Ike highlighted the vulnerability of the region to severe storms and clearly pointed to the need for a comprehensive assessment of risk and the development of mitigation strategies. As a result of this work, the Center identified four zones in which focus will be placed: Houston Ship Channel, West Bayshore, low-lying coastal areas, and Galveston Island.

Significant modeling and GIS-based analyses have been performed on each of these areas in an effort to provide specific strategies for risk mitigation and emergency management. For example, based on ADCIRC modeling of variations of Hurricane Ike, the Center has recommended that a gate structure be placed at the entrance to the Houston Ship Channel near Hartman Bridge. In the West Bayshore area, the SSPEED Center is developing a flood alert system, similar to the one at the Texas Medical Center. The Center is also evaluating the possibility storm surge barrier along SH-146 due to population density in the area.

A very exciting concept is the creation of a recreation, conservation and economic

development area along the upper Texas coast. The Coastal Recreational Partnership is a major non-structural risk mitigation option that would emphasize the natural resources of the region. Details can be found in the concept brochure from the SSPEED Center (forthcoming 2011). Finally, the SSPEED Center has proposed protecting Galveston Island with a bay-side levee due to its extreme vulnerability to storm surge.

The SSPEED Center, through its major conferences (September 2009, May and September 2010), meetings, presentations, websites and publications, has reached out to the public and many organizations, including the Ship Channel, Clear Lake City and surrounding municipalities, Galveston Island leadership, the Surge District, the City of Houston, and the Greater Houston Partnership. These discussions have led to strong commitments of support by groups like Houston Galveston Area Council, Houston Wilderness, Galveston Bay Foundation, the Shell Center, and the Army Corps of Engineers, among others. These meetings have led to an open dialogue and awareness about coastal resiliency and mitigation strategies in the region. The choices that are made in the next several years will have a direct impact on the physical form of the upper Texas coast for decades to come.

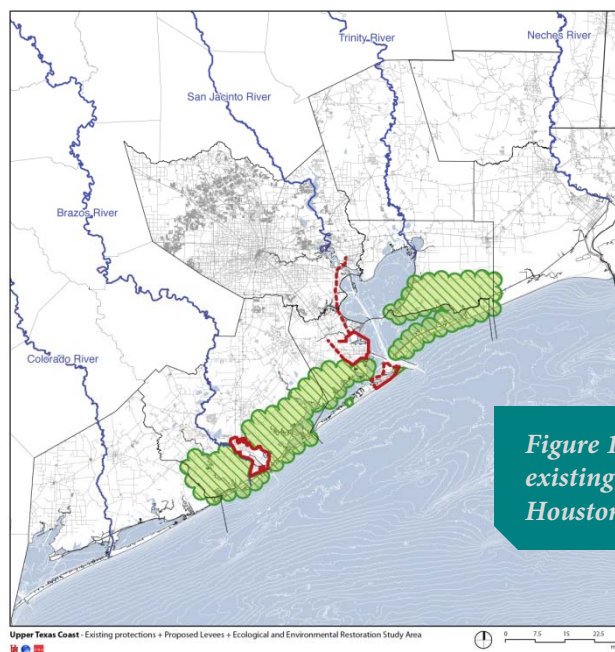


Figure 12: Proposed future and existing conditions for the Houston/Galveston region.

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