



## HOUSTON-AREA SURGE FLOODING AND ITS EFFECTS ON REGIONAL AND NATIONAL SECURITY

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“Houston-Area Surge Flooding and Its Effects on Regional and National Security”

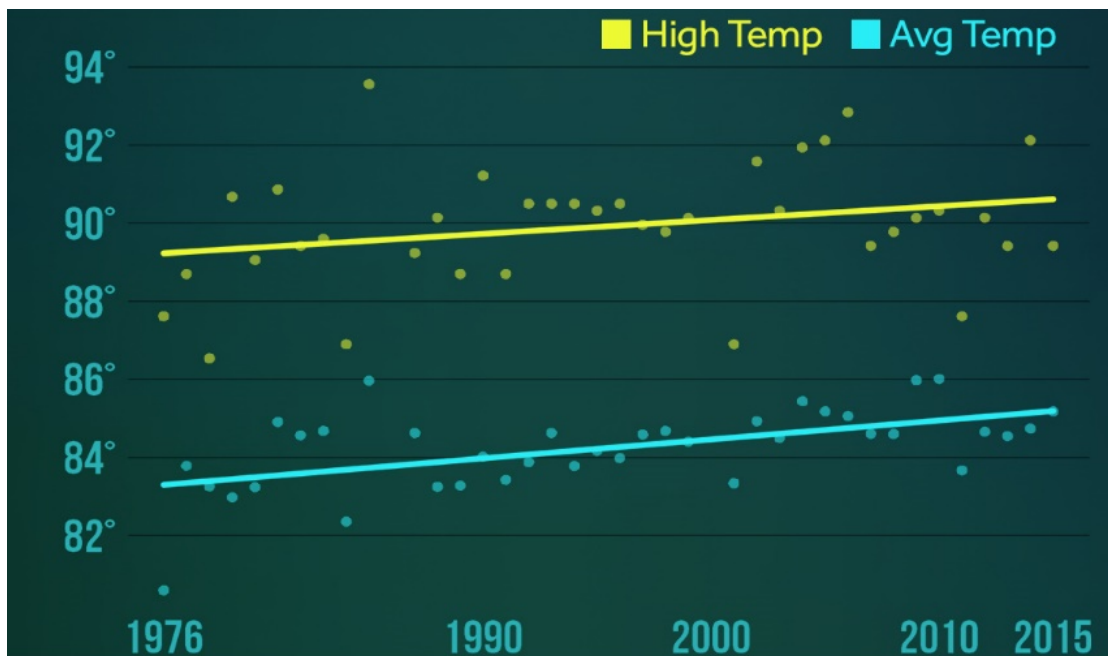
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Hurricane surge flooding is often overlooked in Houston, particularly in the years after Hurricane Harvey, which was a rainfall flooding event. However, no issue poses a greater threat to the economic security of the area than does surge flooding, due to the high likelihood of property damage and a potentially massive loss of life. Surge flooding would also affect the Houston Ship Channel, the Texas City refining complex, and the Bayport Industrial District, all of which represent key suppliers of refined oil products and plastics. The loss of production in the Galveston Bay shoreline area would profoundly affect U.S. national security, regional and local economies in Texas, and people's lives and well-being.

### The Climate Is Changing

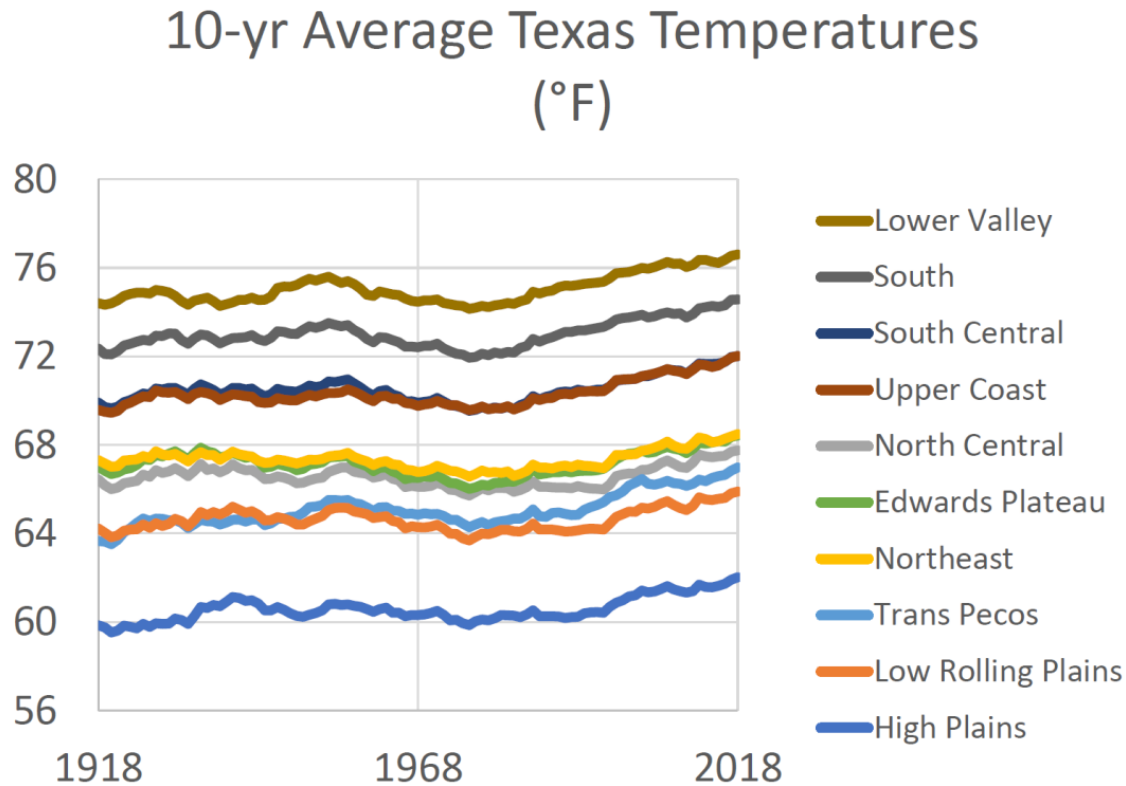
The climate is changing, and it is unfortunately taking a toll on the region through associated flooding. The reality is that the storms of today are different from those of the past; they are larger and more intense. Hurricanes are fueled by the heat of the ocean, and the Gulf of Mexico is getting warmer (Figure 1). The atmosphere is also warming (Figure 2), and hot air holds more moisture. This combination of hotter air and water leads to more evaporation from the Gulf. As these temperatures increase, storms will continue to worsen. Together, these factors will dramatically change the future.

**Figure 1.** Western Gulf of Mexico average and high temperature trends from 1976 to 2015



Source: National Oceanic and Atmospheric Administration, National Data Buoy Center.

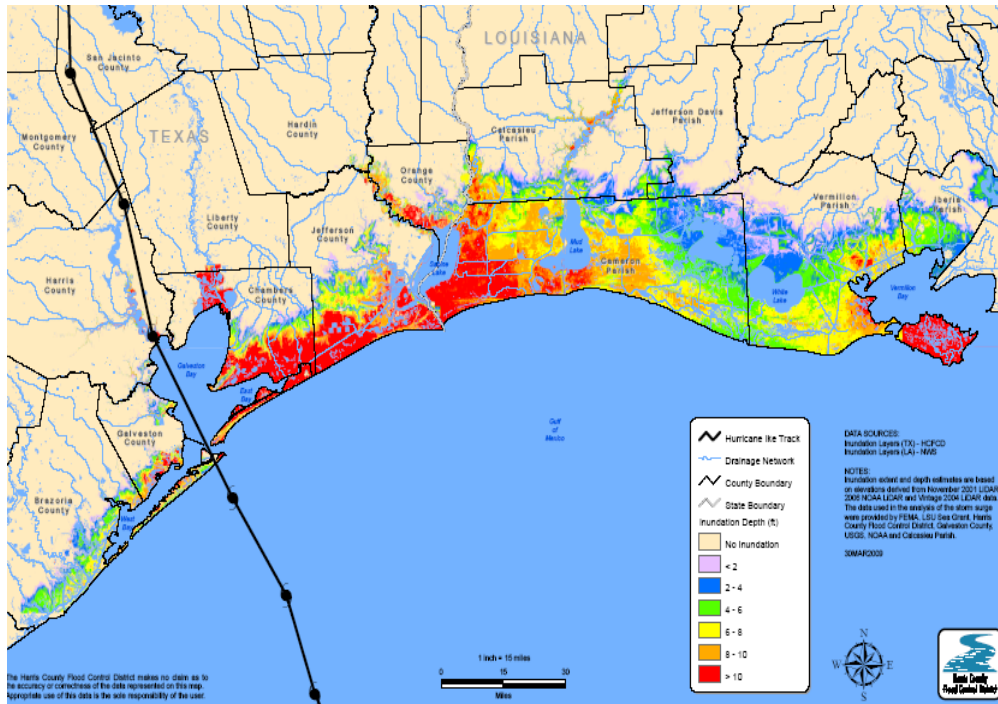
Figure 2. Historic Texas atmospheric temperature trends



Source: John Nielson-Gammon, Texas State Climatologist, personal communication, 2019.

When Tropical Storm Allison hit Houston in 2001, the massive rainfall it generated was considered an aberration. Allison produced 26 inches of rain in 24 hours in east Harris County, doubling the previous 24-hour rainfall record in Houston. When Hurricane Ike hit the area in 2008, it was “only” a Category 2 storm, but it generated a surge much larger than typically associated with these storms. As shown in Figure 3, Ike flooded most of the lands east of Galveston Bay up to as much as 17 feet above sea level. After Ike, the National Weather Service changed their hurricane classification program to separate the category of the storm, which is based on wind speed, from the prediction of surge event size, which is based on other factors such as the size of the hurricane-force wind field. Luckily for Houston, Hurricane Ike’s worst surge did not directly hit Galveston Bay, even though it significantly damaged the city of Galveston and shoreline of Galveston Bay.

Figure 3. Hurricane Ike's path through Galveston Bay



Note: Hurricane Ike's path cut through Galveston Bay, sending the worst of the storm surge to the east. The surge reached greater than ten feet, as depicted in red, well into Louisiana. Some areas east of Houston experienced surge as much as 17 feet.

Source: Graphic courtesy of the Harris County Flood Control District.

However, in terms of intensity, no storm compares with Hurricane Harvey, which dropped upwards of 45 inches of rain on the Houston region over a four-day period. This is as much rain as the area receives in a year. By statistics in use at the time, Harvey was estimated to be a storm with a recurrence interval of once every 40,000 years. Today, climatologists are warning it could happen again in the next couple of decades. In addition to Harvey, 2017 also produced Hurricanes Maria and Irma, two Category 5 storms. Maria had a particularly large eye with associated hurricane force winds extending far beyond the eye wall, a characteristic similar to that observed in Hurricane Ike. Unfortunately, these larger storms are becoming more frequent over time, both with respect to the width of wind fields and high surge areas, and with regard to rainfall amounts.

The changing rainfall levels have been well researched and documented, due in part to the large number of rainfall gauges. The NOAA Atlas 14 presents a new analysis of the rainfall data through 2017, and it demonstrates that the 100-year rainfall in the Houston area had increased to 17 inches in 24 hours from the previous 13 inches in the same time frame. This represents a 30% increase in a 100-year rainfall event.

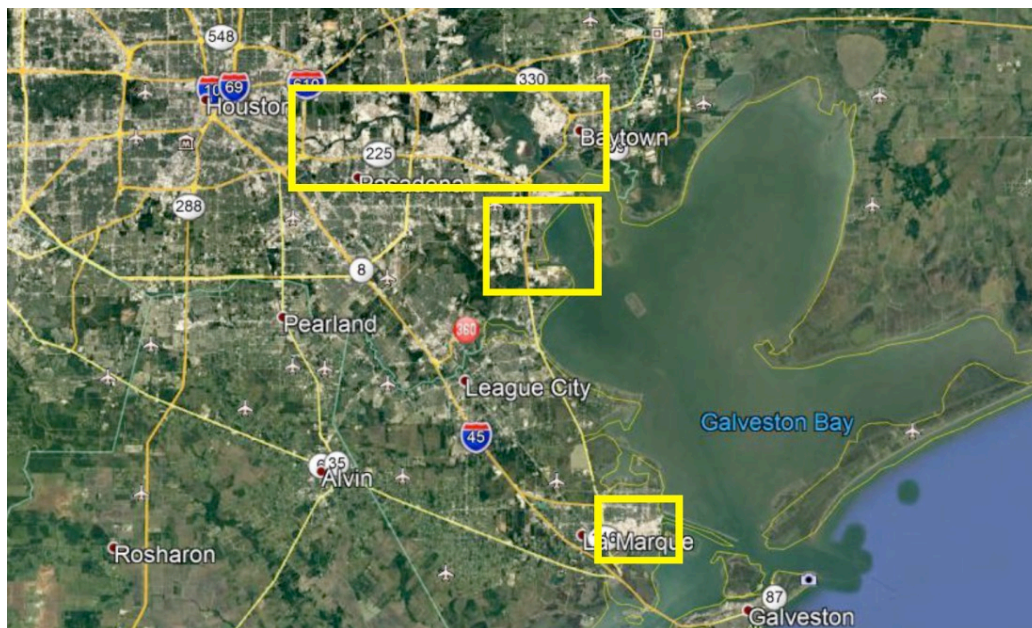
Unfortunately, no similar statistical update has been conducted on hurricane surge flooding. Instead, the storm recurrence intervals are based on data that has not been updated or re-evaluated in the last several decades. Five of the 13 most intense hurricanes (as indicated by millibars of pressure) in the last 100 years have been recorded since 2000, and eight of the most intense since 1980. These storms appear to be getting larger, stronger, more destructive, and they intensify rapidly.

### Impact of Hurricane Surge on the Galveston Bay Region

The developed west side of Galveston Bay has never taken a direct hit from a major hurricane. The storm of 1900 that essentially destroyed the city of Galveston, then the largest port in Texas, likely generated a very high surge in Galveston Bay, but there was little development at the time. The major development of eastern Harris County and the Houston Ship Channel dates to after 1914, when it was opened.

In 2019, the west side of Galveston Bay in both Harris and Galveston Counties is heavily developed. Three major industrial complexes exist: Texas City, the Houston Ship Channel, and the Bayport Industrial District. These three areas are shown in Figure 4. There is also extensive residential development along the west side of Galveston Bay, including numerous smaller cities in Galveston and Harris County, as well as about 20% of the city of Houston (Figure 4).

**Figure 4.** Map image of the Houston region with the three industrial areas highlighted



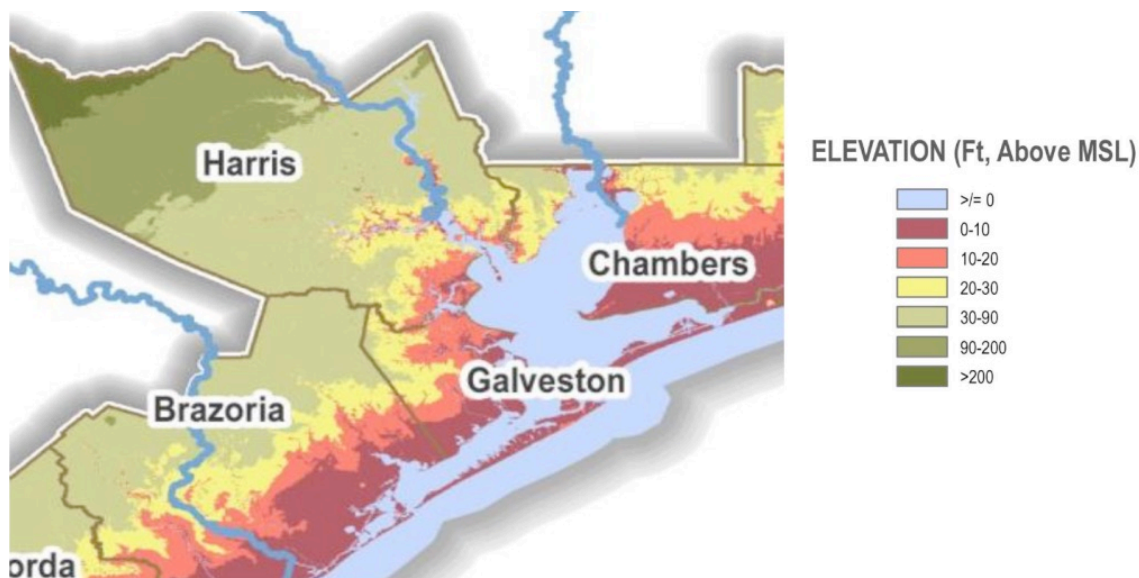
Note: The Houston Ship Channel is located to the north, the Bayport Industrial District in the center, and the Texas City industrial complex to the south.

Source: Author's analysis using Google Earth.

## Houston-Area Surge Flooding and Its Effects on Regional and National Security

This developed west side of Galveston Bay is extremely vulnerable to hurricane surge. As shown in Figure 5, much of this developed area lies below 30 feet in elevation. Since about 2009, the Severe Storm Prediction, Education and Evacuation from Disaster (SSPEED) Center at Rice University has been studying and modeling hurricanes of different sizes, intensities, and tracks. SSPEED Center modelers created Figure 6, which depicts the inundation that would occur from a storm similar to Hurricane Ike but with winds increased by 15% to Category 3. Using the existing statistical methods, this storm would be classified as a 250-year event. In the modeling presented in this paper, sea level rise is not included. Over several decades, such sea level rise would add three to five feet to these projections within the Houston Ship Channel.

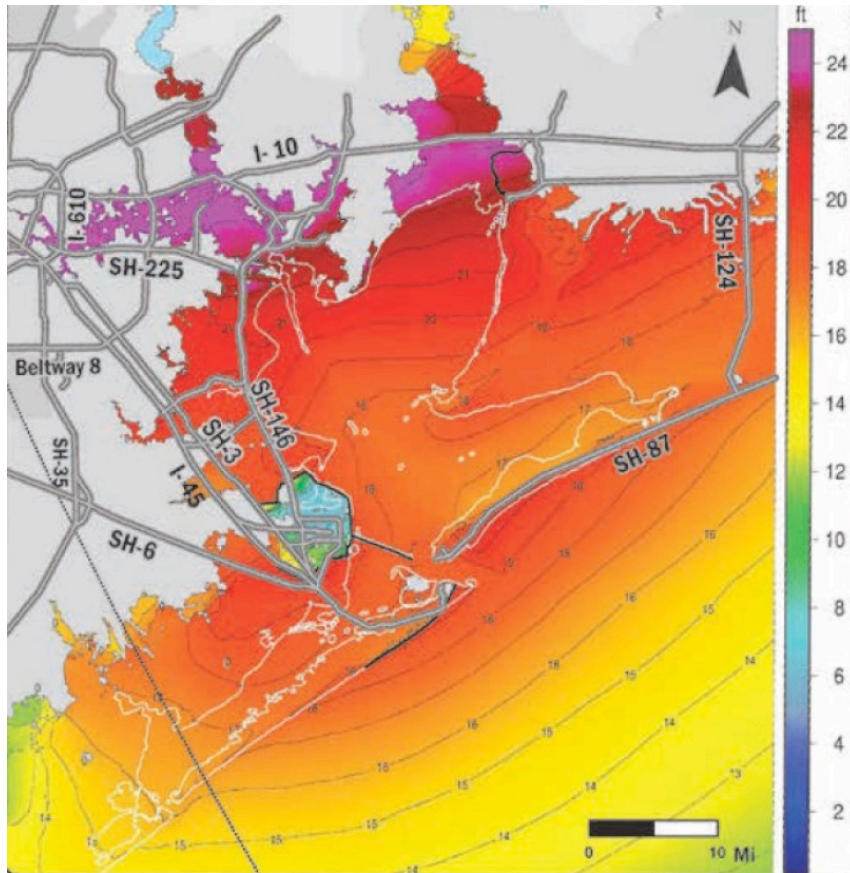
**Figure 5.** Elevation of eastern Harris, Galveston, Chambers, and Brazoria Counties



Source: James Blackburn, *A Texan Plan for the Texas Coast* (College Station: Texas A&M University Press, 2017); GIS work by Christina Walsh.

The devastation from this modeled storm and its associated surge is hard to imagine. Land area that is home to about 800,000 people would be inundated to some extent, and a significant portion of the approximately 200,000 housing units would be destroyed. If evacuation were not timely, thousands would die. This would be a worse human tragedy than Hurricane Katrina in New Orleans.

Figure 6. Surge flooding model of a Category 3 storm making landfall on Galveston Island



Note: Inundation caused by adding 15% to the wind speed of Hurricane Ike and creating a strong Category 3 storm (roughly a 250-year event) making landfall at the southern end of Galveston Island.

Source: Graphic prepared by Christina Walsh from work completed by the SSPEED Center.

The damage to industrial infrastructure would be so serious that it raises national security concerns. The Houston Ship Channel is home to 1.4 million barrels per day of refinery capacity, and Texas City adds another 830,000 barrels. Together, these two areas represent about 12% of U.S. refining capacity—capacity that would partially, if not totally, be inundated by the storm surge shown in Figure 6. The refineries in these areas produce about 27% of the nation’s jet fuel, 13% of the nation’s gasoline, 28% of the diesel production, and approximately 15% and 25% of the U.S. production of ethylene and propylene respectively, which are key building blocks for the plastics industry. According to Rice University’s Jamie Padgett and research conducted at the SSPEED Center, the storm surge of about 25 feet depicted in Figure 6 would at least partially inundate approximately 2,200 of the 4,400 petroleum and hazardous substance storage tanks along the Houston Ship Channel. Of these, some percentage would experience failure, either through tank uplifting (floating), crushing, or penetration by debris and other materials moving with the storm surge. It is estimated that over 90 million gallons



of oil and hazardous substances would be released into adjacent neighborhoods and then into the bay.

To put this disaster into perspective, the Exxon Valdez oil spill released about 12 million gallons of crude oil into the open waters off the Alaskan coast, and the Deepwater Horizon released about 210 million gallons of crude oil into the Gulf of Mexico. The likely spill of 90 million gallons resulting from a hurricane surge event like that in Figure 4 would include toxic chemicals as well as crude oil, and it would likely destroy Galveston Bay, an estuary of national significance, for decades to come.

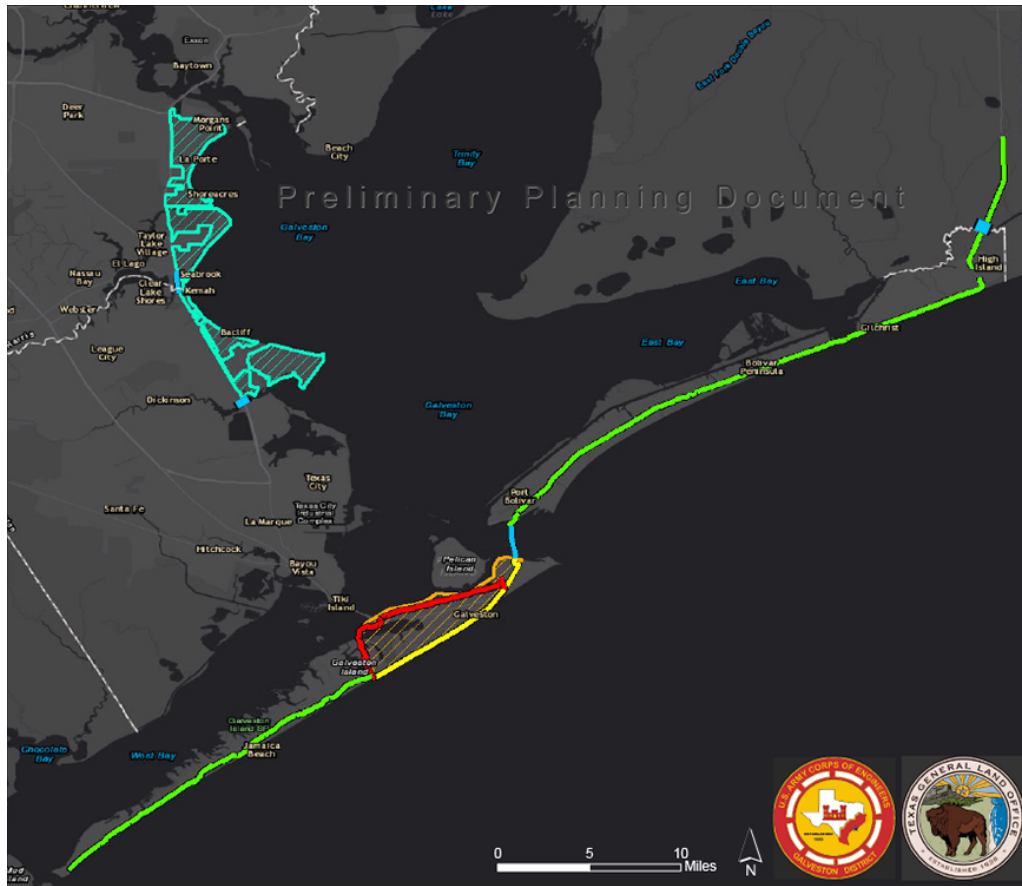
It is difficult to put this damage into perspective, and many industry employees and even residents of the area do not want to believe this analysis, often because they say they've never seen a surge that high, and that is true. Historically, the highest surge has been 13 to 14 feet, which was experienced during Hurricane Ike. Similar surge was also experienced during Hurricane Carla in 1961. Most channel industries and storage tanks are protected to an elevation of 15 feet. Of course, a 25-foot surge exceeds this protection by 10 feet and overtops the existing surge protection levee at Texas City, which is about 17 feet as is shown in Figure 6.

### **Protective Measures**

Since Hurricane Ike, the Houston-Galveston region has been struggling to chart a pathway to hurricane surge protection. The first idea emerged from downtown Galveston, where Bill Merrill of Texas A&M University at Galveston rode out Hurricane Ike and watched the city experience substantial flooding, much of it from the backside—from Galveston Bay—rather than the Gulf. Merrill immediately proposed the Ike Dike, a linear solution of earthen dikes and concrete and steel gates extending from High Island on the north end of the Bolivar Peninsula down to Bolivar Roads, the pass between Bolivar and Galveston. At Bolivar Roads, he proposed two gates, one for the deep navigation channel that would remain open most of the time and a second structure with gravity gates that would allow the daily tide to move through the concrete and steel wall across about 11,000 feet of the pass. The gates then connected with the existing Galveston sea wall, which would be extended as a levee to San Luis Pass on the south end of Galveston Island.

This alternative quickly became a favorite of local, state, and federal officials, and a variation of this alternative called the Coastal Spine became the focal point for the U.S. Army Corps of Engineers when it began its federally authorized study of protecting coastal Texas. In November 2018, the Corps released a Draft Environmental Impact Statement (DEIS) that proposed construction of the Coastal Spine solution for Galveston Bay surge flooding. This spine would be similar to the Ike Dike and would be constructed to an elevation of 17 feet at the coast. Additionally, the Corps proposed a back-side levee for the city of Galveston, as well as two gate structures for the west side of Galveston Bay on Dickinson Bayou and Clear Lake. Additionally, they proposed extensive nonstructural measures for residential areas. Their proposed Coastal Spine is shown in Figure 7.

Figure 7. The Coastal Spine proposal



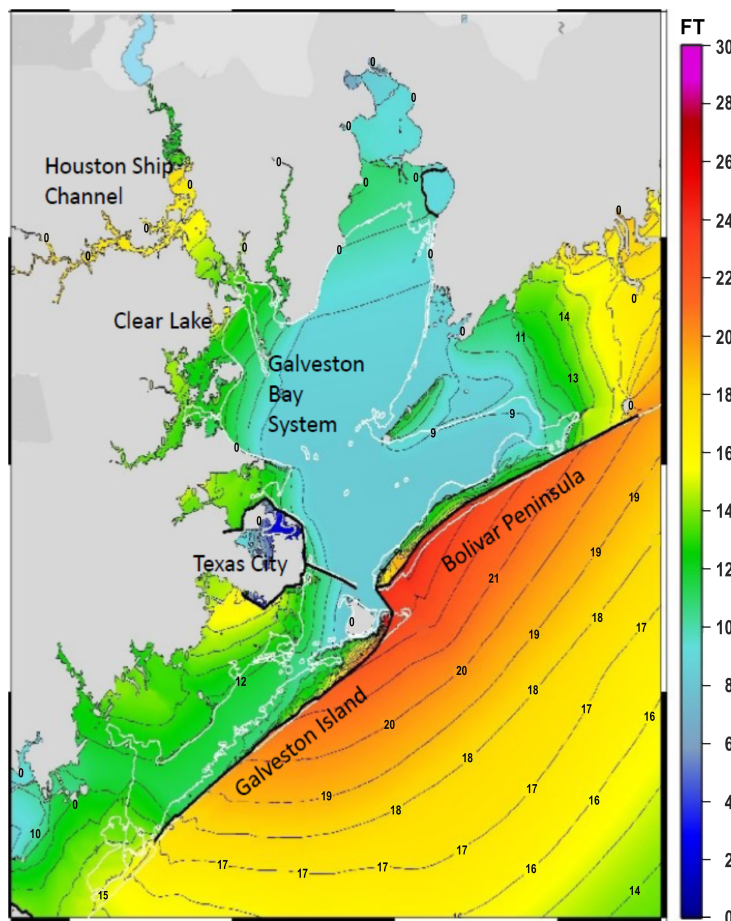
Note: In the DEIS for Galveston Bay surge protection, the U.S. Army Corps of Engineers and the Texas General Land Office identified this “Coastal Spine” as their preferred alternative. The blue line between the yellow and green lines are two gates—one for navigation and one for environmental flows—that span Bolivar Roads. The green line along the coast is a dike structure, and the yellow line is the existing sea wall at the city of Galveston. The red line is a back-side levee for Galveston, and the hatched area is designated for nonstructural controls.

Source: Graphic from the U.S. Army Corps of Engineers and the Texas General Land Office.

Upon public release of the DEIS and at public meetings to solicit comments, significant opposition to the project emerged. Residents of Bolivar Peninsula did not want the project because the proposed protection levee, which is as high as properties in the area, is to be constructed behind their homes, thereby offering no additional protection, and because there also would be substantial land condemnation. The environmental community has also expressed significant concern about the impact of the gates across Bolivar Roads because they will restrict the tidal exchange and affect circulation within one of the most productive estuaries in the United States. Additionally, others have objected to the cost, which is estimated to be between \$14 billion and \$20 billion, and to the fact that the protection is not proposed to be in place until 2035 at the earliest.

Given the structure of the Coastal Spine and the size of the Galveston Bay system, it is reasonable to evaluate the extent of protection offered by the Coastal Spine to a storm such as that shown in Figure 6, which is a 15% increase in wind speed over Hurricane Ike. The SSPEED Center conducted an analysis of this protection, and the results are shown in Figure 8. Here, it is clear that a Coastal Spine height of 17 feet would be inadequate at the coast, and the levee at Galveston would be overtopped along the sea wall if it remains at 17 feet. The spine system does reduce water levels in Galveston Bay, but sufficient water remains in the bay to cause substantial flooding along the western shoreline and in both the Bayport and Houston Ship Channel industrial complexes, where the water would rise to about 20 feet and flood many critical facilities. Padgett estimates that a 20-foot surge would cause the release of about 35 million gallons of oil and other hazardous substances.

**Figure 8.** SSPEED computer model of the flooding from a Category 3 hurricane after construction of the Coastal Spine



Note: Note that the surge overtops the Galveston sea wall, flooding the city, and also causes substantial flooding up the Houston Ship Channel and into the Bayport complex and associated residential areas.

Source: Graphic prepared by Christina Walsh from work completed by the SSPEED Center.

As an alternative to the Coastal Spine, the SSPEED Center developed the Galveston Bay Park Plan (GBPP). This plan is focused on constructing a number of distinct elements that together provide substantial storm surge protection to the west side of Galveston Bay and the city of Galveston. The basic concept is set out in Figure 9, which shows a 25-foot dike that originates in Chambers County at land of similar elevation, proceeds westward below Cedar Bayou and to the ship channel, where it becomes the western wall of disposal areas used for dredge material evacuated from channel. This wall continues on the eastern rim of the channel until it reaches the narrows between Eagle Point in Harris County and Smith Point in Chambers County, where it proceeds along the western edge of the channel until it connects to the Texas City Levee system, which would also be raised to 25 feet elevation. Where the dike crosses the navigation channel, a navigation gate similar to that in the Coastal Spine plan is proposed. A back-side levee is also proposed for the city of Galveston, as are elevated roads to assist in evacuation of the west end of Galveston Island and Bolivar Peninsula. The Galveston Bay Park Plan is estimated to cost from \$3 billion to \$6 billion and could be constructed in segments with potential completion in less than ten years.

Figure 9. The Galveston Bay Park Plan



Note: The Galveston Bay Park Plan extends from Chambers County in the middle of the diagram down the Houston Ship Channel to connect with the Texas City Levee system. As depicted, there are five small vessel navigation gates and one large vessel gate structure.

Source: Graphic by Rogers Partners for the SSPEED Center.

The key to the GBPP is that the protection is proposed within the bay system to address surge from the Gulf as well as surge generated solely within the bay. This plan is compatible with navigation, and it essentially provides disposal capacity for the dredge material generated by widening the Houston Ship Channel, a current priority for oil exporters. These dredged material disposal areas could then be converted into either wetlands or park lands. Currently, the Port of Houston is seeking federal approval to widen the Houston Ship Channel, an action that would provide the construction material for the GBPP barrier wall. Thus, there may be cost sharing opportunities here. The GBPP would likely impact the oyster reef complex that populates the middle portion of Galveston Bay, and over \$20 million has been allocated to oyster reef construction and restoration as part of this plan, with the potential for expanding oyster reefs northward into Trinity Bay to respond to the expected decrease of freshwater inflow and more saline conditions in the future.

As can be seen in Figure 10, the GBPP provides significant protection to the populated western side of Harris and Galveston Counties and to the industrial complexes at Bayport and the Houston Ship Channel. It does not provide flood relief for the undeveloped lands of Galveston and Chamber County and therefore will not induce new development behind its protection. It is intended to protect the already existing infrastructure and development. Further, the back-side levee surrounding the city of Galveston can be expanded at an approximate additional cost between \$500 million and \$1 billion to protect the Port of Galveston and Texas A&M University at Galveston.

### Conclusion

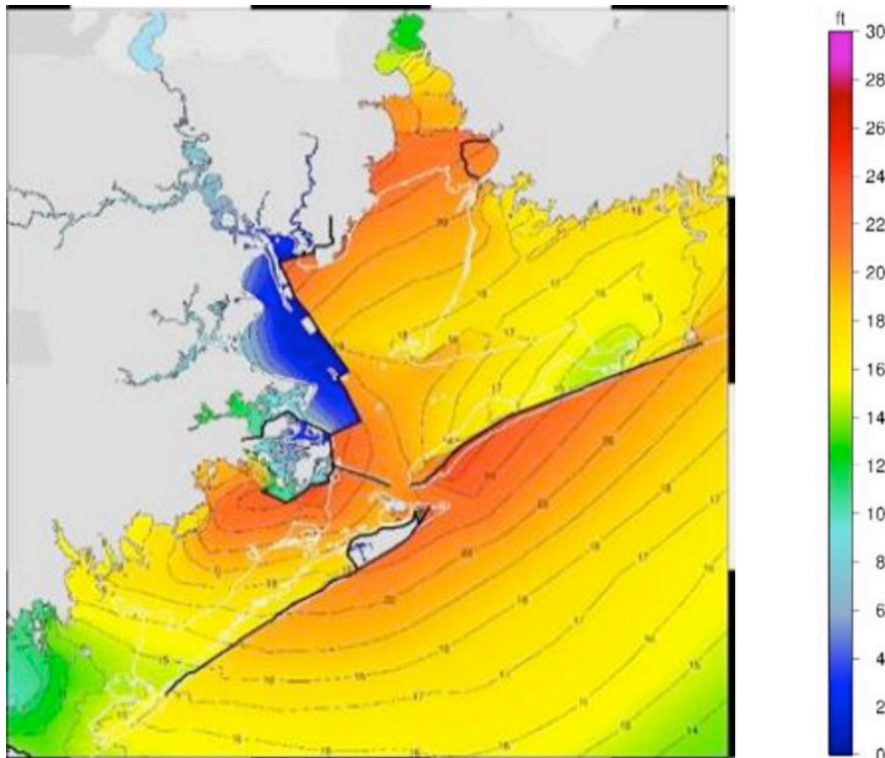
There are several important conclusions that arise from this short summary of the current status of surge protection efforts in the Houston region. First, the failure to talk honestly and directly about climate change is a major problem that could lead to the deaths of thousands of people, harm to the national economy, and destruction of a key economic engine for the region. Kathryn Hayhoe, a climate scientist at Texas Tech University, has stated that we are charting our course forward by “driving using our rearview mirror.”<sup>1</sup> The past is not a good predictor of the future when it comes to the size of these storms and their potential damage. If we simply plan for the past, we will not solve this issue.

Second, the available tools that engineers and scientists use to evaluate severe storm situations are deficient. The tools were not developed to address today’s problems. For example, the U.S. Army Corps of Engineers is bound by regulations to utilize cost-benefit analysis and to integrate the results of past storms to develop the best proposal for mitigating future storm damage. This methodology was not designed to address a changing climate and more intense storms. The issue here is that this methodology is mandated at the national level. It is worrisome that the U.S. Army Corps of Engineers would recommend a project costing \$14 billion to \$20 billion that does not protect the region from a larger storm that is certainly foreseeable.

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<sup>1</sup> Kathryn Hayhoe, “Mitigate and Adapt—Or Suffer: Planning for Climate Resilience in Houston’s Post-Harvey World” (presentation, Progressive Forum, Houston, TX, April 19, 2018).

**Figure 10.** SSPEED computer model of the flooding from a Category 3 hurricane after construction of the GBPP



Note: The protection provided by the GBPP is comprehensive for the developed western shoreline of Galveston Bay and the Houston Ship Channel and Bayport complexes. The Texas City protection is also improved. Galveston is protected by a back-side levee and elevated seawall.

Source: Graphic prepared by Christina Walsh from work completed by the SSPEED Center.

The SSPEED Center was not constrained by such outdated methodology when modeling hurricane storm surge flooding. This approach was based on identifying a reasonable worst-case storm and attempting to develop alternatives to address the resulting surge and flooding issues. The storm modeled using this approach and depicted in Figures 6, 8, and 10 is roughly a 250-year storm. With our changing storm intensity and size, we will easily see one or more storms of this magnitude in the next 50 years. Perhaps encouraging more flexibility in federal methods of calculation would generate better results from a national security and human protection standpoint.

Third, it is reasonable to incorporate multiple tasks into a surge flooding solution. Surge problems exist in every coastal community on Gulf Coast and the Atlantic, so there are competing needs for money everywhere in the country. To dedicate huge amounts of money to single purpose projects may be a luxury the country cannot afford any longer. In the case of Galveston Bay, solutions exist that combine surge flood abatement, navigation

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enhancement, and recreation. All alternatives should be tasked with integrating solutions to multiple problems where possible, such as in the GBPP.

Fourth, urgency is an issue. Of the two alternatives discussed in this paper, the Coastal Spine is projected for completion in 2035 and the Galveston Bay Park Plan is slated for 2027. Implementing these measures sooner could be very important in protecting the region and national security. Sea level is rising, the storms are getting larger, and the clock is ticking.

The problems facing Houston and the United States are serious and must be addressed effectively. We cannot afford to build solutions that are obsolete upon arrival. We cannot afford to ignore issues because they are uncomfortable, and we cannot continue business as usual and expect to solve the incredible problems associated with hurricane surge flooding.