Chapter 4. Consequences of Leaving San Luis Pass Open

Introduction

Layouts of the USACE coastal spine and the Ike Dike concept were compared in Chapter 2. It was noted there that the USACE coastal spine is essentially the middle section of the Ike Dike shown in Figure 2-1, without the eastern and western sections. Also, as mentioned in Chapter 2 and discussed much more in Jackson State University, JSU (2018), the storm surge reduction benefits of the middle and western sections far exceed those of the eastern section. In the USACE Plan, omission of the important western section, which includes a gate system at San Luis Pass and a land barrier on Follets Island, is the basis for the concerns expressed here.

The Ike Dike concept achieves its effectiveness by minimizing entry of the open-coast storm surge into West and Galveston Bays, suppressing generation of internal surge. Once storm surge enters the large, very shallow bays, hurricane-force winds are extremely effective in dragging water from one side of the bay to the other, leading to even higher surge levels on the down-wind side. The specific areas around the Bay's periphery impacted by the enhanced surge can change rapidly as a hurricane transits through the region. The middle section of the Ike Dike concept significantly reduces storm surge entry into the Bays; but so does the western section. Omission of the western section is akin to leaving a "back door" open; it significantly compromises the performance and effectiveness of the coastal spine.

As illustrated in later sections, omission of the western section leads to large increases in peak storm surge throughout West Bay and lesser, but still significant, increases in Galveston Bay. It does so through the following two mechanisms: 1) allowing the hurricane surge forerunner to propagate through San Luis Pass into the Bays, in the days leading up to hurricane landfall, and 2) allowing the main storm surge to flank the western end of the coastal barrier, initially via San Luis Pass and then via an inundated Follets Island, as the hurricane approaches and makes landfall. Increases in peak surge lead to greater flood risk and damage to most, if not all, areas of the Houston-Galveston region fronted by the coastal spine. Adverse impacts are substantial for communities and industries in Brazoria and Galveston Counties that ring West Bay, including all of Galveston Island, as indicated by the high residual damage that remains even with the USACE Plan (see Chapters 2 and 6). Impacts can extend into Galveston Bay and far up the Houston Ship Channel, as surge penetration from West Bay into Galveston Bay occurs. As discussed in JSU (2018) and later in this chapter, rising sea level will exacerbate adverse impacts associated with leaving the "back door" open, throughout the entire Houston-Galveston region. Results from storm surge model simulations, upon which conclusions regarding omission of a western section are based, are described in more detail below.

We recommend that the USACE conduct a thorough analysis of the benefits and costs associated with a western section of the coastal spine, which includes a gate at San Luis Pass. Benefits include direct reduction in damage as well as cost avoidances that arise from being able to reduce design water levels and wave conditions for all in-bay second lines of defense and non-structural measures, which in turn reduces the required extent strength, height and cost of all in-bay measures. The stated goal for the USACE Recommended Plan (the Plan), in USACE (2020), is to "promote a resilient and sustainable economy by reducing the risk of storm damage to residential structures, industries, and businesses critical to the Nation's economy." Examples are shown below that illustrate how achievement of the stated goal is compromised by leaving open a “back door” to West and Galveston Bays. We strongly recommend that the USACE re-evaluate the decision to omit a western dike/gate section in the USACE Plan.

Investigative Approach

To examine the impacts of omitting the western section, storm surge simulations were made for two different alignments of a coastal spine. Each alignment had a different combination of the Ike Dike coastal spine sections shown in Figure 2-1. The Ike Dike concept was comprised of all three dike sections (middle + eastern + western). An alignment comprised of two of the sections (middle + eastern), but with no western section, was also evaluated to isolate the effects of omitting the western section. The crest elevation of all dike sections considered in the surge simulations, for both alignments, was 17 ft, NAVD88.

A set of eight hurricanes was simulated for both coastal spine configurations using the USACE Coastal Modeling System (which includes the ADCIRC storm surge model). Simulated hurricanes were selected from among historic and hypothetical, idealized storms that were considered in the FEMA RiskMap study that was most recently performed for the Texas coast. A summary of the characteristics for all eight simulated hurricanes is provided in Table 4-1.

Table 4-1. Characteristics of Simulated Hurricanes

Storm Identifier	Central Pressure (mb)	Maximum Wind Speed (kt)	Forward Speed (kt)	Radius-to-Maximum-Winds (nm)	Target Average Recurrence Interval Water Level, Location
Hurricane Track 1					
Storm 019	960	88	11	11	10-yr, San Luis Pass
Storm 023	930	102	11	18	100-yr, San Luis Pass
Storm 027	900	113	11	22	500-yr, San Luis Pass
Hurricane Track 2					
Storm 3001	930	102	20	18	100-yr, San Luis Pass
Hurricane Track 3					
Storm 535	975	68	6	18	10-yr, Galveston Bay
Storm 033	930	100	11	26	100-yr, Galveston Bay
Storm 036	900	112	11	22	500-yr, Galveston Bay
Hurricane Ike Track					
Ike	950	80	10	45	

Staff at the USACE Engineer Research and Development Center's Coastal & Hydraulics Laboratory made the surge model simulations; Jackson State University staff performed the analysis of model results.

Hurricanes were selected using the following rationale. Hypothetical hurricanes were selected to best replicate peak surge levels associated with different average recurrence intervals at two locations, as indicated in Table 4-1, for the without-project condition. One set of hypothetical storms was selected to replicate 10-yr, 100-yr and 500-yr water levels along the western shoreline of Galveston Bay and into the upper reaches of the Houston Ship Channel. These are the areas with the highest potential for economic damage and losses. A second set was identified that replicates the 10-yr, 100-yr and 500-yr water levels at the entrance to San Luis Pass. Storm surge at the entrance to San Luis Pass strongly influences the amount of water that enters through the open "back door." The most intense hurricanes (having 900 mb minimum central pressure) are those that closely replicate the 500-yr water levels; less intense hurricanes (having a 960 or 975 mb minimum central pressure) are those that closely replicate the 10-yr water levels. Hurricane Ike was selected because of the high surge forerunner and peak surge it created in the Houston-Galveston Region, and its relatively recent occurrence.

Simulated hurricanes followed one of the four tracks shown in Figure 4-1. Historically, severe land falling hurricanes that have influenced the Texas coast have generally approached from the southeast, like Hurricane Tracks 1 and 3 and the track for Hurricane Ike. Occasionally they have approached from the south, like Track 2. Hurricane Harvey approached from the south.

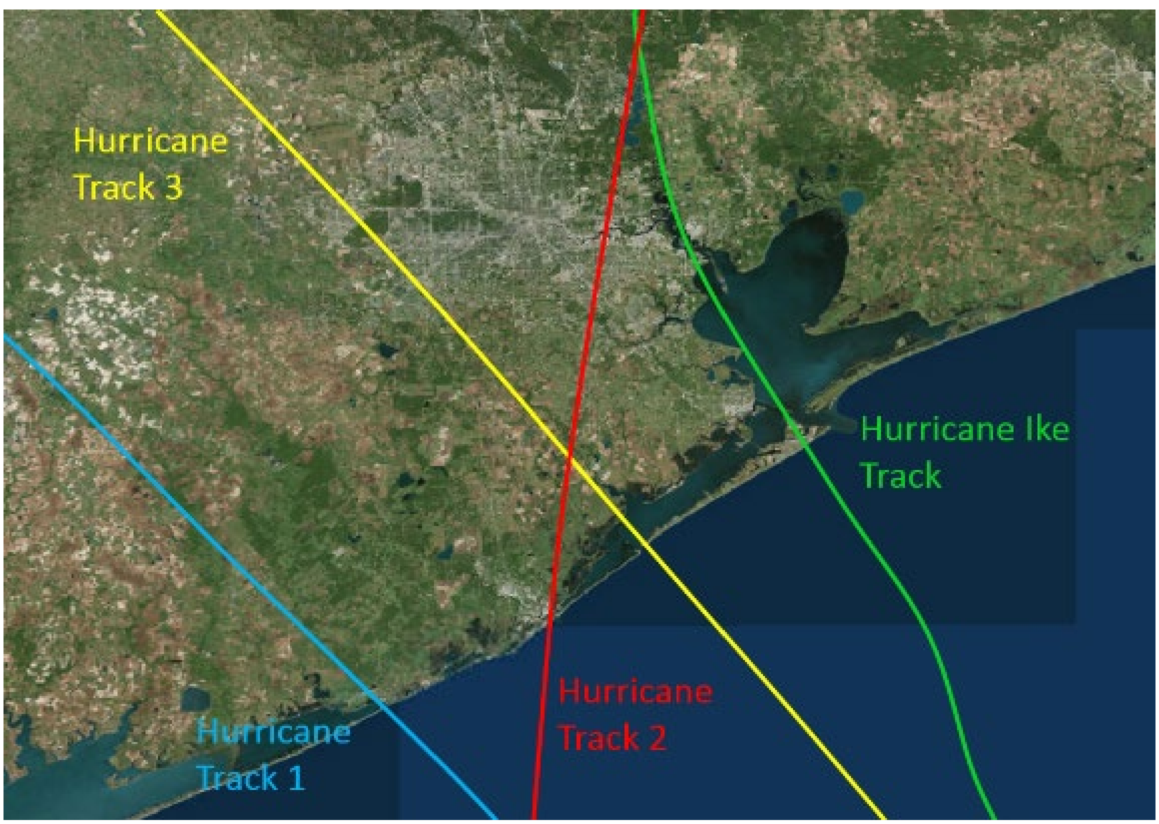

Figure 4-1. Different tracks considered in the hurricane simulations

Simulations were made for each storm identified in Table 4-1, for each of the two coastal spine alignments (with and without a western section), and for both a present mean sea level (0.9 ft NAVD88) and a future sea level scenario that is 2.4 ft above present sea level (3.3 ft NAVD88). This future sea level is the level projected for the year 2085 using the USACE methodology and assuming an intermediate rate of sea level rise. The modeling approach employed reflects the current state of engineering practice, which does not include the effects of hurricane rainfall in the storm surge simulations.

Results are presented for three different aspects of the increased damage and flood risk which results from omission of a western section. The first is surge forerunner propagation through an un-gated San Luis Pass. The second is increase in peak surge elevation and inundation in both West and Galveston Bays caused by the main storm surge that flanks the western end of the USACE coastal spine. The third is the influence of sea level rise on increased peak surge and inundation associated with flanking. All three aspects are discussed in separate sections below. A series of figures visually illustrate the adverse impacts on flood risk and expected damage that arise from omission of the western section, in different parts of the Houston-Galveston region.

Hurricane Surge Forerunner Generation and Propagation through San Luis Pass

Major hurricanes that traverse the Gulf of Mexico, and eventually approach the north Texas coast, can generate a significant surge forerunner. The combination of the quarter-circle shape of the Louisiana/Texas coastline and continental shelf in the northwest corner of the Gulf and the circular wind field about the eye of an approaching hurricane is conducive to formation of a wind-driven forerunner. The forerunner is forced by far-field hurricane winds that circulate in a counterclockwise direction about the hurricane's eye while it is still well offshore in the deep Gulf. Such far field winds blow from east to west to southwest over the Louisiana and north Texas continental shelves. These winds tend to force an east-to-west movement of water along the shelf, which is turned to the "right" in the northern hemisphere by the Coriolis force, and stacked against the Louisiana and north Texas coastlines. The Coriolis force is associated with the earth's rotation. This stacking of water against the shoreline is called Ekman set-up. This is the physical process behind formation of the wind-driven surge forerunner. The forerunner begins as a forced wave that advances along the northern Gulf shelf from east to west with the advancing storm; but then, after landfall on the north Texas coast, the forerunner propagates as a free wave southward along the south Texas continental shelf. This along-shelf propagation of the surge forerunner was first shown for Hurricane Ike by Kennedy et al (2011).

The forerunner is experienced at the coast as a slow steady rise in the water surface elevation which begins while the hurricane eye is well offshore, days before landfall. The rate of water level rise begins to accelerate as the eye moves across the continental shelf. Hurricane Ike produced a sizable forerunner. During Ike, the water level increase began several days before landfall and reached a measured amplitude in excess of 6 ft above the seasonal mean sea level at the Galveston Pleasure Pier, twelve hours before landfall. Water level data acquired by NOAA also show that the forerunner propagated into Galveston Bay through the tidal passes and into the upper reaches of the Houston Ship Channel with little attenuation.

As observed during Ike, the forerunner can propagate into the bays via the tidal passes. Once, closed, the Bolivar Roads Surge Barrier at the much deeper and more hydraulically efficient Bolivar Roads pass will eliminate subsequent forerunner propagation into the Bays through this particular pass. However, leaving the "back door" open at San Luis Pass, albeit a shallower, less hydraulically efficient pass, will still allow some propagation of the forerunner into West and Galveston Bays. This issue was examined using the simulation of Hurricane Ike, for both present and future sea levels.

Hurricane Ike is the only severe hurricane that has made landfall in the Houston-Galveston region, produced a substantial surge forerunner and peak surge, for which we have high-quality measured data to characterize the hurricane's speed, size intensity, winds and pressures, and the water level response. Hurricane Ike is the best example to use for assessing the ability of a large surge forerunner to propagate into West and Galveston Bays through the San Luis Pass open back door. This is because measured far field wind speed and direction data are available for the Bay region while the hurricane eye is well offshore, during the initial stage of the forerunner development process.

Accurate representation of the far field winds within semi-enclosed bays is critical in attempting to model forerunner propagation into the Bays. The wind and pressure field model that is used to simulate hypothetical hurricanes produces highly structured and idealized wind fields in the far field. The directions and strength of these far field winds tend to somewhat retard surge forerunner propagation into West and Galveston Bays. Some of the more extreme hypothetical hurricanes show less forerunner penetration than the Hurricane Ike simulation, for this reason. This might not reflect reality. In the early stages of forerunner development, measured far field wind data during Ike show variable direction and speed, with much less structure to the wind fields. Without masking the winds in some way in both West and Galveston Bays, the current method of modeling storm surge for hypothetical hurricanes will tend to underestimate surge forerunner propagation into both Bays. Surge forerunner generation and simulation of the surge forerunner in the Houston-Galveston region are discussed in in more detail in the JSU (2018) report (see Chapters 5, 6, 7, 13 and 14).

It is also important that low realistic bottom friction on the continental shelf is used in setting up the storm surge model. Excessive bottom friction will over-damp generation of the forerunner and lead to a significant under prediction of its amplitude along the shoreline. The JSU surge modeling, which is reflected in this report, demonstrated good skill in terms of matching measured peak storm surge values in the Houston-Galveston region, see Chapter 2 of the JSU (2018) report, but it still under predicted the forerunner amplitude.

Figure 4-2 shows the simulated surge forerunner elevation for Hurricane Ike, at a snap shot in time, twelve hours before landfall, when the eye (yellow dot in the figure) is well offshore of the Houston-Galveston region. Wind speed and direction are shown as black vectors. At the open coast near San Luis Pass, the amplitude of the forerunner surge reached an elevation of 5.3 ft above the seasonal mean sea level approximately twelve hours prior to landfall. Such a forerunner amplitude inundates the beach berm on Galveston Island and Bolivar Peninsula, which enables wave action to begin eroding the dunes long before landfall. The forerunner amplitude along the Louisiana coast approaches 7.5 ft.

Figures 4-3 and 4-4 show the change in simulated water surface elevation, with time, for Hurricane Ike at two locations: the first inside West Bay (Figure 4-3), midway between San Luis Pass and the City of Galveston; and the second roughly in the center of Galveston Bay (Figure 4-4), with and without a western section of the coastal spine.

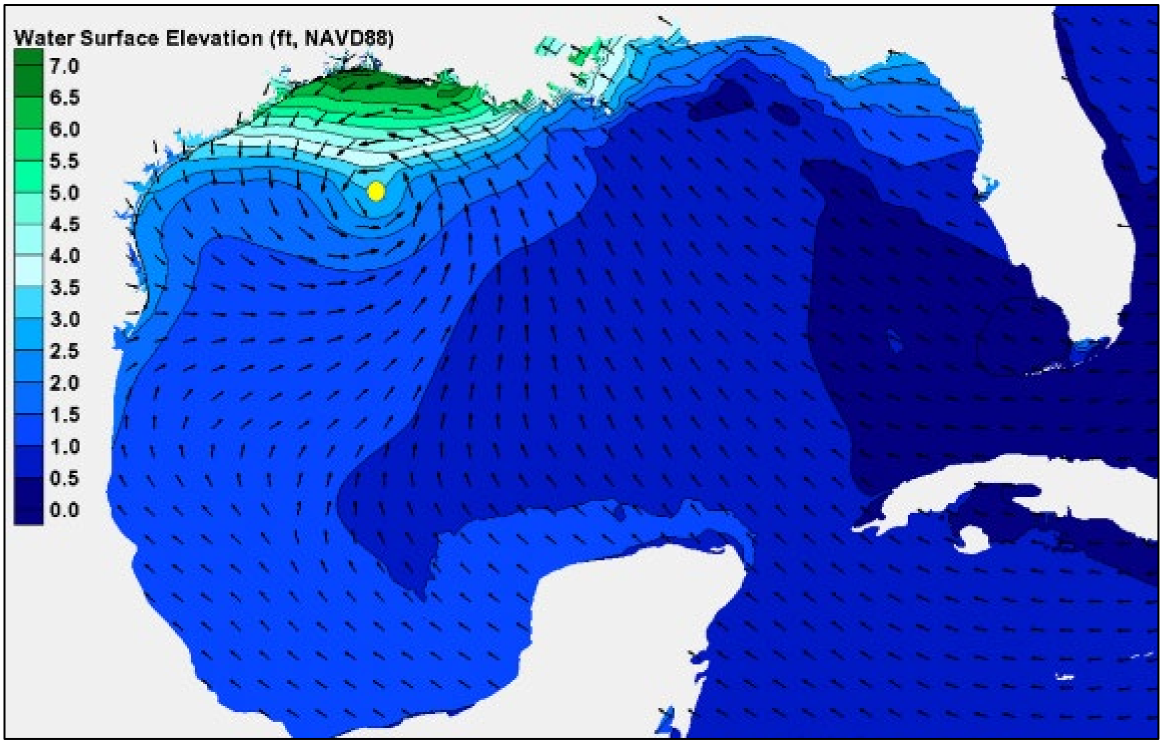

Figure 4-2. Snap-shot of the water surface elevation field associated with the Hurricane Ike surge forerunner, twelve hours prior to landfall

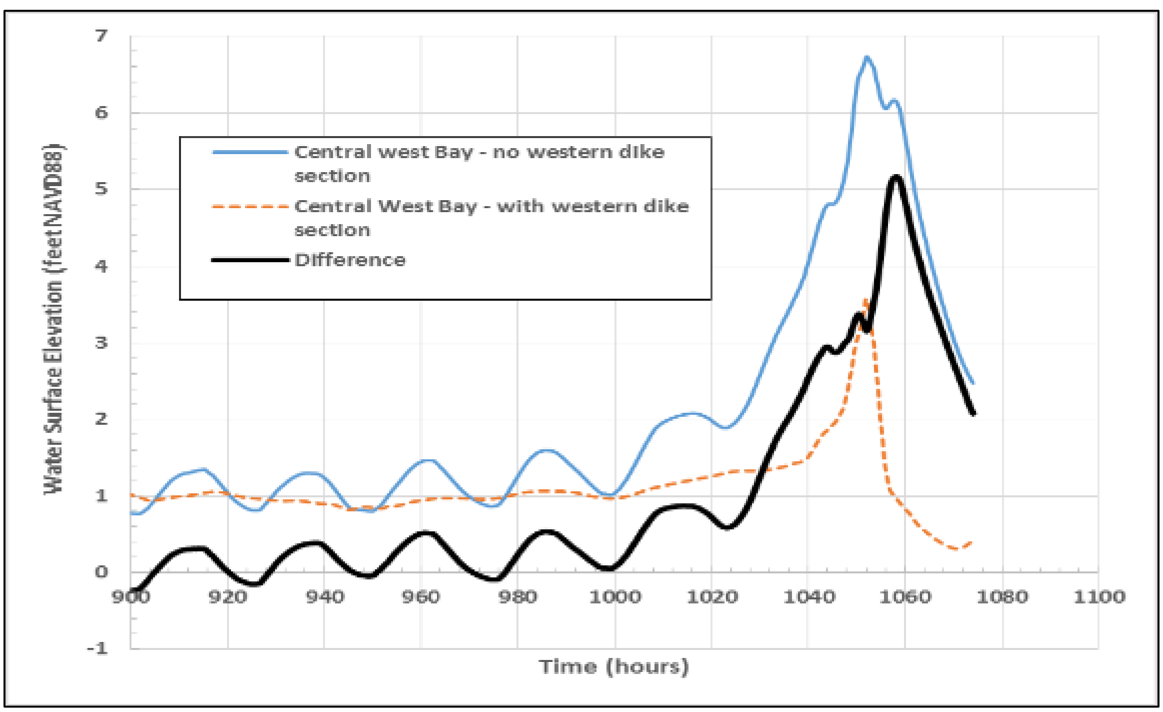

Figure 4-3. Water surface elevation in the center of West Bay, with and without a western section, for Hurricane Ike, present sea level

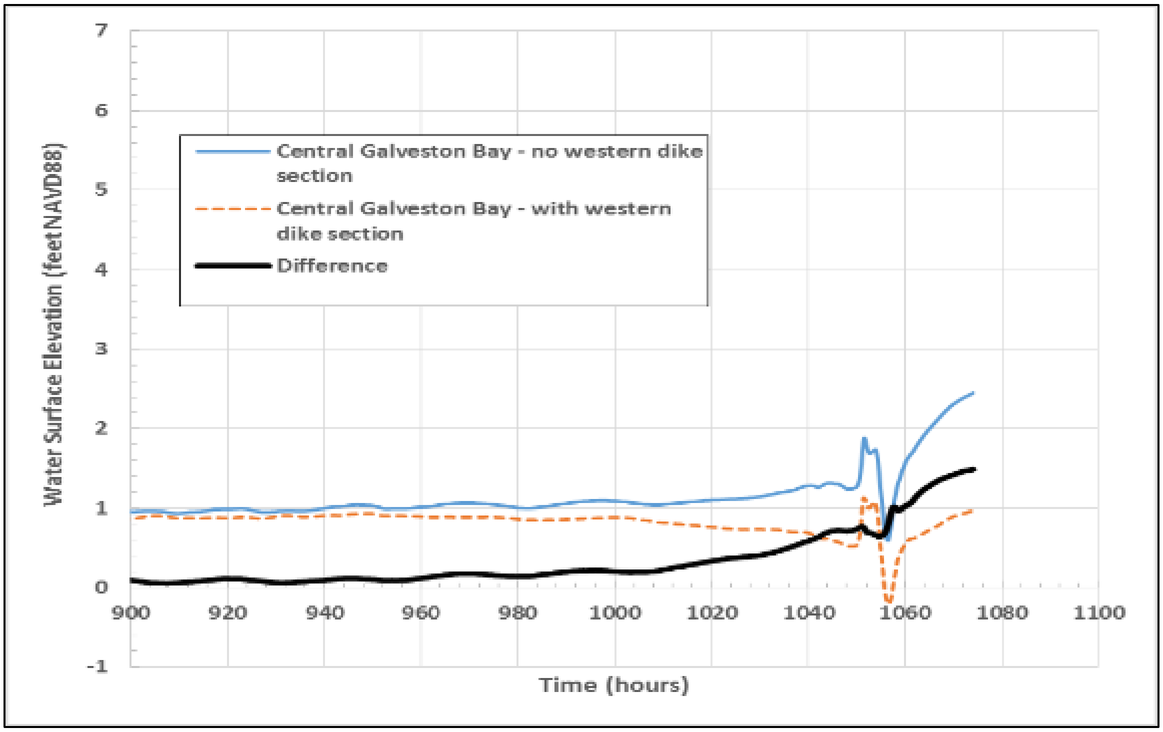

Figure 4-4. Water surface elevation in the center of Galveston Bay, with and without a western section, for Hurricane Ike, present sea level.

Locations in the center of the bays were selected to minimize the influence of local wind, which sets up one side of the bay and sets down the other side, obfuscating the forerunner amplitude. The thin orange dashed curves in both figures show the water surface elevation time series for the 17-ft Ike Dike concept, which has a western section. The thin blue solid curves show the water surface elevation for the coastal spine alignment like the USACE Plan that has no western section. The thick black curve shows the difference between the orange and blue curves; it quantifies the change in water surface elevation due to leaving the “back door” open, i.e., the impact of having no western section.

Prior to hour 1044 of the simulation, the black “difference” curves reflect the influence of forerunner propagation through San Luis Pass. Without the western section, in West Bay, the forerunner surge elevation steadily rises to maximum amplitude of 2.9 ft, 12 hours before landfall. Results indicate some attenuation through the shallow San Luis Pass, from an amplitude of 5.3 ft on the open coast to an amplitude of 2.9 ft inside West Bay. Although additional attenuation occurs as the forerunner propagates from West Bay into Galveston Bay, in Galveston Bay the forerunner also grows steadily in the days prior to landfall and its amplitude reaches 0.7 ft, clear evidence of forerunner propagation from West Bay into Galveston Bay. Results for the Upper Houston Ship Channel, not shown here, are nearly identical to those shown for the center of Galveston Bay. Once inside Galveston Bay, there is little attenuation of the forerunner amplitude, as was observed during the actual Hurricane Ike. For the simulated Hurricane Ike, because of forerunner propagation through an open San Luis Pass, the entire West Bay water level is raised by 2.9 ft, and the entire Galveston Bay water level is raised by 0.7 ft, everywhere, 12 hours before landfall.

As also seen in Figures 4-3 and 4-4, at and after hour 1060 of the simulation, the effect of omitting a western section on peak surge is an increase of approximately 5.2 ft at the central West Bay location and an increase of 1.5 ft at the central Galveston Bay location. The implications of an open "back door" for peak surge and inundation inside the bays are discussed at greater length in the next section.

The Hurricane Ike simulation for future sea level shows that omission of the western section leads to similar results for surge forerunner propagation into West Bay as obtained for the present sea level; a slightly higher hurricane forerunner surge of 3.1 ft twelve hours prior to landfall, and an increase in peak surge of about 5.2 ft. However, in Galveston Bay, the forerunner surge amplitude is 1.2 ft (0.5 ft higher than for present sea level case) and the increase in peak surge is 2 ft (also an increase of 0.5 ft). With the "back door" open, rising sea level apparently reduces the attenuation of, and increases the propagation efficiency of, the surge forerunner from West Bay into Galveston Bay. This leads to higher forerunner surge and peak surge values in Galveston Bay. The effects of higher future sea level on peak surge and inundation inside the bays are discussed at greater length in a subsequent section.

Uncertainty in Understanding and Modeling the Hurricane Surge Forerunner

We believe that the importance and prediction of the hurricane surge forerunner is underestimated in the work that has been done to arrive at the USACE Plan. Generation of the hurricane surge forerunner is not a completely understood process; and accurate simulation of the forerunner is challenging. Relatively little is known regarding the forerunner amplitude on the Texas coast, specifically, the distribution that characterizes its probability of occurrence. There is some understanding of the dependencies of forerunner amplitude on hurricane characteristics. Unfortunately, we only have observed data for a single major hurricane that produced a substantial forerunner and made landfall in the region, Hurricane Ike.

The maximum possible amplitude for a surge forerunner is unknown. During Ike, the forerunner amplitude reached 6.5 ft at the Galveston Pleasure Pier, and apparently 7.5 ft or more along the Louisiana coast. Hurricane Ike was a very large hurricane, but moderate in intensity. Ike was only a Category 2 storm on the Saffir-Simpson wind intensity scale for hurricanes. Research by JSU and others indicates that the forerunner magnitude grows as hurricane size increases, as intensity increases, and as forward speed decreases; forerunner amplitude also appears to be somewhat sensitive to storm track. Ike had an average forward speed and approached from the southeast. JSU research suggests that the worst scenario for forerunner generation appears to be a large, intense, very slow-moving hurricane that approaches from the south or south-southeast direction. More information about forerunner generation is provided in Chapters 5, 6 and 14 of the JSU (2018) report.

In light of uncertainties regarding the surge forerunner, conservatism is warranted in how the forerunner is considered and treated in formulating the USACE Plan. Conservatism also is warranted in light of the accuracy of the USACE surge modeling in simulating the forerunner and its amplitude. Validation results for the USACE storm surge modeling for Hurricane Ike reflect the difficulty, as shown in Annex 1 to Appendix D of USACE (2020). Results indicate that the surge model has limited skill in simulating the forerunner. The surge model consistently under predicts the steady water level build-up that occurs for two days before landfall; and the maximum amplitude is under predicted by approximately 1.5 to 2 ft (a 20% to 30% under prediction).

Under prediction of the hurricane surge forerunner leads not only to understating its role in increasing flooding in the Bays due to forerunner propagation through the open "back door," but also to understating its role in eroding the dune system. Under prediction of the forerunner's amplitude will underestimate how quickly the berm is inundated by the forerunner, which then subjects the dunes to the direct erosive action of waves. The net result is that under prediction of the forerunner leads to under prediction of dune erosion, and for the weak dunes in the USACE Plan, can lead to an underestimate of the storm surge that flows into the bays over the flattened dunes.

In the USACE surge modeling, a higher bottom friction coefficient was applied on the continental shelf, to improve model stability. JSU researchers found that such a choice overdamps generation of the forerunner, leading to underestimates of its amplitude. Therefore, there is good reason to believe that the forerunner being simulated by the USACE for all hurricanes, including those most critical to the design and performance of the USACE Plan, are under predicted. JSU researchers used a smaller bottom friction coefficient on the shelf, a reasonable value for muddy bottoms, and were able to achieve a more accurate simulation of the forerunner for Hurricane Ike, but still with an under prediction.

We recommend that the USACE pursue model improvements that lead to better skill in simulating the forerunner. We recommend validation of model skill in terms of how well the forerunner build-up and maximum amplitude is simulated for Hurricane Ike, and perhaps other major land falling hurricanes in southwest Louisiana where the potential for a significant forerunner exists, as well. We recommend using the improved surge model to examine the distribution of forerunner amplitudes for the Texas coast, including an estimate of the maximum forerunner amplitude that is possible. We recommend using the improved model in the investigation into quantifying benefits of a western section of the coastal spine, and in the beach/dune erosion modeling. Improved understanding of the forerunner climate will undoubtedly prove beneficial in formulating a plan to guide operations of gate systems at both Bolivar Roads Pass and San Luis Pass.

Influence of Flanking of the USACE Plan Coastal Spine by the Main Storm Surge

Without a western section of the coastal spine, as the hurricane eye approaches landfall and as the forerunner development period transitions into development of the main surge, the storm surge continues to propagate into West Bay via San Luis Pass and then over Follets Island as well once the island becomes inundated. Even for relatively frequent hurricane events, omission of the western section leads to inundation within communities on western and central Galveston Island, inundation that is avoided with a western section in place. The adverse effects of flanking are much more widespread for more severe hurricanes.

The effect of surge flanking the western end of the coastal spine in the USACE Plan is illustrated below using both peak surge maps and inundation maps. Colored shaded contour maps of peak surge depict the peak storm surge elevation calculated at every computational point in the ADCIRC storm surge model domain, without regard to when the peak surge elevation occurred during the simulation. These peak surge maps do not represent snap shots in time. To illustrate the spatial extent of inundation, both with and without a western section, a "transparent" peak surge map is superimposed over a background satellite image to create an inundation map that shows what terrain is being inundated.

Pairs of maps are presented in the series of figures below. The map in the top panel of each figure shows the peak surge (or inundation) map for the Ike Dike concept, which has a western section. The map in the bottom panel shows results for the alignment that is similar to the USACE Plan coastal spine, which omits the western section. Peak surge and inundation maps are shown for three of the storms listed in Table 4-1: Hurricane Ike, Storm 023, and Storm 019. The simulation of Hurricane Ike produced a peak surge of approximately 10 ft NAVD88 at San Luis Pass and about 14 ft NAVD88 at the City of Galveston. Storm 023 is a hypothetical hurricane that approximately produced the 100-yr water level at San Luis Pass of 14 ft NAVD88; and Storm 019 is a hypothetical hurricane that approximated the 10-yr water level at San Luis Pass, 7 ft NAVD88.

Figure 4-5 shows peak storm surge maps for Hurricane Ike, for present sea level, with a western section (top panel) and without a western section (bottom panel). Results clearly show that the peak surge is much higher in West Bay with the “back door” open. The increases in peak surge are greatest near San Luis Pass; and they decrease from west to east within West Bay. Without the western section, peak surge at the west end of Galveston Island is 5 to 5.5 ft higher than the peak surge with the western section. The effect of leaving the “back door” open on peak surge extends to the City of Galveston, where the peak surge is 1.5 to 2 ft higher without the western section. Leaving San Luis Pass open influences the design of the Galveston Ring Barrier. The increase in peak surge with the “back door” open is not limited to West Bay. Increases also are evident in Galveston Bay; however, the magnitude of the increase in peak surge is less in Galveston Bay than it is in West Bay. Peak surge differences in Galveston Bay, approximately 1 to 1.5 ft in most places, and are slightly smaller than differences at the City of Galveston.

As illustrated in Figure 4-6, for Hurricane Ike, present sea level, some of lowest-lying areas on western Galveston Island closest to West Bay are inundated even with the western section in place (top panel in Figure 4-6). However, without the western section, inundation of terrain surrounding West Bay is much more widespread; and, western Galveston Island is nearly completely inundated (circled region in the bottom panel of Figure 4-6).

Figure 4-7 shows inundation maps for Hurricane Ike, present sea level, for eastern Galveston Island. Some of lowest-lying areas on eastern Galveston Island and a community on the north side of West Bay are inundated even with the western section in place. However, without the western section, inundation of the circled eastern Galveston Island communities is complete; multiple communities on the north side of West Bay are inundated, as are parts of the City of Galveston, including the airport (see the circled areas in the bottom panel of Figure 4-7). Note that these simulations do not include the Galveston Ring Barrier. Some of the circled areas in Figure 4-7 are included in the Economic Reach 37, which experiences high residual damages for the USACE Plan (see Chapter 6 to locate the boundaries of Reach 37).

Figure 4-8 shows peak surge maps for Storm 023, present sea level, with a western section (top panel) and without a western section (bottom panel). Results show that the peak surge is, again, much higher in West Bay with the “back door” open. Again, as is seen for all the storms that were simulated, the increases in peak surge are greatest nearer San Luis Pass and they decrease from west to east in West Bay. Without the western section, peak surge at the west end of Galveston Island is 7 ft higher than the peak surge with the western section in place. At the City of Galveston, the peak surge is 1 ft higher without the western section. Increase at the City of Galveston influences the design of the Galveston

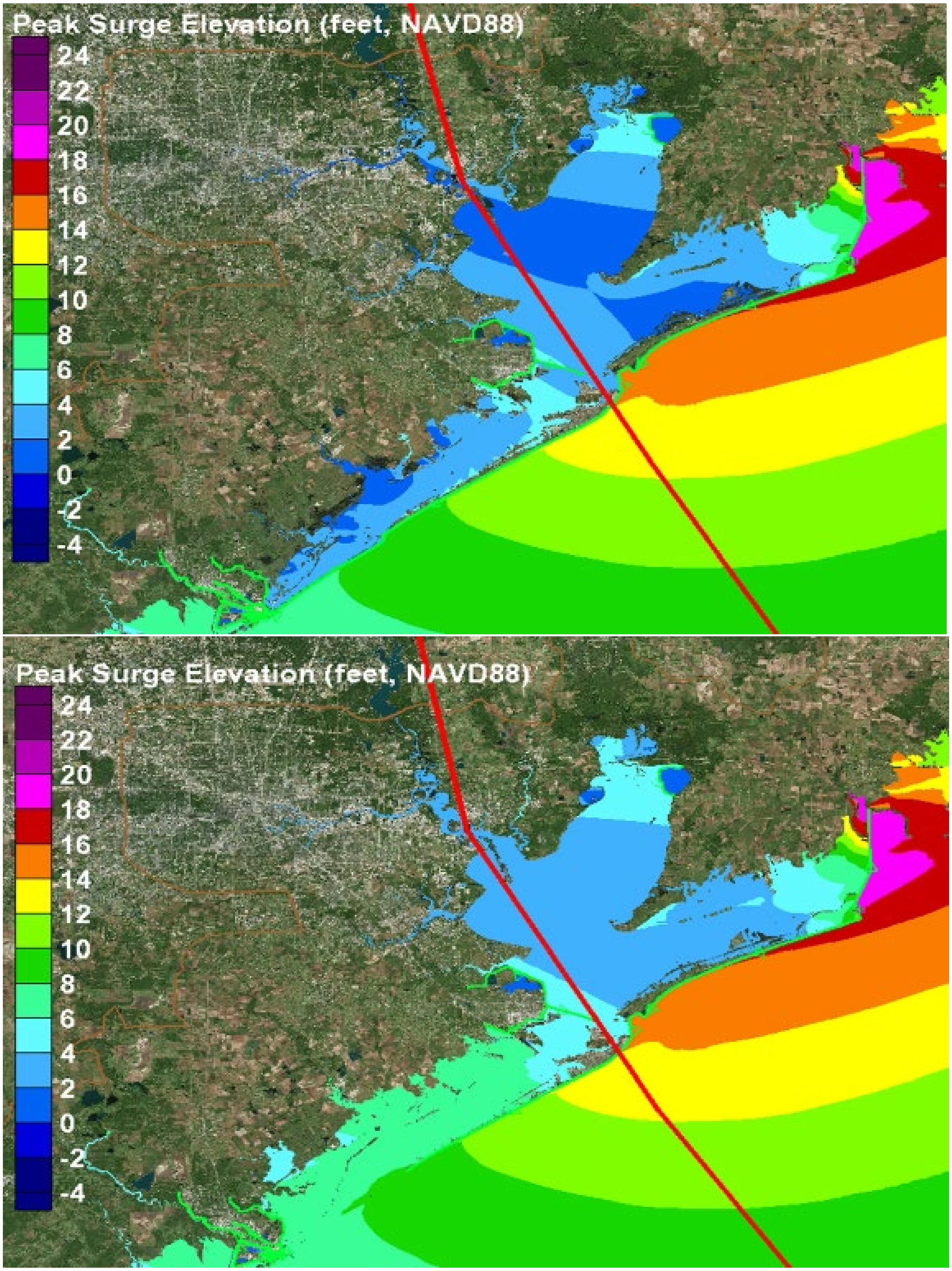

Figure 4-5. Peak surge maps for Hurricane Ike, present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

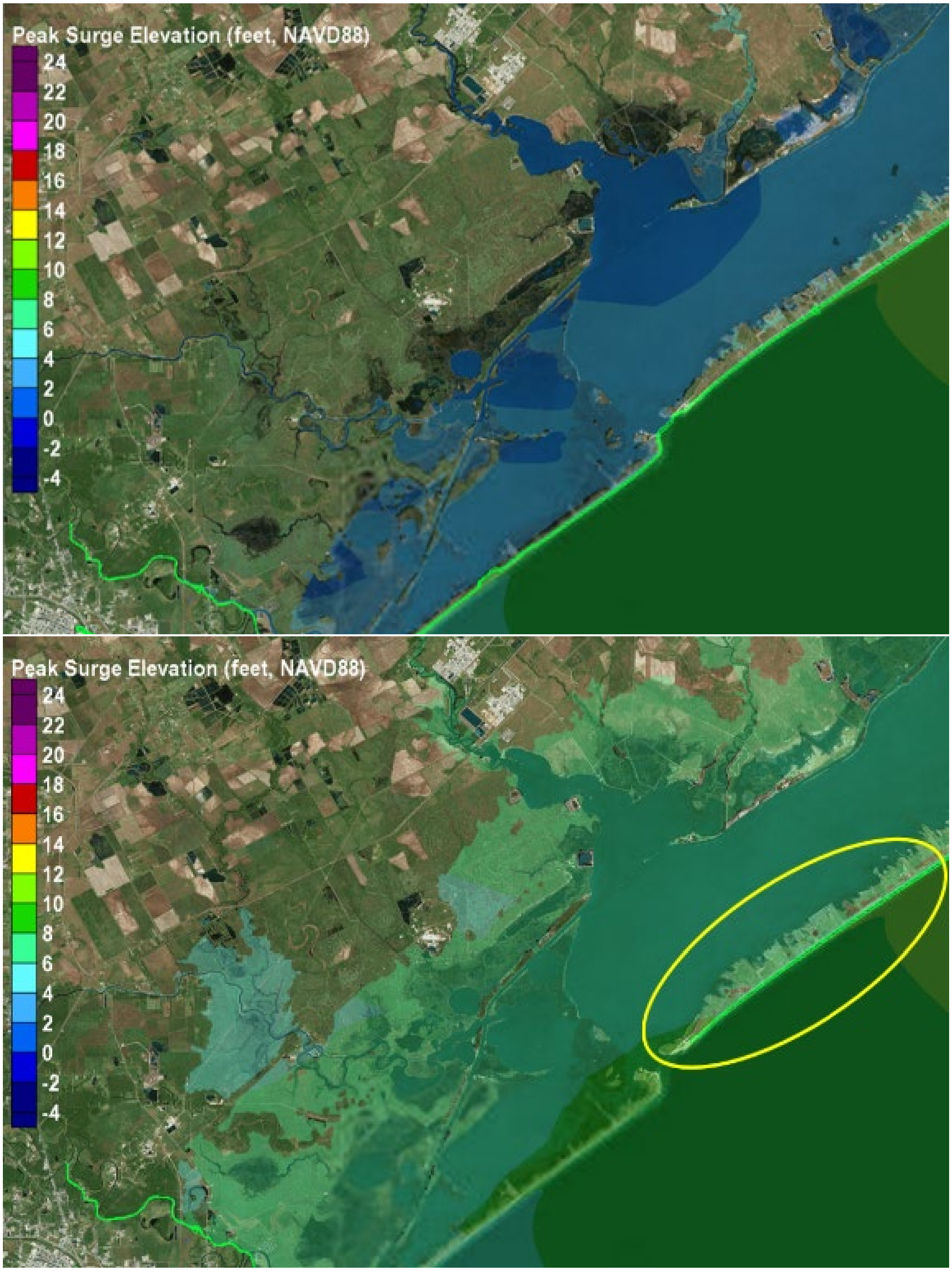

Figure 4-6. Inundation maps in near San Luis Pass, for Hurricane Ike and present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

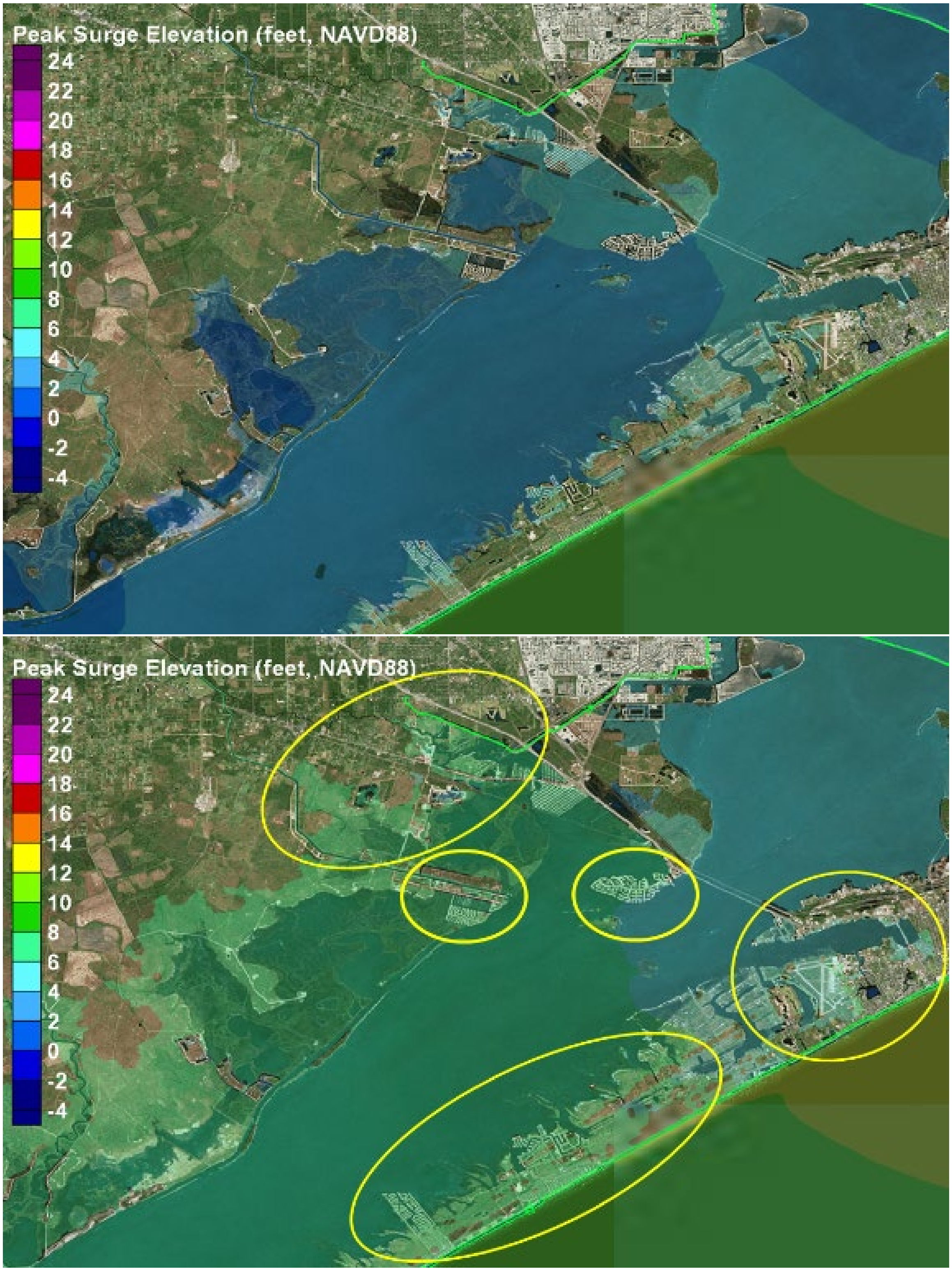

Figure 4-7. Inundation maps in eastern West Bay, for Hurricane Ike and present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

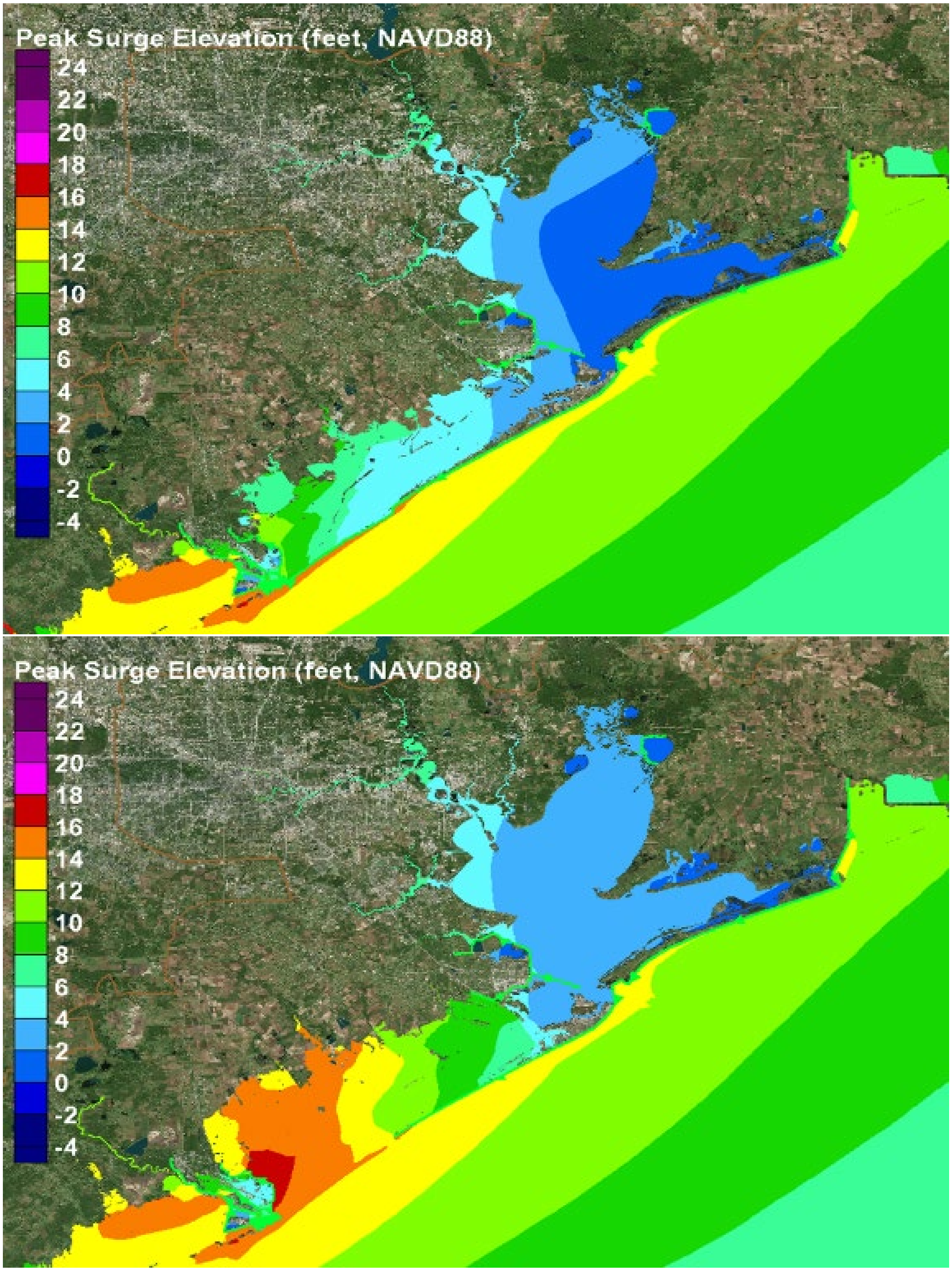

Figure 4-8. Peak surge maps for Storm 023, present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

Ring Barrier. Increases in peak surge also are evident in Galveston Bay; however, the magnitude of the increase in peak surge is less in Galveston Bay than it is in West Bay. Peak surge differences in parts of Galveston Bay are comparable to the differences at the City of Galveston, approximately 1 ft in places, less along the western side of the Bay.

For Storm 023, present sea level, some of lowest-lying areas on western Galveston Island closest to West Bay are inundated with the western section in place (upper panel of Figure 4-9). However, without the western section, inundation of terrain surrounding West Bay is much more widespread and western Galveston Island is completely inundated (see the circled area in the bottom panel of Figure 4-9). Inundation is more severe for Storm 023 than for Hurricane Ike. Without the western section, a LNG complex near Freeport is significantly inundated as are the petro-chemical complexes along Chocolate Bayou; both facilities are circled in the bottom panel of Figure 4-9. The region shown in Figure 4-9 is included in Economic Reach 4, which has high residual damage for the USACE Plan.

For Storm 023, present sea level, some of lowest-lying areas on eastern Galveston Island are inundated with the western section in place (see top panel in Figure 4-10). However, without the western section, inundation of the indicated eastern Galveston Island communities is complete, multiple communities on the north side of West Bay are inundated, as are parts of the City of Galveston, including the airport (see the circled areas in the bottom panel of Figure 4-10). Two of the circled regions shown in Figure 4-10 are included in Economic Reach 37, which has high residual damage for the USACE Plan.

Leaving the "back door" open leads to increased flooding and inundation on Galveston Island even for relatively frequent, weaker, hurricane events, like Storm 019. Storm 019 was selected to replicate the 10-yr average recurrence interval water level at the entrance to San Luis Pass, a peak surge of 7 ft NAVD88. Figures 4-11 and 4-12, show the increase in inundation that occurs for Storm 019, present sea level, with the "back door" open (top panels) and the "back door" closed (bottom panels). Figures 4-11 and 4-12 show the differences in inundation for western and central Galveston Island, respectively. The USACE Plan provides very little protection for parts of western Galveston Island that lie outside the Galveston Ring Barrier.

Influence of Sea Level Rise on Increased Peak Surge and Inundation Associated with Flanking

In general, rising sea level will increase flood risk throughout the Houston-Galveston region, both with and without a western section. Low-lying areas and areas having low topography gradients are most susceptible to increases in sea level. Leaving the "back door" open increases the susceptibility of the most vulnerable areas to flooding as sea level rises. In addition to all those areas around West Bay, there also appear to be areas around the periphery of Galveston Bay where surge levels and inundation are exacerbated because of leaving the open "back door."

For example, for Hurricane Ike and the future sea level scenario, a number of areas in the City of Galveston are exposed to inundation, which otherwise, would not be inundated with the western section in place (see the circled area in Figure 4-13). Most or all of these areas are included inside the Galveston Ring Barrier, but its design elevation for the future sea level rise scenario is influenced by leaving the "back door" open.

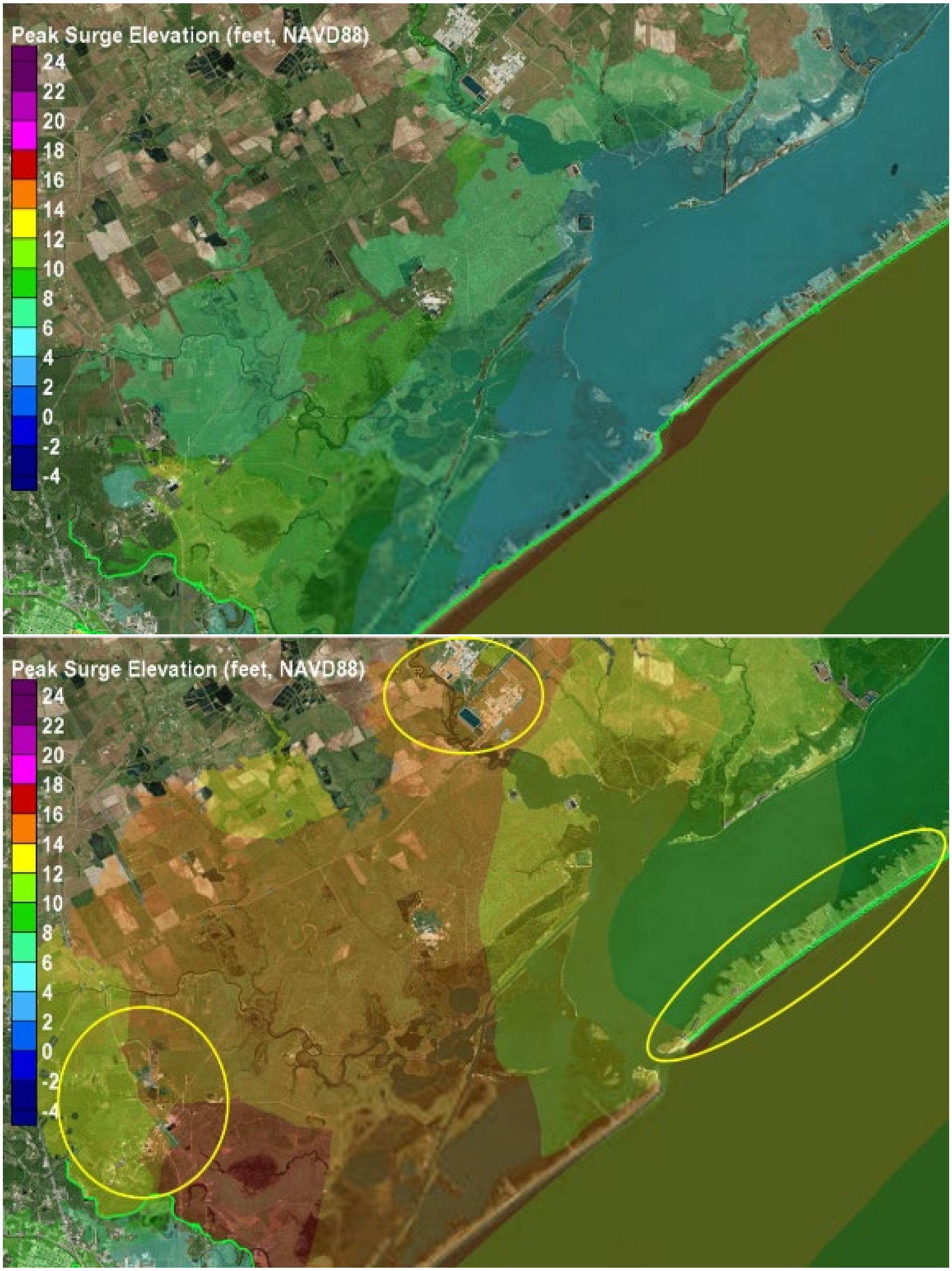

Figure 4-9. Inundation maps near San Luis Pass, for Storm 023 and present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

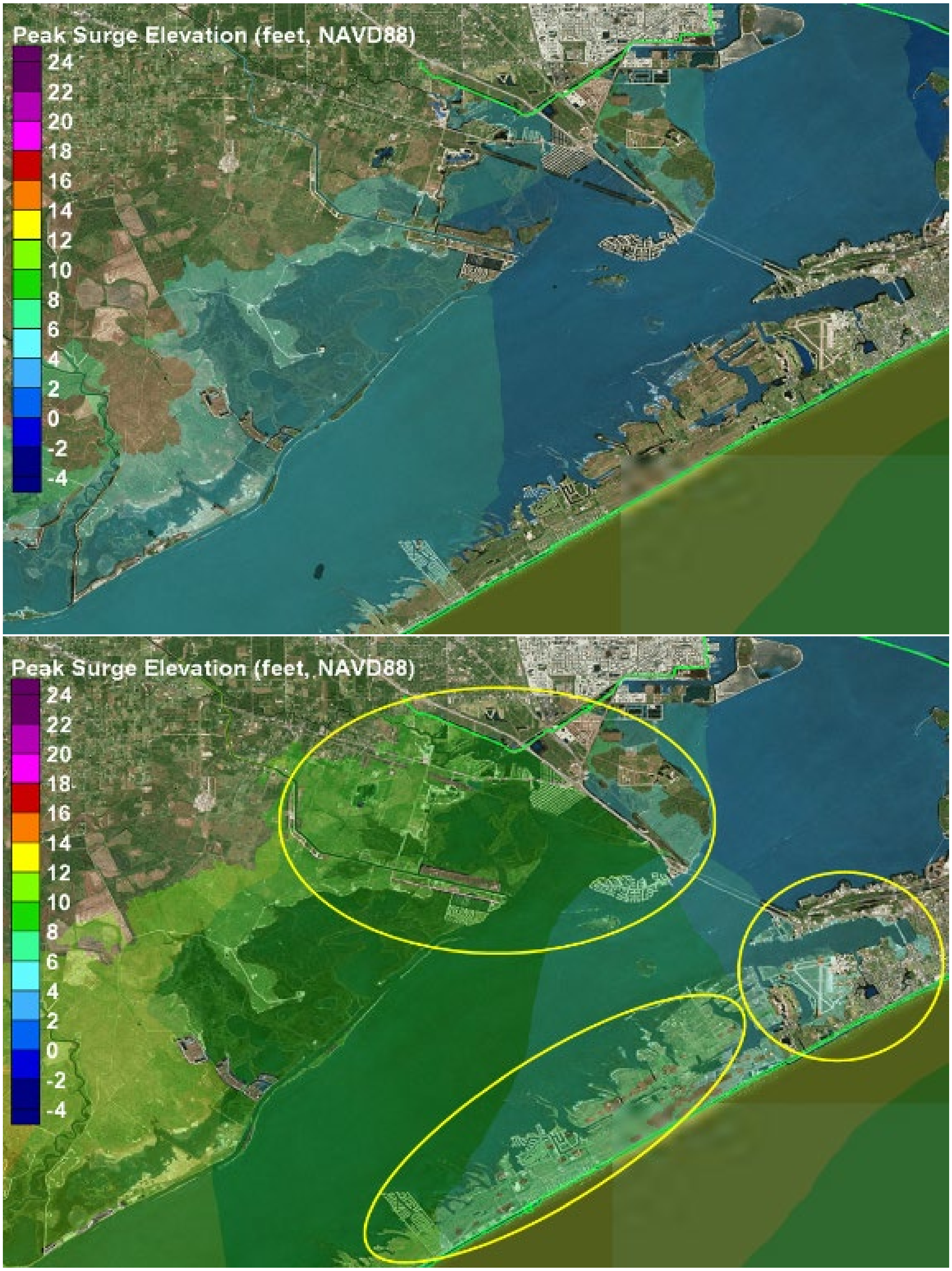

Figure 4-10. Inundation maps in eastern West Bay, for Storm 023 and present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

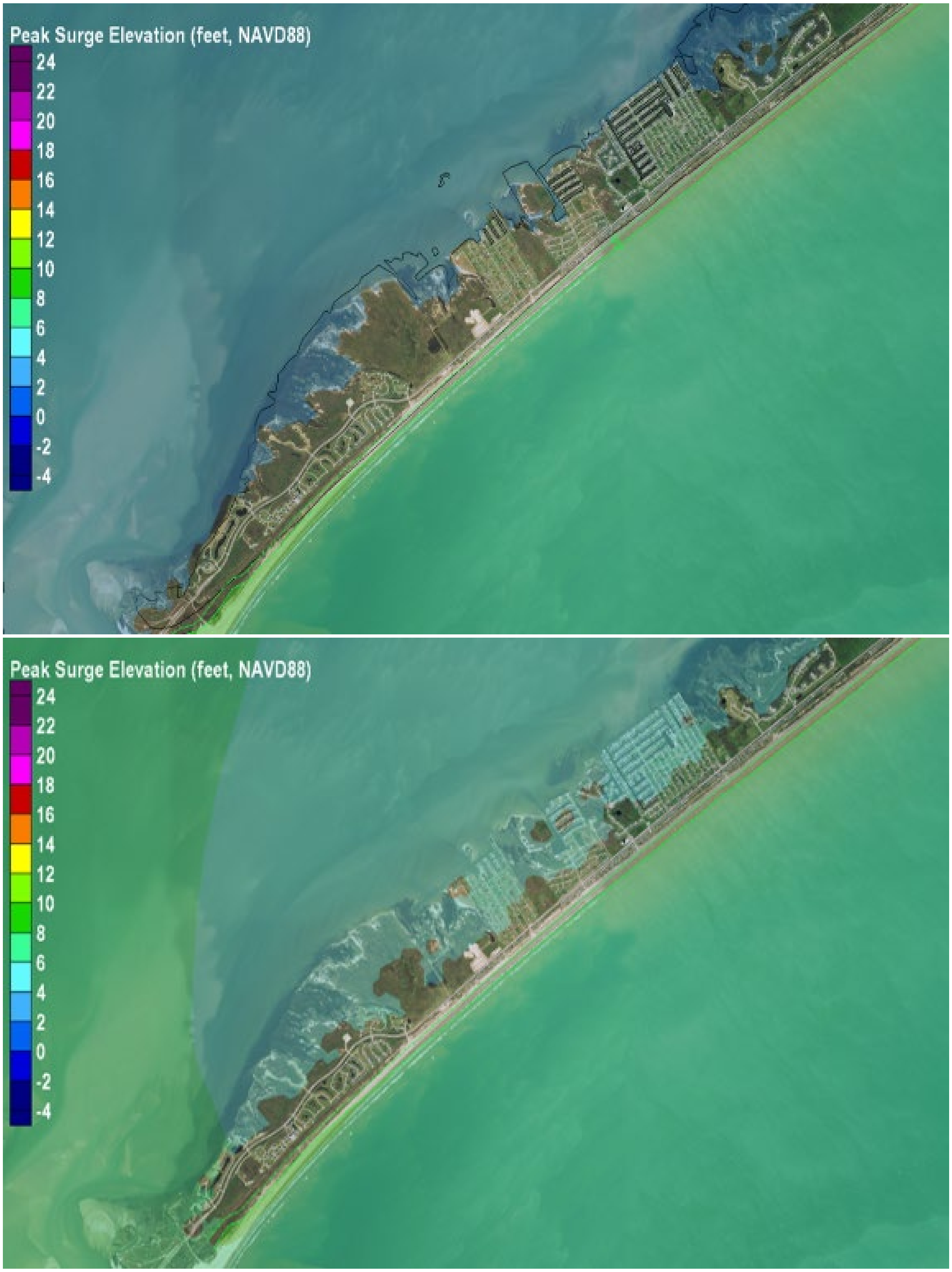

Figure 4-11. Inundation maps for western Galveston Island, for Storm 019 and present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

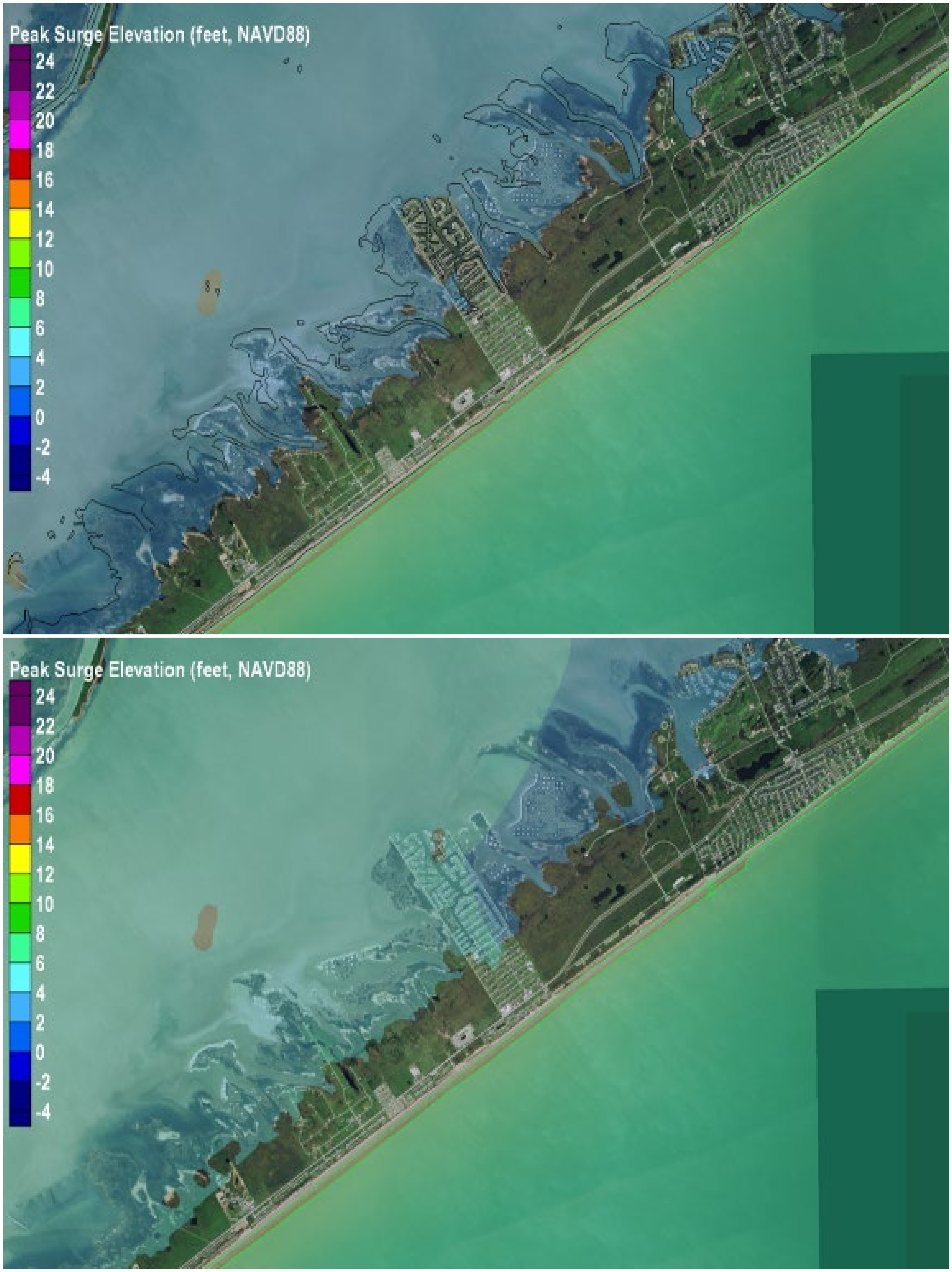

Figure 4-12. Inundation maps for central Galveston Island, for Storm 019 and present sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

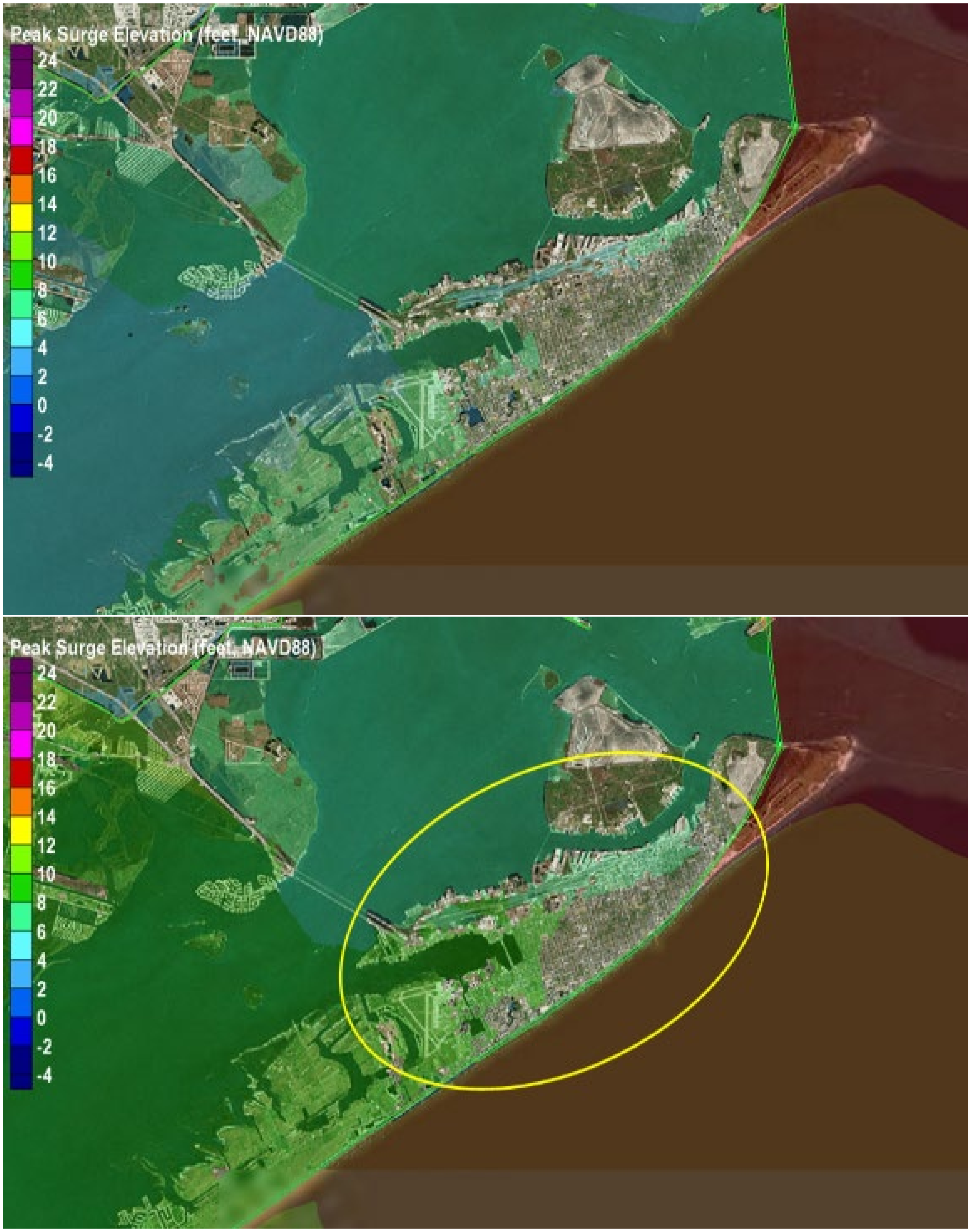

Figure 4-13. Inundation maps for the City of Galveston, for Hurricane Ike and future sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

There also are similarly affected areas along the western shoreline of Galveston Bay. For Hurricane Ike, and the future sea level scenario, parts of the town of San Leon, adjacent to Dickinson Bay, are inundated (circled area in the bottom panel of Figure 4-14) when the “back door” is left open, which are not inundated with the western section in place (top panel of Figure 4-14). Even small changes in peak surge levels that are caused by leaving the “back door” open can induce inundation and damage inside Galveston Bay.

A similar influence is seen along the eastern shoreline of Galveston Bay. For Hurricane Ike, and the future sea level scenario, the town of Oak Island is inundated (circled area in the bottom panel of Figure 4-15), which does not occur with the western section in place (see the top panel of Figure 4-15). With rising sea level, the adverse effects of leaving the “back door” open do not appear to be restricted to West Bay or the western side of Galveston Bay.

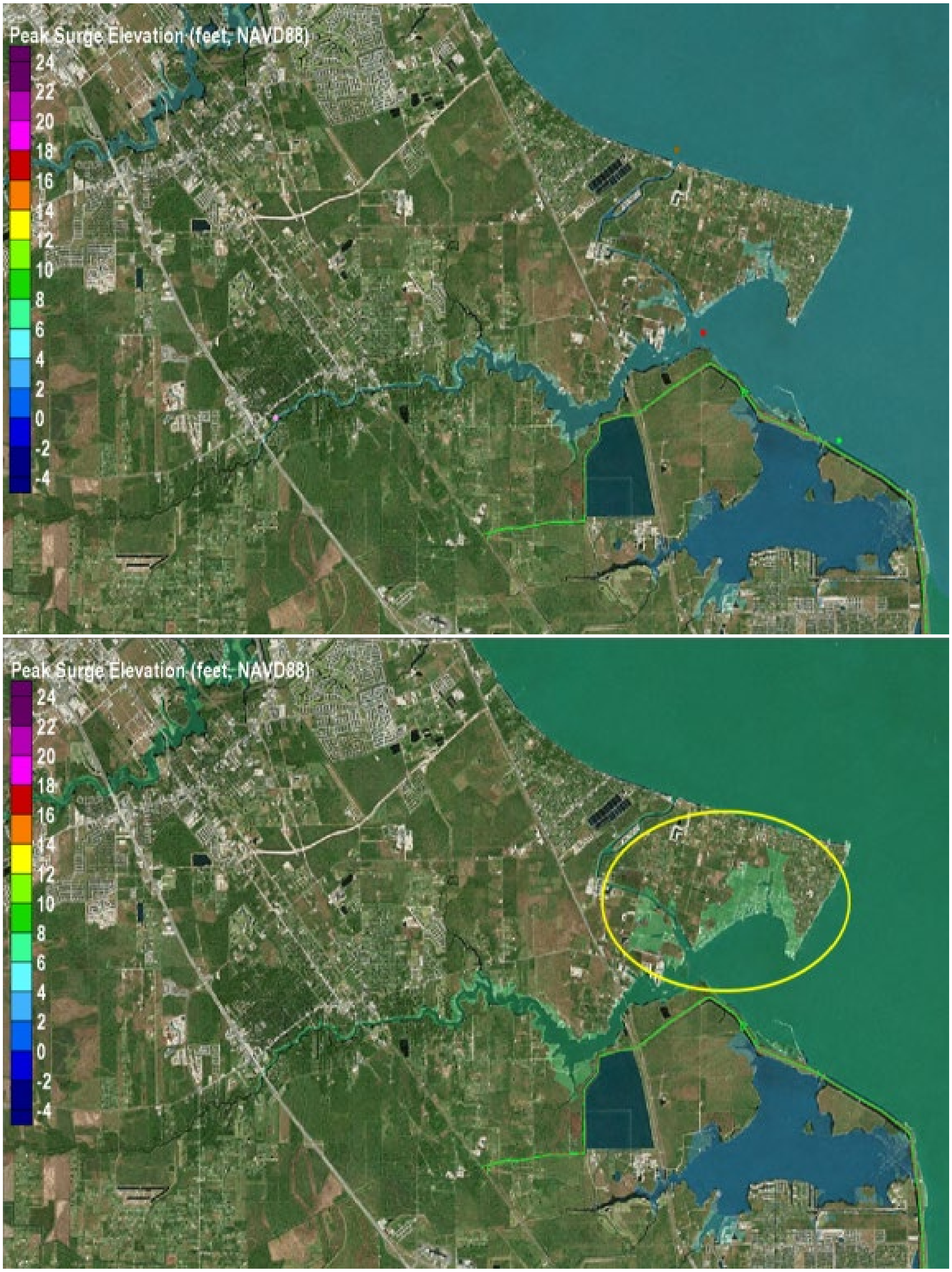

Figure 4-14. Inundation maps for the town of San Leon, for Hurricane Ike and future sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

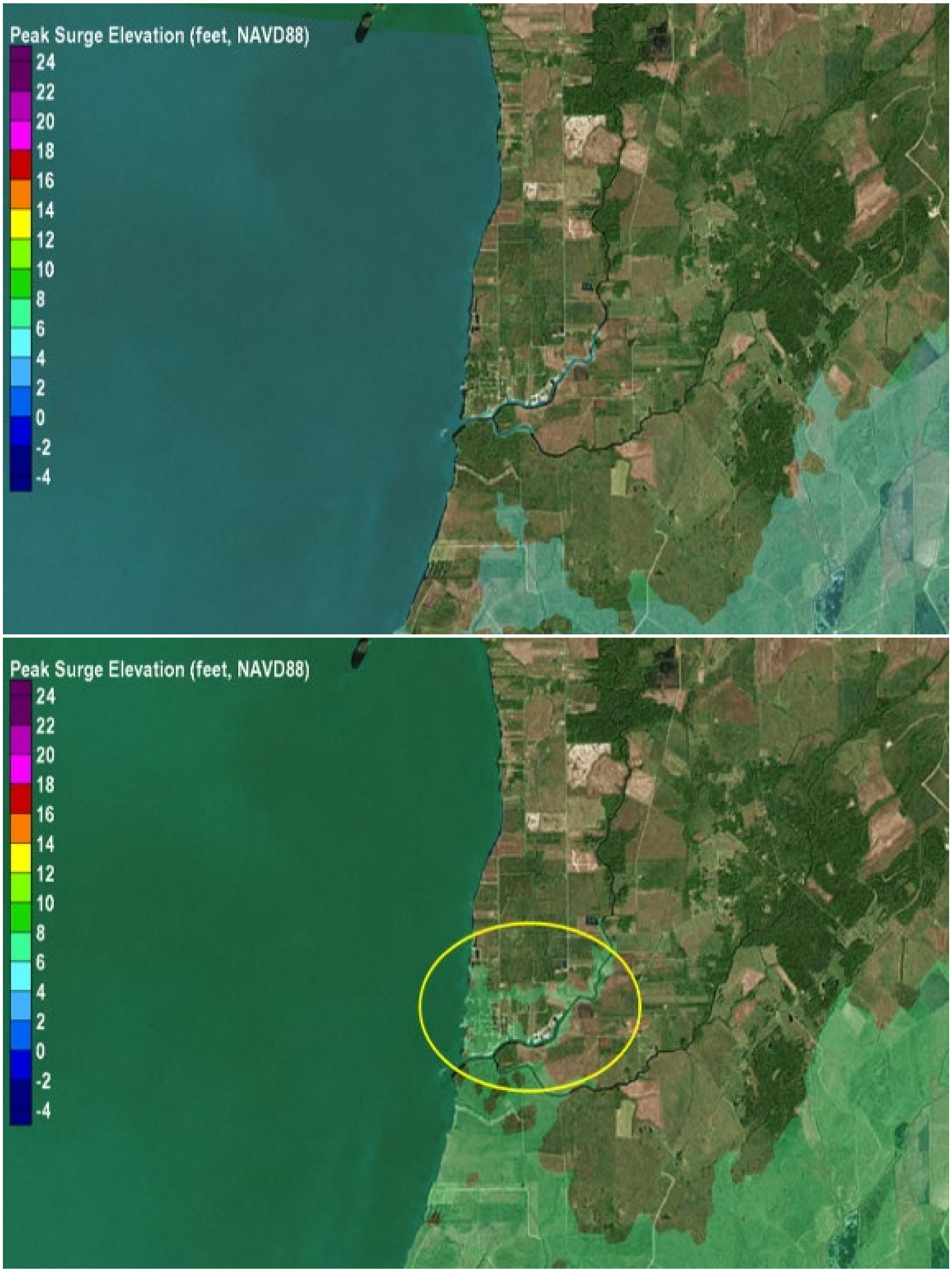

Figure 4-15. Inundation maps for the town of Oak Island, for Hurricane Ike and future sea level, for the Ike Dike coastal spine concept having a western section (top panel) and an alignment similar to the USACE Plan that does not have a western section (bottom panel).

References

Jackson State University. (2018). Final Report - Ike Dike Concept for Reducing Hurricane Storm Surge in the Houston-Galveston Region, Jackson, MS. 549 pp. https://www.tamug.edu/ikedike/pdf/JSU-Final-Report-Ike-Dike-Concept.pdf

Kennedy, A.B., Gravois, U., Zachry, B.C., Westerink, J.J., Hope, M.E., Dietrich, J.C., Powell, M.D., Cox, A.T., Luettich, R.L., and Dean, R.G. (2011). “Origin of the Hurricane Ike forerunner surge”, Geophysical Research Letter, L08805, doi:10.1029/2011GL047090.

U.S. Army Corps of Engineers. (2020). Coastal Texas Study 2020 Draft Feasibility Report, https://www.swg.usace.army.mil/Business-With-Us/Planning-Environmental-Branch/Documents-for-Public-Review/