Part V.

Hurricane Surge Hazard Analysis for Future Conditions

Blum and Roberts 2009

As discussed in Parts I and II hurricane climatology and coastal landscapes are crucial factors in hurricane surge hazard. When these factors are subject to major trends, surge risk managers need to assess the effect of change on the estimate of surge hazard at future horizons. If rates of change are fast or accelerating—and if risk consequences are severe—horizons may be as soon as five to ten years. For slow, steady changes—and for modest impacts—horizons may be several decades.

In order to assess surge hazard at a future time quantitative trend analyses (see GTN-1 Section D) can be employed to forecast changes to key inputs in the surge hazard analysis described in Parts III and IV. For example, to forecast surge hazards in 50 years trend analyses can be used to obtain "best estimates" for a future Year 50 hurricane joint probability expression, LMMSL, ADCIRC mesh node elevations and attributes, and perimeter protection crowns. The complete surge hazard JPA with JPM-OS—as described in Parts III and IV—can then be redone to compute the Year 50 surge hazard CDFs for exterior locations and polder interiors throughout the region. If the Year 100 surge hazards are similarly computed, the three results—current, Year 50, and Year 100—can be used to evaluate trends in hurricane surge hazard.

In addition to providing a best estimate of future conditions, trend analysis also quantifies uncertainty about the estimate. Trend uncertainties can therefore be employed in the JPA—such as by expanding the Monte Carlo techniques—to quantify uncertainty about the estimate of future surge hazard.

For planning purposes, comprehensive trend analyses and JPA expansion may not be practical. This can be the case when trends are not well defined or the primary interest is only in the relative comparison of a few specific "what if" alternatives. To further simplify planning level evaluations, comparisons may be made on the basis of just a few synthetic hurricane scenarios, rather than a surge hazard derived with a full JPM-OS. These evaluations represent selected sensitivity tests of potential future conditions. However, risk managers must realize that as the analysis becomes more simplified the results become more speculative and less suitable for use in decision-making—e.g., engineering design of perimeter protection systems and coastal restoration.

This Part V reviews the current state of the practice for steps needed in hurricane surge hazard analysis for future conditions, including the following subjects:

> Section 18., research on coastal landscape trends for southeast Louisiana, including sea level rise (SLR), regional subsidence, coastal erosion, and changes in vegetation, perimeter protection, and polder interiors.
>
> Section 19., methods for addressing future hurricane climatology and coastal landscape trends, including the use of hurricane scenarios.
>
> Section 20., recent applications of hurricane surge hazard analysis for future conditions, including the USACE's 2009 LaCPR Study, Mississippi Coastal Improvement Plan (MsCIP), and HSDRRS 100-yr design for 2057; the CPRA's 2012 Master Plan; and the SLFPA-E evaluations of the Lake Pontchartrain barrier and polder compartmentalization.

These sections review approaches as presented in the current literature and project documentation, as well as discuss methodology requirements, assumptions, and limitations based on sound scientific and engineering practice. Afterwards, a list of conclusions is presented, together with recommendations for improving hurricane surge analysis for future conditions.

Section 18. Coastal Landscape Trends

This section briefly summarizes current approaches to important coastal landscape trends in southeast Louisiana that influence estimates of future surge hazard and risk. Trend information is largely derived from the extensive literature supporting Louisiana coastal protection and restoration planning—e.g., the State of Louisiana's Master Plan (2012) and the USACE's LaCPR Study (2009). The trends include SLR, regional subsidence, coastal erosion, vegetation changes, and perimeter systems and polders. Assessment of future conditions can also consider alternatives to current trends, such as proposed projects to restore coastal land elevation and vegetation or to modify perimeter protection. The steps needed to assess surge hazards associated with future conditions—based on trends or a proposed project alternative—are addressed in Section 19.

18.1 SLR

Climatologists and ocean scientists generally agree that global average temperatures and SSTs in the Atlantic Basin are both in a significant upward trend (see the website Climate Change at the National Acadamies, http://nas-sites.org/americasclimatechoices/other-reports-on-climate-change/). Coastal scientists and planners—including federal and state agencies responsible for managing coastal resources and planning for coastal infrastructure (e.g., NOAA, USGS, USACE, Louisiana Coastal Protection and Restoration Authority)—agree that current trends on global climate change and SSTs are likely to produce significant SLR due to thermal expansion and the melting of polar land ice. The scientific research on future SLR is therefore being employed by these and other agencies (see Gulf of Mexico Alliance 2011). The USACE applies a general guidance on SLR to all coastal projects (USACE 2009). For planning horizons to the year 2100 the Louisiana CPRA recommends using a SLR range of 1.6 to 4.9 ft for coastal Louisiana LMSL, with a moderate SLR value of 3.3 ft. For a 50-year horizon the recommended SLR range is 0.4 to 2.1 ft, with moderate and less optimistic values of 0.9 and 1.5 ft (see CPRA Coastal Master Plan 2012).

Adjustment for LMMSL to LMSL—i.e., the added water surface elevation for seasonal steric effect—are applied in addition to the SLR modification to LMSL.

18.2 Regional Subsidence

Southeast Louisiana experiences significant regional land subsidence (surface elevation drop with respect to the geoid, see GTN 2 and Reed et al 2009). The magnitude, timing, and rates of general regional subsidence vary under the influence of four geologic factors:

1. Deep crustal plate warping in the lower Mississippi embayment associated with millions of years of deposition (since the Cretaceious Period), as well post-glacial adjustment of the continental plate. These can be manifested in episodic slippage along active faults;
2. Deltaic loading associated with Pleistocene deposition over the past two million years;
3. Ongoing consolidation within the recent Holocene delta lobe sediments; and
4. Oil, gas, and groundwater withdrawals over recent decades.

Scientific research suggests that rates of geologic subsidence may be as high as 3 feet per century in some portions of coastal Louisiana (Reed et al 2009). Figure 18.1 depicts the 50-yr forecast of regional subsidence provided in the CPRA's 2012 Master Plan.

Combining estimates of SLR with regional subsidence yields an estimate of *relative* SLR (RSLR). Figure 18.2 shows a recent USACE estimate of variation in RSLR across southeast Louisiana. The USACE employed a RSLR estimate of 0.9 ft for the 50-year period from 2007 to 2057 in the design of the HSDRRS, which they rounded up to 1 ft (USACE 2010).

RSLR increases future surge hazard (and risk) not only because of the direct rise surge depth, but also because of effects on surge momentum. RSLR increases the cross-section flow area and conveyance, thereby facilitating greater inland movement of surge.

18.3 Coastal Erosion

Much of the southeast Louisiana delta is composed of recently deposited, poorly consolidated and only moderately cohesive fine sediments and organic matter. The coastline is highly fractal, long, and very susceptible to erosion from waves and currents. Abandoned, subsiding delta lobes—and their component barrier islands, headlands, and wetlands—naturally undergo erosion.[1]

The combination of SLR, subsidence, and erosion along shorelines of lakes, bays, and channels expands the open water area, which both

a. Enlarges fetch, thus increasing erosive currents and waves associated with the normal range of coastal winds; and

b. Raises the tidal prism, which modifies salinity and damages sensitive, soil-binding vegetation.

These further accelerate coastal land loss.

Coastal land loss trends for southeast Louisiana have been the subject of frequent research and publication. Currently, RSLR and erosion are estimated to convert about 16 square miles of subaerial land to open water each year (CPRA 2012). Figure 18.3 shows a portion of the recent USGS study depicting land loss in coastal Louisiana from 1932 through 2010 (Couvillion et al 2011). Figure 18.4 depicts the projected cumulative land loss for coastal Louisiana from 1932 through 2050 (USGS 2005).

Coastal erosion especially exacerbates surge hazard (and risk) by expanding shallow water fetch. Longer, open, shallow fetches facilitate higher wind setup force, increasing surge momentum. Expansion of open water also increases hurricane wind wave heights.

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[1] Human activities have contributed significantly to erosion. These include dredging of coastal oil and gas canals and navigation channels (e.g., the MRGO); subsurface fluid extraction induced marsh subsidence (e.g., Leeville area); and modifications to natural barrier islands and shoals which prevent natural replenishment of beach/dune complexes (e.g., Caminada Pass jetty). Southeast Louisiana coastal land loss from subsidence and erosion is also exacerbated by the absence of normal Mississippi River deltaic inputs, caused by damming of the upper tributaries and confining of the delta distributaries.

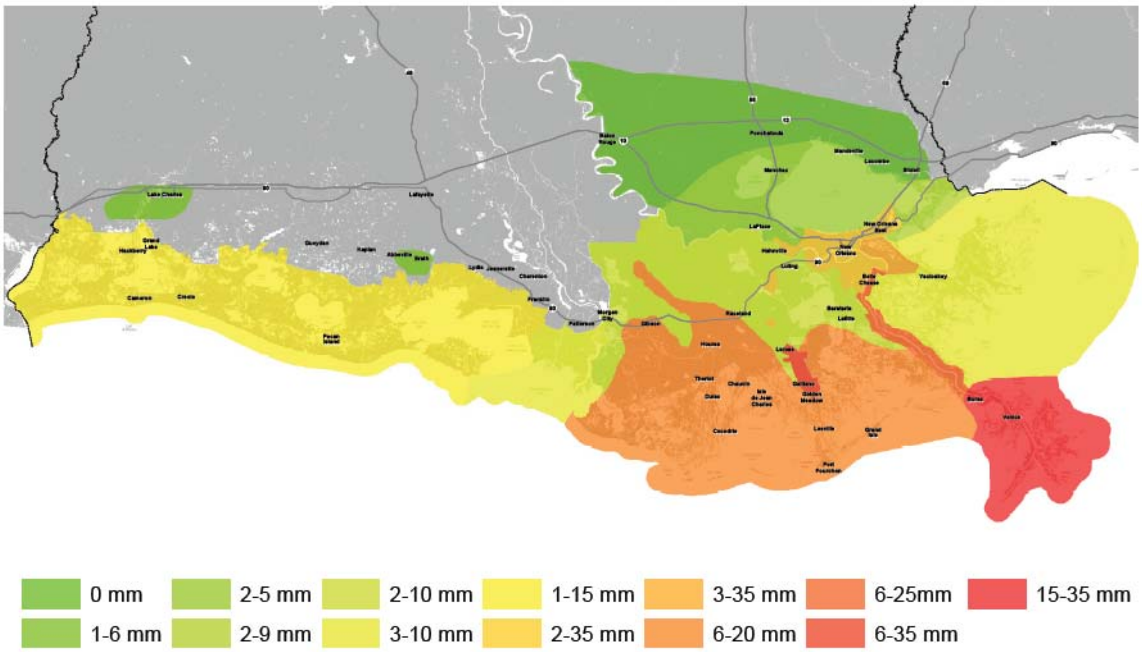

Figure 18.1. 50-Year Forecast of Regional Subsidence
CPRA 2012

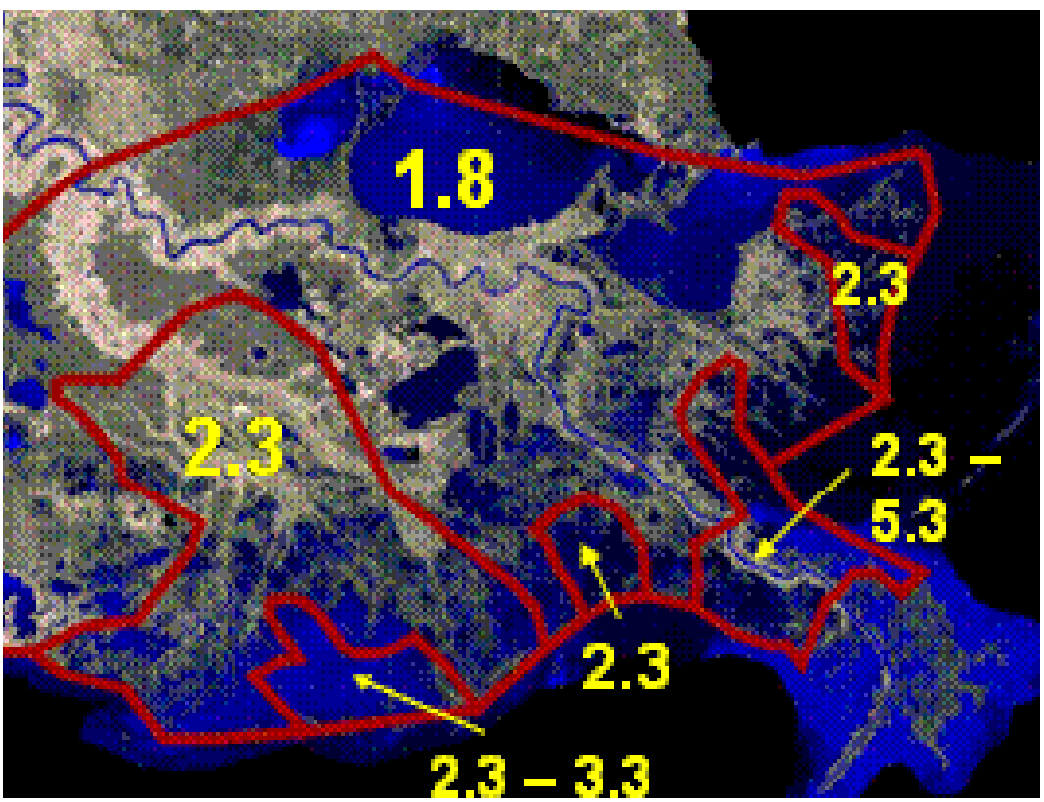

Figure 18.2. Estimates of Relative Sea Level Rise (ft per century)
USACE 2010

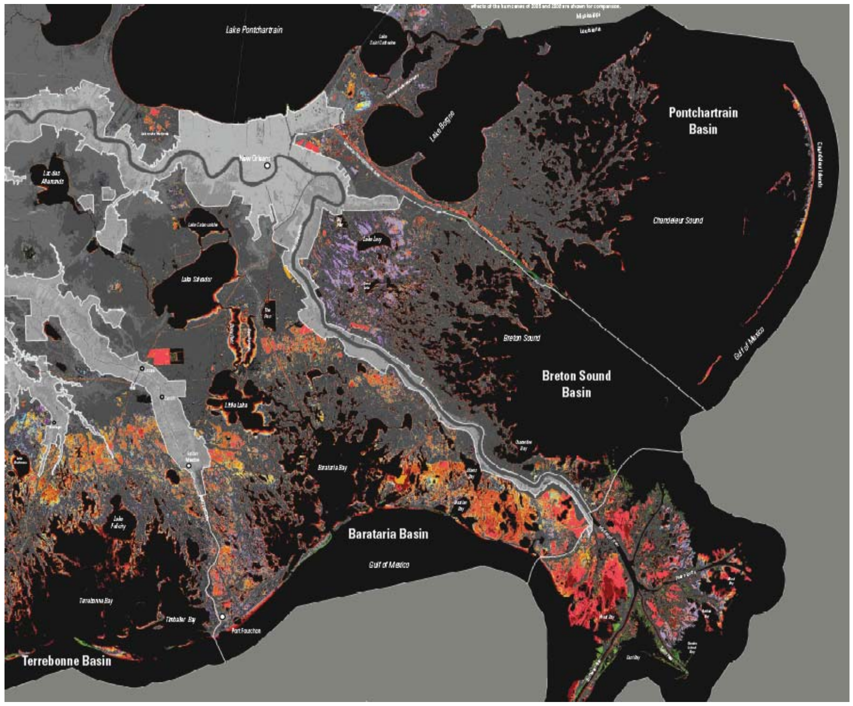

Figure 18.3. Excerpt from Land Area Change in Coastal Louisiana, 1932-2010
Couvillion et al 2011

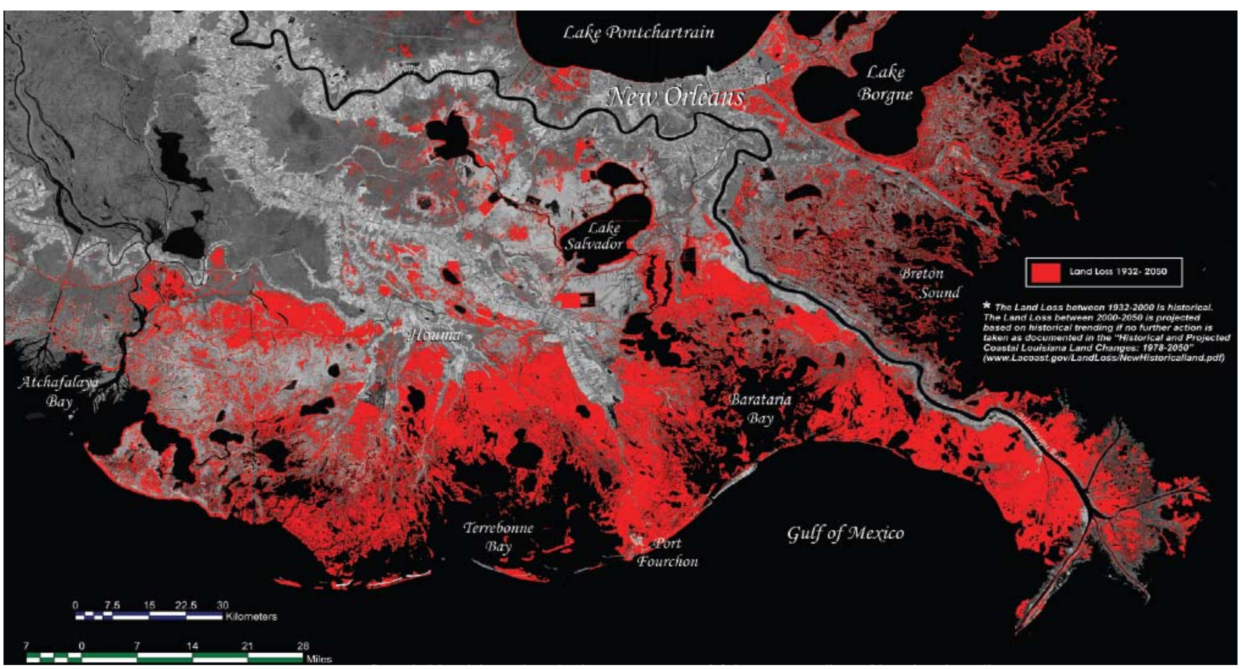

Figure 18.4. Estimated Land Loss in Coastal Louisiana, 1932-2050
USGS 2005

18.4 Vegetation Changes

In addition to direct land loss, RSLR and erosion cause key changes in the coastal land cover, including the decline of natural forested coastal ridges and cheniers and the conversion of more woody freshwater wetlands to more grassy brackish and saline marshes. Coastal wetland vegetation change—such as from woody to grassy—can increase surge hazard by reducing the friction drag which would otherwise slow down winds and the momentum of inland surges.

Historic landscape conversions are documented in updates to land cover databases, which are developed from ground-truthed satellite and aerial imagery.

Researchers have been working on combining forecasted changes to coastal hydrodynamic, sedimentation, RSLR, erosion, water quality, temperature, and other parameters to predict future habitat regimes and vegetation types (see Visser et al 2008). For the 2012 Master Plan Visser et al developed a coastal vegetation model with 500 m cells that forecasts 50 years of annual changes. The specified trends for each cell include the proportion of 19 emergent vegetation types that occupy subaerial wetland; the proportion of empty open water; and the proportion of open water occupied by submerged aquatic vegetation.

18.5 Perimeter Protection and Polders

Three important trends in perimeter protection that can affect future polder interior surge hazard (and risk) are:

- Consolidation, settlement, and subsidence of existing structures. Figure 18.5 depicts total subsidence rates—i.e., regional deltaic subsidence plus local consolidation and settlement—in the New Orleans area between 2002 and 2005. During this period rates along some HSDRRS reaches exceeded 5 ft per century (15 mm/yr). A comprehensive, reach-by-reach investigation of total subsidence rates for the recently completed HSDRRS—critical to forecasting future polder surge risk—is currently not available.
- Changes to foreshore conditions which affect wave heights, runup, and overtopping, including the loss of forested wetlands and settlement of breakwaters. For example, the presence of extensive wetlands is critical to the HSDRRS levee design height in St. Charles Parish, as are breakwaters to Jefferson Parish. A comprehensive, detailed investigation of foreshore trends for forecasting future wave overtopping is currently not available.
- Changes to the integrity and fragility of HSDRRS structures, such as corrosion of steel, deflection of walls, and the expansion of voids in soils and cracks in concrete. Mechanical structures can also experience changes in fragility due to improved or degraded operability. For example: the likelihood of a floodgate not being closed may increase under a future with restricted operations and maintenance resources. A comprehensive, detailed investigation of changing fragility conditions for forecasting future breach probabilities is currently not available.

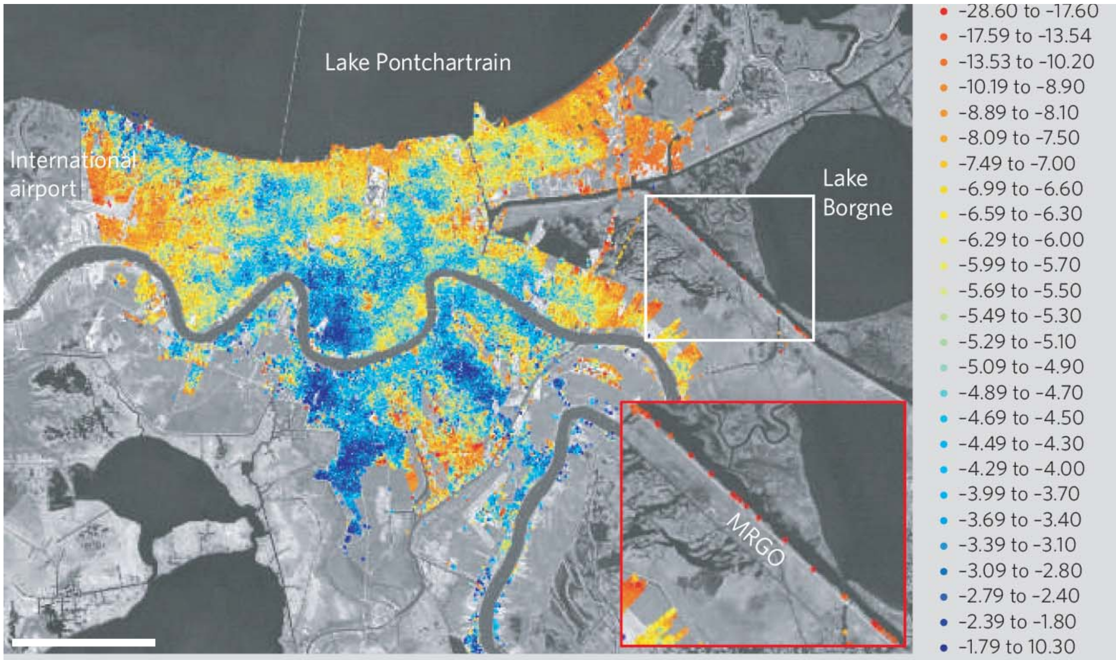

Figure 18.5. New Orleans Total Subsidence, 2002 to 2005
Dixon et al 2006

Proposed projects that can be assessed in a future conditions analysis include both new systems or system components (such as the Lake Pontchartrain Barrier across the New Orleans East Land Bridge) and enhancements to existing structures (such as a proposal to raise nearby non-federal levees). While such projects can reduce interior surge hazard, they have the potential to adversely affect exterior surge hazards—including at locations many miles away.[2]

Interior polder subsidence trends are also an important condition to the analysis of future polder inundation hazard. In addition to regional geologic subsidence, polder interior soils undergo local shrinkage and compaction due to soil drainage and oxidation. Interior subsidence increases the depth of inundation for low-lying locations and reduces the capacity of pump stations by reducing the intake head.

Portions of the New Orleans Metro Polder have experienced over 10 ft of total subsidence since forced drainage began in the early 20th Century. The 2002-05 subsidence trends shown in Figure 18.5 also illustrate the "deepening bathtub" effect facing the New Orleans area polders. More recent, detailed investigations of polder interior subsidence are not available.

Two categories of projects which can affect the interior inundation hazard include increases to interior drainage/pumping capacity and compartmentalization structures. Examples of compartmentalization projects for the New Orleans area polders include enhancing use of the Central Wetlands for diversion of water entering the IHNC/GIWW sub-basin and upgrading legacy levees along the east and west boundaries of east-bank Jefferson Parish.

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[2] These projects can also have adverse environmental impacts, such as a) disrupting the local hydrology (e.g., conveyance patterns and tidal prism) and dependent coastal vegetation and habitats; and b) diverting/concentrating more surge into areas and thereby increasing salinity.

Section 19. Additional Steps for Future Hazard Analysis

This section describes the current technical approaches to incorporating trend forecasts and proposed projects into the analysis of future hurricane surge hazards.[1]

19.1. Changes in Hurricane Climatology

Section 2.3 reviewed the current scientific literature on trends in hurricane climatology, including the influence of important cycles—e.g., ENSO, AMO, and NAO—and secular global climate change. Studies of the influence of secular climate change and SST are ongoing, using both analyses of historic data on the frequency of Atlantic tropical cyclones—primarily according to their core intensity—and global climate models incorporating forecasted conditions. One challenge is discerning the possible presence of a long-term secular hurricane trend from the influence of climate cycles. Some of the research with models of global climate change and increasing SSTs portends increasing numbers of Atlantic hurricanes and/or more intense hurricanes. However, some models also indicate the potential for increased shearing conditions, which can inhibit hurricane development and intensification.

There have been no investigations to date of future hurricane climatology specific to the CN-GoM. As noted in Sections 1 and 3, the Loop Current and associated eddies are crucial to the specific high hazard of this region. Research by Liu et al (2012) suggests—consistent with other research on the Florida Straits Current and Gulf Stream—that global climate change could reduce the Loop Current by up to 25%, significantly *cooling* the GoM. This scenario could *reduce* the landfall frequency of powerful hurricanes along the CN-GoM, and particularly southeast Louisiana, and *lower* the 100-yr and higher surge hazards. More research on this and related topics—including rainfall rates associated with hurricanes—is needed.

Absent research findings on trends in GoM hurricane climatology, surge risk managers can turn to evaluating the sensitivity of surge hazard to a hypothetical future hurricane climatology. Speculative scenarios can be defined by simply proposing modifications to the hurricane joint probability expression, ***p***, shown in Figure 4.2 and discussed in Section 13.1. Various parameters in ***p*** controlling the frequency of hurricanes, CPD (or V_{max}), R_{max} , wind field distribution (e.g., Holland B), V_f, and track θ, and factors related to their uncertainty, can be adjusted.

The hypothetical ***p*** can then be used to develop a new JPM-OS representing the future joint probability. The surge JPA can then be redone to compute the future exterior surge hazard CDFs.

19.2. Coastal Landscape Trends

Section 18 reviewed the current approaches to important coastal landscape trends and discussed potential impacts on surge. Incorporating these forecasts into an estimate of future surge hazard can be accomplished with the following modifications to the storm surge/wave model—e.g., ADCIRC+SWAN:

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[1] Importantly, a key step—modifying the ADCIRC+SWAN model to reflect future conditions—can also support evaluating impacts on general non-surge coastal hydrology and related ecosystem conditions. Simulations forced with basic tidal and non-hurricane meteorological conditions can be employed to evaluate the effect of RSLR, coastal erosion, landscape change, and perimeter protection system modifications on the circulation and tidal prism within complex networks of coastal water bodies. These exert significant control over critical water quality parameters (dissolved oxygen, salinity, nutrients, toxins, etc.), vegetation types, and habitat.

- Projected SLR—increase the open ocean boundary and initial domain water surface elevations, i.e., LMSL in NAVD88, in accordance with the SLR forecast. This does not change the topography/bathymetry of the domain.
- Regional subsidence—adjust the elevations assigned to nodes within mesh regions (e.g., sub-delta) for forecasted subsidence.
- Coastal erosion—further adjust mesh node elevations of barrier islands and wetlands surrounding water bodies to below LMSL to further reflect the total projected areas of land loss (as in Figure 19.1).
- Vegetation conversions—modify mesh node Manning's n and wind reduction coefficients for remaining coastal areas consistent with projected changes to land cover type.
- Perimeter protection (settlement and/or projects)—add/adjust node locations and/or internal weirs in the mesh, as needed to represent the alignment; then modify node/weir elevations to reflect forecasted crown height.

Surge risk managers can then redo the surge JPA using the future ADCIRC-SWAN model and a hypothetical JPM-OS (if appropriate) to compute the future exterior surge hazard CDFs throughout the region. Figure 19.2 is an example of a difference between a current and future conditions 100-yr surge hazard prepared for the LaCPR Study (see Section 20.1)

Figure 19.1. Louisiana Coast in 2100

Blum and Roberts 2009

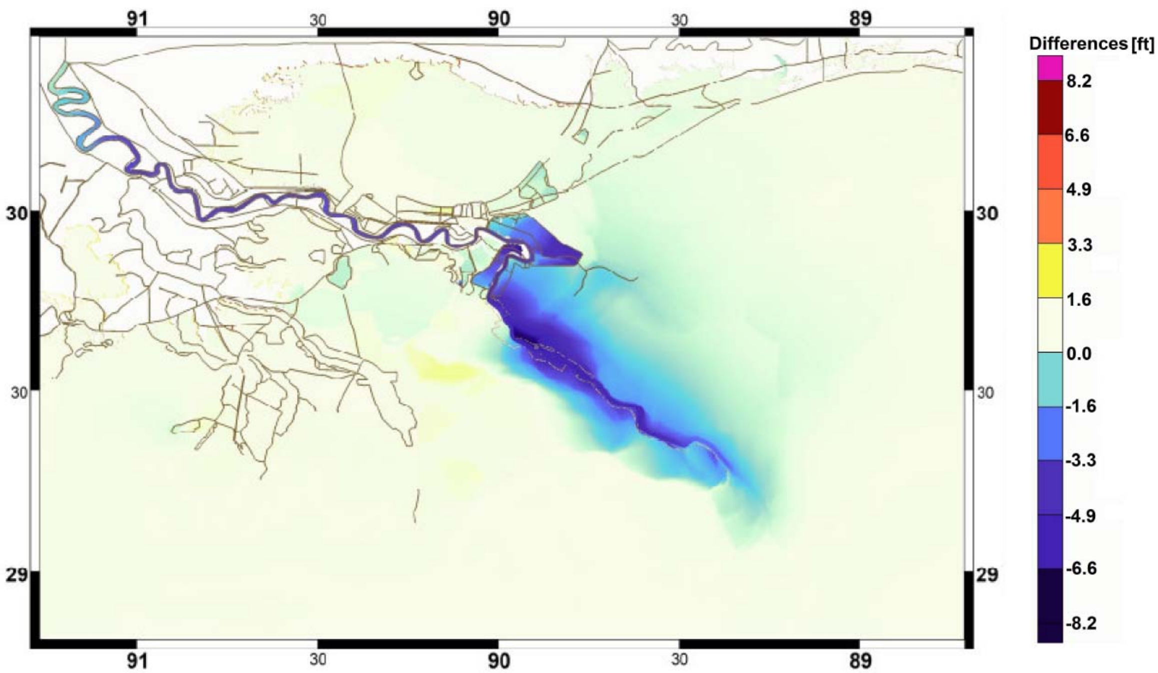


Figure 19.2. Example of Difference Between Baseline and Future Conditions 100-yr Surge Hazard

de Jong et al 2007

To assess the future polder interior hazard, the perimeter SWLs from each of the JPM-OS storms are used in an expanded JPA which includes a coupled SOBRP model, as described in Section 16. For this analysis the following steps can be added:

- Alteration of foreshore wave conditions (wetlands or breakwaters)—revise the exterior wave analysis described in Section 15.1 and use the revised wave characteristics in the overtopping calculation of the SOBRP model.
- Perimeter protection (settlement and projects)—also use the forecasted crown heights in the SOBRP overtopping calculation.
- Fragility changes—modify the breach probability parameters in the expanded joint probability expression, ***p****, discussed in Section 16.2.
- Interior settlement/subsidence—adjust the interior routing model—e.g., stage storage table for level pool routing.
- Change in pumping capacity or compartmentalization projects—adjust the SOBRP and interior routing models.

With increasing HPPC speeds and declining costs, redoing expanded polder JPAs for comparing interior surge hazard CDFs under current and future conditions is becoming more practical.

19.3. Hurricane Scenarios

Despite the increasing practicality of computing future surge hazards, sensitivity analyses employing limited hurricane scenarios are often preferred for basic relative comparisons of current versus future conditions. In its 2006 Third Report of the Committee on New Orleans Regional Hurricane Protection Projects, the National Academy of Engineering/National Research Council recommended that historical and “worst-case” type scenarios be used to improve public understanding of the relative hazards and risks associated with alternative conditions.

To facilitate these comparisons five types of hurricane scenarios can be considered:

1. Important historical hurricanes;
2. The Standard Project Hurricane (SPH);
3. The Probable Maximum Hurricane (PMH);
4. The Maximum Probable/Possible Intensity (MPI) Hurricane;
5. Scenarios selected from a JPM-OS or other set; and
6. NOAA Maximum Envelope of Water (MEOW) and Maximum of the Maximums (MOM) sets.

Historical Hurricanes

Scenarios featuring powerful historical storms provide a well established frame of reference for agency officials and the general public and can often capture their interest better than abstract surge hazards. For southeast Louisiana noteworthy historical storms include Hurricanes 1915, Betsy, Katrina, Gustav, and, most recently, Isaac.

In simulating an historical hurricane GoM maximum CPD/V_{max},, R_{max}, Holland B, and V_f attributes are generally based on observations or consensus best estimates. If the simulation involves the actual historical track θ and landfall point, the observed or best estimate values are also used for pre- and post-landfall CPD/V_{max}, R_{max}, Holland B and V_f. In this case the H*Wind data is often employed to characterize the hurricane’s wind field.

However, if variations in θ are being examined—e.g., modeling Hurricane Katrina on various parallel tracks—pre- and post-landfall decay in CPD/V_{max},, R_{max}, and Holland B, and changes in V_f, might be varied consistent with best judgments about the influence of the new path. In this case, a vortex model (e.g., PBL) can be employed to simulate a “Katrina-like” hurricane, coupled with a standard algorithm for decay. The results of track variations for a “Katrina-like” or other historical hurricane could be used to construct a regional MOM for the particular storm.

To date, track variations for historical hurricanes have not been employed to study future surge hazards for southeast Louisiana.

SPH

The SPH is similar in concept to a standard project flood, which was used for evaluating riverine flooding as early as the 1940s (USACE 1946). Prior to the advent of sophisticated JPA techniques, government agencies responsible for flood risk management often found it more practical to define a single flood scenario in order to simplify decision-making. For federal agencies, Congress has frequently stipulated the use of defined flood scenarios—e.g., the 100-yr flood in the NFIP.

NOAA began providing the attributes of a SPH for use by USACE and other agencies involved in surge risk management in their 1958 National Hurricane Research Project Report. In 1972 NOAA described the SPH as

> a hypothetical hurricane that is intended to represent the most severe combination of hurricane parameters that is *reasonably characteristic* of specified geographic region, excluding extremely rare combinations. The SPH is intended as practical expression of the maximum degree of protection that should be sought as a general rule in the planning and design of coastal structures for communities where protection of human life and destruction of property is involved (NOAA 1972.)

In the 1979 *Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Windfields,* NOAA provided the following definition for a SPH:

> The SPH is a steady state (for several hours prior to landfall) hurricane having a severe combination of values of meteorological parameters that will give high sustained wind speeds reasonably characteristic of a specified coastal location. By reasonably characteristic is meant that only a few hurricanes of record over a large region have had more extreme values of the meteorological parameters. The "SPH wind field" is specified from the parameters. One of several uses of the wind field is to compute critical storm surge at coastal points. . . . The combined frequency for the total wind field will generally have a recurrence interval of several hundred years.

The SPH is defined in terms of CPD, R_{max}, and V_f prior to landfall, together with estimates for infilling and frictional effects on winds. In 1978 NOAA published a report estimating maximum wind fields at various locations throughout the New Orleans area for an SPH based on the above forthcoming update to SPH characteristics (NOAA 1979). Prior to Hurricane Katrina, the USACE employed these wind values—together with calculations for wind setup, barometric impacts, wave setup, and wave runup—to estimate SPH peak surge conditions for the design of southeast Louisiana surge protection systems.

Following Hurricane Katrina—and with the advances in hurricane climatology and surge JPA—surge planning, decision making. and design have relied on hazard-based criteria (e.g., 100- and 500-yr surge) instead of the SPH.

Probable Maximum Hurricane

In the 1979 report NOAA also defined a PMH—distinguished from a SPH—as one that "will give the highest sustained wind speed that can probably occur at a specific location." The report noted that various rare combinations of hurricane attributes would give different wind fields, and that the return frequency of each combination has a very large uncertainty. The 1979 report suggested that PMH CPDs for the entire Atlantic and GoM coasts were about 40 to 60 mb lower than for SPHs. Given that there were eight Category 5 hurricanes between 2003-07, this large differential now seems questionable.

Figure 19.3 presents a preliminary MOM for 10 NOAA PMHs for coastal Louisiana prepared as part of working material for the LaCPR Study by the USACE in 2006. As with the SPH, the NOAA PMH has not been used in any final post-Katrina surge evaluation studies.

Maximum Probable/Possible Intensity Hurricane

Another "worst-case" hurricane—the MPI hurricane—has been defined by the USACE for use in post-Katrina Louisiana and Mississippi coastal planning (USACE 2009a and 2009b). In each case the hurricane was defined with a minimum GoM CP of 880 mb. Interestingly, for Louisiana the MPI was assigned an R_{max} of 25 nm while for Mississippi it was 36 nm. Figure 19.4 presents the southeast Louisiana MPI MOM based on three tracks.

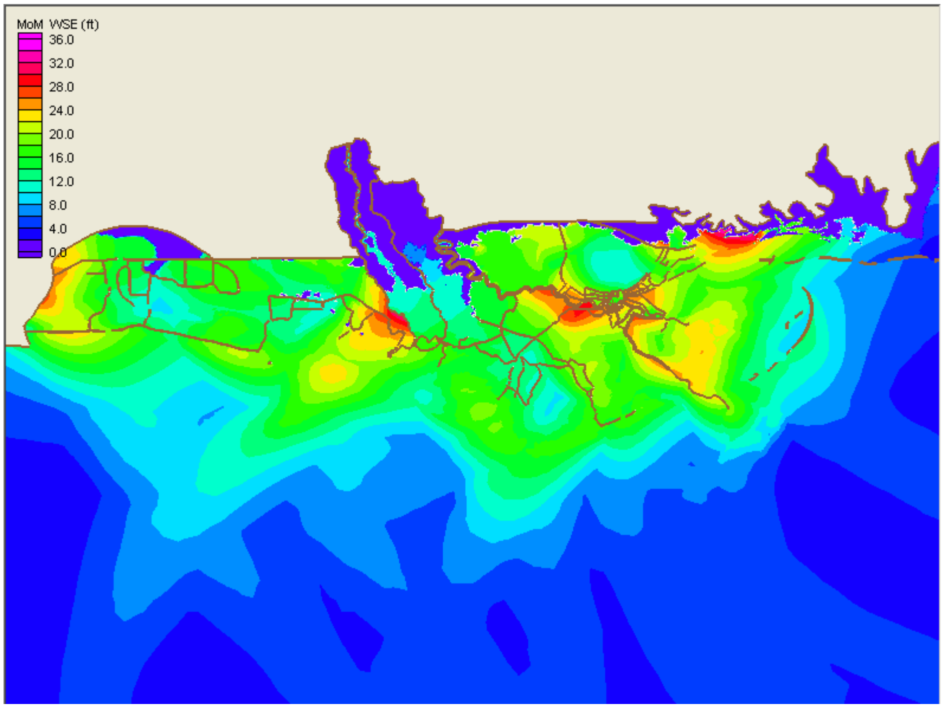


Figure 19.3. PMH MOM for Coastal Louisiana
USACE 2006

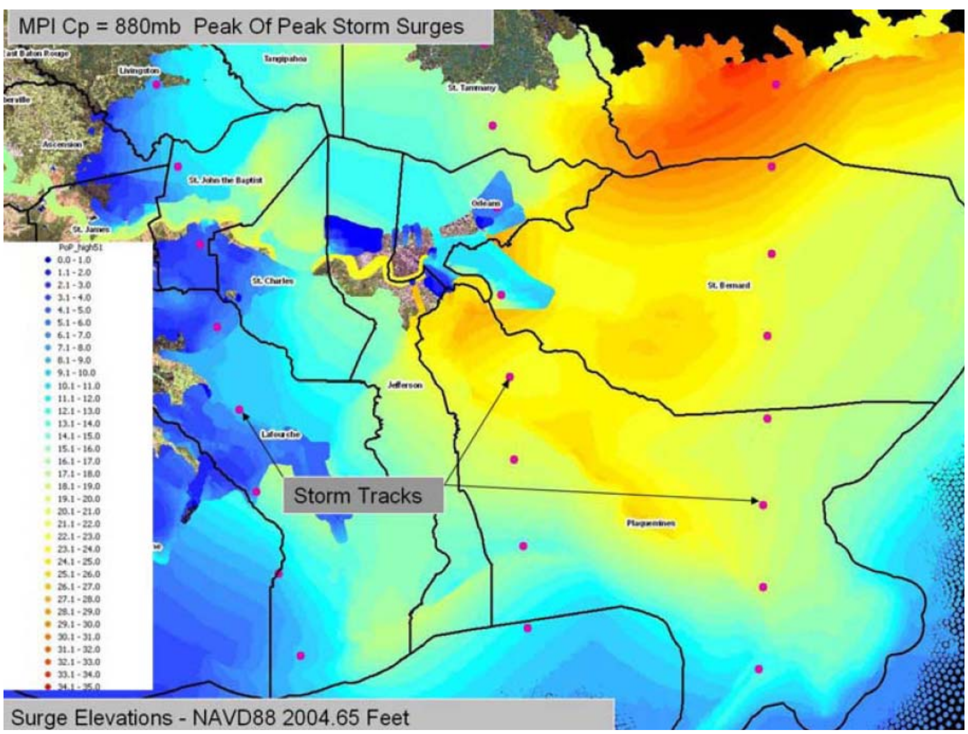


Figure 19.4. MPI MOM for Southeast Louisiana
USACE 2009a

Selected Hurricane Scenarios

Sensitivity tests can be performed for any storm of interest in a set. Figure 7.7 illustrates the surge comparisons for a hypothesized change (not tied to future time) in regional topography/bathymetry and Manning's *n* using two selected hurricanes. A hurricane that comes close to producing a targeted surge hazard—e.g., the 100- or 500-yr surge—can also be selected. Due to the importance of all attributes in effecting surge, a range of appropriate combinations need to be considered for locations of interest. For some locations both smaller more intense hurricanes and slower, larger, lower intensity hurricanes can produce the 100-yr surge.

Surge results for a selected hurricane and current conditions can be compared versus the same storm with future conditions. If there is an increase in this hurricane's probability due to changes in the hurricane climatology, then increases in surge hazard and risks associated with that storm can be computed. Similar computations for multiple locations can provide an indication of their relative vulnerability to changing conditions.

NOAA MEOWs and MOMs

To assist federal, state, and local emergency planners and responders in estimating potential surge elevations, NOAA has provided an atlas of regional maps. The atlas has included MEOW maps, each prepared using a set of synthetic hurricane scenarios for:

a. A particular category intensity (e.g., Category 3);

b. A set of parallel tracks on the same θ (e.g., northwest heading) at roughly equal spacing;

c. A particular V_f (e.g., 5 mph);

d. Some variations in size, wind field, and decay; and

e. A tide level (e.g., mean).

NOAA utilized the SLOSH model (see Section 8) to simulate the set of scenarios and compute the surge peak at locations throughout the region for each hurricane in the set. The highest peak at each location from among the scenarios was then used to create the MEOW map. Figure 19.5 illustrates a MEOW map for southeast Louisiana for the example set of hurricane scenarios. Thus, if a Category 3 hurricane is approaching the coast on a general northwest heading at 5 mph and expected to make landfall at mean tide—but with the absence of a precise forecast of landfall location—a "worst-case" surge elevation could be obtained for everywhere in the region.

For a given a. and e., NOAA combined all the regional MEOWs for b., c., and d., into one MOM map—i.e. five MOMs per tide level. Figure 19.6 presents the MOM map for southeast Louisiana for Category 3 hurricanes at high tide. The MOM represents a worst-case scenario at each location for a Category 3 hurricane making landfall at high tide.

Though MEOW and MOM maps are rapidly becoming obsolete for actual emergency response due to recent advances in real-time surge forecasting, they are still useful for planning purposes. While the SLOSH model lacks the fine resolution and wave physics of the ADCIRC+SWAN model, it can be employed to quickly generate MEOWs and MOMs for coarse assessments of future conditions. In 2012 Preston et al produced future MOMs for six SLR scenarios for SLOSH basins along the Atlantic and GoM coasts. NOAA MEOWs and MOMs have not been recently employed to assess future surge hazards for southeast Louisiana coastal erosion, landscape change, and modifications to hurricane protection systems.

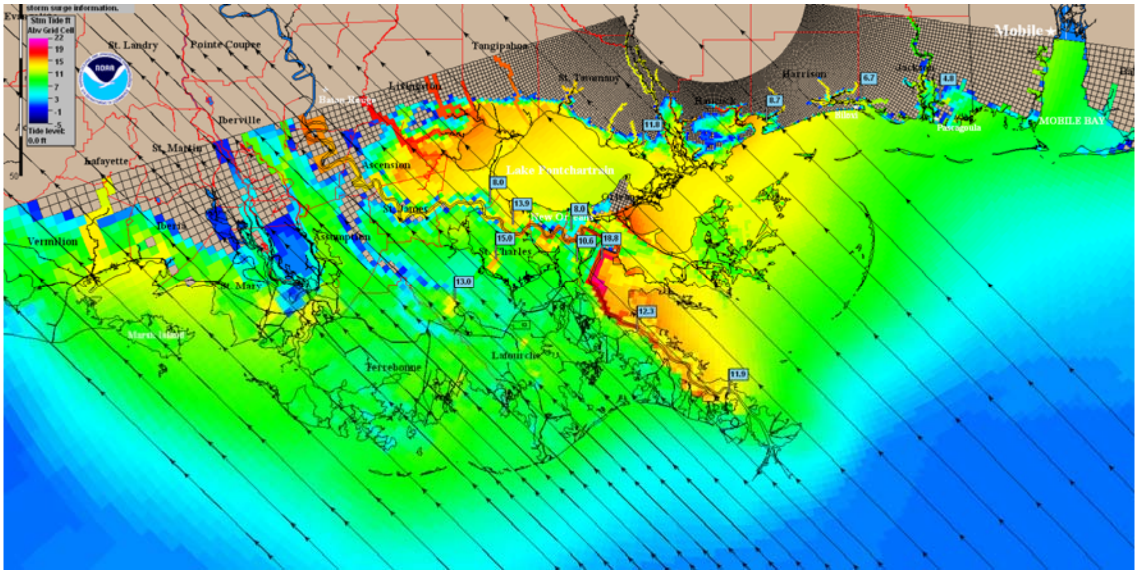


Figure 19.5. NOAA MEOW Map for Southeast Louisiana

Category 3, Northwest Heading, 5 mph Forward Speed, Landfall at Mean Tide

NOAA 2010

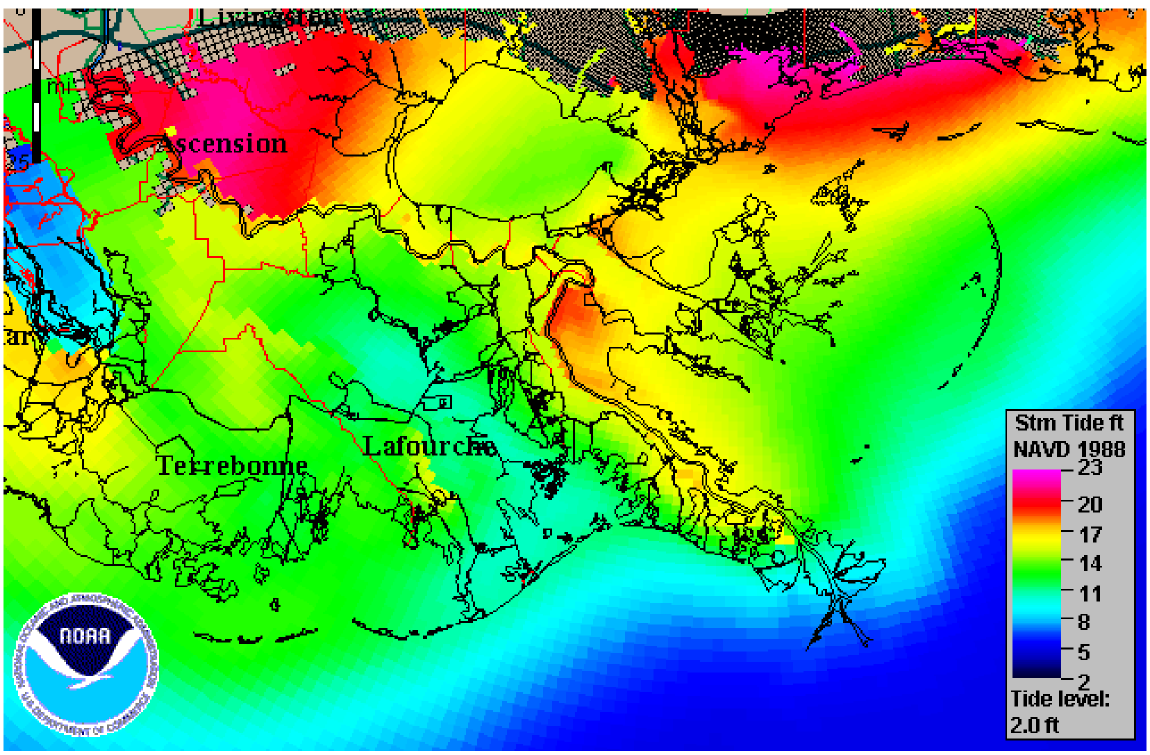


Figure 19.6. NOAA MOM Map for Southeast Louisiana

Category 3 at High Tide

NOAA 2010

Section 20. Recent Applications of Analysis for Future Conditions

In recent years investigators of future southeast Louisiana surge hazard have input forecasts of RSLR and coastal landscape conditions, as well as projects, into the additional analytical steps described in Section 19. Six major investigations include:

- USACE LaCPR Study (USACE 2009a);
- USACE MsCIP (USACE 2009b);
- USACE HSDRRS Design for RSLR (USACE 2010);
- State of Louisiana Master Plan (CPRA 2012);
- SLFPA-E New Orleans East Land Bridge Feasibility Study (Ben C. Gerwick 2012); and
- SLFPA-E Polder Compartmentalization Study (ongoing).

This section reviews the technical approaches employed in these studies, including important assumptions and limitations.

20.1 USACE LaCPR Study

The 2009 USACE LaCPR Study examined both exterior surge SWL hazard and surge-related polder inundation under many large-scale planning alternatives. Sections 14.1 and 17.2 described the USACE's development of 2007 (with post-Katrina HSDRRS improvements) and 2010 (with a nearly final 100-yr HSDRRS) ADCIRC-STWAVE models, in conjunction with a Surge Response-OS, to assess exterior 100-yr surge hazard. These two alternatives were also used to evaluate 400- and 1,000-yr hazards and polder interior scenarios. Table 20.1 lists 18 additional alternative future conditions/projects that were evaluated, a summary of the ADCIRC model changes, and the number of Surge Response-OS storms (out of a total of 152) that were rerun.

Section 17.2 noted that the 2010 alternative exterior 100-, 400-, and 1,000-yr hazards were themselves developed from the 2007 alternative by rerunning a subset of the 152 storms and applying an adjustment algorithm to the results of storms not rerun. This approach introduced additional bias and uncertainty into the 2010 analysis. The full 152-storm set was not rerun apparently due to constraints at the time on HPPC resources. Presumably a similar adjustment algorithm was employed for the various future conditions to account for the storms not rerun.

CDFs for each alternative were presumably calculated using the techniques described in Section 17.2 for the 2010 alternative, which were described as similar to those used in the 2007 FIS (Section 14.1). This approach employed bilinear interpolation, smoothing, and shifting of the CDF to account for epistemic ε.

Polder inundations for the future alternatives were assessed in a manner similar to the 2010 case (see Section 17.2). Polder inundation was evaluated for all SWLs around the entire perimeter at the exterior 100-yr value (and similarly for all SWLs at the 400- and 1,000-yr value). As noted in Section 17.2 these are not true hazards but reflect a much more unlikely "pseudo event." Wave conditions and overtopping rates for the three "pseudo events" for each alternative were estimated using the same methods described in Section 17.2.

Figures 20.1.a and b. show the difference between the 2007 condition and two future Plaquemines Parish levee alternatives, for the 100-yr surge hazard, based on the limited Surge Response-OS. The figures illustrate the kind of planning comparisons that were facilitated by the analyses of future alternatives.

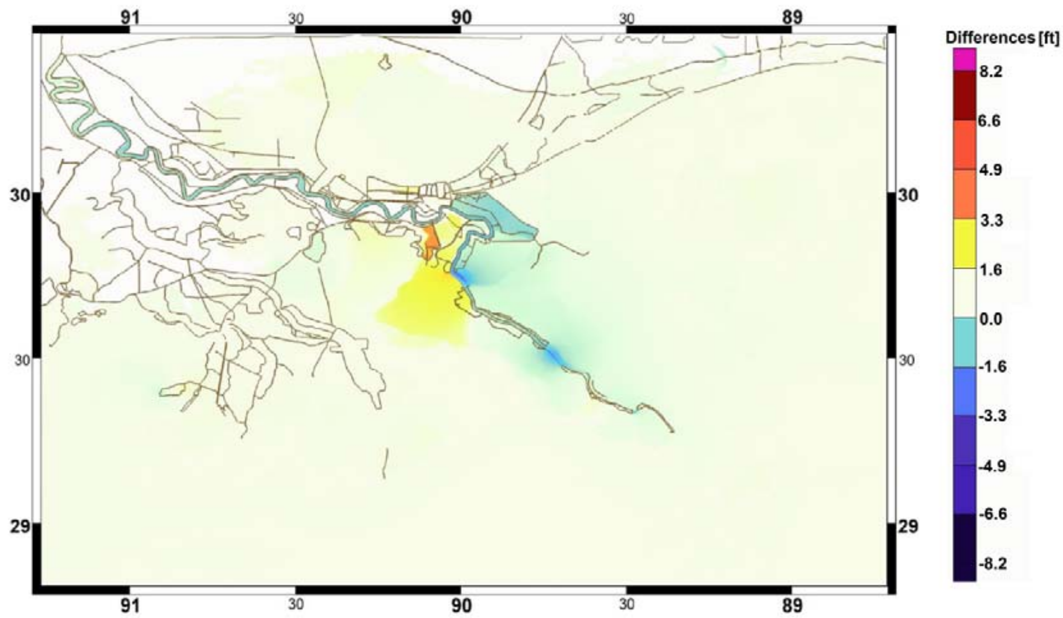
In addition to future hazard analyses using limited rerunning of the Surge Response-OS, the LaCPR Study evaluated surges for the MPI hurricane. The LaCPR MPI hurricane was defined as having a GoM CP of 880 mb and an R_{max} of 25 nm (28.8 mi). The return period of a GoM hurricane with this combined CP and R_{max} was estimated at nearly 75,000 years. (Note, Part I discusses the USACE hurricane joint probability expression including several limitations.) Figure 19.4 illustrates a preliminary depiction of the southeast Louisiana MPI MOM based on three tracks.

Table 20.1. LaCPR Future Surge Hazard Analyses

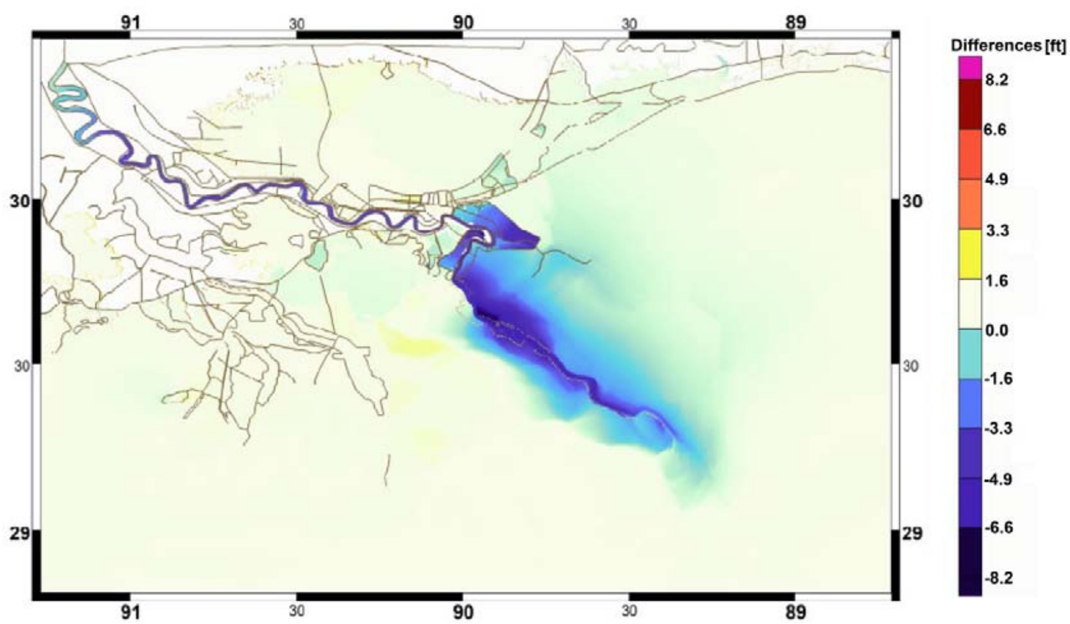
USACE 2009a

Future Condition	Summary of ADCIRC Mesh Changes to 2010 Base Alternative	Surge Response-OS Storms Rerun
Lake Pontchartrain Barrier (New Orleans East Land Bridge) and West Bank (Belle Chase to Larose)	A) Full closure of Lake Pontchartrain along US90; full closure of IHNC/GIWW along west shore of Lake Borgne; full closure West Bank from between Belle Chase to Larose along GIWW. B) Weir closure of Lake Pontchartrain along US90 with structures in Chef and Rigolets tidal passes; full closure of IHNC/GIWW along west shore of Lake Borgne; weir closure West Bank from Belle Chasse to Larose along GIWW. C) Weir closure of Lake Pontchartrain along US90 without structures in Chef and Rigolets tidal passes; full closure of IHNC/GIWW along west shore of Lake Borgne; weir closure West Bank from Belle Chasse to Larose along GIWW. D) Isolating Lakes Pontchartrain and Borgne from each other by building a levee across Lake Borgne from Verret to Slidell; full closure West Bank from Belle Chasse to Larose along GIWW.	48 42 / 152 48 40
Larose to Golden Meadow	A). Non-overtopping levee alignment from Larose to Golden Meadow and along GIWW. B)100-year level alignment from Larose to Golden Meadow; a non-overtopping levee along the ridge and a ring levee alignment in the western part. C) Non-overtopping levee alignment from Larose to Golden Meadow and along the ridge, and an overtopping levee along GIWW with a ring levee around Lake Charles.	28 28 28
Plaquemines Parish	A) Two spillways in the levee system along Plaquemines, B) Full removal of levee system along Plaquemines to river embankment level (for sensitivity analysis only)	17* 17*
Landscape Conditions	1) Degraded marshes 50 years from now without increased action 2) Restored marshes 50 years from now based on a hypothetical alternative (for sensitivity analysis only)	174 46
Sea level Rise Sensitivity Analysis	1) +1 ft sea level rise 2) +2 ft sea level rise 3) +3ft sea level rise	9 9 9
Barrier Islands Sensitivity Analysis	1) No barrier island 2) Restored island 3) Post-Katrina with forest 4) Restored island with forest	15 15 15 15

* Note, de Jong et al 2007 describes rerunning 18 storms.



a. Difference Between 2007 and Alternative with Spillways



b. Difference Between 2007 and Alternative with Levees Removed

Figure 20.1. Evaluation of 100-yr Surge Hazard for Plaquemines Parish Levee Alternatives

de Jong et al 2007

20.2 USACE Mississippi CIP

Surge hazard analysis for future conditions was used in the MsCIP to evaluate two planning alternatives (Lines of Defense Nos. 3 and 4) and the extent of maximum inland surge (Line of Defense No. 5). Line of Defense No. 3 entailed modestly raising the elevations of existing roads and seawalls and adding ring levees for two communities. Line of Defense No. 4 was an inland barrier along the whole coast sufficient to prevent overtopping from several severe storms.

The MsCIP analysis was undertaken by a different team than the one that completed the Mississippi FIS described in Section 14.5. The MsCIP team used a 197-storm Surge Response-OS with a set of tracks shifted eastward to encompass the Mississippi coast.[1] Individual storms were modeled with the PBL vortex model, ADCIRC (using the SL15 mesh developed for Louisiana and modified with weirs to represent Lines of Defense Nos. 3 and 4), WAM (for offshore waves), STWAVE for propagation of waves on the continental shelf and in Mississippi Sound, and a combination of STWAVE and COULWAVE for nearshore waves.

No action exterior surge hazards (SWL, H_s, and T_p) were computed with the entire 197-storm set for the 25-, 50-, 100-, 500-, and 1,000-yr at 80 locations. (Interestingly, the 100-yr SWL hazards were not compared to those identified in the FIS). For Lines of Defense Nos. 3 and 4 a 27-storm subset was rerun to develop an adjustment algorithm (similar to LaCPR). The adjustment algorithm was then used to determine With-project 25-, 50-, 100-, 500-, and 1,000-yr SWL, H_s, and T_p at each of the 80 locations. RLSR was not incorporated into this analysis.

Eleven storms from the set were selected for testing the sensitivity of storm surge and waves to three scenarios involving the configuration of five barrier islands: No Action (post-Katrina diminished) footprint and elevation; a modest restoration; and a massive footprint and elevation expansion. Figure 20.2 illustrates the planning comparisons that were made with the Camille-like hurricane scenario.

The MsCIP also presented a sensitivity test of storm surge and waves to landscape conditions using three cases for the Biloxi Marsh in Louisiana, which front the western third of the Mississippi coast. Two storms—Hurricane Katrina and large Category 1 storm—were used to compare the base case versus an improved case. The base case assumed a degraded entire marsh area lowered to open water with elevation at -2 ft NAVD88 and reduced Manning's n, wind reduction, and sheltering coefficients. The improved case included two strips of marsh raised to 1.05 ft NAVD88 and upgraded to herbaceous wetland. Figure 20.3 illustrates the planning comparisons that were made with the Hurricane Katrina scenario.

Finally, the MsCIP evaluated Line of Defense No. 5 using an MPI MOM developed from six tracks. The MsCIP MPI hurricane was defined as having a GoM CP of 880 mb and an R_{max} of 36 nm (41.4 mi). Figure 20.4 presents the MPI MOM. Interestingly, the MPI MOMs prepared for the LaCPR Study (Figure 19.4) appear to be somewhat higher than those for the MsCIP.

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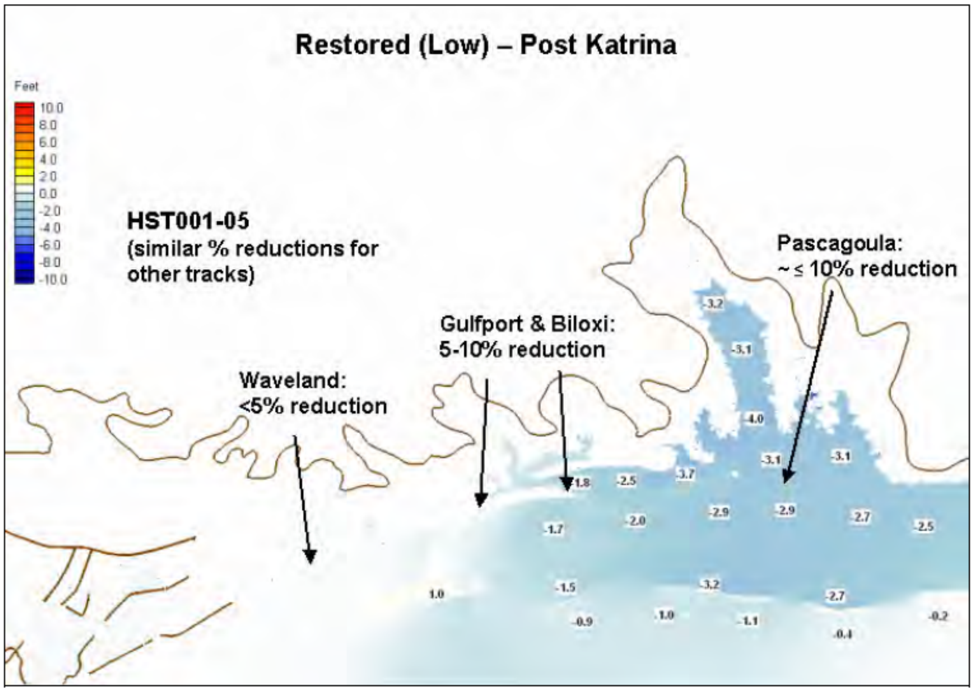
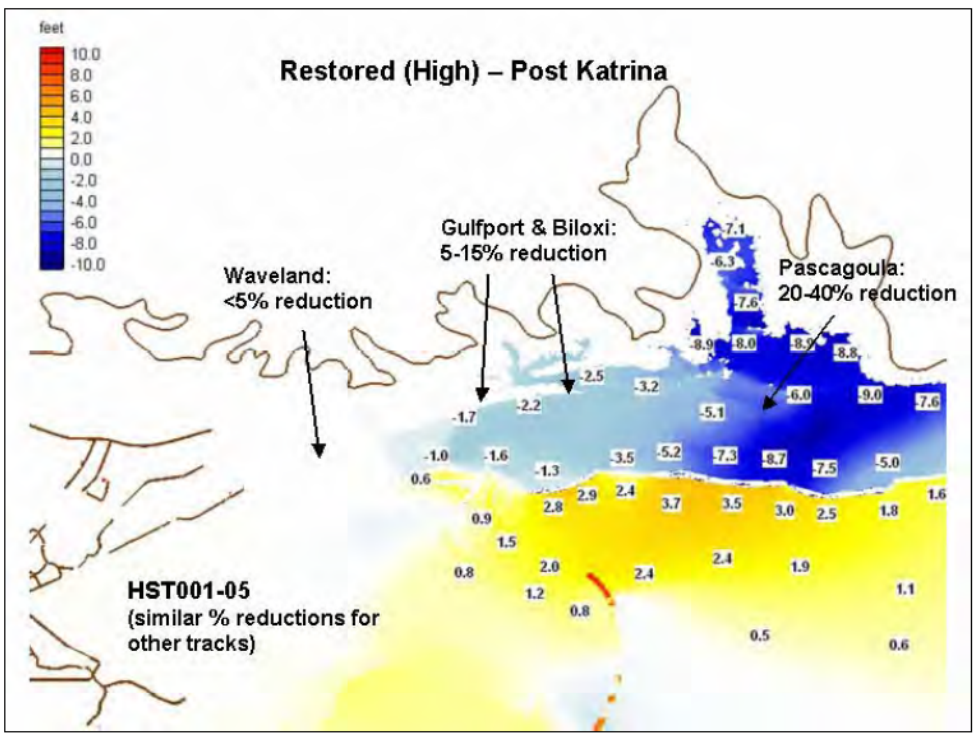
[1] As discussed in Section 14.5, the Mississippi FIS used a 152-storm JPM-OS approach (not a Surge Response-OS).



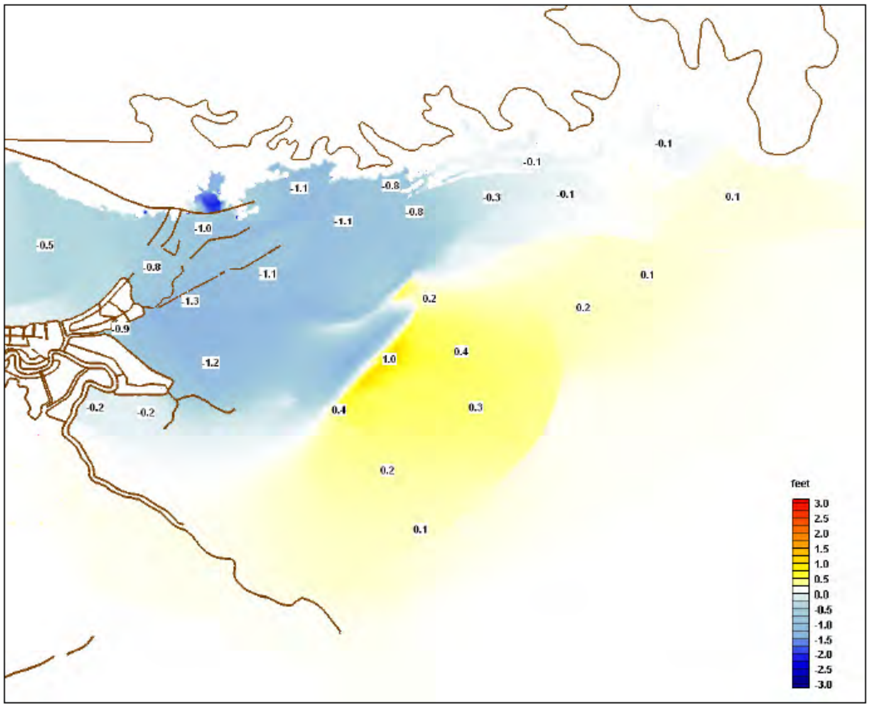
a. Modest Barrier Island Restoration versus No Action



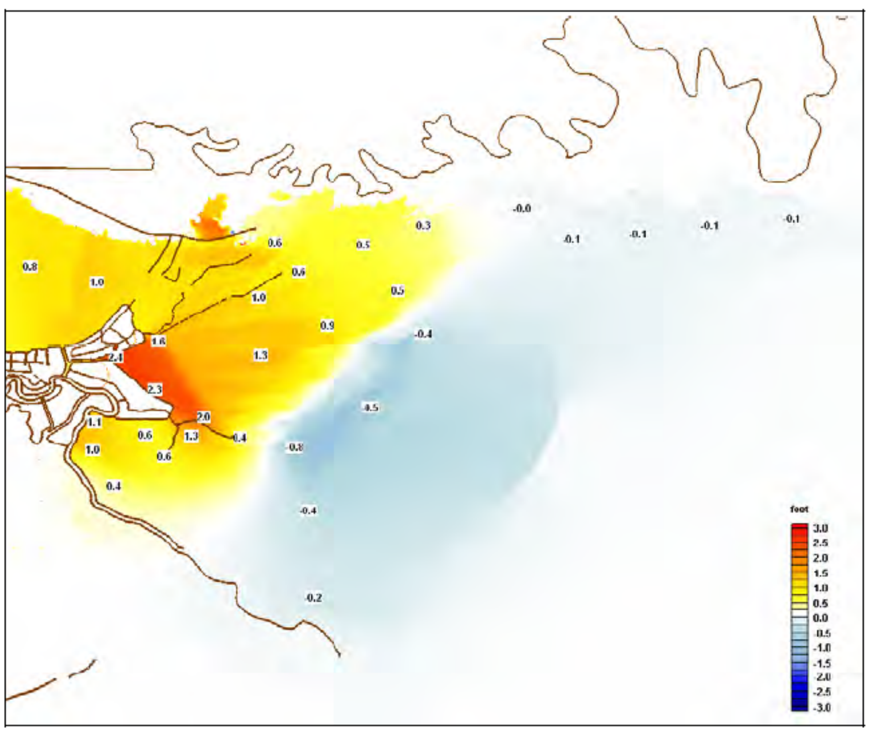
b. Massive Barrier Island Restoration versus No Action

Figure 20.2. Difference in Peak Surge for Barrier Island Restoration Alternatives Camille-Like Hurricane with Biloxi MS Landfall

USACE 2009b



a. Improved Marsh versus No Action



b. Degraded Marsh versus No Action

Figure 20.3. Difference in Peak Surge for Biloxi Marsh Restoration Alternatives Hurricane Katrina

USACE 2009b

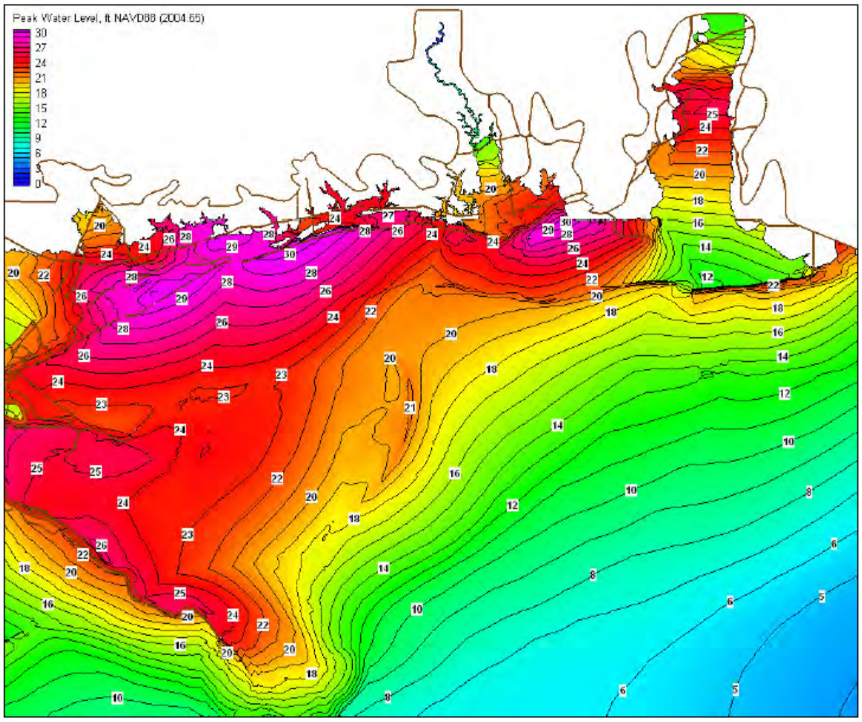


Figure 20.4. MPI MOM for Mississippi

USACE 2009b

20.3 USACE HSDRRS Design for RSLR

Section 17.3 reviewed the USACE's five step process to develop a current (2010) overtopping hazard analysis[2] and apply it to the HSDRRS 100-yr design. In addition, the USACE undertook a sixth step to evaluate future Year 50 (2057) SWL, H_S, and T_P conditions and overtopping (see USACE 2010). In assessing 2057 conditions the USACE incorporated regional forecasts for RLSR (SLR and subsidence) but not coastal erosion or large scale vegetation conversions.

To evaluate the effect of RSLR on exterior surge the USACE performed ADCIRC-STWAVE sensitivity tests with nine storms selected from the 152-storm Surge Response-OS, adjusting the LMMSL by 1.0, 2.0, and 3.0 ft. The impact of the LMMSL increases was assessed at eleven sub-regions listed in Table 20.2

Figure 20.5 shows the range in relative peak surge increase (peak surge increase divided by RSLR) for all 27 simulations for each sub-region. These results were used to estimate a single 100-yr SWL multiplier for each location—ranging from 1.2 to 2.5—provided in Table 20.2. The multiplier times a forecasted RSLR gives an estimated increase to the 100-yr SWL at that location. The USACE also used the STWAVE results to develop a multiplier applied to the 100-yr SWL increase for estimating the increase in Zone B wave heights. The wave height increase multipliers ranged from 0.12 to 0.58 and are also listed in Table 20.2.

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[2] Based on the 2007 FIS analysis for exterior surge hazard, adjusted to 2010 conditions as described in Section 17.2.

Table 20.2. RLSR Sensitivity Test Results for 100-yr SWL and Zone B Waves

USACE 2010

Sub-Region	Range of Relative 100-Yr SWL Increases	100-Yr SWL Increase Multiplier	Wave Height Increase Multiplier
South Shore Lake Pontchartrain (SSP)	1.0-1.5	1.3	0.43
East Orleans (EO)	1.1-1.6	1.2	0.13
North St. Bernard (SBN)	1.2-1.6	1.3	0.17
South St. Bernard (SBS)	0.7-2.3	1.4	0.45
Caenarvon (C)	0.7-4.5	2.1	0.50
Plaquemines East (PE)	1.3-2.0	1.5	0.58
Plaquemines West (PW)	1.4-3.0	1.9	0.41
South West Bank (SWB)	1.3-3.6	2.5	0.12
North West Bank (NWB)	1.0-2.9	2.1	0.13
Golden Meadow (GM)	1.4-2.3	1.8	0.27
Morganza to the Gulf (MtG)	1.4-2.0	1.7	0.37

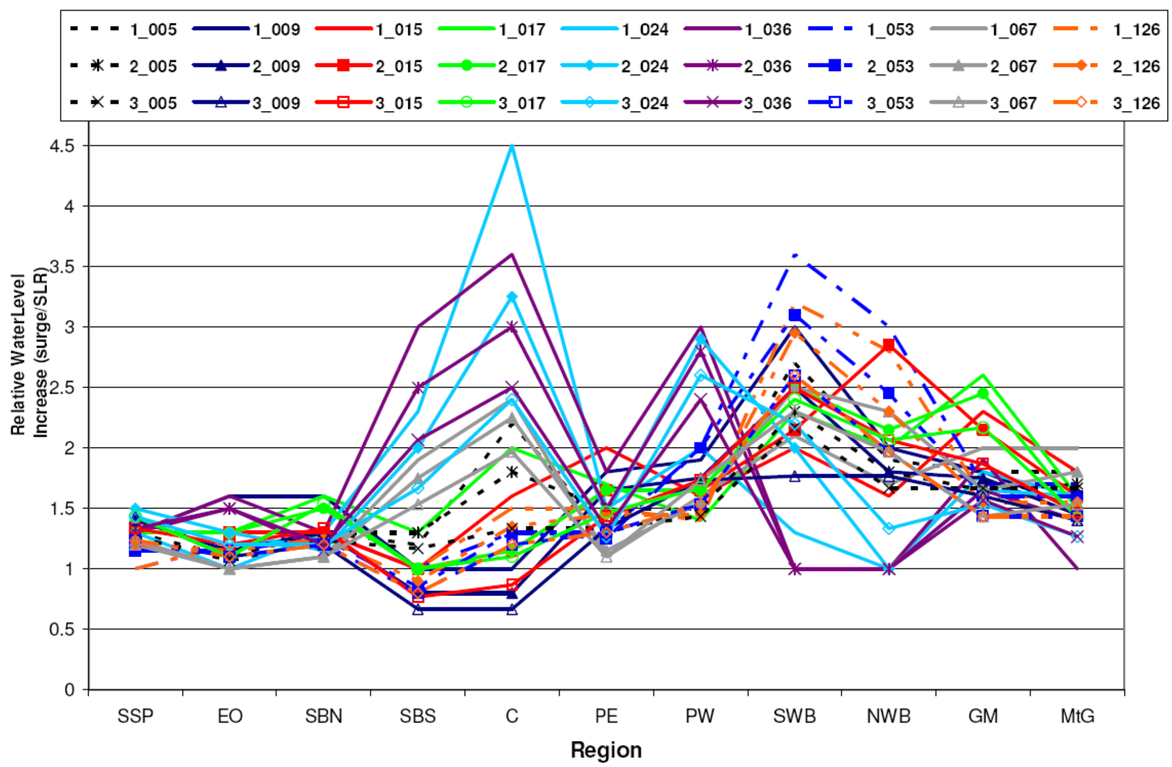

Figure 20.5. Relative Increases in Peak Surge for RSLR Sensitive Tests

USACE 2010

The USACE employed this approach apparently due to insufficient HPPC resources at the time for a complete re-running of the JPA. The USACE also estimated increases for future 500-yr SWL and wave heights with RSLR, presumably using a somewhat similar method. The limitations in this approach include:

a. Those associated with the 2010 analysis previously discussed in Section 17.3—e.g., small set size and simplifications associated with the 152-storm Surge Response-OS, particularly with regard to 500-yr conditions;

b. Not including coastal erosion and vegetation changes in the analysis of future conditions;

c. Simplifications associated with only rerunning nine storms; and

d. Generalizing the analysis to broad sub-regions—e.g., the entire south shore of Lake Pontchartrain.

Using the results of the above analysis the USACE made the following modifications to the 2010 100-yr hazard conditions to estimate 2057 100-yr hazard conditions:

- For HSDRRS reaches in the Metro New Orleans, New Orleans East, and the Lower 9th Ward/St. Bernard Polders—SWL and H_S increases of 1.5 ft and 0.75 ft, respectively.
- For West Bank Polders and the Mississippi River Levee at Caernarvon—SWL and H_S increases of 2 ft and 1 ft, respectively.
- Future increased wave T_P was computed by assuming unchanged wave steepness (i.e., the ratio of H/T^2).

The USACE then evaluated required design elevations for each HSDRRS reach at the 2057 100-yr hazard using the methods described in Section 17.3 (to reduce overtopping at the 50% and 10% Exceedance Levels to the erosion-based criteria of 0.01 and 0.1 cfs/ft). The USACE applied the 2057 100-yr design elevations in the final specifications for floodwall segments of the HSDRRS but not levees, based on considerations of the constructability and costs associated with future raising of reach crowns.[3] The 2057 100- and 500-yr hazard and HSDRRS design elevations are included in the information provided in the Part IV, Attachment 1.

20.4. State of Louisiana Master Plan

For the 2012 Master Plan (see Appendices 24 and 25, prepared by ARCADIS and RAND Corporation, respectively), CPRA evaluated coastal Louisiana (southeast and southwest) surge hazards for current versus many future conditions. As described in Section 11.4, ARCADIS developed and validated a baseline mesh (referred to as OCPR2012_S50) utilizing a tightly coupled ADCIRC+SWAN code. The 50+ day validation period in the late summer of 2008 encompassed both Hurricanes Gustav and Ike.

ARCADIS created two future Year 50 modifications to the current conditions mesh attributes and model to reflect Moderate versus Less Optimistic coastal degradation scenarios. The modifications took into account different estimates of Year 50 SLR (0.89 versus 1.48 ft), subsidence, erosion, and vegetation changes. Figures 20.6.a. and b. show the elevation difference between the current and the two future condition meshes (referred to as OCPR2012_S12_G90 and OCPR2012_S13_G90).

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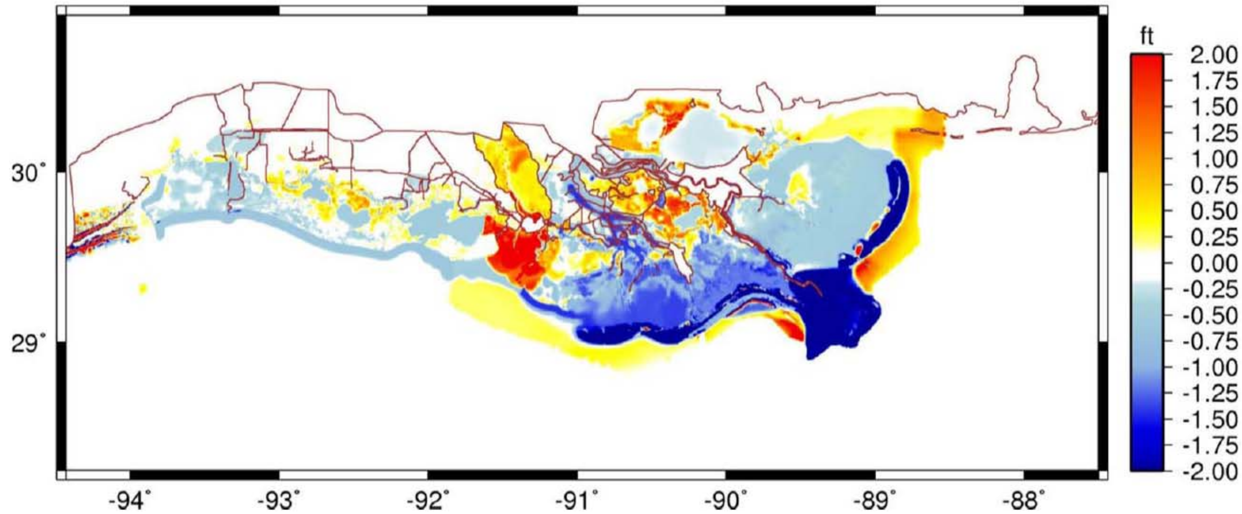
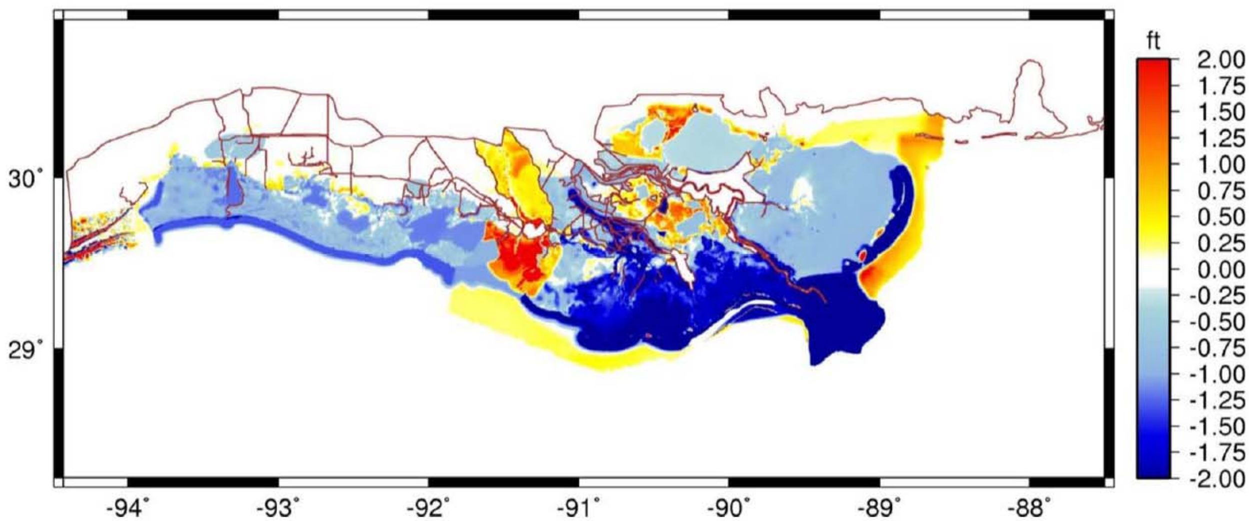
[3] In establishing final crown specifications for floodwalls the USACE also made reach-specific allowances for local structure settlement.



a. Current versus Moderate Coastal Degradation

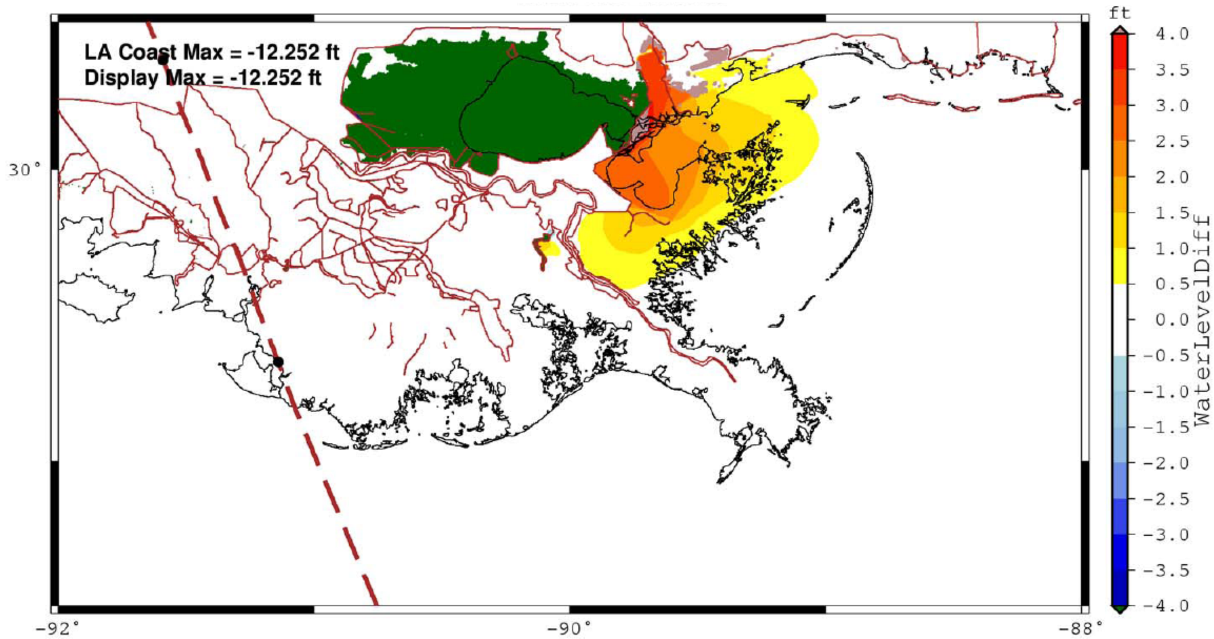


b. Current versus Less Optimistic Coastal Degradation

Figure 20.6. Elevation Difference for Future Year 50 Condition ADCIRC Meshes

CPRA 2012

Additional sub-versions of the two future condition meshes were then created to investigate 34 potential coastal restoration and surge protection projects. To minimize the number of sub-versions, multiple projects were grouped on the sub-version meshes, with projects selected for each mesh to minimize mutual interference and allow the impacts of each project to be evaluated independently. Seven sub-versions were developed for the two future meshes (G91 to G97), or a total of 14 additional meshes. Peak surge differences for selected storms and mesh subversions were included in the Master Plan Report (Appendix 24). Figures 20.7 illustrates peak surge differences for Storm 009 (a large, strong, landfalling Category 2 hurricane) for the current conditions versus a Less Optimistic future conditions mesh that included a Lake Pontchartrain Barrier project.



b. Current versus Less Optimistic Coastal Degradation with Lake Pontchartrain Barrier

Figure 20.7. Peak Surge Difference for Storm 009, Current Conditions versus Less Optimistic Future Conditions with Lake Pontchartrain Barrier

(green indicated surge reduced by >4 ft)

CPRA 2012

As described in Section 14.4, RAND developed a highly simplified 40-storm JPM-OS (truncated from the IPET JPM-OS, which itself was improvised from the original 152-storm Surge Response-OS). Simulation were conducted for the 40 storms with each of the 17 models—the current conditions, two future conditions, and 14 sub-versions of the future conditions. Results were used to define the exterior surge SWL hazards for each alternative (for return periods at 10-yr intervals from 10 to 150 years, and at the 400-, 500-, and 1,000-yr return periods) at locations throughout the Louisiana coast. Wave heights at each SWL hazard level at each location were defined using the SWAN results and additional interpolation techniques.

To define the interior hazard for each alternative RAND conducted a polder inundation JPA, employing a set of exterior points at roughly 300 m intervals along the perimeter of each existing or proposed project. As the 40-storm JPM-OS was too small to support a polder JPA, RAND prepared an expanded set of 720 storms by interpolating from the 40-storm JPM-OS. Each storm—with a corresponding probability—had an associated CPD, R_{max}, and track and produced a peak SWL at each perimeter location. Hydrographs were constructed at each perimeter location for the 720 storms using rising and falling limb σ_R and σ_F values determined from the 40-storm set. Exterior wave conditions for each storm were also computed using a breaking parameter.[4]

[4] The breaking parameter described in Appendix 25 appears to contain an error as it specified a foreshore maximum breaking wave height as 0.4 times the Zone B (nearshore) wave height, instead of 0.4 times the depth.

RAND evaluated SOBRP processes for their polder inundation JPA in a manner generally similar to the IPET approach (see Section 17.1): seepage inflow was ignored; overtopping was computed at each levee and floodwall perimeter location over the course of each storm using the equations described in Section 15.3; rainfall was introduced into each sub-basin based on storm intensity and distance to storm center; and pumping included the 0%, 50%, and 100% scenarios. As performed by IPET, RAND then employed level-pool routing by sub-basins, for each of the 720 storms, to determine probabilistic peak interior SWLs associated with combined overtopping, rainfall, and pumping.

Probabilistic breaching was also incorporated in the RAND polder inundation JPA using pre-defined perimeter reach segments—based on alignment and structural conditions. Each reach included at least one of the 300 m perimeter locations, but could include many more depending on length. A single, simplistic, catastrophic failure condition was defined for each whole reach: the equalization of the interior sub-basin SWL with the storm exterior peak SWL. With a failure, the exterior SWL would equalize with all interconnected sub-basins not isolated by a higher internal barrier. The probability of this failure condition occurring was then assigned based on a combined probability of failure at any location within the reach due to seepage, slope stability, or overtopping erosion.[5] Independent failure probabilities for each of these three mechanisms at each location depended only on the peak SWL, limited inputs for location-specific conditions,[6] and fairly simplistic equations. To define the probability of breach-driven interior inundation levels for each of the 720 storms, RAND conducted 100 random draws for each storm (i.e., a Monte Carlo analysis, see Section 16.4).

In order to assess surge risk associated with the 17 alternative conditions, RAND coupled the exterior and interior surge hazard results with FEMA's HAZUS model. The HAZUS model uses an input of flood depth by census block[7] to estimate damages (in dollars) for a range of assets (residential, commercial, industrial, infrastructure, etc.), together with direct economic losses. For each alternative RAND input values for 50-, 100-, 500-yr hazards for 35,500 coastal Louisiana census blocks, which make up approximately 50 exterior and polder interior communities.

The Master Plan main report and Appendix 25 do not include output from the RAND surge hazard or risk analyses—such as changes to the 100-, 500-, or 1,000 surge hazard or property/economic losses under different alternatives. The influence of future conditions and projects on surge hazard levels and property/economic risk were reportedly incorporated into the State's project evaluation but were not published.

20.5. SLFPA-E New Orleans East Land Bridge Feasibility Study

The SLFPA-E retained Ben C. Gerwick and ARCADIS to further investigate the feasibility of Lake Pontchartrain Barrier concepts—as an extension of the LaCPR Study and 2012 Master Plan assessments. As part of this investigation, ARCADIS utilized the Master Plan version of the ADCIRC+SWAN code and modified the validated Master Plan baseline mesh to examine five future scenarios:

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[5] Operational failures such as an improper gate closure were not considered.

[6] For seepage failure, the conditions include the thickness and permeability of two underlying soil zones plus the slope, width, and height of the perimeter embankment; for overtopping they included the embankment soil type; and for slope stability failure they also included unit weights, friction angles, and strength of key soil components.

[7] Determined by subtracting a typical ground elevation from the surge height.

- Base Case, future regional RSLR and coastal degradation WITH a maintained natural land bridge;
- Scenario 1, future regional RSLR and coastal degradation but WITHOUT a maintained natural land bridge;
- Scenario 2, Base Case PLUS a Barrier WITH closure of the Rigolets and Chef Passes;
- Scenario 3, Base Case PLUS a Barrier WITHOUT closure of the Rigolets and Chef Passes; and
- Scenario 4, Scenario 1 PLUS a Barrier WITHOUT closure of the Rigolets and Chef Passes.

The future scenarios used a RLSR of 2.8 ft and included raising elevations for maintained roads, as well as land bridge features in Scenario 1, 3, and 4. For Scenarios 3, 4, and 5 the barrier crest was set at 22 ft NAVD88.

ARCADIS simulated eight selected storms from the 152-storm Surge Response-OS set to evaluate potential impacts on regional exterior surge hazard. A JPA of exterior hazard impacts was not utilized for the purposes of this preliminary study. ARCADIS reviewed the regional results of the individual 152-storms from the LaCPR Study and selected four storms which approximately produced the 100-yr SWL hazard and four which approximately produced the 400-yr SWL hazard.

Figure 20.8 shows the difference in the exterior surge 100-yr MOMs (from the four storms) between the Base Case and Scenario 2.

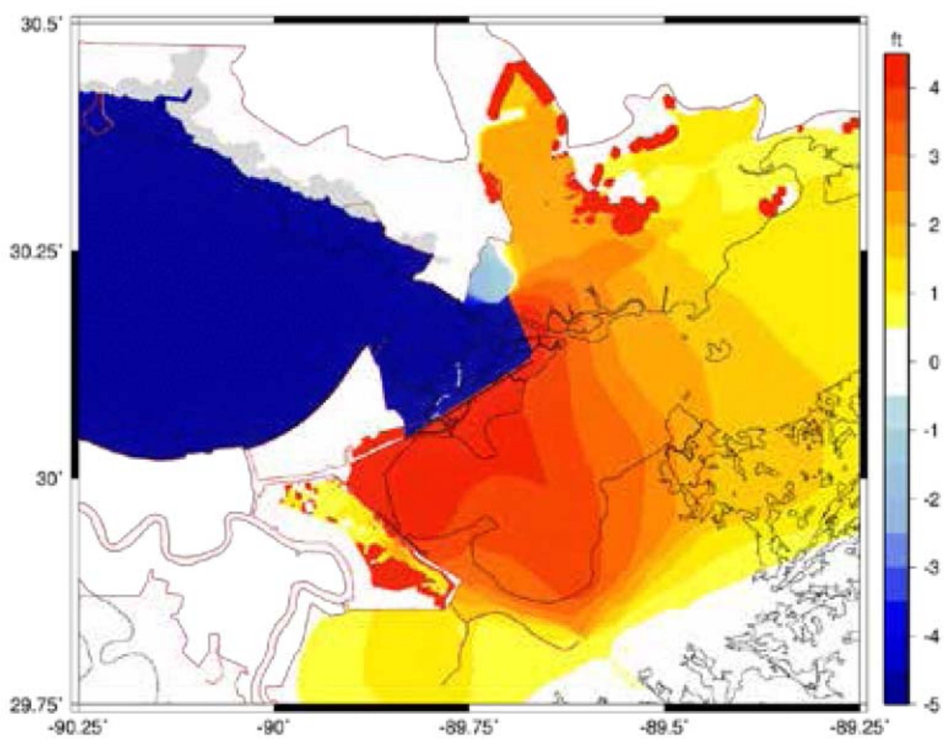

Figure 20.8. Difference in 100-yr Surge Hazard for Proposed Lake Ponchartrain Barrier

Gerwick 2012

20.6. SLFPA-E Polder Compartmentalization Study

The SLFPA-E has also initiated a study of interior polder projects to mitigate residual inundation risks associated with perimeter breaching. The study is focusing on the enhancement of legacy barriers, road and railroad embankments, and natural ridges, as well interior storage areas, to control inundation in the event of a significant perimeter failure.

The study is employing high resolution 2D HPPC ADCIRC polder models (see Figure 15.13) to study interior routing under specific breach and compartmentalization scenarios.[8] The polder meshes include detailed representation of major gravity conveyance features (canals) and pump stations. Breach scenarios—such as the one illustrated in Figure 20.9—are being evaluated at multiple locations around each polder and typically include volumes on the order of 30,000 acre-ft. Simulations are employed to compare the peak footprint and depth of inundation—as well as timing and rate of inundation—for With versus Without compartmentalization project scenarios.

An expansive JPA of interior hazard impacts is not being utilized for the purposes of this preliminary study. The HSDRRS design and IPET study of residual risk indicate that most perimeter breach scenarios generally reflect greater than 500-yr return periods. However, breach scenarios for the IHNC/GIWW sub-basin floodwalls may have a higher probability, particularly due to specific fragility issues.[9]

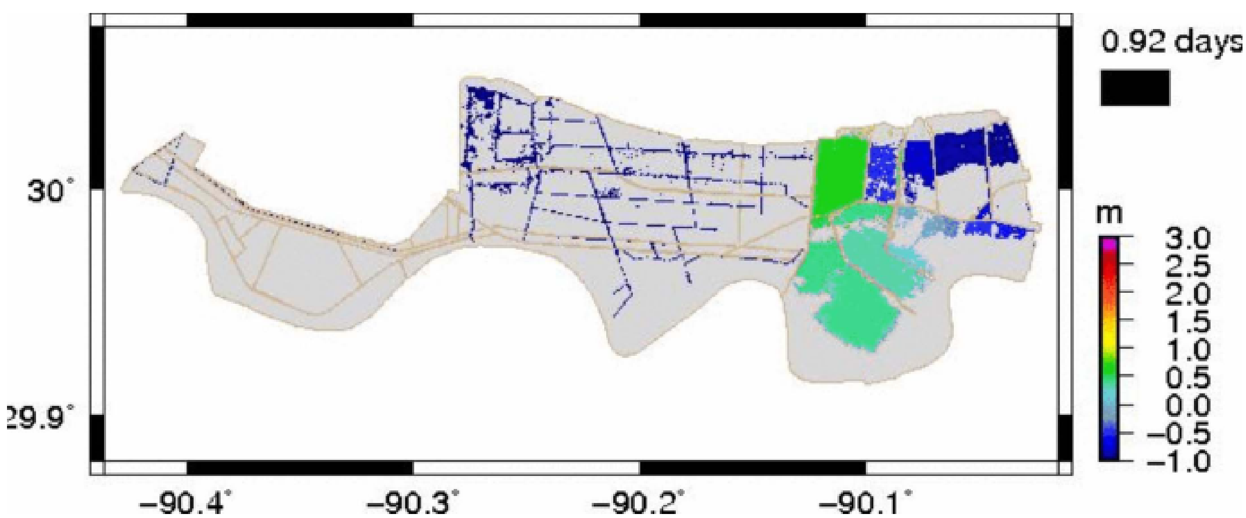

Figure 20.9. Example of Perimeter Breach Scenario for Polder Compartmentalization Study

Bob Jacobsen PE, LLC 2013

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[8] In 2008 Aalberts performed a Hurricane Katrina hindcast for the New Orleans Metro Polder as part of a compartmentalization study using SOBEK (a 2D finite difference code) and simplified structured grid (164 ft square). Royal Haskoning (2009) subsequently used Aalberts model to evaluate additional compartmentalization alternatives. The SOBEK model had limited depiction of canals and other internal features.

[9] These include the vulnerability of the IHNC "I-wall" design (see Section 15.4); the potential for SWL elevations inside the IHNC/GIWW sub-basin during extreme surge events above safe levels for these floodwalls; and the additional hazard of large unsecured vessels and structures ramming these floodwalls during a surge event.

Part V. Conclusions and Recommendations

Conclusions

Part V has reviewed methodologies for analyzing hurricane surge hazards for future conditions and recent applications to southeast Louisiana. This information supports the following important findings:

1. There is currently no scientifically published trend analysis or forecast for long-term secular change to hurricane frequency, intensity, or other characteristics for the CN-GoM. Particular CN-GoM hurricane climatological factors—such as wind shear environment and the Loop Current—are likely to be important to such forecasts.
2. Coastal scientists are publishing research on several critical coastal landscape trends affecting future surge hazard—and providing forecasts for use in critical planning efforts for southeast Louisiana. These encompass SLR, regional subsidence, coastal erosion, and vegetation change.
3. Analysis of future polder inundation hazard conditions can also consider trends in perimeter protection (e.g., localized settlement/consolidation and increasing fragility) and interior subsidence. To date, evaluations for the impact of these trends have not been undertaken.
4. Forecasts of coastal landscape and perimeter system/polder change—as well as proposed projects for coastal restoration and protection—can be readily addressed through ADCIRC+SWAN mesh and code modifications. Surge hazards under these future conditions can be computed by re-running the exterior surge JPA using the modified model. Likewise, changes to perimeter systems and polders can also be incorporated into the more expansive JPA in order to evaluate future polder inundation hazards.
5. When re-running the entire JPA has not been practical, researchers have used hurricane scenarios to assess the sensitivity of surge levels to future conditions. Example include historical storms, SPHs, PMHs, MPI Hurricane, selected storms, or NOAA MEOWs and MOMs.
6. The USACE 2009 post-Katrina planning efforts for Louisiana (LaCPR Study) assessed surge hazards under 18 future conditions using modified ADCIRC-STWAVE models. However, due to limited HPPC resources, the future hazard assessments were based on only re-running a small number of storms for each future condition. The LaCPR Study did not undertake an expanded JPA for future polder inundation hazard analysis.
7. The 2009 USACE Mississippi planning study (MsCIP) applied a limited re-running of a JPA to compare surge hazards for current conditions versus two alternative Lines of Defense. The MsCIP also employed selected storms in sensitivity assessments for barrier island and marsh restoration alternatives.
8. The LaCPR Study and MsCIP both employed an MPI MOM to examine “worst case” storm surge inundation for current conditions. The reports did not provide MPI MOMs for any of the future condition alternatives.
9. The USACE HSDRRS Year 50 (2057) design evaluated the future impact of RSLR with a nine-storm sensitivity test (as opposed to re-running the entire JPA) and estimated multipliers for eleven broad sub-regions to account for increases in the 100-yr hazard under a range of forecasted RSLR. The USACE also developed multipliers for associated wave height increases. The evaluation did not address coastal erosion and vegetation changes. The USACE employed the estimated 2057 100-yr surge hazard in setting design elevations for HSDRRS floodwalls.

10. The CPRA's 2012 Master Plan created 17 ADCIRC+SWAN models: a current condition; a Moderate and a Less Optimistic coastal degradation scenario; and seven sub-versions for both degradation scenarios (14 total) to evaluate 34 potential restoration and protection projects. JPA methods—similar in many ways to those used by IPET—were developed to assess exterior and interior polder hazards. However the Master Plan JPA relied on an improvised JPM-OS with only 40 storms. Simplified breaching probabilities were incorporated into the JPA for interior hazard assessment. The Master Plan assessment of future hazards was coupled with HAZUS to examine surge risks—property and direct economic losses—under the alternatives.
11. A SLFPA-E funded study employed the Master Plan ADCIRC+SWAN model and eight storms to examine the sensitivity of regional surge SWL and wave heights under five future scenarios for the New Orleans East Land Bridge and associated Lake Pontchartrain Barrier project.
12. An ongoing SLFPA-E study is using high resolution ADCIRC-models of polders to evaluate the sensitivity of interior inundation (footprints, depth, and rates) to several potential compartmentalization projects. The study is employing scenarios reflecting significant perimeter breaching generally expected to have return periods greater than 500 years.

Recommendations

The above conclusions indicate several ways in which analyses of surge hazard for future conditions can be improved, particularly given the increasing availability and declining costs for HPPC:

1. Follow the recommendations in Parts II, III, and IV for improved model development, exterior surge hazard analysis, and polder inundation hazard analysis.
2. Re-evaluate the future conditions hazards at appropriate intervals (e.g., Years 10, 25, 50, and 100) based on *all* recognized applicable coastal landscape trends—e.g., RSLR, coastal erosion, vegetation changes, perimeter system degradation, and polder subsidence—when the current exterior surge and interior polder inundation hazards analyses are revised.
3. Re-run all JPM-OS storms for the future conditions JPAs instead of using a small subset of storms to adjust the estimate of future hazard.
4. Use specific storm scenarios—e.g., a Katrina-like hurricane—to provide additional insight and aid public understanding of impacts to future surge hazard.

The Louisiana CPRA, together with federal partners, should fund two critical research topics to improve surge hazard analysis for future conditions:

1. Assess the influence of climate cycles and secular climate change on the CN-GoM hurricane climatology, SLR, and seasonal steric conditions, including influences mediated by the Loop Current. As part of assessing future hurricane climatology for the CN-GoM provide suitable JPM-OS sets for various future surge hazard evaluations.
2. Improve trend analyses for regional subsidence, coastal erosion, and vegetation conversion; elevation changes to perimeter systems and polder interiors; and HSDRRS fragility.

The above recommendations can improve systemic and localized accuracy of surge hazard estimates for future conditions. However, it is important to recognize that the uncertainty in future hazard estimates will be even larger than the substantial uncertainty associated with estimates of current surge hazard.

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