2.4S.5 Probable Maximum Surge and Seiche Flooding

This section addresses the SRP Subsection 2.4.5 Acceptance Criteria Limits from the reference ABWR DCD Tier 2, Table 2.1-1, which states that the probable maximum surge and seiche flooding level should be 30.5 cm (i.e., 1 ft) below site grade. The nominal plant grade for STP 3 & 4 is 34 feet mean sea level (MSL). The surge and seiche level resulting from a probable maximum hurricane is estimated to be 31.1 ft MSL, meeting the specific DCD flood level criterion. Subsection 2.4S.5 develops the hydrometeorological design basis for considering potential hazards to the safety-related facilities due to the effects of probable maximum surge and seiche. Flood analyses for STP 3 & 4 indicated that the PMH would not be the controlling event for the design basis flood elevation of the STP site as the postulated dam failure scenarios discussed in Subsection 2.4S.4 would result in the highest flood level.

2.4S.5.1 Probable Maximum Winds and Associated Meteorological Parameters

The hydrometeorological conditions that would produce the Probable Maximum Storm Surge (PMSS) along the Texas Coast coincide with the probable maximum meteorological winds (PMMW) from the probable maximum hurricane (PMH). The PMH is described by Reference 2.4S.5-1 (p. 2) as "a hypothetical steady state hurricane having a combination of values of meteorological parameters that will give the highest sustained wind speed that can probably occur at a specified coastal location." The meteorological parameters that give the highest sustained wind speed are known as the PMH windfield (Reference 2.4S.5-1, p. 2). These parameters include the peripheral pressure (pn), central pressure (po), radius of maximum winds (R), forward speed (T), track direction (θ), and inflow angles (φ) of the hurricane winds. The initial PMMW parameters are obtained based on identification of the milepost location along the Gulf Coast (Reference 2.4S.5-1, p. 4). Data from historical storms have been used to establish envelope (i.e., upper and lower boundary) conditions for determining the radius of maximum winds and the forward speed (Reference 2.4S.5-1).

The PMH PMMW conditions as determined from Reference 2.4S.5-1 are listed in Table 2.4S.5-2. The peripheral pressure is 30.12 in. Hg. The central pressure is 26.19 in. Hg. Therefore, the PMH P was assumed to be 3.93 in. Hg, or 133.07 millibars. The radius of maximum winds had upper and lower limits of 5 and 21 nautical miles, respectively. The forward speed had upper and lower limits of 6 and 20 knots, respectively.

2.4S.5.2 Surge and Seiche Water Levels

The technical definition of a storm surge is "an abnormal rise of water generated by a storm, over and above the predicted astronomical tide" (Reference 2.4S.5-2, p. 1). The storm surge coinciding with a hurricane typically lasts several hours and affects about one hundred miles of coastline (Reference 2.4S.5-2, p. 1). The setup of the storm surge from the hurricane occurs due to the action of surface wind stress and due to atmospheric pressure reduction. As shown in Figure 2.4S.5-1, the storm surge is the sum of several components, including initial sea level rise, setup due to astronomical forces, setup due to atmospheric pressure reduction, setup due to wind stress effects, and setup due to breaking waves (Reference 2.4S.5-3, p. 20). The initial sea level rise is derived from tide gauge data. Reported tide gauge data in the general area of STP

3 & 4 are available for Port Isabel, Texas, and Freeport, Texas. A site-specific estimate of the initial sea level rise of 2.4 ft. was selected for the coast near STP 3 & 4 using the Freeport, Texas station (Reference 2.4S.5-4, p. 1.59-48). The ten percent exceedance of the astronomical high tide is defined by Reference 2.4S.5-5 (p. 19) as "the 10% exceedance high tide is the high-tide level that is equaled or exceeded by 10% of the maximum monthly tides over a continuous 21-[year] period." As with the initial rise, an estimate of 2.2 feet was selected as the ten percent exceedance high tide based on the reported value for Freeport, Texas (Reference 2.4S.5-4, p. 1.59-48).

2.4S.5.2.1 Historic Storm Surge Events

STP 3 & 4 is located over fifteen miles inland from the Gulf Coast (Figure 2.4S.5-2). A list of hurricanes that have impacted the Texas Coast from 1900 to 2005 is shown in Table 2.4S.5-1. Figure 2.4S.5-3 and Figure 2.4S.5-4 depict hurricane tracks that have impacted the Texas Coast from 1852 to 2006 (Reference 2.4S.5-6). A frequency analysis of hurricanes occurring between 1900 and 1963 along the Gulf Coast of Texas noted that "dangerous and destructive tropical cyclones (hurricanes) can be expected to cross the Texas Coast on the average of about once every three years" (Reference 2.4S.5-7, p. 1). Table 2.4S.5-1 indicates the frequency of hurricanes impacting the Texas Coast between 1900 and 2005 is still about once every three years.

As the Texas coast has a relatively gentle land slope with low-lying coastal elevations, the storm surge resulting from these hurricanes is capable of flooding significant land areas. For example, Reference 2.4S.5-8 (p. 40) states that "reported surges were 16.6 feet above MSL at Port Lavaca, 14.5 feet above MSL at Port O' Connor, 15.2 feet above MSL at Matagorda, and 14.8 feet above MSL on the upper Houston Ship Channel. A high water line varying from 15.7 to 22 feet above MSL, established from debris near the head of Lavaca Bay, probably included the undetermined effects of wave setup and runup." The peak storm surge elevation near STP 3 & 4 was about 16 feet MSL (Reference 2.4S.5-8, p. 46).

2.4S.5.2.2 Storm Surge Analysis

Three different approaches were used to estimate the storm surge at STP 3 & 4. The first approach was based on use of the computer program "Quasi Two-Dimensional Open Coast Storm Surge," known as SURGE (Reference 2.4S.5-3). This approach included two steps to estimate the PMSS water surface elevation near STP 3 & 4. First, SURGE was used to estimate the PMSS water surface elevation at the coast near Matagorda, Texas (Figures 2.4S.5-1 and 2.4S.5-5). Second, the PMSS water surface elevation was used as a boundary condition for a backwater calculation using a calibrated and modified model developed by Halff Associates, Inc., for the Colorado River (References 2.4S.5-9 and 2.4S.5-10).

The second approach was based on the use of the numerical model "Sea, Lake, and Overland Surges from Hurricanes" (SLOSH) (Reference 2.4S.5-2). SLOSH was used to obtain estimates of water surface elevation near STP 3 & 4 due to a hypothetical Category 5 'maximum of maximum' (MOM) hurricane impacting the Matagorda Bay region. The MOM is the maximum of the composite of the maximum envelope of water (MEOW), which incorporates all of the peak values for a hurricane of a particular category, speed, and landfall direction. Therefore, it should be noted that a graphical presentation or hydrograph of the SLOSH output is not available since the MEOW scenarios are composites of numerous runs and are therefore not time dependent for individual cells. Rather, the SLOSH MOM only yields the peak water surface elevations for each cell by hurricane category (i.e., Category 1, Category 2, Category 3, Category 4, and if available, Category 5). It is also noted that SLOSH does not incorporate the ten percent exceedance of the astronomical high tide or a user-specified initial sea-level rise like SURGE (Reference 2.4S.5-2). SLOSH just assumes a constant initial tide elevation of 2 feet above MSL.

The third approach used to predict the PMSS used the numerical Advanced Circulation (ADCIRC) Model, a hydrodynamic circulation model that simulates water level and current over an unstructured gridded domain. The ADCIRC model was selected to validate the results obtained with first two approaches in recognition that that "current best practices" for predicting storm surge are evolving rapidly due to the very high level of interest and active involvement of the Federal Emergency Management Agency (FEMA), the National Oceanic and Atmospheric Administration (NOAA), and the US Army Corps of Engineers (USACE). Associated supporting research has been ongoing at several major universities. These ongoing efforts have resulted in major improvements to the more complex multidimensional computer models used to predict storm surge. Additionally, digital elevation maps based on Light Detection and Ranging (LIDAR) for use with ADCIRC were recently made available for a wider area, including the STP site. The LIDAR based maps improve the accuracy and resolution of the topographic grid, an important input to the computer models, such as ADCIRC, that predict storm surge. Assumptions and initial conditions used with the ADCIRC model were, to the maximum extent possible, consistent with the assumptions and initial conditions used with the SLOSH model.

2.4S.5.2.3 Storm Surge Analysis with SURGE and HEC-RAS

2.4S.5.2.3.1 Storm Surge Analysis with SURGE

SURGE calculates the storm surge water surface elevation near the open coast using as input the PMH windfield characteristics, the offshore bathymetry and a bottom friction factor (References 2.4S.5-3 and 2.4S.5-8). SURGE is based on the solution of a volume-transport form of the two-dimensional hydrodynamic equations over a fixed boundary (Reference 2.4S.5-3). The code implements a simple finite step method for discrete increments of space and time along a single Cartesian axis. The bathymetry used in SURGE was based on the simplifying assumption that the bathymetric contours near the Gulf Coast are parallel to the shoreline. The distance from shore is based on developing a traverse from the coast to where the depth of the Gulf of Mexico is approximately 600 ft (Reference 2.4S.5-4, p. 1.59-43). Based on this assumption, the bathymetry was aligned along a traverse line near Matagorda and STP 3 & 4 (Figure 2.4S.5-5). The bottom profile along the traverse was obtained from the National Oceanic and Atmospheric Administration coastal bathymetry map from Galveston to the Rio Grande (Reference 2.4S.5-11). The hurricane center (i.e., the hurricane eye) was placed to the west of the traverse line in accordance with the geometry of the radius of the maximum wind and the inflow angle as described in

Reference 2.4S.5-3 (p. 32). As the probable maximum wind occurs along this traverse, the surge heights calculated along the traverse result in a prediction of the PMSS water surface elevation.

While the windfield characteristics and bottom topography can be derived from References 2.4S.5-1 and 2.4S.5-11, respectively, the bottom friction factor is not known a priori and needs to be calibrated. This calibration is based on iteratively testing the friction factor to match previously observed overland storm surge elevations with predicted model values. Calibration of the bottom friction factor for the methodology described in SURGE (Reference 2.4S.5-3) is summarized by Reference 2.4S.5-8 (p. 119). PMMW data were obtained for the 1949 Hurricane and Hurricane Carla (Reference 2.4S.5-8, p. 35-36 and p. 36-43, respectively), and used to estimate storm surge water surface elevations along the Galveston and Freeport, Texas traverses (Figure 2.4S.5-5). The estimated storm surge heights were then compared with observed values. As stated on p. 118 of Reference 2.4S.5-8, "the computed surge hydrograph of the Hurricane of 1949 at Galveston showed poor correlation to the recorded surge hydrograph; this may be due to lack of wind data for this traverse. A fair correlation was obtained for the Freeport traverse." From the same page, "good results were obtained using Hurricane Carla data for the Galveston traverse which provided most of the desired conditions for an open-coast station. Good results were obtained for the Freeport traverse." The calibration data indicated that a bottom friction factor of 0.003 produced the closest match between the observed and predicted storm surge elevations. A friction factor of 0.003 was also adopted for the PMSS estimate for Freeport, Texas (Reference 2.4S.5-4, p 1.59-48). Subsequently, a bottom friction factor of 0.003 was adopted for estimating the PMSS with the SURGE code for STP 3 & 4.

A wind stress correction factor of 1.1 was included in the storm surge calculations. This factor accounts for the effect of rainfall on the sea surface stress, with Reference 2.4S.5-12 (p. 148) stating that "since 10-20% of the [drops] momentum is lost to the air, and since in some cases the total momentum transferred to the surfaces by the [drops] can be comparable to that transferred by the air, the stresses introduced into the air by the drops can be 10-20% of the wind stress."

The SURGE program was used to calculate the storm surge for four scenarios that represent limiting combinations of the radius of maximum winds and hurricane forward speed. The four scenarios are shown in Table 2.4S.5-3. The governing PMMW characteristics for each scenario were derived from Reference 2.4S.5-3. The lower and upper limits of the radius of maximum winds used were 5 and 21 nautical miles, respectively. The lower and upper limits of the hurricane forward speed used were 6 and 20 knots, respectively. The maximum storm surge height from the four scenarios occurred for a hurricane with a radius of maximum winds of 21 nautical miles and a forward speed of 20 knots. The estimated peak water surface elevation of the storm surge was 18.79 feet mean low water (MLW). This value is equivalent to 18.11 feet MSL considering the datum shift of 0.68 feet from MLW to mean sea level (MSL) at Freeport, Texas (Reference 2.4S.5-13). To account for the long-term sea level rises due to global climate change, it is assumed that the historical mean sea level trend at Freeport, Texas of 5.87 mm/year or 1.93 feet/century, with a standard error of 0.74

mm/yr, from 1954 to 1999 (Reference 2.4S.5-13) will continue. Therefore, including sea-level rise over the next century, the PMSS at the Gulf coast for the most severe SURGE scenario is estimated as 20.04 feet MSL.

With respect to the assumption of the MSL datum (or NGVD 29) shift relative to actual mean sea level from tidal measurements, it should be noted that the Freeport, Texas, tide gauge does not have a published or official NGVD29 orthometric height mark. Since the one mark that does exist suggests the difference between MSL (or NGVD 29) to actual mean sea level is small (i.e., within ±0.2 ft of the Mean Lower-Low Water datum), the shift to MSL (or NGVD 29) should be considered as an approximation of the actual value.

2.4S.5.2.3.2 Storm Surge Analysis with Halff HEC-RAS Hydraulic Model

A modified version of the Halff HEC-RAS hydraulic model (i.e., Reference 2.4S.5-10) was used to estimate the water surface elevation at STP 3 & 4 based on a backwater calculation on the Colorado River using the storm surge water surface elevation near the open coast as the downstream boundary condition. The Halff HEC-RAS model was developed for Halff's flood damage evaluation study and is discussed extensively in Subsection 2.4S.3. To be on the conservative side, however, the floodplain-extension used in HEC-RAS model of Subsection 2.4S.3 was not adopted in estimating the storm surge at STP 3 & 4. Little Robbins Slough near the STP site, shown in Figure 2.4S.5-8, is a shallow multi-channel slough that joins Robbins Slough, a brackish marsh, which eventually drains to the Gulf Intracoastal Waterway. With the PMSS, it would be completely submerged and drowned out, thereby resulting in negligible water surface slopes for the backwater calculation. Therefore, the Colorado River is used for the PMSS backwater calculation in order to generate a bounding PMSS water level at STP 3 & 4.

The model used for Subsection 2.4S.5 is a truncated version of the reach between Bay City to Matagorda Bay. Bay City to Matagorda Bay covers a reach length of about 24 miles and includes two bridge crossings, one at the Missouri Pacific Railroad (RS 1350+15.3) and another at the FM 521 roadway (RS 843+40.0). The upstream-most cross-section in the Halff model from Bay City to Matagorda Bay is located at the Bay City USGS gauging station (RS 1665+21.6). The downstream-most cross-section (RS 383+64.5) in the model is located about 4,600 ft upstream of the intersection of Lower Colorado River and the Intracoastal Waterway (RS 337+90) (see Volume II-C, Chapter 6, Table I-1 of Reference 2.4S.5-10). For this study, only thirty cross-sections were used, between river stations (RS) 383+64.5 and RS 964+99.7. A truncated version of the model was used since the cross-sections above RS 964+99.7 feet are not needed as flow in the Colorado River is subcritical (Subsection 2.4S.3). However, unlike Subsection 2.4S.3, the cross-sectional geometries between stations 383+64.5 and 964+99.7 feet were not altered from the original Halff HEC-RAS model (Reference 2.4S.5-10), i.e., no extensions into the floodplain areas. This approach provides a more conservative estimate of the water surface elevation at STP 3 & 4.

The peak water surface elevation at STP 3 & 4 (i.e., RS 891+46) resulting from the storm surge was assumed to coincide with a 100-year flood event of 98,751 cfs

(Reference 2.4S.5-10, p. A13-Matagorda-8). Using the truncated HEC-RAS model described above, the water surface elevation near STP 3 & 4 was calculated to be 24.29 feet MSL (Figure 2.4S.5-6). The SURGE estimate of 24.29 feet MSL is less conservative than the SLOSH estimate for STP 3 & 4, which is discussed in Section 2.4S.5.2.4.

2.4S.5.2.4 Storm Surge Analysis with SLOSH and ADCIRC

2.4S.5.2.4.1 Storm Surge Analysis with SLOSH

The second approach for the estimation of the maximum storm surge at STP 3 & 4 used output from the computer model “Sea, Lake, and Overland Surges (SLOSH)” (Reference 2.4S.5-2). SLOSH was developed by the National Oceanic and Atmospheric Administration (NOAA) and evolved from a simpler model known as the “Special Program to List Amplitudes of Surges from Hurricanes (SPLASH).” SLOSH is a two-dimensional finite difference code that uses an adaptive curvilinear grid for regions along the Gulf and Atlantic coasts. SLOSH assumes uniform friction to solve the equations of motion for reference basins along the Gulf of Mexico and Atlantic Ocean coast. Unlike SURGE, SLOSH can estimate water surface elevations due to the storm surge for both the open coast and on land.

The validity of the SLOSH model has been demonstrated and documented extensively (Reference 2.4S.5-14). While the model validity varies by station, the mean error of the SLOSH predictions for 523 observations within the Gulf of Mexico was reported as 0.09 m (0.29 ft) with a standard deviation of 0.61 m (2.0 ft) (Reference 2.4S.5-14, p. 1410). The maximum difference between the predicted storm surge elevations and the measured storm surge elevations was 2.69 m (8.83 ft) (Reference 2.4S.5-14, p. 1410). For Freeport, Texas, the model predictions replicate the observed surge elevations of approximately 11 ft MLW (10.32 ft MSL) within the mean error during Hurricane Carla (1961) (Reference 2.4S.5-2, p. 61).

The SLOSH MOM scenario predicts that STP 3 & 4 is dry for Category 1 through Category 5 hurricanes (Figure 2.4S.5-7). However, an estimate of the PMH PMSS using SLOSH can be made by using cells near STP 3 & 4 in the Lower Colorado River (Figure 2.4S.5-7). With respect to the windfield conditions, the SLOSH MOM estimate is based on a hurricane with a forward speed of 15 mph (13.03 knots) and a northwest wind. Since the Category 5 hurricane is a less severe scenario than the PMH, the SLOSH estimate needs to be adjusted to be comparable to the SURGE results. By assuming an extrapolation based on the maximum water surface elevation of a MOM Category 2 hurricane through a MOM Category 5 hurricane, the SLOSH PMH PMSS was estimated to be 27.2 ft MSL. Additionally, since the SLOSH model assumes an initial condition of 2 feet MSL for Matagorda Bay, its storm surge estimate needs to be adjusted to be comparable to the SURGE results. First, to account for the long-term sea level rises due to global climate change, it is assumed that the historical mean sea level trend at Freeport, Texas of 5.87 mm per year or 1.93 feet per century, with a standard error of 0.74 mm/yr, from 1954 to 1999 (Reference 2.4S.5-13) will continue. Second, the 2 ft MSL tide assumed by SLOSH needs to be differenced with the 10% exceedance of the astronomical high tide of 2.2 feet MLW (1.52 feet MSL) and the initial water rise of 2.4 feet. Therefore, the PMSS at STP 3 & 4 predicted by SLOSH, with the sea level adjustments, is 31.1 feet MSL. This value is more conservative than the SURGE estimate of 24.29 feet MSL at STP 3 & 4.

2.4S.5.2.4.2 Storm Surge Analysis with ADCIRC

The third approach used for the estimation of the maximum storm surge at STP 3 & 4 used output from the computer model Advanced Circulation (ADCIRC). Specifically, version 49 of ADCIRC-2DDI, the two-dimensional, depth-integrated implementation of the ADCIRC coastal ocean model, was used to perform the hydrodynamic computations used to estimate storm surge levels at the site. This model uses depth-integrated equations of mass and momentum conservation subject to incompressibility, Boussinesq, and hydrostatic pressure approximations (References 2.4S.5-15 through 2.4S.5-18). ADCIRC is linked to a computer program called SWAN that calculates the wave-induced setup in addition to the wind-induced setup calculated by ADCIRC. SWAN is a third-generation wave model developed by Delft University of Technology. SWAN computes random, short-crested wind-generated waves in coastal regions and inland waters (Reference 2.4S.5-19). The unstructured-mesh SWAN spectral wave model and the ADCIRC shallow-water circulation model have been integrated into a tightly coupled SWAN + ADCIRC model. Hurricane waves and storm surge as estimated by the coupled SWAN + ADCIRC model have been validated for Hurricane Katrina and Hurricane Rita, demonstrating the importance of inclusion of the wavecirculation interactions.

The Federal Emergency Management Agency (FEMA) certified ADCIRC for use in performing storm surge analyses as part of their program for developing Flood Insurance Rate Maps (FIRMs) along coastal areas of the United States. This model is the standard coastal model used by the Unites States Army Corps of Engineers (USACE). In addition to USACE projects, it is used the National Oceanic and Atmospheric Administration (NOAA) and the Naval Research Laboratory (NRL).

The ADCIRC model as applied to the STP analysis underwent an extensive flood level evaluation process to validate it over a range of conditions to ensure that the flow physics of the system were accurately characterized. The set of validation storms specific to the Texas coastal areas included Hurricanes Carla (1961), Celia (1970), Allen (1980), Alicia (1983), Bret (1999), Rita (2005), and Ike (2008). Hurricanes Rita and Ike were particularly useful storms for validation because of the large degree of surge they produced, and the accurate measurements of wind, atmospheric pressure, waves, and surge levels that exist for these two storms.

Topography for Texas was obtained predominantly using 10-meter LIDAR data supplied by FEMA. Light Detection and Ranging (LIDAR) is a remote sensing system used to collect topographic data. All topographic and bathymetric data were spatially averaged to the local mesh scale. The topographic data were applied to the grid by searching for all LIDAR points within a rectangle defined by the average distance from the node for which we are assigning a topographic value to the connected nodes. The topographic grid used for the ADCIRC analysis at STP accounts for pronounced vertical features with small horizontal scales relative to the grid scale. While features such as barrier islands and riverbanks are generally well resolved in grids with resolutions down to about 100 feet, features like levees, floodwalls, railroads, and raised highways will not be sufficiently well resolved with 100-foot grid resolution. Frequently, these small-scale features can be significant horizontal obstructions to flow causing water to rise or be diverted elsewhere, which proved to be the case at STP. These obstructions must therefore be carefully incorporated into the model. All raised feature heights are defined using the most recent surveys available from the various sources, including LIDAR sources, USACE SWG surveys, and surveys from local jurisdictions. In this case, vertical positions were typically defined from the Texas 10-meter-by-10-meter LIDAR data set. However, the elevations were also confirmed or adjusted with 1-meter-by-1- meter LIDAR where available.

A series of hurricane scenarios were simulated using ADCIRC to determine the maximum water surface elevation near STP Units 3 and 4 resulting from storm surge. The PMH parameters selected for the ADCIRC runs were based on the storm scenario that that produced the maximum surge at the site during the prior analysis with SLOSH. Specifically, the PMH parameters selected for the ADCIRC runs based on NWS 23 are a radius to maximum winds of 24 miles (21 nm); an approach direction of 135° clockwise from the north (i.e. a northwesterly direction); a forward speed of 23 mph (20 knots); a central pressure of 26.19 in Hg; and a peripheral pressure of 30.12 in Hg. The only variables were the distance of the storm track from the site and the track direction.

The PMSS generated by ADCIRC, using NWS 48 wind profile, is estimated to be 29.3 ft above MSL. This PMSS will occur as the result of a hurricane traveling in a northwesterly direction (i.e., an approach direction of 135° clockwise from the north) passing within 24 miles of the STP site. During its life up to the point of landfall, the storm will have a constant forward speed of 23 mph, a central barometric pressure of 887 Mb, and a maximum sustained wind speed of 160 knots (184 mph). Upon landfall, the storm will continue in a northwesterly direction and began to decay gradually as it moves inland. The limiting storm and corresponding ADCIRC prediction are shown in Figures 2.4S.5-9 and 2.4S.5-10.

2.4S.5.2.4.3 Storm Surge Analysis Conclusions

Subsection 2.4S.4 provides the flood elevation caused by a Main Cooling Reservoir (MCR) embankment breach. The flood level caused by the MCR breach is significantly higher than the probable maximum storm surge as calculated by SURGE, SLOSH, or ADCIRC. Therefore, the probable maximum storm surge caused by the PMH is not a design basis event for the maximum floodwater surface elevation at the safety-related STP 3 & 4 plant structures or for hydraulic forces acting against those structures.

2.4S.5.2.5 Storm Surge from Regulatory Guide 1.59

The PMH PMSS at Freeport, Texas, predicted by Regulatory Guide 1.59 (i.e., Reference 2.4S.5-4) is 23.48 ft MLW (22.8 MSL) (p. 1.59-48). The individual components contributing to the storm surge were 15.99 ft due to wind setup, 2.89 feet due to pressure setup, 2.4 ft due to initial rise, and 2.2 ft MLW (1.52 ft MSL) due to the 10% exceedance of the astronomical high tide. Assuming a historical mean sea level trend at Freeport, Texas, of 1.93 ft per century (Reference 2.4S.5-13) will continue, the adjusted storm surge elevation for Reference 2.4S.5-4 is 24.7 ft MSL.

However, the windfield calculations in Regulatory Guide 1.59 are based on an interim and unpublished 1959 report that has been superseded by NWS 23 (i.e., Reference 2.4S.5-1). Therefore, the determination of the storm surge from the bathystrophic model in Reference 2.4S.5-8, which is based on these earlier windfield calculations, is not considered valid and the PMSS estimate from Reference 2.4S.5-4 is not considered further.

2.4S.5.2.6 Seiches

Seiches are standing waves of relatively long period which occur in lakes, canals, bays, and on the open coast. Other than the Gulf of Mexico and Matagorda Bay, there are no large bodies of water in the immediate vicinity of the site, and seiche has not been considered as the controlling influence for these bodies of water. Other than for floods on the Colorado River, the hurricane storm surge is the dominant factor responsible for coastal area flooding. Therefore, the flooding at the site due to seiche effects ~~is considered insignificant. Seiche effects of the MCR are discussed in Subsection 2.4S.8.~~from seismic or atmospheric external forcing mechanisms is considered insignificant in comparison to the water level at STP 3 & 4 resulting from the failure of the MCR. Failure of the MCR is discussed in Section 2.4S.4. Seiche effects in the MCR due to atmospheric mechanisms are discussed in Subsection 2.4S.8.2.4.

2.4S.5.3 Wave Action and Breaking Wave Setup (Sw)

Evaluation of the wave runup component as illustrated in Figure 2.4S.5-1 was performed as part of the dam break analysis discussed in Subsection 2.4S.4. Wave runup is more critical when it is combined with the dam failure flood level because the water surface elevation of 31.1 feet MSL resulting from the PMH is lower than the flood level (before wave runup) of 32.5 feet MSL predicted for the postulated upstream dam failure scenario. Breaking wave setup was in generally small and would have no impact to the conclusion of the flood risk assessment considering the conservatism in the analysis.

2.4S.5.4 Resonance

Resonance effects are not considered as there are no resonance effects in the site area.

2.4S.5.5 Protective Structures

The controlling event for the design basis flood is the MCR embankment breach discussed in Subsection 2.4S.4 and flood protection for the safety related facilities are discussed in Subsection 2.4.10. Real-time monitoring of hurricanes through the National Hurricane Center (NHC) are considered adequate warning of impeding hurricanes to allow for the implementation of the plant safety procedures discussed in Subsection 2.4S.14.

2.4S.5.6 References

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2.4S.5-14 "An evaluation of the SLOSH Storm-Surge Model," Bulletin of the American Meteorological Society 66(11): 1408-1411, Jarvinen, B. R. and Lawrence, M. B. 1985.

2.4S.5-15 "Design and Implementation of a Real-Time Storm Surge and Flood Forecasting Capability for the State of North Carolina," Mattocks et al, Carolina Environmental Program, University of North Carolina, November 30, 2006

2.4S.5-16 "A Basin- to Channel-Scale Unstructured Grid Hurricane Storm Surge Model Applied to Southern Louisiana," Westerlink et al, American Meteorological Society, March 2008.

2.4S.5-17 "A High-Resolution Coupled Riverine Flow, Tide, Wind, Wind Wave, and Storm Surge Model for Southern Louisiana and Mississippi. Part I: Model Development and Validation," Bunya et al, American Meteorological Society, February 2010.

2.4S.5-18 "A High-Resolution Coupled Riverine Flow, Tide, Wind, Wind Wave, and Storm Surge Model for Southern Louisiana and Mississippi. Part II: Synoptic Description and Analysis of Hurricanes Katrina and Rita," Dietrich et al, American Meteorological Society, February 2010.

2.4S.5-19 "Modeling Hurricane Waves and Storm Surge using Integrally-Coupled, Scalable Computations," J.C. Dietrich et al., Coastal Engineering, July 9, 2010.

Table 2.4S.5-1 Major Historic Hurricanes Impacting the Texas Coast 1900 to 2005

Date of Landfall	Name
24 Sep 2005	Hurricane Rita
24 Sep 2004	Hurricane Ivan
15 Jul 2003	Hurricane Claudette
23 Aug 1999	Hurricane Bret
1 Aug 1989	Hurricane Chantal
16 Oct 1989	Hurricane Jerry
18 Sep 1988	Hurricane Gilbert
26 Jun 1986	Hurricane Bonnie
18 Aug 1983	Hurricane Alicia
10 Aug 1980	Hurricane Allen
8 Sep 1974	Hurricane Carmen
10 Sep 1971	Hurricane Fern
3 Aug 1970	Hurricane Celia
20 Sep 1967	Hurricane Beulah
17 Sep 1963	Hurricane Cindy
11 Sep 1961	Hurricane Carla
25 Jun 1959	Hurricane Debra
4 Oct 1949	1949 Hurricane
27 Aug 1945	1945 Hurricane
27 Jul 1943	1943 Hurricane
30 Aug 1942	1942 Hurricane
23 Sep 1941	1941 Hurricane
7 Aug 1940	1940 Hurricane
5 Sep 1933	1933 Hurricane
4 Aug 1933	1933 Hurricane
13 Aug 1932	1932 Hurricane
23 Jun 1929	1929 Hurricane
21 Jun 1921	1921 Hurricane
14 Sep 1919	1919 Hurricane
18 Aug 1916	1916 Hurricane
16 Aug 1915	1915 Hurricane
21 Jul 1909	1909 Hurricane
8 Sep 1900	Galveston Hurricane

Source: References 2.4S.5-6 and 2.4S.5-7

Table 2.4S.5-2 Probable Maximum Hurricane Characteristics

Peripheral Pressure (p_w)	30.12 in. Hg.
Central Pressure (p_o)	26.19 in. Hg.
Radius of Maximum Winds (R)	5 to 21 nautical miles
Forward Speed (T)	6 to 20 knots

Table 2.4S.5-3 Probable Maximum Hurricane Scenarios and Probable Maximum Surge Elevations

Scenario (R, T) (units)	V_{xs} (mph)	Wind Setup (feet)	Pressure Setup (feet)	Initial Rise (feet)	10% Exc. High Tide [1] (feet MLW)	Total Surge Elevation (feet MLW)
1 (21 n. mi., 6 knots)	152.2	10.45	2.48	2.4	2.2	17.53
2 (21 n. mi., 20 knots)	158.2	11.74	2.44	2.4	2.2	18.79
3 (5 n. mi., 6 knots)	153.5	6.58	1.85	2.4	2.2	13.03
4 (5 n. mi., 20 knots)	159.6	6.89	1.75	2.4	2.2	13.24

Notes:
The parameters given in the table are:
R radius of maximum winds
T translation speed
V_{XS} maximum stationary wind speed

[1] 10% Exceedance of the High Tide (Reference 2.4S.5-5, p.19)

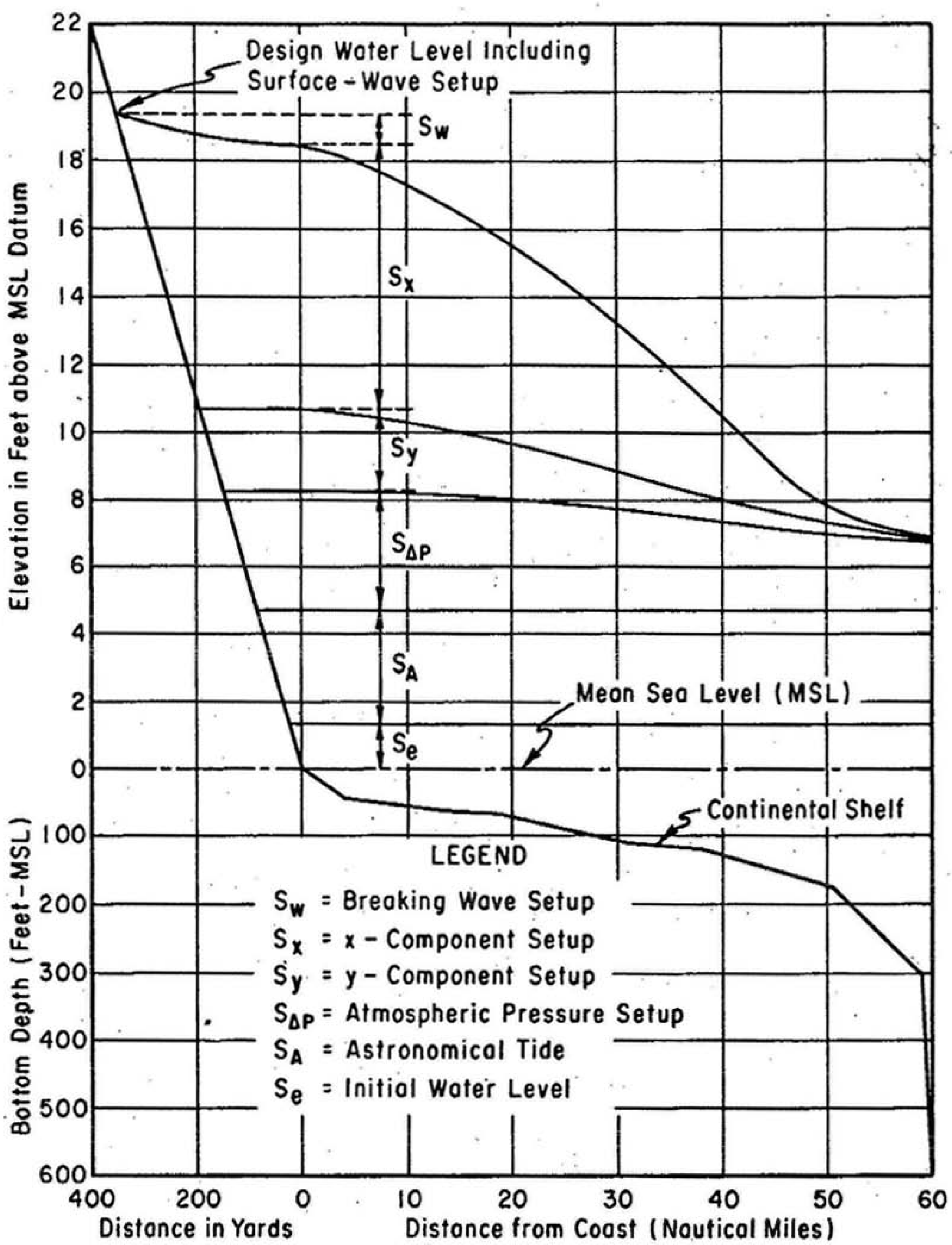

Figure 2.4S.5-1 Components of the PMSS Coinciding With the PMH

Source: Reference 2.4S.5-3, p.20

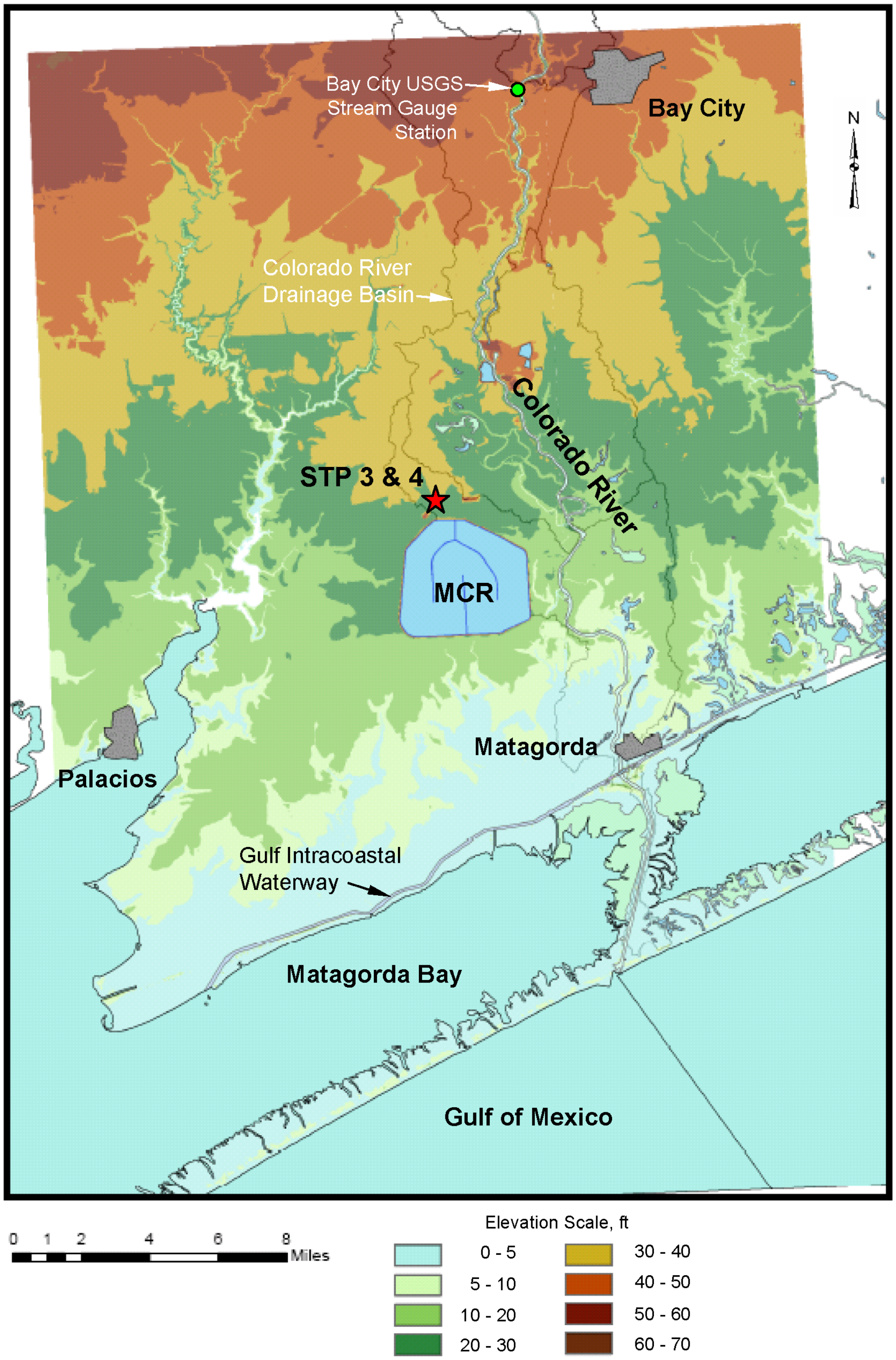

Figure 2.4S.5-2 Location of the Main Cooling Reservoir (MCR) and STP 3 & 4 Relative to the Lower Colorado River Mouth

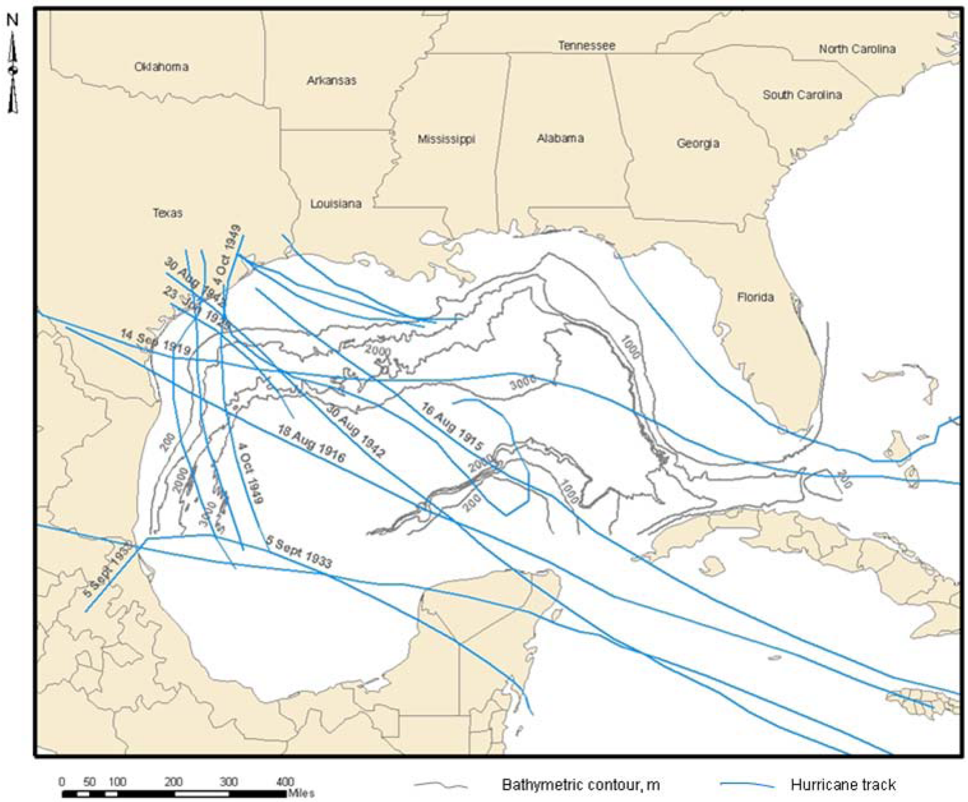

Figure 2.4S.5-3 Historic Hurricane Tracks of Major (i.e., Category 1 and Larger) Unnamned Hurricanes Impacting the Texas Coast Between 1852 and 1950

Source: Reference 2.4.S.5-6

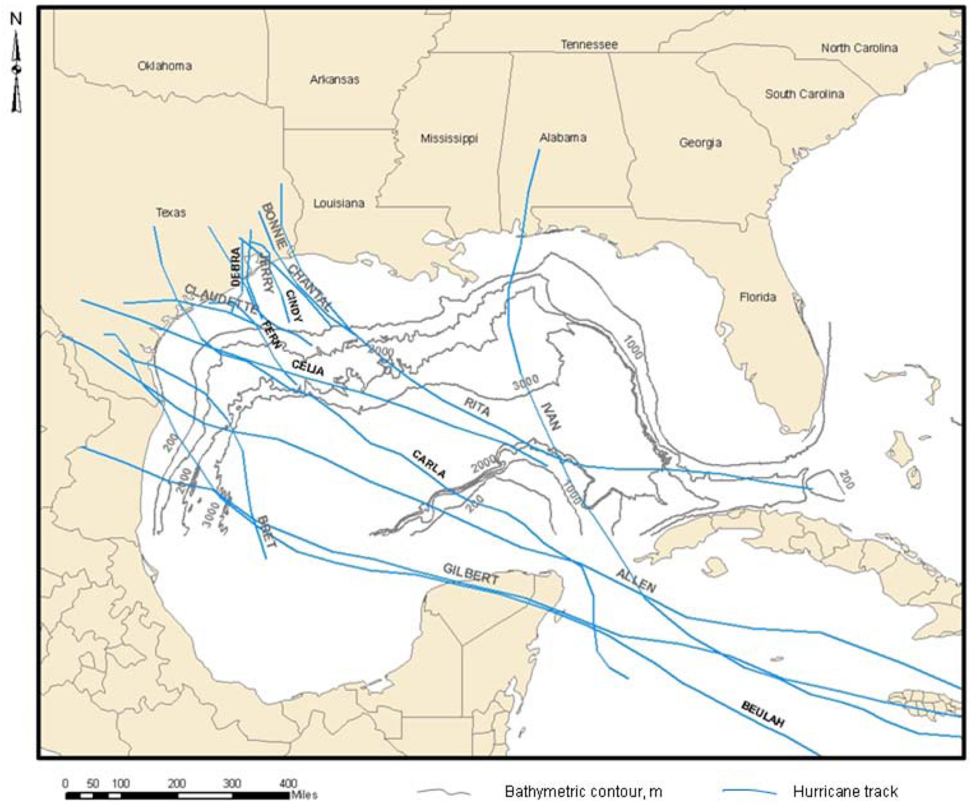

Figure 2.4S.5-4 Historic Hurricane Tracks of Major (i.e., Category 1 and Larger) Unnamned Hurricanes Impacting the Texas Coast from 1950 to 2006

Source: Reference 2.4S.5-6

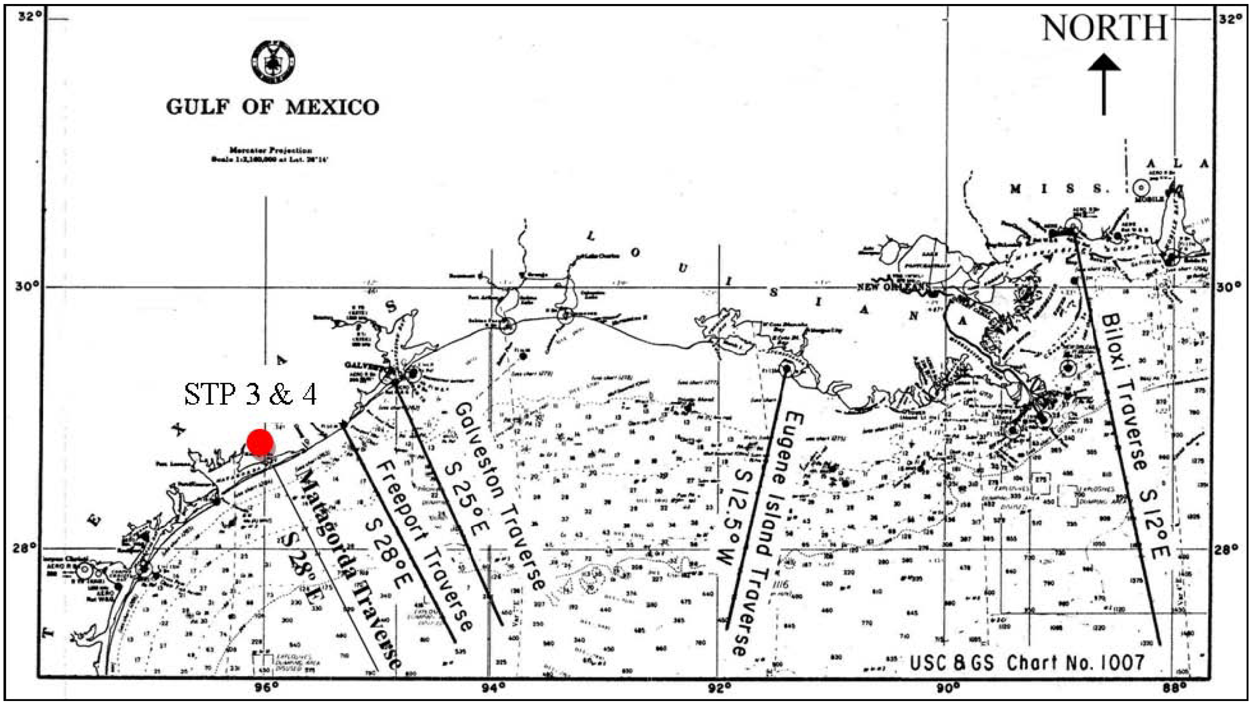

Figure 2.4S.5-5 Schematic of Matagorda, Freeport and Galveston Traverses

Source:Modified from Reference 2.4S.5-8, p. 78 to include Matagorda Traverse. The bottom profile along the traverse was obtained from the National Oceanic and Atmospheric Administration coastal bathymetry map (Reference 2.4S.5-11). The general location of STP 3 & 4 is noted with a red dot.

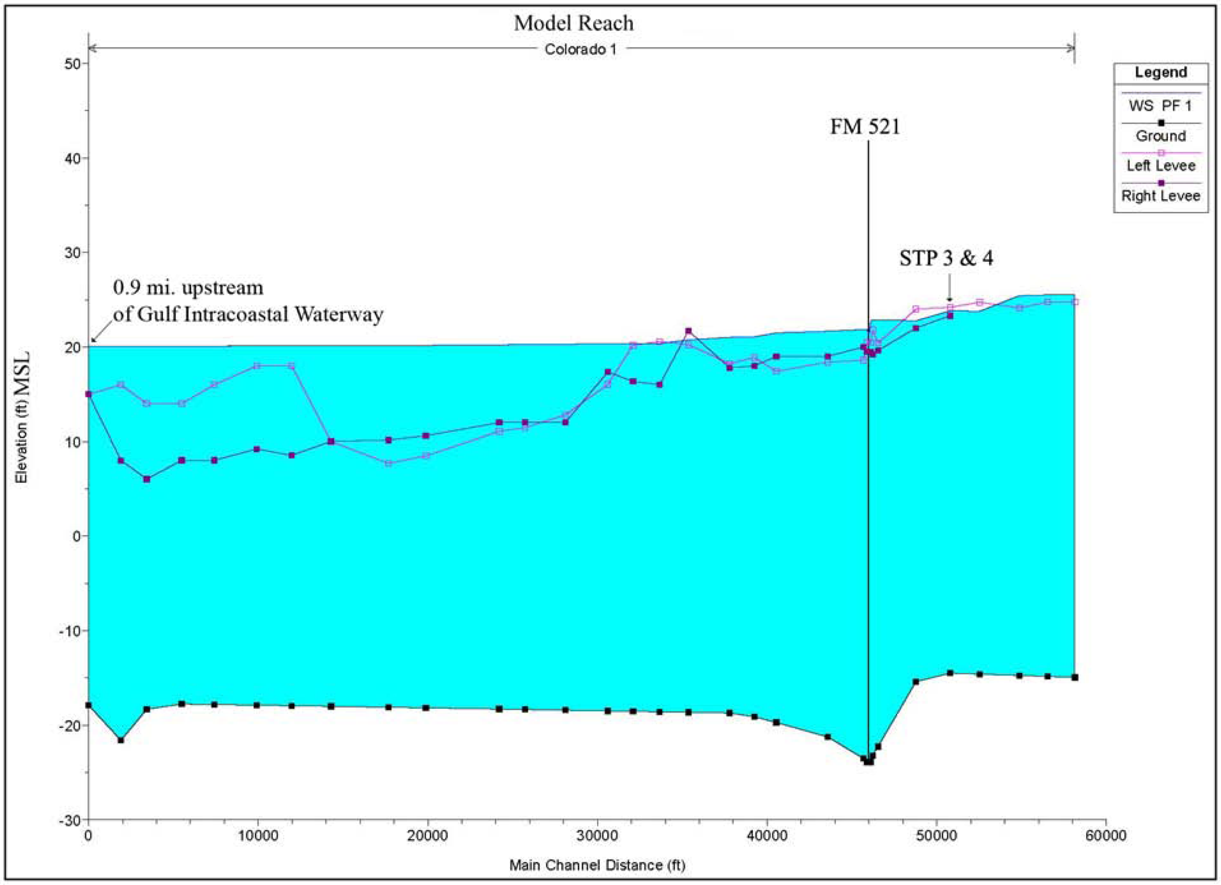

Figure 2.4S.5-6 Longitudinal Profile of Water Surface (WS) Elevation

Source:Predicted by modified Halff-HEC-RAS model assuming unaltered cross-sectional geometry of Reference 2.4S.5-10, a 100-year flood in the Lower Colorado River, and PMSS conditions.

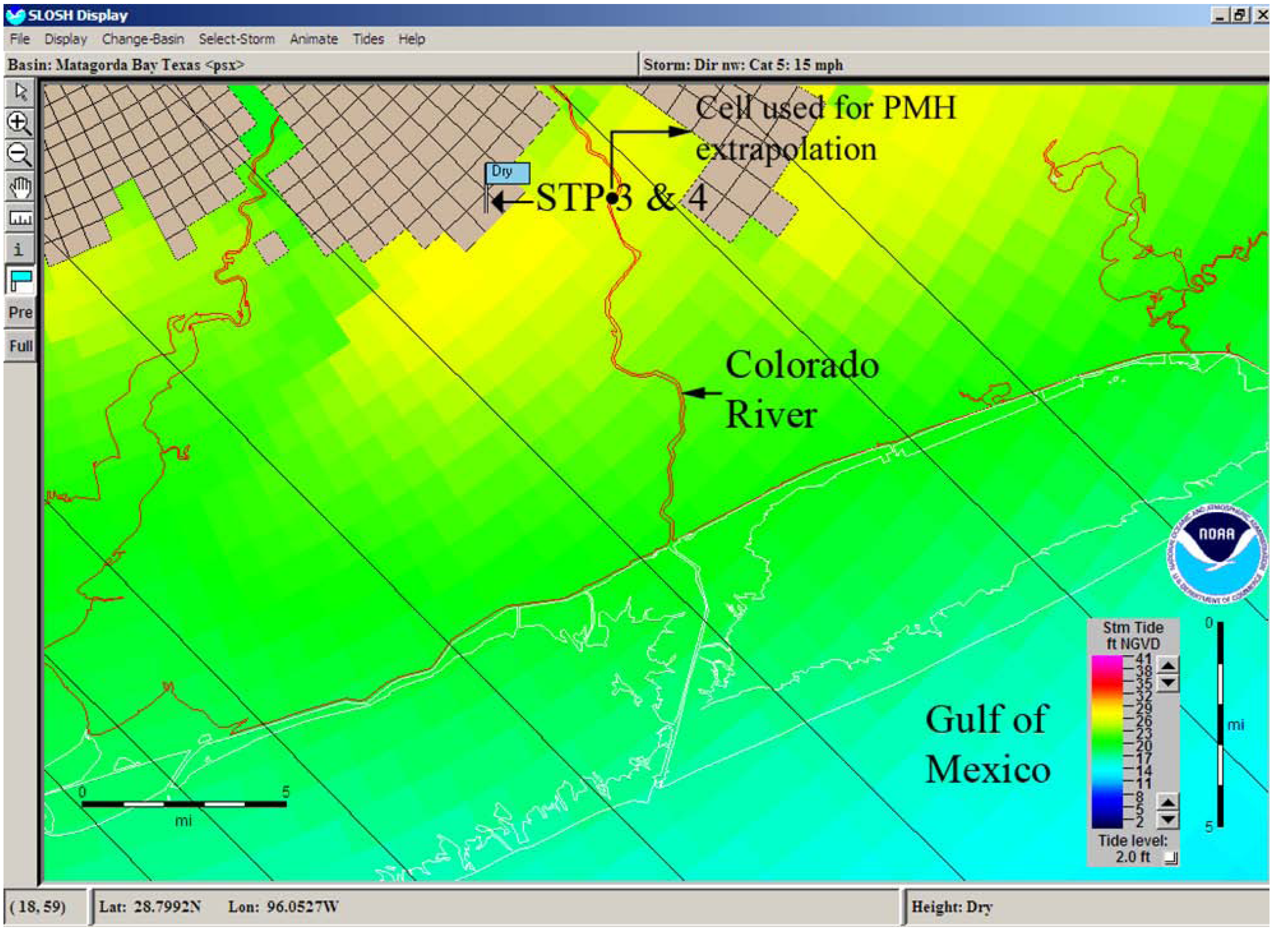

Figure 2.4S.5-7 The Maximum of Maximum (MOM) Storm Surge for a Category 5 Hurricane at STP 3 & 4

Source:Predicted by SLOSH for STP 3 & 4 to occur for a storm with a 15 mph forward speed and northwest winds. STP 3 & 4 is identified with a blue flag. The cell used for the STP 3 & 4 PMH PMSS extrapolation is noted by a black dot. (Modified from Reference 2.4S.5-2).

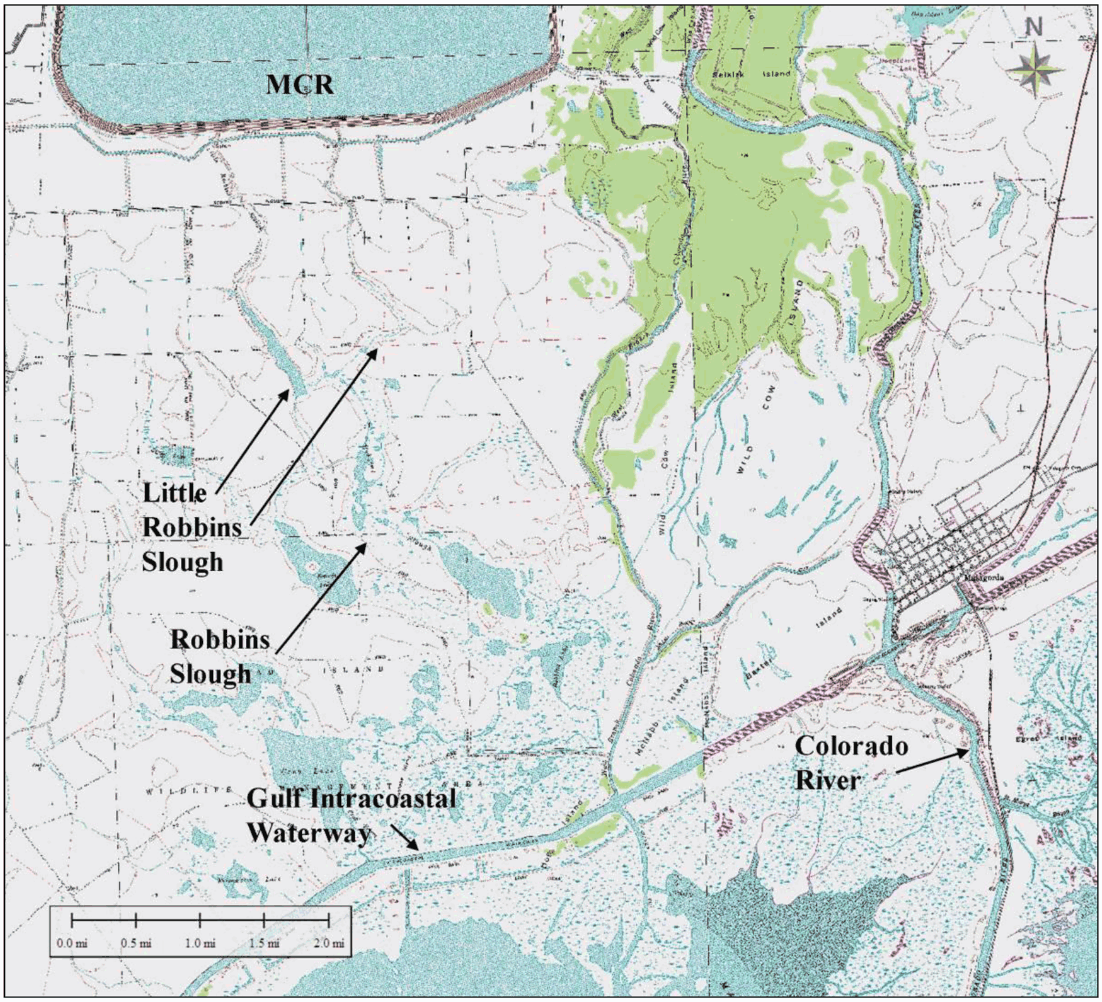

Figure 2.4S.5-8 USGS Quadrangle showing Little Robbins Slough and Colorado River relative to the STP 3 & 4 Main Cooling Reservoir (MCR)

Center of Eye	Time to Landfall (hrs)	Coordinates Latitude (°N)	Coordinates Longitude (°W)	Storm Features Category (SSI)	Storm Features Central Pressure (Mb)	Storm Features Radius to Max. Winds (miles)	Distance Between Points (nm)	Distance Between Points (miles)	Forward Speed (mph)	Forward Speed (knots)
D	-12	30.26	98.43	1	994	10	26	30	10	8.7
C	-9	29.95	98.06	2	979	13	34	39	13	11.3
B	-6	29.56	97.60	3	964	16	44	51	17	14.7
A	-3	29.04	97.01	4	944	20	52	60	20	17.3
Landfall	0	28.42	96.32	5	887	24	60	69	23	20
1	3	27.72	95.52	5	887	24	60	69	23	20
2	6	26.99	94.73	5	887	24	60	69	23	20
3	9	26.27	93.96	5	887	24	60	69	23	20
4	12	25.54	93.19	5	887	24	60	69	23	20
5	15	24.81	92.43	5	887	24	60	69	23	20
6	18	24.09	91.67	5	887	24	60	69	23	20
7	21	23.37	90.91	4	944	20	60	69	23	20
8	24	22.68	90.12	3	964	16	60	69	23	20
9	27	21.98	89.34	2	979	13				

NORTHWEST

PMH Storm Features		
Central Pressure:	887 Mb	(26.19 in. Hg)
Peripheral Pressure:	1020 Mb	(30.12 in. Hg)
Radius to Maximum Winds:	21 nm	(24 miles)
Forward Speed:	20 knots	(23 mph)
Maximum Sustained Wind:	160 knots	(184 mph)
Shortest Distance from site:	20.9 nm	(24 miles)

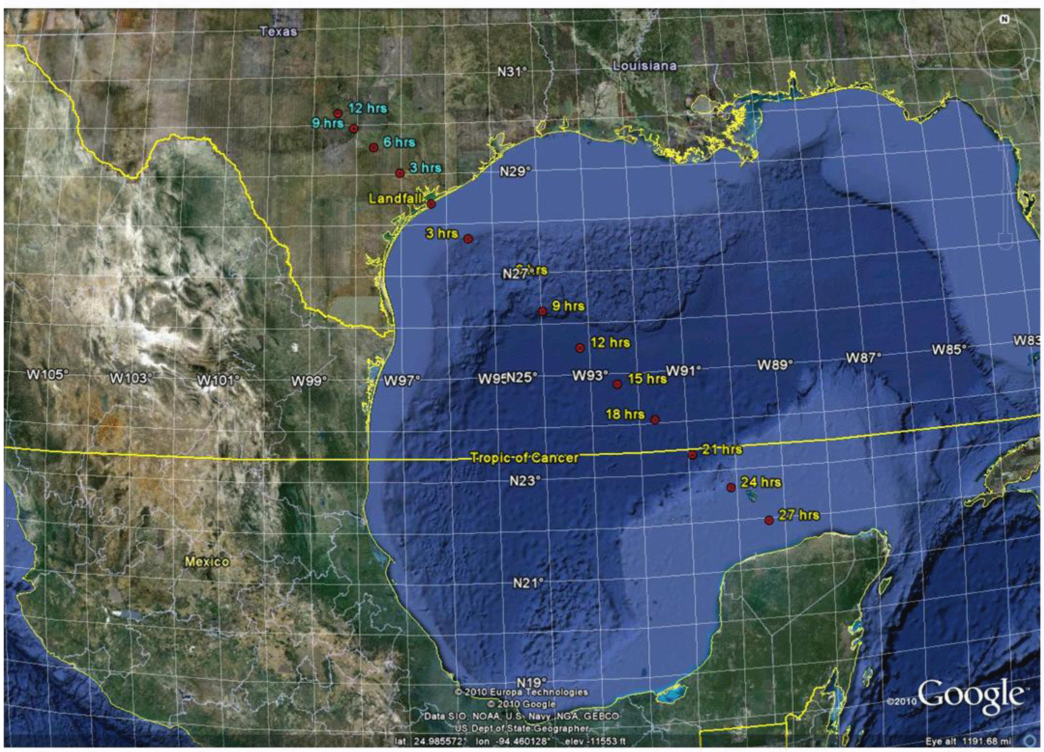

Figure 2.4S.5-9 PMH used in conjunction with ADCIRC model

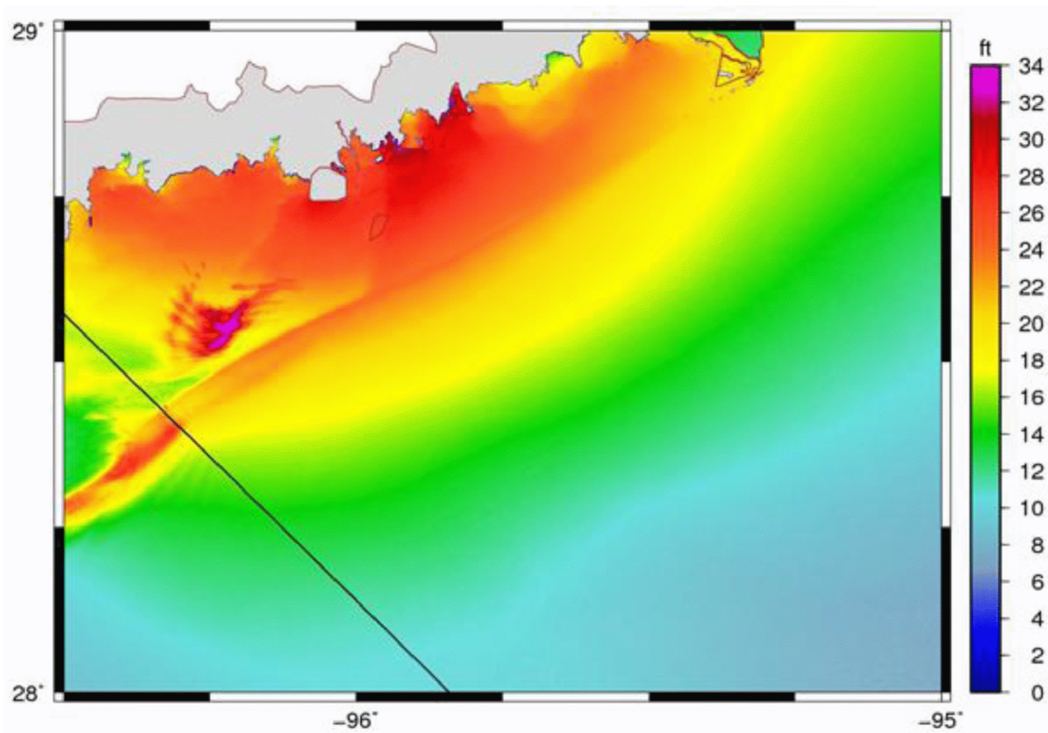

Figure 2.4S.5-10 PMSS Prediction based on the ADCIRC model