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2.4.5 Probable Maximum Surge and Seiche Flooding

The following site-specific information describes the effects of probable maximum surge and seiche flooding on the power block at the VCS site.

2.4.5.1 Probable Maximum Winds and Associated Meteorological Parameters

The probable maximum storm surge (PMSS) is defined in Subsection 2.4.5 of NUREG-0800 as the surge that results from a combination of meteorological parameters of a probable maximum hurricane (PMH), a probable maximum wind storm, or a moving squall line and has virtually no probability of being exceeded in the region involved. Based on historical tide gage records described in Subsection 2.4.5.2, it is evident that the meteorological event that would produce the PMSS along the Texas Gulf Coast near the VCS site would be a PMH. According to Subsection 2.4.5 of NUREG-0800 for sites such as VCS that are not located on the Great Lakes or any other lake, moving squall lines or the probable maximum windstorm would not produce the PMSS. The PMH is described as a hypothetical steady-state hurricane with a combination of meteorological parameters that will give the highest sustained wind speed that can probably occur at a specified coastal location (Reference 2.4.5-1). The meteorological parameters that define the PMH wind field include the hurricane peripheral pressure (p_n), central pressure (p_o), radius of maximum winds (R), forward speed (T), track direction (θ), and inflow angles of the hurricane winds (φ).

The PMH parameters at the Texas Gulf Coast near the VCS site are obtained from the National Oceanic and Atmospheric Administration (NOAA) Technical Report NWS-23 (Reference 2.4.5-1), and are summarized in Table 2.4.5-1. The PMH parameter values were established based on data from historical hurricanes from 1851-1977 and were presented for multiple locations along the Gulf and Atlantic Coast shoreline in accordance with their milepost distances from the U.S.-Mexico border. The milepost distance to the shoreline location nearest to the VCS site is estimated to be 300 nautical miles (Reference 2.4.5-1).

The pressure difference between the hurricane peripheral and central pressures, Δp, is identified as the most important meteorological parameter in defining the hurricane wind field (Reference 2.4.5-1). NOAA Technical Report NWS-23 provides single values of PMH peripheral and central pressures along the mileposts. However, a range of values (i.e., lower and upper bounds) is provided for the other PMH parameters. At milepost 300 nautical miles, the PMH peripheral and central pressures are 30.12 inches of mercury (Hg) and 26.19 inches Hg, respectively, with a Δp of 3.93 inches Hg, or 133.1 millibars. The corresponding lower and upper bounds of the radius of maximum wind are 5 and 21 nautical miles (9.3 and 38.9 km). The lower and upper bounds of the forward speed are 6 and 20 nautical miles per hour (knots) (11.1 and 37.0 km per hour). The track direction, θ, is correlated to the hurricane forward speed, and the lower and upper bounds of θ are given as 86 and 191 degrees (clockwise from the north), respectively. The inflow angle, φ, varies depending on the radius of maximum winds and the distance from the center of the PMH. At the selected milepost, φ has a range of 2 to 10 degrees at a distance from the PMH center equal to the lower and upper bounds of the radius of maximum winds, respectively (Reference 2.4.5-1).

The effect of long-term climate variability on hurricane intensity is an area of active research. Since 1977, several intense hurricanes had made landfall in the Gulf of Mexico Coast, including Hurricanes Katrina and Rita in 2005, the two most intense hurricanes in recent times. Research on the effects of El Nino/Southern Oscillation indicated that while El Nino conditions tend to suppress hurricane formation in the Atlantic Basin, La Nina conditions tend to favor hurricane development (Reference 2.4.5-2). Additionally, research in the Atlantic Multi-Decadal Oscillation (AMO), which is the variation of long-duration sea surface temperature in the North Atlantic Ocean with cool and warm phases that may last for 20 to 40 years, investigates its relation with hurricane intensity (Reference 2.4.5-2). It shows that hurricane activities increase during the warm phases of the AMO compared to hurricane activities during the AMO cool phases. Recent hurricane data indicates that Atlantic hurricane seasons have been significantly more active since 1995. However, hurricane activities during the earlier years, such as from 1945 to 1970, were apparently as active as in the recent decade (Reference 2.4.5-2). The most severe hurricane that made landfall near the VCS site shoreline is the Indianola Hurricane of August 1886, with p_o of 27.33 inches Hg, or 925 millibars, as described in Subsection 2.4.5.2.1.

The PMH p_o for the Gulf Coast near the VCS site is lower than the p_o of the most intense hurricane recorded in history. Because NOAA Technical Report NWS-23 (Reference 2.4.5-1) includes the last active hurricane period from 1945 to 1970 (and any such earlier periods from 1851) in the analysis, it is reasonable to assume that the PMH parameters thus derived are sufficiently conservative even in the considerations of future climate variability.

2.4.5.2 **Surge and Seiche Water Level**

The VCS site is located in the Guadalupe River Basin, approximately 4 miles (6.4 km) west of the Guadalupe River and approximately 36 miles (57.6 km) inland from the Texas Gulf Coast shoreline. The natural ground at the site varies in elevation from approximately 60 feet (18.3 meters) to above 80 feet (24.4 meters) in North American Vertical Datum of 1988 (NAVD 88). The minimum finished site grade of the power block is at 95.0 feet (29.0 meters) NAVD 88. The PMSS at the site is postulated to be caused by storm surges that would propagate upstream through the San Antonio-Guadalupe Bay system and the Guadalupe River from the Gulf of Mexico shoreline. Figure 2.4.5-1 shows the location of the site relative to the Texas Gulf Coast and the San Antonio-Guadalupe Bay system. Because the site is not located on an open coast or a large body of water, seiche events would not affect the site. Oscillations in the cooling basin and their impact on the power block structures, systems, and components (SSCs) are described in Subsection 2.4.8.

2.4.5.2.1 **Historical Hurricane Events and Storm Surges**

A list of hurricanes that had made landfall on the Texas Gulf Coast from 1851 to 2007 is presented in Table 2.4.5-2 (References 2.4.5-3 and 2.4.5-4). Figure 2.4.5-2 shows the tracks of all hurricanes in the Gulf of Mexico from 1851 to 2006, with intensities of Hurricane Category 3 and above in the Saffir-Simpson Hurricane Scale. Figure 2.4.5-3 shows the variation of the central pressures of the hurricanes tabulated in Table 2.4.5-2. As indicated in Table 2.4.5-2 and Figure 2.4.5-3, the August 1886 Indianola Hurricane was the most intense hurricane that affected the Texas Gulf Coast. The hurricane had made landfall on the Calhoun County, Texas coast near the VCS site as shown on Figure 2.4.5-2.

The most severe recent hurricane that made landfall near the VCS site was Hurricane Carla in September 1961. This Category 4 hurricane had landfall on the Matagorda Bay coast and resulted in a surge water level of about 16.6 feet (5.1 meters) above MSL at Port Lavaca (Reference 2.4.5-5), which is approximately 17.3 feet (5.3 meters), NAVD 88 based on the vertical datum conversion factor at Rockport, Texas (Reference 2.4.5-6). A high-water line varying from 15.7 to 22 feet (4.8 to 6.7 meters) above MSL (approximately 16.4 to 22.7 feet, or 5.0 to 6.9 meters, NAVD 88) was established from debris lines near the head of Lavaca Bay, including, probably, the effects of wave setup and run-up (Reference 2.4.5-5).

Storm surges from severe hurricanes in the Gulf of Mexico region with landfall beyond the Texas Coast, as shown on Figure 2.4.5-2, could also affect the coastal region near the VCS site. However, the impact of such hurricane surges on the VCS site would be small. The top five highest water levels observed at NOAA tide gage stations at Corpus Christi, Texas and Freeport, Texas are shown in Table 2.4.5-3. The Corpus Christi gage was established in 1983 and moved to its present location in 1989 (Reference 2.4.5-7). The Freeport gage was installed in 1954 and moved to its present location in 1995 (Reference 2.4.5-8). The table shows that the occurrences of high water levels at the stations are coincidental with known hurricane or tropical storm events in the Gulf of Mexico. The Corpus Christi and Freeport stations are located on and near the Gulf of Mexico coast, approximately 45 miles (72 km) southwest and 110 miles (176 km) northeast, respectively, from the Matagorda Island shoreline that is closest to the VCS site. The high water levels at these two stations are lower than the observed surge water level at Port Lavaca from Hurricane Carla.

2.4.5.2.2 **Storm Surge Analysis**

The maximum storm surge elevation at the VCS site is estimated based on the propagation of the PMSS through the Guadalupe River. The PMSS near the coast is predicted using the numerical simulation results of the NOAA computer model “Sea, Lake, and Overland Surges from Hurricanes” (SLOSH) (Reference 2.4.5-9). The effect of the PMSS in the Guadalupe River near the site is estimated using the U.S. Army Corps of Engineers' computer model HEC-RAS (Reference 2.4.5-10).

The SLOSH computer model was developed by the National Weather Service (NWS) to forecast real-time hurricane storm surge levels on continental shelves, across inland water bodies, along coastlines, and for inland routing of water. The SLOSH simulation is a depth-averaged, two-dimensional finite difference model on curvilinear polar grid schemes. Modification of storm surges due to overtopping of barriers, including levees, dunes, and spoil banks, and due to flow through channels and floodplains and barrier cuts/breaches, are included in the model. The effects of local bathymetry and hydrography are also included in the SLOSH simulation (Reference 2.4.5-11).

The NOAA NWS published the results of SLOSH simulation runs for different hurricane strengths and directions of movement for individual model basins (Reference 2.4.5-9). Although the VCS site is not included within any of the SLOSH basin models, the coastal region near the VCS site is included within the Matagorda Bay Texas Basin. The SLOSH model results for the Matagorda Bay Texas Basin include simulated storm surge levels for Hurricane Categories 1 to 5 in the Saffir-Simpson hurricane scale. The Saffir-Simpson scale is summarized in Table 2.4.5-4 (Reference 2.4.5-3).

For each of the five hurricane categories, the SLOSH model simulated many different hurricane sizes, forward speeds, and track directions. At the end of each computer simulation, an envelope of water levels was generated that contains the highest surge level at each grid cell in the basin model for the simulation period. The generated envelopes from the simulations are then combined to obtain two different water level composites at each grid cell. The first composite is called the maximum envelope of water (MEOW), which is the maximum storm surge level at a grid cell for a particular hurricane category, forward speed, and track direction. The second composite is the maximum of MEOWs, or MOM, which combines all the MEOWs at a grid cell and provides the maximum storm surge level for a hurricane category.

The SLOSH model predictions have been validated against measured hurricane surge data at several locations (References 2.4.5-11 and 2.4.5-12). The errors of the SLOSH model predictions, defined as the difference between model predictions and observed surge water levels, were evaluated for 10 storms in eight SLOSH model basins (Reference 2.4.5-12). Based on a comparison of the SLOSH results against 523 observations, 90 percent of which were for hurricanes that made landfall within the Gulf of Mexico, a mean error of –0.3 feet (–0.09 meters) was reported. The range of errors is from –7.1 feet (–2.16 meters) to 8.8 feet (2.68 meters) with a standard deviation of 2.0 feet (0.61 meters) (Reference 2.4.5-12). The observed maximum surge height at Freeport during Hurricane Carla was approximately 11 feet or 3.4 meters, in mean low water datum (MLW) (11.4 feet or 3.5 meters, NAVD 88) (Reference 2.4.5-11). The difference between model predicted and observed maximum surge heights at Freeport, Texas during Hurricane Carla remains within the standard deviation of the prediction error.

SLOSH simulation results indicate that the Matagorda Island near the San Antonio Bay area would be flooded by storm surges from hurricanes of Category 2 and above (Reference 2.4.5-9). The location of the island can be seen on Figure 2.4.5-1. Storm surges overtopping this barrier island are postulated to propagate northwest ward through the San Antonio-Guadalupe Bay system and up the Guadalupe River in the direction of VCS. The maximum storm surge height at the VCS site is simulated using the HEC-RAS model (Reference 2.4.5-10). The downstream boundary of the one-dimensional HEC-RAS model is selected near the United States Geological Survey (USGS) stream gaging station near Tivoli, Texas.

The PMSS near the Tivoli gage derived from the SLOSH model results of the Matagorda Bay Texas Basin at grid cell (43, 4), before accounting for wave effect, is used as the downstream boundary condition in the HEC-RAS steady-state flow routing model. The Tivoli gage station is near the Guadalupe-Blanco River Authority (GBRA) Saltwater Barrier and Diversion Dam, an inflatable dam, that operates based on upstream and downstream water levels in the river to prevent saltwater intrusion up the Guadalupe River (Reference 2.4.5-13).

Because the PMH event is more severe than a Category 5 hurricane, PMH surge level at a model grid cell is projected from the SLOSH model results for Categories 1 to 5 using an extrapolation approach. The extrapolation considers the effects of the important parameters that characterize the PMH.

Projection of SLOSH Results

The projections of the storm surge levels for the PMH condition are conducted at two coastal locations near the VCS site, as shown in Figure 2.4.5-4. Figure 2.4.5-4 also shows the extent of the Matagorda Bay Texas SLOSH model basin. The first location for the PMH surge level projection is on Matagorda Island near the Texas Gulf Coast shoreline at SLOSH model grid cell (50, 19), near 28.2076° N, 96.6485° W. The second location is near the Tivoli gage on the Guadalupe River at SLOSH grid cell (43, 4), near 28.5058° N, 96.8843° W. The model grid cells for the two locations were predicted to be dry during Category 1 hurricanes, while the cells were shown to be inundated for hurricanes of Category 2 and above. The MOMs obtained from the SLOSH model include an initial tide elevation of 2.0 feet (0.61 meters) above the National Geodetic Vertical Datum of 1929 (NGVD 29) (Reference 2.4.5-9). The storm surge elevations corresponding to the MOMs at the two locations are presented in Table 2.4.5-5. Table 2.4.5-5 also shows the hurricane track direction and forward speed that produced the MOM for each hurricane category. Additionally, the magnitudes of Δp for different hurricane categories, as used in the SLOSH model, are shown in the table.

The vertical elevations in the SLOSH model simulations are referenced to NGVD 29. The predicted PMSS elevations at the two grid cells are converted to NAVD 88 elevations to be consistent with the VCS plant datum and the geometric input data of HEC-RAS model.

For the SLOSH grid cell (50, 19) along the Matagorda Island shoreline, the MOM surge elevations are due to hurricanes moving in the westerly direction with a forward speed of 15 knots (27.8 km per hour). For the grid cell (43, 4) near Tivoli, however, the MOM surge elevations for different hurricane categories are due to hurricane directions ranging between northwest and west-northwest, and with forward speeds varying from 5 to 15 knots (9.3 to 27.8 km per hour). This variation in the MOM surge elevations for different locations within the model basin indicates that the maximum surge elevation at any particular location is dependent on a combination of input hurricane parameters that may not be the same for all locations.

The input hurricane parameters to the SLOSH model are the hurricane central pressure difference Δp, hurricane size (given as the radius of maximum wind), track direction, and forward speed. Based on the input parameters, the wind speeds and inflow angles are computed within the model by applying the principles of force balance (Reference 2.4.5-11). For each basin, the SLOSH model is run for a particular track direction with various landfall locations and storm sizes while keeping all other parameters unchanged. The MEOW is then computed for the set of model runs. Consequently, the MEOWs would only be dependent on the track direction and forward speed for a hurricane category.

The hurricane category in the SLOSH model is specified based on the input Δp, which is also indicated to be the most important hurricane parameter (Reference 2.4.5-11). A correlation of the surge elevations with Δp for different hurricane categories is first developed to form the basis for the extrapolation of the surge elevations for the PMH condition. Figure 2.4.5-5 shows both a linear fit and a second-order-polynomial fit of the surge levels predicted by SLOSH at grid cell (50, 19). The second-order-polynomial fit provides a perfect fit of surge water level against Δp (with mean-square error, R^2, of 1). The linear relationship also provides a good fit with a R^2 of 0.9997, and the projected PMH surge water level is higher than that from the polynomial fit. Therefore, the linear correlation between the surge elevations and Δp is selected for the PMH surge elevation projection, as shown on Figure 2.4.5-5.

The effect of hurricane forward speed on surge elevations is established separately. The SLOSH model results (MEOWs) are available for two hurricane forward speeds, 5 knots and 15 knots (9.3 and 27.8 km per hour). The model results indicate that the surge elevations increase with faster hurricane forward speeds. Therefore, it is assumed that the PMH upper bound forward speed (20 knots or 37 km per hour) would result in the highest storm surge elevation. The increase in surge elevation due to the faster forward speed of the PMH is also estimated using a linear relationship between surge levels and hurricane forward speeds from the SLOSH model results, as shown on Figure 2.4.5-6. Combining the two contributions, the PMH surge elevation at grid cell (50, 19) on the Matagorda Island shoreline is estimated to be about 23.0 feet (7.0 meters) NGVD 29.

A similar approach is adopted at SLOSH grid cell (43, 4) near Tivoli. At this location, the MOM surge elevations for Hurricane Categories 2 and 3 result from a hurricane forward speed of 5 knots (9.3 km per hour). The hurricane track direction also changes for different hurricane categories. For Category 5 hurricanes, the highest surge elevation was predicted when the hurricane moves towards the west-northwest direction and with a forward speed of 15 knots (27.8 km per hour). Figure 2.4.5-7 shows the correlation of MOM surge elevations with Δp for different hurricane categories at this location. A linear extrapolation also results in a higher surge elevation for the PMH condition, compared to that from the second-order-polynomial fit. Because the PMH intensity at this location is greater than the intensity of the Category 5 hurricane, it is postulated that the maximum storm surge due to the PMH would also be moving towards west-northwest. Accordingly, the effect of change in hurricane forward speed is estimated based on the west-northwest hurricane track direction. The adjustment due to the change in the PMH forward speed is shown in Figure 2.4.5-8. The PMH surge elevation at this location including the forward speed adjustment is estimated to be approximately 42.8 feet (13.0 meters) NGVD 29.

The Probable Maximum Storm Surge Elevation near the Coast

The predicted storm surge elevations corresponding to the PMH at the Matagorda Island shoreline and near Tivoli include pressure and wind setup, and an initial tide elevation of 2 feet (0.61 meters) NGVD 29. The surge elevations need to be adjusted for the appropriate antecedent water level in the bay to obtain the PMSS levels at the two locations. The adjustment is made by subtracting the initial tide level (2 feet or 0.61 meters, NGVD 29) from the surge elevation and then adding the antecedent water level at the Texas Gulf Coast shoreline. According to RG 1.59, the 10 percent exceedance high spring tide including initial rise should be used to represent the antecedent water level. The 10 percent exceedance high spring tide is defined as the high tide level that is equaled or exceeded by 10 percent of the maximum monthly tides over a continuous 21-year period (Reference 2.4.5-14). For locations where the 10 percent exceedance high spring tide is estimated from observed tide data, a separate estimate of initial rise (or sea level anomaly) is not necessary (Reference 2.4.5-14).

The 10 percent exceedance high spring tide at the Matagorda Island shoreline near the VCS site is estimated to be about 3.4 feet (1.04 meters) NGVD 29. It is the average of the 10 percent exceedance high spring tides of 3.6 feet (1.10 meters) NGVD 29 and 3.2 feet (0.98 meters) NGVD 29, derived from the observed tide data at the NOAA tide gage stations at Freeport, Texas (Reference 2.4.5-8) and Corpus Christi, Texas (Reference 2.4.5-7).

In addition to the 10 percent exceedance high spring tide, the effect of long-term sea level rise is also considered in obtaining the antecedent water level for the PMSS. The locations closest to the site that have long-term sea level rise data available are Freeport, Texas at 1.93 feet (0.6 meters) per century (Reference 2.4.5-8), and Rockport, Texas at 1.51 feet (0.5 meters) per century (Reference 2.4.5-6). Assuming that the sea level in the region would continue to rise at the same rate in the next century, a sea level rise of 1.8 feet (0.55 meters) is postulated for the Matagorda Island shoreline near the VCS site.

The PMSS elevations at the two locations, on the Matagorda Island shoreline and near Tivoli, are obtained by first subtracting the SLOSH model initial tide level from the extrapolated surge elevations and then combining with the antecedent water level for the PMH surge including the 10 percent exceedance high tide and long-term sea level rise. The PMSS elevation at the Matagorda Island shoreline is about ([23.0 – 2.0] feet + 3.4 feet NGVD 29 + 1.8 feet =) 26.2 feet (8.0 meters) NGVD 29. At the SLOSH grid cell (43, 4) near Tivoli, the PMSS elevation is obtained as about ([42.8 – 2.0] feet + 3.4 feet NGVD29 + 1.8 feet =) 46.0 feet (14.0 meters) NGVD 29. Using the datum conversion relations at the Matagorda Island shoreline and near Tivoli, the PMSS elevations are converted to about 25.8 feet (7.9 meters) NAVD 88 and 45.6 feet (13.9 meters) NAVD 88, respectively.

The 10 percent exceedance high spring tide of 3.4 feet (1.04 meters) NGVD 29, calculated based on the tidal records of the Freeport gage and the Corpus Christi gage, is conservatively applied to the location near the Tivoli gage. Located approximately 24.5 miles (39.2 km) inland from the Gulf, the Tivoli gage location is expected to have a smaller tidal range. This can be construed from the small average tidal range of 0.3 feet (0.09 meters) in the San Antonio Bay (Reference 2.4.5-15), which is sheltered by the Matagorda Island barrier island. In comparison, the mean range of tide is 1.41 feet (0.43 meters) at the Freeport gage (Reference 2.4.5-8) and 1.31 feet (0.4 meters) at the Corpus Christi gage (Reference 2.4.5-7). Because the SLOSH model was set up to have an initial tide level (2 feet or 0.61 meters, NGVD 29) uniformly assigned to the entire model basin, applying the antecedent water level at the Matagorda Island shoreline location to grid cell (43, 4) near Tivoli is appropriate and conservative.

RG 1.59 provides estimates of the PMSS along the U.S. Gulf and Atlantic Coasts. The locations closest to and on either side of the Matagorda Island shoreline near the VCS site where PMSS water levels are available from RG 1.59 are Port Isabel, Texas and Freeport, Texas. The PMSS elevations at these locations are 17.84 feet (5.44 meters) above MLW and 23.48 feet (7.16 meters) MLW, respectively. It is assumed that the corresponding surge water level at the Matagorda Island shoreline is the same as the surge water level at Freeport, that is, 23.48 feet (7.16 meters) MLW or 23.88 feet (7.28 meters) NAVD 88. Combining this surge water level with the postulated long-term sea level rise, the PMSS elevation at the Matagorda Island shoreline can be obtained as about (23.88 feet NAVD 88 + 1.8 feet =) 25.68 feet (7.83 meters) NAVD 88. The predicted PMH surge water level projected based on the SLOSH model results is higher, and therefore more conservative, than the PMSS water level obtained from RG 1.59.

Storm Surge Elevation in the Guadalupe River near the VCS Site

The HEC-RAS hydraulic model of the Guadalupe River, as described in Subsection 2.4.4, provides the basis for the backwater calculation into the Guadalupe River due to the PMSS. The river reach from Victoria, Texas to near Tivoli, Texas, with a length of about 44 river miles (RM), is modeled in HEC-RAS to calculate the hurricane induced flood level near the VCS site.

The predicted PMSS elevation at grid cell (43, 4) near Tivoli, Texas, with the 10 percent exceedance high spring tide and long-term sea level rise as the antecedent water level, is specified as the downstream boundary condition in the HEC-RAS model. The downstream boundary (at RM 11.1811) is located approximately 4 miles (6.4 km) downstream of the confluence of the Guadalupe and San Antonio Rivers. In simulating the flood level at the site, the PMSS is combined with the maximum recorded peak flood flows in the Guadalupe and San Antonio Rivers, and in Coleto Creek. The stream flow records are available at Victoria, Texas for the Guadalupe River; at Goliad, Texas for the San Antonio River; and near Victoria, Texas for Coleto Creek. The historical peak stream flows at these locations are given in the USGS National Water Information System database as 466,000, 138,000, and 236,000 cubic feet per second (13,196, 3908, 6683 cubic meters per second), respectively (References 2.4.5-16, 2.4.5-17, and 2.4.5-18). The combined recorded peak stream flow from the Guadalupe River and Coleto Creek of 702,000 cubic feet per second (19,878 cubic meters per second) is greater than one-half of the probable maximum flood (PMF) flow in the Guadalupe River near the site. The PMF peak flow near the VCS site is predicted to be about 1,123,300 cubic feet per second (31,808 cubic meters per second), as described in Subsection 2.4.3. Flood frequency in the Guadalupe River at the confluence with Coleto Creek is presented in Table 2.4.1-7. As can be postulated from Table 2.4.1-7, one-half of the PMF peak flow at the site would be higher than the peak discharges of all return periods up to 500 years near the site.

In the HEC-RAS model, the historical peak flow in the Guadalupe River at the Victoria gage is specified as a constant inflow at the upstream-most boundary (at RM 56.1333 upstream of the Texas Route 59 crossing). The model inflow from Coleto Creek and San Antonio River is approximated by the observed historical peak streamflows at the Coleto Creek near Victoria gage and at the San Antonio River at Goliad gage.

The river cross sections in the model reach are obtained from the USGS National Elevation Dataset (Reference 2.4.5-19). The locations of the channel cross sections represented in the HEC-RAS model are shown on Figure 2.4.5-9. The cross sections are generally extended beyond the floodplains to higher elevations. Near the downstream boundary, the river cross sections are completely flooded by the combined PMSS and river floods. The flood flows in such cases are conservatively assumed to be bounded within the river cross sections. Similar to the roughness values used in Subsection 2.4.3 and 2.4.4, a uniform Manning's roughness coefficient, n, of 0.1 is used to represent the friction loss of all channel reaches, including the floodplains. The longitudinal water surface profile as obtained from the HEC-RAS model is presented on Figure 2.4.5-10. The water surface elevation at the cross section RM 29.5984 obtained from the HEC-RAS model is 48.3 feet (14.7 meters) NAVD 88. The cross section RM 29.5984 is located nearest to the power block of the VCS site. The obtained PMSS flood elevation, which includes the effects of the PMH and coincident river flood flow, remains below the minimum finished site grade of 95 feet (29.0 meters) NAVD 88 of the power block.

According to ANSI/ANS-2.8-1992 (Reference 2.4.5-14), four alternatives of combined events should be considered for design basis flood evaluations for streamside reactor locations:

1. One-half PMF or 500-year return period flood, whichever is less, combined with surge or seiche from the worst regional hurricane, 10 percent exceedance high tide, and wind-wave activity
2. PMF combined with 25-year return period surge or seiche with 10 percent exceedance high tide and wind-wave activity
3. 25-year return period flood combined with the PMSS with 10 percent high tide and wind-wave activity
4. PMF combined with PMH and 10 percent exceedance high tide for drainage areas less than 300 square miles (768 square km)

As described above, the PMSS still water level at the VCS site is postulated based on the surge level resulting from the PMH event, coincidental with the historical flood peaks from the Guadalupe River, the San Antonio River, and the Coleto Creek, and includes a conservative estimate of the 10 percent exceedance high tide. This selected scenario of combined events provides a more conservative flood level at the site than Alternatives 1 and 3.

Regarding Alternative 2, a review of the historical hurricane data from Table 2.4.5-2 indicates that a 25-year return period hurricane would be less severe than a Category 4 hurricane like Hurricane Carla. The analysis of flood elevation for the PMF event in the Guadalupe River shows that the normal water depth during PMF condition at cross section RM 7.2467, about 4 miles (6.4 km) downstream of the PMSS HEC-RAS model boundary, is approximately 28.9 feet (8.8 meters) NAVD 88. This is higher than the documented high-water line of 22.7 feet (6.9 meters) NAVD 88 near the head of Lavaca Bay during Hurricane Carla, as described in Subsection 2.4.5.2.1. Therefore, during a PMF event, the flood levels on the Guadalupe River upstream of cross section RM 7.2467 would not be controlled by the potential storm surge resulting from a 25-year return period hurricane. The PMF flood level of 44.6 feet (13.6 meters) NAVD 88 predicted at the VCS site, as described in Subsection 2.4.3, is lower than the postulated PMSS still water level of 48.3 feet (14.7 meters) NAVD

88. The selected scenario of combined events, therefore, produces a more conservative flood level at the site than Alternative 2.

The last alternative is not applicable to the VCS site, as the Guadalupe River basin at the site is larger than 300 square miles (768 square km).

Seiches

The VCS site is located approximately 4 miles (6.4 km) west of the Guadalupe River and approximately 36 miles (57.6 km) from the Gulf of Mexico shoreline. Although seismic seiches are observed in the Gulf of Mexico and within the barrier islands along the Gulf coast, as described in Subsection 2.4.6, the seiche magnitudes are too small to affect the power block, which has a minimum finished site grade elevation of 95 feet (29.0 meters) NAVD 88. Therefore, flooding of the site due to seiches in the Guadalupe River or Gulf of Mexico is precluded. The effects of seiches in the cooling basin are described in Subsection 2.4.8.

2.4.5.3 **Wave Actions**

The effect of PMH wind field on the PMSS still water level near the VCS site is investigated to estimate the PMH-induced waves, setup, and run-up. The maximum sustained wind speed at the VCS site is calculated based on the procedures described in the NOAA Technical Report NWS-23 (Reference 2.4.5-1). The steps followed in establishing the maximum wind speed are described below. First, the maximum gradient wind speed for a stationary PMH is calculated using the PMH parameters. Second, the maximum 10-minute average 32.8 foot (10 meters) high over water wind speed for a moving PMH is estimated based on the range of PMH forward speeds and inflow angles. The maximum surface wind vector is assumed to be parallel to the hurricane track to maximize the wind speed. Lastly, the surface frictional effects and overland filling of the PMH after landfall are included to obtain the PMH maximum wind speed at the site. The last step also considers that the PMH track is directed towards northwest and the PMH center is located at a distance equal to the radius of maximum wind to maximize the wind speed at the site. Additionally, a wind speed correction factor of 0.78 is applied as recommended in NWS-23 (Reference 2.4.5-1). The maximum PMH wind speed thus obtained at the VCS site is 105.5 knots (196 km per hour), which is then used to calculate the coincidental wind wave activities.

The wind setup within the Guadalupe River is calculated considering a one-dimensional schematization across the river (Reference 2.4.5-20). Based on the topography of the river reach near the site, the PMH maximum wind is postulated to act from the east bank near cross section RM 17.6457 to the west bank near cross section RM 29.5984. Based on the distance between the two cross sections and the width of the river, a fetch length of approximately 9 miles (14.4 km) is estimated that would produce a wind setup of about 4.0 feet (1.2 meters) near the site (RM 29.5984).

The maximum still water depth of 38.3 feet (11.7 meters) at RM 29.5984, as obtained from the HEC-RAS simulation, is used in estimating the wind setup.

Considering the maximum still water depth in the Guadalupe River at RM 29.5984, it is conservatively assumed that wave run-up on the west bank would be controlled by the breaking wave height. By definition, the breaking wave height represents the limiting wave condition beyond which waveforms cannot be sustained. Consequently, the significant and 1 percent wave heights are bounded by the breaking wave condition and are not presented separately. Following the procedures given in the Coastal Engineering Manual of the U.S. Army Corps of Engineers (Reference 2.4.5-21), breaking wave height and wave run-up near the VCS site are calculated as 29.9 feet (9.1 meters) and 17.3 feet (5.3 meters), respectively. The riverbank slope used for estimating wave run-up is approximately 1/25 and is obtained from HEC-RAS channel cross section at RM 29.5984. The surf similarity parameter is calculated using deepwater wave parameters, which are obtained based on the consideration of breaking wave at the riverbank. Combining the PMSS still water level in the Guadalupe River at RM 29.5984 (48.3 feet or 14.7 meters NAVD 88, wind setup (4.0 feet or 1.2 meters), and wave run-up (17.3 feet or 5.3 meters), the maximum water level near the VCS site is obtained as 69.6 feet (21.2 meters) NAVD 88.

2.4.5.4 **Resonance**

Except for the cooling basin, the site is not located near a semi-enclosed or large body of water. Atmospheric or other seiches are, therefore, unlikely to cause flooding of the power block structures at the site. However, a natural period of oscillation (Reference 2.4.5-20) can be estimated by hypothetically assuming that the Guadalupe River were an enclosed water body with a width equal to the top water surface width of the river and a depth equal to the PMSS maximum water depth at RM 29.5984 as obtained from the HEC-RAS simulation. The natural period of oscillation, estimated to be approximately 10.5 minutes, is greater than the limiting shallow water wind-wave period of about 10.7 seconds near the VCS site and much smaller than the periods of hurricane surge waves, which are expected to be on the order of several hours or more. Because of the large differences between the period of natural oscillation across the Guadalupe River section and the period of wind waves and hurricane surges, resonance or seiche effects from the Guadalupe River would not impact the power block structures at VCS.

2.4.5.5 **Protective Structures**

The PMSS flood level in the Guadalupe River near the VCS site, along with coincidental wind setup and wave run-up, is conservatively estimated to be about 69.6 feet (21.2 meters) NAVD 88. This estimated maximum PMH-induced water level is much lower than the minimum finished site grade of 95 feet (29.0 meters) NAVD 88 of the power block. Therefore, the postulated PMH event would not impact the safety functions at the site. Because the maximum PMH-induced water level would be much lower than the minimum finished site grade of the power block, debris, waterborne projectiles, sediment erosion, and deposition would not be of concern to the SSCs of VCS. Further discussion on flood protection measures is provided in Subsection 2.4.10.

2.4.5.6 References

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Table 2.4.5-1
Probable Maximum Hurricane Characteristics

Hurricane Parameter	Magnitude
Peripheral Pressure (p_n)	30.12 inch mercury
Central Pressure (p_o)	26.19 inch mercury
Radius of Maximum Winds (R)	5 to 21 nautical miles
Forward Speed (T)	6 to 20 knots
Track Direction (θ)	86 to 191 degrees (clockwise from north)
Inflow angle (φ)	2 to 10 degrees (at a distance R from the hurricane center)

Source: (Reference 2.4.5-1)

Table 2.4.5-2 (Sheet 1 of 2)
Summary of Historical Hurricane Events in the Texas Gulf Coast

Serial Number	Date[(a)] (month & year)	Hurricane Name[(b)]	Saffir-Simpson Hurricane Category at Landfall[(c)]	Central Pressure at Landfall[(d)] (millibars)	Maximum Winds[(e)] (knots)
1	June 1851		1	977	80
2	June 1854		1	985	70
3	September 1854	Matagorda	2	969	90
4	September 1865	Sabine River — Lake Calcasieu	2	969	90
5	July 1866		2	969	90
6	October 1867	Galveston	2	969	90
7	August 1869	Lower Texas Coast	2	969	90
8	September 1875		3	960	100
9	August 1879		2	964	90
10	August 1880		3	931	110
11	September 1882		2	969	90
12	June 1886		2	973	85
13	August 1886	Indianola	4	925	135
14	September 1886		1	973	80
15	October 1886		3	955	105
16	September 1887		2	973	85
17	June 1888		1	985	70
18	July 1891		1	977	80
19	August 1895		1	973	65
20	September 1897		1	981	75
21	September 1900	Galveston	4	936	125
22	June 1900		2	972	85
23	July 1900	Valesco	3	959	100
24	August 1900		1	955	65
25	September 1910		2	965	95
26	October 1912		2	973	85
27	July 1913		1	988	65
28	August 1915	Galveston	4	945	
29	August 1916		3	948	
30	September 1919		4	927	
31	June 1921		2	979	
32	June 1929		1	982	
33	August 1932	Freeport	4	941	
34	August 1933		2	975	
35	September 1933		3	949	
36	July 1934		2	975	
37	June 1936		1	987	
38	August 1940		2	972	
39	September 1941		3	958	
40	August 1942		1	992	

Table 2.4.5-2 (Sheet 2 of 2)
Summary of Historical Hurricane Events in the Texas Gulf Coast

Serial Number	Date[a] (month & year)	Hurricane Name[b]	Saffir-Simpson Hurricane Category at Landfall[c]	Central Pressure at Landfall[d] (millibars)	Maximum Winds[e] (knots)
41	August 1942		3	950	
42	July 1943		2	969	
43	August 1945		2	967	
44	August 1947		1	992	
45	October 1949		2	972	
46	June 1957	Audrey	4	945	
47	July 1959	Debra	1	984	
48	September 1961	Carla	4	931	
49	September 1963	Cindy	1	996	
50	September 1967	Beulah	3	950	
51	August 1970	Calia	3	945	
52	September 1971	Fern	1	979	
53	August 1980	Allen	3	945	100
54	August 1983	Alicia	3	962	100
55	June 1986	Bonnie	1	990	75
56	August 1989	Chantal	1	986	70
57	October 1989	Jerry	1	983	75
58	August 1999	Bret	3	951	100
59	July 2003	Claudette	1	979	80
60	September 2005	Rita	3	937	100
61	September 2007	Humberto	1	985	80

(a) Some hurricanes made landfall over Mexico, but also caused sustained hurricane force surface winds in Texas.
(b) Hurricane names are formally maintained from 1957.
(c) The highest Saffir-Simpson Hurricane Scale impact in the United States based on estimated maximum sustained surface winds produced at the coast.
(d) The observed (or analyzed by NOAA from peripheral pressure measurements) central pressure of the hurricane at landfall.
(e) Estimated maximum sustained (1 minute) surface (at 32.8 feet or 10 meters) winds to occur along the U.S. Coast. Winds are estimated to the nearest 10 knots for the period of 1851 to 1885 and to the nearest 5 knots for the period of 1886 to date.

Source: References 2.4.5-3 and 2.4.5-4

Table 2.4.5-3
Recorded Maximum Water Surface Elevations at Corpus Christi, Texas and Freeport, Texas Tide Gage Stations

	Corpus Christi, Texas				Freeport, Texas			
		Water Level				Water Level		
Rank	Date	Stn. Datum[a] (feet)	NAVD 88[b] (feet)	Coincident Hurricane[c]	Date	Stn. Datum[a] (feet)	NAVD 88[b] (feet)	Coincident Hurricane[c]
1	19980910 10:00	25.80	4.51	Tropical Storm Frances	20030715 12:00	10.76	6.85	Hurricane Claudette
2	20050924 04:30	25.73	4.44	Hurricane Rita	19980911 02:42	9.95	6.04	Tropical Storm Frances
3	19980911 00:00	25.60	4.31	Tropical Storm Frances	19980910 10:42	9.27	5.36	Tropical Storm Frances
4	19980909 23:54	25.57	4.28	Tropical Storm Frances	19800809 00:00	9.00	5.09	Hurricane Allen
5	19880916 18:18	25.52	4.23	Hurricane Gilbert	19710910 00:00	8.59	4.68	Hurricane Edith

(a) In Station Datum

(b) NAVD 88 Datum at Corpus Christi, Texas is 21.29 feet above the station datum. NAVD 88 Datum at Freeport, Texas is approximately 3.91 feet above the station datum.

(c) Coincident hurricanes are identified from NOAA historical hurricane database

Source: References 2.4.5-4, 2.4.5-7, and 2.4.5-8

Table 2.4.5-4
The Saffir-Simpson Hurricane Scale

Hurricane Category	Wind Speed (mph)	Hurricane Properties: Central Pressure (millibars)	Surge Height (feet)	Damage
1	74–95	>979	4–5	Minimal
2	96–110	965–979	6–8	Moderate
3	111–130	945–964	9–12	Extensive
4	131–155	920–944	13–18	Extreme
5	>155	<920	>18	Catastrophic

Source: Reference 2.4.5-3

Table 2.4.5-5
MOM Storm Surge Elevation at the SLOSH Matagorda, Texas Basin Model Grid Cell (50, 19) on the Matagorda Island Shoreline and Grid Cell (43, 4) near Tivoli, Texas for Different Hurricane Categories

Hurricane Category	Pressure Difference, Δp (millibars)	MOM Surge Elevation at Grid Cell (50, 19)			MOM Surge Elevation at Grid Cell (43, 4)		
		Direction[(a)]	FS[(b)] (knots)	Surge Elevation[(c)] (feet NGVD29)	Direction[(a)]	FS[(b)] (knots)	Surge Elevation[(c)] (feet NGVD29)
1	20			Dry			Dry
2	40	W	15	7.9	NW	5	9.7
3	60	W	15	10.9	NW	5	17.0
4	80	W	15	13.9	NW	15	23.1
5	100	W	15	16.7	WNW	15	28.6

(a) Hurricane track direction
(b) Hurricane forward speed
(c) Storm surge elevation as obtained from SLOSH model results
Source: Reference 2.4.5-9

Figure 2.4.5-1 Location Map of the VCS Site and Surrounding Water Bodies

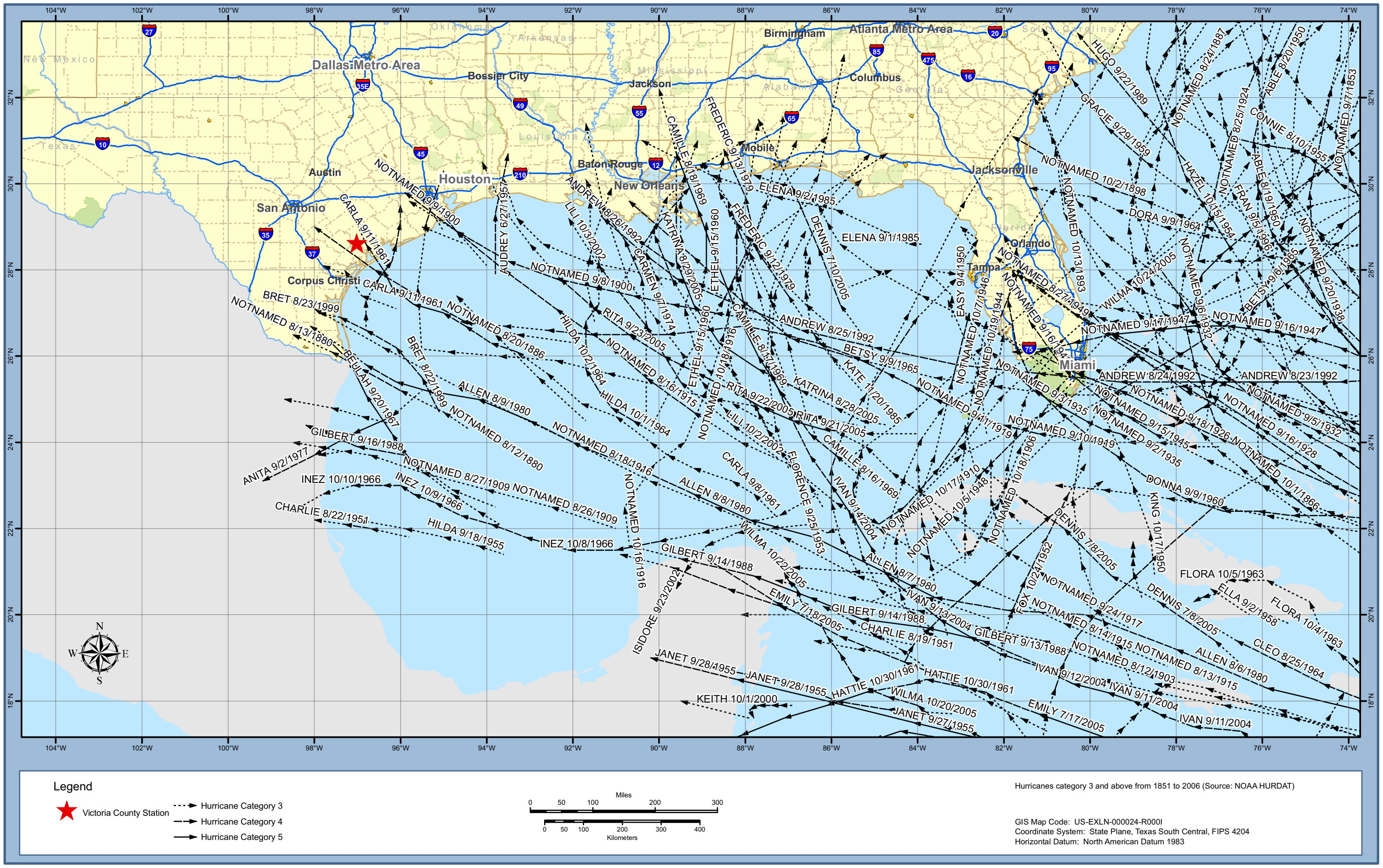

Figure 2.4.5-2 Tracks of Hurricanes with Intensity Category 3 and Above in Saffir-Simpson Hurricane Scale Affecting the Gulf of Mexico Region (Reference 2.4.5-22)

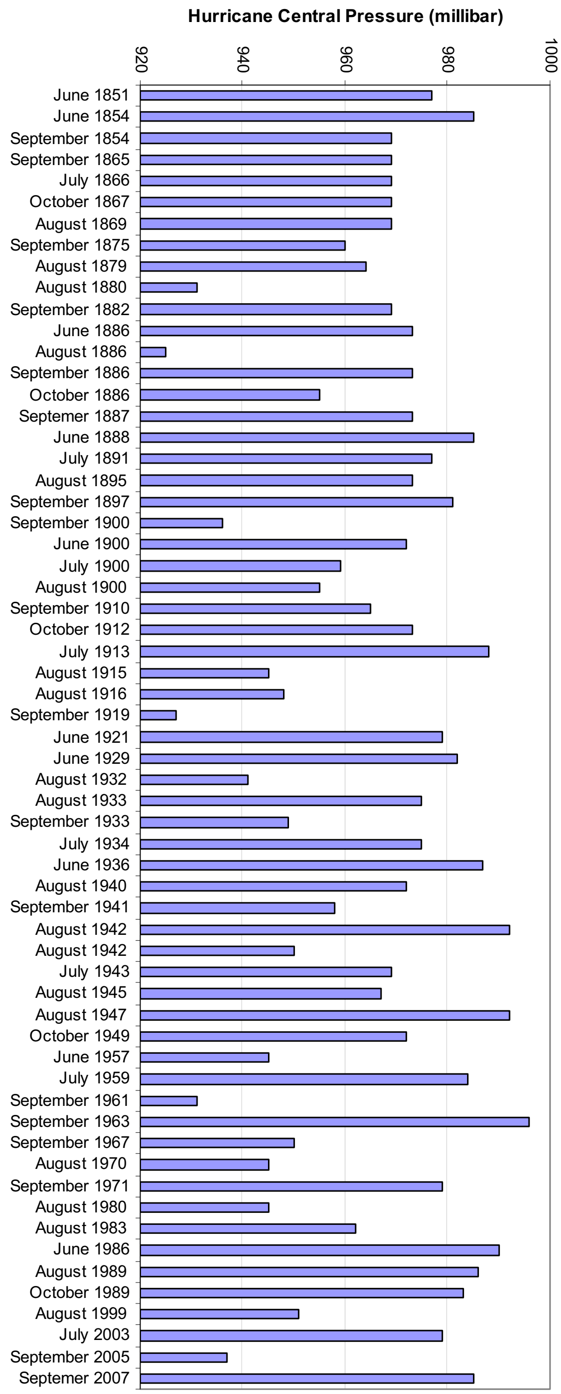

Figure 2.4.5-3 Distribution of Hurricane Central Pressure at Landfall for Hurricanes that Made Landfall on the Texas Gulf Coast (References 2.4.5-3 and 2.4.5-4)

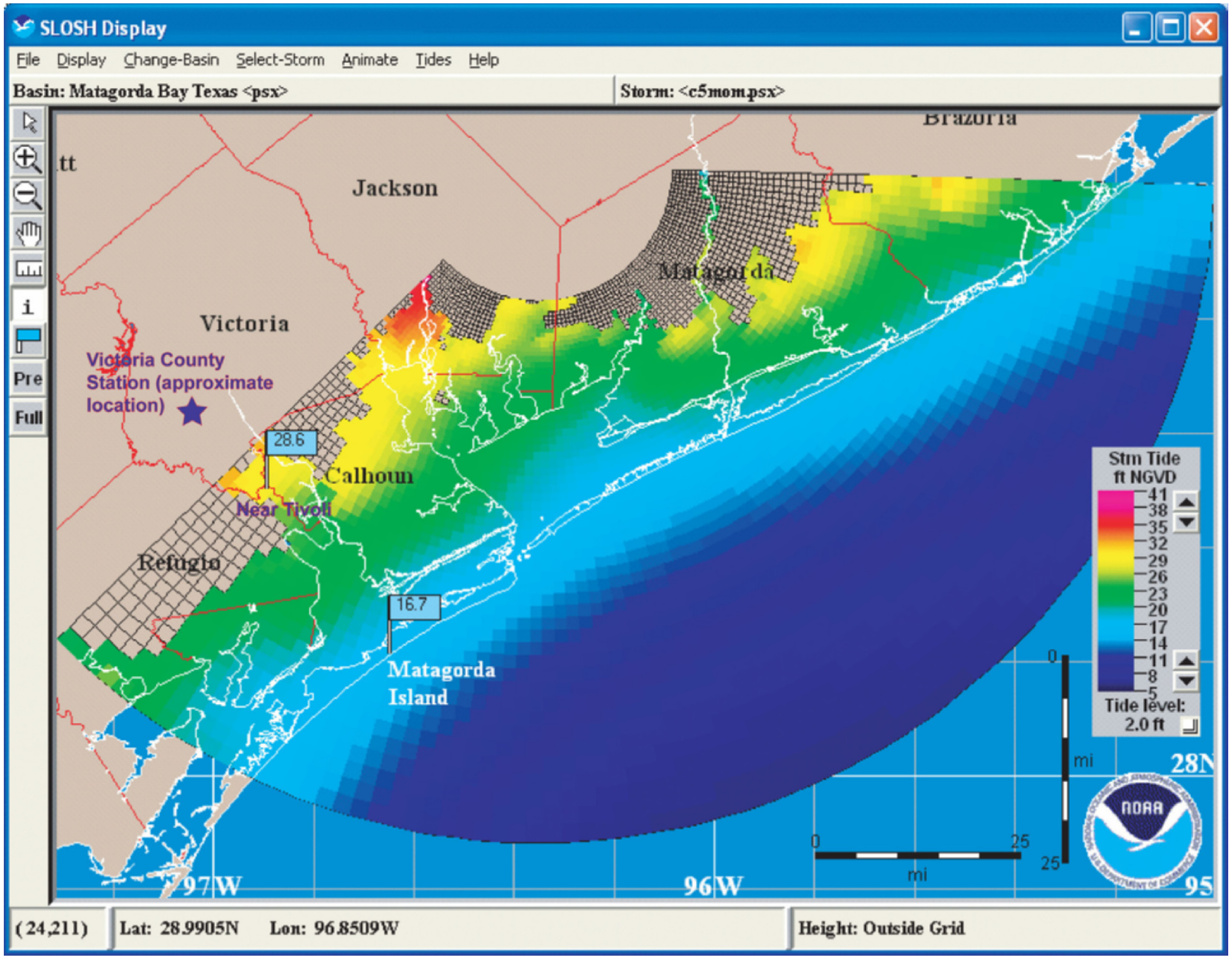

Figure 2.4.5-4 The SLOSH Matagorda, Texas Basin Model Showing the Grid Cells on the Matagorda Island Shoreline (50, 19) and near Tivoli, Texas (43, 4) (Reference 2.4.5-9)

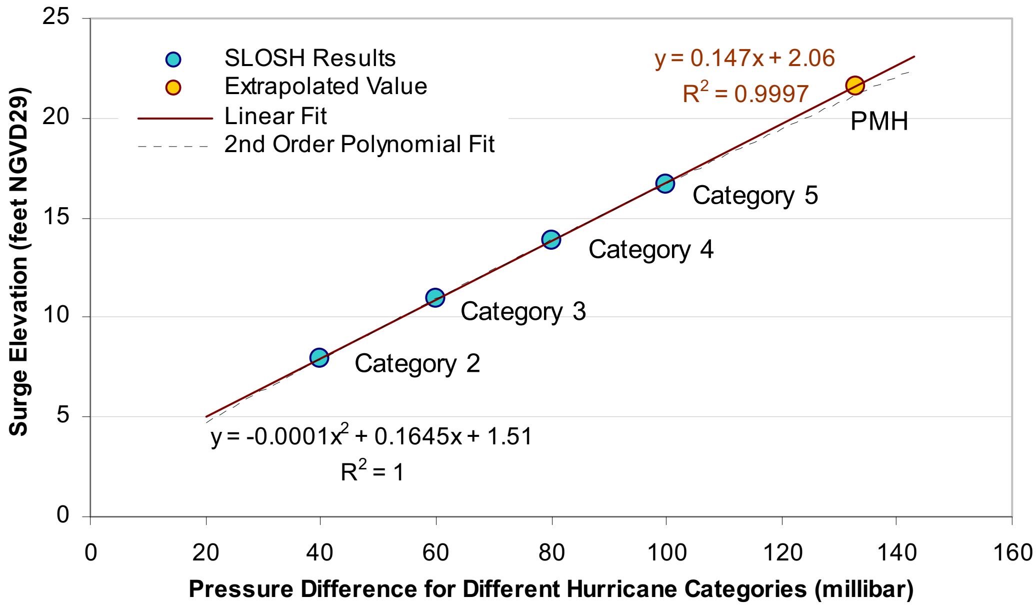

Figure 2.4.5-5 Projection of Surge Elevation from the SLOSH Model Results to PMH Pressure Difference for SLOSH Matagorda, Texas Basin Model Grid Cell (50, 19) (Reference 2.4.5-9)

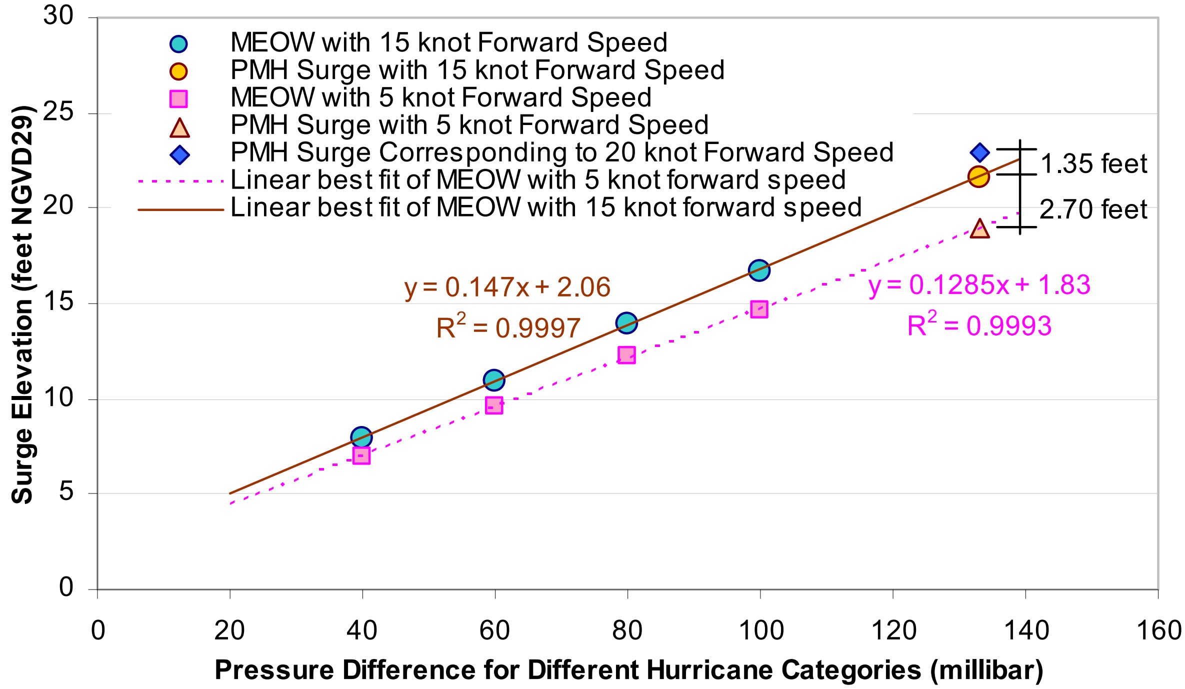

Figure 2.4.5-6 Adjustment to the Projected PMH Surge Elevation due to PMH Forward Speed of 20 knots for SLOSH Matagorda, Texas Basin Model Grid Cell (50, 19) (Reference 2.4.5-9)

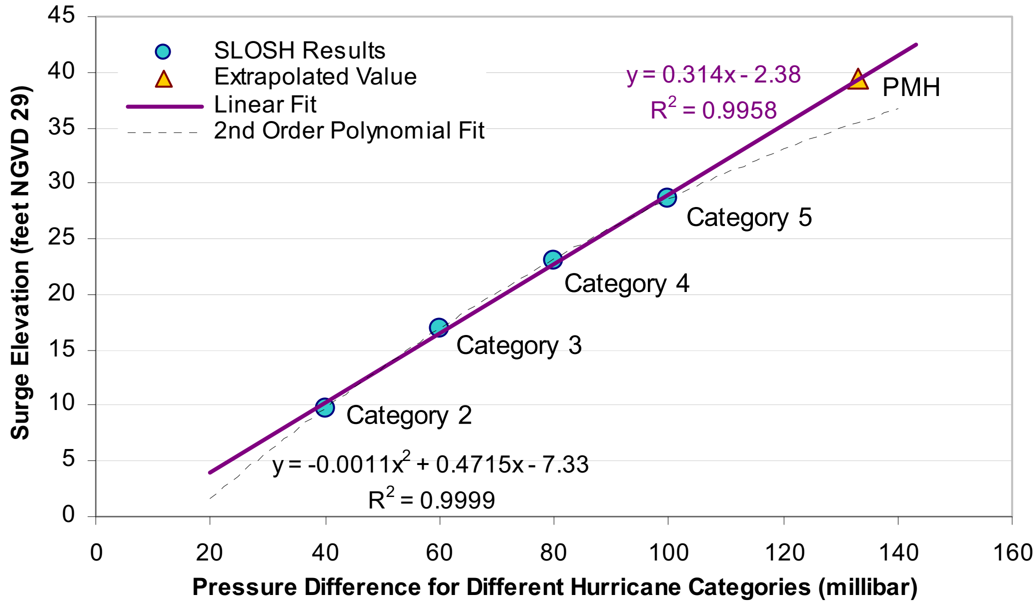

Figure 2.4.5-7 Projection of Surge Elevation from the SLOSH Model Results to PMH Pressure Difference for SLOSH Matagorda, Texas Basin Model Grid Cell (43, 4) (Reference 2.4.5-9)

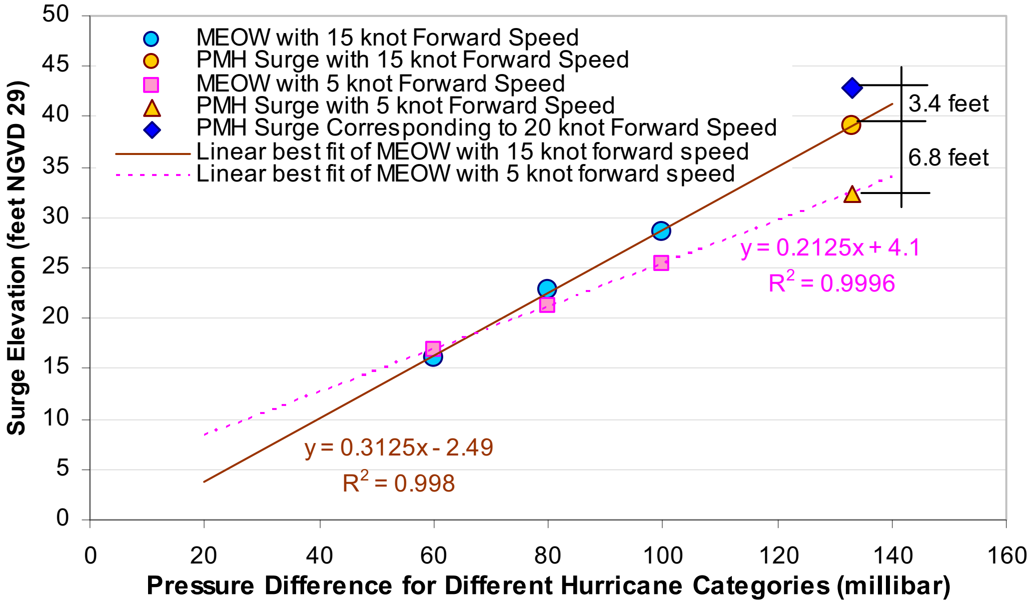

Figure 2.4.5-8 Adjustment to Projected PMH Surge Elevation due to PMH Forward Speed of 20 knots for SLOSH Matagorda, Texas Basin Model Grid Cell (43, 4) (Reference 2.4.5-9)

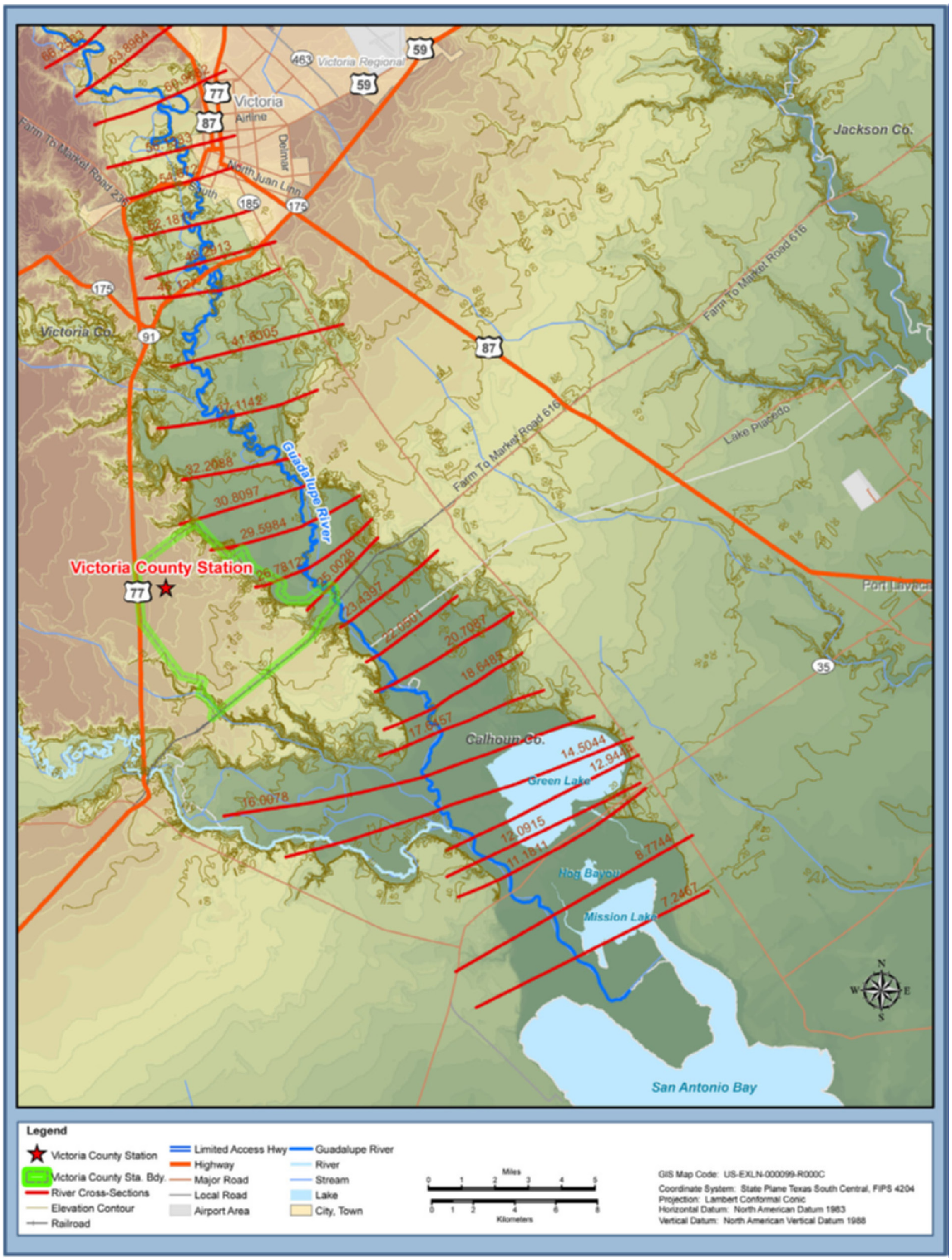

Figure 2.4.5-9 Locations of River Cross Sections Used in the HEC-RAS Model of the Guadalupe River

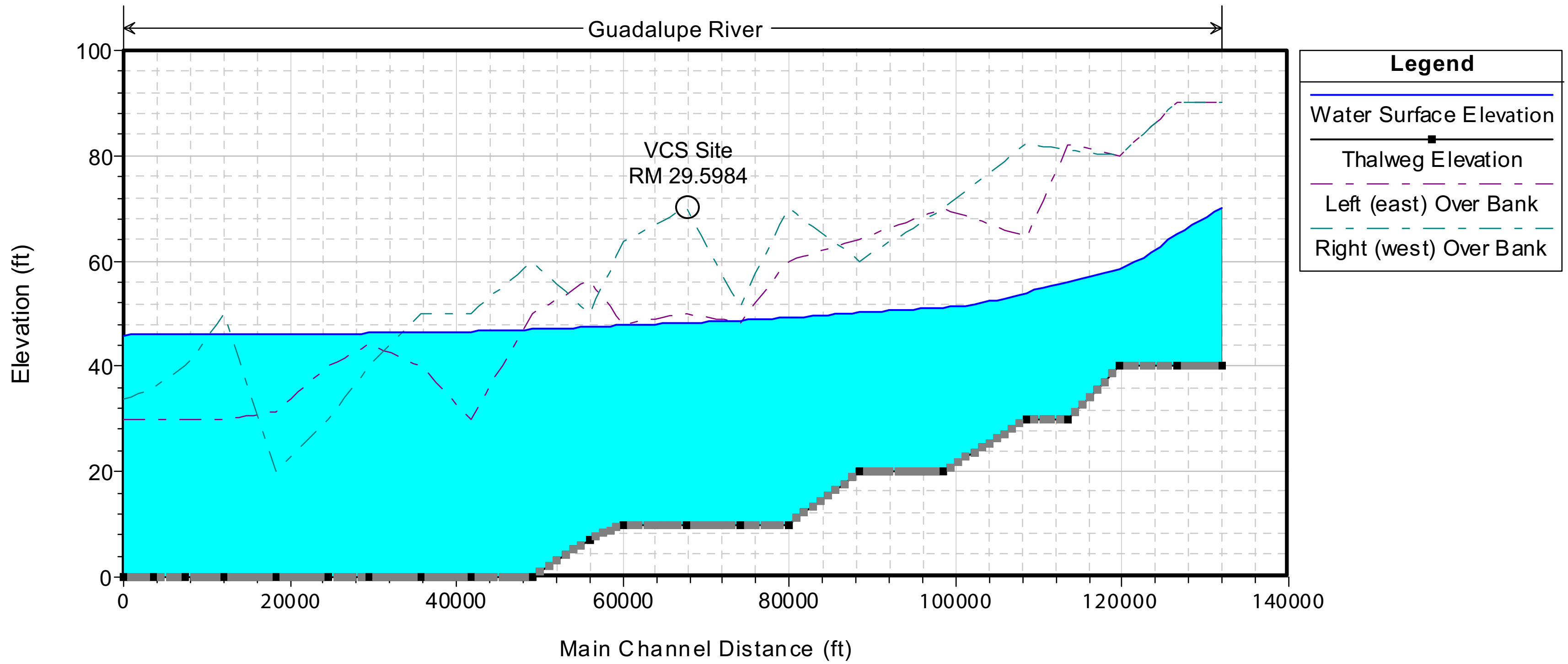

Figure 2.4.5-10 Longitudinal Profile of Simulated Water Surface Elevation (in feet NAVD 88) within the Guadalupe River (VCS Site is Located on the Right or West Overbank)