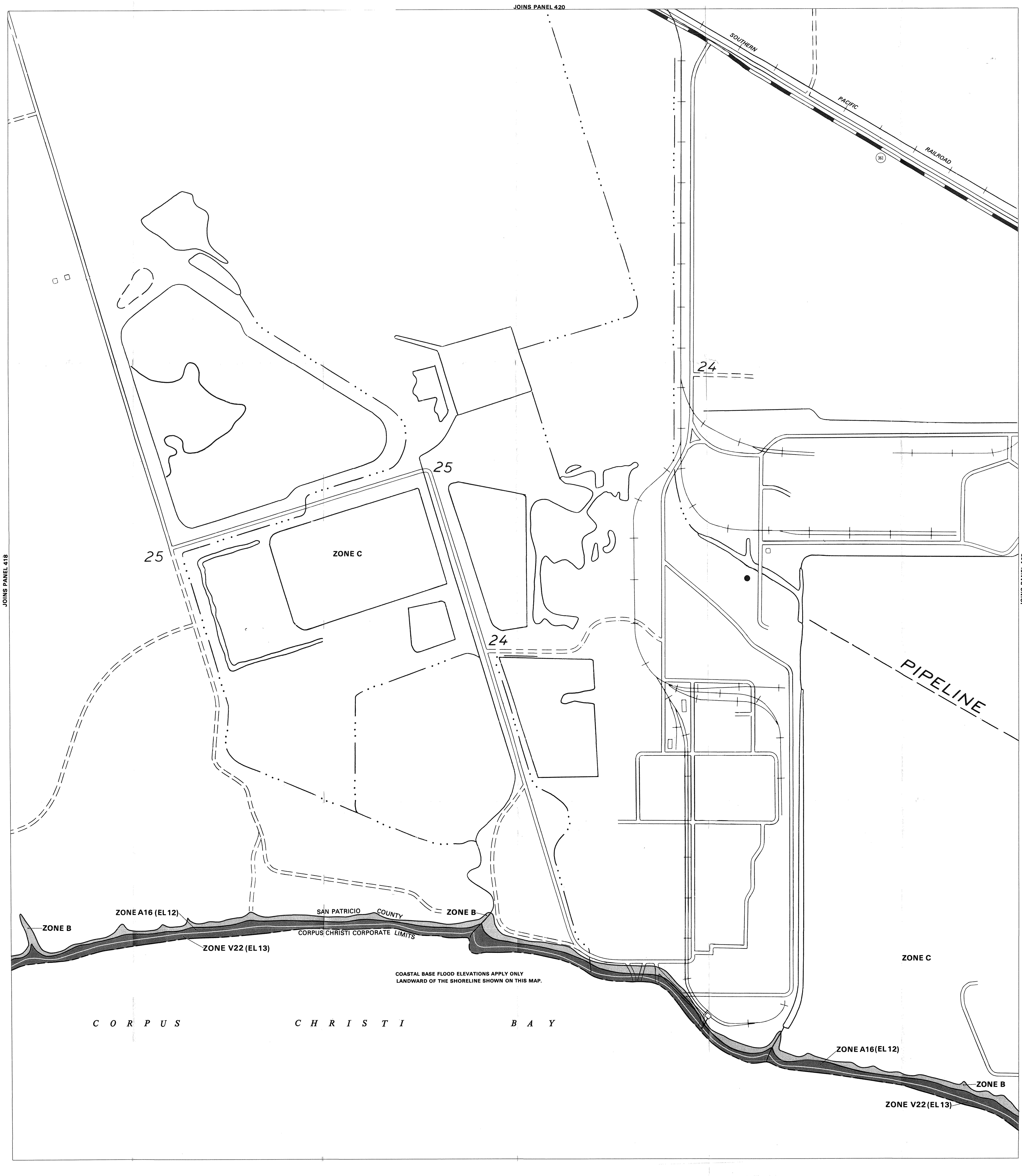
Resource Report 13 – Engineering Data Appendix U.13-7 Floodplain Maps	
Document Number	**Title**
FEMA Rate Map	FIRM Flood Insurance Rate Map - San Patricio County, Texas, March 18, 1985.
Surge Report	Desktop Investigation of Storm Surge CCLNG 2006-07-06 Rev.1



KEY TO MAP

500-Year Flood Boundary	ZONE B
100-Year Flood Boundary	
Zone Designations* With Date of Identification e.g., 12/2/74	ZONE A1 DATE / ZONE A0 DATE
100-Year Flood Boundary	
500-Year Flood Boundary	ZONE B
Base Flood Elevation Line With Elevation In Feet**	513
Base Flood Elevation in Feet Where Uniform Within Zone**	(EL 987)
Elevation Reference Mark	RM7×
Zone D Boundary	
River Mile	•M1.5

**Referenced to the National Geodetic Vertical Datum of 1929

*EXPLANATION OF ZONE DESIGNATIONS

ZONE	EXPLANATION
A	Areas of 100-year flood; base flood elevations and flood hazard factors not determined.
A0	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; average depths of inundation are shown, but no flood hazard factors are determined.
AH	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; base flood elevations are shown, but no flood hazard factors are determined.
A1-A30	Areas of 100-year flood; base flood elevations and flood hazard factors determined.
A99	Areas of 100-year flood to be protected by flood protection system under construction; base flood elevations and flood hazard factors not determined.
B	Areas between limits of the 100-year flood and 500-year flood; or certain areas subject to 100-year flooding with average depths less than one (1) foot or where the contributing drainage area is less than one square mile; or areas protected by levees from the base flood. (Medium shading)
C	Areas of minimal flooding. (No shading)
D	Areas of undetermined, but possible, flood hazards.
V	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors not determined.
V1-V30	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors determined.

NOTES TO USER

Certain areas not in the special flood hazard areas (zones A and V) may be protected by flood control structures.

This map is for flood insurance purposes only; it does not necessarily show all areas subject to flooding in the community or all planimetric features outside special flood hazard areas.

For adjoining map panels, see separately printed Index To Map Panels.

Coastal Base Flood Elevations shown on this map include the effects of wave action.

Coastal Base Flood Elevations apply only landward of the shoreline shown on this map.

INITIAL IDENTIFICATION:
NOVEMBER 27, 1971

FLOOD HAZARD BOUNDARY MAP REVISIONS:
NONE

FLOOD INSURANCE RATE MAP EFFECTIVE:
NOVEMBER 27, 1971

FLOOD INSURANCE RATE MAP REVISIONS:

July 1, 1974-to change zone designations.

September 3, 1976-to reflect curvilinear flood boundary and to add special flood hazard areas.

March 18, 1985-to change corporate limits, to add new special flood hazard areas, to reduce special flood hazard areas, to change zone designations, to change base flood elevations, to change zone boundary line designations, to add street names, to add streets, and to include the effects of wave action.

To determine if flood insurance is available in this community, contact your insurance agent, or call the National Flood Insurance Program at (800) 638-6620.

N

APPROXIMATE SCALE

500 0 500 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

SAN PATRICIO COUNTY, TEXAS
(UNINCORPORATED AREAS)

PANEL 419 OF 533
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
485506 0419 C

MAP REVISED:
MARCH 18, 1985

Federal Emergency Management Agency

DESKTOP INVESTIGATION OF STORM SURGE

CORPUS CHRISTI LNG, L.P.
PORTLAND, TX

Prepared for

CHENIERE

Prepared by

HDR | SHINER MOSELEY AND ASSOCIATES, INC.

STATE OF TEXAS
M. CAMERON PERRY
94056
LICENSED
7-6-06

This document is released for the purpose of review; it is not intended to be used for bidding or construction purposes.

200.30175.19/42045 July 6, 2006 (Rev. 1)

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1.0 INTRODUCTION

1.1 Authorization

This desktop investigation of storm surge was authorized by Cheniere Energy (Cheniere) for the proposed Corpus Christi LNG, L.P. (CCLNG) facility in San Patricio County, Texas.

1.2 Purpose

This report provides a qualitative summary of potential vulnerability at the proposed CCLNG site to storm surge and waves from hurricanes. Herein, storm surge refers to still-water level elevation above normal tide levels caused by wind and pressure effects associated with hurricanes. When possible, wave effects such as wave run-up and wave crest elevation have been separated from storm surge elevations. The investigation primarily focused on gathering and analyzing observations made during significant hurricanes in the region and comparing observations with existing numerical modeling results for hurricane impacts in the vicinity of the site. A qualitative wave analysis was also performed. Beyond information published by the Federal Emergency Management Agency (FEMA), this report does not address surface water flooding that may occur from local or upstream rainfall.

Key information presented includes readily available data pertaining to historic and recent hurricanes, results from storm surge modeling performed by the National Oceanic and Atmospheric Administration (NOAA), FEMA Flood Insurance Studies, regional topography and bathymetry, tide and river gage data, and information provided by Cheniere personnel. The bulk of the information contained within the report is publicly available, with the exception of the qualitative wave analysis and some specific facility information provided by Cheniere. Primary sources included NOAA and the affiliated National Weather Service (NWS), National Hurricane Center (NHC), National Ocean Service (NOS), U.S. Army Corps of Engineers (USACE), and FEMA.

The intent of this report is to provide information for use in determining design elevations for critical infrastructure at the proposed CCLNG site. The qualitative wave analysis presented should not be used for structural design of shoreline protection, critical infrastructure, or equipment subject to wave attack. Due to the qualitative nature of this report, information and analyses presented herein should not be used for bidding or construction purposes.

2.0 BACKGROUND INFORMATION

2.1 Location and Site Description

The proposed CCLNG facility will be located along the northern shore of Corpus Christi Bay between the cities of Portland and Ingleside (see Figure 2.1). La Quinta Ship Channel currently runs along the north side of the bay between the mainland and the outlying dredge spoil island. The berthing area, as shown in Figure 2.2, will be located west of the existing La Quinta Ship Channel turning basin and adjacent to the existing Sherwin Alumina Facility.

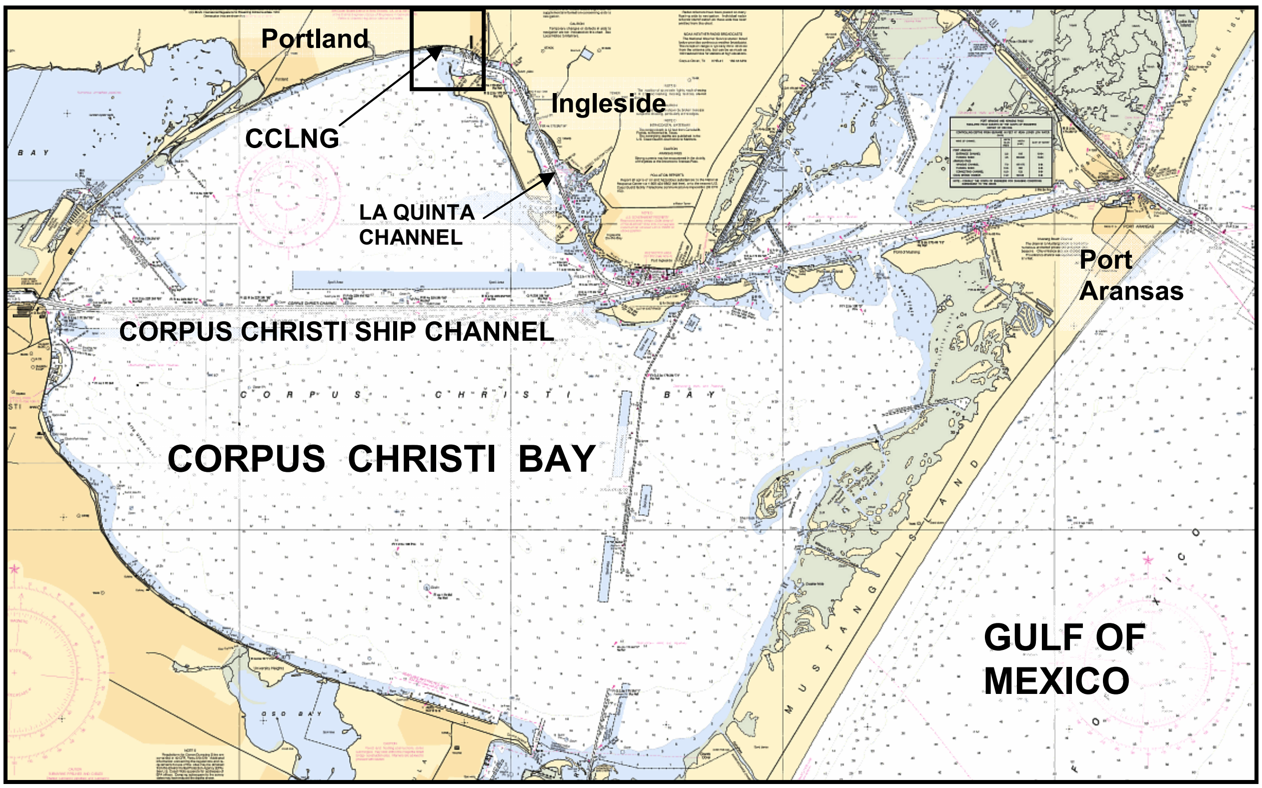

Figure 2.1 – Site vicinity map.

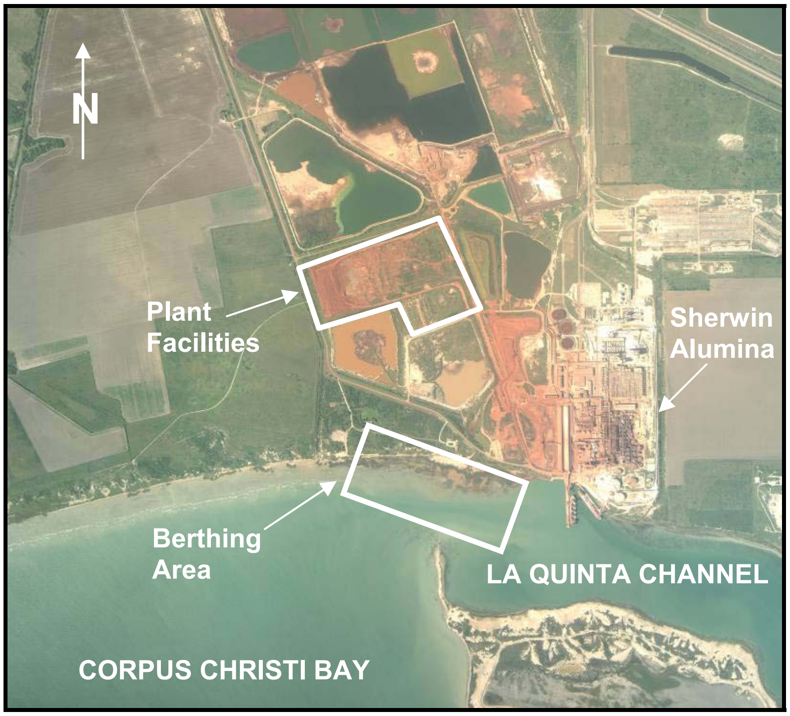

Figure 2.2 – Aerial Photograph of the proposed CCLNG site (undated).

Figure 2.2 shows an undated aerial photograph of the proposed CCLNG site. The box outlined in Figure 2.1 is keyed to Figure 2.2 to better show the location. Cheniere has identified critical infrastructure components for the proposed CCLNG, presented in Table 2.1. It is assumed that these will be located within the Plant Facilities area shown in Figure 2.2.

Table 2.1 – Critical infrastructure components

Component	Type
Control Room	Building
Standby Generator	Equipment
Transformers	Equipment
Switchgear & MCCs	Equipment
Fuel Gas Heaters	Equipment
Air Compressors	Equipment
Electrical & Instrument Wire	Connections

2.2 Topography

Light Detection and Ranging (LIDAR) survey conducted on December 15, 2005 was used to evaluate key topographic features in the vicinity of the site. Figure 2.3 shows a large scale orthographic projection of topography in the vicinity of the CCLNG site. The berthing area sits on a generally shallow bay fronted by a large bluff that rapidly transitions to uplands. The upland areas, where plant facilities will be located, have an average elevation of approximately 24 ft above the National Geodetic Vertical Datum of 1929 (NGVD ’29).

Due to the limitations of LIDAR survey methods, bathymetric data cannot be accurately determined and thus should be ignored in Figure 2.3. The raised areas in the figure represent bauxite residue storage areas used by adjacent property owners. The high areas in the far right corner are man made structures at the adjacent Sherwin Alumina plant.

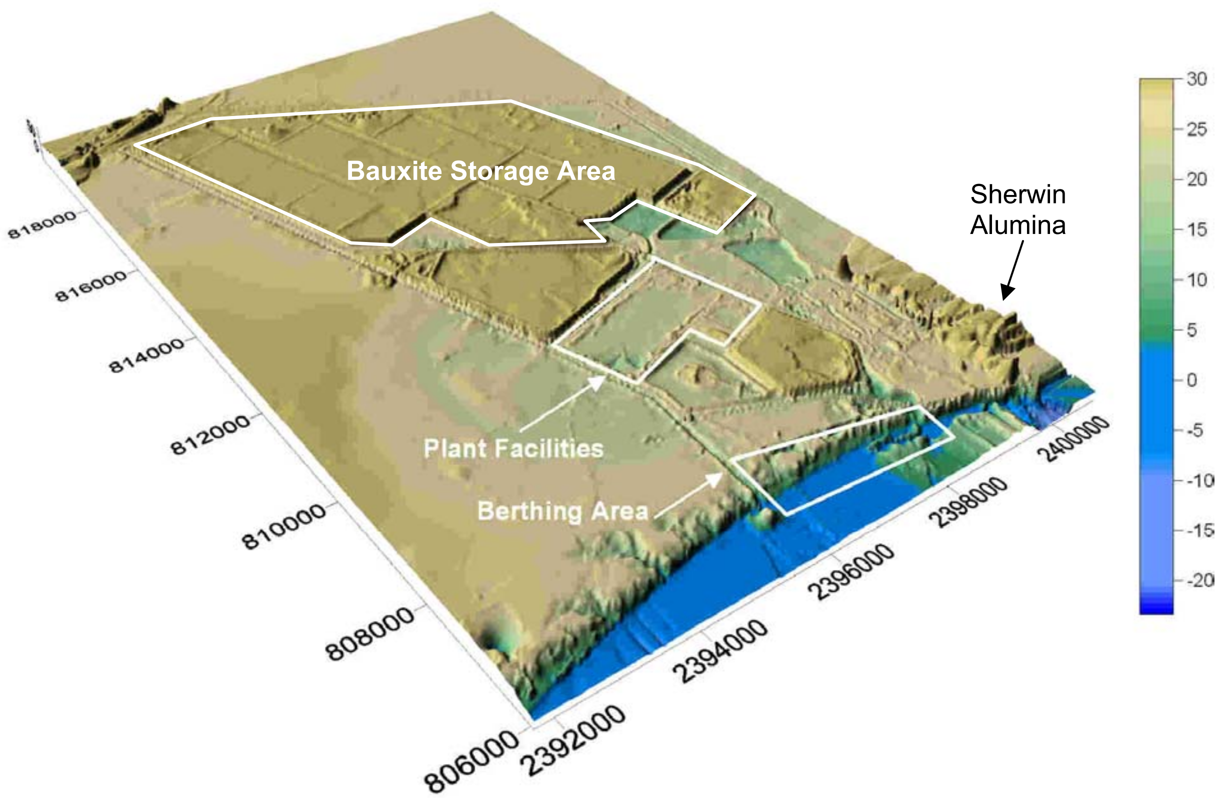

Figure 2.3 – Topographic map showing the proposed CCLNG site.

3.0 HURRICANE INVESTIGATION

3.1 General

Over the past century, scores of hurricanes have impacted the Texas coastline. Actual and potential storm surge and wave effects from hurricanes depend upon a number of characteristics including landfall location, approach direction, approach speed, wind speed, and central pressure. As will be illustrated in the next two sections, storm surge cannot always be directly correlated with hurricane intensity or category. Likewise, it is difficult to accurately associate hurricane intensity with specific return intervals for most geographic locations. Topography also affects the magnitude of localized storm surge and waves.

Hurricanes are categorized based on intensity, which can be used to estimate potential damage to property. Table 3.1 shows the Saffir-Simpson Hurricane Scale, where sustained 1-minute average wind speeds determine the hurricane category (NHC 2006B). A range of storm surge magnitudes generally associated with the indicated hurricane category is also included. Actual storm surge values at CCLNG will be discussed in Section 4 of this report.

Table 3.1 – Saffir-Simpson Hurricane Scale

Category	Wind Speed (mph)	Storm Surge (ft)
1	74 - 95	4 - 5
2	96 - 110	5 - 9
3	111- 130	9 - 12
4	131 - 155	13 - 18
5	> 155	> 18

3.2 Regional Hurricane Information

The NOAA Coastal Services Center has compiled a database of historic hurricanes and tropical storms for the Gulf coast through 2003. Table 3.2 presents characteristics of historic hurricanes passing within 65 nautical miles (nm) of Ingleside, Texas, from 1851 to 2005 (NOAA 2006A). Table 3.2 gives the maximum wind speed and category each storm reached within the 65 nm radius. Note that Hurricane Allen is not within the 65 nm radius, but is included in the investigation because of the storm's significant impact on the Corpus Christi area. Storms not reaching hurricane strength near the site are excluded due to the relatively small magnitude of associated storm surge.

Figure 3.1 shows the tracks of these storms (NOAA 2006A). The grey area in the figure represents a 65 nm radius, centered in Ingleside, TX. The complexity of storm surge analysis for the site is illustrated by the variability in characteristics of the storms shown and presented herein.

Table 3.2 – Catalog of historical hurricanes near CCLNG (NOAA 2006A).						
Year	**Month**	**Day**	**Name***	**Wind Speed (knots)**	**Category**	**Pressure (mb)**
1851	6	25	-	80	1	-
1866	7	15	-	90	2	-
1869	8	17	-	90	2	-
1875	9	16	-	100	3	-
1886	8	20	-	135	4	925
1886	9	23	-	80	1	-
1902	6	26	-	65	1	-
1910	9	14	-	95	2	-
1912	10	16	-	85	2	-
1913	6	28	-	65	1	-
1916	8	18	-	100	3	-
1919	9	14	-	85	2	-
1929	6	28	-	70	1	986
1934	7	25	-	65	1	-
1936	6	27	-	70	1	-
1945	8	27	-	115	4	-
1961	9	11	Carla	145	5	935
1967	9	20	Beulah	90	2	-
1970	8	3	Celia	110	3	945
1980	8	7	Allen**	165	5	899
1999	8	22	Bret	120	4	946
2003	7	15	Claudette	75	1	982

* Storms were not named prior to 1953
** Was not within 65 nm but still had an impact on the CCLNG vicinity

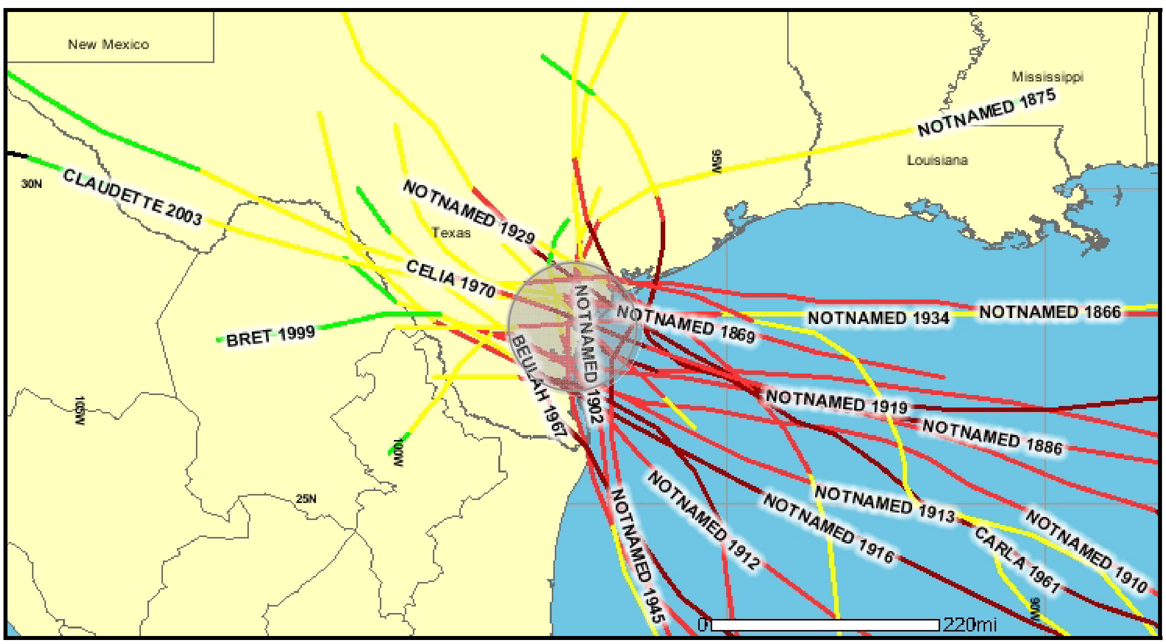

Figure 3.1 – Historic storm tracks for hurricanes passing within 65 nm of Ingleside, TX.

Based in part on the record of storms provided in Table 3.2, the NHC has applied statistical methods to estimate hurricane return periods at a number of locations along the Gulf coast (Neumann 1987). Note that these probabilities include large uncertainties due to the small number of storms impacting specific locations and limited reliable information on hurricanes prior to 1960. Return periods for intense storms (i.e., Category 3 or greater) are particularly suspect due to the limited record of these storms as illustrated in Table 3.2.

Figure 3.2 shows Category 3 hurricane return periods for locations throughout the Gulf coast, with the proposed CCLNG site indicated by an arrow. Table 3.3 provides representative return periods for Corpus Christi for each hurricane category (data provided by NHC 2006A). Note that return periods reflect long term trends and do not indicate a schedule of occurrences. For example, two Category 3 storms could impact the same location during a single hurricane season.

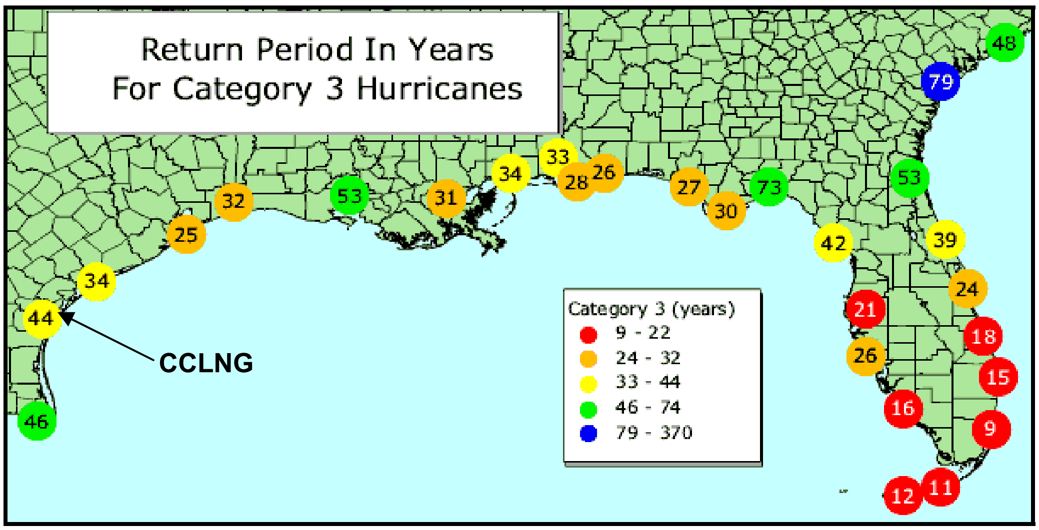

Figure 3.2 – Estimated return periods for Category 3 hurricanes (NHC 2006A).

Table 3.3 – Hurricane return periods for Corpus Christi, TX.

Category	Return Period (years)
1	15
2	29
3	44
4	78
5	170

3.3 Significant Storms

Of the storms presented in Table 3.2 and shown in Figure 3.1, five will be discussed because of the significant surge observed in the vicinity of the proposed CCLNG site: the 1919 Hurricane, Hurricane Carla, Hurricane Beulah, Hurricane Celia, and Hurricane Allen. Data and observations are available for these hurricanes, though many of the storms predated the modern hurricane monitoring and reporting systems. Figure 3.3 shows the tracks of the five major hurricanes to be discussed. Many of the storm surge measurements before 1980 referenced surge elevations to mean sea level (MSL). MSL and NGVD '29 were often used interchangeably and it is not always clear what datum was really used. For the purposes of this study, the difference between MSL and NGVD '29 are not significant enough to be of concern. The magnitude of the surge at a given location is more important.

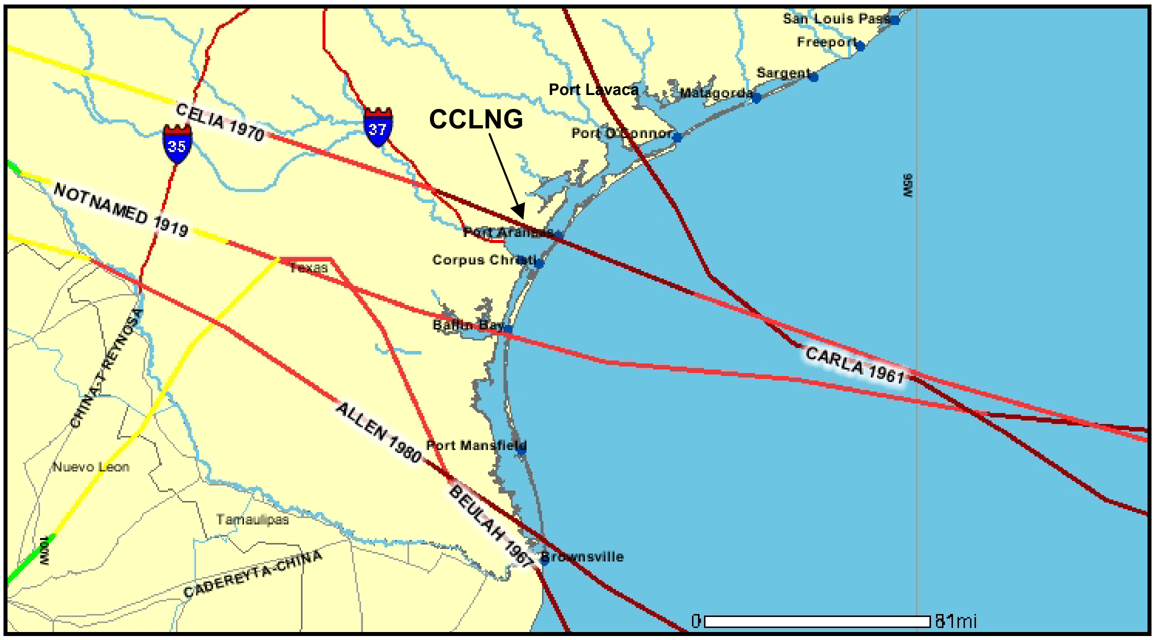

Figure 3.3 – Significant hurricanes to affect CCLNG vicinity (NOAA 2006A).

Hurricane of 1919

The Hurricane of 1919 formed in the Caribbean Sea and took its course over Florida. The storm made landfall just south of Corpus Christi, around Baffin Bay (Frankenfield 1919), as a Category 4 storm (NHC 2005). Since the hurricane occurred prior to modern hurricane monitoring, little is known about this storm except of the devastation it caused in Corpus Christi and the surrounding areas. All but three structures were completely destroyed on North Beach, located just north of downtown Corpus Christi. Winds were measured up to 72 mph when the anemometer in Corpus Christi failed due to the forces of the winds. Maximum winds were estimated to be around 110 mph. In some parts of the Corpus Christi Bay, storm surge was estimated at 16 ft (Ellis 1988).

Hurricane Carla, 1961

Hurricane Carla developed on September 3, 1961 in the Caribbean Sea and steadily moved northwest into the Gulf of Mexico, continuously increasing in strength (Dunn 1962). The hurricane passed within 65 miles to the east of Corpus Christi and made landfall between Port O'Connor and Port Lavaca on September 11, 1961 (NWS 2006B) as a Category 4 storm (NHC 2005). Wind gusts up to 86 mph were reported in the Corpus Christi area (Ellis 1988).

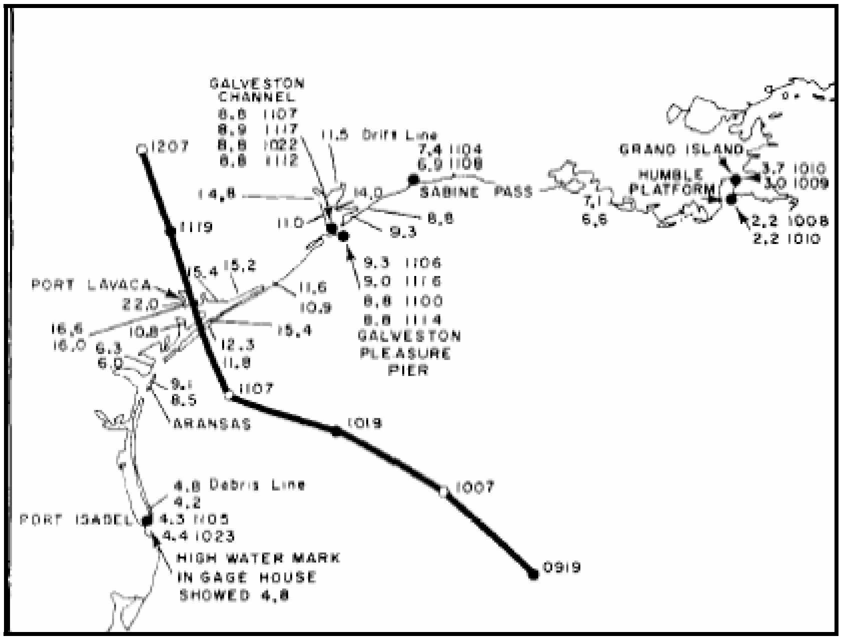

Figure 3.4 – Storm surge and high water marks (feet) on Texas coast during Hurricane Carla (Dunn 1962).

As shown in Figure 3.4, a surge of approximately 9 ft was observed around Aransas Pass. The storm also produced up to 18.5 ft surge in Port Lavaca, Texas and a surge on the order of 22 ft in Port O'Connor, Texas (Dunn 1962). Because this storm predated the tide gages in the area, surge magnitude estimates at the CCLNG site are not available but likely ranged from 6 to 9 ft.

Hurricane Beulah, 1967

Hurricane Beulah formed off the African coast on August 28, 1967 and traveled west to the Caribbean Sea where it became a hurricane. The storm then moved into the Gulf of Mexico, making landfall just south of Brownsville, Texas (USACE 1968) as a Category 3 storm (NHC 2005). Winds were estimated to be around 86 mph in the Corpus Christi area (Sugg & Pelissier 1971). Still-water mark elevations near the CCLNG site were between 5.7 and 6.8 ft above MSL (USACE 1968).

Hurricane Celia, 1970

Hurricane Celia first developed in the Caribbean Sea July 30, 1970 and entered the Gulf of Mexico crossing the western tip of Cuba on July 31. Celia made landfall just north of Corpus Christi (USACE 1971) as a Category 3 storm (NHC 2005). Wind gusts were measured over 150 mph (USACE 1971) with sustained winds of approximately 115 mph (NWS 2006A). The storm produced a 9 ft surge above MSL at the Port Aransas jetties (Simpson & Pelissier 1971). Still-water mark elevations near the CCLNG site were between 7.5 and 9.7 ft above MSL (USACE 1971).

Hurricane Allen, 1980

Hurricane Allen was detected in the Atlantic Ocean approximately 1,300 miles east of the Winward Islands. As it crossed the islands into the Caribbean Sea, the storm strengthened into a hurricane and proceeded into the Gulf of Mexico (Herbich & Watanabe 1981). Hurricane Allen made landfall as a Category 3 storm (NHC 2005) about 30 miles north of Brownsville, Texas on August 9, 1980 (Herbich & Watanabe 1981). Wind gusts of 109 mph and 92 mph were recorded at Aransas Pass and Corpus Christi Airport, respectively (Herbich and Watanabe 1981).

Figure 3.5 shows the infrared image for Hurricane Allen. This image illustrates the intensity of the storm and the area affected by the storm. The triangle in the figure indicates the approximate location of the CCLNG site. A surge of approximately 9 ft above mean sea level (MSL) was observed at Corpus Christi, Texas (Lawrence & Pelissier 1981). Port Ingleside recorded a surge of 6.8 ft above MSL from a crest gage (USACE 1981).

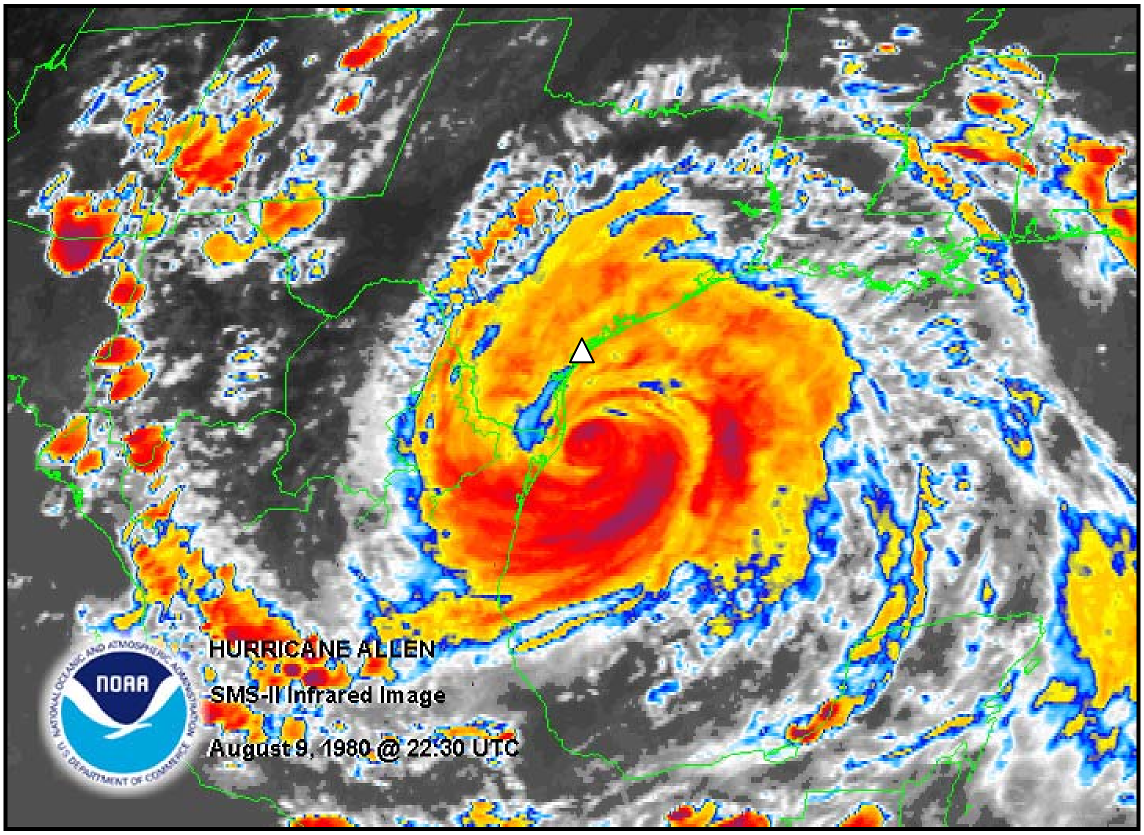

Figure 3.5 – Infrared image Hurricane Allen, 1980 (NOAA 2006B).

Other Storms of Interest

A number of other storms have impacted the region, most recently Hurricane Bret in 1999 and Hurricane Claudette in 2003. Hurricane Bret was the more intense of the two, making landfall as a Category 3 (NHC 2005), but with little effect on the CCLNG site. Hurricane Bret, landing about midway between Brownsville and Corpus Christi, produced a surge of approximately 2.6 ft NGVD '29 on North Padre Island (Lawrence & Kimberlain 2001). Hurricane Claudette made landfall north of Corpus Christi around Matagorda Island and generated a surge of approximately 2.7 feet on North Padre Island. The tide gage at Ingleside topped out at 2.5 ft above MLLW, although there may have been a higher surge in the area (Beven 2003).

The landfall location, approach direction, approach speed, wind speed, and central pressure of the hurricane greatly affect the surge produced at a given location. The historical storms discussed herein represent only a portion of the possible scenarios that could and have occurred; therefore a better understanding of potential impacts from a wide range of hypothetical storms is needed.

4.0 STORM SURGE ANALYSES

To account for the wide range of hypothetical storm conditions, FEMA, USACE, NWS, and NOAA have applied techniques to estimate the extent and elevation of storm surge impacts throughout the Gulf and Atlantic Coasts. The results of this work are primarily available through FEMA Flood Insurance Studies (FIS), Flood Insurance Rate Maps (FIRM), and Hurricane Evaluation Studies (HES). The FEMA information is most helpful in determining coastal flooding associated with a particular return period (i.e. 100-year base flood elevation). Whereas the HES information, which is typically derived from the Sea, Lake, Overland Surges from Hurricanes (SLOSH) model, provides estimates of storm surge inundation for emergency and evacuation planning purposes. The SLOSH model does not correlate storm surge estimates with a return period; instead it provides worst case surge information for a range of hypothetical storm scenarios.

4.1 FEMA

FEMA FISs and FIRMs report coastal flooding and riverine flooding as a function of return period, or annual chance of occurrence. The 100-year event corresponds to a 1% annual chance of occurrence. Estimates of coastal flooding and associated return period are available in the immediate vicinity of the site. According to the San Patricio County FEMA FIRM map shown in Figure 4.1, the 100-year base flood elevation (BFE) for the site varies with distance from the shoreline. The areas designated as velocity zones (V22) run along the shoreline. For this zone, the BFE is 13 ft NGVD '29 and waves exceeding 3 feet in height can occur during the 100-year event. Areas immediately landward of the V-zone have been designated A16, with a corresponding BFE of 12 ft NGVD '29. According to FEMA, these areas are not likely to be impacted by storm waves during the 100-year event. FEMA recommends elevating structures located in V-zones and A-zones above the BFE.

It appears that the remainder of uplands areas at CCLNG are designated as zones B and C because they are not at risk for flooding during a 100-yr event. These areas could experience minor flooding from an event greater than the 100-yr event. According to FEMA, waves are not expected to impact these areas during the 100-yr event.

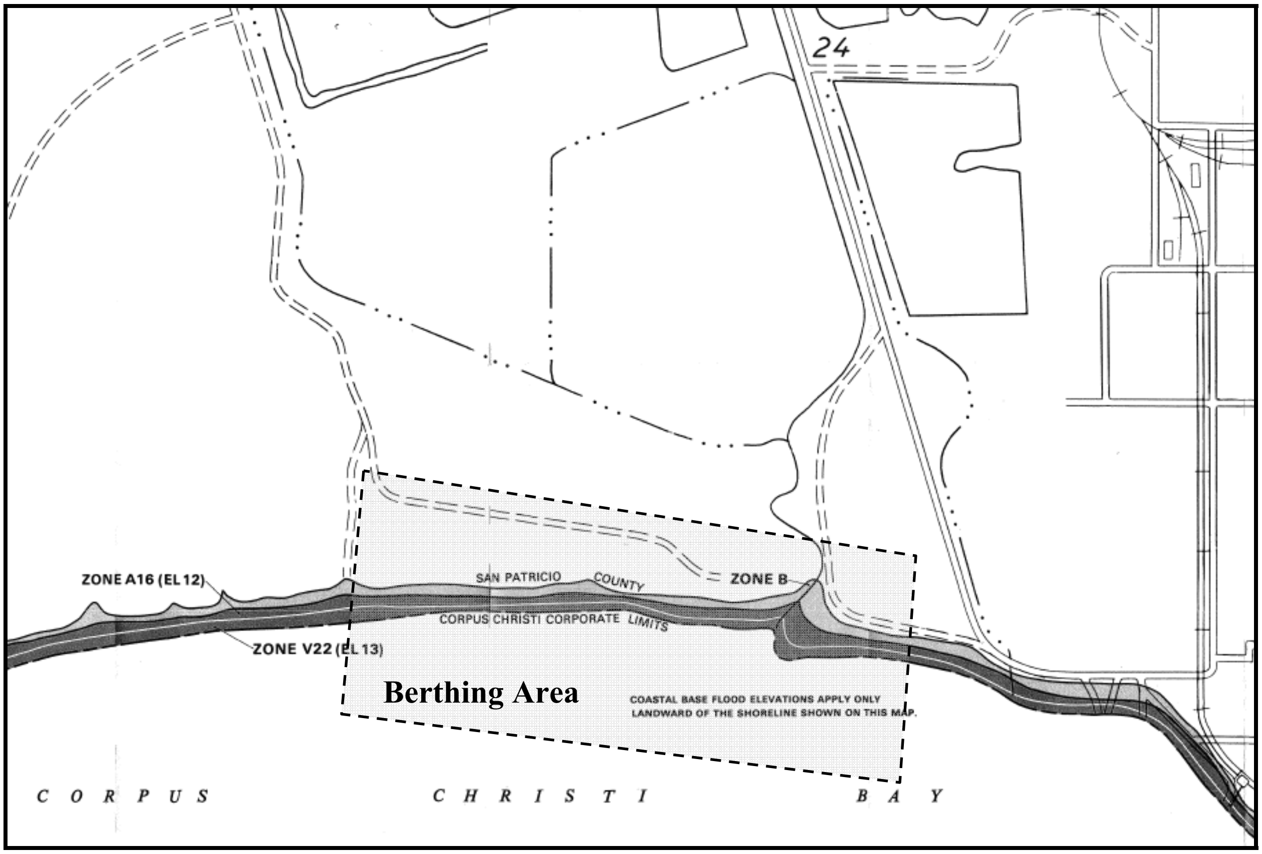

Figure 4.1 – FEMA Flood Insurance Rate Map for the proposed CCLNG site (FEMA 1985).

4.2 SLOSH Model

SLOSH modeling performed by the NWS provides Maximum Envelopes of Water Elevations (MEOWs) for specific geographic locations that are subject to storm surge. By simulating many combinations of hypothetical forward speed, approach angle, wind speed, central pressure, and landfall location, SLOSH modeling provides reasonable estimates of the range of storm surge anticipated for each hurricane category at the site. SLOSH is capable of simulating storm surge over both upland and open water areas and accounts for key topographic and bathymetric features within the model domain. SLOSH can also be run in real-time by the NWS during hurricanes to assist emergency managers and local governments.

Figure 4.2 shows the Corpus Christi Basin SLOSH modeling domain that extends from Willacy County, TX to Calhoun County, TX. NWS has simulated more than 600 storms for the Corpus Christi Basin. It is noted that SLOSH provides still-water elevation, but does not take into account the waves that could be generated during hurricanes.

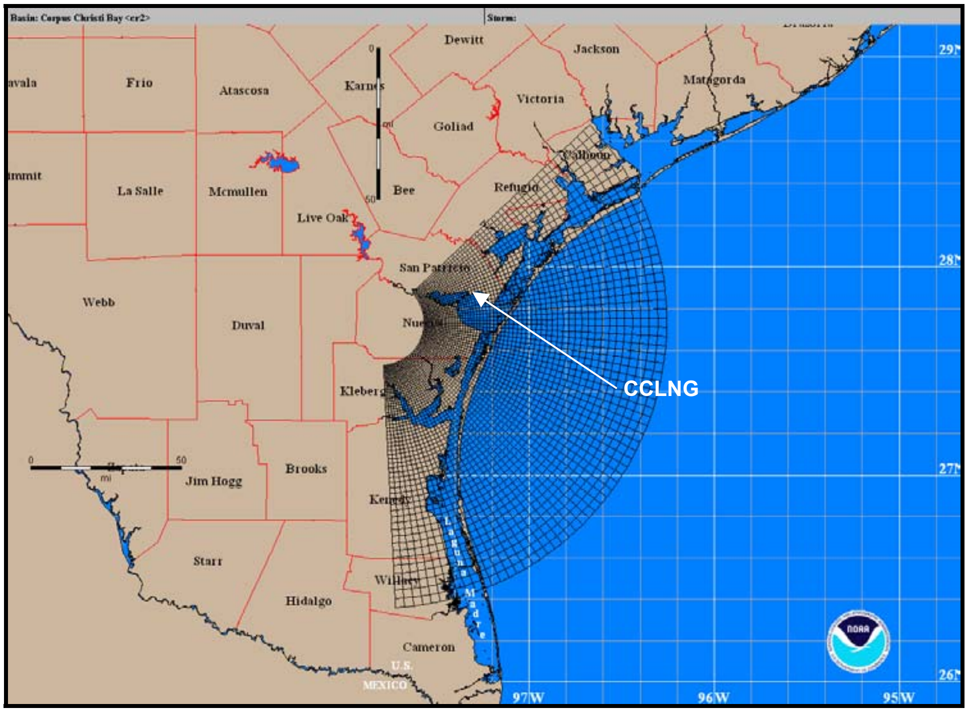

Figure 4.2 – Corpus Christi Basin SLOSH modeling domain.

Results of the SLOSH model are computed across the entire modeling domain for each grid cell, which varies in size. Smaller grid cells make it possible to see more detail in the area of interest. Since water level elevations vary in both space and time, the maximum surge at the center of each grid cell is recorded for each simulation, relative to NGVD '29. MEOWs, which represent the maximum surge at each grid cell, are compiled for various simulated scenarios (USACE 2005). The Maximum of MEOWs (MOM) for each cell is computed for each hurricane category and used to create surge inundation maps for emergency management purposes. Therefore, SLOSH MOMs represent the simulated worst case scenario for hurricanes of a known intensity and do not necessarily reflect storm surge for a particular storm throughout the domain.

Figure 4.3 shows the MOMs for Category 5 hurricanes in feet NGVD'29. Colors indicate the magnitude of storm surge, with blue being the smallest surge and red the largest. In the figure, areas receiving the largest surge are located in Nueces Bay, west of the CCLNG site.

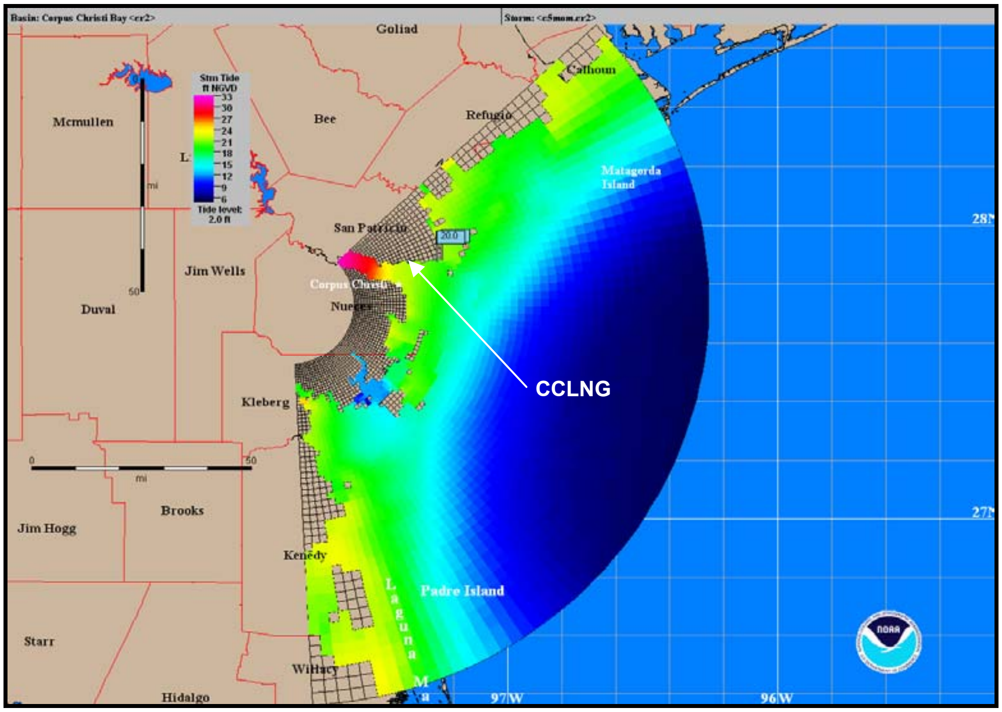

Figure 4.3 – SLOSH MOMs for Category 5 Hurricanes.

Representative MEOWs for the CCLNG site are presented in Figure 4.4. The middle bar represents the mean MEOW for each of the hurricane categories, the top bar shows the MOM, and the bottom bar shows the minimum MEOW. Overall, SLOSH results are accurate to within ± 20 percent. Based on SLOSH, still-water storm surge at the site is not expected to exceed approximately 20.3 ft NGVD '29 during a Category 5 hurricane. Since MEOWs represent peak surge independent of landfall location, actual storm surge elevations can be less than the range of values shown in Figure 4.4.

Figure 4.4 also shows that lower category storms have the potential to cause a storm surge that exceeds that of a higher category storm. For example, the MOM of a Category 3 storm exceeds the minimum MEOW of a Category 4 storm. This can primarily be attributed to the influence of hurricane landfall location and approach direction on simulated and actual storm surge elevations.

The MOMs for the Category 1 through 3 hurricanes resulted from a hurricane traveling due west at 5 miles per hour. For a Category 4 or 5 hurricane, the maximum surge was a result of the storm traveling due west at 15 miles per hour. Figure 4.5 illustrates how the different travel directions (headings) of a hurricane can impact the elevation of the storm surge.

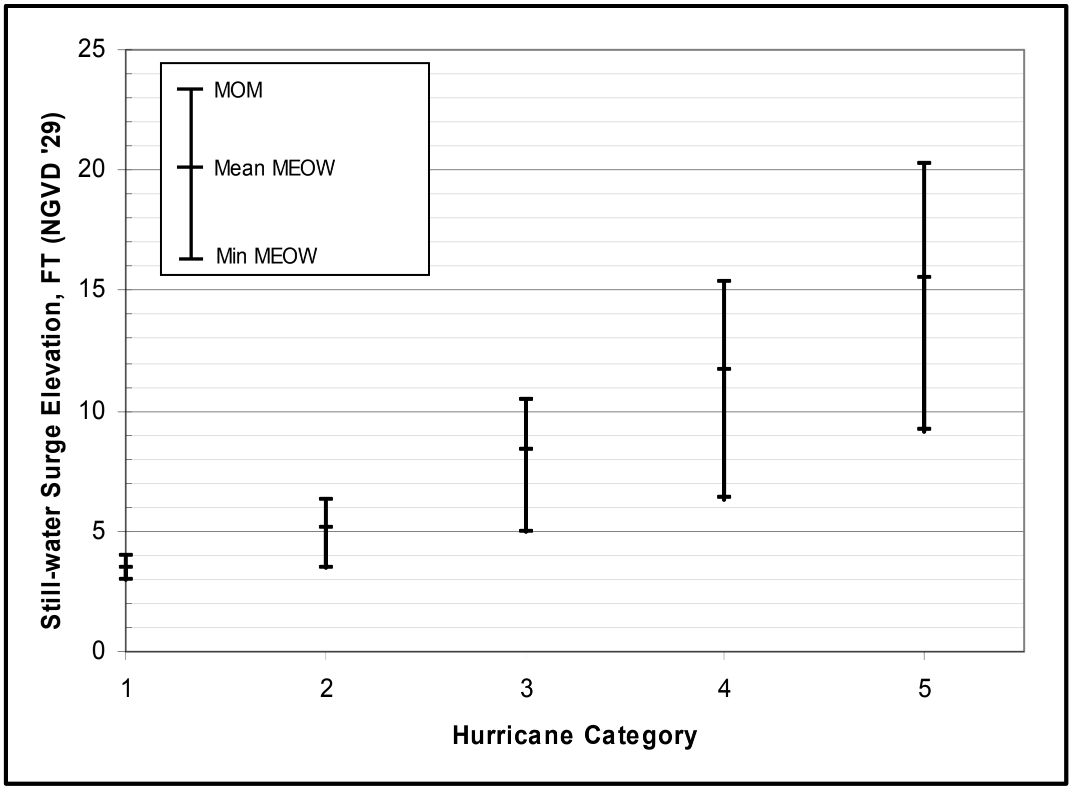

Figure 4.4 – Representative SLOSH MEOWs at the proposed CCLNG site.

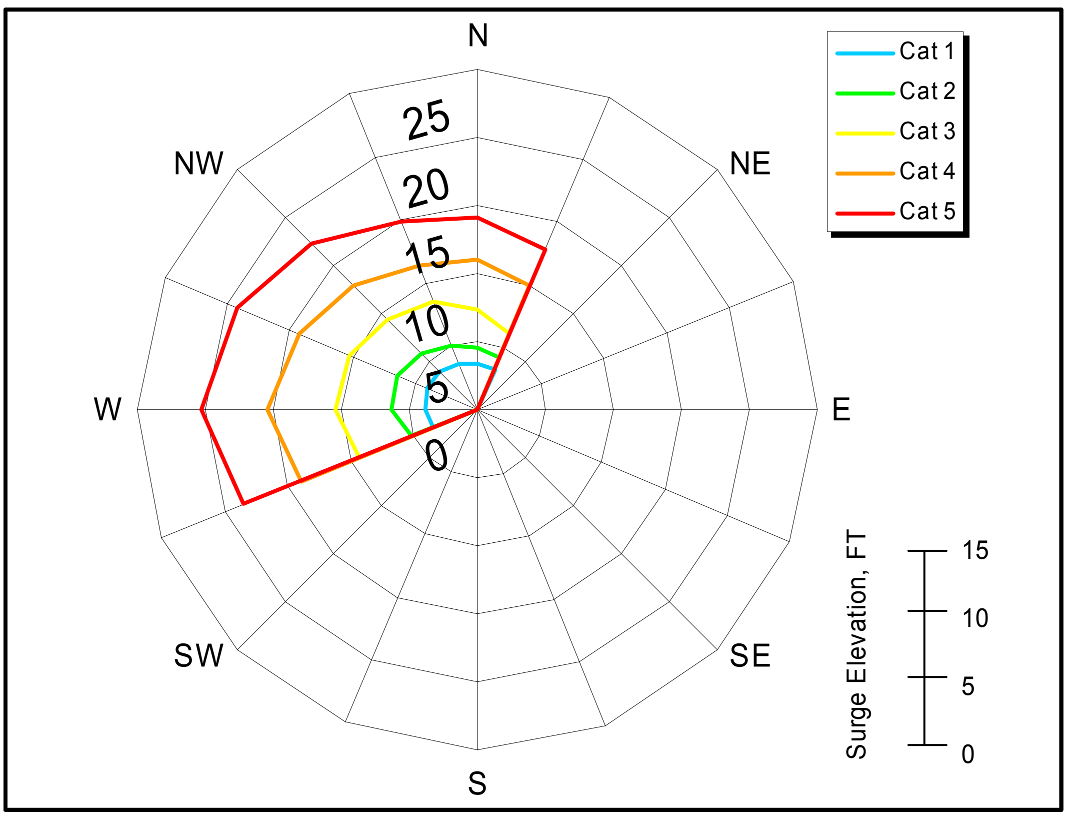

Figure 4.5 – Representative SLOSH MEOWs based on heading and strength of hurricane.

4.3 Surge Summary

The SLOSH model results represent the range of worst case surge for many possible hurricane scenarios. The surge observed during historical hurricanes was generally consistent with the results from the SLOSH model. For example, the SLOSH indicated that for a hurricane making landfall as a Category 3, the surge at the CCLNG site could be between 4.9 ft and 10.2 ft. Hurricane Beulah, Hurricane Celia, and Hurricane Allen were Category 3 hurricanes at landfall and produced surge values within the envelope given by the SLOSH model.

The SLOSH model results for a Category 4 hurricane similar to Hurricane Carla indicated surge for the Port Aransas area to be between 9 ft and 12.5 ft. Actual surge data for Hurricane Carla found in the Port Aransas area showed a range of surge between 8.5 ft and 9.2 ft. This surge falls on the lower end of the SLOSH model results but is still within the stated accuracy of the model.

The SLOSH model was also compared with the data from the FEMA Flood Insurance Studies performed for the area. The BFE for a 100-year flood event in the vicinity of CCLNG ranged from 11 to 13 ft NGVD'29 (FEMA 2004). This roughly corresponds to the surge from a Category 4 hurricane, as indicated by the SLOSH model results presented in Figure 4.4. The FEMA BFE and SLOSH results are also consistent with return period estimates given in Table 3.3.

5.0 WAVE ANALYSES

The proposed CCLNG site is relatively sheltered from waves under normal conditions. For this study, it was assumed that the La Quinta Ship Channel will be extended in front of the proposed site for access to the berthing area. Extending the channel may expose the site to larger wind-waves generated by local hurricane-strength winds acting on water levels elevated by storm surge. The height and period of waves impacting the site would be limited by wind speed, storm duration, and fetch (the effective distance over which the wind can contribute to wave growth).

Because of its inland location, no wave measurements were available for evaluation of wind-wave conditions at the site. Therefore, the magnitude of the wind waves was empirically estimated using the wind speeds given in Table 3.1 for each Saffir-Simpson hurricane category. For this qualitative analysis, water depth throughout the bay was based on the MOM for each category of storm analyzed, as presented in Figure 4.4.

5.1 Wind-Wave Analysis

In order to investigate the potential for local wave generation during hurricanes, navigation charts, bathymetry, and topography were reviewed to determine the directions from which significant waves might propagate toward the sight during storm conditions. Wave height and period were then estimated using the Automated Coastal Engineering System (ACES) as described by Leenknecht et al. (1992).

Since the site is only open to the bay from the south and has reasonably good protection from the island southeast of the site, wind-waves propagating from south to approximately west-southwest were analyzed. Because the La Quinta Ship Channel is fairly open and deep, wind-waves generated along the channel were also considered. Table 5.1 provides spectral significant wave height (H_{mo}) and peak wave period (T_p) predicted using ACES for the primary wind directions analyzed. Wind directions in the table indicate direction from which the wind blows (meteorological convention). H_{mo} is a statistical representation of wave height, not the maximum wave height that could occur. Therefore, some wave heights larger than the given H_{mo} could occur, but most will be smaller.

The wave heights for all directions are fairly similar, with largest waves propagating from due south. The waves generated in the channel are smaller than the waves from the open bay, but are included because the heights are still relatively significant. The highlighted direction of 210° was used for further analysis since it was representative of all the wind directions considered. As shown in Table 5.1, the largest wave heights could reach upwards of 16 ft for a Category 5. Note that the values in Table 5.1 are likely conservative and will not necessarily occur for every given hurricane because the analysis presented here assumed concurrent and uniform peak surge, wind speed, wind direction, and sustained wind duration. Therefore, the wave results presented can be considered as worst case conditions.

Table 5.1 – Wind-Wave characteristics during hurricanes at CCLNG.										
	Hurricane Category									
Wind Direction	1		2		3		4		5	
	H_{mo} (ft)	T_P(sec)	H_{mo} (ft)	T_P(sec)	H_{mo} (ft)	T_P(sec)	H_{mo} (ft)	T_P(sec)	H_{mo} (ft)	T_P(sec)
180°	6.7	5.4	8.1	5.9	10.6	6.7	13.8	7.5	16.1	8.0
190°	6.7	5.5	8.2	6.0	10.6	6.7	13.9	7.5	16.2	8.0
200°	6.7	5.4	8.1	5.9	10.6	6.7	13.8	7.5	16.1	7.9
210°	6.6	5.4	8.1	5.9	10.5	6.6	13.7	7.5	16.0	7.9
220°	6.6	5.3	8.0	5.8	10.4	6.5	13.6	7.4	15.8	7.8
230°	6.5	5.3	7.9	5.8	10.3	6.5	13.4	7.3	15.5	7.7
240°	6.3	5.2	7.7	5.6	10.0	6.3	13.0	7.1	15.1	7.5
Channel	6.7	5.4	8.1	5.9	10.6	6.7	13.8	7.5	16.1	8.0

Assuming non-linear wave shape, the wave crest height above still-water can be estimated as $0.7H_{mo}$. This crest height was then added to the MOM elevation (see Figure 5.1) to yield an approximate upper limit for total water levels (η_{tot}) presented in Table 5.2. This analysis shows that in a worst case scenario, the total water surface elevation (combined surge and waves) could reach heights of approximately 31.5 ft above NGVD '29 along the shoreline.

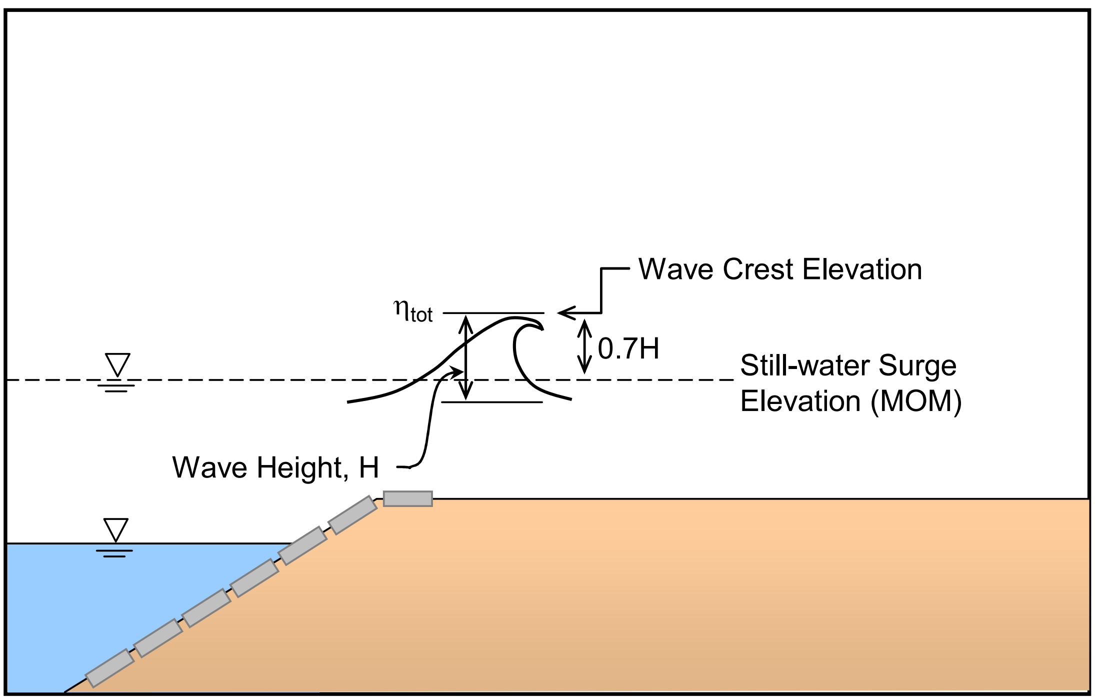

Figure 5.1 – Illustration of total water level elevation with combined surge and waves.

Table 5.2 – Total water level elevations summary.					
	Hurricane Category				
	1	2	3	4	5
MOM (ft NGVD)	4	6.3	10.5	15.4	20.3
η_{tot} (ft NGVD)	*8.6*	*11.9*	*17.9*	*25*	*31.5*

5.2 Depth-Limited Wave Analysis

Because of the relatively high elevations of existing upland areas, still-water levels resulting from storm surge presented in Table 5.2 would not support waves of significant height within areas away from the shoreline and berthing area. However, even though the surge alone may not overtop the bluff, waves breaking along the shoreline could spill landward, causing some inundation of the CCLNG upland areas near the shoreline. In general, the upland facilities are not at risk from significant wave damage.

It is important to note that the wave analyses presented herein do not include complex non-linear wave/structure or wave/wave interaction, wave shoaling effects, wave run-up, or spectral/statistical analysis required for design of shoreline protection measures or structures. Further analysis and more comprehensive numerical modeling would be required for final design of shoreline protection measures and critical infrastructure subject to wave attack. Therefore, the information presented here should be considered qualitative and used to determine design elevations for critical infrastructure at the proposed CCLNG site.

6.0 CONCLUSIONS

- The proposed CCLNG terminal is located in the area subject to coastal flooding from hurricane storm surge and wave effects. However, the existing site elevations and the position of the island just to the southeast of the site provide some protection against storm surge and wind generated waves.

- The SLOSH model appears to provide a reasonable representation of potential hurricane surge elevations, considering observations from previous hurricanes. Based on the SLOSH data, still-water surge elevations at the site are not likely to exceed approximately 20.3 ft NGVD '29 for Category 5 hurricanes. The SLOSH model results do not include wave effects.

- Based on a qualitative wave analysis, wind-waves produced by local hurricane-strength winds acting on elevated water levels in Corpus Christi Bay should be considered in the design of critical infrastructure at the proposed CCLNG site. Equipment and structures located along the shoreline and within the berthing area would be subjected to the most destructive wave effects. Significant wave height could range from 6 to 16 ft in certain worst case scenarios.

- The combined effects of storm surge and wind-waves greatly increase potential water level elevations. Design of facilities along the shoreline and near the berthing area should consider the combined effect of storm surge and waves as provided in Table 5.2.

- The upland areas of the CCLNG are unlikely to experience flooding from storm surge alone. However, large waves may overtop the existing bluff or shoreline protection during severe Category 5 conditions and inundate portions of the upland site.

- According to FEMA, zones along the shoreline are subject to flooding during a 100-yr storm event. FEMA recommends that structures in these zones be elevated to reduce damage from a 100-yr event.

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