Interim Guidance on Hurricane Conditions in the Gulf of Mexico

API BULLETIN 2INT-MET
MAY 2007

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Upstream Segment

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CONTENTS

Page

Tables

Interim Guidance on Hurricane Conditions in the Gulf of Mexico

1 Introduction

This interim document presents hurricane-driven metocean conditions (wind, wave, current and surge) for use with and reference by other API standards. These conditions are intended to replace the conditions documented in Sections 2.3.4.c and 17.6.2.a of API RP 2A-WSD, 21st Edition and Appendix C.4 of ISO 19901-1.

The metocean conditions documented herein are for guidance and will not generally provide as accurate a result as a dedicated site-specific study. Performance of a site-specific metocean study is the preferred way of ensuring that regional variations in storm climate and local topographic and bathymetric effects are properly accounted for, and that sufficient data is available to properly identify the phasing between wind, wave, current and surge. When performing response-based analyses, a site-specific study must be performed to develop the necessary time histories of metocean parameters. Site-specific studies should be performed within the guidelines included in this document.

1.1 BACKGROUND

The hurricane metocean conditions presently contained in the 21st Edition of API RP 2A-WSD have not been updated since 1993. Since that time, several major severe storms, most notably Opal (1995), Ivan (2004) and Katrina (2005), have affected the Gulf, resulting in increases to local extremes in the areas affected by these storms. Most importantly, however, industry's understanding of hurricane risk has continued to evolve. Strong evidence now exists for there being a regional dependence for large, intense wave-making storms. Also, investigations into the underlying hurricane record, HURDAT, used as the foundation for the industry's storm hindcast database, have revealed that storms from the early period of the database are probably biased low in terms of intensity.

A new set of hurricane conditions has been derived for reference by other API standards using the latest hindcast storm record and incorporating the industry's best understanding to date of the regional dependence of storm intensity. Conditions are presented for four regions, the boundaries of which are:

- West, between 97.5°W and 95°W
- West Central, between 94°W and 90.5°W
- Central, between 89.5°W and 86.5°W
- East, between 85.5°W and 82.5°W

The database used to establish conditions has been restricted to the years from approximately 1950 through 2005, the period for which better characterization of storms offshore exists by virtue of aerial reconnaissance and later satellite observations.

Of the four regions, changes relative to previous API RP 2A-WSD values are most pronounced in the Central region. Conditions in other regions are similar to those contained in API RP 2A-WSD.

The conditions presented herein are based on an "as-is" acceptance of the hindcast record from approximately 1950 through 2005. They do not include artificial increases to values derived from statistical analysis of the hindcast record beyond those associated with several of the extrapolations involved and make no claim to be conservative. Nor do they consider the possibility of storms with a wave-making potential like Opal, Ivan and Katrina affecting the non-Central regions with a frequency similar to that which has been observed in the Central region.

1.2 ORGANIZATION

The document is organized as follows:

- Section 1: Introduction.
- Section 2: Definitions of terms used.
- Section 3: A description of the four regions, and notes of areas and water depths where the conditions do not apply.
- Section 4: Hurricane-driven independent extremes of wind, wave, current and surge.
- Section 5: Factors for combining the independent extremes in Section 4 into load cases centered on a particular extreme (peak wind, peak wave or peak current).
- Section 6: Example applications of deriving conditions at sites.
- Section 7: A description of "sudden" hurricane conditions for the Northern Gulf of Mexico.

- Section 8: Recommendations for deriving "seasonal" hurricane conditions.
- Section 9: Guidelines for the performance of site-specific studies of hurricane conditions.
- Section 10: Commentary on the conditions presented, summarizing how they were derived and listing select references.

Users of this interim document should thoroughly review the commentary on hurricane conditions included in Section 10 prior to referencing any of the conditions or methods presented herein. The commentary summarizes the technical basis and assumptions used in deriving the conditions. A review of Section 6 is also recommended, as it presents several examples on how wind, wave, current and surge conditions can be established for a given site from the charts and tables in this document.

1.3 LIMITATIONS AND ONGOING WORK

This document only addresses hurricane conditions for the Gulf of Mexico. It does not address other phenomena such as winter storms, the Loop Current, and other deepwater currents, or the joint occurrence of hurricane and Loop/deepwater current phenomena. Furthermore, it does not specify conditions for hurricane-generated bottom currents for water depths beyond 70 m (230 ft). Conditions for these phenomena should be derived through site-specific studies using appropriate hindcast models and quality measurements.

Users of this interim document should be aware that work on hurricane conditions by the API RP 2MET work group is ongoing; additional work is in progress to further examine the following:

- Extremal estimates for all parameters, for return periods in excess of 200 years.
- Wave-current interaction.
- Hurricane currents in shallow and deep water.
- Sudden hurricane conditions.
- Conditions in extremely shallow water (0 m – 10 m or 0 ft – 33 ft).

The provisions in this document are intended to remain in force until a new API recommended practice covering metocean conditions (not limited to hurricanes), API RP 2MET, is published.

2 Definitions

WD	Water depth, referenced to MLLW
MLLW	Mean lower low water
WS	Wind speed
H_s	Significant wave height, defined by $4(m_0)^{0.5}$
$H_{\max}$	Expected maximum individual wave height
$\eta_{\max}$	Expected maximum individual crest height
m_0	The energy contained in the wave spectrum
Surge	The change in sea level caused by the passage of a storm
Tide	Astronomically-driven changes in sea level
Heading	Heading convention is "towards" i.e., the direction T_0 which wind, wave or current are acting
COV	Coefficient of Variation
Shallow	Water depths between 10 m and 70 m (33 ft and 230 ft)
Deep	Water depths greater than or equal to 150 m (492 ft)
Transition	Water depths greater than 70 m (230 ft) and less than 150 m (492 ft)

3 Regions and Areas of Applicability

Hurricane-driven metocean conditions are provided for most areas of the Gulf of Mexico north of 26°N, in water depths (WD) greater than or equal to 10 m (33 ft) mean lower low water level (MLLW). Conditions are presented for four approximate regions of differing hurricane climatology, as shown in Figure 3-1. The regions have been selected based on consideration of trends in (1) storm size and intensity, (2) regional wind and wave extremes, (3) frequency of Loop Current and eddies, and (4) paths storms may take entering the Gulf. The regions are:

- West, between 97.5°W and 95°W
- West Central, between 94°W and 90.5°W
- Central, between 89.5°W and 86.5°W
- East, between 85.5°W and 82.5°W

Between each region are areas of transition (unshaded), 1° longitude wide. Conditions for these transition areas should be derived by linearly interpolating between the values of the two adjacent regions across the width of the transition. For example, if a site lies at 90.25°W, then conditions for that site would be derived by using those from the West Central region weighted 0.75 and those from the Central region weighted 0.25.

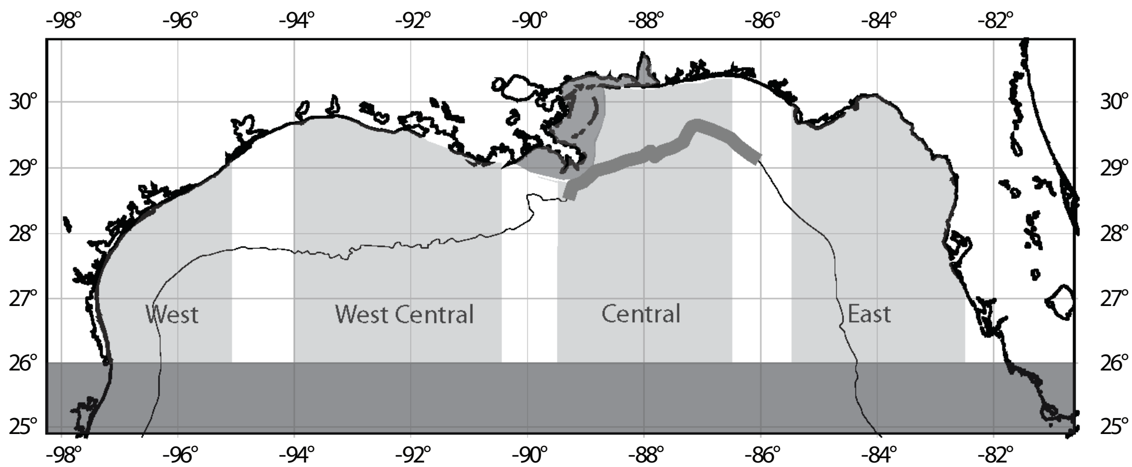


Figure 3.1—Gulf Regions and Areas of Applicability

The conditions in this document do not apply to the following:

- Water depths less than 10 m (33 ft). Shallow areas near the coast will be subject to high surge levels which will depend on the steepness of the local terrain (both bathymetry and overland elevation) as well as the coastal profile. The storm surge very near the coast may allow for the existence of large waves which otherwise would not be possible for calm water conditions.
- Areas inside barrier islands and those around the Mississippi Delta. The shaded areas around the Delta and inside barrier islands will be subject to sheltering, limited fetch and possible attenuation of waves by interaction with mud, and may have complicated surge and current patterns, while areas east of the barrier islands will be subject to complicated currents.
- The steep bathymetry transition (70 m – 500 m or 230 ft – 1640 ft) of the Central region. This shaded area is subject to complicated currents following the passage of hurricanes, which result from the superposition of local wind-generated currents and offshore flow from surge trapped in the area of Eastern Louisiana.

Conditions for areas where the conditions do not apply must be derived by site-specific studies, the performance of which is discussed in Section 9.

4 Independent Extreme Wind, Wave, Current and Surge

Independent extreme values of wind, wave, current and surge have been calculated for return periods of 10, 25, 50, 100, 200, 1000, 2000, and 10000 years for each region and are presented in the tables and figures in 4.5.

Each table shows the following parameters for a given region:

- N-year wind velocities for all water depths.
- N-year waves for water depths greater than or equal to 1000 m (3281 ft).

- Associated periods for n-year waves in all water depths.
- N-year current profiles for water depths greater than or equal to 150 m (492 ft).
- N-year depth-averaged currents for water depths between 10 m and 70 m (33 ft and 230 ft).
- N-year surge for water depths greater than or equal to 500 m (1640 ft).
- Astronomical tide amplitude (0.42 m or 1.4 ft) from MLLW for all water depths (constant for all return periods).

The figures show the following parameters for each region over the water depth range from 10 m – 1000 m (33 ft – 3281 ft):

- N-year H_s.
- N-year H_{max}.
- N-year η_{max} (including associated storm surge and astronomical tide).
- N-year storm surge including astronomical tide.

Each of the parameters is further described below.

4.1 WIND

The 10 m (32.8 ft) elevation wind velocities presented in Tables 4.5.1 to 4.5.4 are applicable to all water depths. The extreme winds should be treated as omni-directional. When adjusting these wind speeds to different averaging intervals and/or elevations, or when developing wind spectra, the following formulas should be used. These formulas are dimensional; one set is provided in SI Units and the other in U.S. Customary Units. It should be noted the spatial coherence formulas (2.3.2-6 and 2.3.2-7) contained in API RP 2A-WSD, 21st Edition (with Supplement 2) are not dimensionally correct for U.S. Customary Units, and the value of α_3 is incorrect. This error has been fixed in API RP 2A-WSD, 21st Edition Supplement 3.

4.1.1 Wind Profiles and Gusts, SI Units

For strong wind conditions (near-neutral stratification) the design wind speed $u(z, t)$ (m/s) at height z (m) above sea level and corresponding to an averaging time period $t \le t_0 = 3600$ s is given by:

$$u(z, t) = U(z)[1 - 0.41 I_u(z)\ln(t/t_0)]$$

where the 1-hour mean wind speed $U(z)$ (m/s) at level z is given by:

$$U(z) = U_0\left[1 + C\ln\left(\frac{z}{10}\right)\right], \qquad C = 0.0573\sqrt{1 + 0.15U_0}$$

and where the turbulence intensity $I_u(z)$ at level z is given by:

$$I_u(z) = 0.06[1 + 0.043U_0]\left(\frac{z}{10}\right)^{-0.22}$$

where U_0 (m/s) is the 1-hour average wind speed at 10 m elevation.

4.1.2 Wind Profiles and Gusts, U.S. Customary Units

For strong wind conditions (near-neutral stratification) the design wind speed $u(z, t)$ (ft/s) at height z (ft) above sea level and corresponding to an averaging time period $t \le t_0 = 3600$ s is given by:

$$u(z, t) = U(z)[1 - 0.41 I_u(z)\ln(t/t_0)]$$

where the 1-hour mean wind speed $U(z)$ (ft/s) at level z is given by:

$$U(z) = U_0\left[1 + C\ln\left(\frac{z}{32.8}\right)\right], \qquad C = 0.0573\sqrt{1 + 0.0457U_0}$$

and where the turbulence intensity $I_u(z)$ at level z is given by:

$$I_u(z) = 0.06[1 + 0.013\,U_0]\left(\frac{z}{32.8}\right)^{-0.22}$$

where U_0 (ft/s) is the 1-hour average wind speed at 32.8 ft elevation.

4.1.3 Wind Spectra, SI Units

For structures and structural elements for which the dynamic wind behavior is of importance, the following 1-point wind spectrum may be used for the energy density of the longitudinal wind speed fluctuations:

$$S(f) = \frac{320\left(\frac{U_0}{10}\right)^2\left(\frac{z}{10}\right)^{0.45}}{(1+\tilde{f}^{\,n})^{(5/3n)}}$$

$$\tilde{f} = 172f\left(\frac{z}{10}\right)^{2/3}\left(\frac{U_0}{10}\right)^{-0.75}$$

where $n = 0.468$ and where:

- $S(f)$ (m^2s^{-2}/Hz) is the spectral energy density at frequency f (Hz)
- z (m) is the height above sea level
- U_0 (m/s) is the 1-hour mean wind speed at 10 m above sea level

4.1.4 Wind Spectra, U.S. Customary Units

For structures and structural elements for which the dynamic wind behavior is of importance, the following 1-point wind spectrum may be used for the energy density of the longitudinal wind speed fluctuations:

$$S(f) = \frac{3444.8\left(\frac{U_0}{32.8}\right)^2\left(\frac{z}{32.8}\right)^{0.45}}{(1+\tilde{f}^{\,n})^{(5/3n)}}$$

$$\tilde{f} = 172f\left(\frac{z}{32.8}\right)^{2/3}\left(\frac{U_0}{32.8}\right)^{-0.75}$$

where $n = 0.468$ and where:

- $S(f)$ (ft^2s^{-2}/Hz) is the spectral energy density at frequency f (Hz)
- z (ft) is the height above sea level
- U_0 (ft/s) is the 1-hour mean wind speed at 32.8 ft above sea level

4.1.5 Spatial Coherence, SI Units

The squared correlation between the spectral energy densities $S(f)$ of the longitudinal wind speed fluctuations of frequency f between two points in space is described by the 2-point coherence spectrum.

The recommended coherence spectrum between two points (x_i , y_i , z_i in m)

- at levels z_1 and z_2 above the sea surface
- with across-wind positions y_1 and y_2
- with along-wind positions x_1 and x_2

is given by:

$$\mathrm{Coh}(f) = \exp\left\{-\frac{1}{U_0}\left[\sum_{i=1}^{3} A_i^{2}\right]^{\frac{1}{2}}\right\}$$

where

$$A_i = \alpha_i f^{r_i} \Delta_i^{q_i} z_g^{-p_i}, \qquad z_g = \sqrt{\frac{z_1 z_2}{10}}$$

and where the coefficients α, p, q, r and the distances Δ are given in Table 4.1.3.1.

4.1.6 Spatial Coherence, U.S. Customary Units

The squared correlation between the spectral energy densities $S(f)$ of the longitudinal wind speed fluctuations of frequency f between two points in space is described by the 2-point coherence spectrum.

The recommended coherence spectrum between two points (x_i, y_i, z_i in ft)

- at levels z_1 and z_2 above the sea surface
- with across-wind positions y_1 and y_2
- with along-wind positions x_1 and x_2

is given by:

$$\mathrm{Coh}(f) = \exp\left\{-\frac{1}{U_0/3.28}\left[\sum_{i=1}^{3} A_i^{2}\right]^{\frac{1}{2}}\right\}$$

where

$$A_i = \alpha_i f^{r_i}\left(\frac{\Delta_i}{3.28}\right)^{q_i} z_g^{-p_i}, \qquad z_g = \sqrt{\frac{z_1 z_2}{32.8}}$$

and where the coefficients α, p, q, r and the distances Δ are given in Table 4.1.3.1.

Table 4.1.3.1—Coefficients and Distances for the 3-D (i = 1,2,3) Coherence Spectrum

i	Δ_i	q_i	p_i	r_i	α_i
1	$\lvert x_2 - x_1 \rvert$	1.00	0.4	0.92	2.9
2	$\lvert y_2 - y_1 \rvert$	1.00	0.4	0.92	45.0
3	$\lvert z_2 - z_1 \rvert$	1.25	0.5	0.85	13.0

4.2 WAVES

Wave conditions are presented in the form of H_s, H_{max}, and η_{max} as well as associated T_p and T_{Hmax}. The wave heights in the tables are applicable for water depths greater than or equal to 1000 m (3281 ft), while the associated periods in the tables are applicable to all water depths. For wave heights in depths between 10 m and 1000 m (33 ft and 3281 ft), the appropriate regional wave height depth decay curve figure should be consulted.

4.2.1 Wave Crests

The crest elevations η_{max} shown in the tables and figures include associated surge and tide. The crest elevations provided in this document do not include any artificial air gap allowance like the 1.5 m (5 ft) previously recommended in API RP 2A-WSD. It should be noted that the maximum n-year η_{max} does not necessarily occur together with the n-year H_{max}.

It must be understood that these crests are based on the risk of exceedance at a single point; as a platform deck is in affect represented by many points, the probability of exceeding this value at some location within the deck area is higher than the single point exceedance probability. For the same risk of non-exceedance, the highest local maximum crest which could occur within a typical deck area may be as much as 15% higher than the point estimate.

4.2.2 Extreme Wave Direction

The extreme waves presented in the tables and figures in 4.5 are omni-directional. Directional extreme waves for return periods greater than 10 years and for water depths greater than 30 m (98 ft) may be approximated by factoring the omni-directional value using Figure 4.2.2-1. The principal wave heading varies with longitude. The factors listed apply within ±22.5° of the headings shown. When estimating directional extreme waves, the directional extreme should not be reduced below the level of the omni-directional 10-year return period wave. Figure 4.2.2-1 does not apply to depths less than 30 m (98 ft), as inside this depth refraction will begin to turn the wave crests parallel to the local bathymetry. It also does not apply east of 84°W, where principal wave direction becomes quite variable depending on proximity to the Florida coast.

4.2.3 Wave Spectra and Spreading

Hurricane-driven seas can be reasonably represented by the JONSWAP spectrum with a γ of 2.0 – 2.5. Wave spreading can be represented using the form $\cos^{n}(\theta)$, with n in the range of 2.0 – 2.5.

4.3 CURRENTS

Currents are shown in the tables for water depths between 10 m and 70 m (33 ft and 230 ft), and water depths greater than 150 m (492 ft). It should be noted no deepwater bottom currents from hurricanes are provided; these should be derived by site-specific studies.

4.3.1 Shallow Water Currents

Currents in water depths less than or equal to 70 m (230 ft) are nearly uniform with depth due to their driving mechanism (horizontal pressure gradients). The table for each region lists uniform currents for 10 m and 70 m (33 ft and 230 ft); between these depths, the current should be derived by interpolation. Extreme currents in water depths less than or equal to 70 m (230 ft) generally follow the shelf contours, and flow in a westerly direction. Figure 4.3.1-1 provides guidance for current headings in water depths less than 70 m (230 ft).

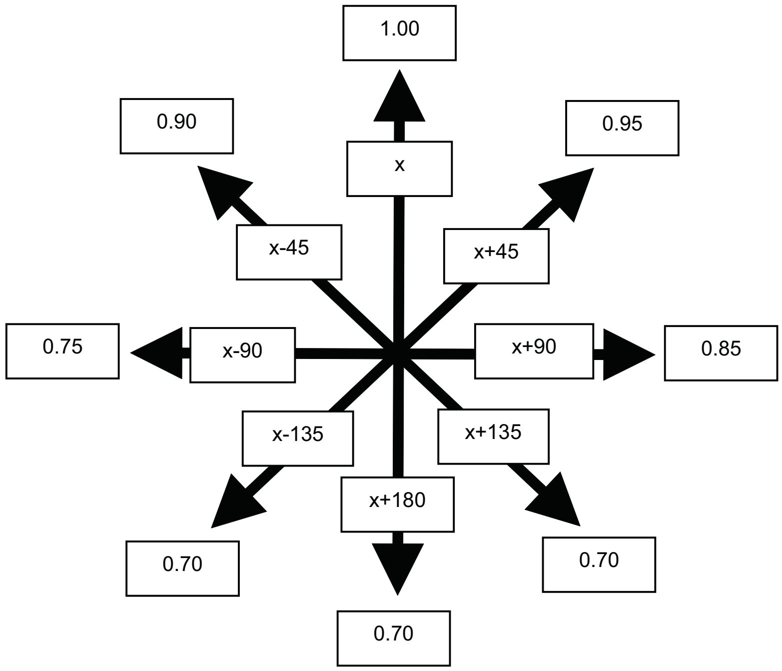
4.3.2 Deepwater Currents

Currents in water depths greater than or equal to 150 m (492 ft) have a sheared velocity profile which penetrates to the bottom of the mixed layer of the upper ocean. They are represented in the regional tables as a 3-point profile:

- Surface speed: current speed at the surface (WD = 0) of the ocean, including any surge and tide.
- Speed at mid-profile: current speed at a depth halfway between the surface (WD = 0) and the depth of the bottom of the profile (0-speed depth).
- 0-speed depth: the depth, measured from the surface, at which the current speed goes to zero, which is the bottom of the profile.

Current speeds between the surface, mid-profile and 0-speed depths should be derived by linear interpolation.

The deepwater currents provided in the tables represent those which are generated at or within 12 hours of the closest approach of a hurricane to a given site. As such the currents are confined to the upper layer of the ocean. No current is specified below the 0-speed depth in the tables, however this should not be taken as an indication that hurricane-driven currents do not penetrate deeper into the water column. Over a time period of several days, some of the momentum in the upper layer of the ocean will be transferred downward, resulting in currents below the 0-speed depth given in the table. Resolution of these deeper hurricane current components should be resolved by site-specific studies.



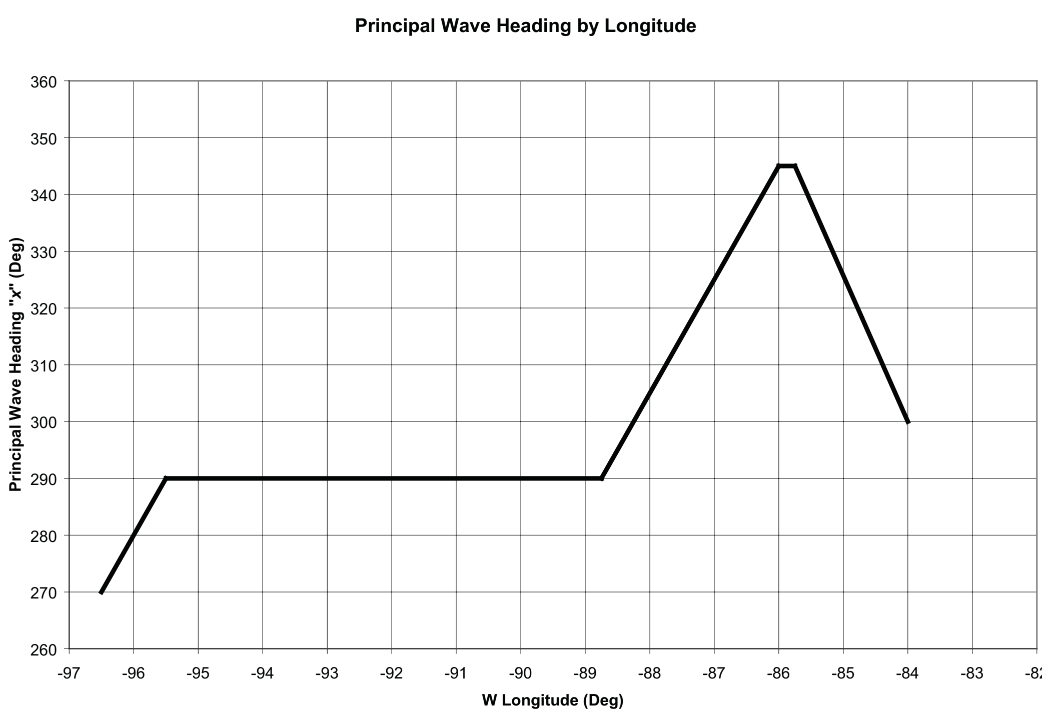


Figure 4.2.2-1—Direction Factor for Wave Heights North of 26°N, West of 84°W, WD > = 30m (98 ft), Return Periods > 10 Year

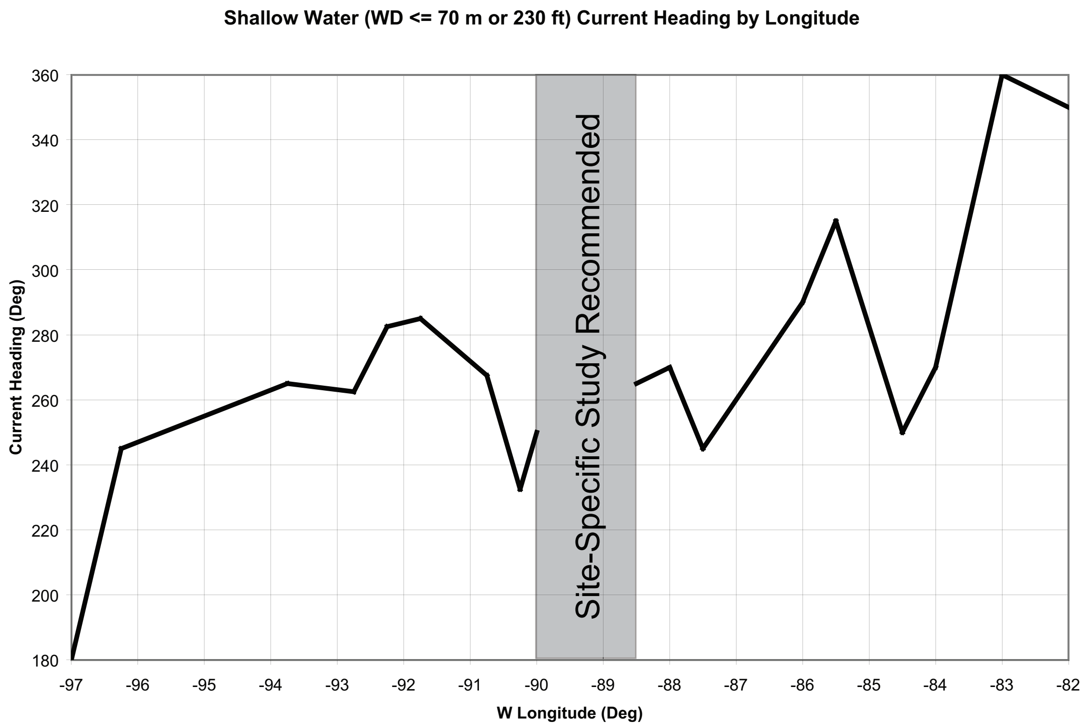


Figure 4.3.1-1—Current Heading North of 26°N, WD < = 70m (230 ft)

Extreme currents in water depths greater than or equal to 150 m (492 ft) should be treated as omni-directional; they should not be factored in proportion to wave height. The headings of these currents will generally rotate clockwise in time under the action of coriolis force as they slowly decay following the passage of a storm. For the latitude range of the Gulf of Mexico, the current heading will rotate a full 360° clockwise approximately every 22 hours.

4.3.3 Currents in Transition Zone

Currents in water depths between 70 m and 150 m (230 ft and 492 ft) will be in a state of transition as controlled by the relative magnitudes of the two current forcing mechanisms (horizontal pressure gradients and local wind stress). Currents in these water depths can be approximated by interpolating between the nearly uniform current profile specified for 70 m (230 ft) (assuming it has a 3-point shape), and the deepwater storm current 3-point profile specified for water depths greater than or equal to 150 m (492 ft). The interpolation involves several steps; the example in Section 6 should be reviewed carefully.

When determining currents in the transition zone, current profiles for the shallow and deep areas should first be determined. The shallow water current should be assumed to also follow a 3-point profile for the purpose of interpolation by the following conversion:

- Surface speed: 70 m (230 ft) current speed
- Speed at "mid-profile": 70 m (230 ft) current speed, mid-point set to 70 m (230 ft)
- 0-speed depth: 70 m (230 ft)

The resulting profile at the depth between 70 m and 150 m (230 ft and 492 ft) should then be derived by linearly interpolating between the 70 m and 150 m (230 ft and 492 ft) profiles to the desired depth for each of the three points (surface speed, mid-profile level and speed, and 0-speed depth) to define a new 3-point profile. For example, if a site is in 100 m (328 ft), the new profile would be derived by weighting the points from the profile at 70 m by (150 m – 100 m)/(150 m – 70 m), or 230 ft by (492 ft – 328 ft)/(492 ft – 230 ft), and the points from the profile at 150 m by (100 m – 70 m)/(150 m – 70 m), or 492 ft by (328 ft – 230 ft)/(492 ft – 230 ft).

The peak current in the transition region may be considered omni-directional, however, in reality the current would tend to align parallel to the local bathymetry in depths closer to 70 m (230 ft). In situations where the 70 m and 150 m (230 ft and

492 ft) currents have prescribed headings, the direction of the new profile can be approximated as the heading of the resultant derived from the 70 m (230 ft) current and the average current over the upper 70 m (230 ft) of the 150 m (492 ft) current profile. The magnitudes of each should be weighted to the desired depth as is done for the profile calculation, prior to resolving the resultant direction.

4.4 SURGE AND TIDE

The tables show storm surge for water depths greater than or equal to 500 m (1640 ft), and astronomical tidal amplitude applicable to all water depths. For storm surge in water depths between 10 m and 500 m (33 ft and 1640 ft), the appropriate regional figure should be consulted; note that the curves in the figures include the tidal amplitude.

4.5 INDEPENDENT EXTREMES BY REGION

The following subsections present the independent extremes for each of the four geographical regions (West, West Central, Central and East). Tables and figures marked “A” are in SI Units, while those marked “B” are in U.S. Customary Units.

4.5.1 West

Table 4.5.1-1A—Independent Extreme Values for Hurricane Wids, Waves, Currents and Surge, Western Gulf of Mexico (97.5°W to 95.0°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (10 m Elevation)								
1-hour Mean Wind Speed (m/s)	22.5	31.2	36.0	39.9	43.0	49.9	51.9	57.9
10-min Mean Wind Speed (m/s)	24.5	34.4	40.0	44.7	48.4	56.8	59.3	66.8
1-min Mean Wind Speed (m/s)	27.0	38.6	45.2	50.8	55.3	65.7	68.8	78.3
3-sec Gust (m/s)	30.2	43.9	52.0	58.8	64.4	77.3	81.2	93.1
Waves, WD > = 1000 m								
Significant Wave Height (m)	6.8	9.8	11.3	13.1	13.7	16.4	17.0	19.0
Maximum Wave Height (m)	12.0	17.3	20.0	23.1	24.2	28.9	30.1	33.6
Maximum Crest Elevation (m)	8.0	11.4	13.1	15.2	16.0	18.9	19.6	21.7
Peak Spectral Period (s)	12.2	13.8	14.4	15.1	15.3	16.7	17.1	18.0
Period of Maximum Wave (s)	11.0	12.4	13.0	13.6	13.8	15.1	15.4	16.2
Currents, WD > = 150 m								
Surface Speed (m/s)	1.13	1.56	1.80	2.00	2.15	2.49	2.59	2.89
Speed at Mid-profile (m/s)	0.84	1.17	1.35	1.50	1.61	1.87	1.95	2.17
0-Speed Depth (m)	47.3	65.5	75.6	83.8	90.3	104.7	108.9	121.5
Currents, WD 10 m – 70 m								
Uniform Speed at 10 m Depth (m/s)	0.61	1.17	1.56	1.91	2.22	2.69	2.91	3.61
Uniform Speed at 70 m Depth (m/s)	0.46	0.88	1.17	1.43	1.66	2.01	2.18	2.71
Water Level, WD > = 500 m								
Storm Surge (m)	0.17	0.32	0.46	0.60	0.76	0.84	0.91	1.14
Tidal Amplitude (m)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.1-1A, 4.5.1-2A and 4.5.1-3A for wave and crest elevation values for water depths between 10 m and 1000 m.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 70 m and 150 m should be estimated as described in 4.3.3.

See Figure 4.5.1-4A for surge and tide in water depths less than 500 m.

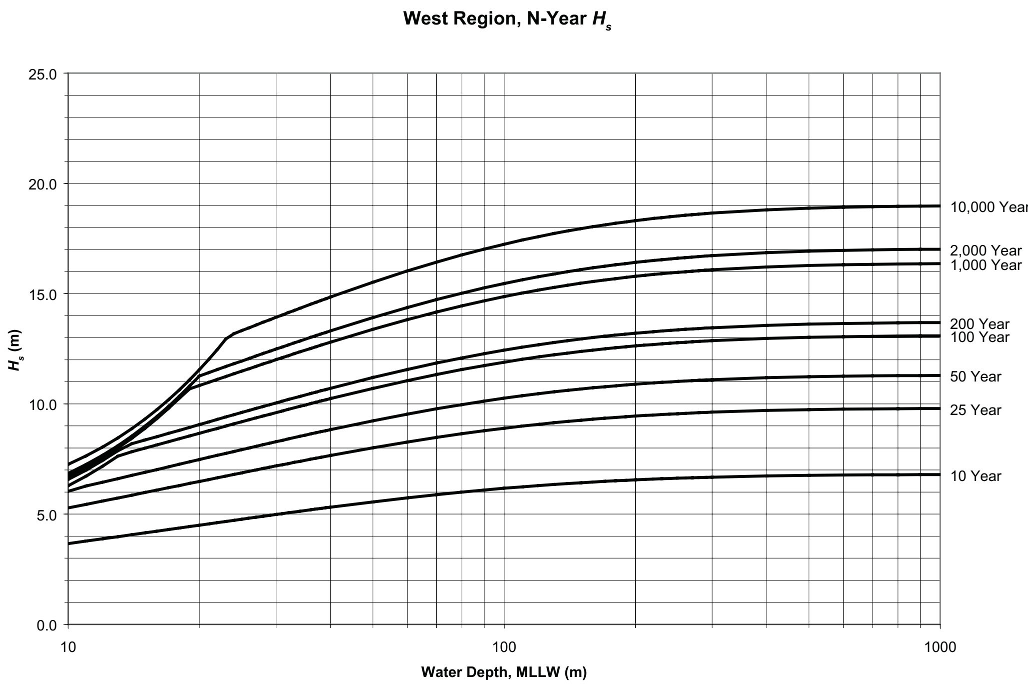


Figure 4.5.1-1A—N-Year H_s, West Region

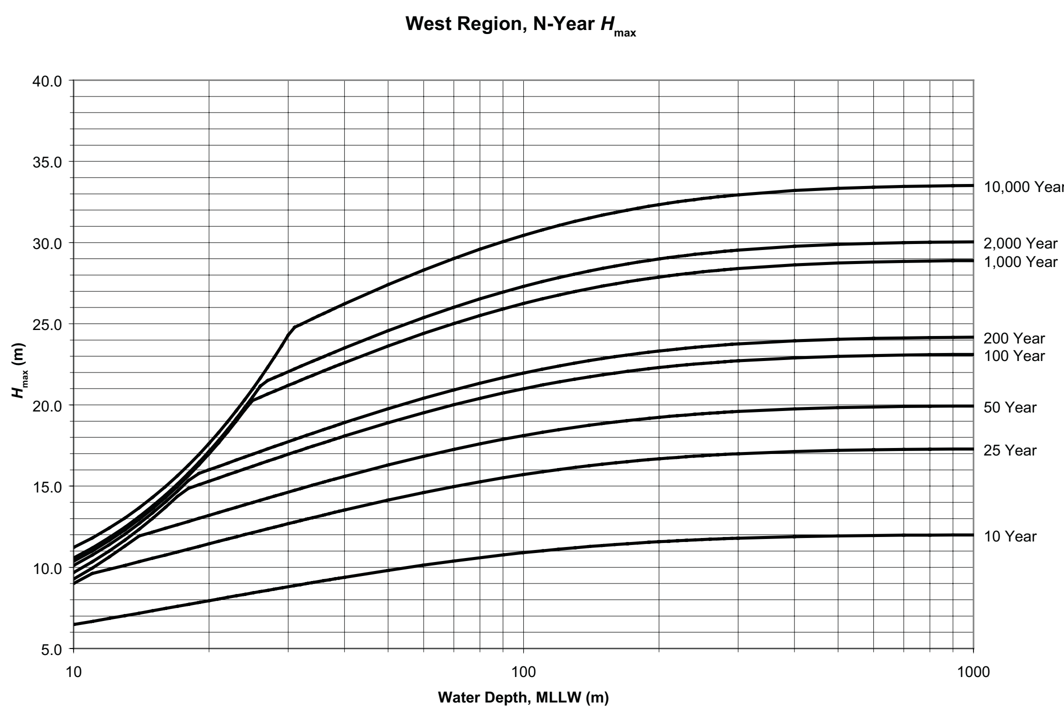


Figure 4.5.1-2A—N-Year H_{max}, West Region

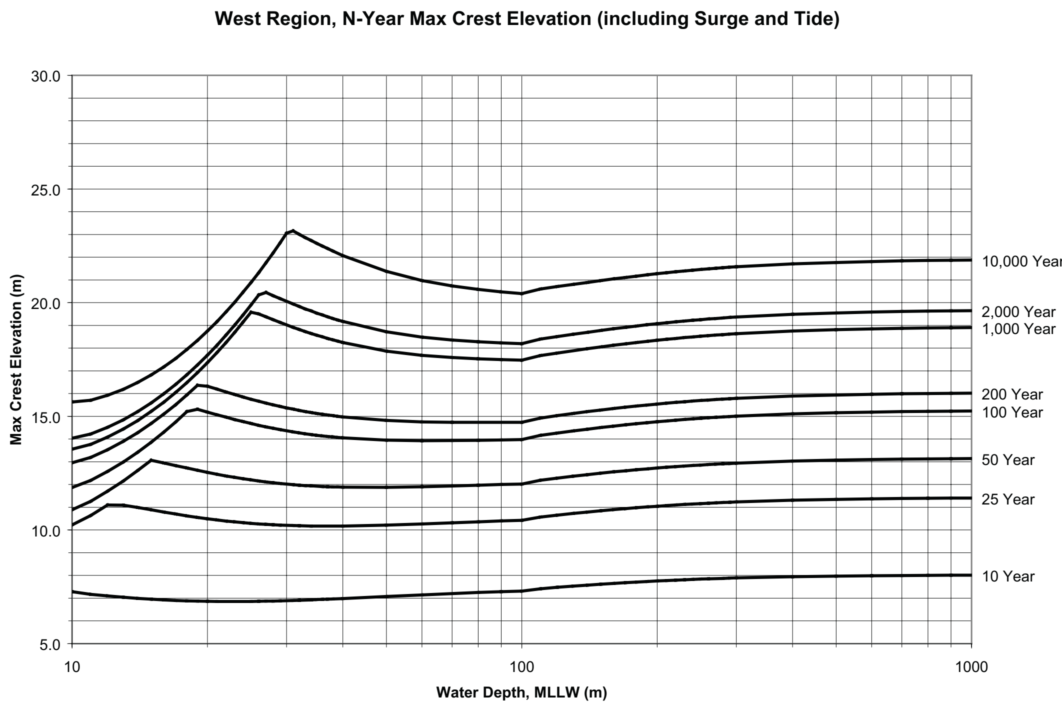


Figure 4.5.1-3A—N-Year Max Crest Elevation, West Region

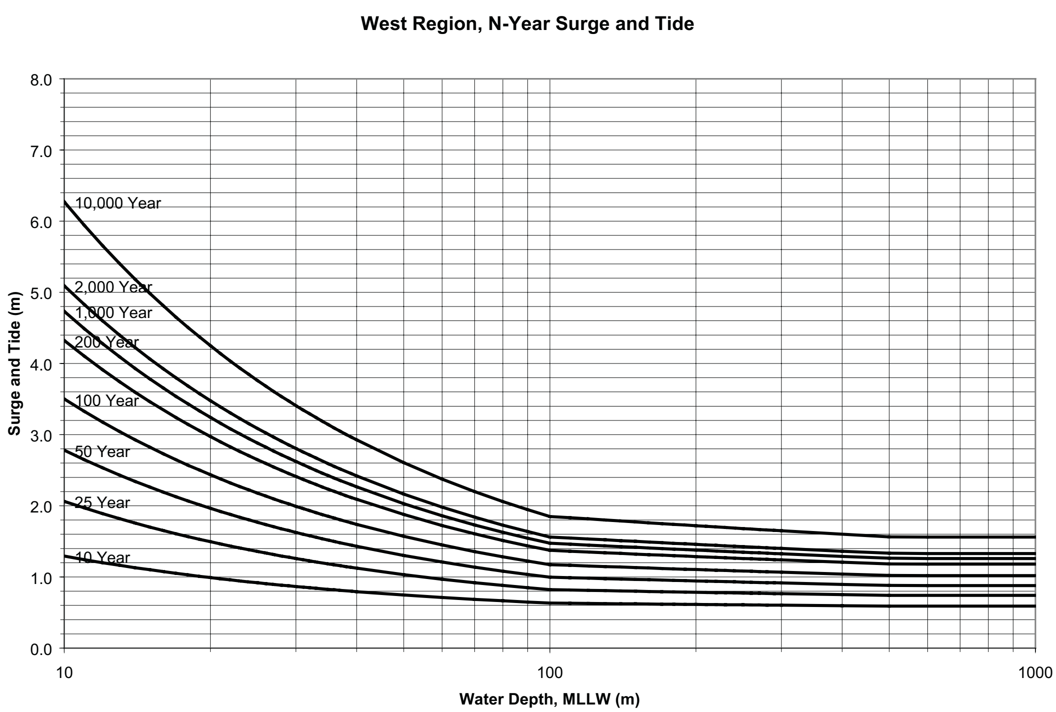


Figure 4.5.1-4A—N-Year Surge with Tide, West Region

Table 4.5.1-1B—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, Western Gulf of Mexico (97.5°W to 95.0°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (32.8 ft elevation)								
1-hour Mean Wind Speed (ft/s)	73.8	102.4	118.1	130.9	141.1	163.7	170.3	190.0
10-min Mean Wind Speed (ft/s)	80.4	112.9	131.2	146.7	158.8	186.4	194.6	219.2
1-min Mean Wind Speed (ft/s)	88.6	126.6	148.3	166.7	181.4	215.6	225.7	256.9
3-sec Gust (ft/s)	99.1	144.0	170.6	192.9	211.3	253.6	266.4	305.5
Waves, WD > = 3280 ft								
Significant Wave Height (ft)	22.3	32.2	37.1	43.0	44.9	53.8	55.8	62.3
Maximum Wave Height (ft)	39.4	56.8	65.6	75.8	79.4	94.8	98.8	110.2
Maximum Crest Elevation (ft)	26.2	37.4	43.0	49.9	52.5	62.0	64.3	71.2
Peak Spectral Period (s)	12.2	13.8	14.4	15.1	15.3	16.7	17.1	18.0
Period of Maximum Wave (s)	11.0	12.4	13.0	13.6	13.8	15.1	15.4	16.2
Currents, WD > = 492 ft								
Surface Speed (ft/s)	3.7	5.1	5.9	6.6	7.1	8.2	8.5	9.5
Speed at Mid-profile (ft/s)	2.8	3.8	4.4	4.9	5.3	6.1	6.4	7.1
0-Speed Depth (ft)	155	215	248	275	296	344	357	399
Currents, WD 33 ft– 230 ft								
Uniform Speed at 33 ft Depth (ft/s)	2.0	3.8	5.1	6.3	7.3	8.8	9.5	11.8
Uniform Speed at 230 ft Depth (ft/s)	1.5	2.9	3.8	4.7	5.4	6.6	7.2	8.9
Water Level, WD > = 1640 ft								
Storm Surge (ft)	0.6	1.0	1.5	2.0	2.5	2.8	3.0	3.7
Tidal Amplitude (ft)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.1-1B, 4.5.1-2B and 4.5.1-3B for wave and crest elevation values for water depths between 33 ft and 3280 ft.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 230 ft and 492 ft should be estimated as described in 4.3.3.

See Figure 4.5.1-4B for surge and tide in water depths less than 1640 ft.

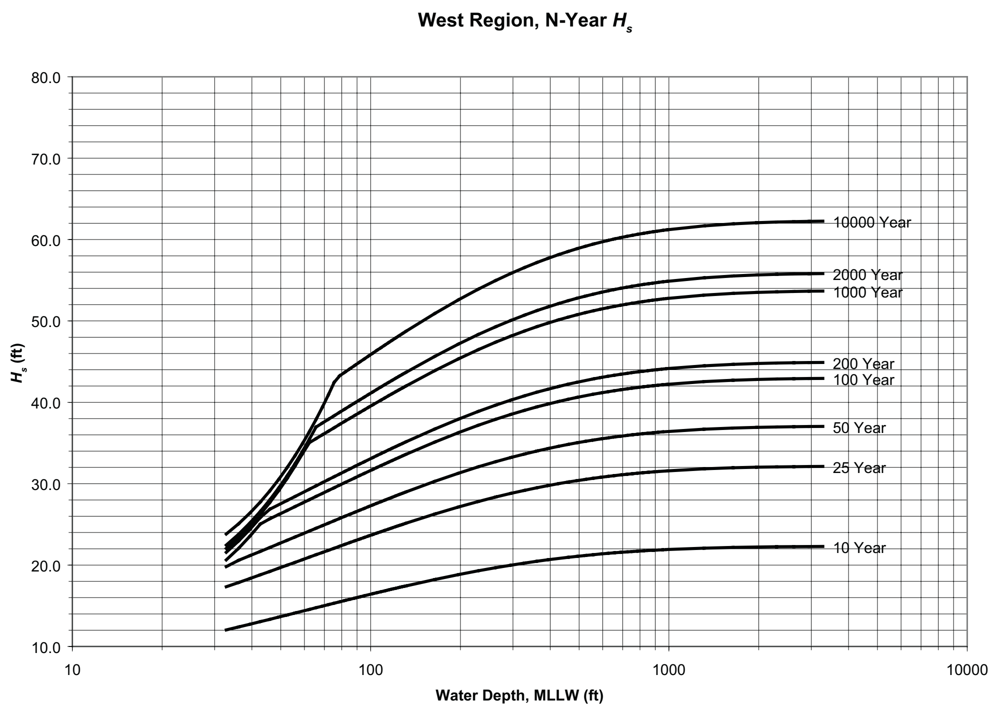


Figure 4.5.1-1B—N-Year H_s, West Region

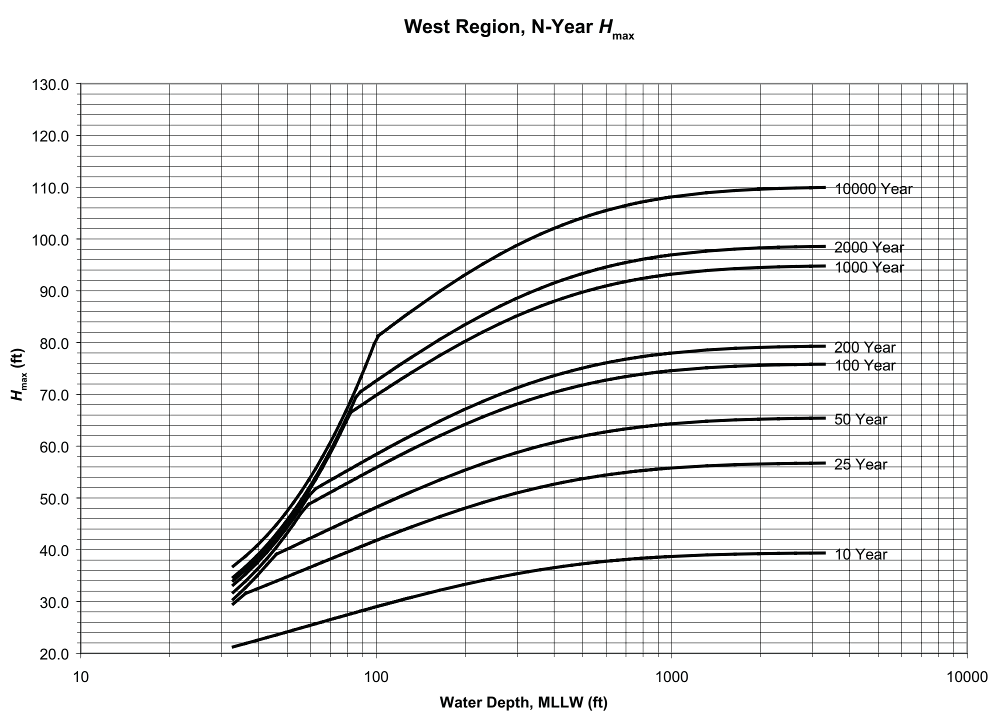


Figure 4.5.1-2B—N-Year H_{max}, West Region

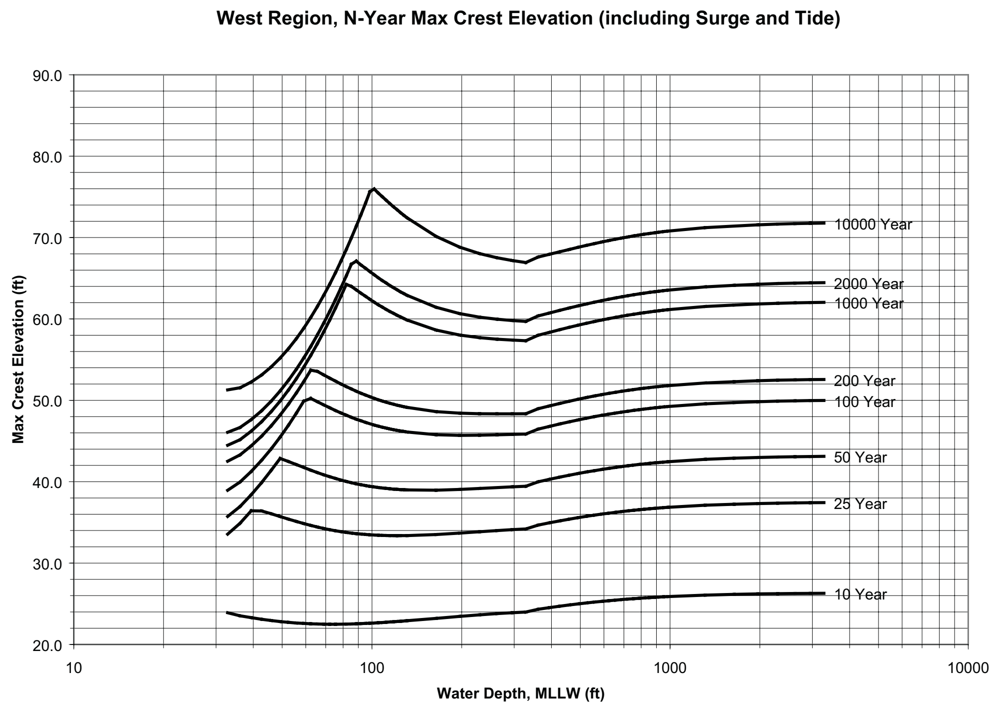


Figure 4.5.1-3B—N-Year Max Crest Elevation, West Region

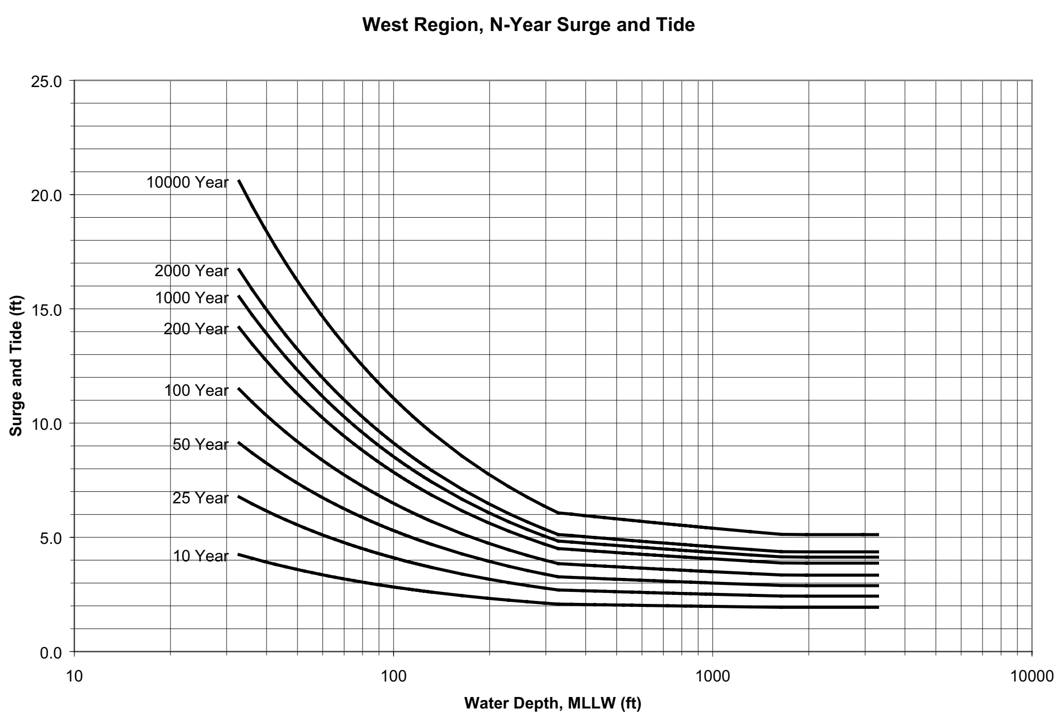


Figure 4.5.1-4B—N-Year Surge with Tide, West Region

4.5.2 West Central

Table 4.5.2-1A—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, West Gulf of Mexico (94.0°W to 90.5°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (10 m elevation)								
1-hour Mean Wind Speed (m/s)	24.9	30.4	34.3	38.1	41.6	47.6	49.3	55.2
10-min Mean Wind Speed (m/s)	27.2	33.5	38.0	42.5	46.7	54.0	56.1	63.4
1-min Mean Wind Speed (m/s)	30.1	37.5	42.9	48.2	53.3	62.2	64.8	74.0
3-sec Gust (m/s)	33.9	42.6	49.1	55.6	61.8	72.9	76.1	87.7
Waves, WD > = 1000 m								
Significant Wave Height (m)	8.1	10.2	11.5	12.3	13.5	15.4	16.0	17.8
Maximum Wave Height (m)	14.3	18.0	20.3	21.7	23.8	27.2	28.2	31.5
Maximum Crest Elevation (m)	9.6	12.0	13.5	14.5	15.9	18.0	18.6	20.7
Peak Spectral Period (s)	12.6	13.6	14.2	14.4	14.8	15.8	16.1	17.0
Period of Maximum Wave (s)	11.3	12.3	12.8	13.0	13.3	14.2	14.5	15.3
Currents, WD > = 150 m								
Surface Speed (m/s)	1.25	1.52	1.72	1.91	2.08	2.38	2.46	2.76
Speed at Mid-profile (m/s)	0.93	1.14	1.29	1.43	1.56	1.79	1.85	2.07
0-Speed Depth (m)	52.3	63.8	72.0	80.0	87.4	100.0	103.5	115.9
Currents, WD 10 m – 70 m								
Uniform Speed at 10 m Depth (m/s)	0.80	1.19	1.51	1.87	2.22	2.63	2.84	3.54
Uniform Speed at 70 m Depth (m/s)	0.56	0.83	1.06	1.31	1.56	1.84	1.99	2.48
Water Level, WD > = 500 m								
Storm Surge (m)	0.27	0.42	0.54	0.66	0.78	0.93	1.00	1.25
Tidal Amplitude (m)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.2-1A, 4.5.2-2A and 4.5.2-3A for wave and crest elevation values for water depths between 10 m and 1000 m.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 70 m and 150 m should be estimated as described in 4.3.3.

See Figure 4.5.2-4A for surge and tide in water depths less than 500 m.

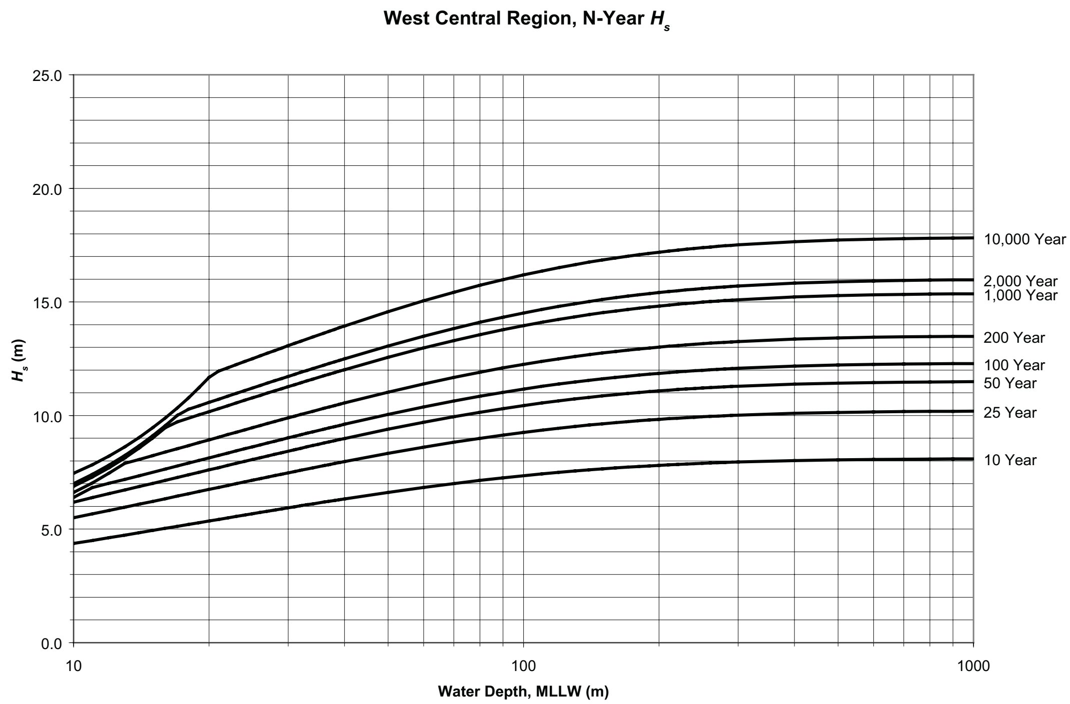


Figure 4.5.2-1A—N-Year H_S, West Central Region

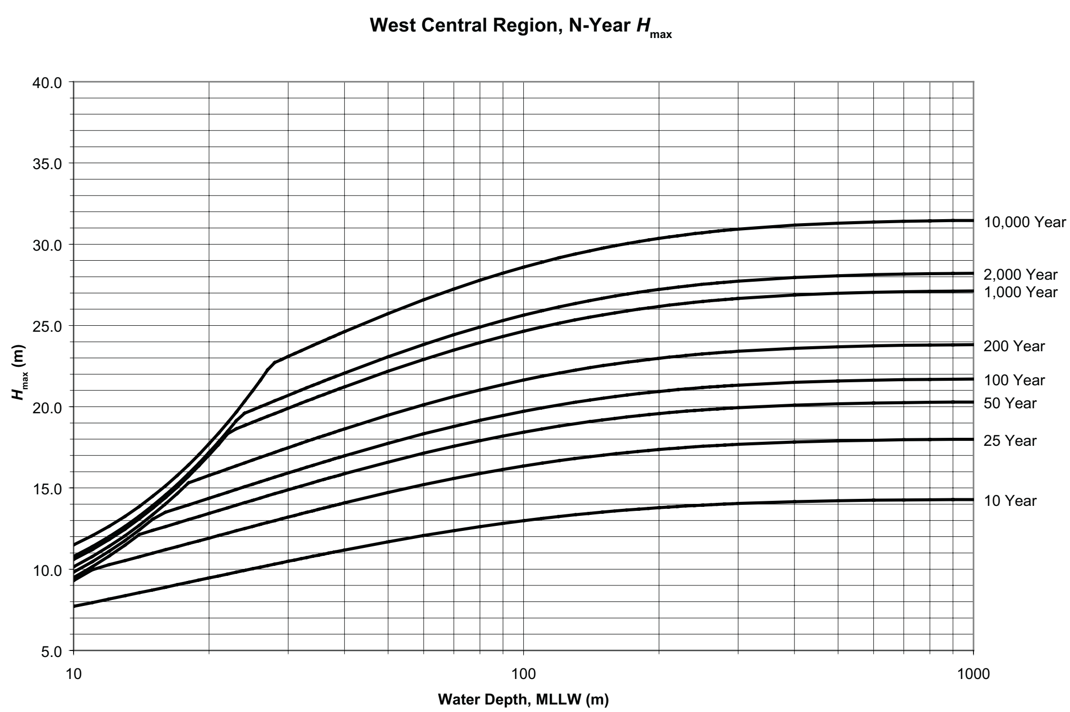


Figure 4.5.2-2A—N-Year H_{max}, West Central Region

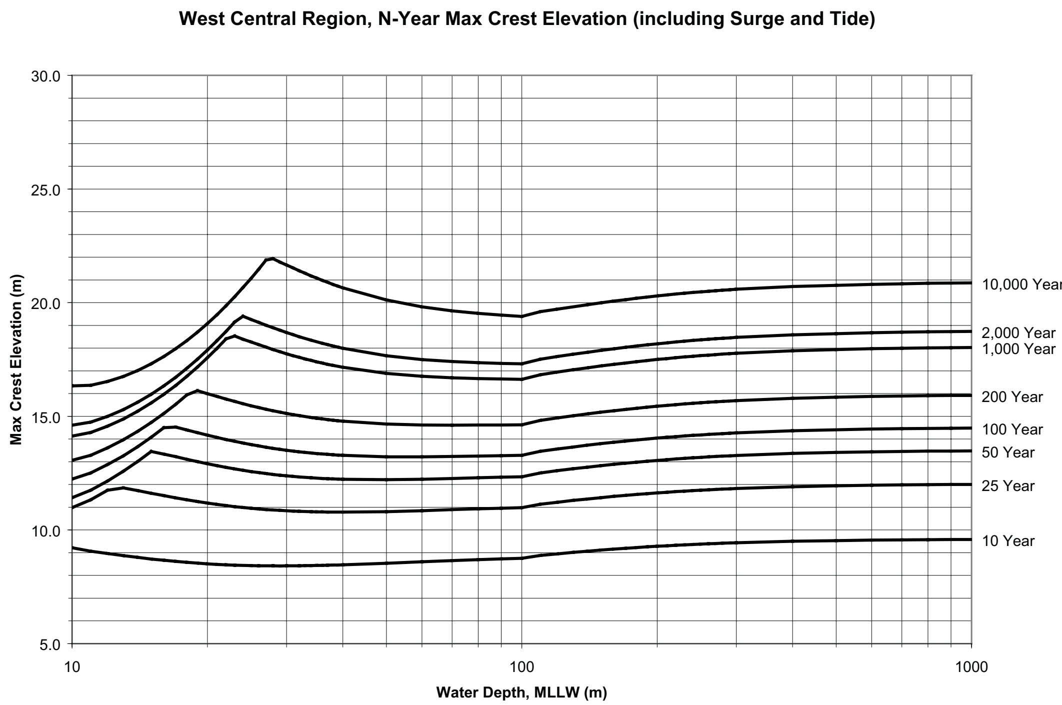


Figure 4.5.2-3A—N-Year Max Crest Elevation, West Central Region

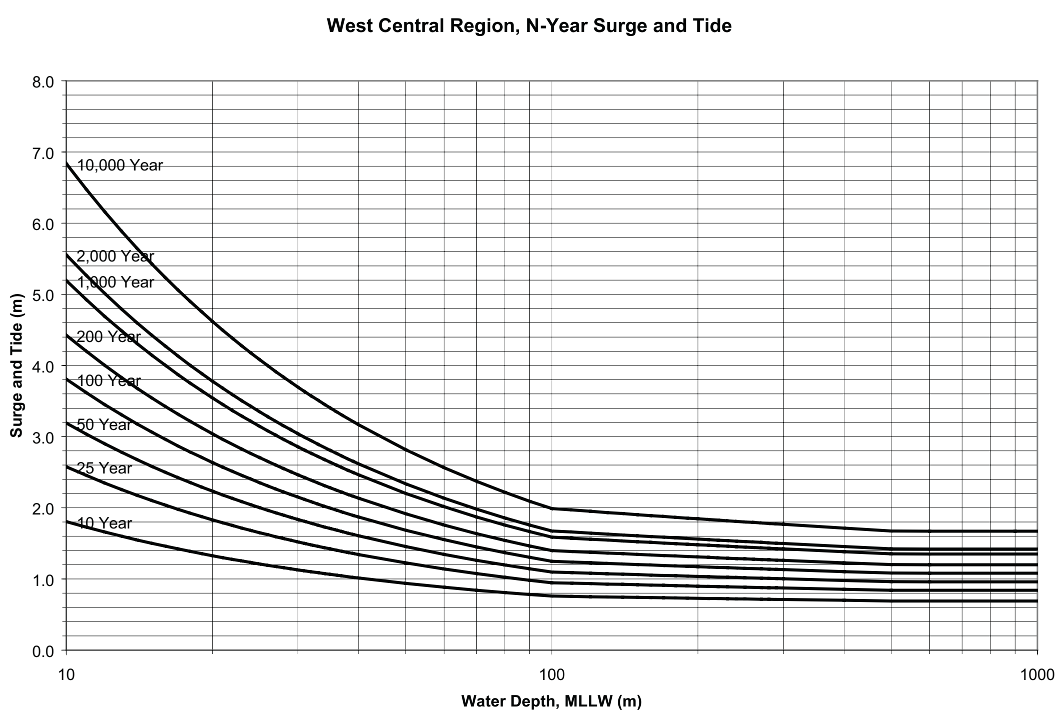


Figure 4.5.2-4A—N-Year Surge with Tide, West Central Region

Table 4.5.2-1B—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, Western Central Gulf of Mexico (94.0°W to 90.5°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (32.8 ft Elevation)								
1-hour Mean Wind Speed (ft/s)	81.7	99.7	112.5	125.0	136.5	156.2	161.8	181.1
10-min Mean Wind Speed (ft/s)	89.2	109.9	124.7	139.4	153.2	177.2	184.1	208.0
1-min Mean Wind Speed (ft/s)	98.8	123.0	140.8	158.1	174.9	204.1	212.6	242.8
3-sec Gust (ft/s)	111.2	139.8	161.1	182.4	202.8	239.2	249.7	287.7
Waves, WD > = 3280 ft								
Significant Wave Height (ft)	26.6	33.5	37.7	40.4	44.3	50.5	52.5	58.4
Maximum Wave Height (ft)	46.9	59.1	66.6	71.2	78.1	89.2	92.5	103.4
Maximum Crest Elevation (ft)	31.5	39.4	44.3	47.6	52.2	59.1	61.0	67.9
Peak Spectral Period (s)	12.6	13.6	14.2	14.4	14.8	15.8	16.1	17.0
Period of Maximum Wave (s)	11.3	12.3	12.8	13.0	13.3	14.2	14.5	15.3
Currents, WD > = 492 ft								
Surface Speed (ft/s)	4.1	5.0	5.6	6.3	6.8	7.8	8.1	9.1
Speed at Mid-profile (ft/s)	3.1	3.7	4.2	4.7	5.1	5.9	6.1	6.8
0-Speed Depth (ft)	172	209	236	262	287	328	340	380
Currents, WD 33 ft – 230 ft								
Uniform Speed at 33 ft Depth (ft/s)	2.6	3.9	5.0	6.1	7.3	8.6	9.3	11.6
Uniform Speed at 230 ft Depth (ft/s)	1.8	2.7	3.5	4.3	5.1	6.0	6.5	8.1
Water Level, WD > = 1640 ft								
Storm Surge (ft)	0.9	1.4	1.8	2.2	2.6	3.1	3.3	4.1
Tidal Amplitude (ft)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.2-1B, 4.5.2-2B and 4.5.2-3B for wave and crest elevation values for water depths between 33 ft and 3280 ft.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 230 ft and 492 ft should be estimated as described in 4.3.3.

See Figure 4.5.2-4B for surge and tide in water depths less than 1640 ft.

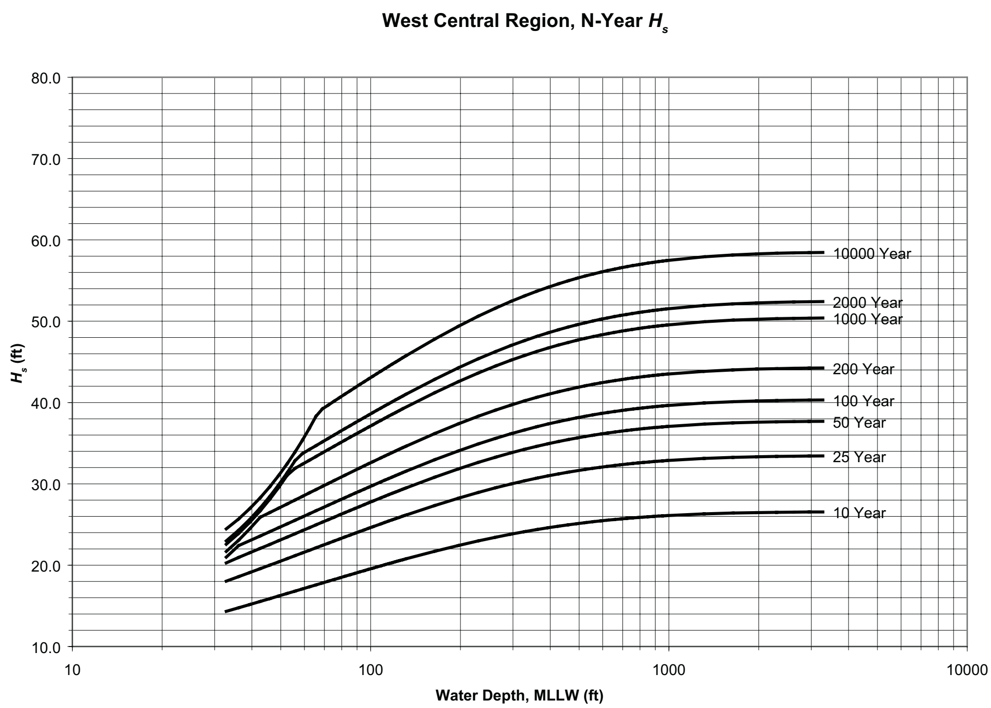


Figure 4.5.2-1B—N-Year H_s, West Central Region

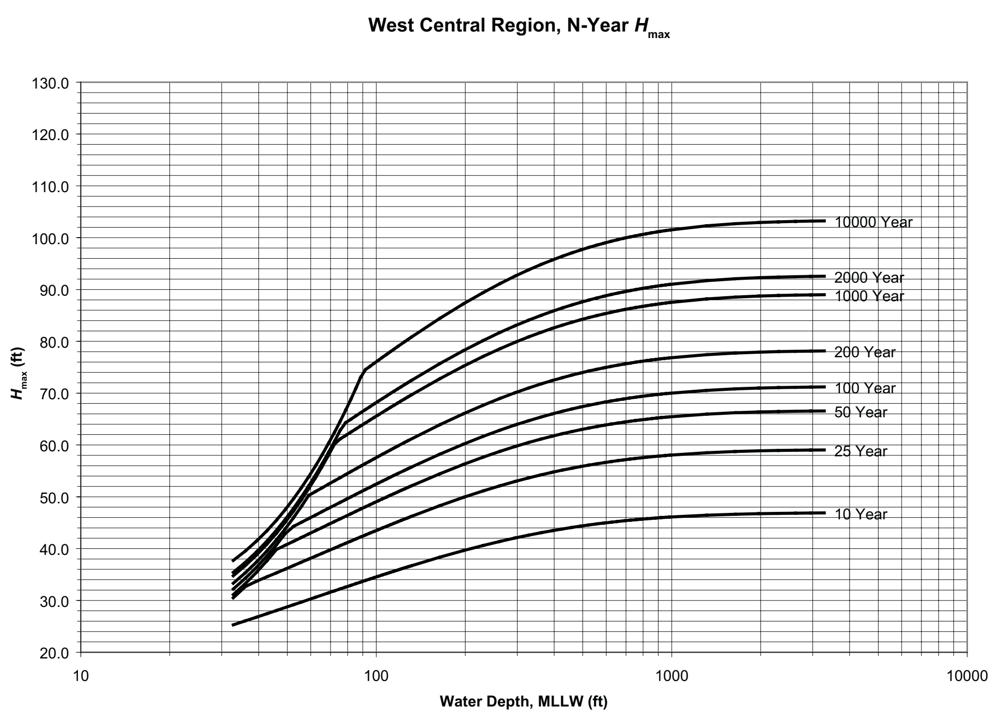


Figure 4.5.2-2B—N-Year H_{max}, West Central Region

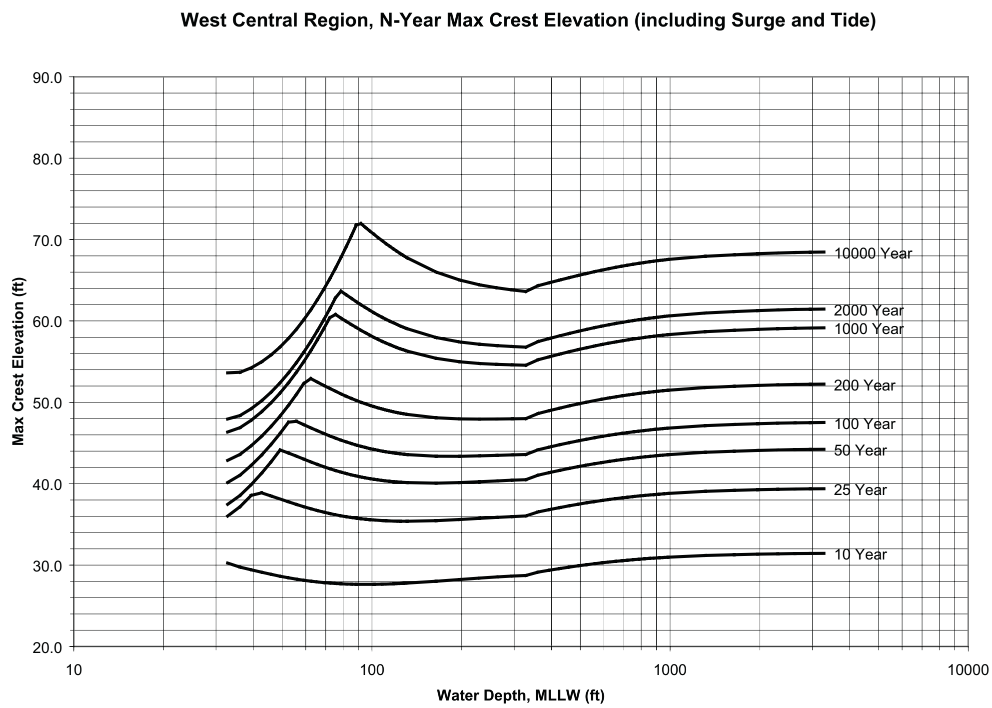


Figure 4.5.2-3B—N-Year Max Crest Elevation, West Central Region

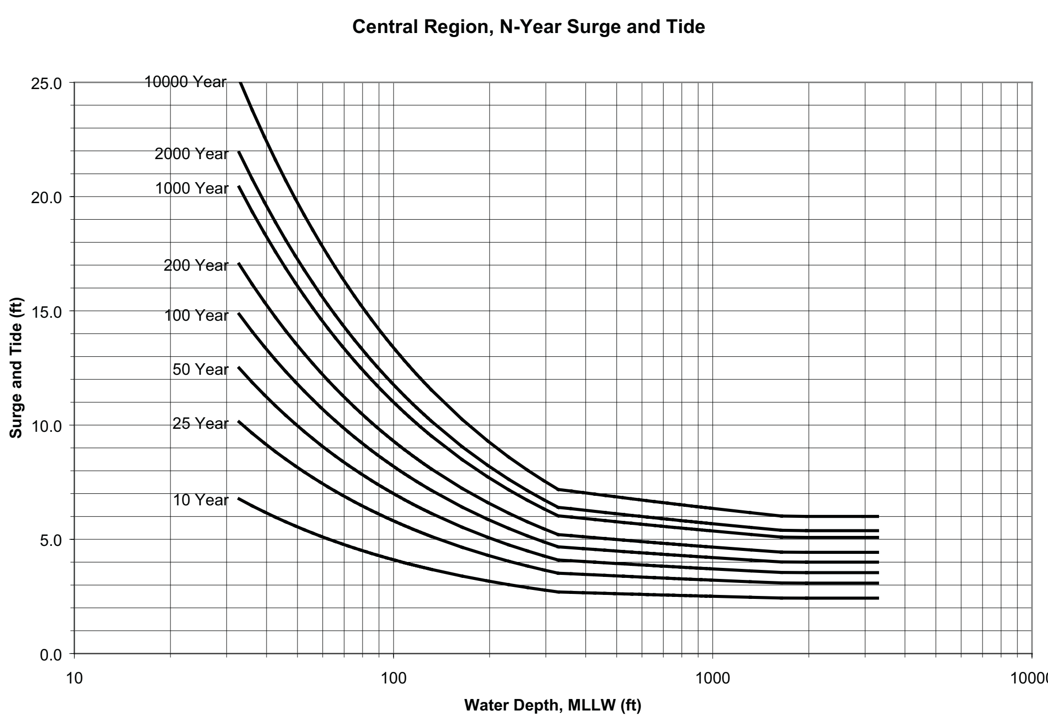


Figure 4.5.2-4B—N-Year Surge with Tide, West Central Region

4.5.3 Central

Table 4.5.3-1A—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, Central Gulf of Mexico (89.5°W to 86.5°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (10 m Elevation)								
1-hour Mean Wind Speed (m/s)	33.0	40.1	44.4	48.0	51.0	60.0	62.4	67.2
10-min Mean Wind Speed (m/s)	36.5	44.9	50.1	54.5	58.2	69.5	72.5	78.7
1-min Mean Wind Speed (m/s)	41.0	51.1	57.4	62.8	67.4	81.6	85.6	93.5
3-sec Gust (m/s)	46.9	59.2	66.9	73.7	79.4	97.5	102.5	112.8
Waves, WD > = 1,000 m								
Significant Wave Height (m)	10.0	13.3	14.8	15.8	16.5	19.8	20.5	22.1
Maximum Wave Height (m)	17.7	23.5	26.1	27.9	29.1	34.9	36.3	39.1
Maximum Crest Elevation (m)	11.8	15.7	17.4	18.6	19.4	23.0	23.8	25.6
Peak Spectral Period (s)	13.0	14.4	15.0	15.4	15.7	17.2	17.5	18.2
Period of Maximum Wave (s)	11.7	13.0	13.5	13.9	14.1	15.5	15.8	16.4
Currents, WD > = 150 m								
Surface Speed (m/s)	1.65	2.00	2.22	2.40	2.55	3.00	3.12	3.36
Speed at Mid-Profile (m/s)	1.24	1.50	1.67	1.80	1.91	2.25	2.34	2.52
0-Speed Depth, Bottom of Profile (m)	69.3	84.2	93.2	100.8	107.1	126.0	131.0	141.1
Currents, WD 10 m – 70 m								
Uniform Speed at 10 m Depth (m/s)	1.09	1.61	1.97	2.30	2.60	3.23	3.50	4.05
Uniform Speed at 70 m Depth (m/s)	0.98	1.45	1.77	2.07	2.34	2.91	3.15	3.65
Water Level, WD > = 500 m								
Storm Surge (m)	0.32	0.52	0.66	0.80	0.93	1.13	1.22	1.41
Tidal Amplitude (m)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.3-1A, 4.5.3-2A and 4.5.3-3A for wave and crest elevation values for water depths between 10 m and 1000 m.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 70 m and 150 m should be estimated as described in 4.3.3.

See Figure 4.5.3-4A for surge and tide in water depths less than 500 m.

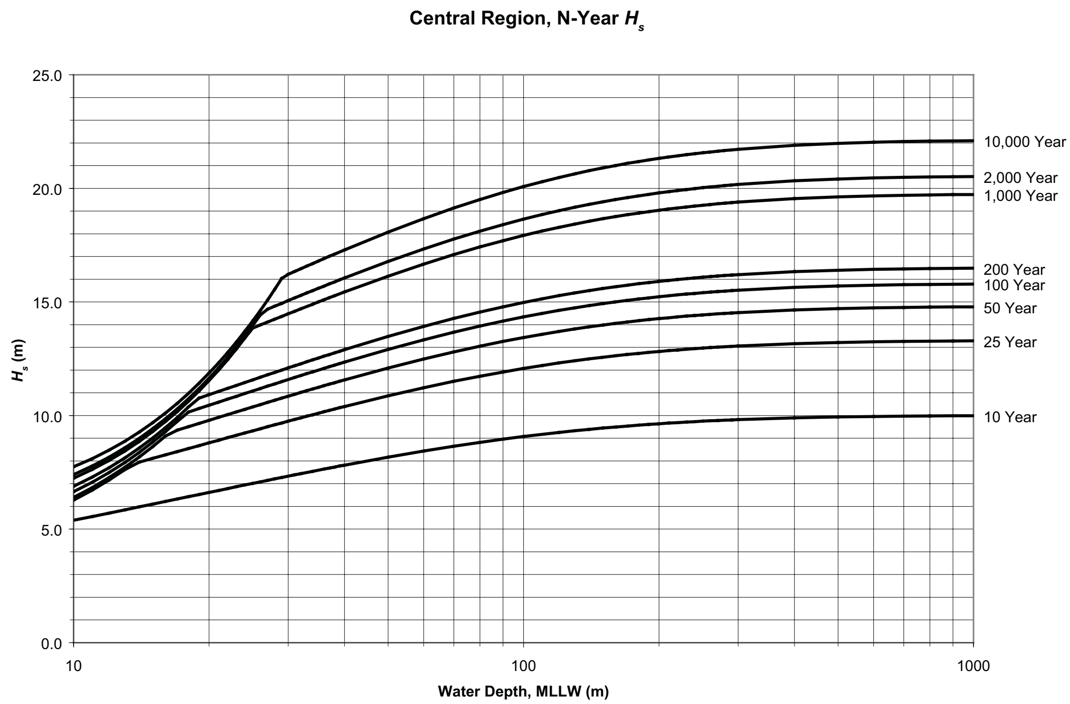


Figure 4.5.3-1A—N-Year H_s, Central Region

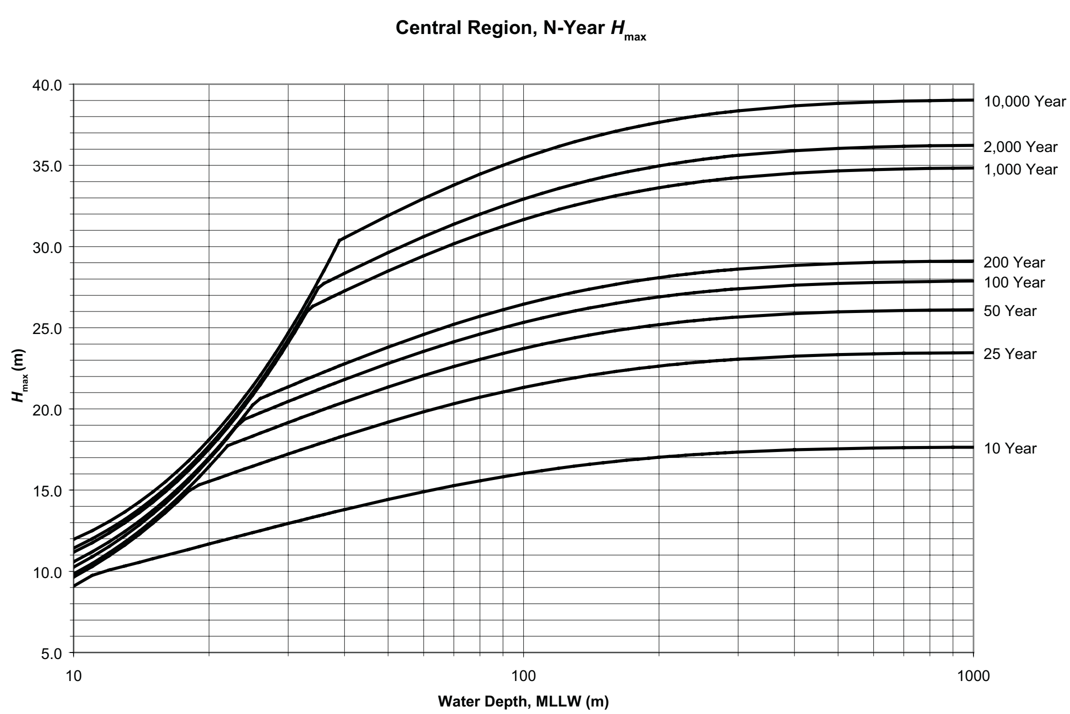


Figure 4.5.3-2A—N-Year H_{max}, Central Region

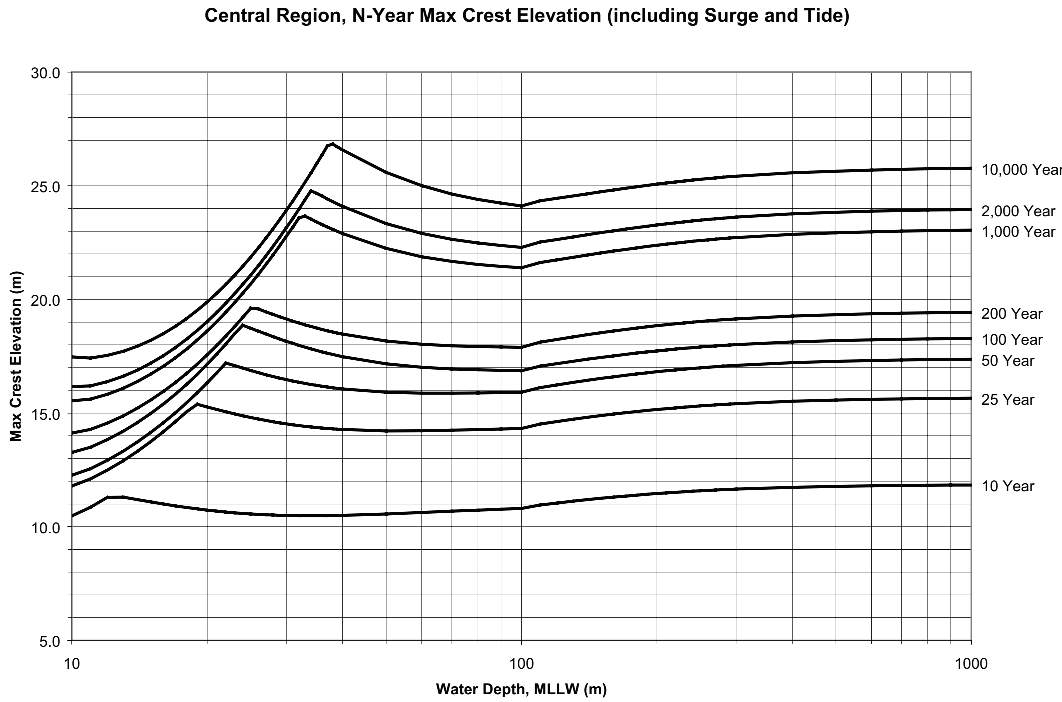


Figure 4.5.3-3A—N-Year Max Crest Elevation, Central Region

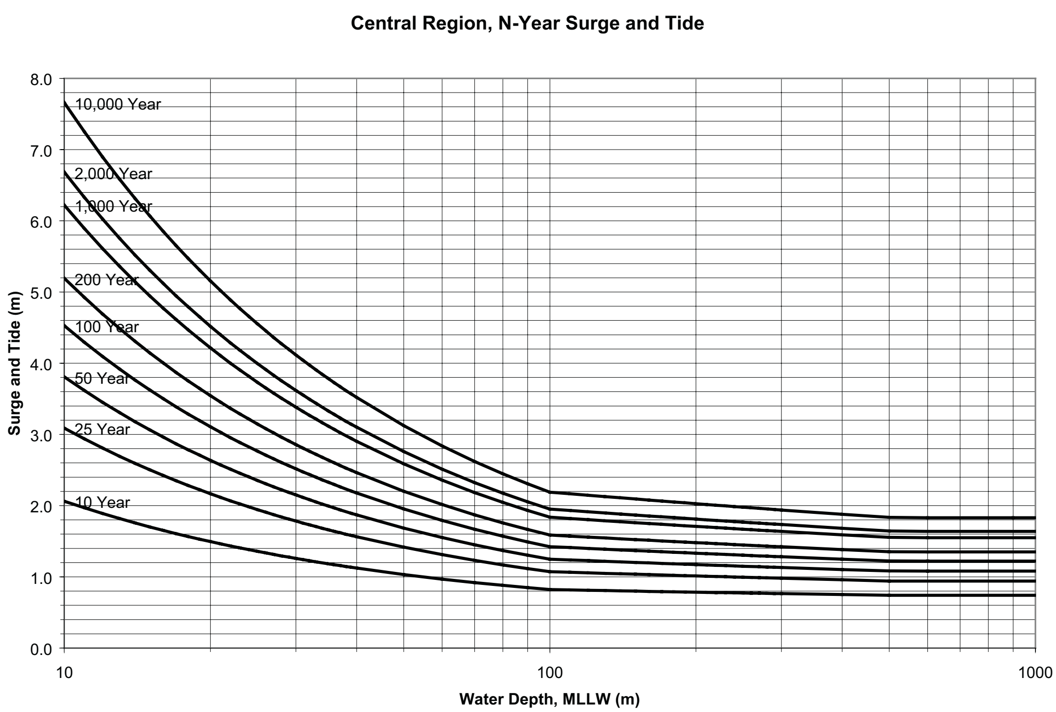


Figure 4.5.3-4A—N-Year Surge with Tide, Central Region

Table 4.5.3-1B—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, Central Gulf of Mexico (89.5°W to 86.5°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (32.8 ft Elevation)								
1-hour Mean Wind Speed (ft/s)	108.3	131.6	145.7	157.5	167.3	196.9	204.7	220.5
10-min Mean Wind Speed (ft/s)	119.8	147.3	164.4	178.8	191.0	228.0	237.9	258.2
1-min Mean Wind Speed (ft/s)	134.5	167.7	188.3	206.0	221.1	267.7	280.9	306.8
3-sec Gust (ft/s)	153.9	194.2	219.5	241.8	260.5	319.9	336.3	370.1
Waves, WD > = 3280 ft								
Significant Wave Height (ft)	32.8	43.6	48.6	51.8	54.1	65.0	67.3	72.5
Maximum Wave Height (ft)	58.1	77.1	85.6	91.5	95.5	114.5	119.1	128.3
Maximum Crest Elevation (ft)	38.7	51.5	57.1	61.0	63.7	75.5	78.1	84.0
Peak Spectral Period (s)	13.0	14.4	15.0	15.4	15.7	17.2	17.5	18.2
Period of Maximum Wave (s)	11.7	13.0	13.5	13.9	14.1	15.5	15.8	16.4
Currents, WD > = 492 ft								
Surface Speed (ft/s)	5.4	6.6	7.3	7.9	8.4	9.8	10.2	11.0
Speed at Mid-profile (ft/s)	4.1	4.9	5.5	5.9	6.3	7.4	7.7	8.3
0-Speed Depth (ft)	227	276	306	331	351	413	430	463
Currents, WD 33 ft – 230 ft								
Uniform Speed at 33 ft Depth (ft/s)	3.6	5.3	6.5	7.5	8.5	10.6	11.5	13.3
Uniform Speed at 230 ft Depth (ft/s)	3.2	4.8	5.8	6.8	7.7	9.5	10.3	12.0
Water Level, WD > = 1640 ft								
Storm Surge (ft)	1.0	1.7	2.2	2.6	3.1	3.7	4.0	4.6
Tidal Amplitude (ft)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.3-1B, 4.5.3-2B and 4.5.3-3B for wave and crest elevation values for water depths between 33 ft and 3280 ft.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 230 ft and 492 ft should be estimated as described in 4.3.3.

See Figure 4.5.3-4B for surge and tide in water depths less than 1640 ft.

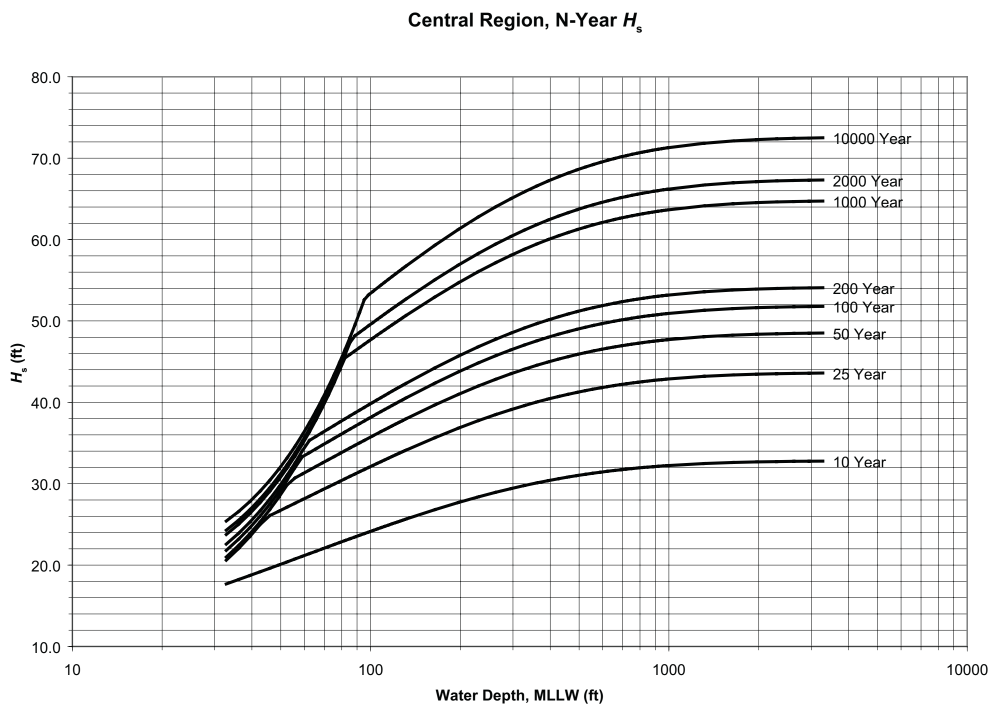


Figure 4.5.3-1B—N-Year H_s, Central Region

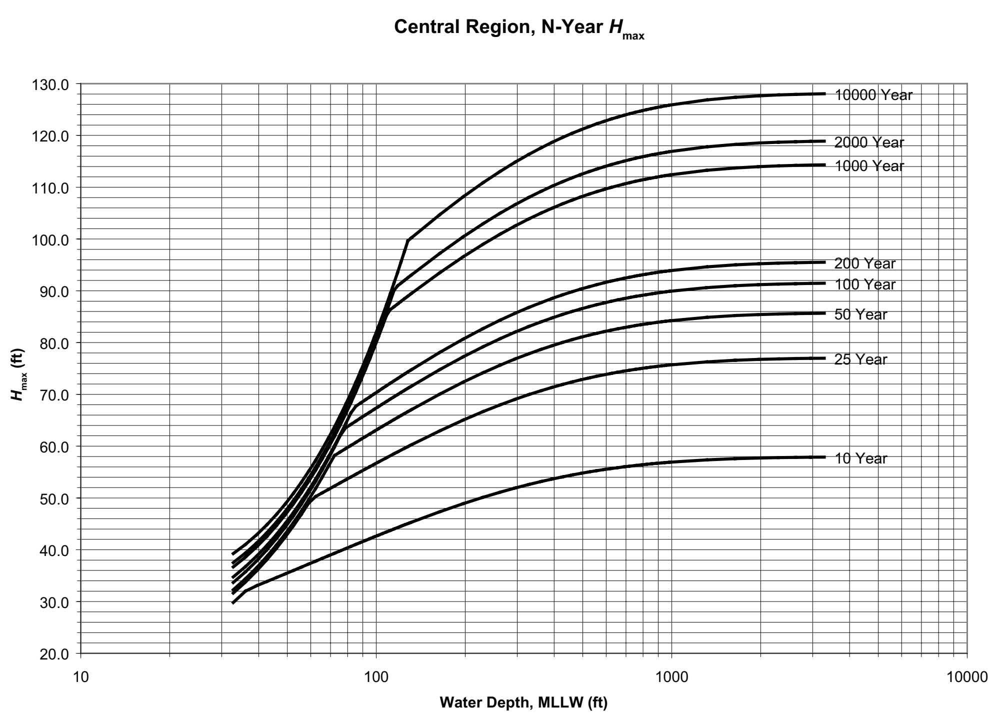


Figure 4.5.3-2B—N-Year H_{max}, Central Region

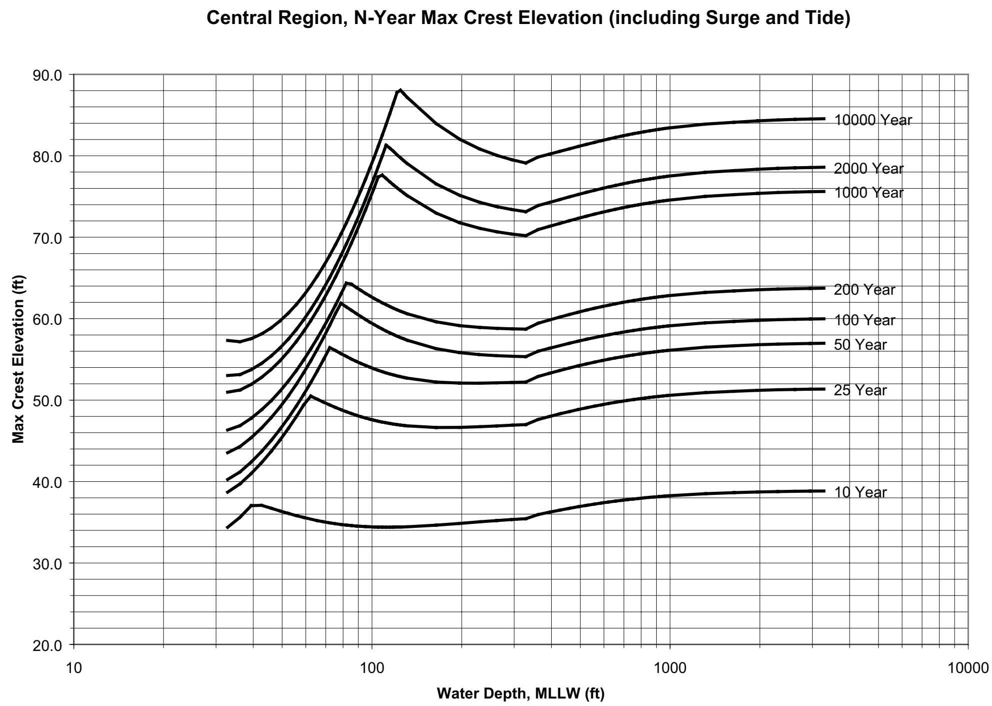


Figure 4.5.3-3B—N-Year Max Crest Elevation, Central Region

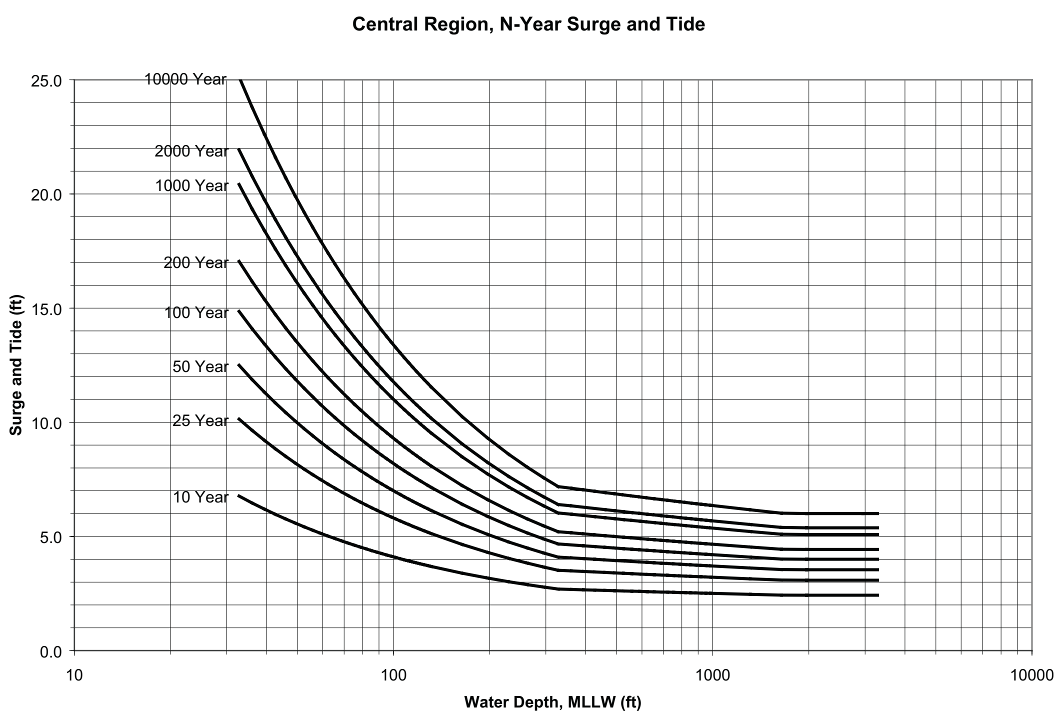


Figure 4.5.3-4B—N-Year Surge with Tide, Central Region

4.5.4 East

Table 4.5.4-1A—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, Eastern Gulf of Mexico (85.5°W to 82.5°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (10 m Elevation)								
1-hour Mean Wind Speed (m/s)	28.4	33.0	35.7	38.4	40.8	48.0	49.9	55.8
10-min Mean Wind Speed (m/s)	31.2	36.5	39.7	42.9	45.8	54.5	56.8	64.2
1-min Mean Wind Speed (m/s)	34.8	41.0	44.8	48.7	52.1	62.8	65.7	74.9
3-sec Gust (m/s)	39.4	46.9	51.5	56.2	60.4	73.7	77.3	88.9
Waves, WD > = 1000 m								
Significant Wave Height (m)	8.2	10.1	11.1	12.2	12.9	15.3	15.9	17.7
Maximum Wave Height (m)	14.5	17.9	19.6	21.6	22.8	26.9	28.0	31.2
Maximum Crest Elevation (m)	9.8	12.0	13.1	14.5	15.2	17.8	18.4	20.4
Peak Spectral Period (s)	11.8	12.7	13.3	13.7	14.3	15.6	15.9	16.8
Period of Maximum Wave (s)	10.6	11.4	12.0	12.3	12.9	14.0	14.3	15.1
Currents, WD > = 150 m								
Surface Speed (m/s)	1.42	1.65	1.79	1.92	2.04	2.40	2.50	2.78
Speed at Mid-profile (m/s)	1.07	1.24	1.34	1.44	1.53	1.80	1.87	2.09
0-Speed Depth (m)	59.6	69.3	75.0	80.6	85.7	100.8	104.8	116.9
Currents, WD 10 m – 70 m								
Uniform Speed at 10 m Depth (m/s)	1.04	1.40	1.64	1.90	2.14	2.67	2.89	3.59
Uniform Speed at 70 m Depth (m/s)	0.73	0.98	1.15	1.33	1.50	1.87	2.02	2.52
Water Level, WD > = 500 m								
Storm Surge (m)	0.23	0.35	0.43	0.53	0.61	0.75	0.85	1.00
Tidal Amplitude (m)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.4-1A, 4.5.4-2A and 4.5.4-3A for wave and crest elevation values for water depths between 10 m and 1000 m.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 70 m and 150 m should be estimated as described in 4.3.3.

See Figure 4.5.4-4A for surge and tide in water depths less than 500 m.

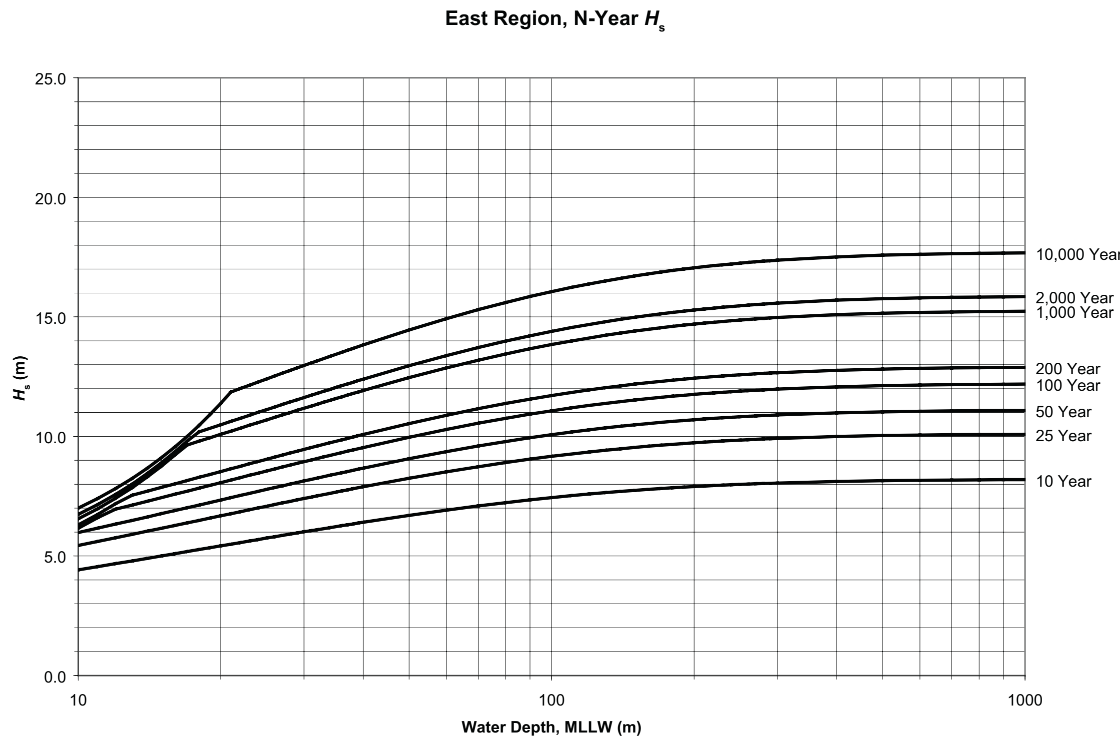


Figure 4.5.4-1A—N-Year H_s, Eastern Region

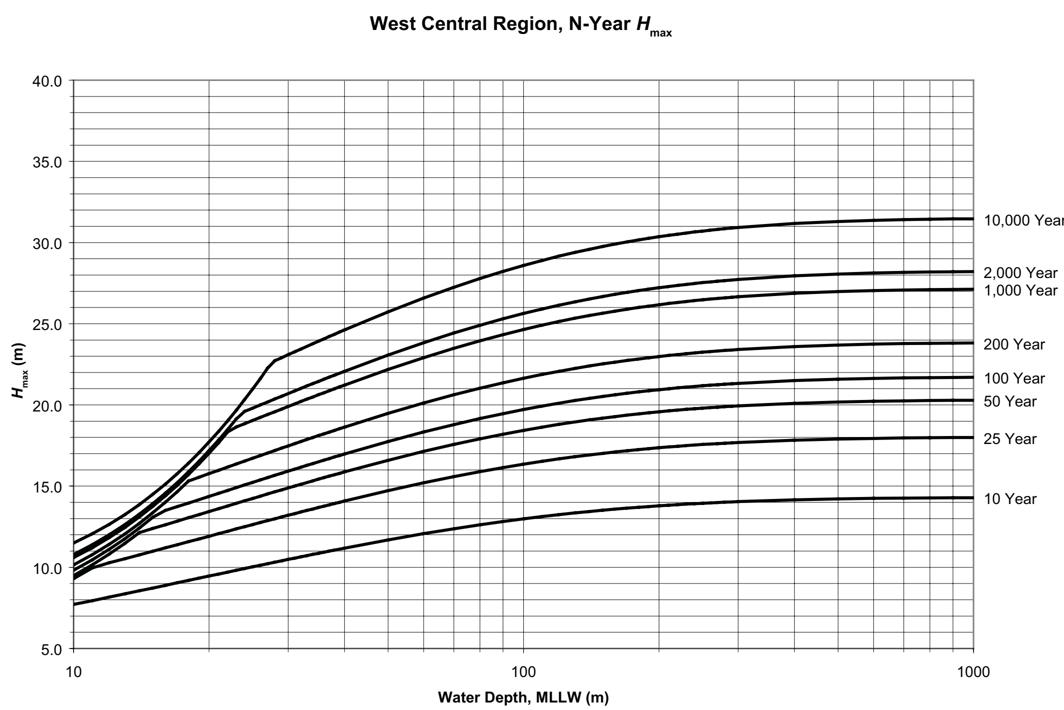


Figure 4.5.4-2A—N-Year H_{max}, Eastern Region

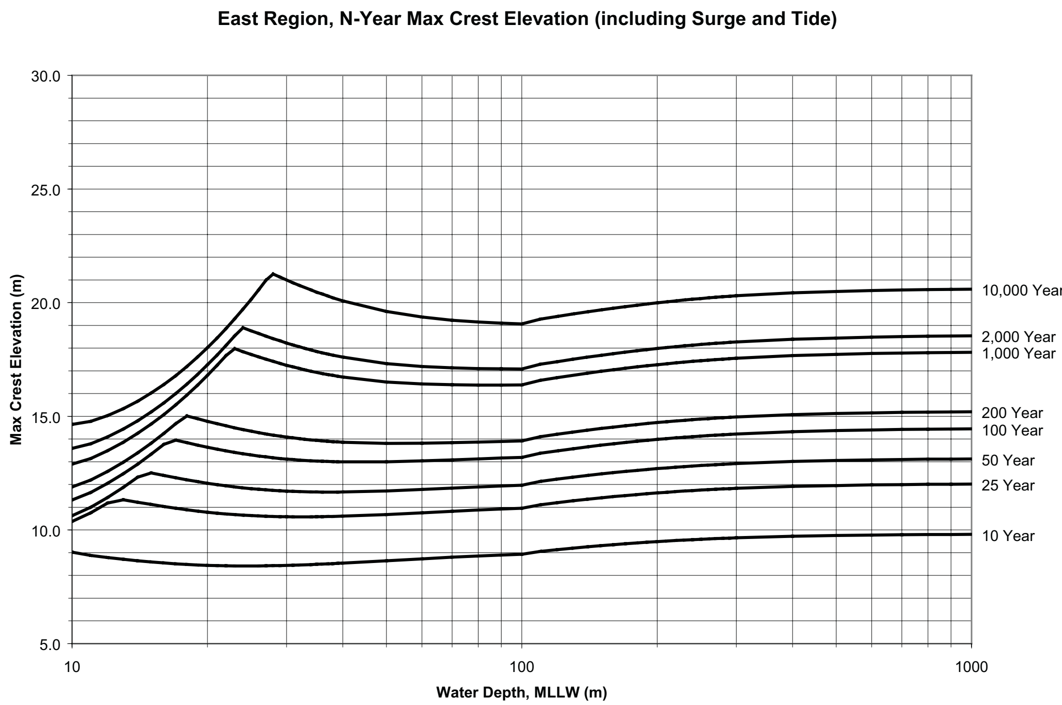


Figure 4.5.4-3A—N-Year Max Crest Elevation, Eastern Region

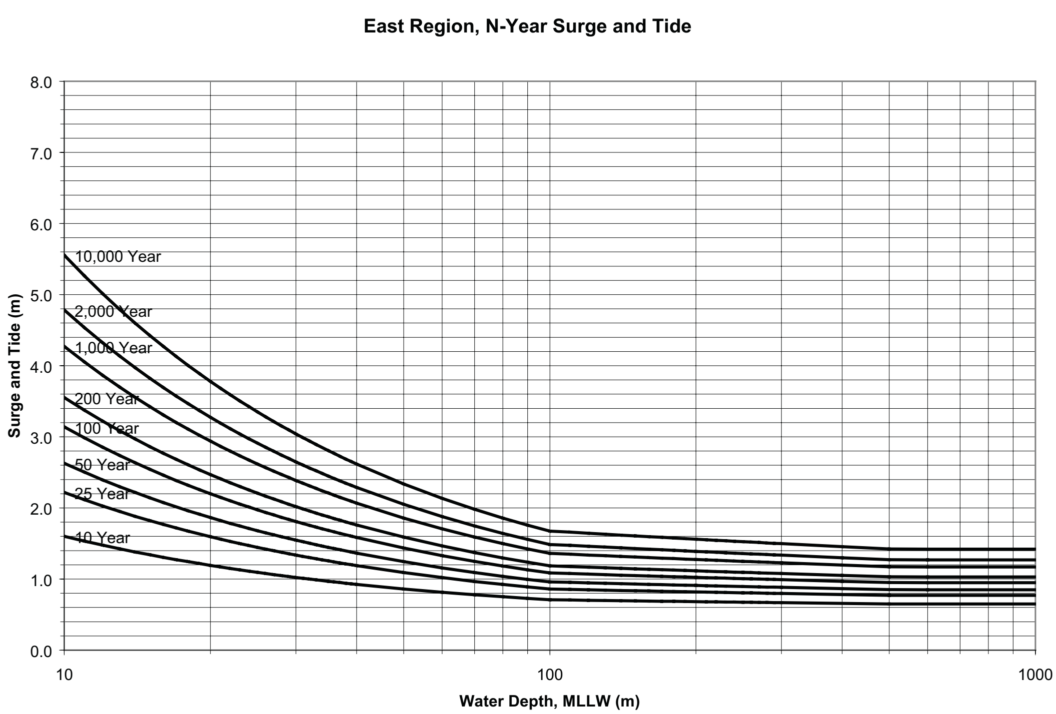


Figure 4.5.4-4A—N-Year Surge with Tide, Eastern Region

Table 4.5.4-1B—Independent Extreme Values for Hurricane Winds, Waves, Currents and Surge, Eastern Gulf of Mexico (85.5°W to 82.5°W)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Wind (32.8 ft Elevation)								
1-hour Mean Wind Speed (ft/s)	93.2	108.3	117.1	126.0	133.9	157.5	163.7	183.1
10-min Mean Wind Speed (ft/s)	102.4	119.8	130.3	140.8	150.3	178.8	186.4	210.6
1-min Mean Wind Speed (ft/s)	114.2	134.5	147.0	159.8	170.9	206.0	215.6	245.7
3-sec Gust (ft/s)	129.3	153.9	169.0	184.4	198.2	241.8	253.6	291.7
Waves, WD > = 3280 ft								
Significant Wave Height (ft)	26.9	33.1	36.4	40.0	42.3	50.2	52.2	58.1
Maximum Wave Height (ft)	47.6	58.7	64.3	70.9	74.8	88.3	91.9	102.4
Maximum Crest Elevation (ft)	32.3	39.4	43.0	47.6	49.9	58.4	60.4	66.9
Peak Spectral Period (s)	11.8	12.7	13.3	13.7	14.3	15.6	15.9	16.8
Period of Maximum Wave (s)	10.6	11.4	12.0	12.3	12.9	14.0	14.3	15.1
Currents, WD > = 492 ft								
Surface Speed (ft/s)	4.7	5.4	5.9	6.3	6.7	7.9	8.2	9.1
Speed at Mid-profile (ft/s)	3.5	4.1	4.4	4.7	5.0	5.9	6.1	6.9
0-Speed Depth (ft)	196	227	246	264	281	331	344	384
Currents, WD 33 ft – 230 ft								
Uniform Speed at 33 ft Depth (ft/s)	3.4	4.6	5.4	6.2	7.0	8.8	9.5	11.8
Uniform Speed at 230 ft Depth (ft/s)	2.4	3.2	3.8	4.4	4.9	6.1	6.6	8.3
Water Level, WD > = 1640 ft								
Storm Surge (ft)	0.8	1.1	1.4	1.7	2.0	2.5	2.8	3.3
Tidal Amplitude (ft)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 4.5.4-1B, 4.5.4-2B and 4.5.4-3B for wave and crest elevation values for water depths between 33 ft and 3280 ft.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 230 ft and 492 ft should be estimated as described in 4.3.3.

See Figure 4.5.4-4B for surge and tide in water depths less than 1640 ft.

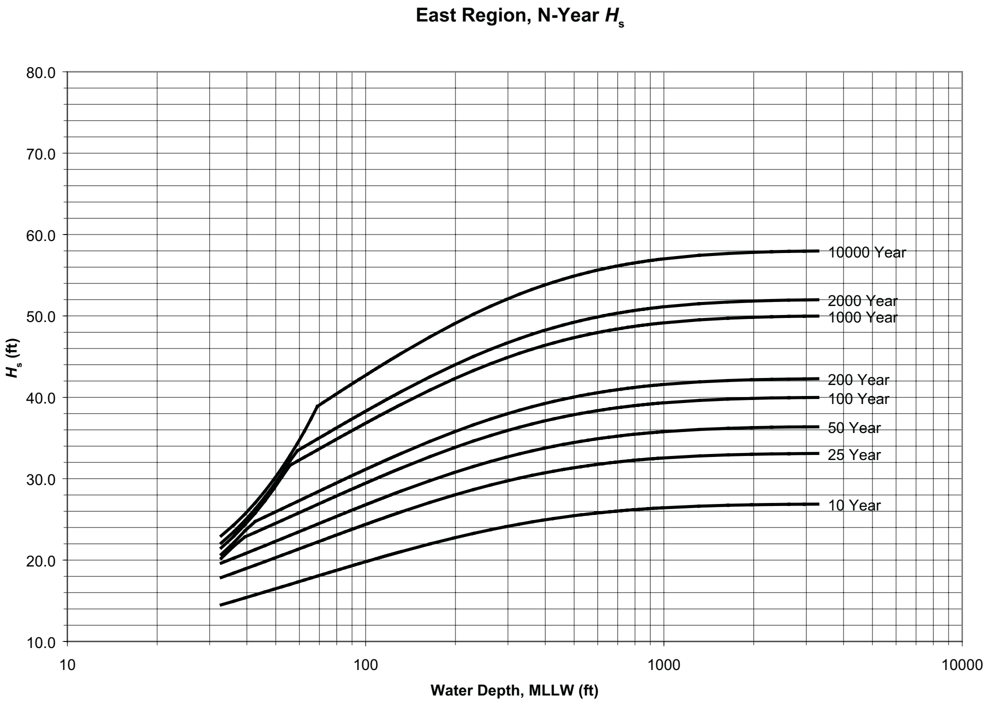


Figure 4.5.4-1B—N-Year H_s, Eastern Region

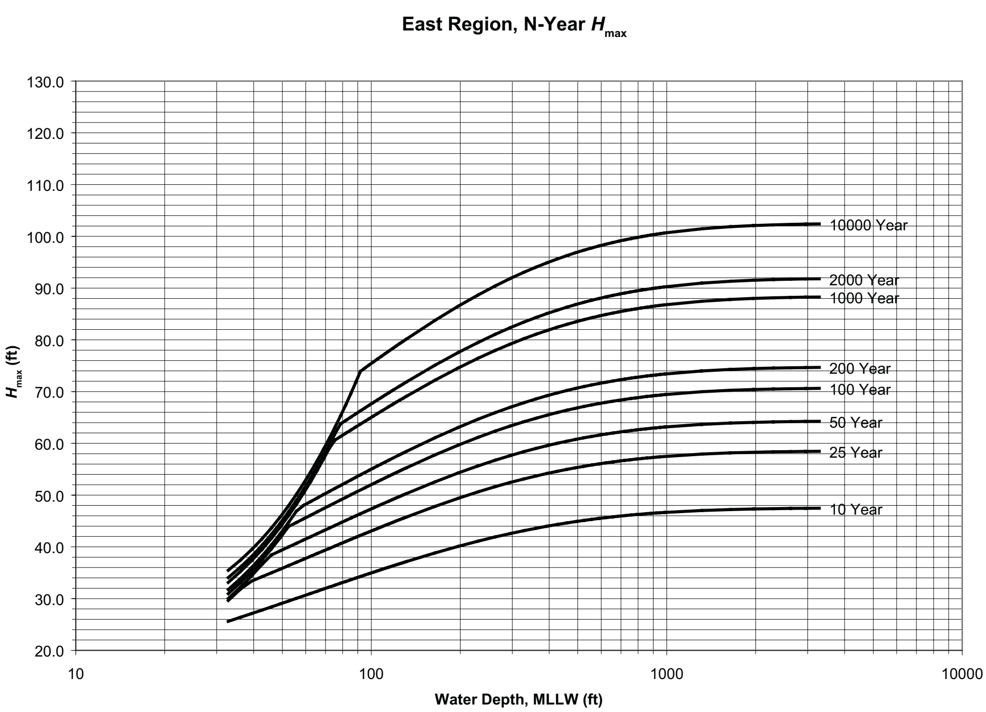


Figure 4.5.4-2B—N-Year H_{max}, Eastern Region

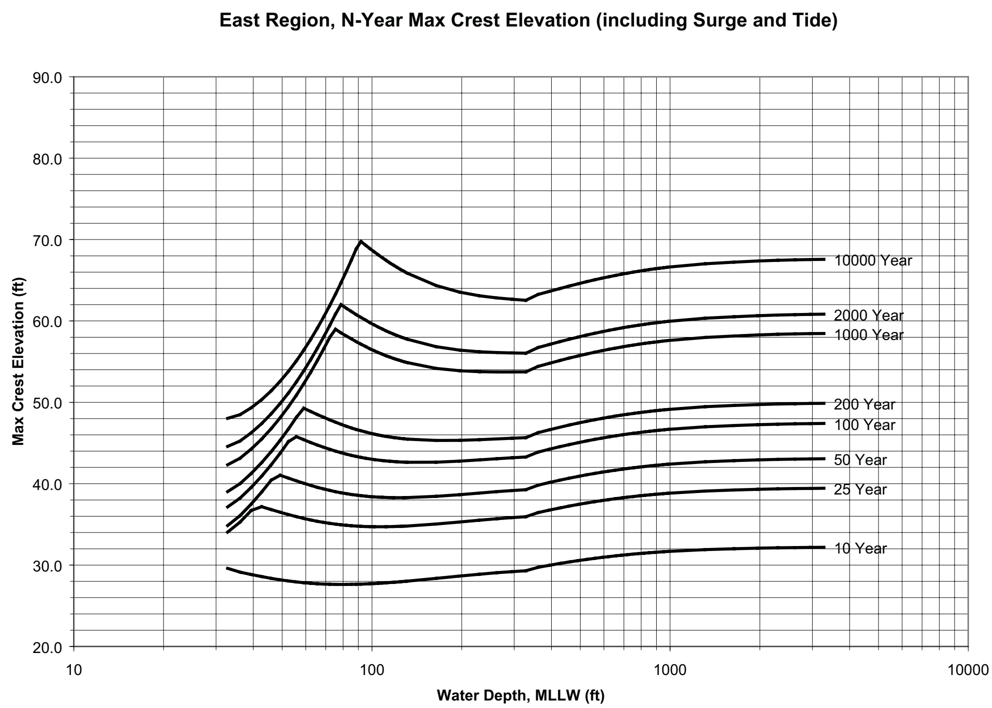


Figure 4.5.4-3B—N-Year Max Crest Elevation, Eastern Region

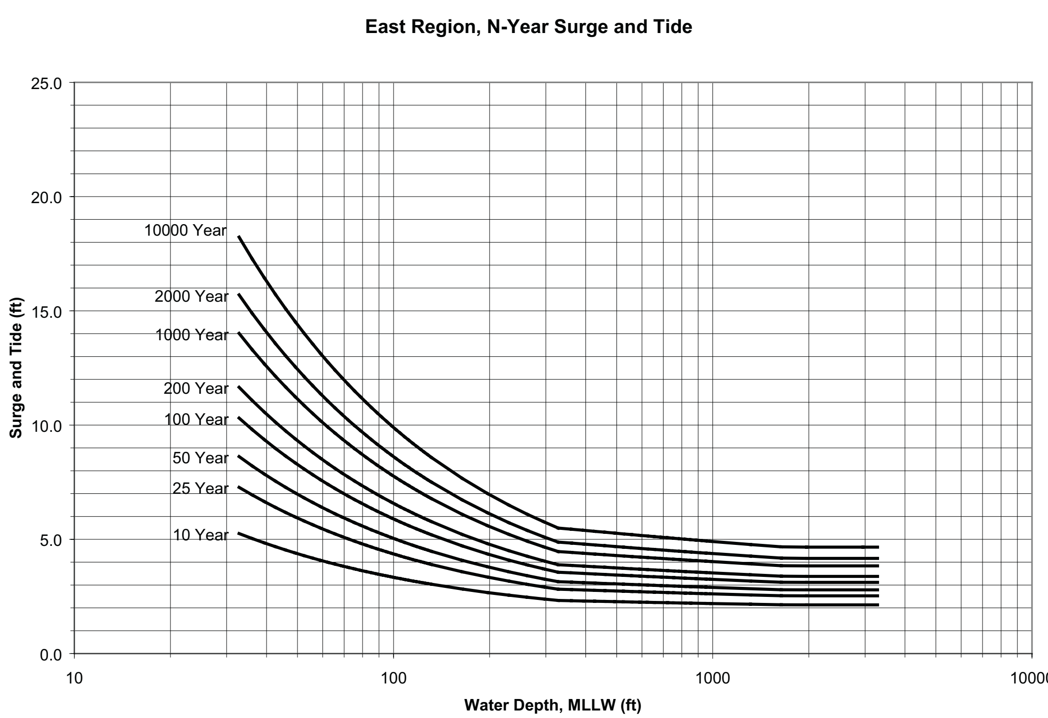


Figure 4.5.4-4B—N-Year Surge with Tide, Eastern Region

5 Associated Wind, Wave, Current and Surge for Load Cases

The metocean conditions presented in 4.5 are extreme values. To combine all extremes at the same return period together when constructing a wind, wave, current and surge load case is very conservative, as the different variables will seldom peak at the same time during a given storm, and the n-year values of different parameters may not even occur in the same storm event. A set of combination factors is provided in Tables 5-1 and 5-2 to allow for derivation of associated wind, wave, current and surge parameters to go with the n-year peak wave, peak wind or peak current.

Where appropriate, directional offsets of wind heading from wave heading and current heading from wave heading are also provided. These are always measured as positive clockwise, i.e., if the table lists "wind direction from the wave direction" as +45°, the meaning is that the wind heading (to) is rotated 45° to the right of the wave heading (to).

When factoring surge and tide in water depths less than 500 m (1640 ft), the tidal amplitude (0.42 m or 1.4 ft) should be removed, the surge factored, and then the tide added back in.

For locations which fall in the transition zone between 70 m and 150 m (230 ft and 492 ft), the appropriate factor to use for deriving associated wind speed or wave height should be derived by linear interpolation. For currents, associated values should be derived for 70 m and 150 m (230 ft and 492 ft) and then interpolated linearly to the proper intermediate depth. The factor for the deepwater current should be applied to both the current speeds at surface and mid-profile, as well as the depths defining the bottom and mid-depth point of the profile.

Table 5-1—Factors for Combining Independent Extremes into Load Cases in Deep Water (WD > = 150 m or 492 ft)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Peak Wave Case:								
Wind Speed	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Wave Height	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Current (both speed and depth level)	0.80	0.80	0.75	0.75	0.75	0.75	0.75	0.75
Surge	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Wind Direction from Wave (deg)	–15	–15	–15	–15	–15	–15	–15	–15
Current Direction from Wave (deg)	+15	+15	+15	+15	+15	+15	+15	+15
Peak Wind Case:								
Wind Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wave Height	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Current (both speed and depth level)	0.80	0.80	0.75	0.75	0.75	0.75	0.75	0.75
Surge	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Wind Direction from Wave (deg)	–15	–15	–15	–15	–15	–15	–15	–15
Current Direction from Wave (deg)	+15	+15	+15	+15	+15	+15	+15	+15
Peak Current Case:								
Wind Speed	0.75	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Wave Height	0.75	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Current (both speed and depth level)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Surge	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Wind Direction from Wave (deg)	0	0	0	0	0	0	0	0
Current Direction from Wave (deg)	+50	+50	+50	+50	+50	+50	+50	+50

Note: When factoring surge from Figures 4.5.1-4, 4.5.2-4, 4.5.3-4 and 4.5.4-4, remove the tidal amplitude, factor the surge, then add the tidal amplitude back in.

Table 5-2—Factors for Cominbing Independent Extremes into Load Cases in Shallow Water (10 m or 33 ft < = WD < = 70 m or 230 ft)

Return Period (Years)	10	25	50	100	200	1000	2000	10000
Peak Wave Case:								
Wind Speed	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Wave Height	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Uniform Current	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Surge	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Wind Direction from Wave (deg)	–15	–15	–15	–15	–15	–15	–15	–15
Peak Wind Case:								
Wind Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wave Height	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Uniform Current	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Surge	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Wind Direction from Wave (deg)	–15	–15	–15	–15	–15	–15	–15	–15
Peak Current Case:								
Wind Speed	0.80	0.75	0.70	0.70	0.70	0.70	0.70	0.70
Wave Height	0.80	0.75	0.70	0.70	0.70	0.70	0.70	0.70
Uniform Current	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Surge	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
Wind Direction from Wave (deg)	0	0	0	0	0	0	0	0

Notes:

Current headings in WD <= 70 m (230 ft) are independent of wind and wave, and are given by Figure 4.3.1-1.

When factoring surge from Figures 4.5.1-4, 4.5.2-4, 4.5.3-4 and 4.5.4-4, remove the tidal amplitude, factor the surge, then add the tidal amplitude back in.

6 Example Applications: Determining Conditions at a Site

Example applications of the various extractions of information from the tables and figures, and interpolations between regions and water depths, are provided below. Each example is worked with both U.S. Customary and SI Units. In general the conditions at most shallow water sites can be determined simply by reading values off the tables and figures, with one interpolation to determine the uniform current. More effort is required for sites which fall in the transitions between regions and between shallow and deep water.

6.1 EXAMPLE: SHALLOW WATER SITE

EXAMPLE (SI Units): 100-year conditions for a site at 91°W in 50 m water depth.

The site is in the West Central region.

Independent extremes:

1-hour 10 m WS, from Table 4.5.2-1 = 38.1 m/s
H_{max}, from Figure 4.5.2-2 = 17.8 m
T_{Hmax}, from Table 4.5.2-1 = 13.0 s
Surge and Tide, from Figure 4.5.2-4 = 1.7 m

The current must be derived by interpolating between the 10 m and 70 m values from Table 4.5.2. The 10 m value should be weighted by (70–50)/(70–10) = 0.33 and the 70 m value by (50–10)/(70–10) = 0.67.

Current = 0.33(1.87) + 0.66(1.31) = 1.48 m/s

The current heading is determined from Figure 4.3.1-1 = 272°

Suppose a peak wave case is desired. H_{max} and T_{Hmax} are unchanged from the above. Assume the wave direction selected for analysis is 290°. The remaining independent extremes would be factored and modified using values from Table 5-2 as follows:

Associated 1-hour 10 m WS = 0.95(38.1) = 36.2 m/s
Heading = 290 –15 = 275°

Associated surge and tide = 0.7(1.7 – 0.42) + 0.42 = 1.32 m

Associated current = 0.7(1.48) = 1.04 m/s
Heading = 272° (unchanged)

EXAMPLE (U.S. Customary Units): 100-year conditions for a site at 91°W in 164 ft water depth.

The site is in the West Central region.

Independent extremes:
1-hour 32.8 ft WS, from Table 4.5.2-1 = 125 ft/s
H_{max}, from Figure 4.5.2-2 = 58.4 ft
T_{Hmax}, from Table 4.5.2-1 = 13.0 s
Surge and Tide, from Figure 4.5.2-4 = 5.6 ft

The current must be derived by interpolating between the 33 ft and 230 ft values from Table 4.5.2. The 328 ft value should be weighted by (230 – 164)/(230 – 32.8) = 0.33 and the 230 ft value by (164 – 32.8)/(230 – 32.8) = 0.67.

Current = 0.33(6.1) + 0.66(4.3) = 4.9 ft/s

The current heading is determined from Figure 4.3.1-1 = 272°

Suppose a peak wave case is desired. H_{max} and T_{Hmax} are unchanged from the above. Assume the wave direction selected for analysis is 290°. The remaining independent extremes would be factored and modified using values from Table 5-2 as follows:

Associated 1-hour 32.8 ft WS = 0.95(125) = 118.8 ft/s
Heading = 290 –15 = 275°

Associated surge and tide = 0.7(5.6–1.4) + 1.4 = 4.3 ft

Associated current = 0.7(4.9) = 3.4 ft/s
Heading = 272° (unchanged)

6.2 EXAMPLE: INTERMEDIATE DEPTH SITE BETWEEN REGIONS

EXAMPLE (SI Units): 100-year conditions for a site at 90.25° W in 100 m water depth.

As the site is in the transition region between the West Central and Central regions, conditions will need to be derived using interpolation between West Central and Central values. In addition, currents will need to be interpolated between the 70 m and 150 m regimes.

As the site is 0.25 deg from the West Central boundary, and 0.75 deg from the Central boundary, West Central values should be weighted by (1 – 0.25) = 0.75 and Central values by (1 – 0.75) = 0.25 when deriving conditions at the site.

Independent extremes:

1-hour 10 m WS:

Central WS, from Table 4.5.3-1: 48.0 m/s
West Central WS, from Table 4.5.2-1: 38.1 m/s
WS = 0.75(38.1) + 0.25(48.0) = 40.6 m/s

H_{max}:

Central H_{max}, from Figure 4.5.3-2: 25.4 m
West Central H_{max}, from Figure 4.5.2-2: 19.8 m
H_{max} = 0.75(19.8) + 0.25(25.4) = 21.2 m

T_{Hmax}:

Central T_{Hmax}, from Table 4.5.3-1: 13.9 s
West Central T_{Hmax}, from Table 4.5.2-1: 13.0 s
T_{Hmax} = 0.75(13.0) + 0.25(13.9) = 13.2 s

Surge and Tide:

Central Surge and Tide, from Figure 4.5.3-4: 1.45 m
West Central Surge and Tide, from Figure 4.5.2-4: 1.22 m
Surge and Tide = 0.75(1.22) + 0.25(1.45) = 1.28 m

Currents must first be derived for each depth regime, i.e., the 70 m contour and 150 m water depth or greater, prior to interpolation to the site water depth.

70 m:

Central current, from Table 4.5.3-1: 2.07 m/s
West Central current, from Table 4.5.2-1: 1.31 m/s
Uniform current = 0.75(1.31) + 0.25(2.07) = 1.5 m/s
Current direction, from Figure 4.3.1-1: 235°

150 m:

Central surface speed, from Table 4.5.3-1: 2.40 m/s
West Central surface speed, from Table 4.5.2-1: 1.91 m/s
Surface speed = 0.75(1.91) + 0.25(2.40) = 2.03 m/s

Central speed at mid-profile, from Table 4.5.3-1: 1.80 m/s
West Central speed at mid-profile, from Table 4.5.2-1: 1.43 m/s
Speed at mid-profile = 0.75(1.43) + 0.25(1.80) = 1.52 m/s

Central 0-speed depth, from Table 4.5.3-1: 100.8 m
West Central 0-speed depth, from Table 4.5.2-1: 80.0 m
0-speed depth = 0.75(80) + 0.25(100.8) = 85.2 m

Mid-profile depth = 85.2 m / 2 = 42.6 m

Once the 70 m and 150 m currents have been calculated, they can be used to define the current profile and direction at the 100 m depth site. First, the new profile is estimated. This is done by approximating the 70 m as a 3-point profile like the 150 m current, and then interpolating between the 70 m and 150 m currents for the surface, mid-profile depth and 0-speed depth points of the profile. In this case, the 70 m value would be weighted by (150 – 100)/(150 – 70) = 0.625 and the 150 m value by (100 – 70)/(150 – 70) = 0.375.

Approximate 3-point profile for 70 m current:

Surface speed = 1.5 m/s
Mid-profile speed and level = 1.5 m/s at 70 m
0-speed depth = 70 m

100 m profile:

Surface speed = 0.625(1.5) + 0.375(2.03) = 1.7 m/s
Mid-profile speed = 0.625(1.5) + 0.375(1.52) = 1.51 m/s
Mid-profile level = 0.625(70) + 0.375(42.6) = 59.7 m
0-speed depth = 0.625(70) + 0.375(85.2) = 75.7 m

The profile at 100 m would thus be defined by the following three (speed, depth) points:

(1.7 m/s, 0 m), (1.51 m/s, 59.7 m), (0 m/s, 75.7 m)

Second, the direction of the profile must be resolved. For peak current cases the current in the transition region may be considered omni-directional (although realistically would tend to align with local bathymetry in depths closer to 70 m).

However, the example will instead assume a 100-year peak wave case is being analyzed, for which the shallow and deepwater currents both have proscribed headings. Table 5-1 shows the deepwater current will have a heading +15° from the wave heading. The shallow water current has a heading of 235° as noted above. Assume a wave heading of 282° is selected (note, as 282° is within ±22.5° of 290°, the wave height is not factored); thus the deepwater current component has a heading of (282° + 15°) = 297°.

As this is a peak wave case, the associated current must first be derived. The process for estimating the 100 m current profile above is repeated, with the addition of load case factors from Tables 5-1 and 5-2. From Table 5-2 a factor of 0.7 should be applied to the 70 m current (speed only), while from Table 5-1 a factor of 0.75 must be applied to the 150 m current (speed and depth levels).

100 m peak-wave associated profile:

Surface speed = 0.625(1.5)0.7 + 0.375(2.03)0.75 = 1.23 m/s
Mid-profile speed = 0.625(1.5)0.7 + 0.375(1.52)0.75 = 1.08 m/s
Mid-profile level = 0.625(70) + 0.375(42.6)0.75 = 55.7 m
0-speed depth = 0.625(70) + 0.375(85.2)0.75 = 67.7 m

The associated profile at 100 m would thus be defined by the following three (speed, depth) points:

(1.23 m/s, 0 m), (1.08 m/s, 55.7 m), (0 m/s, 67.7 m)

The associated current direction is the heading of the resultant of the 70 m current and the average current speed over the upper 70 m of the 150 m profile. First, find the average speed over the upper 70 m of the 150 m profile (applying the factor from Table 5-1):

150 m profile:

Surface speed = 0.75(2.03) = 1.52 m/s
Speed at mid-profile = 0.75(1.52) = 1.14 m/s
0-speed depth = 0.75(85.2) = 63.9 m

Mid-profile depth = 0.75(42.6) = 32.0 m

The average speed over the upper 70 m of the 150 m profile is thus:

[(1.52+1.14)/2](32/70) + (1.14/2)(32/70) = 0.87 m/s

With the factor from Table 5-2, the 70 m current is:

0.7(1.5) = 1.05 m/s

Now find the direction of the resultant of the 70 m current and the average current over the upper 70 m of the 150 m profile, both weighted to 100 m. For convenience, resolve to east-west, north-south components (east and north are positive):

Average 70 m current, 150 m profile: 0.375(0.87) = 0.33 m/s, heading 297°
East = 0.33 sin(297) = –0.29
North = 0.33 cos(297) = 0.15

70 m current: 0.625(1.05) = 0.66 m/s, heading 235°
East = 0.66 sin(235) = –0.54
North = 0.66 cos(235) = –0.38

Resultant direction:
East = –0.29 – 0.54 = –0.83
North = 0.15 – 0.38 = –0.23
Heading = arctan(–0.83/–0.23) = –105° or (360–105) = 255°

Thus, the associated current for the 100-year peak wave case for this 100 m site would be given by a profile defined by:

(1.23 m/s, 0 m), (1.08 m/s, 55.7 m), (0 m/s, 67.7 m)

with a heading of 255°.

To complete the peak case, the wind and surge for this peak wave case would then be adjusted using the factors from either Table 5-1 or Table 5-2 (the wind and surge factors are the same for shallow and deep when evaluating peak wind or peak wave cases). The final associated values would be:

Associated 1-hour 10 m WS = 0.95(40.6) = 38.5 m/s
Heading = 282 – 15 = 267°
Associated surge and tide = 0.7(1.28 – 0.42) + 0.42 = 1.02 m

EXAMPLE (U.S. Customary Units): 100-year conditions for a site at 90.25°W in 328 ft water depth.

As the site is in the transition region between the West Central and Central regions, conditions will need to be derived using interpolation between West Central and Central values. In addition, currents will need to be interpolated between the 230 ft and 492 ft regimes.

As the site is 0.25 deg from the West Central boundary, and 0.75 deg from the Central boundary, West Central values should be weighted by (1 – 0.25) = 0.75 and Central values by (1– 0.75) = 0.25 when deriving conditions at the site.

Independent extremes:

1-hour 32.8 ft WS:

Central WS, from Table 4.5.3-1: 157.5 ft/s
West Central WS, from Table 4.5.2-1: 125.0 ft/s
WS = 0.75(125.0) + 0.25(157.5) = 133.2 ft/s

H_{max}:

Central H_{max}, from Figure 4.5.3-2: 83.3 ft
West Central H_{max}, from Figure 4.5.2-2: 65.0 ft
H_{max} = 0.75(65.0) + 0.25(83.3) = 69.6 ft

T_{Hmax}:

Central T_{Hmax}, from Table 4.5.3-1: 13.9 s
West Central T_{Hmax}, from Table 4.5.2-1: 13.0 s
T_{Hmax} = 0.75(13.0) + 0.25(13.9) = 13.2 s

Surge and Tide:

Central Surge and Tide, from Figure 4.5.3-4: 4.8 ft
West Central Surge and Tide, from Figure 4.5.2-4: 4.0 ft
Surge and Tide = 0.75(4.0) + 0.25(4.8) = 4.2 ft

Currents must first be derived for each depth regime, i.e., the 230 ft contour and 492 ft water depth or greater, prior to interpolation to the site water depth.

230 ft:

Central current, from Table 4.5.3-1: 6.8 ft/s
West Central current, from Table 4.5.2-1: 4.3 ft/s
Uniform current = 0.75(4.3) + 0.25(6.8) = 4.9 ft/s
Current direction, from Figure 4.3.1-1: 235°

492 ft:

Central surface speed, from Table 4.5.3-1: 7.9 ft/s
West Central surface speed, from Table 4.5.2-1: 6.3 ft/s
Surface speed = 0.75(6.3) + 0.25(7.9) = 6.7 ft/s

Central speed at mid-profile, from Table 4.5.3-1: 5.9 ft/s
West Central speed at mid-profile, from Table 4.5.2-1: 4.7 ft/s
Speed at mid-profile = 0.75(4.7) + 0.25(5.9) = 5.0 ft/s

Central 0-speed depth, from Table 4.5.3-1: 331 ft
West Central 0-speed depth, from Table 4.5.2-1: 262 ft
0-speed depth = 0.75(262) + 0.25(331) = 280 ft

Mid-profile depth = 280 ft / 2 = 140 ft

Once the 230 ft and 492 ft currents have been calculated, they can be used to define the current profile and direction at the 328 ft depth site. First, the new profile is estimated. This is done by approximating the 230 ft as a 3-point profile like the 492 ft current, and then interpolating between the 230 ft and 492 ft currents for the surface, mid-profile depth and 0-speed depth points of the profile. In this case, the 230 ft value would be weighted by (492–328)/(492–230) = 0.625 and the 492 ft value by (328–230)/(492–230) = 0.375.

Approximate 3-point profile for 230 ft current:

Surface speed = 4.9 ft/s
Mid-profile speed and level = 4.9 ft/s at 230 ft
0-speed depth = 230 ft

328 ft profile:

Surface speed = 0.625(4.9) + 0.375(6.7) = 5.6 ft/s
Mid-profile speed = 0.625(4.9) + 0.375(5.0) = 5.0 ft/s
Mid-profile level = 0.625(230) + 0.375(140) = 196 ft
0-speed depth = 0.625(230) + 0.375(280) = 248 ft

The profile at 328 ft would thus be defined by the following three (speed, depth) points:

(5.6 ft/s, 0 ft), (5.0 ft/s, 196 ft), (0 ft/s, 248 ft)

Second, the direction of the profile must be resolved. For peak current cases the current in the transition region may be considered omni-directional (although realistically would tend to align with local bathymetry in depths closer to 230 ft).

However, the example will instead assume a 100-year peak wave case is being analyzed, for which the shallow and deepwater currents both have proscribed headings. Table 5-1 shows the deepwater current will have a heading +15° from the wave heading. The shallow water current has a heading of 235° as noted above. Assume a wave heading of 282° is selected (note, as 282° is within ±22.5° of 290°, the wave height is not factored); thus the deepwater current component has a heading of (282° + 15°) = 297°.

As this is a peak wave case, the associated current must first be derived. The process for estimating the 328 ft current profile above is repeated, with the addition of load case factors from Tables 5-1 and 5-2. From Table 5-2 a factor of 0.7 should be applied to the 230 ft current (speed only), while from Table 5-1 a factor of 0.75 must be applied to the 492 ft current (speed and depth levels).

328 ft peak-wave associated profile:

Surface speed = 0.625(4.9)0.7 + 0.375(6.7)0.75 = 4.0 ft/s
Mid-profile speed = 0.625(4.9)0.7 + 0.375(5.0)0.75 = 3.5 ft/s
Mid-profile level = 0.625(230) + 0.375(140)0.75 = 183 ft
0-speed depth = 0.625(230) + 0.375(280)0.75 = 222 ft

The associated profile at 328 ft would thus be defined by the following three (speed, depth) points:

(4.0 ft/s, 0 ft), (3.5 ft/s, 183 ft), (0 ft/s, 222 ft)

The associated current direction is the heading of the resultant of the 230 ft current and the average current speed over the upper 230 ft of the 492 ft profile. First, find he average speed over the upper 230 ft of the 492 ft profile (applying the factor from Table 5-1):

492 ft profile:

Surface speed = 0.75(6.7) = 5.0 ft/s
Speed at mid-profile = 0.75(5.0) = 3.7 ft/s
0-speed depth = 0.75(280) = 210 ft

Mid-profile depth = 0.75(140) = 105 ft

The average speed over the upper 230 ft of the 492 ft profile is thus:

[(5.0+3.7)/2](105/230) + (3.7/2)(105/230) = 2.9 ft/s

With the factor from Table 5-2, the 230 ft current is:

0.7(4.9) = 3.4 ft/s

Now find the direction of the resultant of the 230 ft current and the average current over the upper 230 ft of the 492 ft profile, both weighted to 328 ft. For convenience, resolve to east-west, north-south components (east and north are positive):

Average 230 ft current, 492 ft profile: 0.375(2.9) = 1.1 ft/s, heading 297°
East = 1.1 sin(297) = –1.0
North = 1.1 cos(297) = 0.5

230 ft current: 0.625(3.4) = 2.1 ft/s, heading 235°
East = 2.1 sin(235) = –1.7
North = 2.1 cos(235) = –1.2

Resultant direction:
East = –1.0 – 1.8 = –2.7
North = 0.5 – 1.2 = –0.7
Heading = arctan(–2.7/–0.7) = –105° or (360 – 105) = 255°

Thus, the associated current for the 100-year peak wave case for this 328 ft site would be given by a profile defined by:

(4.0 ft/s, 0 ft), (3.5 ft/s, 183 ft), (0 ft/s, 222 ft)

with a heading of 255°.

To complete the peak case, the wind and surge for this peak wave case would then be adjusted using the factors from either Table 5-1 or Table 5-2 (the wind and surge factors are the same for shallow and deep when evaluating peak wind or peak wave cases). The final associated values would be:

Associated 1-hour 32.8 ft WS = 0.95(133.2) = 126.3 ft/s
Heading = 282 –15 = 267°
Associated surge and tide = 0.7(4.2 – 1.4) + 1.4 = 3.3 ft

7 Sudden Hurricane Conditions

A "sudden" hurricane is one which forms locally in the Gulf of Mexico, and due to speed of formation and proximity to infrastructure at time of formation may not allow sufficient time to evacuate manned facilities. The exact population of storms used to derive sudden hurricane conditions at a given site may be based on where storms form and how quickly storms move and intensify after formation, in comparison to the accuracy of storm forecasts and how quickly personnel and/or facilities may be removed from the site.

A set of sudden hurricane conditions is provided below in Table 7-1A and Figures 7-1A to 7-4A; those marked "A" are in SI Units while those marked "B" are in U.S. Customary Units. These conditions have been derived from a subset of storms defined by those whose center crossed 26°N within 60 hours of becoming named storms. In operational terms, this subset bounds those storms which generate 10 m (32.8 ft) 1-hour wind speeds of 15 m/s (49 ft/s) or greater at locations at or above 28°N within 24 hours of becoming named storms. As the conditions from this population of storms are essentially uniform across the Gulf of Mexico, only one set of conditions is provided, applicable to all regions within the limits of Section 3.

Load cases for sudden hurricane conditions may be developed in accordance with the guidelines in Section 5, using the following modifications:

- 100-year sudden hurricane load cases should be developed using the combination factors in the 10-year column. The 100-year sudden hurricane wave condition should be considered omni-directional.

- 1,000- and 10,000-year sudden hurricane load cases should be developed using the combination factors in the 100-year column. The 1,000- and 10,000-year sudden hurricane directional wave conditions may be approximated using Figure 4.2.2-1.

Table 7-1A—Independent Extreme Values for Sudden Hurricane Winds, Waves, Currents and Surge (All Regions)

Return Period (Years)	100	1000	10000
Wind (10 m Elevation)			
1-hour Mean Wind Speed (m/s)	29.1	39.3	48.0
10-min Mean Wind Speed (m/s)	32.0	44.0	54.5
1-min Mean Wind Speed (m/s)	35.7	49.9	62.8
3-sec Gust (m/s)	40.5	57.7	73.7
Waves, WD > = 1000 m			
Significant Wave Height (m)	8.0	10.8	13.2
Maximum Wave Height (m)	14.0	19.1	23.3
Maximum Crest Elevation (m)	9.8	12.8	15.6
Peak Spectral Period (s)	12.2	14.2	15.7
Period of Maximum Wave (s)	11.0	12.8	14.1
Currents, WD > = 150 m			
Surface Speed (m/s)	1.46	1.97	2.40
Speed at Mid-profile (m/s)	1.10	1.48	1.80
0-Speed Depth (m)	61.0	82.3	100.8
Currents, WD < = 70 m			
Uniform Speed at 10 m Depth (m/s)	1.09	1.98	2.67
Uniform Speed at 70 m Depth (m/s)	0.76	1.39	1.87
Water Level, WD > = 500 m			
Storm Surge (m)	0.42	0.60	0.75
Tidal Amplitude (m)	0.42	0.42	0.42

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 7-1A, 7-2A and 7-3A for wave and crest elevation values for water depths between 10 m and 1000 m.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 70 m and 150 m should be estimated as described in 4.3.3.

See Figure 7-4A for surge and tide in water depths less than 500 m.

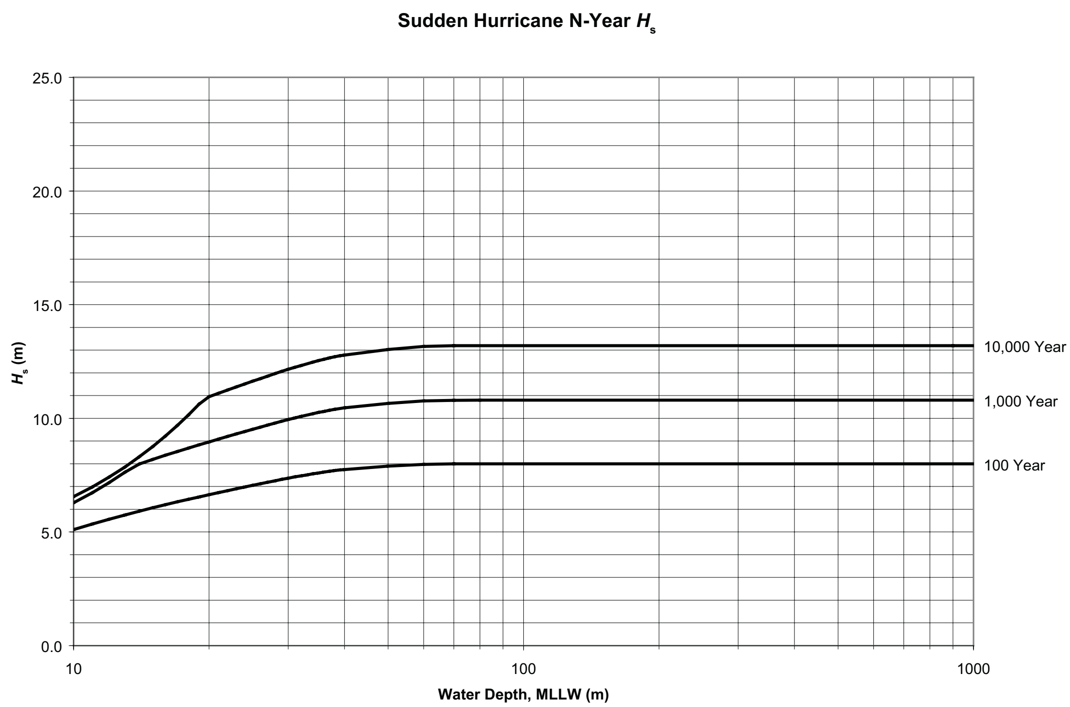


Figure 7-1A—N-Year H_s, All Regions

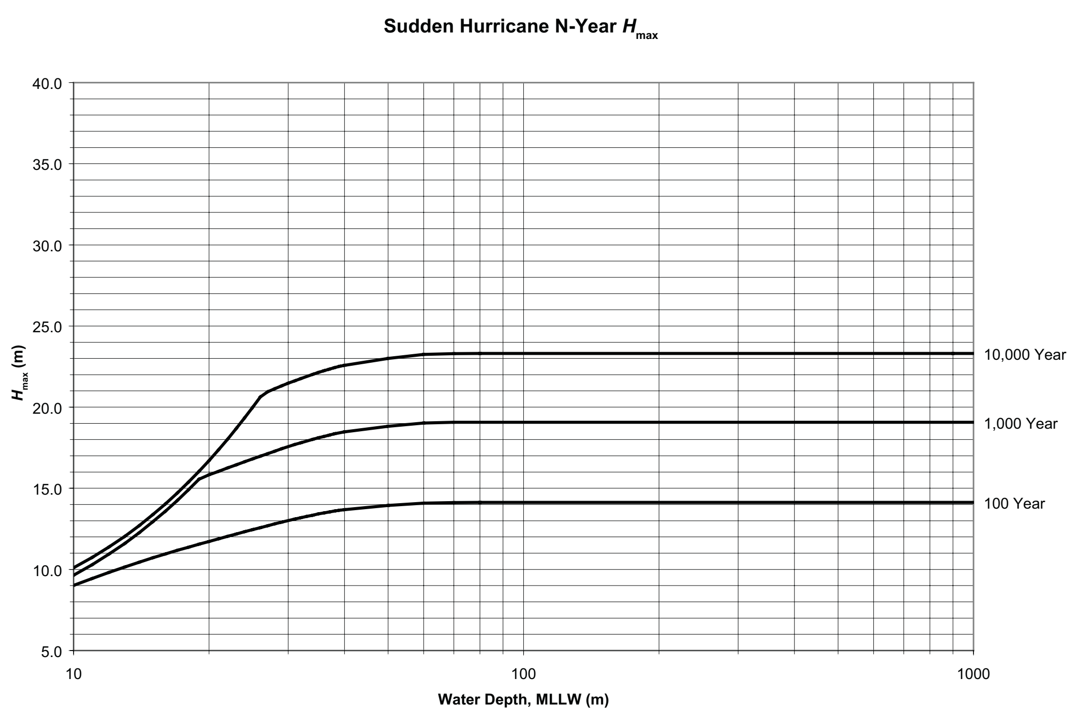


Figure 7-2A—N-Year H_{max}, All Regions

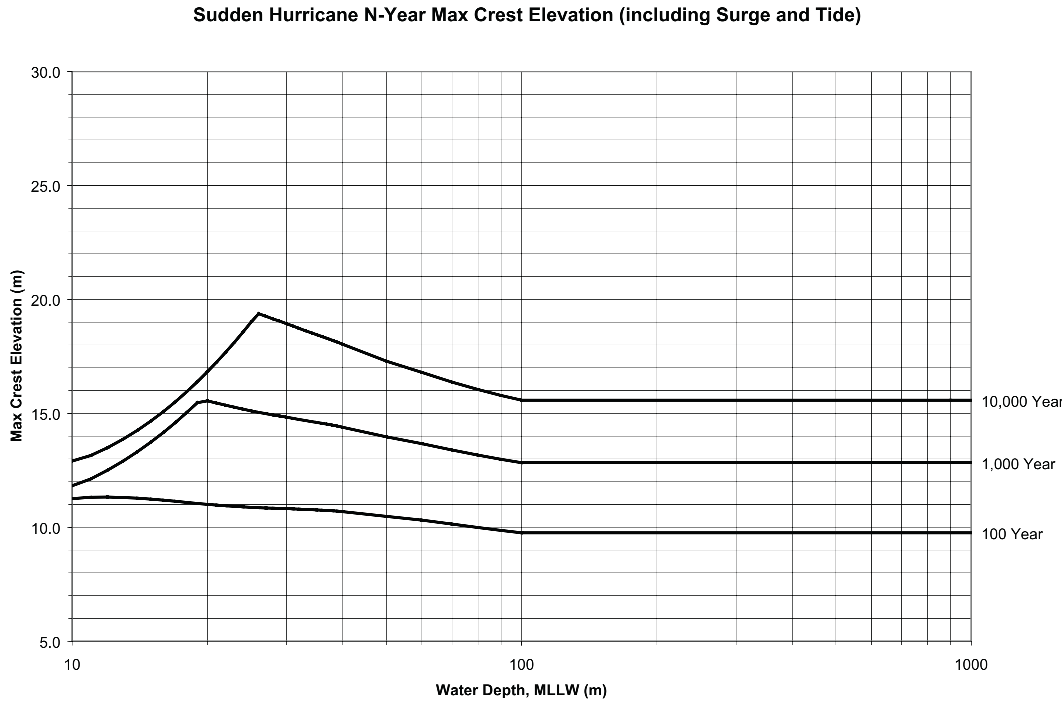


Figure 7-3A—N-Year Max Crest Elevation, All Regions

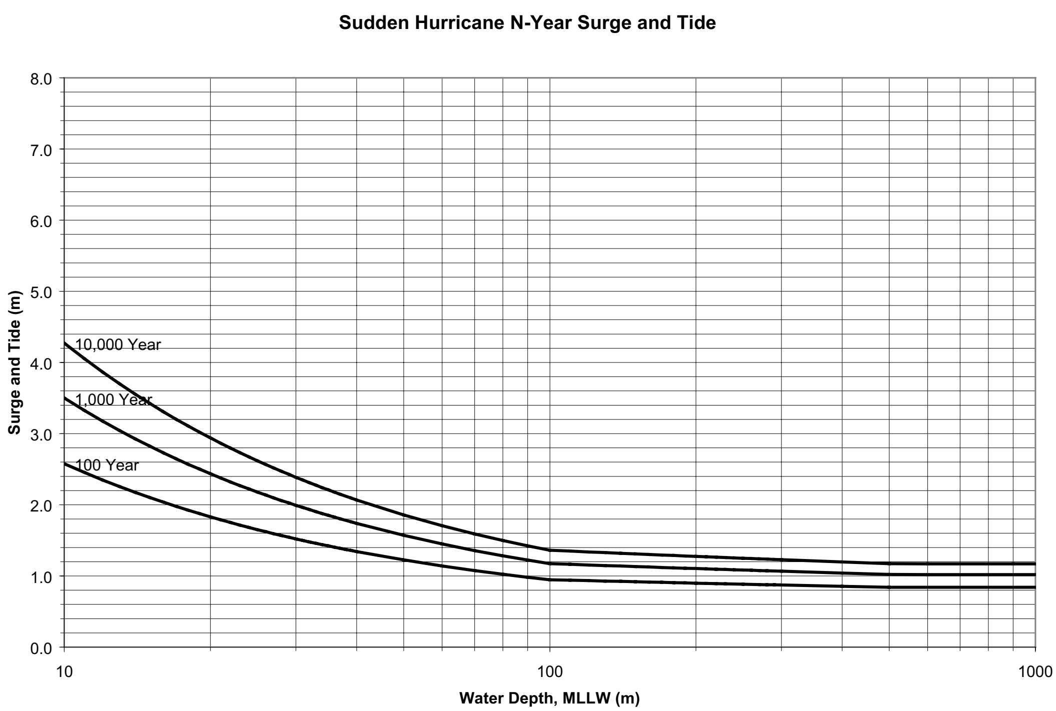


Figure 7-4A—N-Year Surge with Tide, All Regions

Table 7-1B—Independent Extreme Values for Sudden Hurricane Winds, Waves, Currents and Surge (All Regions)

Return Period (Years)	100	1000	10000
Wind (32.8 ft elevation)			
1-hour Mean Wind Speed (ft/s)	95.5	128.9	157.5
10-min Mean Wind Speed (ft/s)	105.0	144.4	178.8
1-min Mean Wind Speed (ft/s)	117.1	163.7	206.0
3-sec Gust (ft/s)	132.9	189.3	241.8
Waves, WD > = 3280 ft			
Significant Wave Height (ft)	26.2	35.4	43.3
Maximum Wave Height (ft)	45.9	62.7	76.4
Maximum Crest Elevation (ft)	32.2	42.0	51.2
Peak Spectral Period (s)	12.2	14.2	15.7
Period of Maximum Wave (s)	11.0	12.8	14.1
Currents, WD > = 492 ft			
Surface Speed (ft/s)	4.8	6.5	7.9
Speed at Mid-profile (ft/s)	3.6	4.9	5.9
0-Speed Depth (ft)	200	270	331
Currents, WD 33 ft – 230 ft			
Uniform Speed at 33 ft Depth (ft/s)	3.6	6.5	8.8
Uniform Speed at 230 ft Depth (ft/s)	2.5	4.6	6.1
Water Level, WD > = 1640 ft			
Storm Surge (ft)	1.4	2.0	2.5
Tidal Amplitude (ft)	1.4	1.4	1.4

Notes:

Wind speeds for a given return period are applicable to all water depths throughout the region.

Crest elevation includes associated surge and tide.

See Figures 7-1B, 7-2B and 7-3B for wave and crest elevation values for water depths between 33 ft and 3280 ft.

The peak spectral period and period of maximum wave apply to waves in all water depths.

Currents in water depths between 230 ft and 492 ft should be estimated as described in 4.3.3.

See Figure 7-4B for surge and tide in water depths less than 1640 ft.

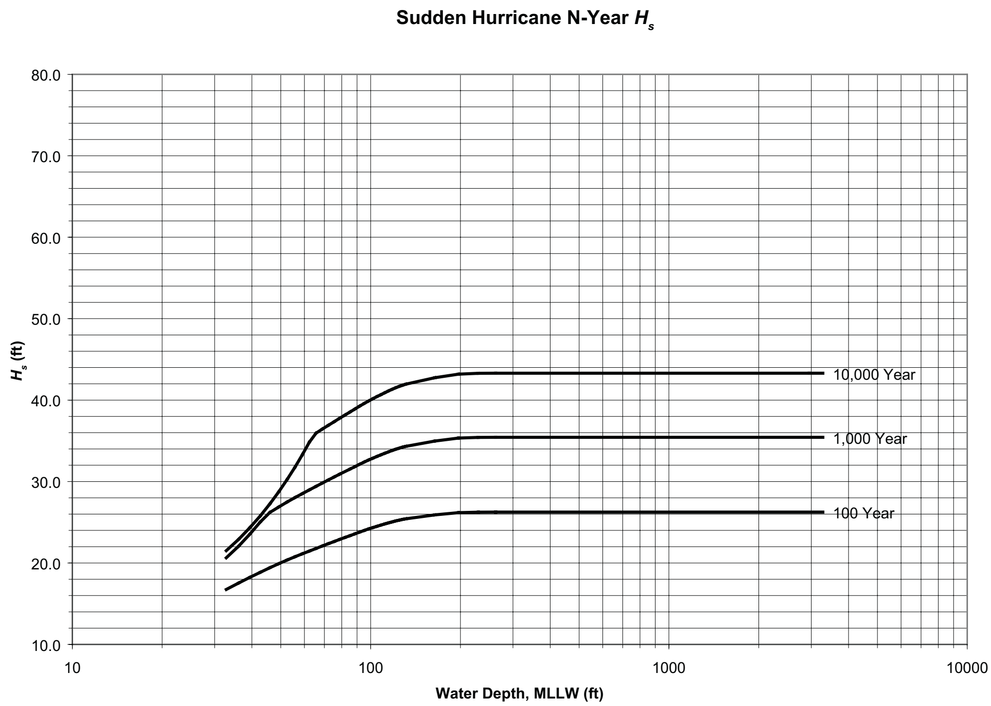


Figure 7-1B—N-Year H_s, All Regions

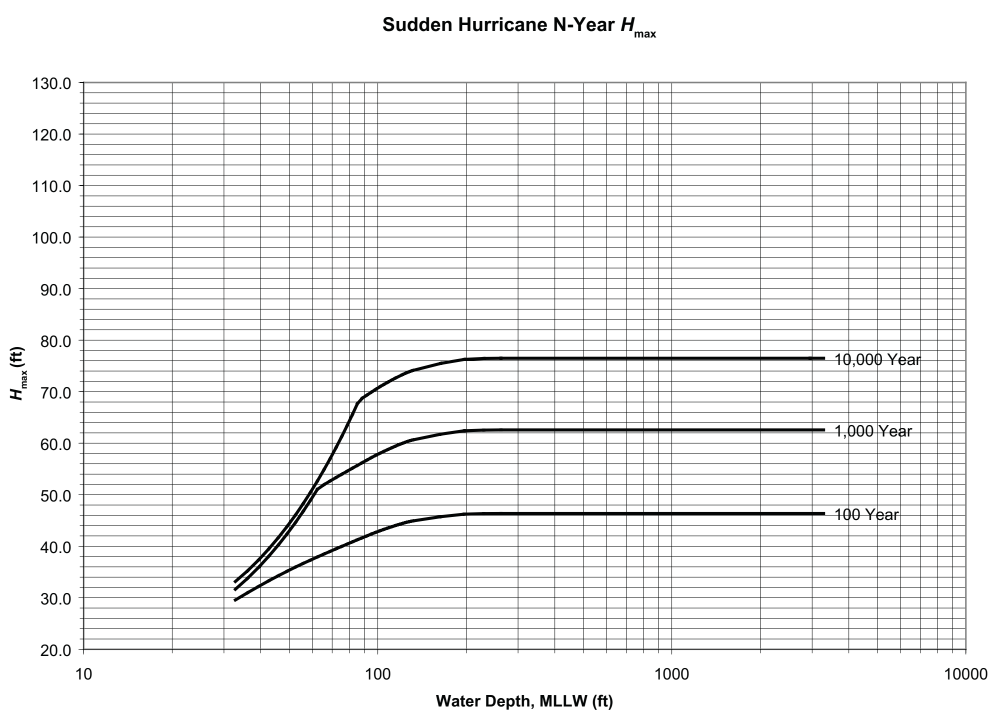


Figure 7-2B—N-Year H_{max}, All Regions

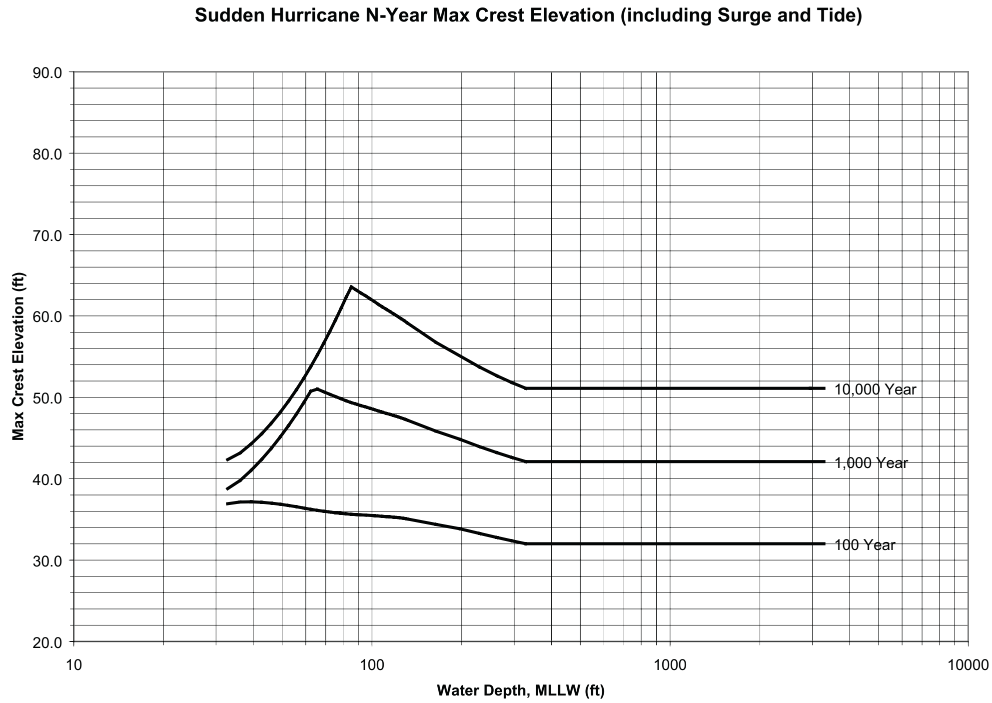


Figure 7-3B—N-Year Max Crest Elevation, All Regions

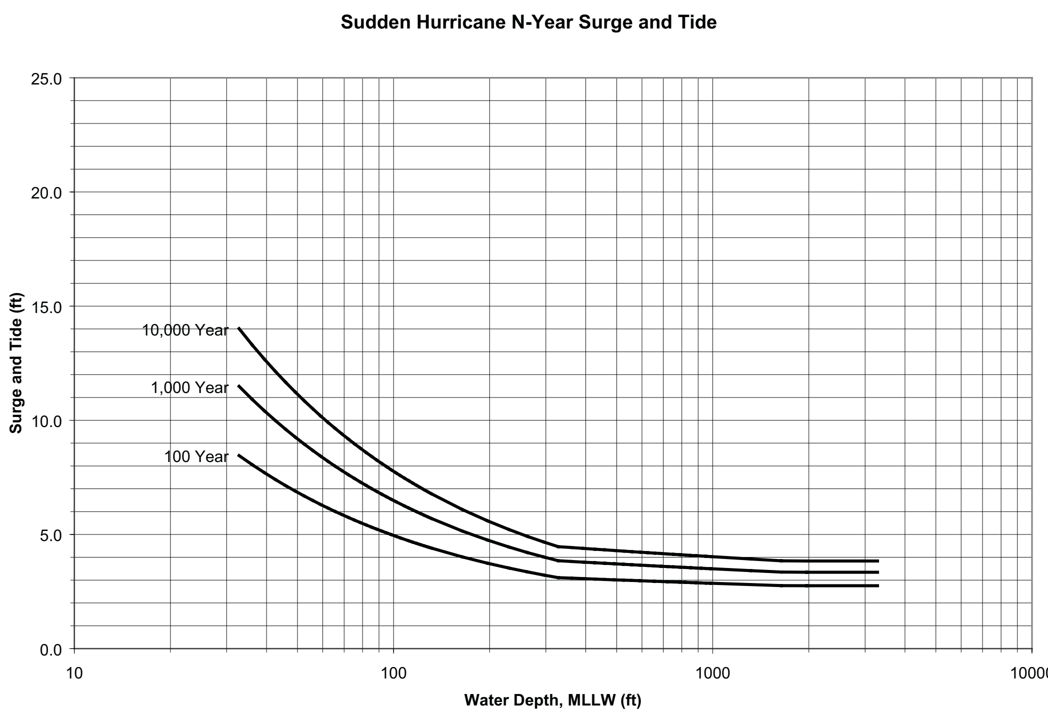


Figure 7-4B—N-Year Surge with Tide, All Regions

8 Seasonal Hurricane Conditions

The regional conditions presented in this document have been derived assuming an exposure period to hurricane encounters over the full year. Should a facility operate in such a manner as to restrict its exposure to hurricanes in the Gulf of Mexico (or one of the regions in the Gulf of Mexico) to periods less than one year, i.e. a seasonal operation, it would be reasonable to consider the facility subject to hurricane conditions derived from a limited exposure period. For example, most of the severe hurricanes which have affected the Gulf of Mexico occur in the months of August, September and October; conditions derived considering only these three months will be more severe than those derived from the three months of May, June and July. Should seasonal conditions be used, care should be taken to evaluate the increasing risk incurred by operating close to the transition date to a “severe” season.

9 Guidelines for Site-specific Metocean Studies

Performance of a site-specific metocean study is the preferred way of ensuring regional variations in storm climate and local topographic and bathymetric effects are properly accounted for, as well as ensuring sufficient data is available to properly identify the phasing between wind, wave, current and surge and to serve as inputs to response-based analyses aimed at determining n-year forces. It is emphasized that the goal of a site-specific study is more accurate information on the metocean conditions at a site; site-specific studies should not focus on determining the lowest set of design conditions possible.

A site-specific study of hurricane metocean conditions should be based on a hindcast database of winds, waves, currents and surge derived from models that have been validated against severe historical storms from 1950 through 2005 including Opal, Ivan and Katrina. Validation should show the wind, wave and surge models have a coefficient of variation (COV) no more than 15% when comparing model peak wind speed, wave height or surge height to their respective measured peak values. An acceptable COV for the current model validations can be as high as 30%. Any bias between the model and data should be removed with at least a simple linear fitting process. Use of numerical wave, current and surge models based upon discrete finite element or finite difference solutions of the governing partial differential equations is preferred; grid resolution for models should be equal to or finer than 15 km (8 nm) and the overall domain should be sufficient to prevent boundary conditions from affecting the solution. Parametric models of wave, current and surge should only be used if they have been extensively calibrated against major severe storms like Opal, Ivan and Katrina.

The hindcast period used should at a minimum consider all Gulf of Mexico cyclones of tropical storm strength or greater between 1960 and the present date. The metocean specialist performing the study may choose to use a database starting period as early as 1945; data prior to 1945 should not be used as storm characterizations from earlier periods are unreliable, particularly when a storm is far from land. Data used for storm wind field characterization should use as a starting point the National Hurricane Center “best tracks” data set. Additional storm parameters such as radius to maximum winds should be determined from surface measurements, aviation reconnaissance, and satellite observations.

Because of the low frequency of occurrence and relatively small diameter of hurricanes, estimates of extremes made from a limited (in this case, 50 years) database can vary substantially over relatively small distances, even within a region that would be expected on the basis of physical arguments to be statistically homogeneous. Specifically, sites that are very near the tracks of one or more of the few historical Category 4 or 5 hurricanes will have much greater estimates of 100-year winds, waves, current and surge than sites that are not near one of those tracks. It is not reasonable to expect that extreme hurricanes in the next few centuries will have exactly the same tracks as historical hurricanes. Therefore, some means of smoothing site-specific conditions estimated from a limited database, accounting for track variability, should be used. Commonly used methods include simple spatial smoothing of site specific estimates, track shifting, and grid point pooling. With regard to grid point pooling, there is no uniquely “correct” way to do it. However, using three or more grid points, all lying within the region that is expected to be homogeneous on the basis of physical arguments, arranged in a curvilinear array oriented more or less perpendicular to the tracks of the most severe hurricanes in deep water, or oriented along a bathymetric contour in shallow water, with a spacing of at least 75 km (41 nm) between grid points to reduce the correlation among grid point statistics, generally provides reasonable results. Some deepwater locations may need a south-north and east-west arrangement of grid points (such as a five-point “cross” centered on the site) to capture the influence of both south-to-north and east-to-west tracking storms near the site. The distance over which pooling is performed should generally not be less than 150 km (82 nm) or greater than 300 km (164 nm) wide, and should be selected with attention to local water depth, fetch limitations, proximity to the Loop Current or areas with frequency warm-core eddies, and orientation of major storm tracks.

For return periods greater than 200 years, extremes may be derived either using the methods above or through the use of deductive models or Monte Carlo simulations of synthetic storms.

10 Commentary

New hurricane metocean conditions are provided for four regions, West, West Central, Central and East, spanning the northern Gulf of Mexico from southern Florida to southern Texas, for most water depths 10 m (33 ft) and deeper. The new conditions between 86.5° and 89.5°W are significantly higher than the conditions currently contained in the 21st Edition of API RP 2A [1], due to several subsequent severe storms, most notably Opal (1995), Ivan (2004), and Katrina (2005); however, the new conditions in the other three regions are similar to those currently in API RP 2A.

10.1 BASIS OF NEW METOCEAN CONDITIONS

The conditions contained herein are based to a large extent on deepwater metocean conditions developed in the MODU Mooring Strength and Reliability JIP managed by ABS Consulting [3] using select data from the Oceanweather, Inc., GOMOS-USA tropical cyclone hindcast [4] plus dedicated hindcasts of hurricanes Katrina [7] and Rita [8], as well as results from a deepwater hurricane current hindcast performed by one of the JIP participants. GOMOS is a wind, wave, current (2D as well as 1D in water depths > = 100 m or 328 ft) and surge hindcast of over 300 tropical storms and hurricanes known to have affected the Gulf of Mexico from 1900 through 2005. Deepwater currents were derived using a scaling relationship developed by one of the API work group members relating the peak current profile to peak wind speed at each return period as described in [9].

As the GOMOS hindcast is a commercial product under licensing restrictions, extremes for shallow water regions were derived using a variety of extrapolation procedures to relate the deepwater conditions to those in shallow water. The extrapolations were derived using the older public domain GUMSHOE [5] hindcast, a wind, wave, current (2D only) and surge hindcast of 100 storms from the period 1900 through 1989 plus a dedicated hindcast of Hurricane Andrew [6], as well as through reference to in-house metocean studies performed by several API work group members. The deep-to-shallow extrapolation procedures are described more fully in [9], however they can be summarized as follows:

- Wind velocity is considered constant over all water depths in each region.
- H_s is scaled from deep to shallow water using a normalizing curve (normalized by the deepwater value) derived from GUMSHOE. The same normalizing curve was used for all regions and all return periods.
- The associated wave periods are assumed constant over all water depths.
- Surge is scaled from deep to shallow water using an n-year surge normalizing curve (normalized by deepwater n-year value) derived from GUMSHOE. The same normalizing curve was used for all regions.
- Current on the shelf is scaled from the 70 m (230 ft) depth value using an n-year scaling curve derived from GUMSHOE. Three normalizing curves were used: one for the East and West Central regions, one for the Central and one for the West regions. The n-year current at 70 m (230 ft) was then related to n-year wind speed in GUMSHOE; this scaling relationship was then used to estimate currents at 70 m (230 ft) using the GOMOS-derived deepwater winds.
- N-year H_{max} was estimated at each water depth assuming it is equal to $1.77 \times H_s$ (considering an average storm peak seastate duration and including an adjustment factor to correct H_{max} given n-year H_s to n-year H_{max}), subject to a breaking limit in shallow water.
- N-year η_{max}, including associated surge and tide, was estimated at each water depth using the n-year H_s and associated Tp, including associated surge and tide adjustments for water level, using the Forristall 2nd-order distribution [10] together with an average storm peak seastate duration, subject to breaking and including an adjustment factor to correct η_{max} given n-year H_s to n-year η_{max}. The adjustment factor varies from 1.2 at 10 m (33 ft) to 1.03 at 100 m (328 ft). It should be noted the crest estimates are derived considering the risk of exceedance at a single point. However, as described by Forristall [11], when the true area of exposure to wave crests is considered (i.e. the full platform deck area), the probability of having this point estimate exceeded somewhere locally within the deck is naturally higher than the probability of having it exceeded just at one point, as the potential crest encounter area is more than one point. When deck area is considered, the potential local crest height may exceed the point-estimated crest height by as much as 15% for the same level of non-exceedance.

As noted above, individual wave and crest heights have been provided based on industry-accepted distributions. No explicit accounting is made for the possibility of “freak” or “rogue” wave occurrence in tropical storm-driven sea states, where in this case, a freak or rogue wave is defined as one which is statistically unexpected given the prevailing sea state during the measurement period. While there are a number of peer-reviewed and apparently high-quality measurements showing rogue waves during extratropical storms, in the case of Gulf of Mexico tropical cyclones to date there have been no published high-quality measurements of rogue waves. While recent high-quality measurements analyzed by Cooper et al., [25] clearly show large individual waves during Hurricane Ivan at two locations, the largest waves do not appear statistically unexpected.

Conditions for return periods in excess of 200 years were estimated by factoring the 100-year extremes by a set of scaling factors relating the 100-year level to the 1,000-, 2,000- and 10,000-year level derived from in-house studies by API work group members as well as reference to the 10-4 JIP [12]. It should be noted that the confidence intervals on the rarer return periods (1,000-year or more) are much wider than those on the 100-year estimate, due to the uncertainties in extrapolating a limited data set to those return periods.

The n-year extremes provided in 4.5 do not include artificial increases to values derived from statistical analysis of the hindcast record beyond those associated with several of the extrapolations involved and make no claim to be conservative. It is possible to apply equally defensible statistical methods to the same hindcast data used here, or to site-specific data within one of the regions, and derive slightly higher or slightly lower extreme values than those presented here. The extremes also do not consider the possibility of storms with a wave-making potential like Opal, Ivan and Katrina affecting the non-Central regions with a frequency similar to that which has been observed in the Central region.

The sets of combination factors provided allow for derivation of associated wind, wave, current and surge parameters to go with the n-year peak wave, peak wind or peak current cases. The combination factors for each case are based on the ratio between an independent extreme of a given parameter and the values of that parameter associated with other independent extremes. These factors were derived by comparing results among the API Task Group members based on independent evaluations of these factors performed in-house. Where appropriate, directional offsets of wind heading from wave heading, and current heading from wave heading, are also provided. When factoring surge and tide, the tidal amplitude should be removed, the surge factored, and then the tide added back in.

As equations 2.3.2-6 and 2.3.2-7 from API RP 2A-WSD, 21st Edition were still incorrect in Supplement 2, corrected versions have been supplied in this document in 4.1, along with the wind profile and gust equations and the 1-point wind spectra, in SI and U.S. Customary Units. The basis of the wind formulas used by API RP 2A-WSD, 21st Edition is documented in [23]. While these formulas were derived from wind data collected at a coastal location in Norway for frontal system type storms, they appear to be applicable to winds generated by strong tropical cyclones as demonstrated in [25].

The factors for estimating directional n-year waves have been derived using the standard industry practice of examining the peak waves in the eight cardinal direction sectors, and then normalizing the peak in each sector by the greatest peak from all sectors; the same approach was used in development of the directional factors in [1]. An alternative approach to determining directional extremes which is statistically risk-consistent is described in [13]; this paper points out the potential pitfall of using directional metocean criteria to overly "optimize" a structure, without consideration for the effect on platform reliability.

The JONSWAP spectrum as described in [2] is recommended for characterization of hurricane sea states.

Current headings on the shelf have been derived from GUMSHOE and are consistent with those previously presented in API RP 2A-WSD.

Sudden hurricane conditions have been derived in a manner identical to that as the "full" hurricane conditions. Conditions were derived using the MODU JIP data, and then scaled into shallow water using the GUMSHOE-derived relationships. The population used for sudden hurricanes was restricted to those storms which:

- Are from the time period 1945 through 2005.
- Took less than 60 hours after becoming a named storm to crossing 26°N.

In operational terms, this subset bounds those storms which generate 10 m 1-hour wind speeds of 15 m/s (49 ft/s) or greater at locations at or above 28°N within 24 hours of becoming named storms. The conditions derived using this reduced storm population do not show strong variation across the four regions, and are similar to the sudden hurricane conditions presented in the 21st Edition RP 2A-WSD, Section 17.6.2.a. As such, a single set of conditions has been provided for the entire Gulf of Mexico.

General guidance is provided for the derivation of seasonal hurricane conditions.

10.2 REGIONAL CONSIDERATIONS

As noted, conditions are provided for four regions of the Gulf of Mexico as opposed to the prior API practice of recommending one set of conditions to apply over the entire Gulf. The four regions are:

- West, between 97.5°W and 95°W
- West Central, between 94°W and 90.5°W
- Central, between 89.5°W and 86.5°W

- East, between 85.5°W and 82.5°W

The decision to use four regions is based on work by a number of researchers over the past 15 years; key publications on the subject include those by Cooper [14] and Choiunard et al., [15] which indicate that the substantial differences in hurricane conditions across the Gulf are real as opposed to the result of "chance" due to the randomness of historical storms. Furthermore, recent research continues to link hurricane size and intensity to energy available due to the presence of the Loop Current or warm eddies such as discussed by Shay et al., [16]. The regions are defined based on areas of similar bathymetric orientation, track direction of major hurricanes, and the likelihood of encounter of deep warm water either due to the Loop Current or eddies spun off from the Loop Current. A 1° transition separates adjacent regions; in the transition region, conditions should be derived by interpolation from the two adjacent regions.

10.3 LENGTH OF HINDCAST DATABASE

Another fundamental change from past API practice is the basing of the conditions on the hindcast period to approximately 1950 through 2005 (sudden hurricane conditions were derived using a population from 1945 through 2005). Previous API conditions such as those in RP 2A-WSD were based on as long a record as possible, which for GUMSHOE and GOMOS included storms back to 1900 from the NHC HURDAT record [17], with the understanding that the uncertainty in extreme estimates decreases as the data record length increases. However, since 1995, the Gulf of Mexico has been subject to three large, intense wave-generating storms, Opal, Ivan and Katrina, of a type not seen in the previous hindcast record. These storms, in particular the storm activity from 2004 through 2005, have led many industry professionals to suspect there is a low bias in terms of size and intensity in the early storm records.

First, the following should be noted about the HURDAT record:

- HURDAT contains storm tracks from identified tropical cyclones dating back to 1851.
- Storms in HURDAT have intensity characterized by two measures: a peak wind speed and possibly a central pressure. Most storms in the database prior to 1944 lack central pressure reports, while the peak wind speeds reported for early storms are those inferred from surface measurements, observed sea states or damage at coastal locations.
- HURDAT does not report radius to maximum winds, which is needed to define storm size, and central pressure is missing for most pre-overflight year observations; this information must be recovered separately by review of weather observations such as those from the NHC, and for early storms prior to routine aerial and satellite observations of storms must be inferred from surface measurements or approximated statistically from the later storm population.

A close examination of raw HURDAT records over the full period of the database (1851 through 2005) yields several surprising trends for storms affecting the area of the Gulf of Mexico north of 24°N and west of 82°W. The HURDAT archive shows one Category 5 hurricane occurring in this region in the period prior to 1960, and 9 afterwards. Similarly, if the threshold is lowered to Category 4, the database shows 14 occurrences prior to 1960 and 19 afterwards. As the threshold is dropped, the annual frequency of intense storms in each time period comes closer into alignment. The trend implies that either (1) storms are truly increasing in intensity after 1960, or (2) there is a low bias in the intensity measurements made prior to 1960. Given the poor ability to identify storm parameters prior to the era of overflights and satellite observations, combined with an anecdotal record of annual frequency intense storm strikes at coastal locations within the Gulf of Mexico which does not seem to change in annual frequency, the second conclusion is more plausible.

This issue of low bias is explored further by Cooper and Stear [18]. It is noted that most well-documented severe hurricanes display a significant increase in storm central pressure before landfall (and hence a decrease in intensity), typically caused by infilling of the storm eye-wall with less humid terrestrial air. They noted that in the hindcast database between 1900 and 1949 about 45% of the storms show infilling, while between 1950 and 2005 85% of the storms show infilling. They also note that before initiation of routine aircraft reconnaissance of hurricanes around 1950, the available pressure measurements were typically only at landfall and perhaps the occasional ship observation, so, when used in hindcasting it was assumed that the offshore intensity was the same as at landfall. The likely result is that the intensity of at least some hurricanes in the pre-1950 period were underestimated while they were offshore.

Perhaps the best recommendation for limiting use of hindcast hurricane data to post-1950 for the characterization of offshore storms has come from researchers at the National Hurricane Center. In [19] the authors of the HURDAT database warn users that the early hurricanes are biased low in terms of sustained wind speed by 5 m/s – 8 m/s (17ft/s – 25 ft/s). This bias is not accounted for in either HURDAT or in derived products like GOMOS. One of the factors cited by [19] for the low bias is under sampling of the early storms; when only a few observations are made of a hurricane, the resulting severity estimate is biased low. Furthermore, in personal correspondence between Dr. Christopher Landsea of the NHC, lead author of [19], and several of the API work group members, Dr. Landsea emphasizes his view that the hindcast record should not be used to characterize storms offshore from the pre-overflight years, i.e., prior to 1944. A good example indicating the dangers of trusting completely the early years of the HURDAT database cited by Dr. Landsea is the characterization of Hurricane Opal (1995); if Opal is characterized simply by shore crossing central pressure and radius to maximum winds and projected backwards to a starting location somewhere in the Central Gulf, the resulting storm wave hindcast yields a peak significant wave height 3 m (10 ft) less than that developed using the complete size and intensity record of Opal as determined by satellite and aircraft observations.

Given the questionable accuracy of storm characterization for the period 1900 through 1949 (the period before routine overflights of storms and the later availability of satellite observation), only data from the period 1950 through 2005 has been used. The quality of the earlier, pre-1950, data is now regarded as dubious, so a trade off is made between quantity and quality; the new conditions are based on a shorter, but higher quality, storm record.

The impact of using hindcast data from the period 1900 through 2005 vs. 1950 through 2005 on 10-year and 100-year H_S was examined for each of the four MODU JIP deepwater locations. The most noticeable changes were in the 10-year values for the West and Central regions; post-1950 10-year values changed by –12% and +11% respectively from values derived from 1900 – 2005. The 100-year conditions in the West, Central and East regions each increased by 3% – 4% when the 1950 through 2005 data set was used as opposed to the 1900 through 2005. Remaining 10- and 100-year values were essentially unchanged.

10.4 SITE-SPECIFIC STUDIES

The recommendations for the performance of site-specific studies follow the latest methods used by industry professionals for the estimating of hurricane conditions. Descriptions of site averaging and pooling can be found in Haring and Heideman [20], Ward et al., [24] and Heideman and Mitchell [21]. Toro et al., [22] has compared the pooling method against other site data handling methods using typical Gulf of Mexico extremal distributions and has found that the pooling method works quite well for return periods of several hundred years and less. Guidance on site separation or averaging distances when performing site studies based on pooled over averaged data can be found in Chouinard et al., [15] and Toro et al., [22]. For estimating extremes at return periods four or five times the length of the data set, alternative approaches such as use of a deductive model as described by Toro et al. [22] or performance of Monte Carlo simulations of synthetic storms should be considered.

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