Inclusion of Tropical Storms for the Combined Total Storm Tide Frequency Restudy for Gulf County, Florida

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1.0 Background

In accordance with the objectives and rationale of the Florida Coastal Construction Control Line, the establishment of the line is based on the damage potential of 100 year return period hurricanes. A report entitled "Combined Total Storm Tide Frequency Restudy for Gulf County, Florida" (Reference (1)) was completed in January, 2007. This study includes the most updated tropical storms and hurricanes in the storm surge simulations. Since the methodology and procedures used for this study are the same as for the report mentioned above, only the storm statistics and the results are presented in this report.

2.1 Introduction and Data Source

The statistical parameters are based on historical storm data as presented in References (2) and (3). In brief, the empirical cumulative probability distributions are plotted for each of the parameters of interest and are then approximated by a series of straight line segments for computer application. All of the parameters are considered to be independent. The following subsections describe the statistical characteristics of the individual parameters of interest.

2.2 Storm Frequency and Direction

The storms causing appreciable storm tides in the vicinity of the Gulf County shoreline are classified as "landfalling", "exiting" or "alongshore" storms. Reasonably good data are available describing the characteristics of the storms impacting the area from 1900 to 2013. For purposes of this report, the data contained in References (2) and (3) that fall within a 275 n. mi. segment of the coast comprising the study area are used. The storm direction is defined here as the azimuth from which the storm is translating at the time of landfall, or, if an alongshore storm, when in close proximity to the site.

For purposes of this study, landfalling and exiting storms are considered to be of possible significance if they made landfall within a 275 n. mi. segment of the coast comprising the study area. This segment is extended 175 n. mi. west and 100 n. mi. east from the midpoint of the Gulf County shoreline. Accordingly, there were 73 landfalling and 5 alongshore storms occurring in the years 1900 through 2013. The table in Appendix A lists the storms used in this study.

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Based on historical data, it is expected that within a 1,000 year period a total of 684 storms will occur within the 275 n. mi. segment of the coast comprising the study area. Of the 684 storms, 640 will be landfalling, and 44 alongshore storms.

For purposes of computer use, the cumulative probability distribution of storm track direction (θ_N) is presented in Figure 1.

GULF COUNTY
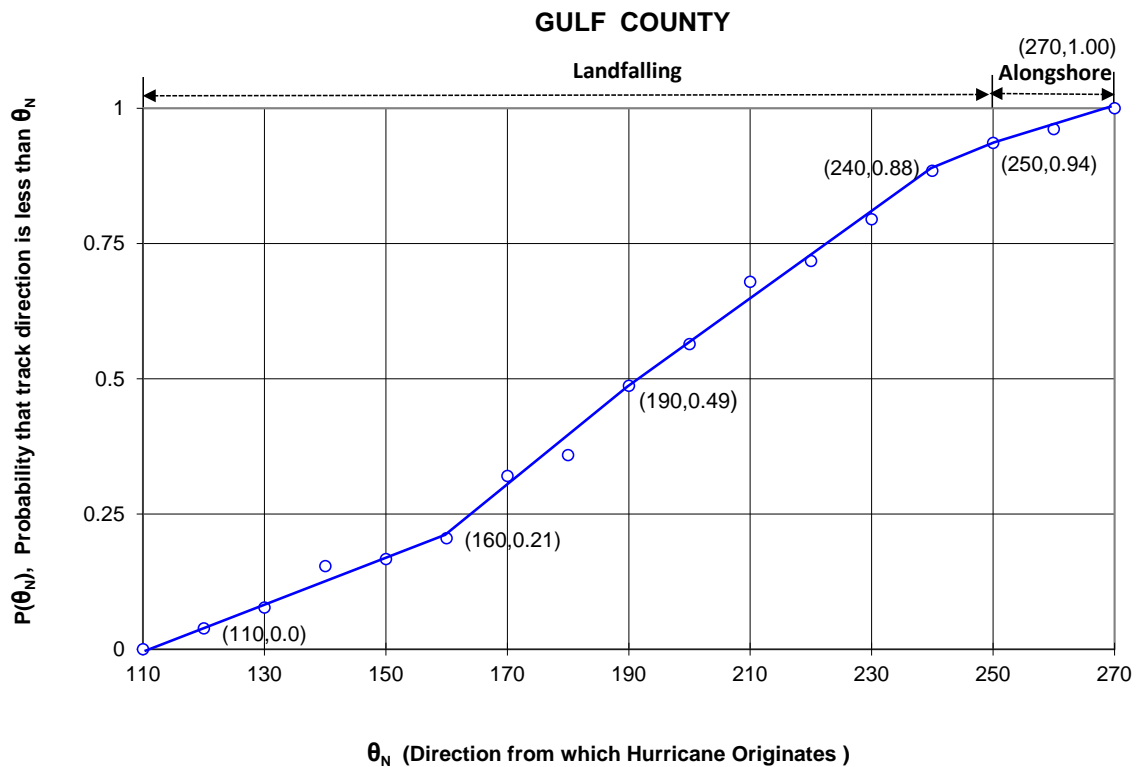
Figure 1: Cumulative Probability Distribution of Storm Track Direction, θ_N

2.3 Radius to Maximum Winds and Central Pressure Deficit

The cumulative probability distribution of radius to maximum winds for landfalling and alongshore storms is presented in Figures 2. The cumulative probability distributions of pressure deficit for landfalling and alongshore storms is presented in Figure 3.

GULF COUNTY
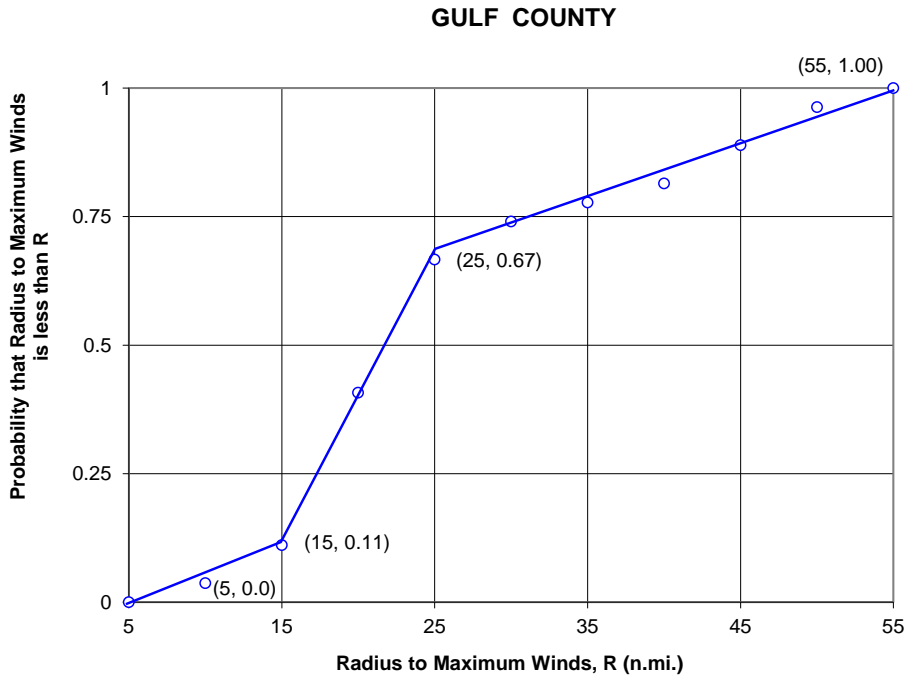
Figure 2: Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Alongshore Storms

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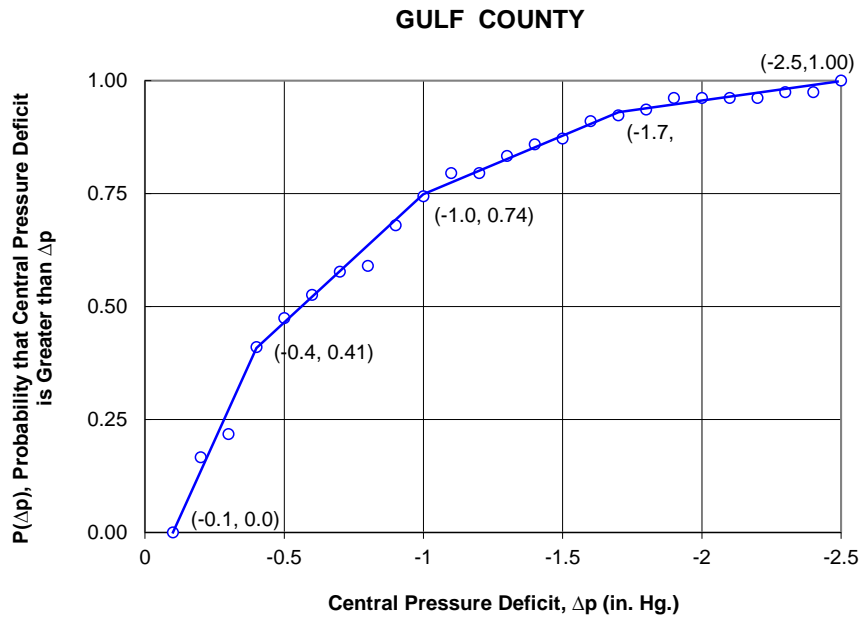
Figure 3: Cumulative Probability Distribution of Central Pressure Deficit, Δp for Landfalling and Alongshore Storms

2.4 Forward Speed

The cumulative probability distribution of the forward speed of translation is presented in Figure 4.

GULF COUNTY
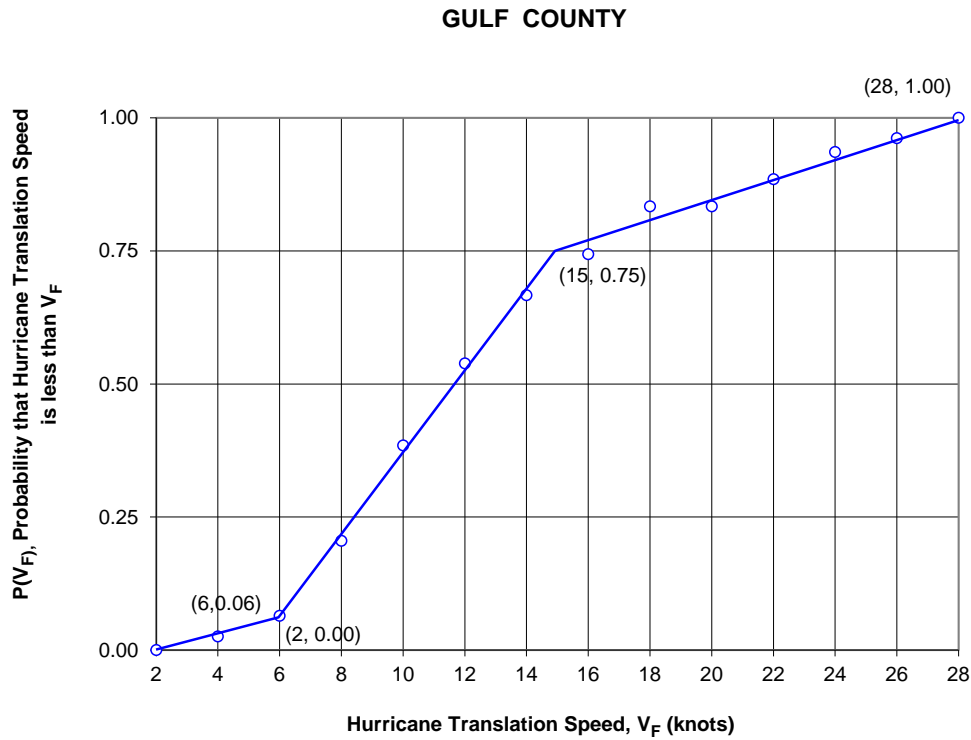
Figure 4: Cumulative Probability Distribution of Translation Speed, V_F

2.5 Track Position

For the landfalling storms, the track position is determined by the y coordinate, Y_F, representing the landfalling. Figure 5 presents the cumulative probability distribution for the actual landfalling position, Y_F, for landfalling storms. Figure 6 presents the cumulative probability distribution for the actual offshore distance, X_L, for alongshore storms.

GULF COUNTY - Landfalling
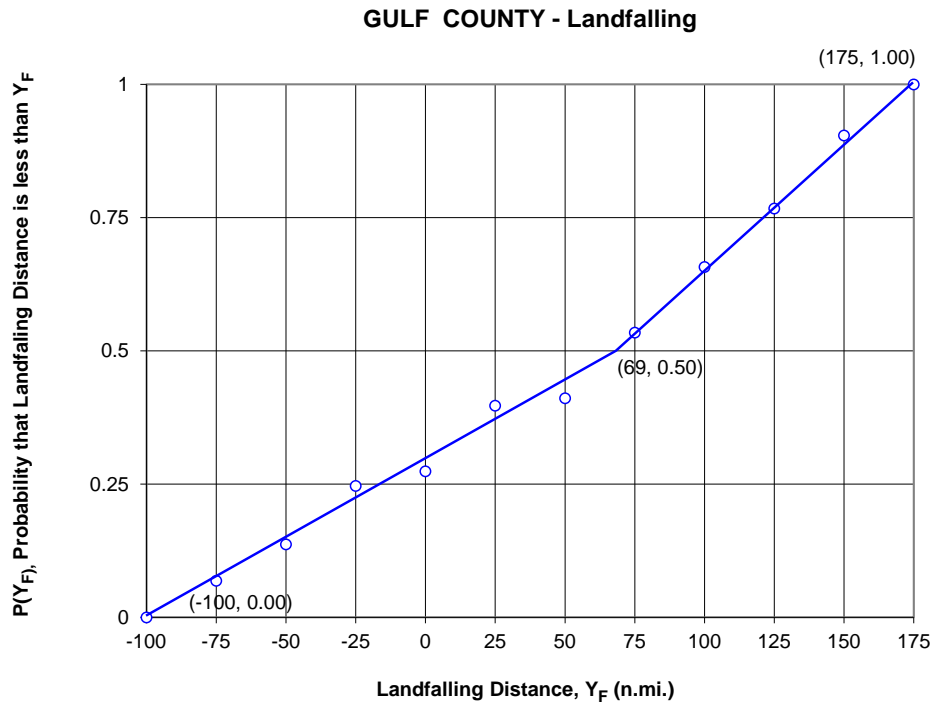
Figure 5: Cumulative Probability Distribution of Landfalling Distance, Y_F, for Landfalling and Exiting Storms

GULF COUNTY - Alongshore
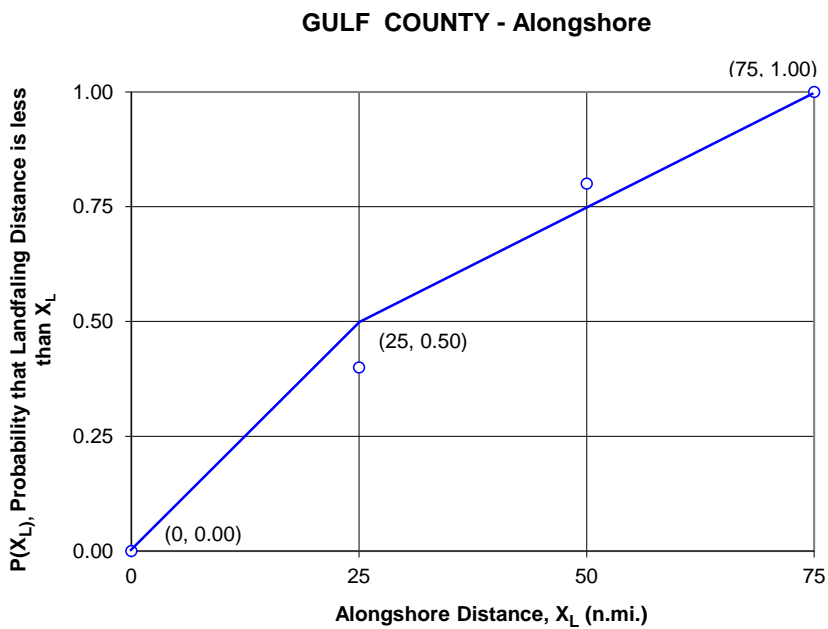
Figure 6: Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

3.1 Simulation of a n-Year Sequence of Storm Associated Storm Tides

With the statistical characteristics of historical storms available and the two-dimensional model calibrated as described in the preceding section, the simulation shown in Figure 7 is carried out.

The first phase of the simulation comprises the selection of the storm characteristics in accordance with the historical data. In each storm, this involves the following:

1) Quantifying Δp, R, V_F, θ_N and storm track in accordance with the historical   probabilities.

2) For these characteristics, a random astronomical tide from the storm season is generated as a boundary condition to the two-dimensional numerical model and the model is run to determine the storm surge at the site of interest. This storm surge with dynamic wave set up is then adjusted in accordance with the factors obtained from the two-dimensional model calibration runs for the landward grid at each time step to yield the combined total storm tide.

3) Determining whether enough storms have been simulated for the n-year simulation.

4) After the required number of storms and associated storm tides have been simulated, the peak water levels for each storm are ranked and the return period, TR, is calculated, according to

$$TR = 1000/M$$

where M is the rank of the combined total storm tide level. (For example, since the simulation was carried out for a 1,000 year period, the highest combined total tide level would have a return period of 1,000 years, the tenth highest water level would have a return period of 100 years, etc.). Finally, by presenting these results on semi-log paper, it is possible to interpolate return periods of 5, 10, 15, 20, 25, 30 and 50 years.
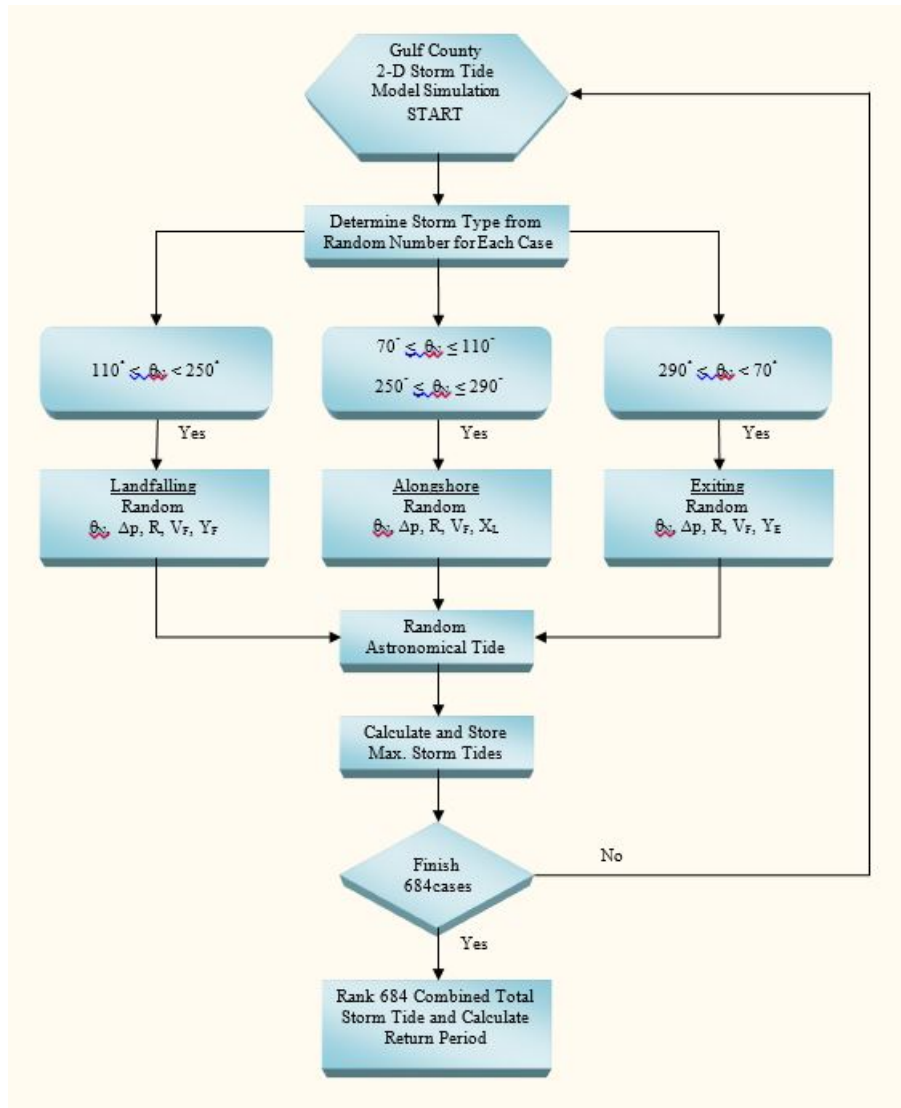
Figure 7: Flow Chart for Two-Dimensional Storm Tide Simulations

<u>3.2 Simulation</u>

To summarize information presented earlier, this phase includes the simulation of the occurrence of 1,000 years of storms along a shoreline segment of 275 n. mi. The simulated storms are given directional distributions according to Figure 1. In an average 1,000 year period, there would be a total of 684 storms.

<u>Selection of Storm Parameters</u> - Each of the five idealized storm parameters, [Radius to Maximum Winds, R; Central Pressure, p_o (or Central Pressure Deficit, Δp); Track Direction, θ_N;

System Forward Speed, V_F; and Track Position] is determined randomly in accordance with the associated cumulative probability distribution functions. The procedure is described below for the track direction, θ_N, and is similar for all other variables.

The approximate piece-wise linear cumulative probability distribution function for track direction, θ_N, is shown in Figure 1. The nature of this function is such that the predominant directions are those where the function rises steeply. To randomly select a track direction in accordance with the distribution function, the computer first generates a random number between 0 and 1 and then selects the θ_N corresponding to that cumulative probability. The other four parameters are determined similarly with a separate and independent random number being generated for each parameter and the appropriate cumulative probability distribution used.

Calculation of Storm Surge with the Effect of Astronomical Tide - A particular storm can be "phased" such that the maximum resulting storm surge is increased or decreased by astronomical tidal fluctuations. Considering the predicted ocean astronomical tidal fluctuations off Gulf County from June 1 to November 30, 1984 to be representative of those occurring during the storm season and assuming the phasing of storm occurrence and astronomical tides to be independent, the combination of these tidal components is carried out in the following manner.

With the storm parameters established, a starting time for the storm is selected randomly between June 1 and November 30, 1984. The corresponding astronomical tide at the starting time is generated and varies with time thereafter according to the input astronomical tide data. The calculation of the storm surge history by the calibrated two-dimensional model is thus phased with the astronomical tide to yield the combined storm surge and astronomical tide water level history at the site of interest.

3.3 Computation of Return Periods

With a sufficient number (684) of maximum combined total storm tides simulated to represent a typical 1,000 year time interval, the tides associated with various return periods of interest are determined. The 684 maximum combined total storm tides are ranked in descending order with the largest occurring first. The return period, TR, of the ranked tides is then

$$TR = 1000 / M$$

in which

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TR = Return period in years between expected exceedances of the associated maximum storm tide

M = Rank of maximum storm tide

As an example, for M = 684 (associated with the lowest water level) the return period would be:

$$TR_{684} = 1000 / 684 = 1.46 \text{ years}$$

which indicates that the smallest storm tide could be expected to be exceeded approximately once every 2 years. As a second example, the return period for M = 40 is

$$TR_{40} = 1000/40 = 25 \text{ years}$$

The ranked maximum combined total storm tides and associated return periods can be plotted and the combined total storm tide associated with any return period determined. Finally, it is noted that it is possible to run the simulation procedure any number of times to determine the stability (constancy) of any combined total storm tide associated with a given return period. It is expected that for a 1,000 year simulation, the storm tides associated with the longer (> 250 year) return periods would not be well-defined by one simulation and would exhibit variation from simulation to simulation. However, the storm tides associated with the lower return periods (TR < 100 years) should be well-defined by a 1,000 year simulation and hence are not expected to vary significantly for various simulations.

4.0 Results

Five 1,000-year simulations for Gulf County were carried out employing the computer methods and storm statistics presented in the preceding sections. The combined total storm tides above NAVD and the associated return periods are plotted on semi-log paper in Figure 8. The general locations of six profiles for Gulf County are depicted in Appendix C. Each data point represents the average value of five simulations and a curve drawn through the data points is adopted to represent the tide-frequency relationship.
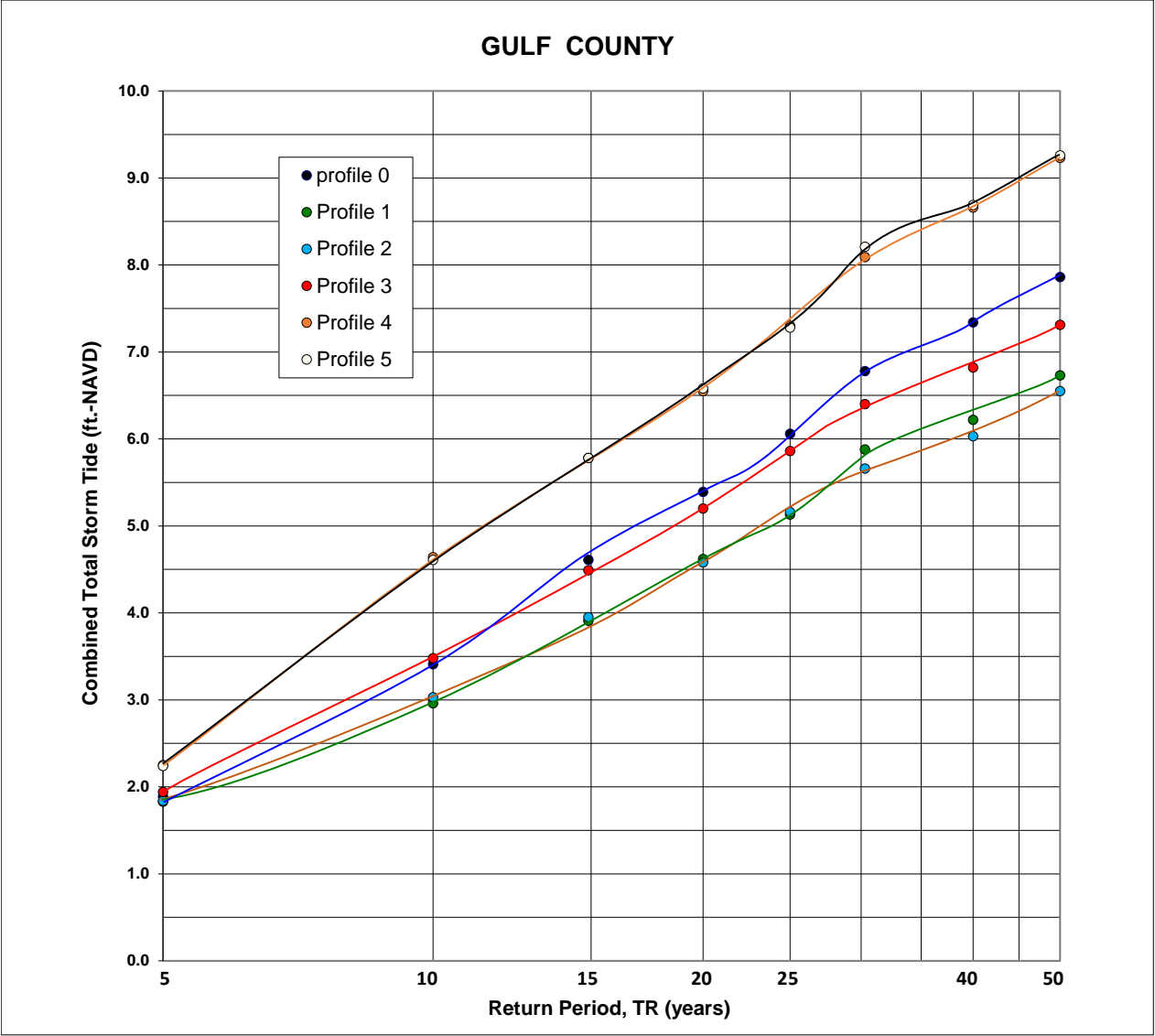
Figure 8: Combined Total Storm Tide Elevation versus Return Period for Study Area

Table I below gives the combined total storm tide values and corresponding return periods for Gulf County.

Table I

Combined Total Storm Tide Levels* (ft.-NAVD) for Various Return Periods

Return Period, TR (years)	Profile 0	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
50	7.9	6.7	6.6	7.3	9.2	9.3
30	6.8	5.9	5.7	6.4	8.1	8.2
25	6.1	5.1	5.2	5.9	7.3	7.3
20	5.4	4.6	4.6	5.2	6.6	6.6
15	4.6	3.9	4.0	4.5	5.8	5.8
10	3.4	3.0	3.0	3.5	4.6	4.6
5	2.3	2.4	2.7	1.8	1.9	2.2

* Includes contributions of: wind stress, barometric pressure, dynamic wave set-up and astronomical tide.

REFERENCES

1. Wang, S. Y., Manausa, M., Dean, R. G. and Walton, T. L., "Combined Total Storm Tide Frequency Restudy for Gulf County, Florida," Beaches and Shores Resource Center, Florida State University, January 2007.

2. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, "Storm Climatology for the Atlantic and Gulf Coasts of the United States," NOAA Technical Report NWS 38, April 1987.

3. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Hurricane Center, "Atlantic hurricane database (HURDAT2) , 1851 – 2013," http://www.nhc.noaa.gov/data/#hurdat

APPENDIX A

Summary of Historical Storms affecting
Gulf County

#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	10/10/1900		251	(48)	22	-0.24		A
2	6/11/1901		180	-38.0	8	-0.18		L
3	9/9/1901		208	92.0	15	-0.38		L
4	9/21/1901		185	-37.0	22	-0.24		L
5	6/12/1902		192	-83.0	10	-0.38		L
6	10/3/1902		206	121.0	20	-0.38		L
7	9/9/1903		157	4.0	8	-0.97		L
8	10/31/1904		225	110.0	17	-0.18		L
9	6/8/1906		180	15.0	15	-0.31		L
10	9/19/1906		168	164.0	10	-1.36	43	L
11	6/24/1907		239	92.0	23	-0.38		L
12	9/27/1907		237	59.0	28	-0.31		L
13	6/26/1909		134	-89.0	7	-0.18		L
14	8/8/1911		134	73.0	7	-0.74		L
15	9/10/1912		147	144.0	5	-0.85		L
16	10/3/1912		265	(57)	12	-0.14		A
17	8/31/1915		172	2.0	16	-0.97		L
18	6/28/1916		167	137.0	11	-1.51	45	L
19	10/9/1916		186	113.0	24	-1.27	19	L
20	9/20/1917		231	121.0	11	-1.51	33	L
21	7/2/1919		174	81.0	8	-0.46		L
22	10/12/1922		173	127.0	7	-0.14		L
23	9/13/1924		240	1.0	6	-0.98		L
24	9/27/1924		221	-52.0	26	-0.42		L
25	9/11/1926		134	51.0	7	-1.83	17	L
26	8/3/1928		139	-70.0	9	-0.31		L
27	8/7/1928		164	-36.0	9	-0.31		L
28	9/19/1929		199	40.0	5	-0.85	55	L
29	8/26/1932		139	118.0	11	-0.85		L
30	9/9/1932		246	-31	26	-0.38		L
31	8/29/1935		180	-100.0	9	-1.42	6	L
32	7/27/1936		157	51.0	7	-1.09	19	L
33	9/16/1937		262	(0)	7	-0.18		A
34	6/12/1939		188	123	6	-0.38		L
35	8/7/1939		125	4.0	11	-0.64		L
36	10/3/1941		180	-38.0	14	-0.92	18	L
37	9/3/1945		122	150.0	13	-0.14		L
38	9/7/1947		152	130.0	6	-0.38		L
39	7/7/1948		215	130.0	12	-0.18		L
40	8/18/1950	BAKER	192	146.0	16	-1.01	21	L
41	10/18/1950	LOVE	203	-100.0	16	-0.54		L
42	9/14/1953		254	(14)	7	-0.46		A
43	9/23/1953	FLORENCE	190	77.0	10	-1.22		L
44	8/23/1955		112	167.0	13	-0.24		L

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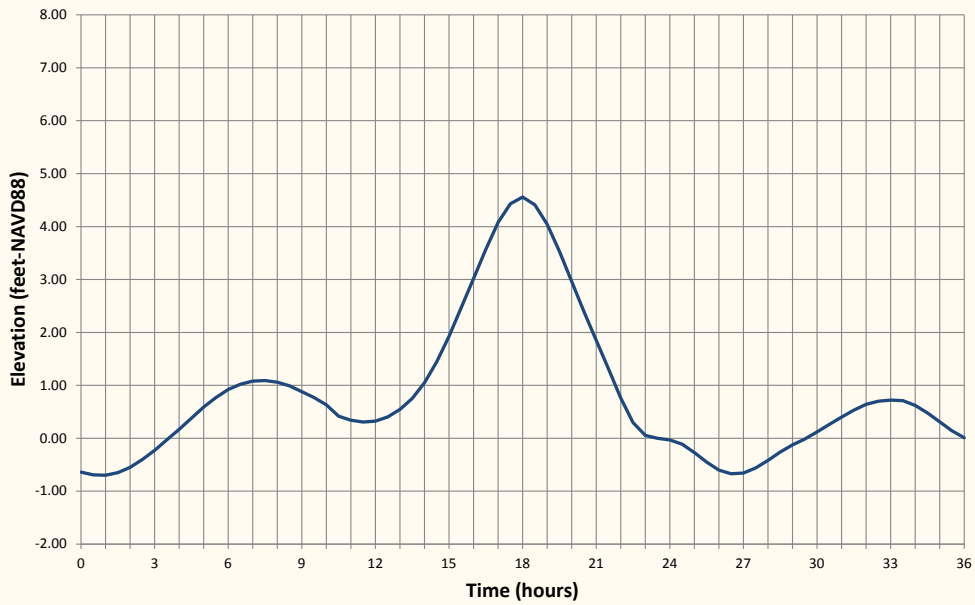| #	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
45	9/21/1956	FLOSSY	244	154.0	12	-0.89		L
46	6/8/1957		223	-36.0	24	-0.18		L
47	9/7/1957	DEBBIE	202	85.0	14	-0.18		L
48	10/6/1959	IRENE	196	128.0	9	-0.36		L
49	6/11/1965		227	81.0	20	-0.31		L
50	6/4/1966	ALMA	169	-38.0	9	-1.27	20	L
51	7/19/1970	BECKY	206	-5.0	8	-0.24		L
52	6/14/1972	AGNES	201	13.0	10	-0.89	20	L
53	9/13/1975	ELOISE	206	66.0	20	-1.63	18	L
54	5/21/1976		233	-59	22	-0.45		L
55	8/29/1979	FREDERIC	169	139.0	13	-1.86		L
56	8/28/1985	ELENA	111	98.0	13	-1.77	16	L
57	10/26/1985	JUAN	231	169.0	16	-1.04		L
58	11/15/1985	KATE	217	19.0	14	-1.36	19	L
59	6/30/1994	ALBERTO	185	73.0	11	-0.48		L
60	8/14/1994	BERYL	249	18.0	3	-0.15		L
61	6/3/1995	ALLISON	221	-36.0	12	-0.68		L
62	7/31/1995	ERIN	123	55.0	9	-1.01	20	L
63	9/27/1995	OPAL	202	108.0	21	-2.22	47	L
64	10/4/1996	JOSEPHINE	217	-60	16	-0.89	40	L
65	8/31/1998	EARL	234	54	12	-0.83		L
66	9/15/1998	GEORGE	161	174	5	-1.54	27	L
67	9/15/2000	HELENE	208	92.0	11	-0.36		L
68	8/2/2001	BARRY	180	51.0	11	-0.62	14	L
69	8/3/2004	BONNIE	238	-19	17	-0.33	16	L
70	8/25/2004	FRANCES	164	-76.0	9	-0.92	36	L
71	9/2/2004	IVAN	193	139.0	11	-2.42	24	L
72	6/8/2005	ARLENE	168	108.0	12	-0.68	28	L
73	7/4/2005	DENNIS	160	77.0	15	-2.45	14	L
74	6/10/2006	ALBERTO	221	-73.0	7	-0.5	24	L
75	8/16/2009	CLAUDETTE	139	19.0	9	-0.15		L
76	11/4/2009	IDA	186	172.0	9	-0.59	21	L
77	8/10/2010	FIVE	117	133.0	9	-0.18		L
78	6/23/2012	DEBBY	270	(42)	3	-0.56		A

Landfalling Storms = 73; Alongshore Storms = 5
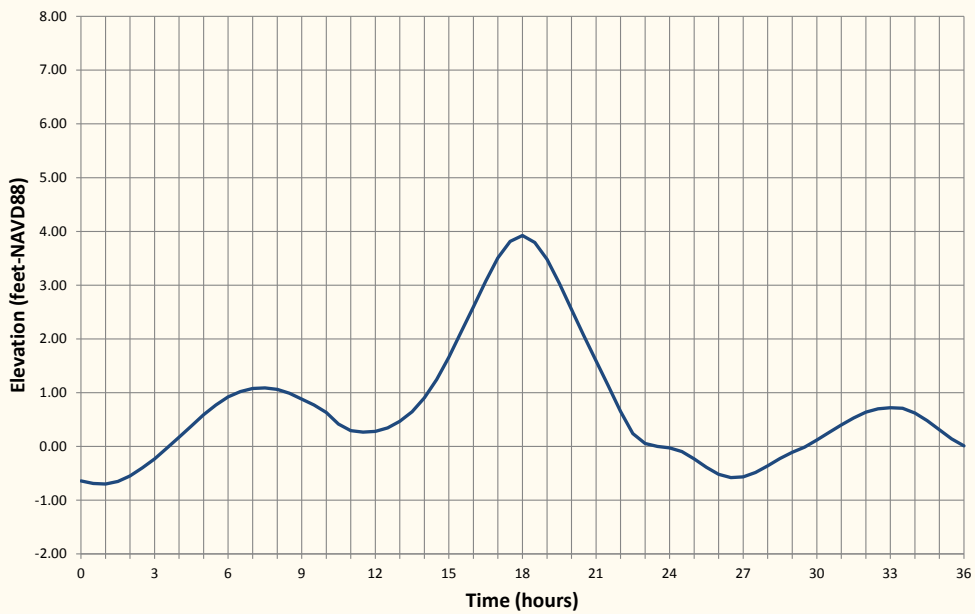
[1] Values are estimated prior to landfall.

APPENDIX B

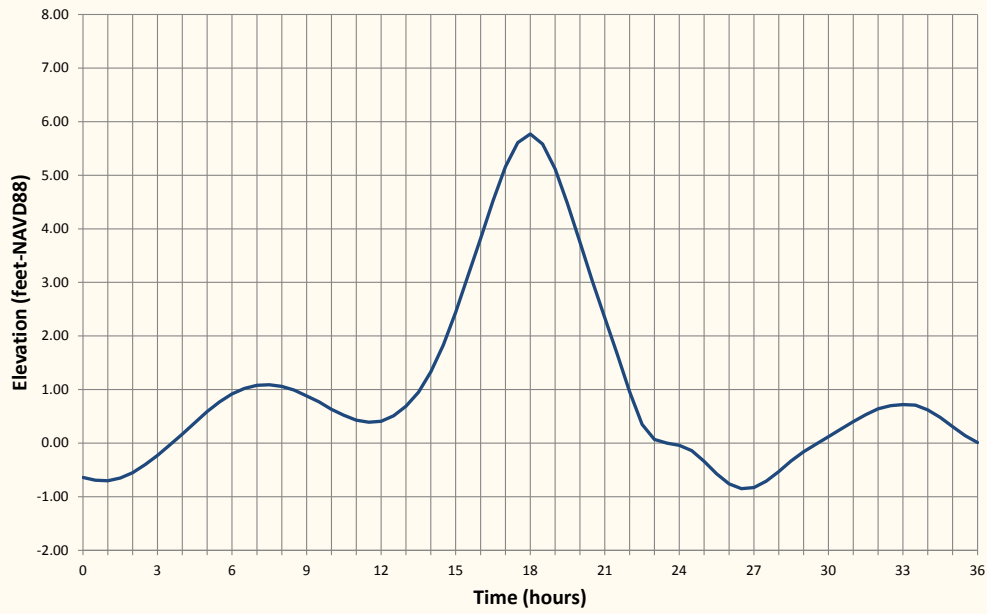Computed 15 and 25 Year Hydrographs for
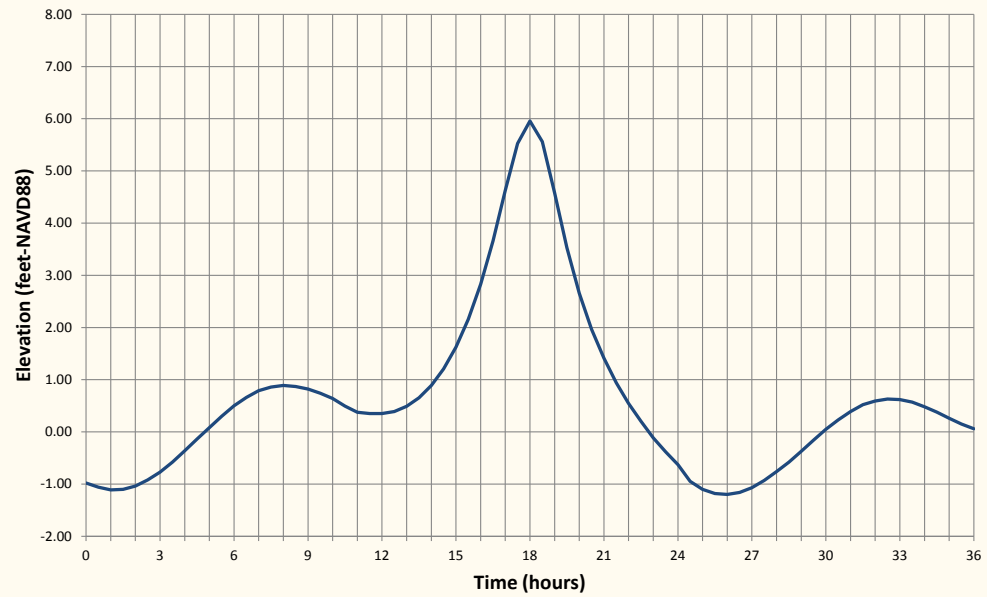Gulf County

Gulf County
15 -Year Hydrograph
Profiles 0 and 3
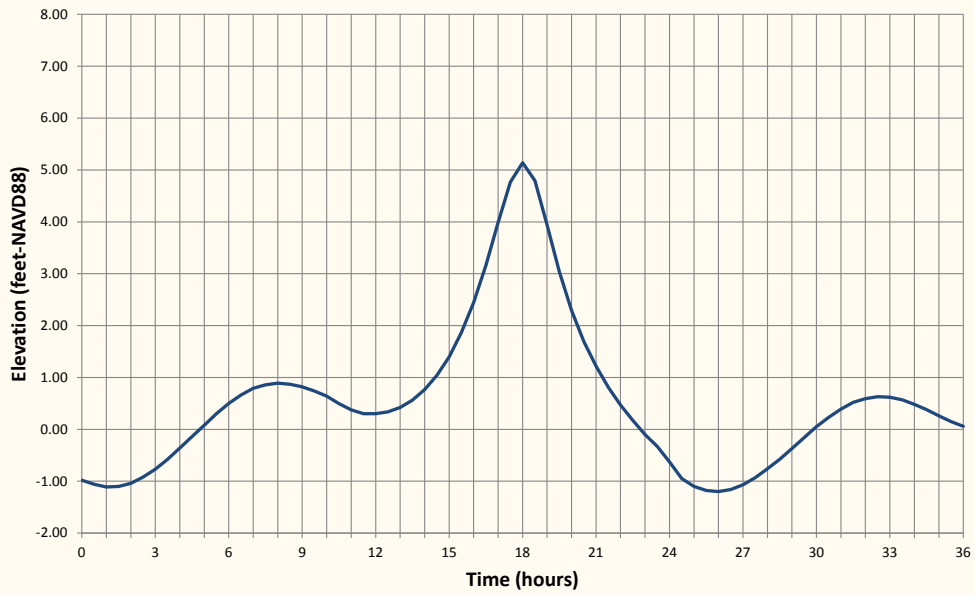

Gulf County
15 -Year Hydrograph
Profiles 1 and 2

17

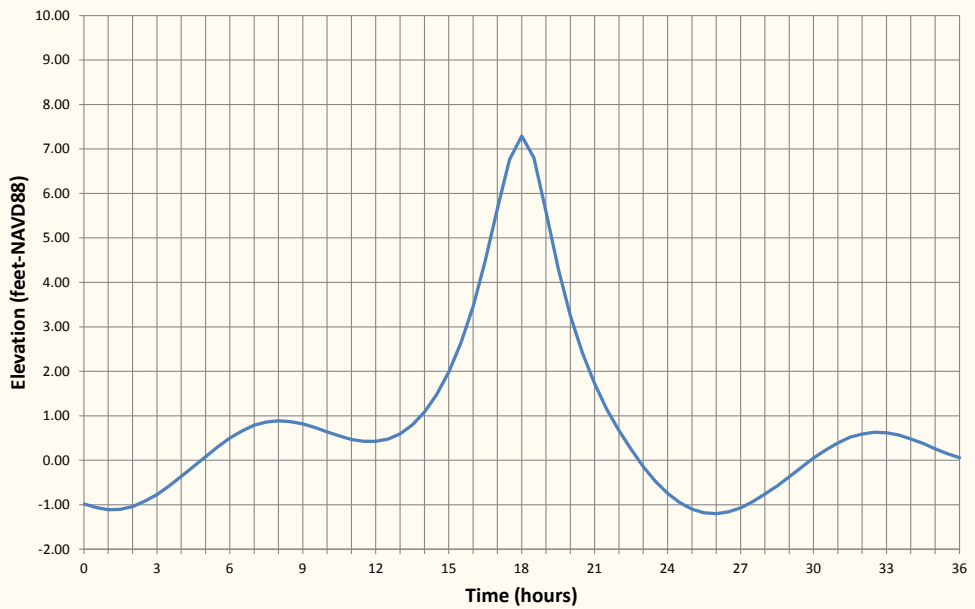**Gulf County**
15 -Year Hydrograph
Profiles 4 and 5

Gulf County
25 -Year Hydrograph
Profiles 0 and 3

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Gulf County
25 -Year Hydrograph
Profiles 1 and 2

Gulf County
25 -Year Hydrograph
Profiles 4 & 5

APPENDIX C

The General Locations of Six Profiles
for Gulf County