INCLUSION OF TROPICAL STORMS FOR THE COMBINED TOTAL STORM TIDE FREQUENCY RESTUDY FOR ESCAMBIA AND SANTA ROSA COUNTIES, FLORIDA

(Revised May 2009)

Sponsored by
Florida Department of Environmental Protection,
Bureau of Beaches and Coastal Systems

Submitted by
Beaches and Shores Resource Center
Institute of Science and Public Affairs
Florida State University

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1.0 Background

In accordance with the objectives and rationale of the Florida Coastal Construction Control Line, the reestablishment 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 Escambia and Santa Rosa Counties, Florida” (Reference (1)) was submitted to FDEP in December 2008. This additional study is requested by the FDEP to include the tropical storms 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. This report revises the hydrograph in Appendix B from the previous report, which was submitted to the FDEP March 2009.

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. Storm 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 Escambia and Santa Rosa Counties shoreline are classified as "landfalling" or "alongshore" storms. Reasonably good data are available describing the characteristics of the storms impacting the area from 1900 to 2008. For purposes of this report, the data contained in References (2) and (3) that fall within a 250 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 storms are considered to be of possible significance if they made landfall within a 250 n. mi. segment of the coast comprising the study area. This segment is extended 130 n. mi. west and 120 n. mi. east from the midpoint of the Escambia County shoreline.

Accordingly, there were 66 landfalling and 5 alongshore storms occurring in the years 1900 through 2008. The table in Appendix A lists the storms used in this study.

Based on historical data, it is expected that within a 1,000 year period a total of 651 storms will occur within the 250 n. mi. segment of the coast comprising the study area. Of the 651 storms, 605 will be landfalling and 46 alongshore storms.

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

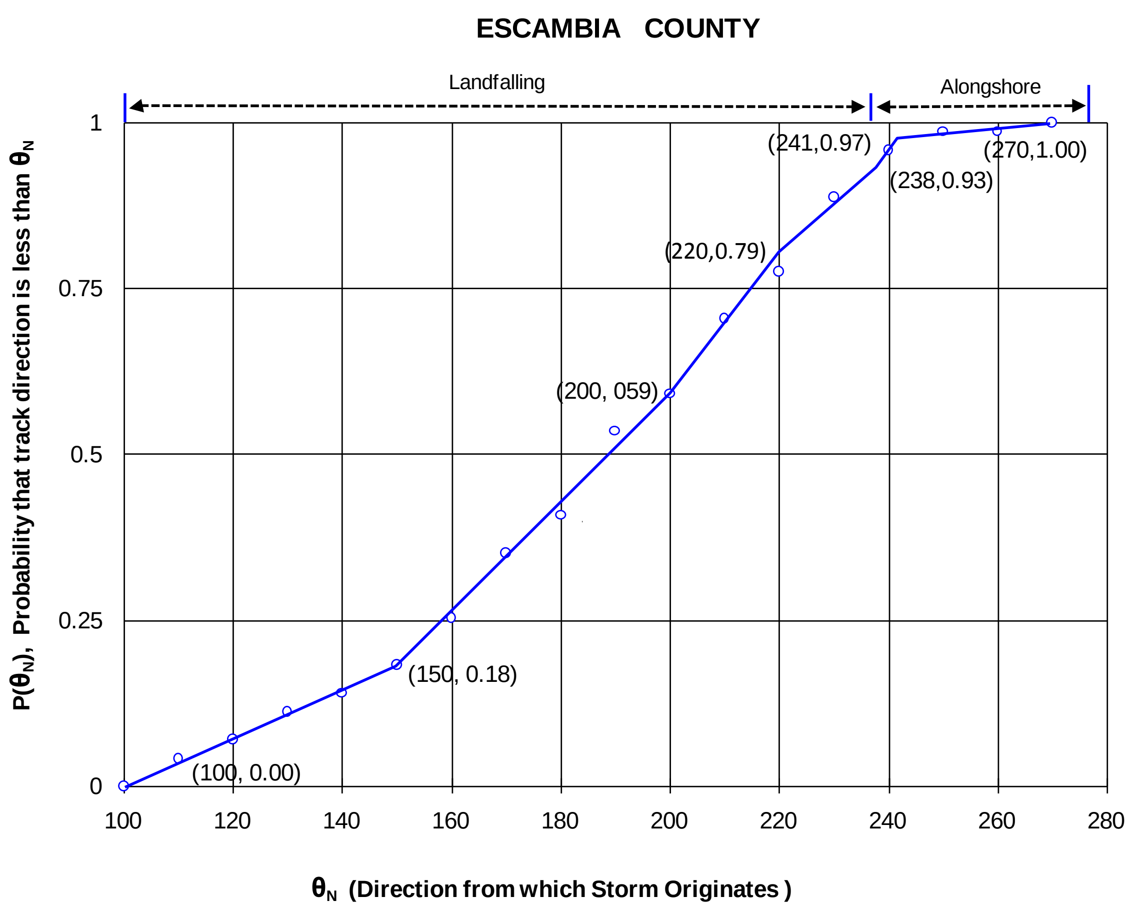


Figure 1 Cumulative Probability Distribution of Storm Track Direction, θ_N

2.3 Radius to Maximum Winds and Central Pressure Deficit

The cumulative probability distributions of radius to maximum winds for landfalling and alongshore storms are presented in Figures 2 and 3, respectively. The cumulative probability distributions of pressure deficit for landfalling and alongshore storms is presented in Figure 4.

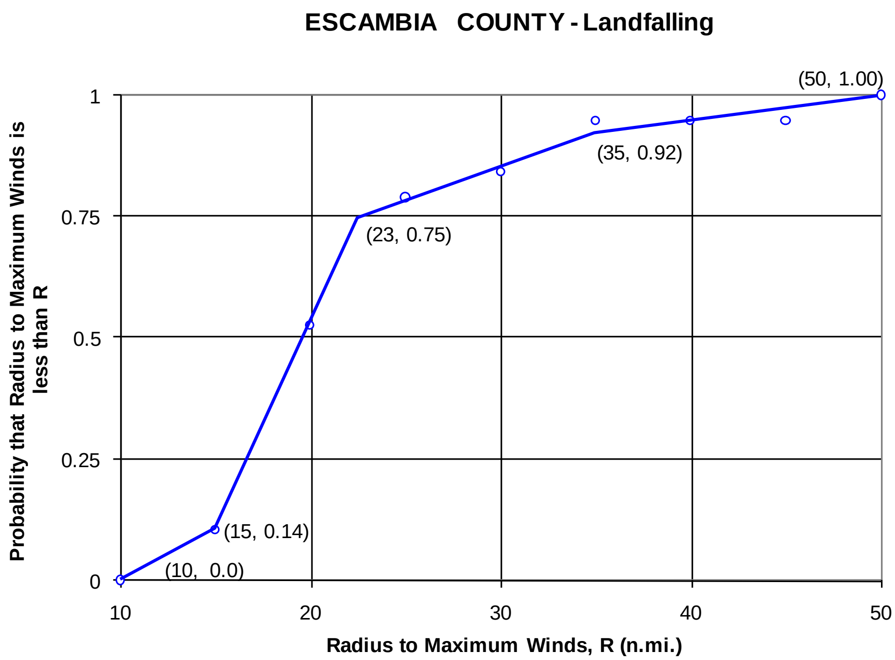


Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling Storms

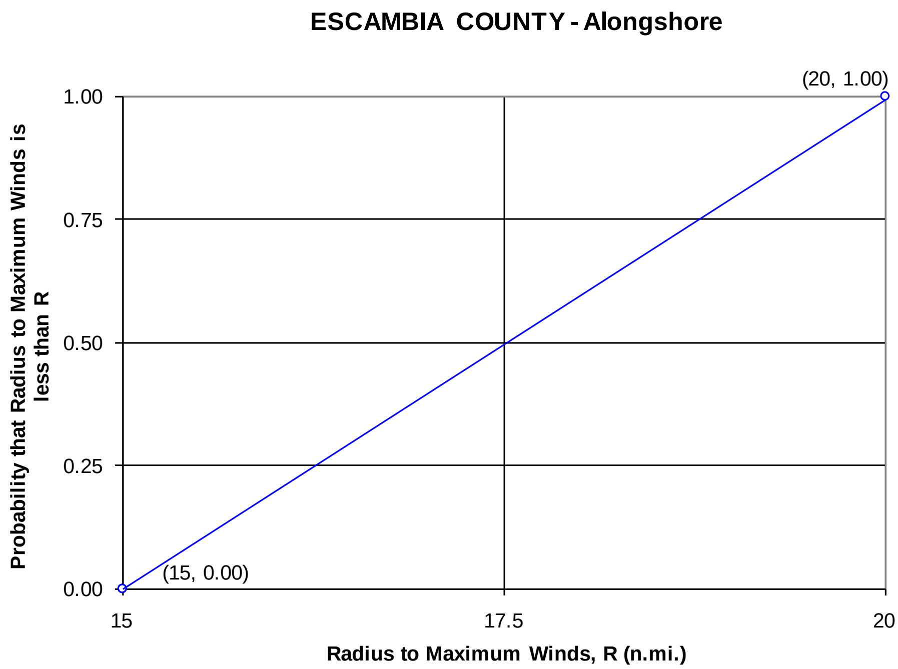


Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

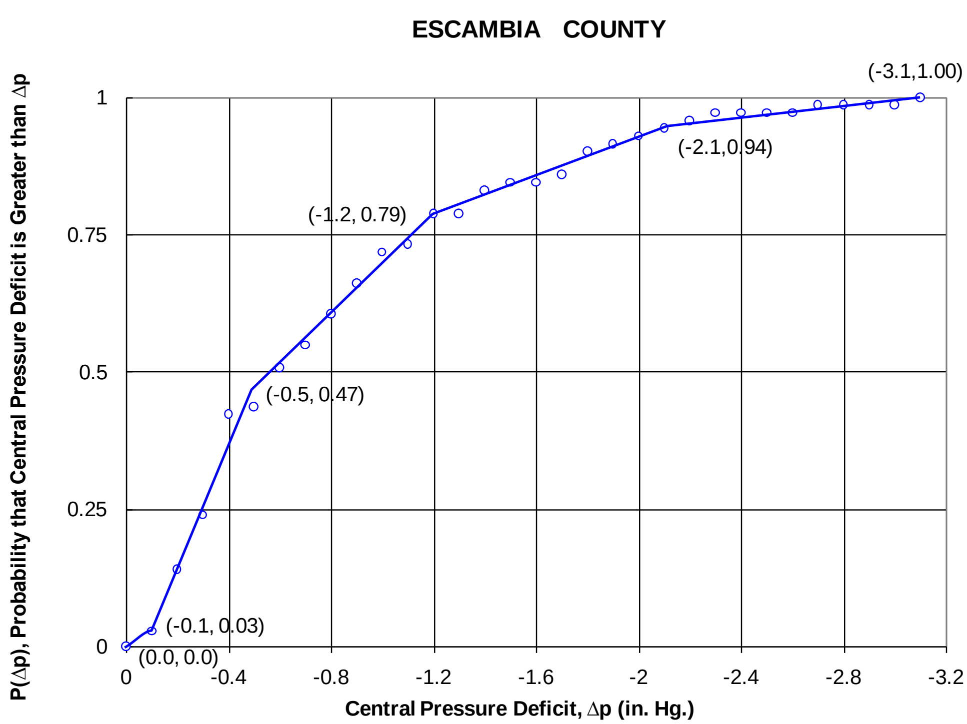


Figure 4 Cumulative Probability Distribution of Central Pressure Deficit, Δp

2.4 Forward Speed

The cumulative probability distribution of the forward speed of translation for landfalling and alongshore storms is presented in Figure 5.

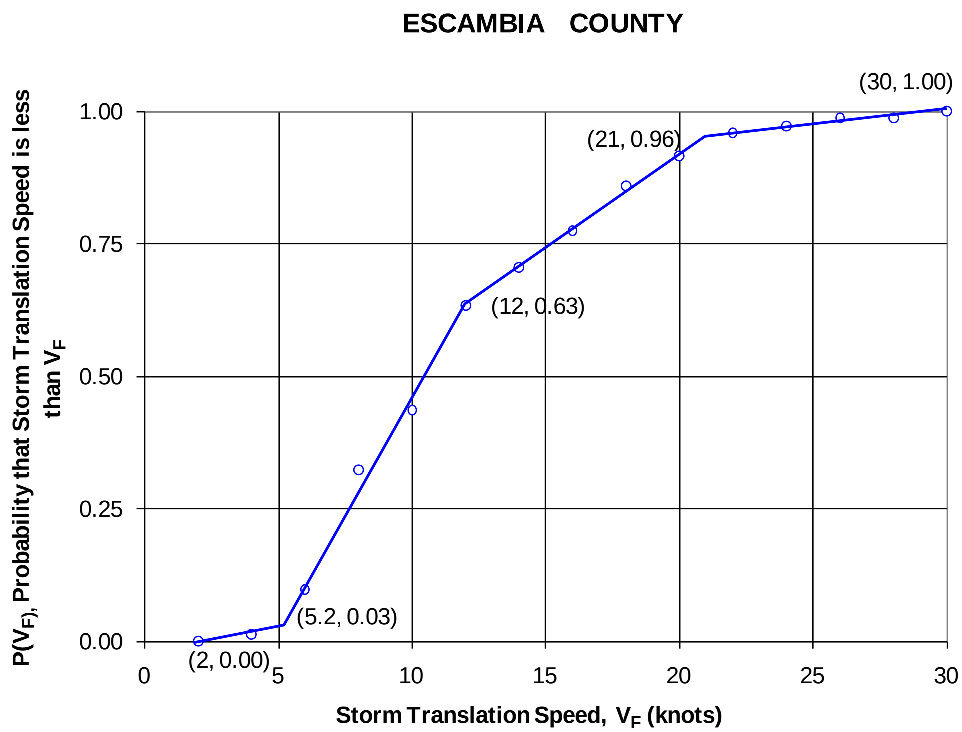


Figure 5 Cumulative Probability Distribution of Translation Speed , V_F

2.5 Track Position

For the landfalling storms, the track position is determined by the y coordinate, Y_F, representing the landfalling point. Figure 6 presents the cumulative probability distribution for the actual landfalling position, Y_F, for landfalling storms. Figure 7 presents the cumulative probability distribution for the actual offshore distance, X_L, for alongshore storms.

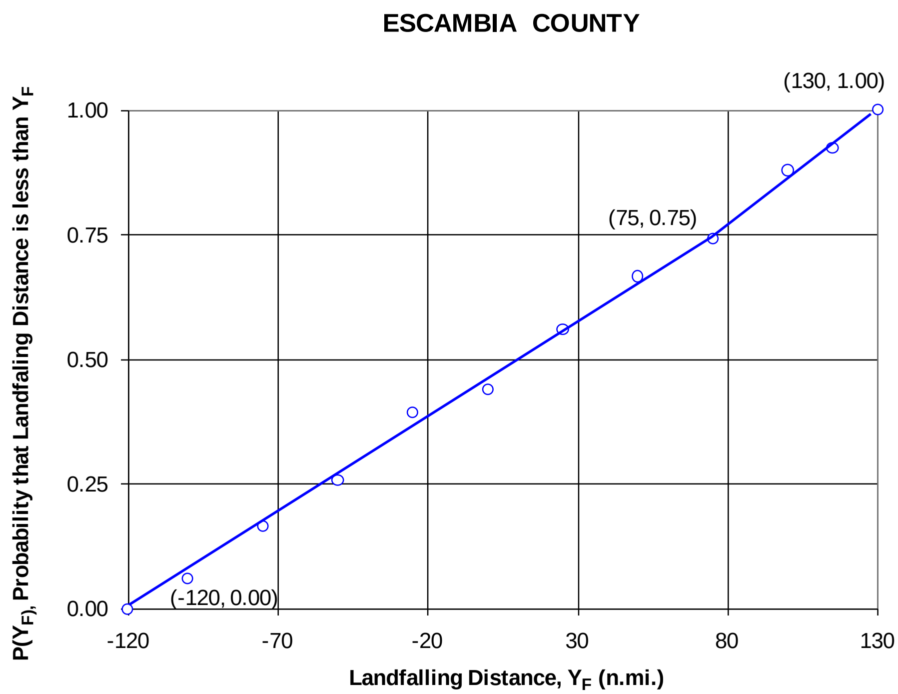


Figure 6 Cumulative Probability Distribution of Landfalling Distance, Y_F, for Landfalling Storms

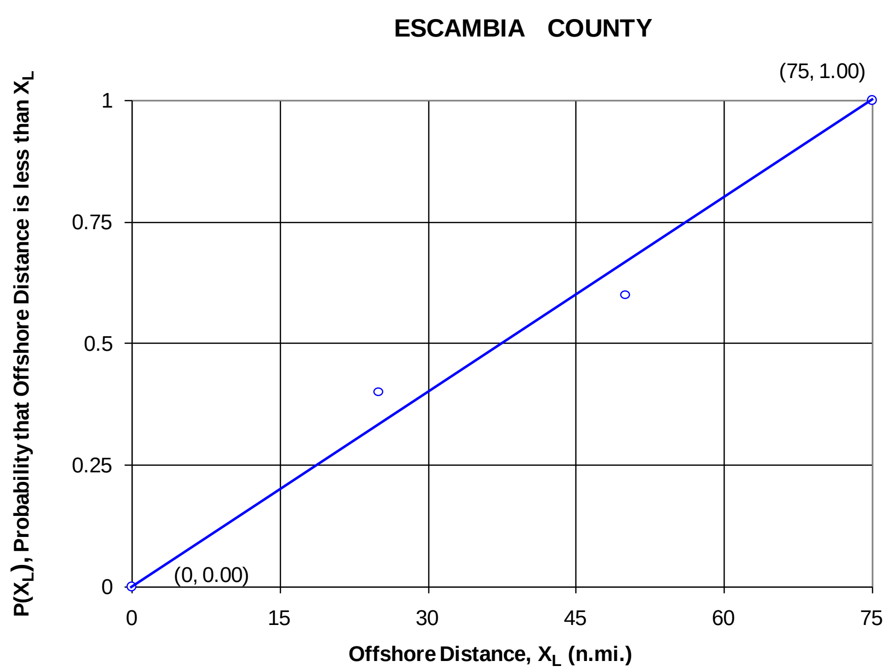


Figure 7 Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

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 8 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 and 50 years.

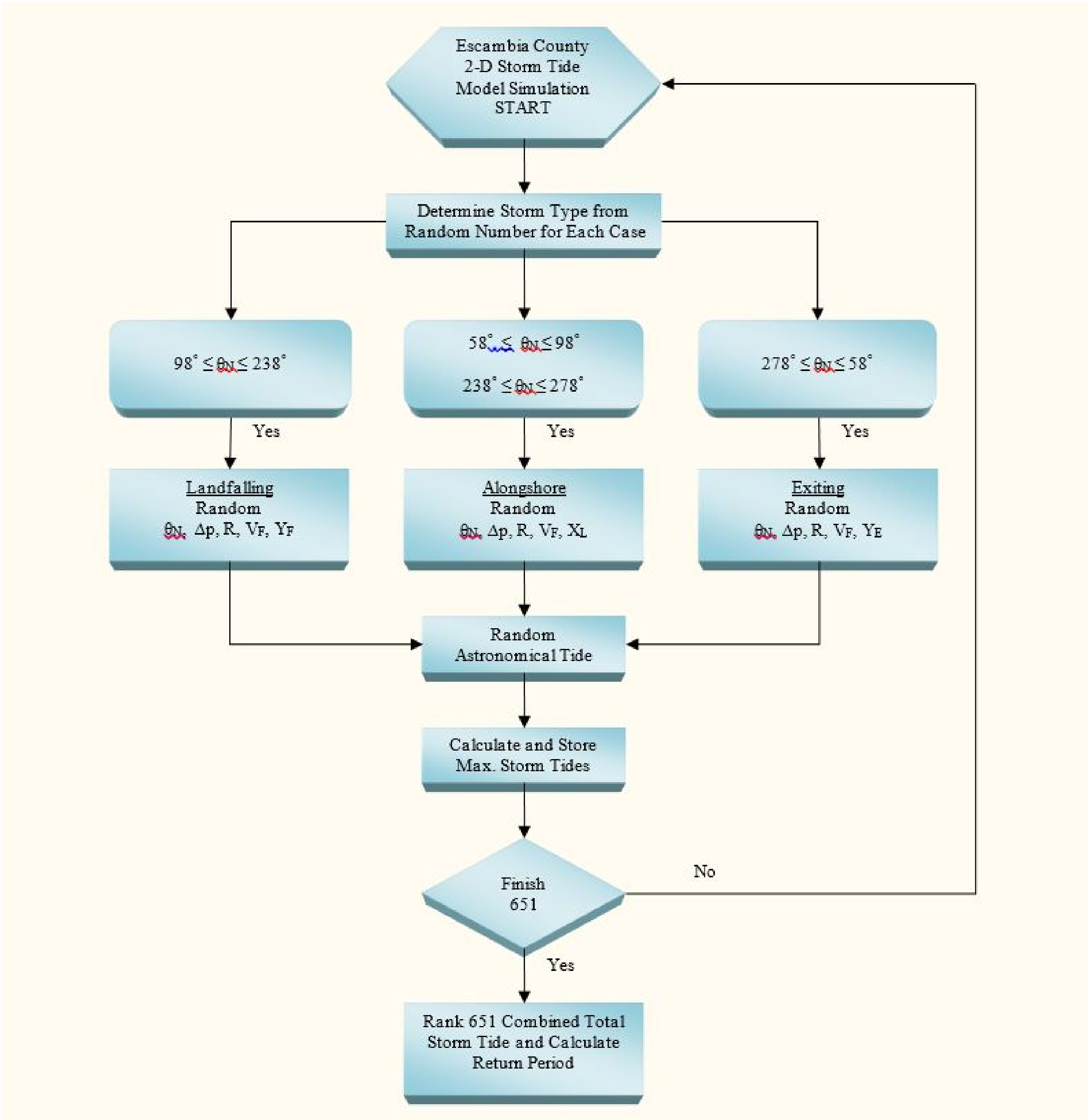


Figure 8 Flow Chart for Two-Dimensional Storm Tide Simulations

3.2 Simulation

To summarize information presented earlier, this phase includes the simulation of the occurrence of 1,000 years of storms along a shoreline segment of 250 n. mi. The simulated storms are given directional distributions according to Figure 5. In an average 1,000 year period, there would be a total of 651 storms.

Selection of Storm Parameters - 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 5. 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 at Dog Island West End, Gulf of Mexico 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 (651) 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 651 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

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 = 651 (associated with the lowest water level) the return period would be:

$$TR_{651} = 1000 / 651 = 1.54 \text{ years}$$

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 = 20 is

$$TR_{20} = 1000/20 = 50 \text{ years}$$

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 Escambia and Santa Rosa Counties were carried out employing the computer methods and storm statistics presented in the preceding sections. The combined total storm tides above NGVD and the associated return periods are plotted on semi-log paper in Figure 9. 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.

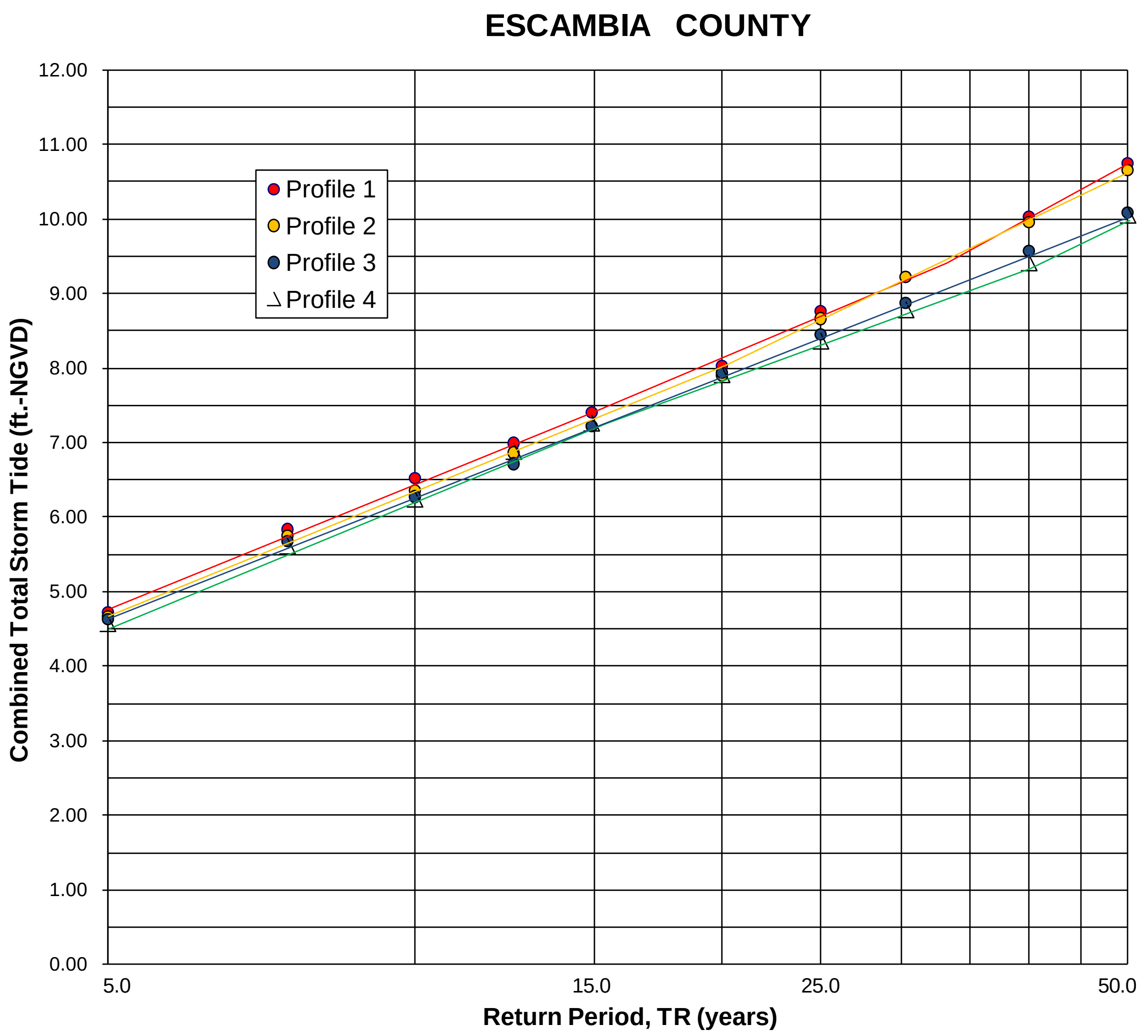


Figure 9 Combined Total Storm Tide Elevation Versus Return Period for Study Area

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

Table I

Combined Total Storm Tide Level (ft.) for Various Return Periods

Return Period, TR (years)	Profile 1 NGVD29	Profile 1 NAVD88	Profile 2 NGVD29	Profile 2 NAVD88	Profile 3 NGVD29	Profile 3 NAVD88	Profile 4 NGVD29	Profile 4 NAVD88
50	10.8	10.7	10.7	10.5	10.1	9.8	10.1	9.7
40	10.0	9.9	10.0	9.8	9.6	9.3	9.4	9.0
25	8.8	8.7	8.7	8.5	8.5	8.2	8.4	8.0
20	8.0	7.9	7.9	7.7	7.9	7.6	7.9	7.5
15	7.4	7.3	7.2	7.0	7.2	6.9	7.3	6.9
10	6.5	6.4	6.4	6.2	6.3	6.0	6.2	5.8
5	4.7	4.6	4.7	4.5	4.6	4.3	4.6	4.2

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

These results are not intended to replace the storm surges as produced in the report, “Combined Total Storm Tide Frequency Restudy for Escambia and Santa Rosa Counties, Florida“ (Reference (1)). Based on the actual storm event data by Leadon (Reference (4)), hydrographs for return periods of 15 and 25 years are selected from simulated storms and are presented in Appendix B.

<u>REFERENCES</u>

1. Wang, S., Manausa, M., Dean, R. and Walton, T., “Combined Total Storm Tide Frequency Restudy for Escambia and Santa Rosa Counties, Florida”, Beaches and Shores Resource Center, Florida State University, December 2008.

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

3. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, "Storm Best Track Files (HURDAT), 1851 – 2007," http://www.nhc.noaa.gov.

4. Leadon, M., “Evaluation of Storm Tide Measurements at Panama City Beach, Florida 1993-2007”, Beaches and Shores Resource Center, Florida State University, May 2009.

APPENDIX A

SUMMARY OF HISTORICAL STORMS AFFECTING ESCAMBIA AND SANTA ROSA COUNTIES

#	Date	Name	θ_N (deg.)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	8/ 4/1901		214.63	97.7	6.07	-1.18		L
2	9/ 9/1903		166.16	-73	7.21	-0.97		L
3	9/19/1906		165.48	76.2	10.33	-1.63		L
4	8/ 8/1911		127.68	18.1	6.54	-0.74		L
5	9/10/1912		166.15	60.7	7.21	-0.74		L
6	8/31/1915		183.09	-91.6	16.02	-0.85		L
7	6/29/1916		150.08	81.5	10.38	-1.86	26	L
8	10/12/1916		189.79	10.7	20.3	-1.15	19	L
9	9/21/1917		229	-32.7	9.15	-1.39	33	L
10	9/13/1924		243.58	65.3	6.74	-0.64		AL
11	9/11/1926		100.93	35.8	5.27	-1.72	17	L
12	8/26/1932		132.02	40.7	8.71	-0.74		L
13	7/27/1936		144.27	-29.4	7.39	-1.18	19	L
14	9/4/1947		109.62	124.7	11.91	-1.39	25	L
15	8/20/1950	BAKER	190.48	40.8	14.24	-0.85	21	L
16	9/23/1953	FLORENCE	220.78	-51.3	9.24	-0.97		L
17	9/21/1956	FLOSSY	247.15	11.6	10.3	-0.98	18	AL
18	9/14/1960	ETHEL	180	97.4	8	-0.95	22	L
19	8/14/1969	CAMILLE	161.64	113.6	13.7	-3.07	18	L
20	6/14/1972	AGNES	200.99	-97.6	9.64	-0.89	20	L
21	9/13/1975	ELOISE	190.48	-48.9	28.47	-1.72	18	L
22	8/29/1979	FREDERIC	158.58	55	11.82	-1.98	33	L
23	8/28/1985	ELENA	111.1	69.3	12.45	-1.77	16.2	L
24	10/26/1985	JUAN	230.09	35.5	15.7	-1.04		L
25	11/15/1985	KATE	220.78	-115	13.21	-1.36	18.6	L
26	7/31/1995	ERIN	135.86	1.6	11.15	-1.15	19.5	L
27	9/27/1995	OPAL	201.23	-3.4	21.46	-2.22	46.9	L
28	7/16/1997	DANNY	220.8	48.1	2.78	-0.86	13	L
29	8/31/1998	EARL	230.72	-92.5	18.96	-0.77		L
30	9/15/1998	GEORGES	163.95	85.7	6.24	-1.45	17	L
31	9/2/2004	IVAN	187.03	37.7	14.11	-2.07	24	L
32	7/ 4/2005	DENNIS	156.66	-2.2	17.43	-2.1	14	L
33	8/23/2005	KATRINA	180	129.2	16	-2.66	30	L
34	9/11/1900		214.63	97.7	6.08	-0.18		L
35	9/9/1901		222.91	-25.5	17.75	-0.38		L
36	10/3/1902		205.9	6.9	17.79	-0.38		L
37	10/31/1904		238.63	21.9	19.21	-0.18		AL
38	6/8/1906		180	-82.6	11	-0.31		L
39	6/24/1907		239.92	38.7	19.95	-0.38		AL
40	9/18/1907		189.79	91.9	5.07	-0.24		L
41	9/27/1907		236.78	-95.9	23.73	-0.31		L
42	7/2/1919		166.15	-6.9	7.21	-0.38		L
43	10/12/1922		152.62	23.8	5.63	-0.24		L
44	10/16/1923		177.94	96.1	24.02	-0.31		L

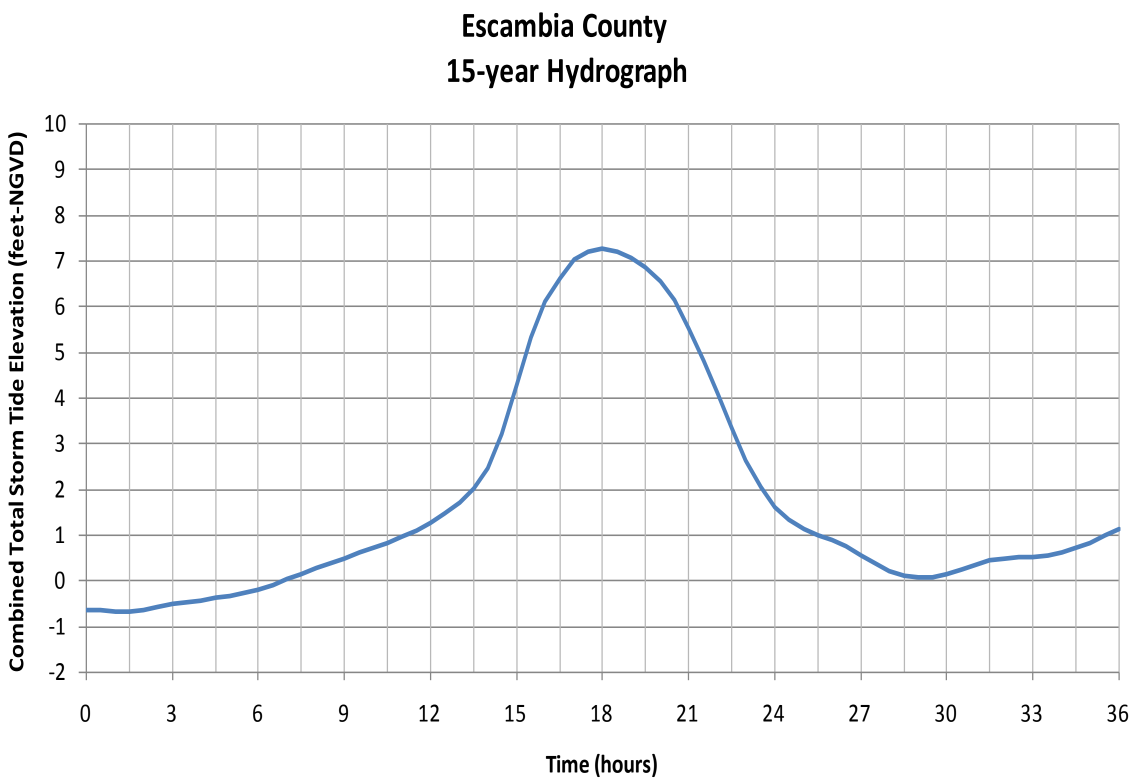
#	Date	Name	θ_N (deg.)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
45	8/7/1928		158.59	-107.6	11.82	-0.24		L
46	9/22/1929		207.36	-102.4	5.63	-0.38		L
47	10/1/1934		193.85	56	7.21	-0.24		L
48	9/16/1937		264.9	58.6	11.26	-0.24		AL
49	6/12/1939		163.95	40.8	6.24	-0.18		L
50	8/7/1939		127.7	-57.7	6.54	-0.54		L
51	9/9/1944		212.33	125	17.75	-0.18		L
52	9/7/1947		129.04	55	11.11	-0.18		L
53	7/7/1948		203.34	-53.1	6.53	-0.18		L
54	5/25/1953	ALICE	180	-77.6	6	-0.24		L
55	7/31/1955	BRENDA	144.27	123.9	7.39	-0.54		L
56	8/23/1955		112.48	111.4	13.08	-0.24		L
57	9/7/1957	DEBBIE	224.61	-38.2	9.83	-0.18		L
58	10/6/1959	IRENE	209.92	21.3	10.38	-0.36		L
59	9/17/1960	FLORENCE	143.5	6.3	8.71	-0.03		L
60	6/11/1965		226.35	-55.7	20.28	-0.31		L
61	9/29/1969		180	-34.9	15	-0.5		L
62	7/19/1970	BECKY	190.86	-111.6	18.33	-0.12		L
63	9/3/1971	FERN	171.81	127.3	6.06	-0.09	12	L
64	6/30/1994	ALBERTO	203.34	-35	8.71	-0.59		L
65	8/14/1994	BERYL	212.92	-93.6	4.76	-0.39		L
66	9/15/2000	HELENE	207.38	-27.3	11.26	-0.36		L
67	8/2/2001	BARRY	175.51	-40.9	11.03	-0.62		L
68	9/12/2002	HANNA	220.8	84.9	10.57	-0.3		L
69	6/8/2005	ARLENE	176.2	18.7	13.03	-0.65		L
70	7/3/2005	CINDY	218.35	112.4	15.3	-0.56		L
71	8/15/2008	FAY	106.2	-59.2	5.83	-0.45		L

Landfalling Storms = 66; Alongshore Storms = 5; Exiting Storms = 0

[1] Values are estimated prior to landfall.

APPENDIX B

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR
ESCAMBIA AND SANTA ROSA COUNTIES


Escambia County
15-year Hydrograph
Combined Total Storm Tide Elevation (feet-NGVD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
0
3
6
9
12
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18
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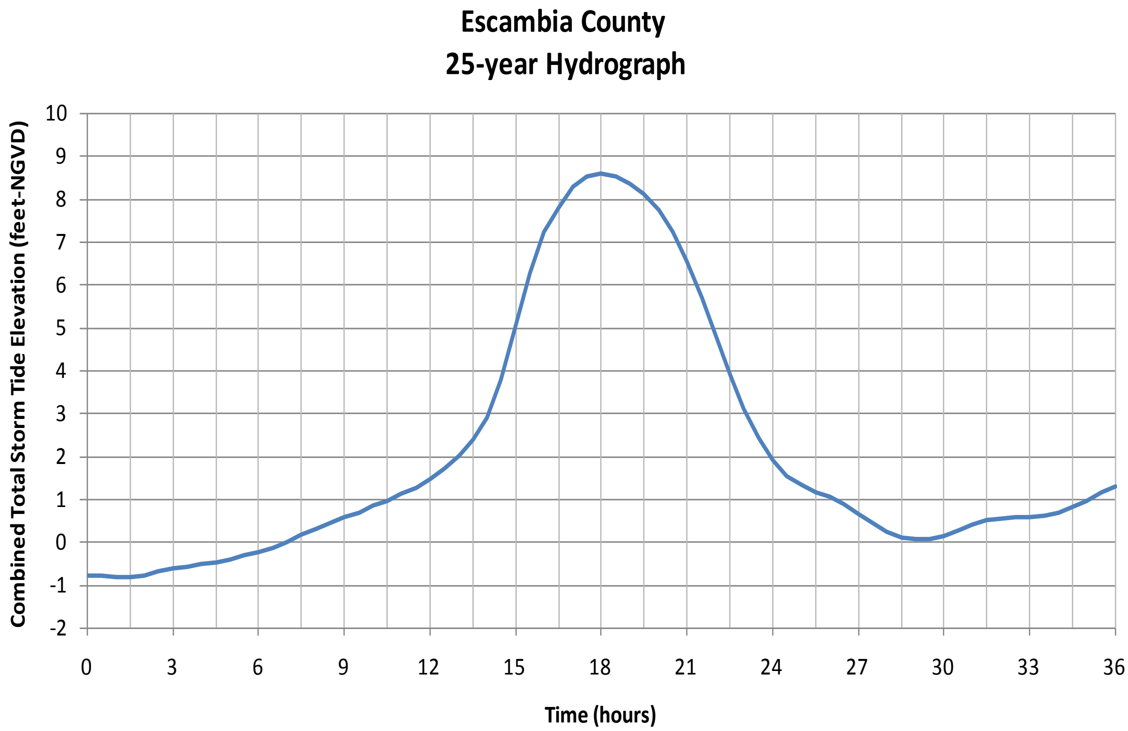
30
33
36
Time (hours)


Escambia County
25-year Hydrograph
Combined Total Storm Tide Elevation (feet-NGVD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
0
3
6
9
12
15
18
21
24
27
30
33
36
Time (hours)