INCLUSION OF TROPICAL STORMS FOR THE COMBINED TOTAL STORM TIDE FREQUENCY RESTUDY FOR VOLUSIA COUNTY, FLORIDA

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

Submitted by
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Institute of Science and Public Affairs
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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 for Volusia County, Florida” (Reference (1)) was submitted to FDEP in July, 1989. This study is requested by the FDEP to include 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 Volusia 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 2008. 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 125 n. mi. north and 150 n. mi. south from the midpoint of the Volusia County shoreline. Accordingly, there were 21 landfalling, 49 exiting and 11 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 743 storms will occur within the 275 n. mi. segment of the coast comprising the study area. Of the 743 storms, 193 will be landfalling, 449 exiting and 101 alongshore storms.

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

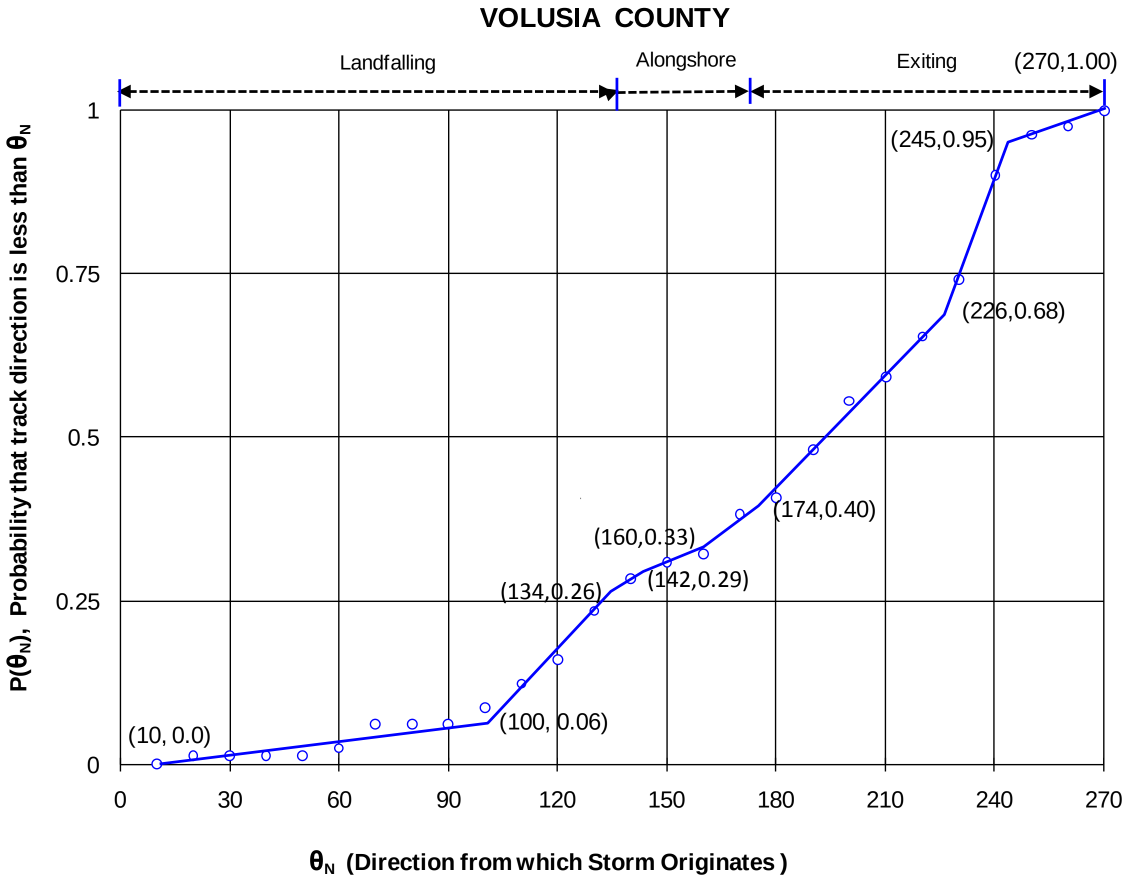


Figure 1 Cumulative Probability Distribution of Storm Track Direction, θ_N

2.3 Radius to Maximum Winds and Central Pressure Deficit

The cumulative probability distribution of radius to maximum winds for landfalling and exiting storms is presented in Figures 2. Figure 3 presents the same for alongshore storms. The cumulative probability distributions of pressure deficit for landfalling and alongshore storms is presented in Figure 4. Figure 5 presents the same for exiting storms.

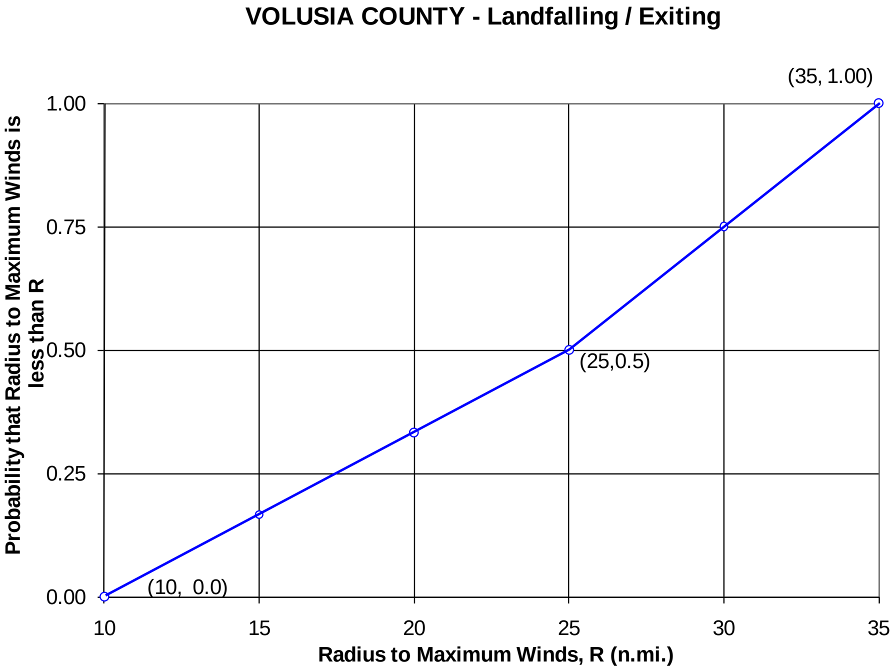


Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Exiting Storms

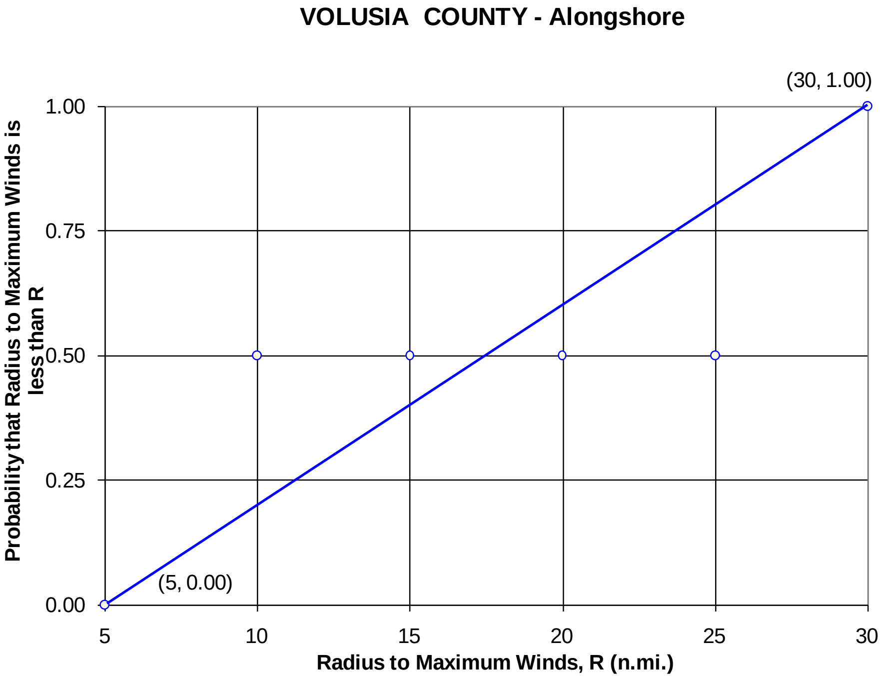


Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

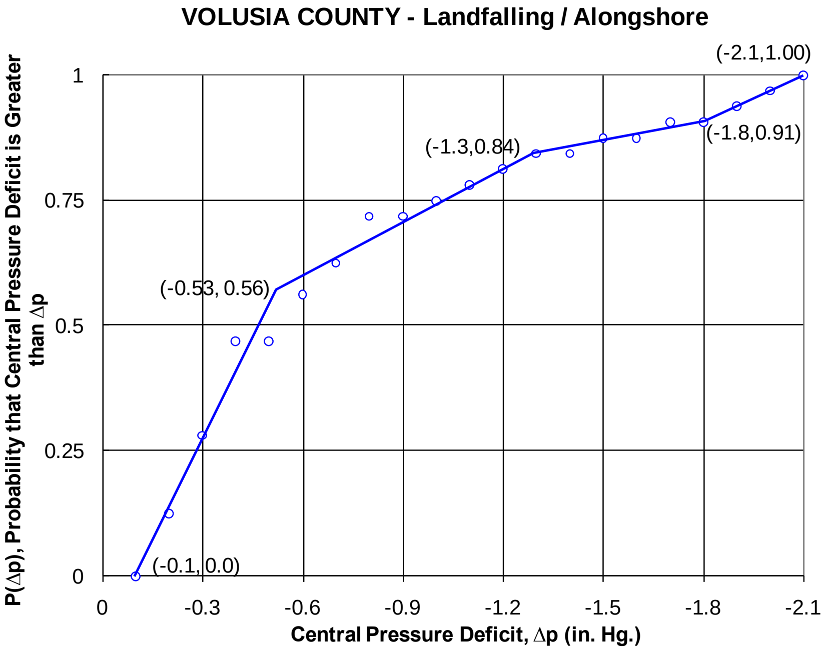


Figure 4 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Landfalling and Alongshore storms

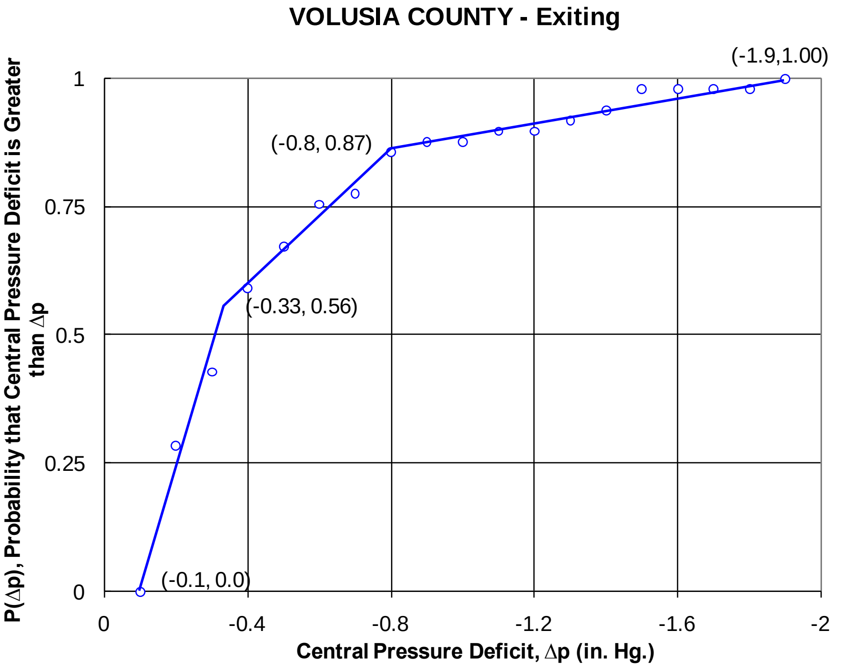


Figure 5 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Exiting storms

2.4 Forward Speed

The cumulative probability distribution of the forward speed of translation for landfalling, exiting and alongshore storms is presented in Figure 6.

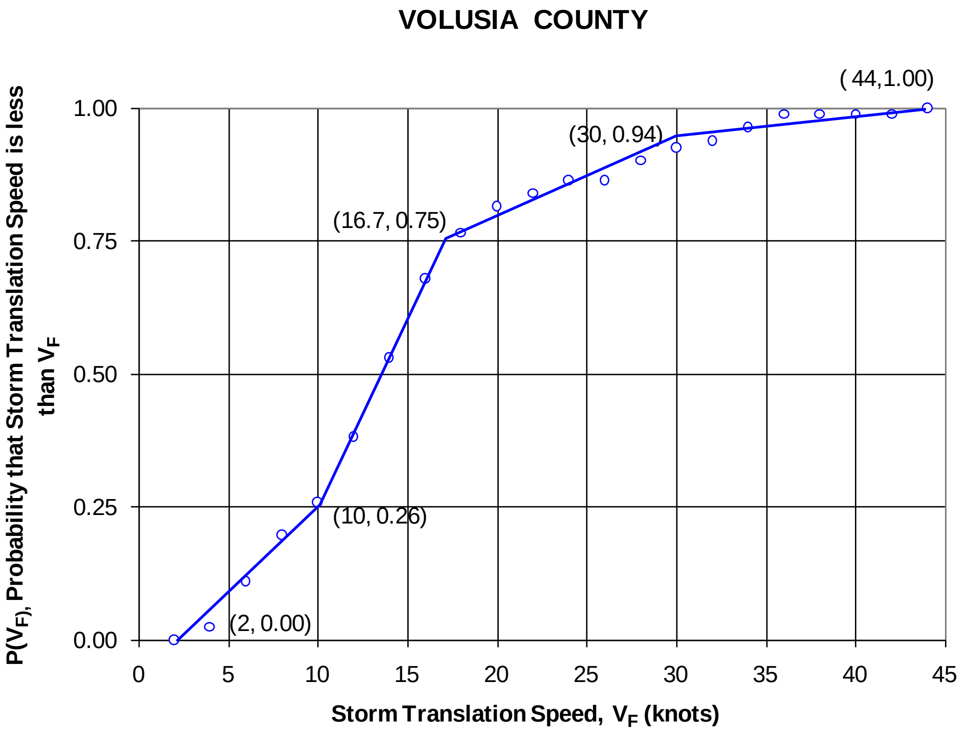


Figure 6 Cumulative Probability Distribution of Translation Speed , V_F

2.5 Track Position

For the landfalling and exiting storms, the track position is determined by the y coordinate, Y_F, representing the landfalling or exiting point. Figure 7 presents the cumulative probability distribution for the actual landfalling and exiting position, Y_F, for landfalling and exiting storms. Figure 8 presents the cumulative probability distribution for the actual offshore distance, X_L, for alongshore storms.

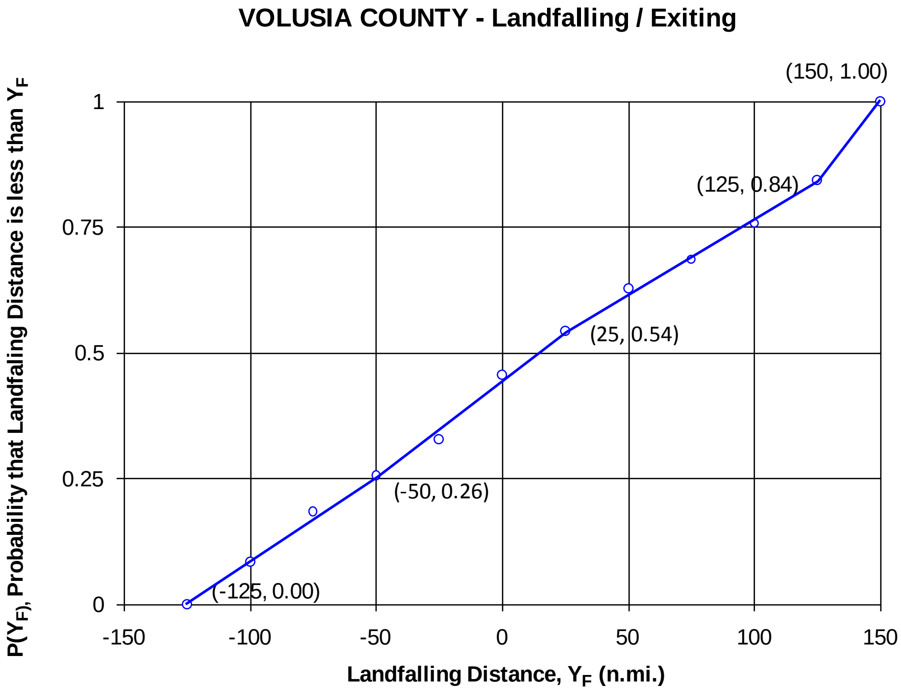


Figure 7 Cumulative Probability Distribution of Landfalling Distance, Y_F, for Landfalling and Exiting Storms

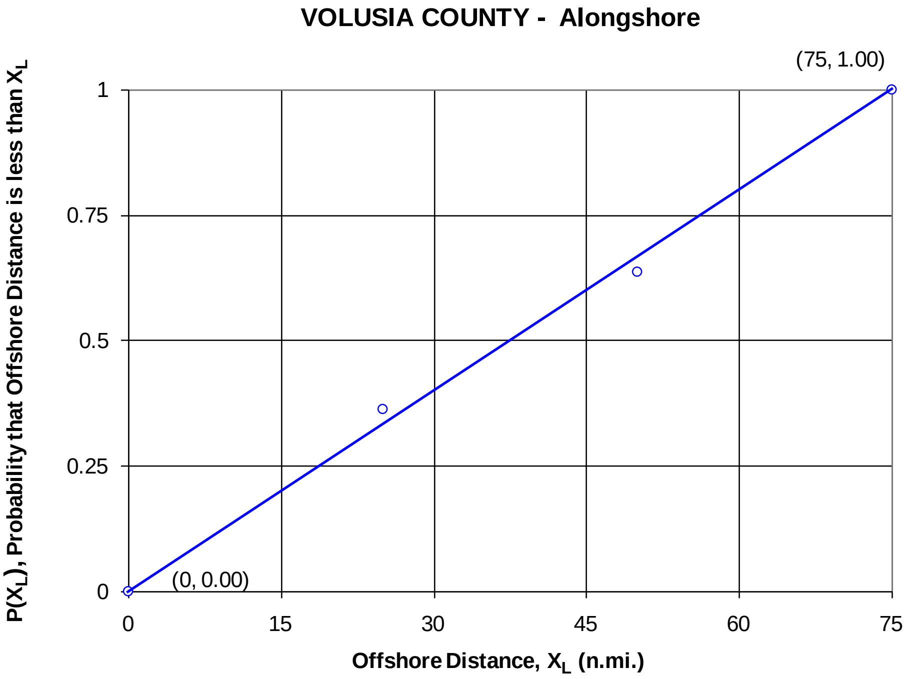


Figure 8 Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

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 9 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.

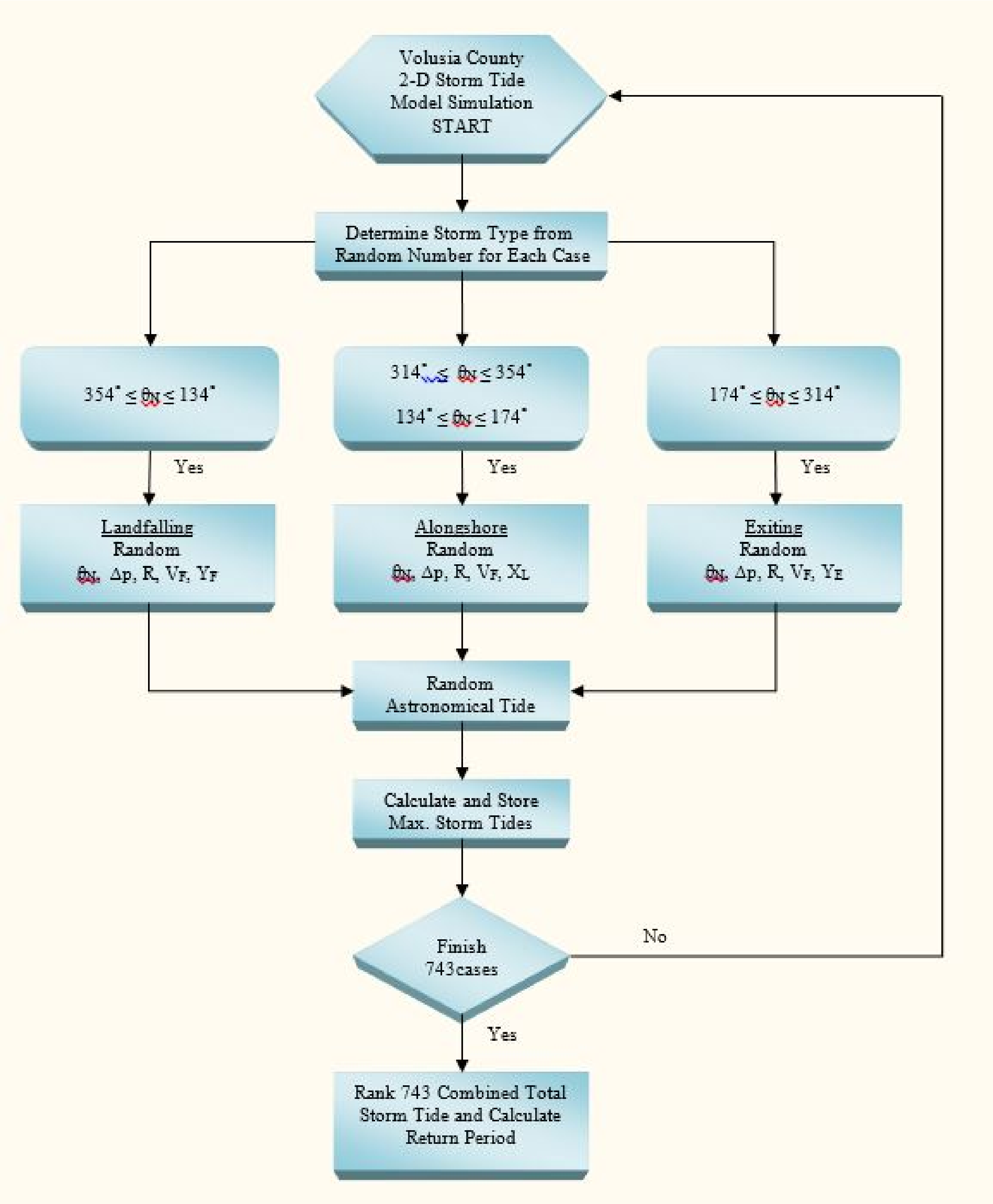


Figure 9 Flow Chart for Two-Dimensional Storm Tide Simulations

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 275 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 743 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 off Volusia 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 (743) 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 743 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 = 743 (associated with the lowest water level) the return period would be:

$$TR_{743} = 1000 / 743 = 1.35 \text{ years}$$

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 Volusia County 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 10. 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.

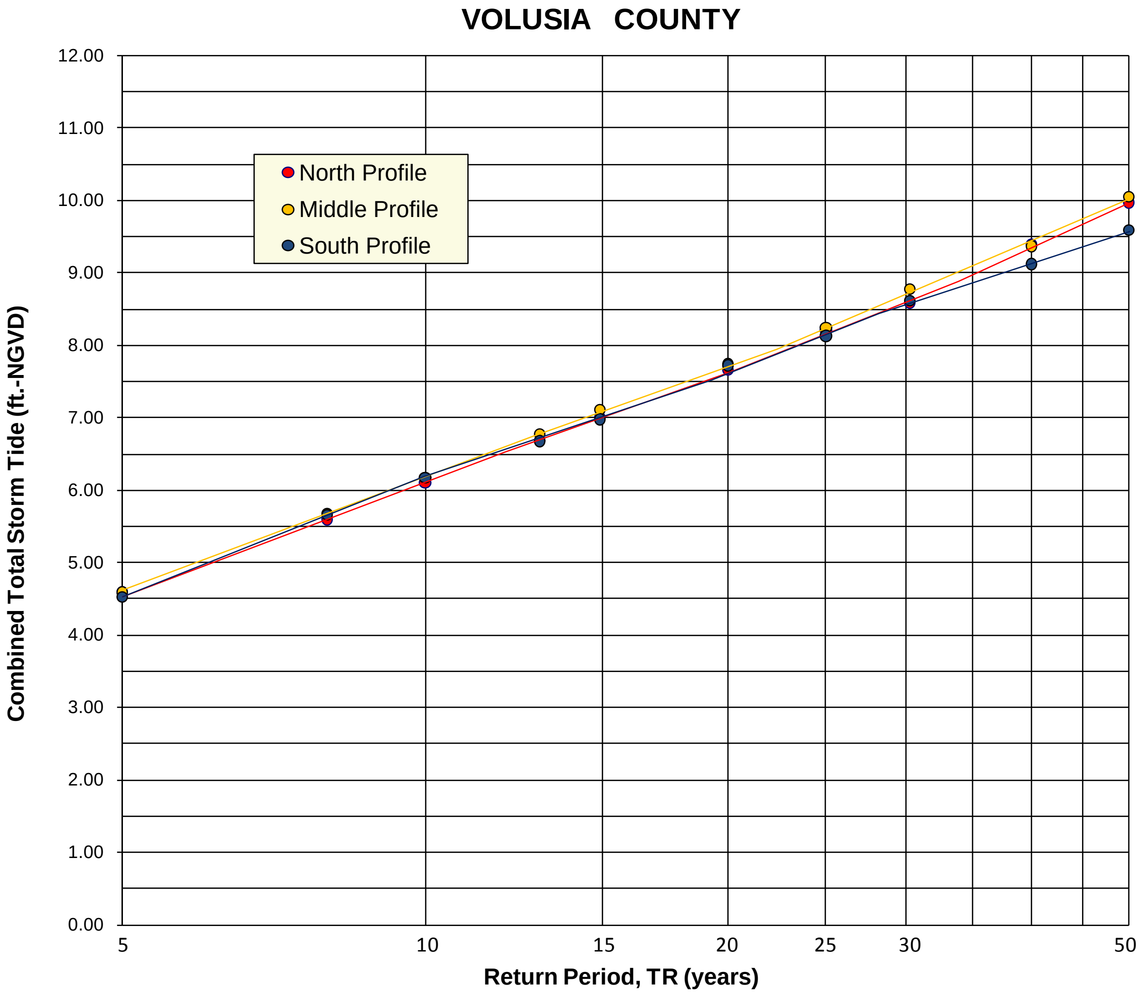


Figure 10 Combined Total Storm Tide Elevation Versus Return Period for Study Area

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

Table I

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

Return Period, TR (years)	North Profile NGVD29	North Profile NAVD88	Middle Profile NGVD29	Middle Profile NAVD88	South Profile NGVD29	South Profile NAVD88
50	10.0	8.9	10.1	8.9	9.6	8.3
30	8.6	7.5	8.8	7.6	8.6	7.3
25	8.2	7.1	8.2	7.0	8.1	6.8
20	7.7	6.6	7.7	6.5	7.7	6.4
15	7.0	5.9	7.1	5.9	7.0	5.7
10	6.1	5.0	6.2	5.0	6.2	4.9
5	4.6	3.5	4.6	3.4	4.5	3.2

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

Disclaimer

These results are not intended to be published or to replace the storm surges as produced in the report, “Combined Total Storm Tide Frequency for Volusia County, Florida” (Reference (1). The hydrograph presented in Appendix B for the return periods for 15 and 25 years is based on actual storm event data by Leadon (Reference (4)). Adjustment of the tide elevations in the hydrograph are required such that the peak corresponds to the desired storm tide level provided in Table I for each specific case.

REFERENCES

1. Dean, R. G., Chiu, T. Y. and Wang, S.Y., “Combined Total Storm Tide Frequency for Volusia County, Florida,” Beaches and Shores Resource Center, Florida State University, July 1989.

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, "Storm Best Track Files (HURDAT), 1851 – 2008," http://www.nhc.noaa.gov.

4. Leadon, M., “Florida Atlantic Coast Tide Gage Data Evaluation”, Beaches and Shores Resource Center, Florida State University, June 2010.

APPENDIX A

SUMMARY OF HISTORICAL STORMS AFFECTING VOLUSIA COUNTY

#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	7/31/1915		125	34.9	5.3	-0.68		L
2	10/20/1921		248	7.8	13.2	-0.74		E
3	11/27/1925		221	31.1	13.3	-0.64		E
4	7/22/1926		133	75	7.4	-1.12	14	L
5	8/3/1928		133	109.8	5.3	-1.07		L
6	9/6/1928		120	95	14.1	-2.00	28	L
7	7/25/1933		111	119.8	4.1	-0.74		L
8	8/31/1933		120	140	14.4	-1.92	13	L
9	8/7/1939		120	135.7	10.1	-0.74		L
10	10/12/1944		197	-70.2	14.7	-1.04		E
11	6/20/1945		230	-42.3	12.5	-0.74		E
12	9/12/1945		196	-63.4	12.5	-0.77		E
13	9/18/1948		221	133.6	6.6	-1.45	16	E
14	8/29/1960	DONNA	209	-17.4	16.0	-1.30	24	E
15	10/16/1963	GINNY	168	(+75)	4.1	-0.73		A
16	8/28/1964	DORA	99	-50	6.2	-1.45	34	L
17	10/13/1968	GLADYS	230	-41.3	17.2	-1.42	17	E
18	8/25/1979	DAVID	172	(+9)	11.0	-1.27	27	A
19	7/31/1995	ERIN	123	110.2	14.6	-0.92		L
20	10/22/1998	MITCH	251	140.1	27.7	-0.77		E
21	10/12/1999	IRENE	186	101.5	8.1	-0.83		E
22	8/9/2004	CHARLEY	199	-14.6	21.2	-1.27	22	E
23	8/25/2004	FRANCES	106	136.4	7.3	-1.63	30	L
24	9/13/2004	JEANNE	101	131.6	10.7	-1.83	26	L
25	10/15/2005	WILMA	227	134	26.3	-1.86		E
26	10/10/1900		232	-88.4	17.7	-0.18		E
27	10/8/1906		12	-51	12.3	-0.38		L
28	8/28/1909		215	9.3	12.2	-0.14		E
29	9/24/1909		232	127.9	9.9	-0.14		E
30	10/9/1910		196	-93.3	9.4	-0.38		E
31	10/3/1912		263	-6.2	15.9	-0.14		E
32	5/13/1916		202	-83.8	11.8	-0.18		E
33	8/21/1916		180	20.3	11.0	-0.14		E
34	9/25/1920		242	-31.5	34.3	-0.31		E
35	10/15/1921		221	56.5	19.9	-0.14		E
36	10/1/1927		151	(+68)	16.1	-0.38		A
37	8/31/1930		229	-10.5	4.6	-0.18		E
38	9/9/1932		239	-95.5	23.3	-0.31		E
39	5/27/1934		166	(+67)	14.4	-0.38		A
40	7/21/1934		65	-36	16.3	-0.24		L
41	8/20/1936		117	-29.2	15.5	-0.31		L
42	7/29/1937		232	-18	13.1	-0.24		E
43	8/24/1937		111	15.9	11.1	-0.38		L
44	10/23/1938		232	-110.4	42.6	-0.24		E

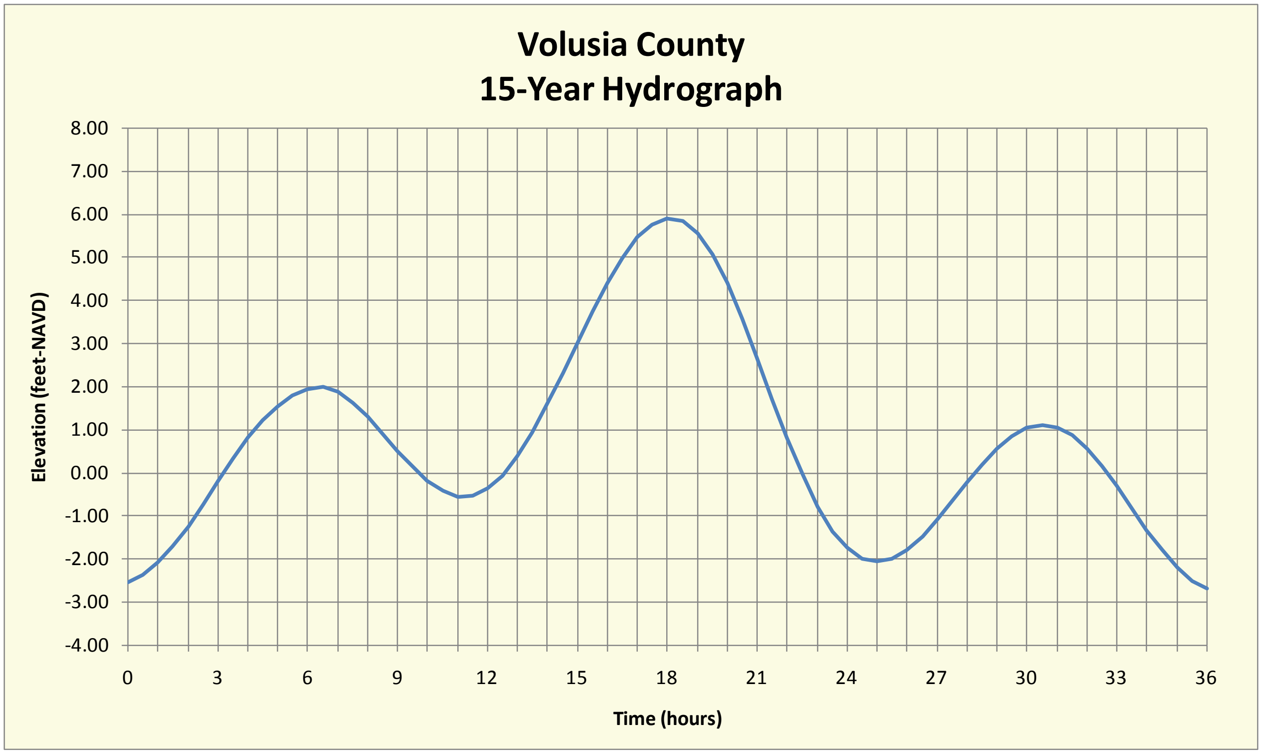
#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
45	8/2/1940		56	-23.5	12.5	-0.18		L
46	10/6/1947		104	-105	21.6	-0.24		L
47	9/28/1951	HOW	221	99.4	18.6	-0.54		E
48	2/2/1952		217	146.6	28.9	-0.31		E
49	9/14/1953		231	-110	31.4	-0.24		E
50	10/7/1953	HAZEL	234	79	23.7	-0.56		E
51	6/18/1959		240	36	32.0	-0.14		E
52	10/17/1959	JUDITH	264	139.8	28.1	-0.42		E
53	7/28/1960	BRENDA	216	-119.4	14.8	-0.14		E
54	8/26/1962	ALMA	183	81.9	15.0	-0.18		E
55	6/2/1964		236	-78.4	15.8	-0.14		E
56	8/20/1964	CLEO	167	(+0)	11.3	-0.53	7	A
57	6/1/1968	ABBY	162	(+2.6)	8.4	-0.38		A
58	10/1/1969	JENNY	180	32.3	3.0	-0.14		E
59	5/23/1972	ALPHA	66	-117.1	12.4	-0.65		L
60	6/24/1974		228	-3.1	32.8	-0.39		E
61	10/4/1974		191	132.6	13.3	-0.24		E
62	5/21/1976		245	-123.4	19.2	-0.45		E
63	8/18/1976	DOTTIE	183	110	16.0	-0.21		E
64	8/7/1981	DENNIS	180	20.3	10.0	-0.27		E
65	6/18/1982		219	-63.6	34.6	-0.42		E
66	8/8/1984	DIANA	139	(+45.8)	4.0	-0.53		A
67	9/25/1984	ISIDORE	216	-82.6	7.4	-0.36		E
68	7/21/1985	BOB	175	70.4	11.0	-0.21		E
69	10/7/1985	ISABEL	139	(+50)	9.3	-0.21		A
70	8/21/1988	CHRIS	165	(+35)	26.9	-0.15		A
71	11/17/1988	KEITH	233	50.1	16.4	-0.42		E
72	11/8/1994	GORDON	234	87	15.1	-0.53		E
73	8/22/1995	JERRY	128	111	6.6	-0.24		L
74	9/11/2001	GABRIELLE	247	31.8	7.6	-0.53		E
75	9/1/2002	EDOUARD	69	-14.6	5.6	-0.15		L
76	9/20/2002	KYLE	146	(+55.9)	10.9	-0.12		A
77	9/3/2003	HENRI	237	14	14.6	-0.18		E
78	10/5/2005	TAMMY	149	(+12.8)	13.5	-0.27		A
79	8/24/2006	ERNESTO	191	43.4	13.3	-0.39	25	E
80	5/31/2007	BARRY	200	-93.3	18.1	-0.36		E
81	8/15/2008	FAY	90	-10	2.0	-0.59	33	L

Landfalling Storms = 21; Alongshore Storms = 11; Exiting Storms = 49

[1] Values are estimated prior to landfall.

APPENDIX B

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR VOLUSIA COUNTY


Volusia County
15-Year Hydrograph
Elevation (feet-NAVD)
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6.00
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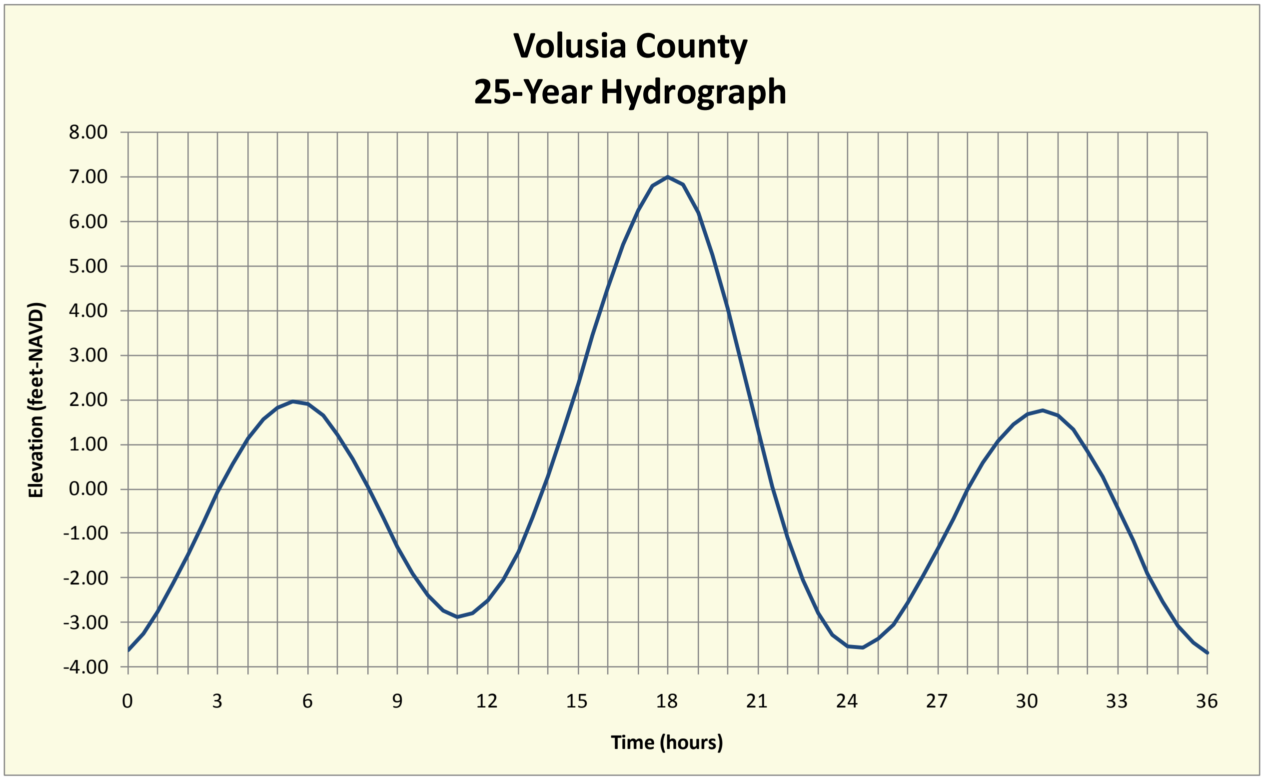
Time (hours)


Volusia County
25-Year Hydrograph
Elevation (feet-NAVD)
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3
6
9
12
15
18
21
24
27
30
33
36
Time (hours)