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

By

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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 Franklin County, Florida" (Reference (1)) was submitted to FDEP in September, 1983. 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 Franklin 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 2012. For purposes of this report, the data contained in References (2) and (3) that fall within a 300 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 hurricanes are considered to be of possible significance if they made landfall within a 300 n. mi. segment of the coast comprising the study area. This segment is extended 125 n. mi. northeast and 175 n. mi. southwest from the midpoint of the Franklin County shoreline. Accordingly, there were 60 landfalling and 9 alongshore storms occurring in the years 1900 through 2012. 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 611 storms will occur within the 300 n. mi. segment of the coast comprising the study area. Of the 611 storms, 531 will be landfalling and 80 alongshore storms.

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

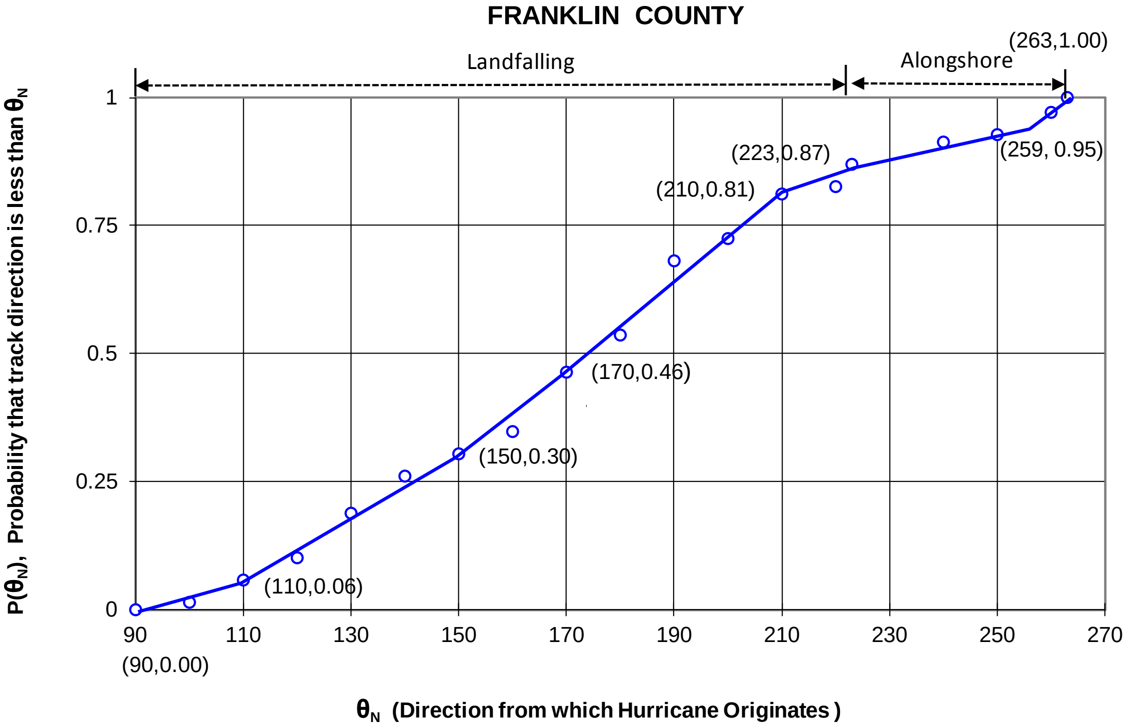


Figure 1 Cumulative Probability Distribution of Storm Track Direction, θ_N

2.3 Radius to Maximum Winds and Central Pressure Deficit

The cumulative probability distribution of radius to maximum winds for landfalling 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.

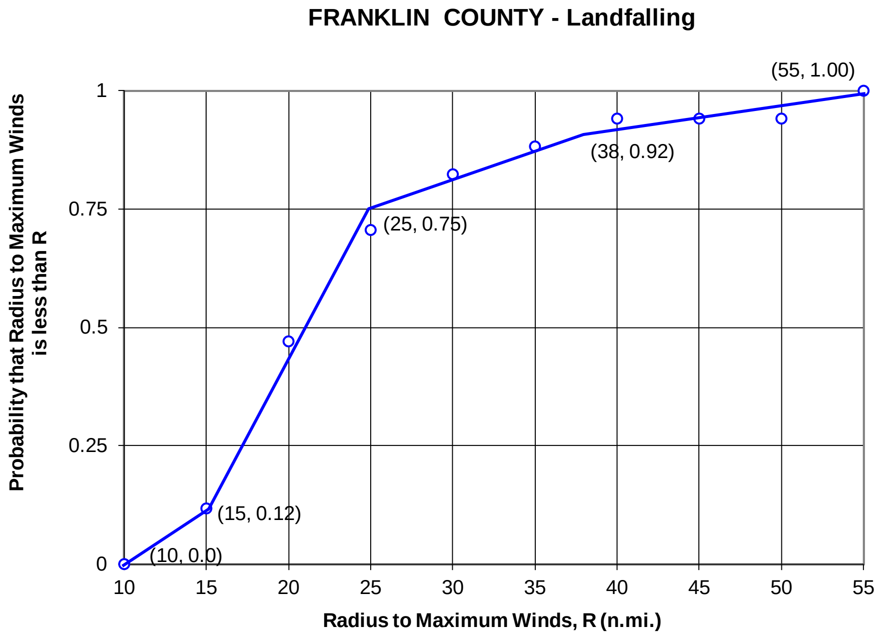


Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling Storms

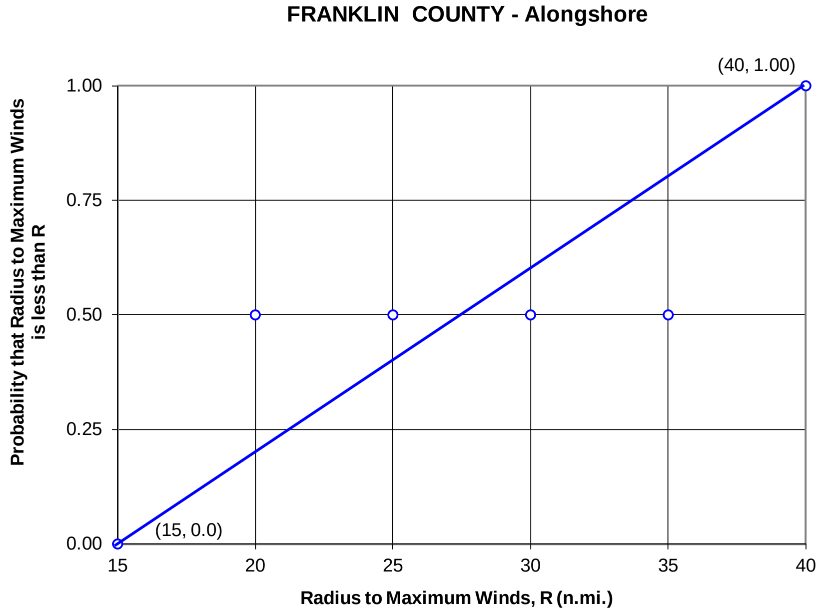


Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

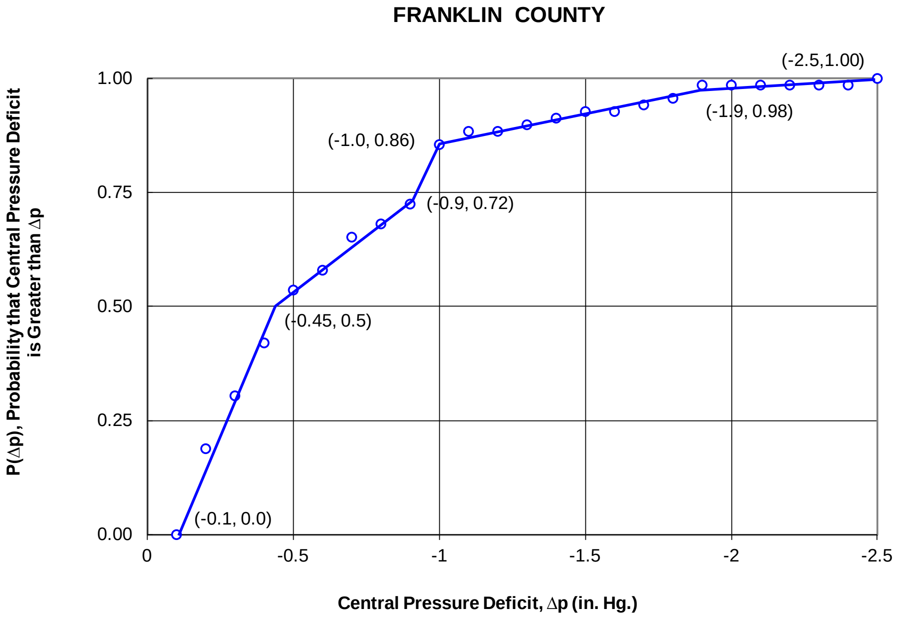


Figure 4 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Landfalling and Alongshore storms

2.4 Forward Speed

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

2.5 Track Position

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

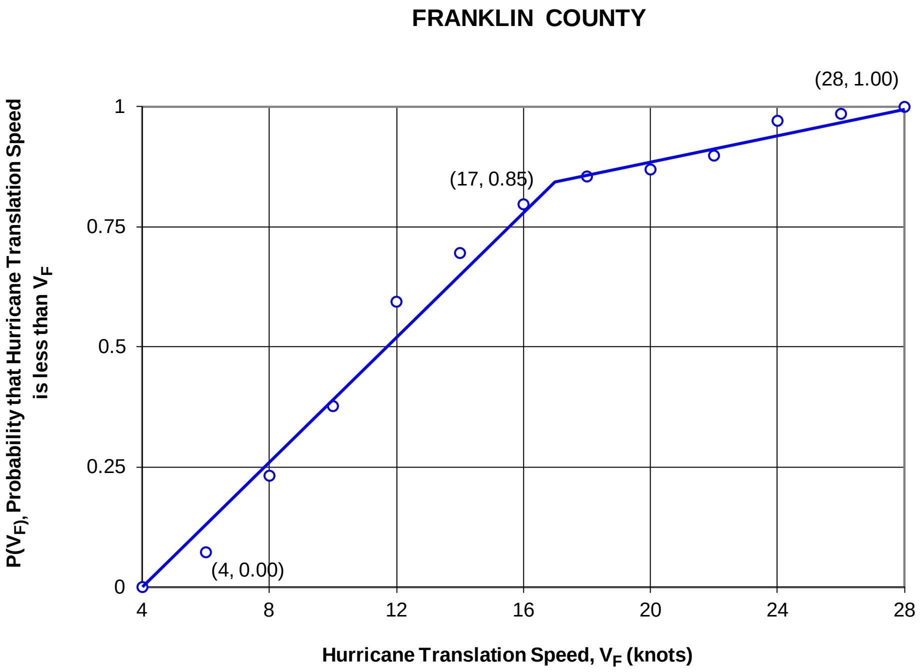


Figure 5 Cumulative Probability Distribution of Translation Speed , V_F

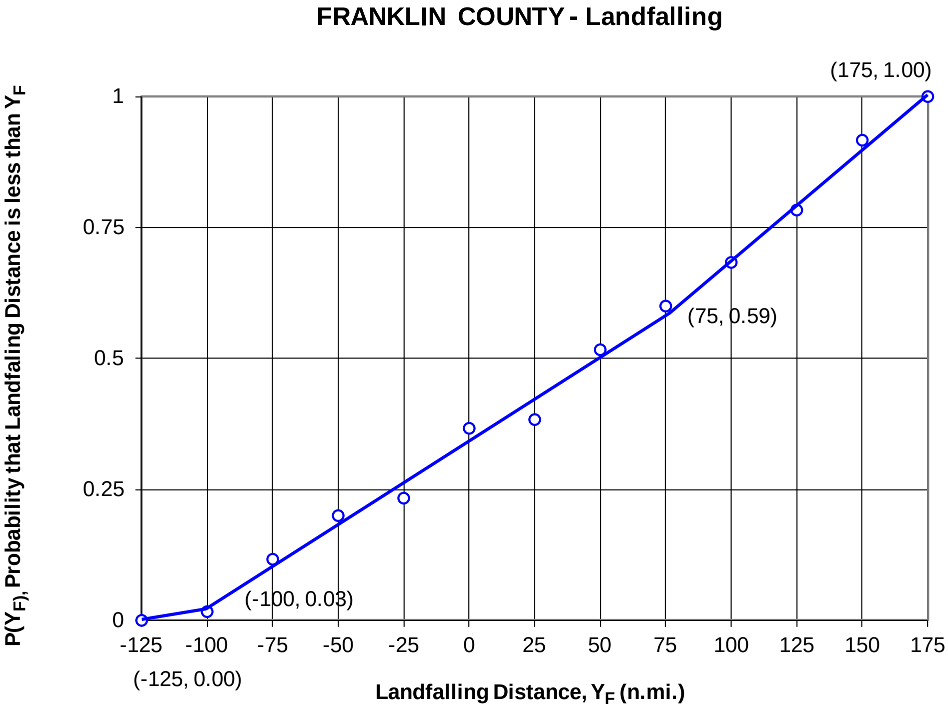


Figure 6 Cumulative Probability Distribution of Landfalling Distance, $Y_{F,}$ for Landfalling Storms

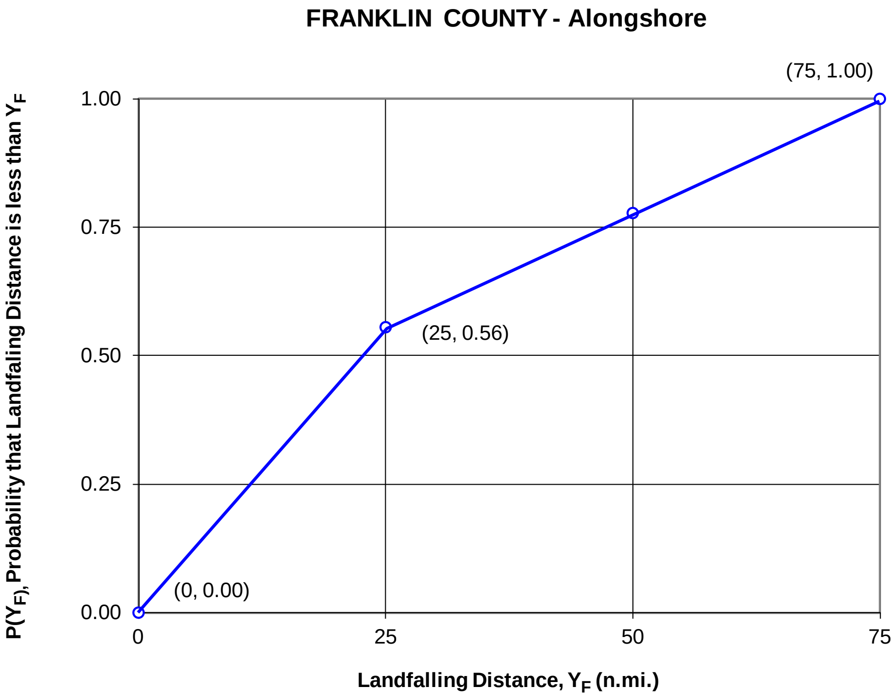


Figure 7 Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

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, <u>it is possible to interpolate return periods of 5, 10, 15, 20, 25, 30 and 50 years.</u>

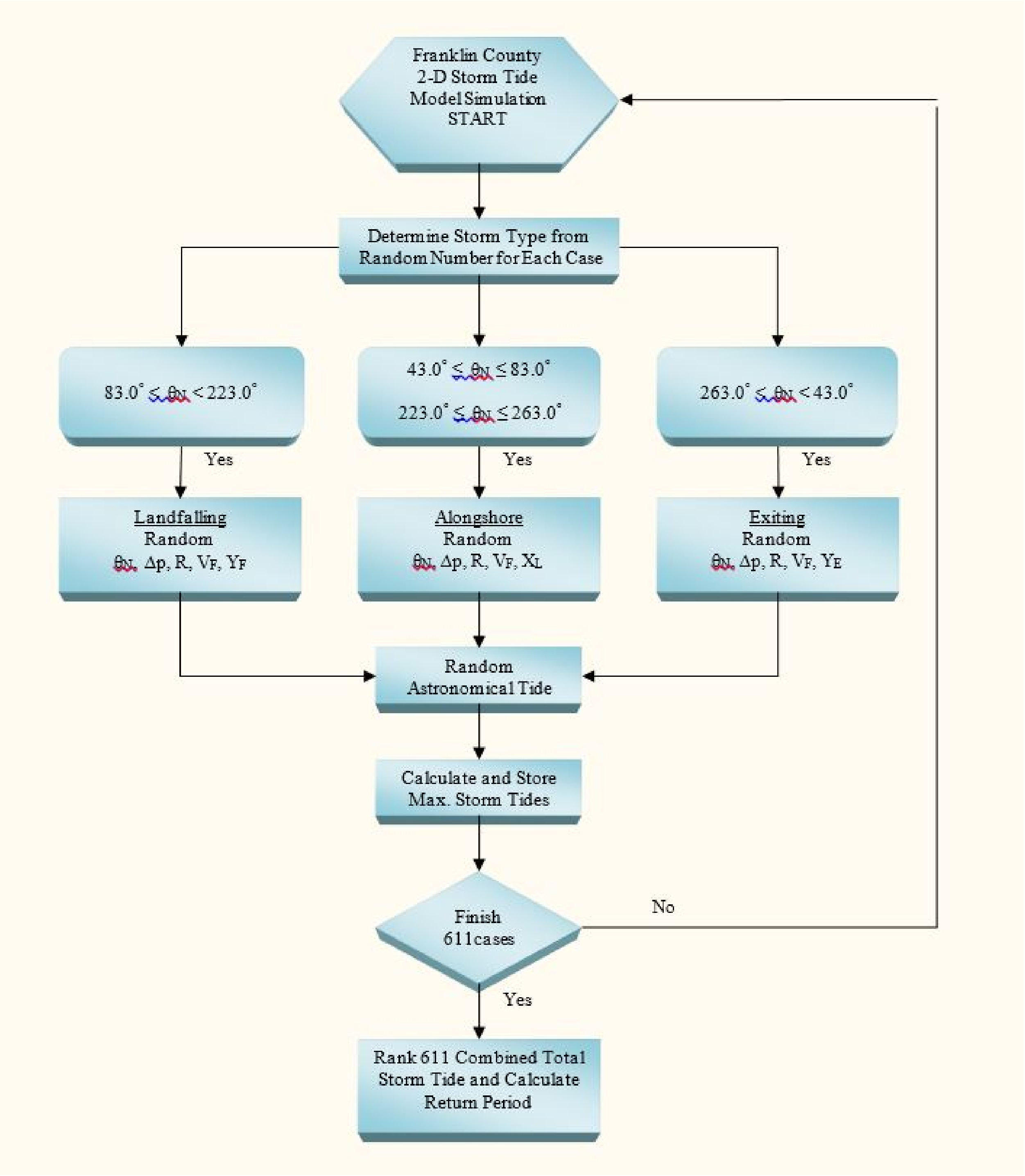


Figure 8 Flow Chart for Two-Dimensional Storm Tide Simulations

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 300 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 611 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 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 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 (611) 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 611 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 = 611 (associated with the lowest water level) the return period would be:

$$TR_{611} = 1000 / 611 = 1.64 \text{ years}$$

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 Franklin 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 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.

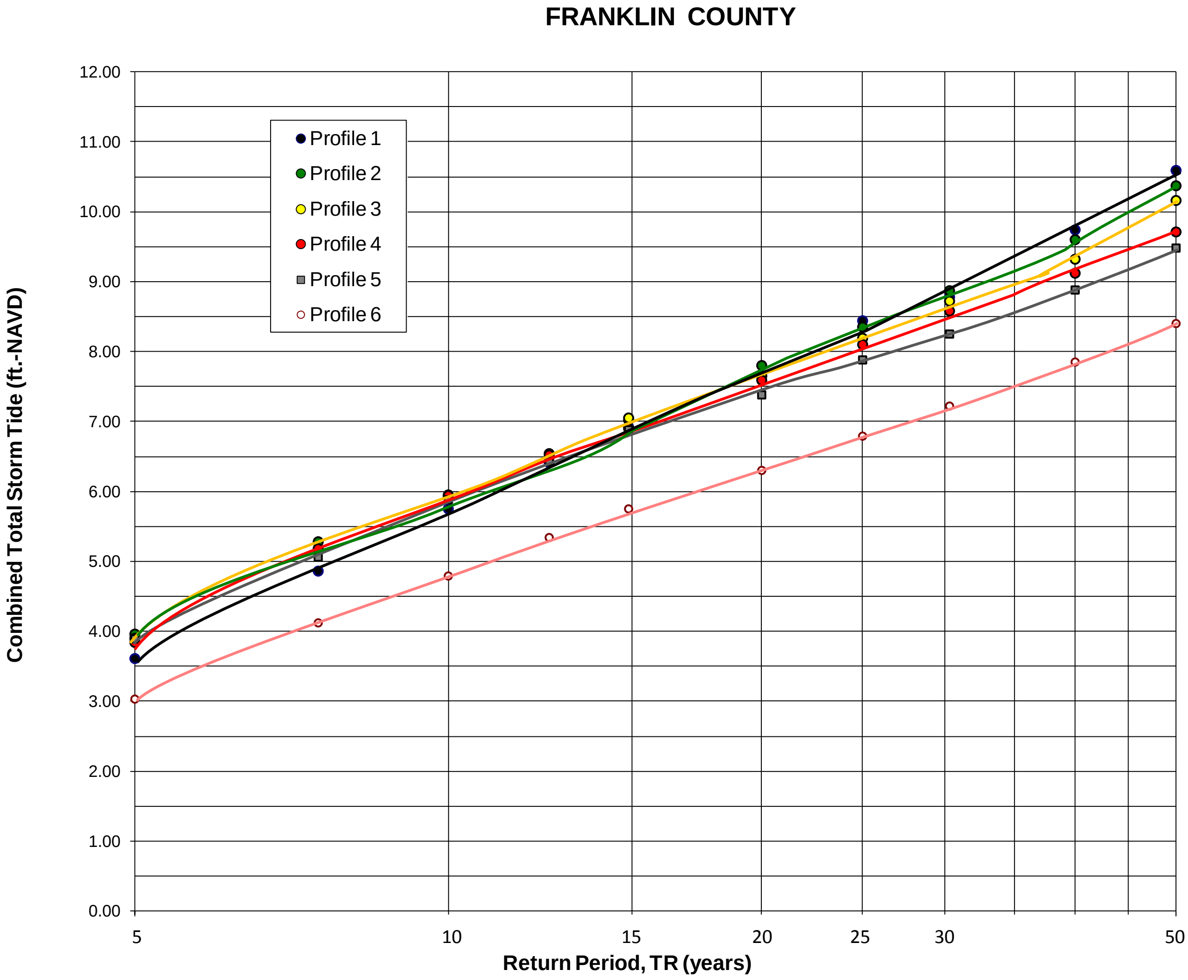


Figure 9 Combined Total Storm Tide Elevation Versus Return Period for Study Area

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

Table I Combined Total Storm Tide Level* (ft-NAVD) for Various Return Periods

Return Period, TR (years)	Profile 1	Profile 2	Profile 3	Profile 4	Profile 4	Profile 6
50	10.6	10.4	10.2	9.7	9.5	8.4
30	8.8	8.9	8.7	8.6	8.3	7.2
25	8.4	8.4	8.2	8.1	7.9	6.8
20	7.7	7.8	7.7	7.6	7.4	6.3
15	6.9	7.0	7.1	6.9	6.9	5.8
10	5.8	5.9	6.0	5.9	5.9	4.8
5	3.6	4.0	3.9	3.8	3.9	3.0

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

The hydrograph for the return periods for 15 and 25 years with and without wave set up are listed in Appendix B. Adjustment of the tide elevations in the hydrograph may be 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 Franklin County, Florida,” Beaches and Shores Resource Center, Florida State University, September 1983.

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 – 2012", http://www.nhc.noaa.gov.

APPENDIX A

SUMMARY OF HISTORICAL STORMS AFFECTING FRANKLIN COUNTY

#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	10/10/1900		250	(38)	22	-0.24		A
2	6/11/1901		180	-14.0	10	-0.18		L
3	9/9/1901		202	172.9	14	-0.38		L
4	9/21/1901		185	-13.4	22	-0.24		L
5	6/12/1902		199	-78.8	11	-0.31		L
6	9/9/1903		144	25.7	7	-0.97		L
7	6/8/1906		174	42.8	9	-0.31		L
8	9/18/1907		128	148.2	7	-0.24		L
9	6/26/1909		139	-47.5	4	-0.18		L
10	8/8/1911		134	71.2	7	-0.64		L
11	9/10/1912		120	124.1	4	-0.97		L
12	10/3/1912		261	(58)	12	-0.14		A
13	8/31/1915		172	27.9	16	-0.97		L
14	6/28/1916		172	163.7	12	-1.36		L
15	7/2/1919		168	110.8	8	-0.46		L
16	10/12/1922		157	153.1	7	-0.18		L
17	9/27/1924		221	-53.6	27	-0.46		L
18	9/11/1926		135	55.6	9	-1.83	17	L
19	8/3/1928		139	-35.3	8	-0.18		L
20	8/7/1928		164	-11.1	9	-0.31		L
21	9/19/1929		164	73.9	6	-0.97	55	L
22	8/26/1932		142	113.8	11	-0.74		L
23	9/9/1932		246	(3)	20	-0.38		A
24	8/31/1933		170	-81.0	23	-0.38		L
25	8/29/1935		195	-92.5	10	-0.85		L
26	7/27/1936		157	69.2	7	-0.97	19	L
27	8/20/1936		105	-53.2	15	-0.18		L
28	8/24/1937		116	-50.3	12	-0.31		L
29	9/16/1937		262	(0)	7	-0.18		A
30	8/7/1939		125	18.3	11	-0.64		L
31	10/3/1941		175	-11.1	11	-0.85	18	L
32	9/3/1945		107	92.3	14	-0.14		L
33	6/13/1946		116	148.4	7	-0.18		L
34	9/4/1947		123	138.7	22	-0.97	25	L
35	9/7/1947		128	97.3	18	-0.24		L
36	5/25/1953	ALICE	180	56.2	5	-0.24		L
37	9/14/1953		254	(6)	7	-0.46		A
38	9/23/1953	FLORENCE	190	126.2	10	-1.22		L
39	8/23/1955		145	123.4	14	-0.24		L
40	6/8/1957		222	-21.1	24	-0.18		L
41	9/7/1957	DEBBIE	205	156.6	14	-0.18		L
42	8/28/1964	DORA	103	-63.5	5	-0.74	34	L
43	6/4/1966	ALMA	216	-19.9	7	-0.95	20	L
44	9/29/1969		185	100.6	10	-0.4		L

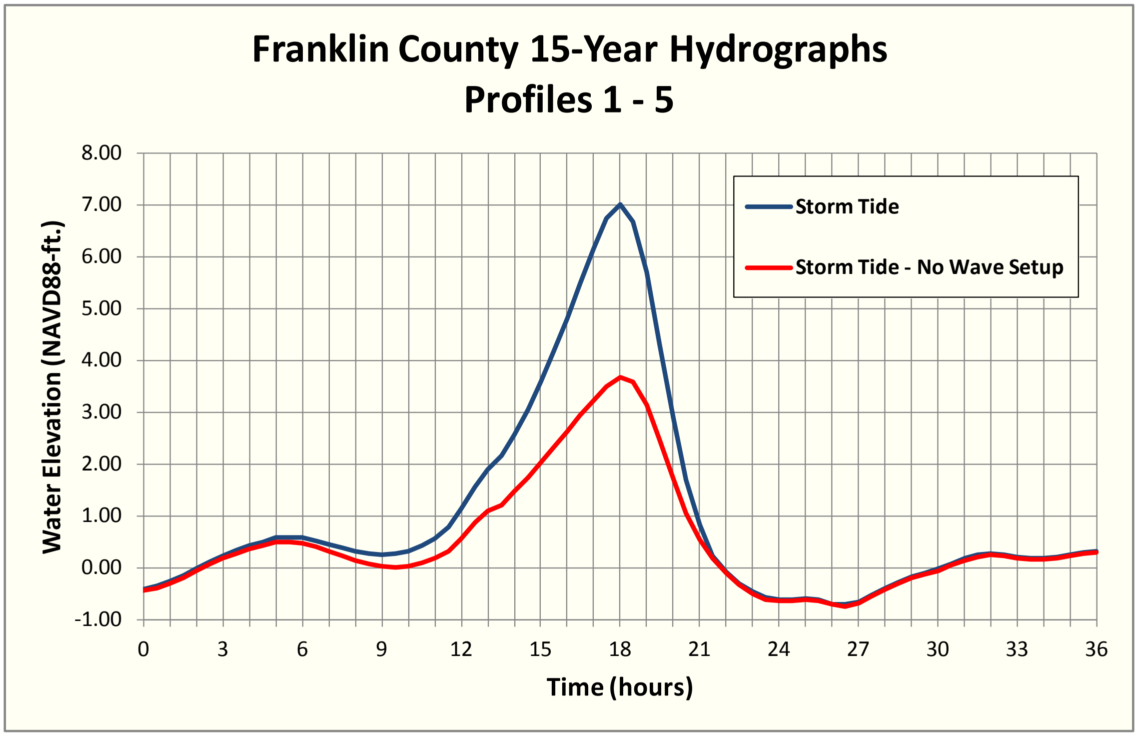
#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
45	7/19/1970	BECKY	206	30.7	8	-0.24		L
46	6/14/1972	AGNES	185	46.0	11	-1.04	20	L
47	9/13/1975	ELOISE	206	136.1	20	-1.63	18	L
48	5/21/1976		233	(24)	22	-0.45		A
49	7/18/1977		168	142.4	12	-0.14		L
50	8/29/1979	FREDERIC	169	167.4	13	-1.86		L
51	8/28/1985	ELENA	118	49.0	11	-1.75	16	L
52	11/15/1985	KATE	201	76.6	10	-1.42	19	L
53	10/9/1990	MARCO	183	-106.9	16	-0.42		L
54	6/30/1994	ALBERTO	185	114.7	11	-0.48		L
55	6/3/1995	ALLISON	221	-22.1	12	-0.68		L
56	7/31/1995	ERIN	120	49.7	10	-1.01	20	L
57	8/22/1995	JERRY	188	-95.9	6	-0.27		L
58	10/4/1996	JOSEPHINE	230	(29)	17	-0.89	40	A
59	9/15/2000	HELENE	180	138.1	11	-0.5		L
60	8/2/2001	BARRY	186	88.7	9	-0.65	14	L
61	8/3/2004	BONNIE	235	(0)	17	-0.33	16	A
62	8/25/2004	FRANCES	164	-50.1	9	-0.92	36	L
63	9/13/2004	JEANNE	152	-83.1	11	-0.95		L
64	6/8/2005	ARLENE	164	133.4	13	-0.59	28	L
65	7/4/2005	DENNIS	160	96.5	15	-2.45	14	L
66	6/10/2006	ALBERTO	203	-77.0	15	-0.45	24	L
67	8/15/2008	FAY	97	-15.4	8	-0.5		L
68	8/16/2009	CLAUDETTE	139	33.7	9	-0.15		L
69	6/23/2012	DEBBY	250	(52)	4	-0.65		A

Landfalling Storms = 60 ; Alongshore Storms = 9

[1] Values are estimated prior to landfall.

APPENDIX B

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR FRANKLIN COUNTY


Franklin County 15-Year Hydrographs
Profiles 1 - 5
Water Elevation (NAVD88-ft.)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
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3
6
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12
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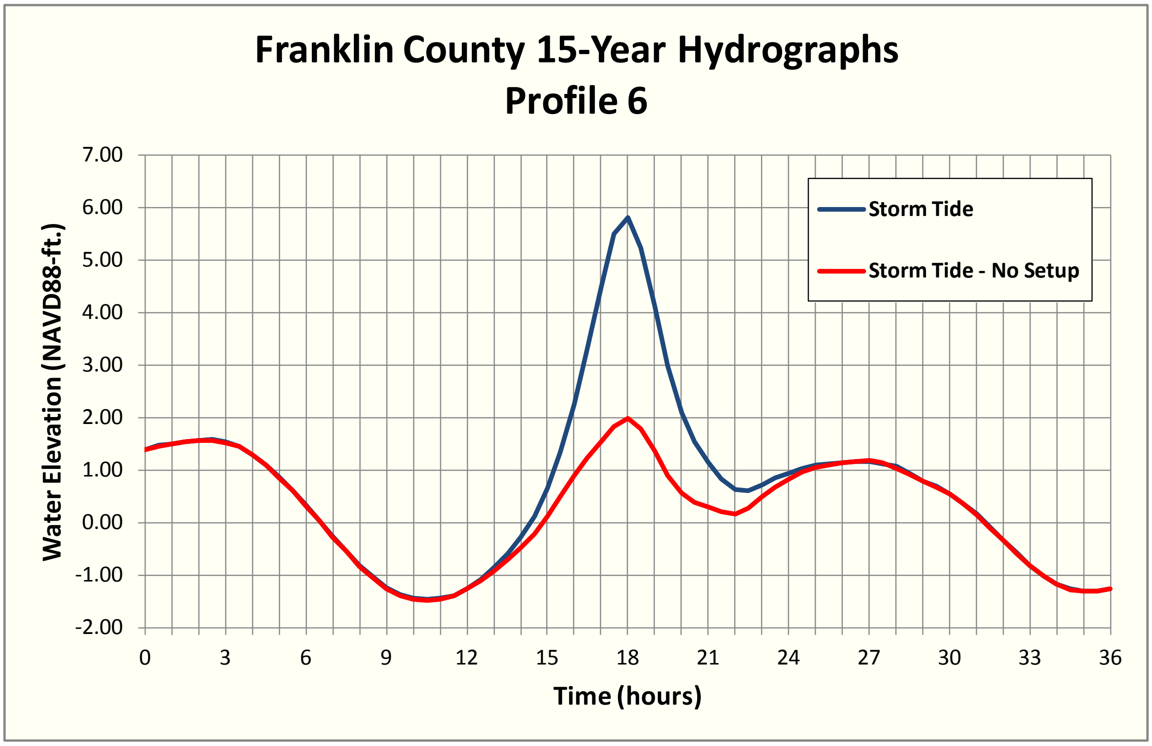
30
33
36
Time (hours)
Storm Tide
Storm Tide - No Wave Setup


Franklin County 15-Year Hydrographs
Profile 6
Water Elevation (NAVD88-ft.)
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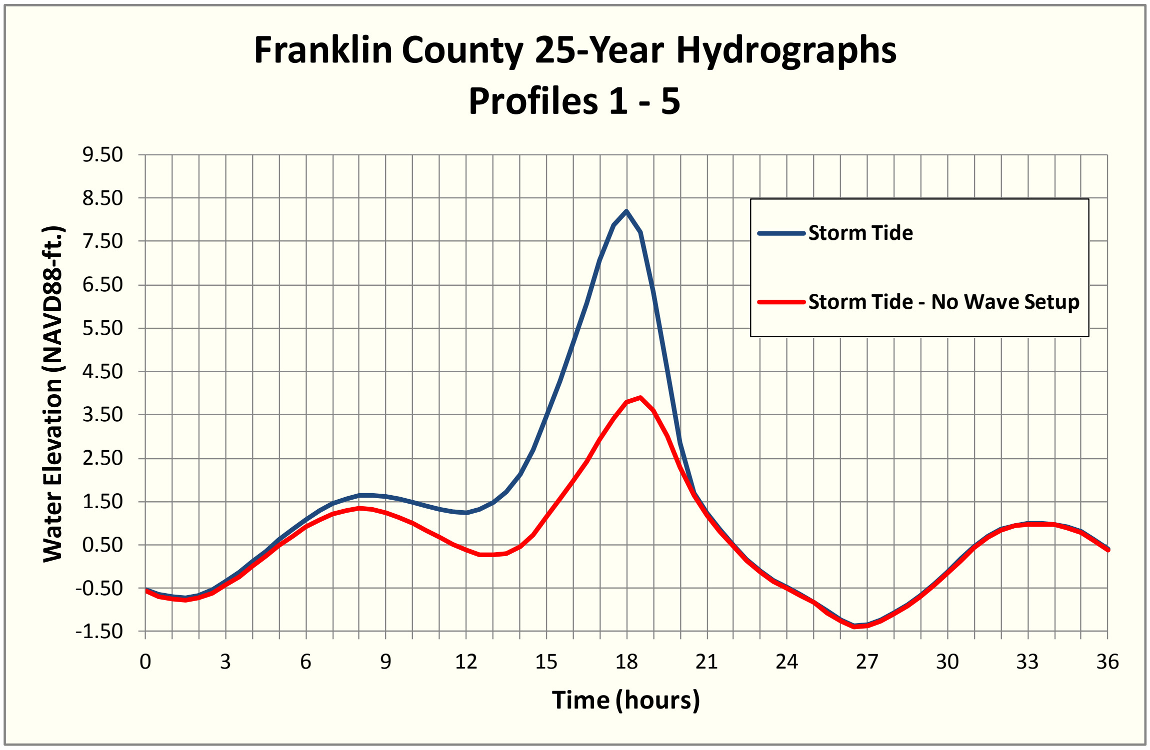
36
Time (hours)
Storm Tide
Storm Tide - No Setup


Franklin County 25-Year Hydrographs
Profiles 1 - 5
Water Elevation (NAVD88-ft.)
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6.50
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3.50
2.50
1.50
0.50
-0.50
-1.50
0
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12
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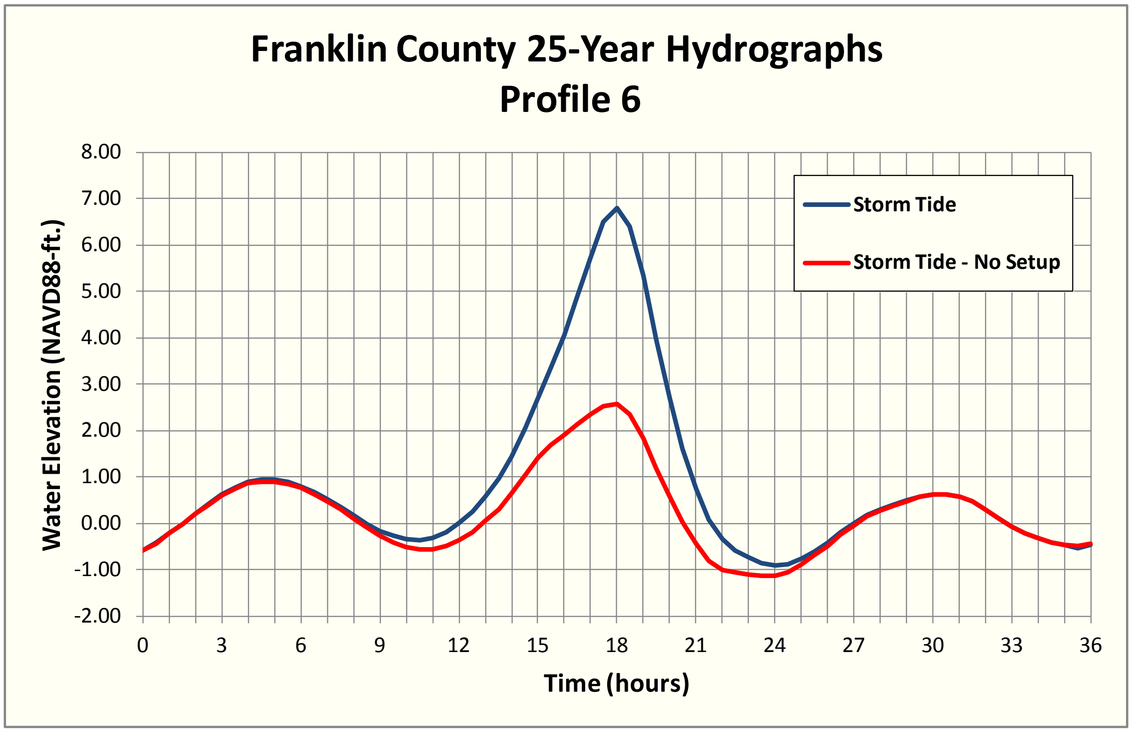
18
21
24
27
30
33
36
Time (hours)
Storm Tide
Storm Tide - No Wave Setup


Franklin County 25-Year Hydrographs
Profile 6
Water Elevation (NAVD88-ft.)
8.00
7.00
6.00
5.00
4.00
3.00
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0.00
-1.00
-2.00
0
3
6
9
12
15
18
21
24
27
30
33
36
Time (hours)
Storm Tide
Storm Tide - No Setup