INCLUSION OF TROPICAL STORMS FOR THE COMBINED TOTAL STORM TIDE FREQUENCY RESTUDY FOR PALM BEACH 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
Florida State University

February 2011

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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 Palm Beach County, Florida” (Reference (1)) was submitted to FDEP in April, 1992. 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 Palm Beach 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 2009. 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 and exiting storms 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 150 n. mi. north and south from the midpoint of the Palm Beach County shoreline. Accordingly, there were 46 landfalling, 31 exiting and 4 alongshore storms occurring in the years 1900 through 2009. 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 736 storms will occur within the 300 n. mi. segment of the coast comprising the study area. Of the 736 storms, 418 will be landfalling, 391 exiting and 36 alongshore storms.

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

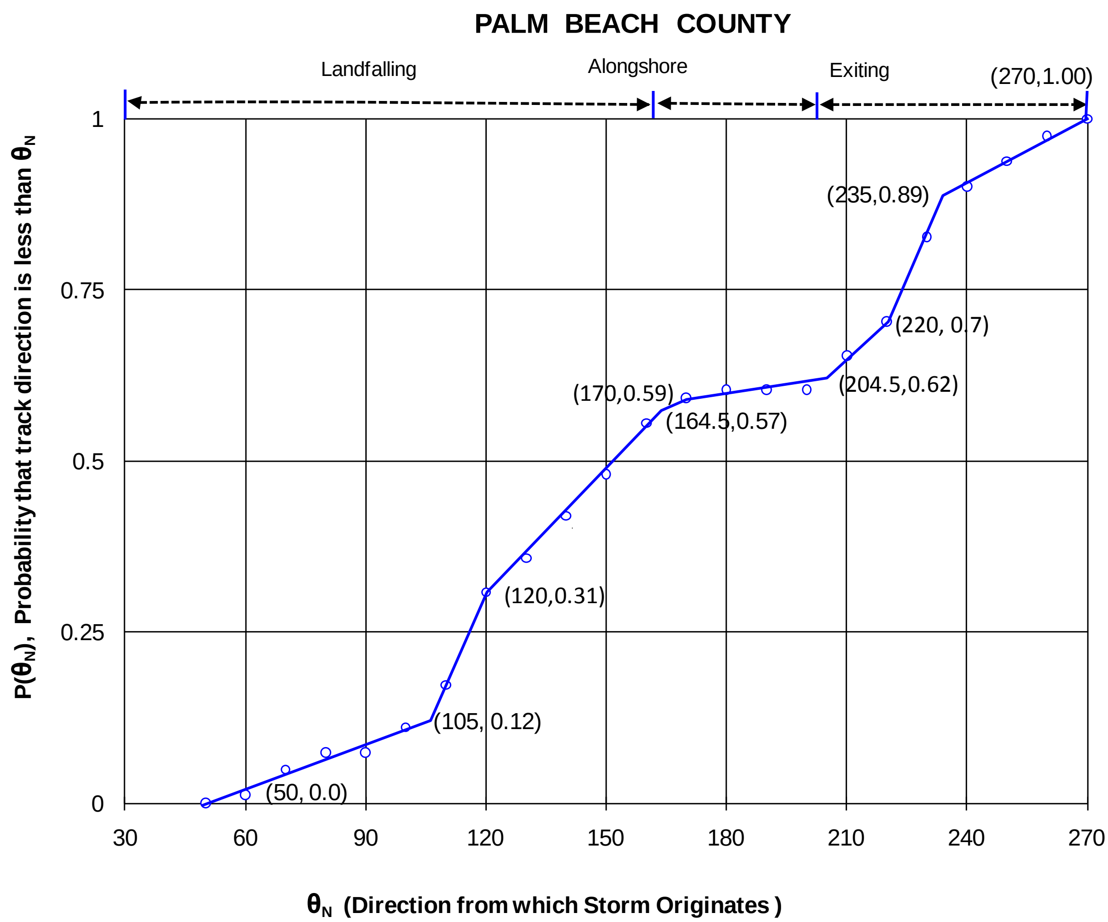


Figure 1 Cumulative Probability Distribution of Storm Track Direction, θ_N

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.

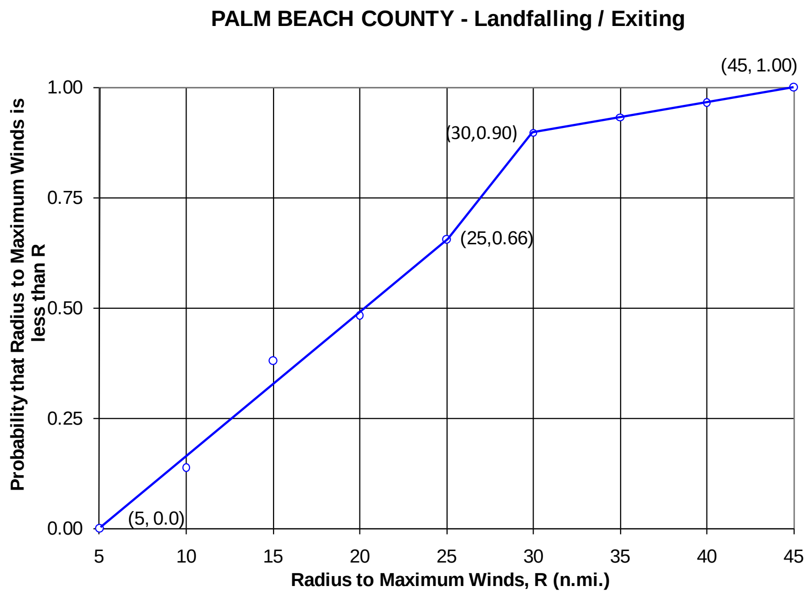


Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Exiting Storms

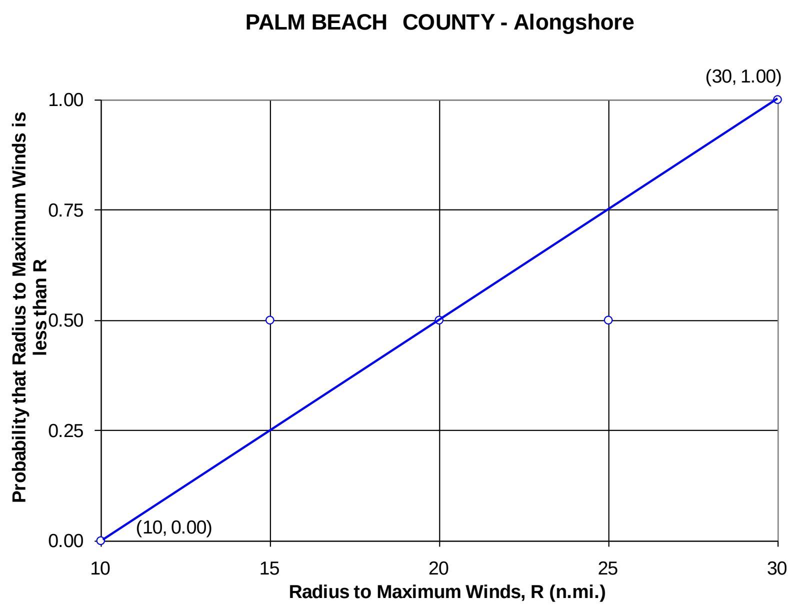


Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

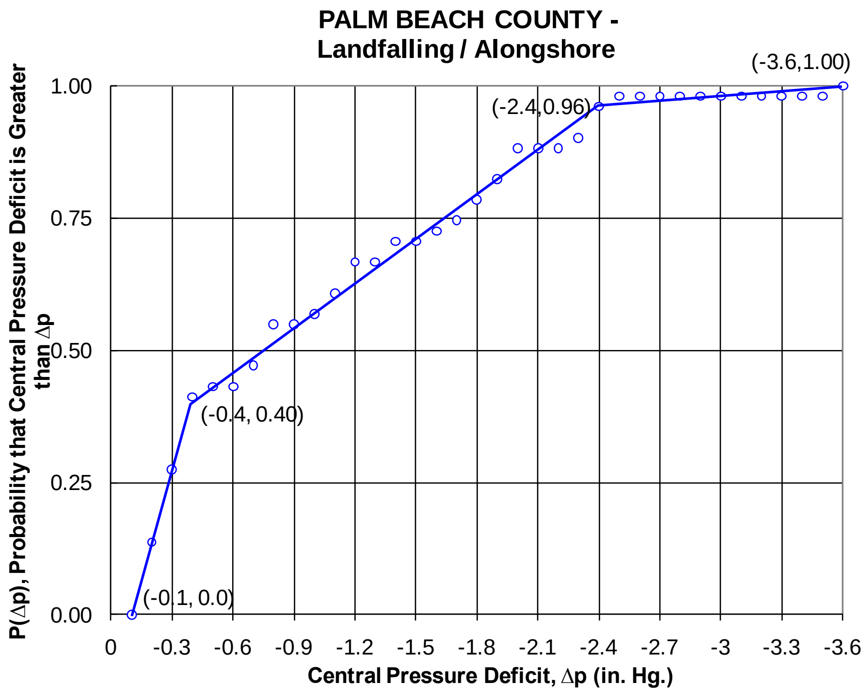


Figure 4 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Landfalling and Alongshore storms

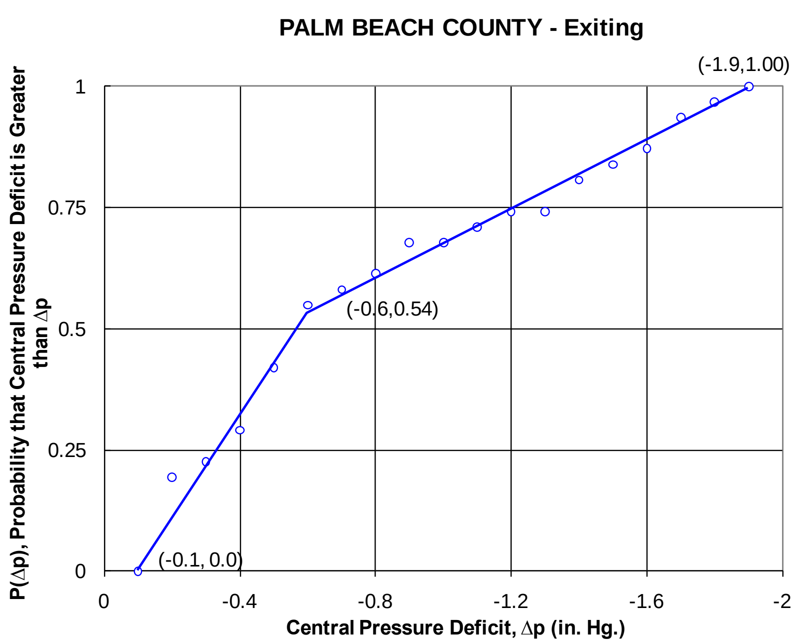


Figure 5 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Exiting storms

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.

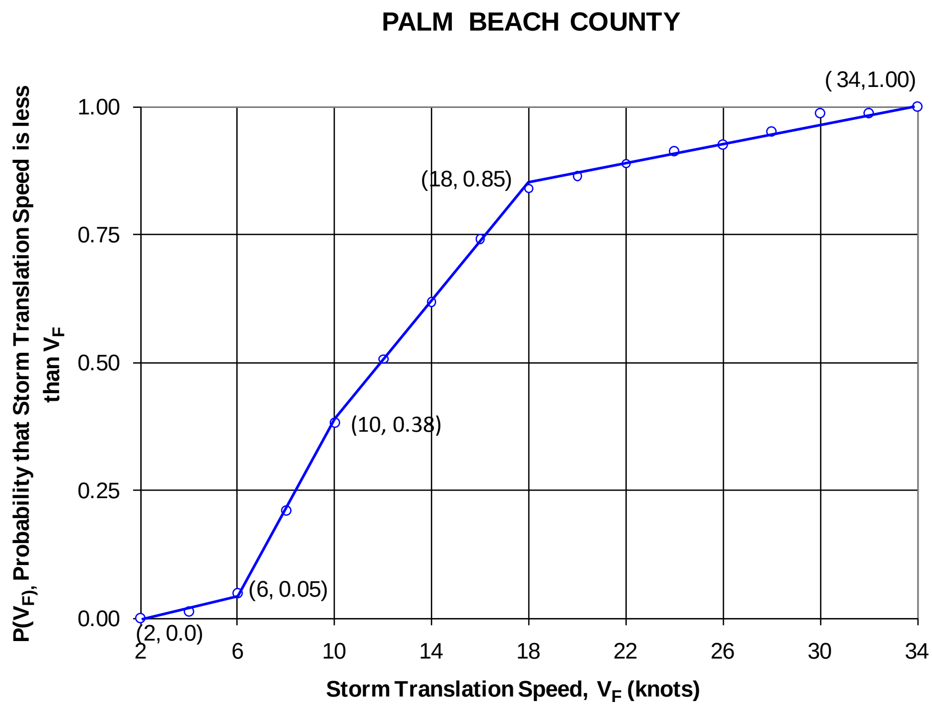


Figure 6 Cumulative Probability Distribution of Translation Speed , V_F

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.

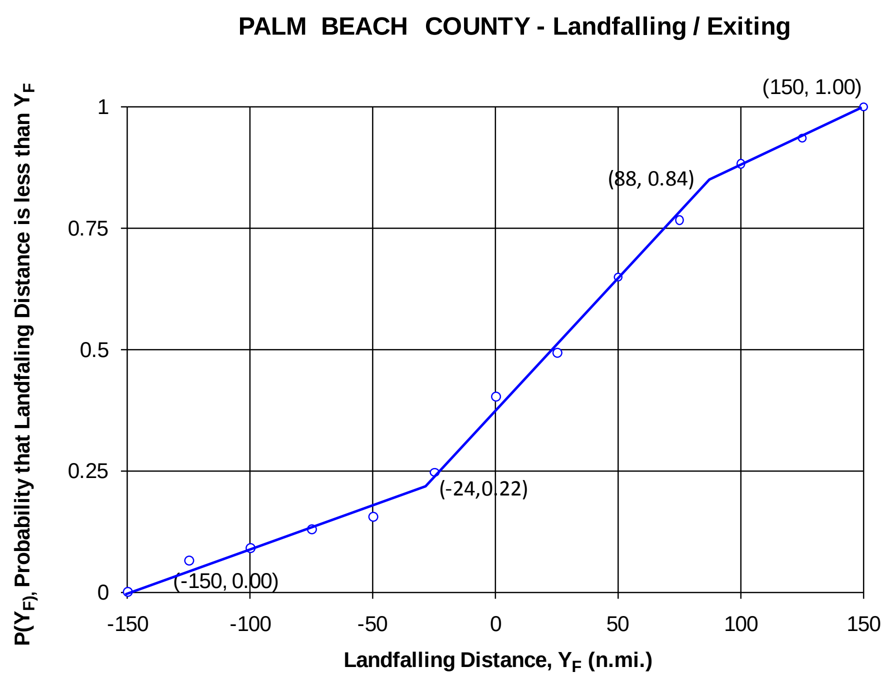


Figure 7 Cumulative Probability Distribution of Landfalling Distance, Y_F, for Landfalling and Exiting Storms

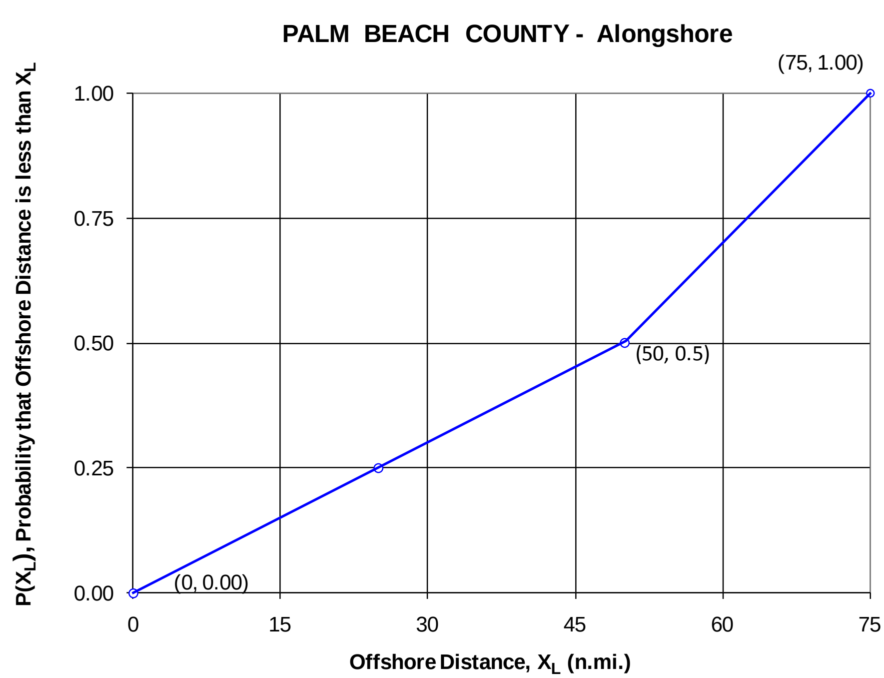


Figure 8 Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

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.

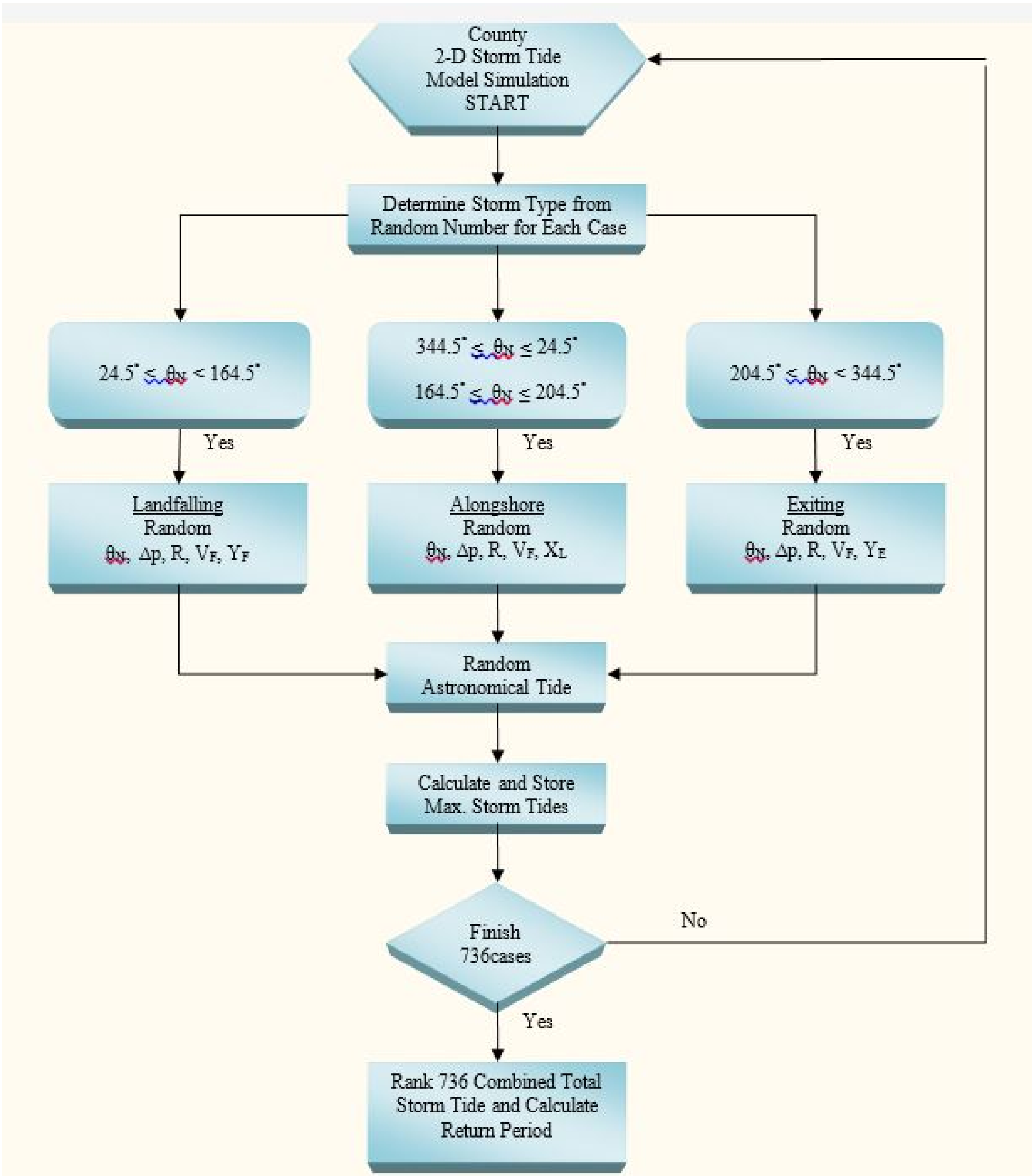


Figure 9 Flow Chart for Two-Dimensional Storm Tide Simulations

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 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 736 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 Lake Worth Pier 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 (736) 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 736 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 = 736 (associated with the lowest water level) the return period would be:

$$TR_{736} = 1000 / 736 = 1.36 \text{ years}$$

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 Palm Beach 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.

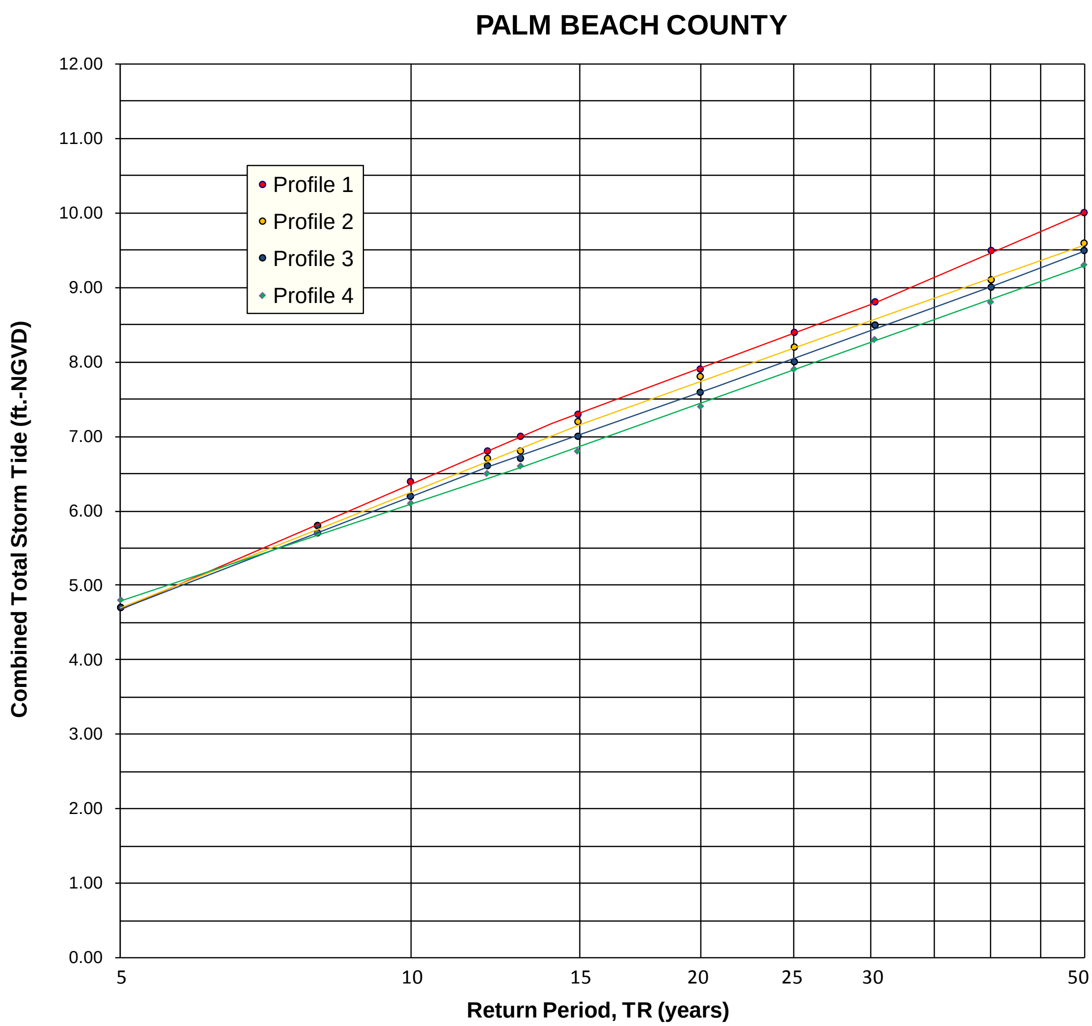


Figure 10 Combined Total Storm Tide Elevation Versus Return Period for Study Area

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

Table I

Combined Total Storm Tide Values for Various Return Periods

Return Period, TR (years)	Profile 1 NAVD88	Profile 1 NGVD29	Profile 2 NAVD88	Profile 2 NGVD29	Profile 3 NAVD88	Profile 3 NGVD29	Profile 4 NAVD88	Profile 4 NGVD29
50	8.5	10.0	8.1	9.6	7.9	9.5	7.7	9.3
30	7.3	8.8	7.0	8.5	6.9	8.5	6.7	8.3
25	6.9	8.4	6.7	8.2	6.4	8.0	6.3	7.9
20	6.4	7.9	6.3	7.8	6.0	7.6	5.8	7.4
15	5.8	7.3	5.7	7.2	5.4	7.0	5.2	6.8
10	4.9	6.4	4.7	6.2	4.6	6.2	4.5	6.1
5	3.2	4.7	3.2	4.7	3.1	4.7	3.2	4.8

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

REFERENCES

1. Dean, R. G., Chiu, T. Y. and Wang, S.Y., “Combined Total Storm Tide Frequency for Palm Beach County, Florida,” Beaches and Shores Resource Center, Florida State University, April 1992.
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.

APPENDIX A

SUMMARY OF HISTORICAL STORMS AFFECTING
PALM BEACH COUNTY

#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	9/9/1903		116	32	6.9	-1.1	43	L
2	10/12/1904		138	89	8.1	-0.74		L
3	6/14/1906		229	48	15.3	-1.01	26	E
4	10/8/1906		219	42	16.8	-1.77	35	E
5	10/6/1909		235	86	22.8	-1.66	22	E
6	7/31/1915		124	-92	5.3	-0.68		L
7	10/14/1924		254	38	14.1	-0.80		E
8	7/22/1926		156	-38	6.6	-1.09	14	L
9	9/11/1926		114	67	9.8	-2.31	19	L
10	10/14/1926		215	101	15.8	-1.36	21	E
11	8/3/1928		144	-24	6.2	-1.07		L
12	9/6/1928		138	-22	8.1	-2.48	28	L
13	9/22/1929		111	103	5.7	-1.92	28	L
14	7/25/1933		111	-43	2.9	-0.74		L
15	8/31/1933		119	-10	16.4	-1.92	13	L
16	10/1/1933		239	115	15.6	-1.66		E
17	8/29/1935		123	125	7.4	-3.58	6	L
18	9/23/1935		205	150	13.1	-1.51		E
19	10/30/1935		64	45	15.9	-1.18	10	L
20	10/3/1941		108	74	16.0	-1.51		L
21	9/12/1945		132	78	12.0	-1.83	12	L
22	9/4/1947		76	16	8.3	-1.95	26	L
23	10/9/1947		222	18	10.7	-0.65	13	E
24	9/18/1948		222	-21	6.7	-1.45	16	E
25	10/3/1948		222	58	17.4	-1.12	16	E
26	8/23/1949		126	-7	12.0	-1.75	23	L
27	10/13/1950	KING	158	60	11.9	-1.36	6	L
28	8/29/1960	DONNA	133	140	7.3	-2.39	24	L
29	8/20/1964	CLEO	161	37	8.4	-1.33	7	L
30	10/8/1964	ISBELL	226	-16	20.0	-1.33	13	E
31	8/27/1965	BETSY	90	93	10.7	-1.75	22	L
32	9/21/1966	INEZ	67	91	7.8	-0.77		L
33	8/25/1979	DAVID	149	-17	10.5	-1.18	27	L
34	8/16/1992	ANDREW	97	69	17.1	-2.25	10	L
35	7/31/1995	ERIN	123	-49	14.8	-0.92		L
36	10/22/1998	MITCH	251	-21	28.3	-0.77		E
37	10/12/1999	IRENE	205	35	9.7	-0.80		E
38	8/25/2004	FRANCES	106	-31	7.4	-1.63	30	L
39	9/13/2004	JEANNE	101	-34	10.9	-1.83	26	L
40	8/23/2005	KATRINA	64	39	6.9	-0.74	8	L
41	10/15/2005	WILMA	227	-22	26.7	-1.86		E
42	8/2/1901		113	22	7.7	-0.24		L
43	9/18/1907		113	72	12.7	-0.14		L
44	6/26/1909		143	37	9.8	-0.31		L
45	8/28/1909		97	11	8.1	-0.31		L

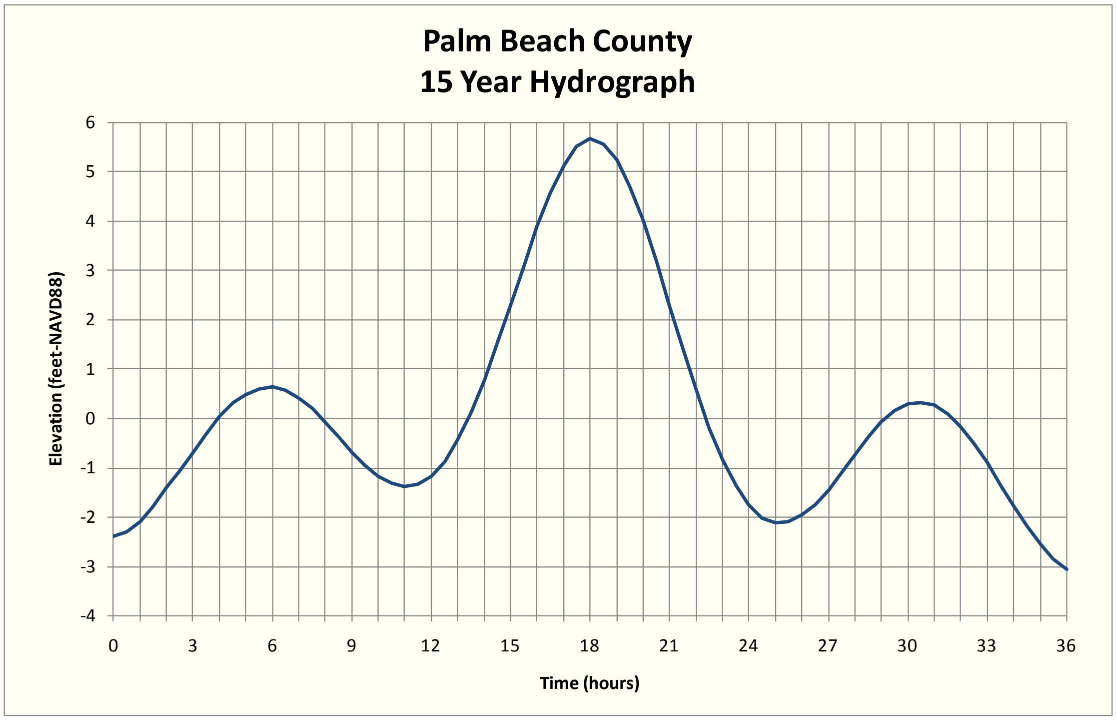
#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
46	9/24/1909		233	-32	10.0	-0.14		E
47	8/23/1910		172	64	19.0	-0.14		A
48	8/21/1916		156	80	8.8	-0.24		L
49	11/11/1916		242	67	32.3	-0.21		E
50	10/15/1921		227	-135	22.0	-0.18		E
51	9/11/1926		53	67	6.7	-0.18		L
52	8/26/1932		116	89	9.0	-0.46		L
53	5/27/1934		207	-105	15.7	-0.18		E
54	6/12/1936		259	56	21.8	-0.18		E
55	7/27/1936		106	95	7.4	-0.38		L
56	8/20/1936		119	-140	16.4	-0.31		L
57	8/24/1937		119	-111	8.2	-0.38		L
58	8/7/1939		119	-33	10.2	-0.64		L
59	10/31/1946		138	6	13.4	-0.24		L
60	9/28/1951	HOW	222	-74	18.8	-0.54		E
61	2/2/1952		218	2	29.1	-0.31		E
62	8/28/1953		265	34	12.6	-0.18		E
63	10/3/1953		204	56	13.5	-0.18		A
64	10/7/1953	HAZEL	234	-96	24.0	-0.56		E
65	10/17/1959	JUDITH	264	-24	28.5	-0.42		E
66	9/26/1970	GRETA	103	147	13.7	-0.24		L
67	9/5/1972	DAWN	222	38	8.1	-0.18		E
68	10/4/1974		165	18	11.0	-0.24		A
69	9/8/1984	DIANA	156	-135	4.4	-0.33		L
70	9/25/1984	ISIDORE	145	-4	11.0	-0.39		L
71	10/9/1987	FLOYD	247	87	15.5	-0.59		E
72	8/21/1988	CHRIS	169	26	14.3	-0.15		A
73	11/17/1988	KEITH	233	-134	16.7	-0.42		E
74	10/15/1991	FABIAN	215	119	15.8	-0.33		E
75	11/8/1994	GORDON	233	-85	16.7	-0.59		E
76	8/22/1995	JERRY	143	-9	7.5	-0.15		L
77	9/19/1999	HARVEY	249	15	27.6	-0.42		E
78	9/11/2001	GABRIELLE	228	-150	13.3	-0.45		E
79	9/2/2004	IVAN	76	38	8.3	-0.12		L
80	10/5/2005	TAMMY	156	-69	11.0	-0.21		L
81	8/24/2006	ERNESTO	151	133	9.2	-0.24	25	L

Landfalling Storms = 46 ; Alongshore Storms = 4 ; Exiting Storms = 31

[1] Values are estimated prior to landfall.

APPENDIX B

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR
PALM BEACH COUNTY


Palm Beach County
15 Year Hydrograph
Elevation (feet-NAVD88)
Time (hours)
6
5
4
3
2
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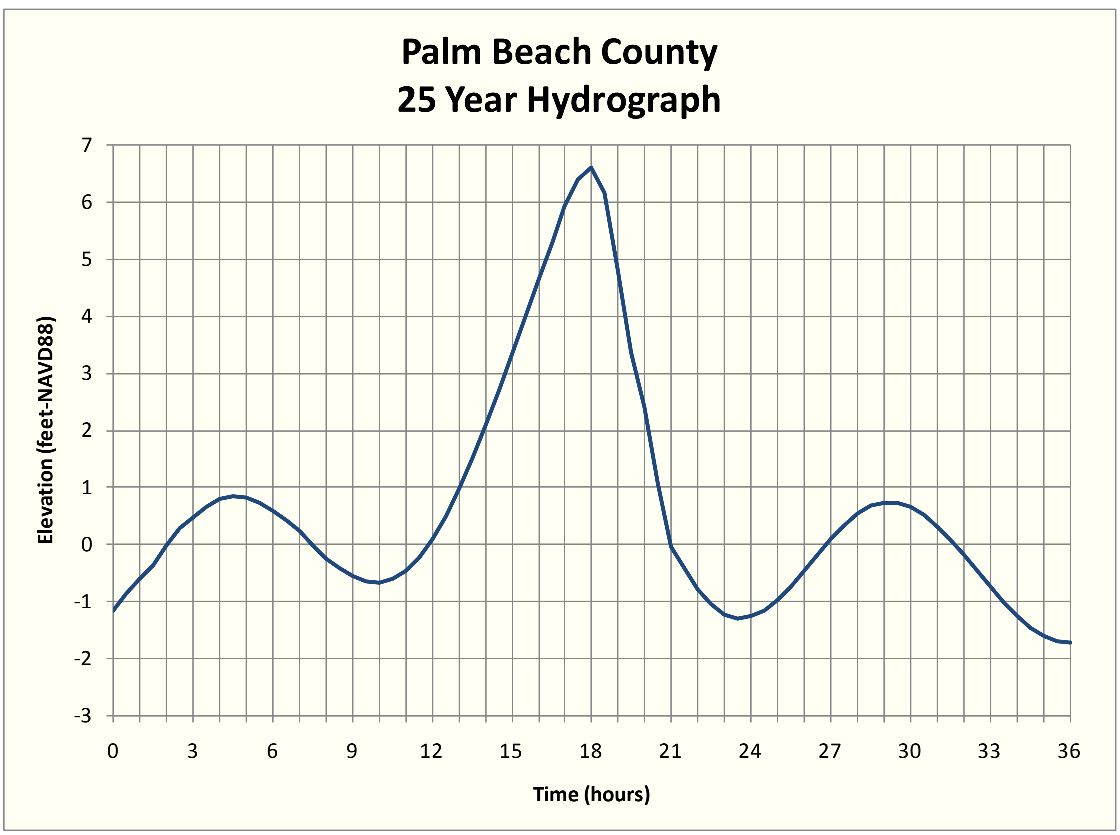
-2
-3
-4
0
3
6
9
12
15
18
21
24
27
30
33
36


Palm Beach County
25 Year Hydrograph
Elevation (feet-NAVD88)
Time (hours)
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