

**INCLUSION OF TROPICAL STORMS  
FOR THE COMBINED TOTAL STORM TIDE FREQUENCY RESTUDY  
FOR INDIAN RIVER COUNTY, FLORIDA**

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



**Submitted 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 Indian River County, Florida” (Reference (1)) was submitted to FDEP in October, 1986. 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 Indian River 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 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 and exiting 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 125 n. mi. north and 125 n. mi. south from the midpoint of the Indian River County shoreline. Accordingly, there were 24 landfalling, 45 exiting and 7 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 697 storms will occur within the 250 n. mi. segment of the coast comprising the study area. Of the 697 storms, 220 will be landfalling, 413 exiting and 64 alongshore storms.

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

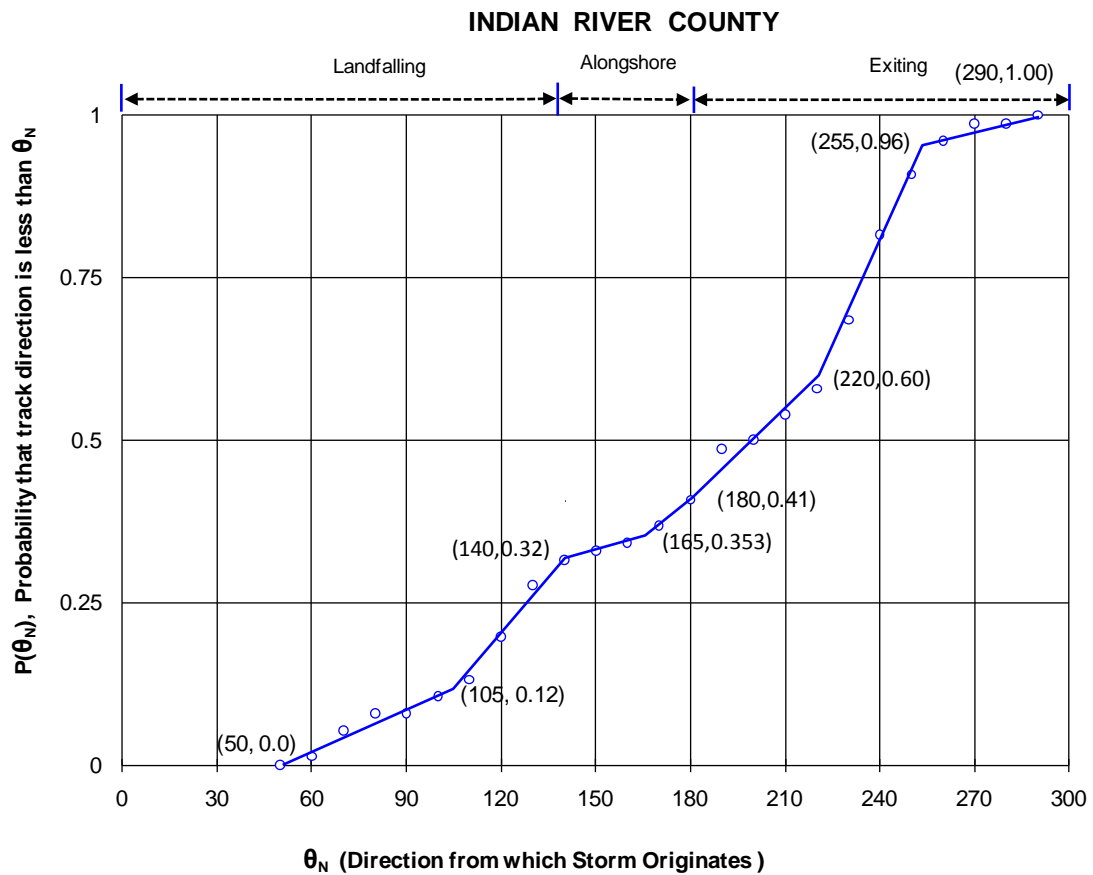


Figure 1 Cumulative Probability Distribution of Storm Track Direction,  $\theta_N$

### 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.

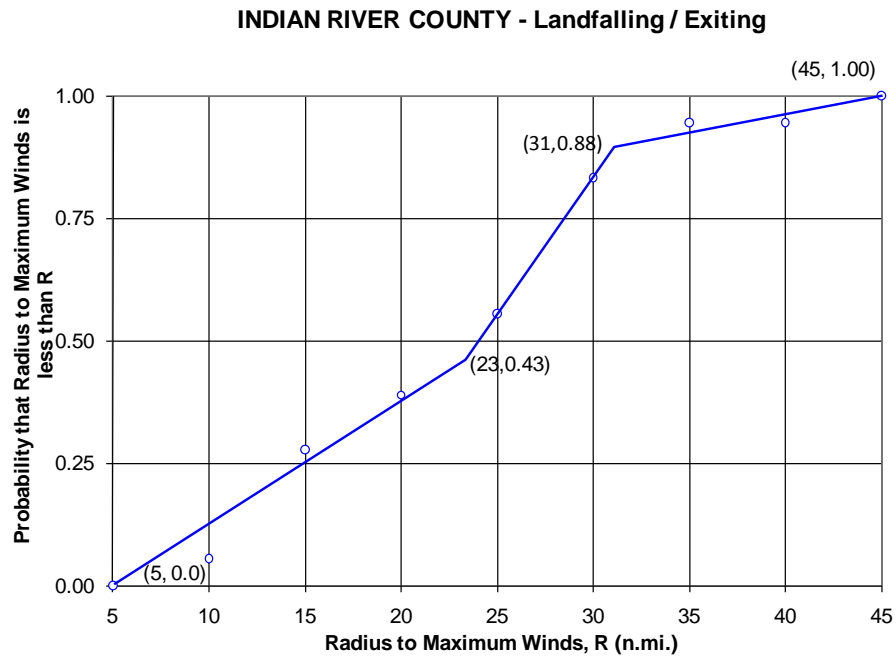


Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Exiting Storms

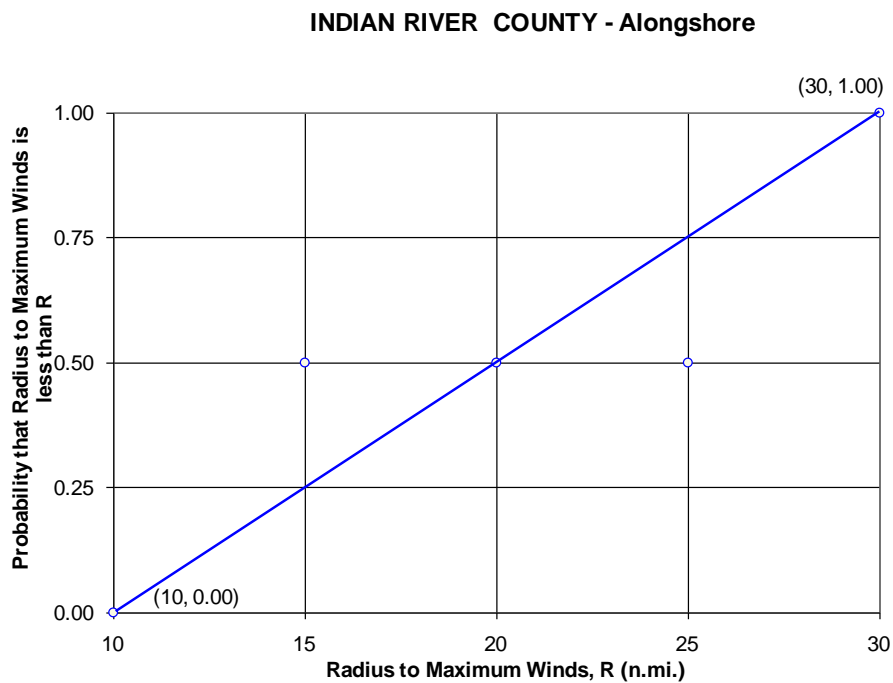


Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

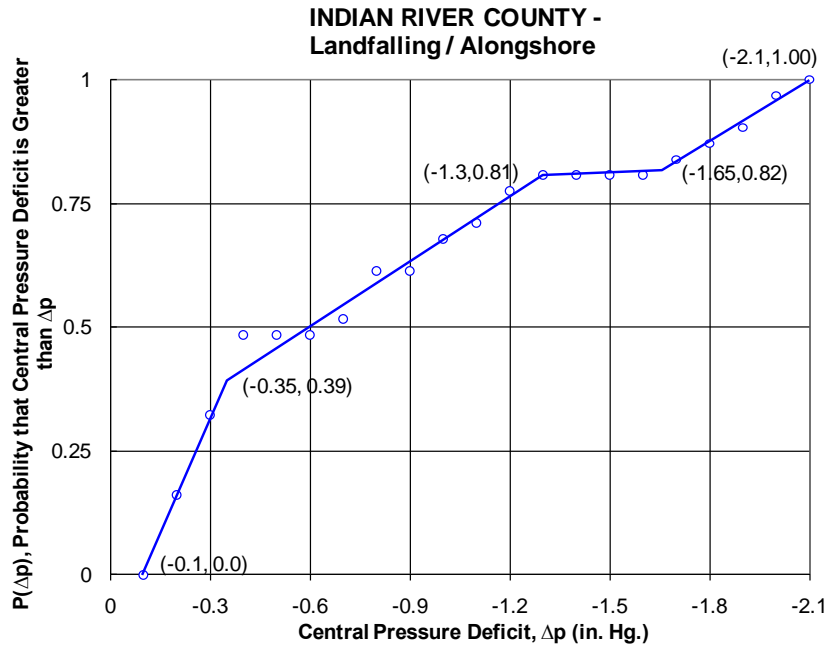


Figure 4 Cumulative Probability Distribution of Central Pressure Deficit,  $\Delta p$  for Landfalling and Alongshore storms

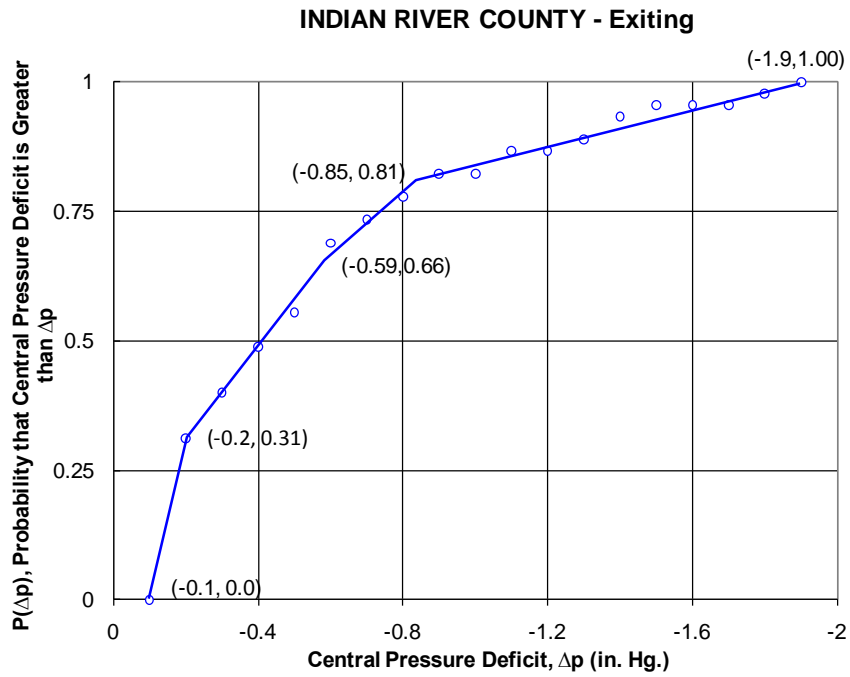


Figure 5 Cumulative Probability Distribution of Central Pressure Deficit,  $\Delta p$  For Exiting storms



## 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.

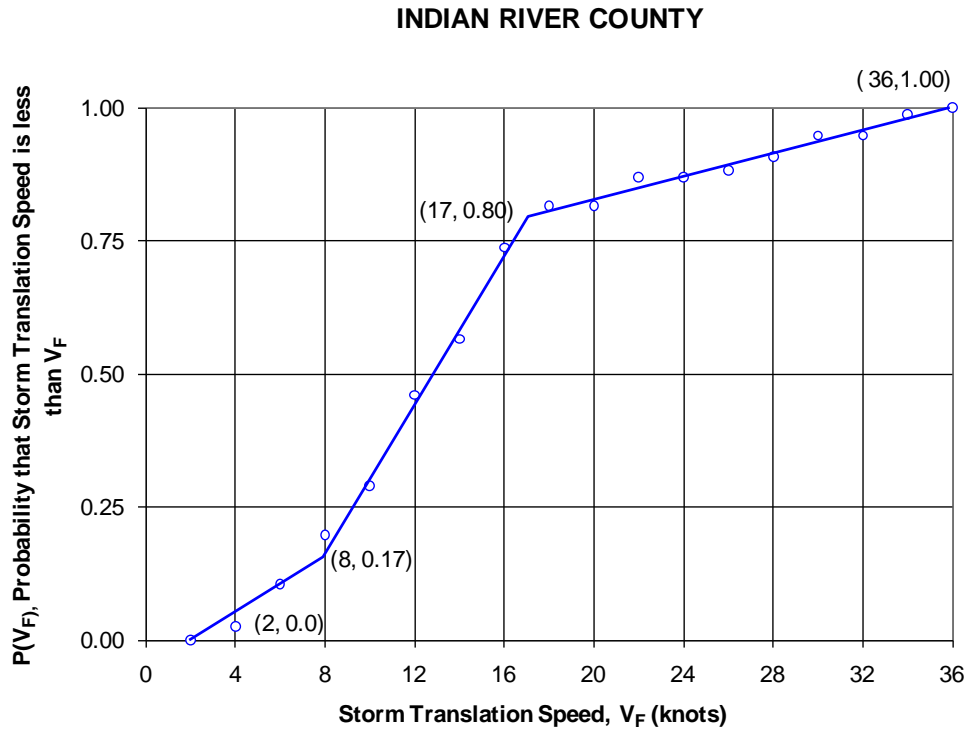


Figure 6 Cumulative Probability Distribution of Translation Speed ,  $V_F$

## 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.

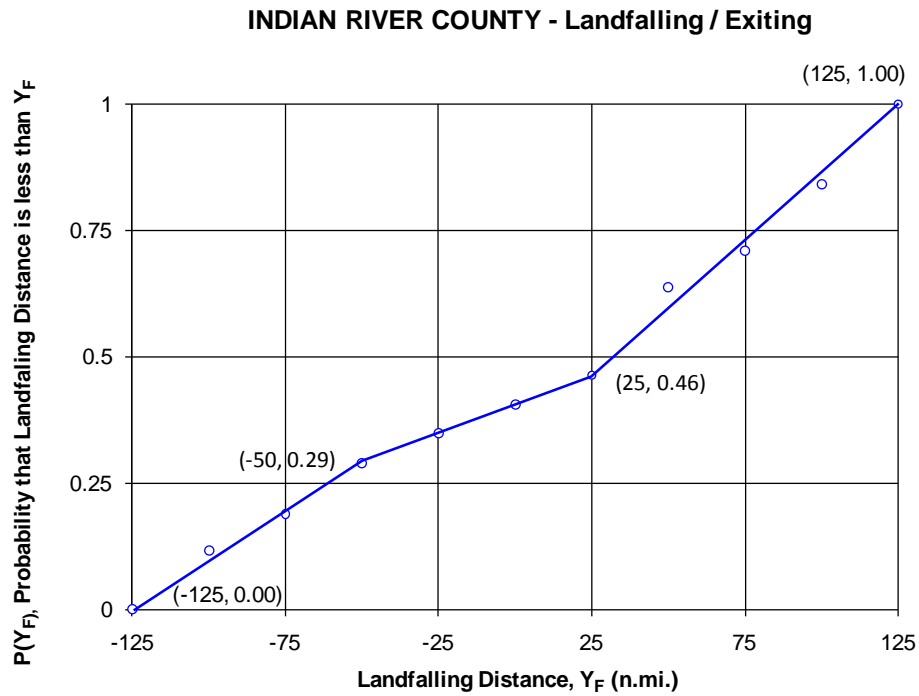


Figure 7 Cumulative Probability Distribution of Landfalling Distance,  $Y_F$ , for Landfalling and Exiting Storms

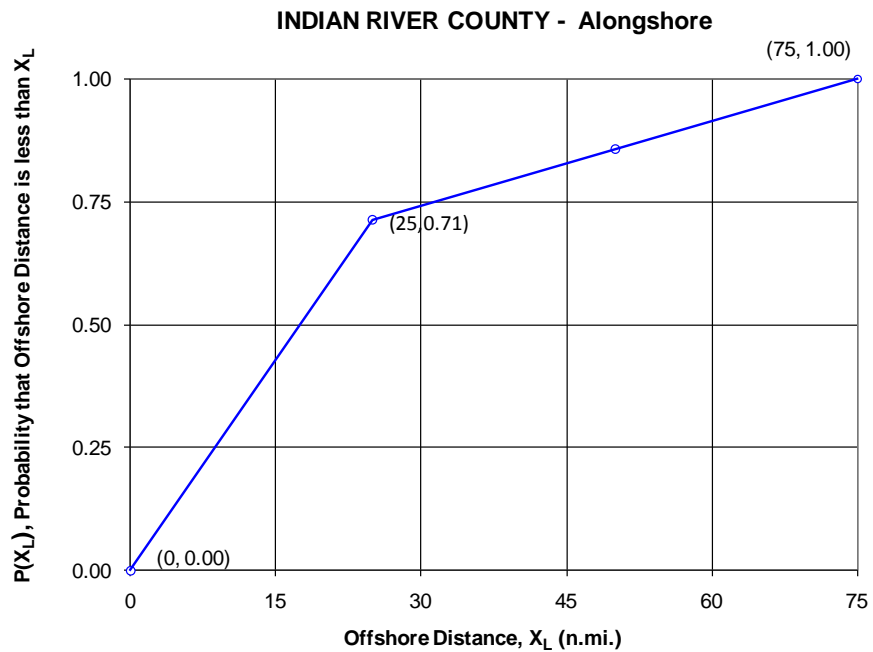


Figure 8 Cumulative Probability Distribution of Offshore Distance,  $X_L$ , for Alongshore Storms

### 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  $\Delta p$ ,  $R$ ,  $V_F$ ,  $\theta_N$  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.

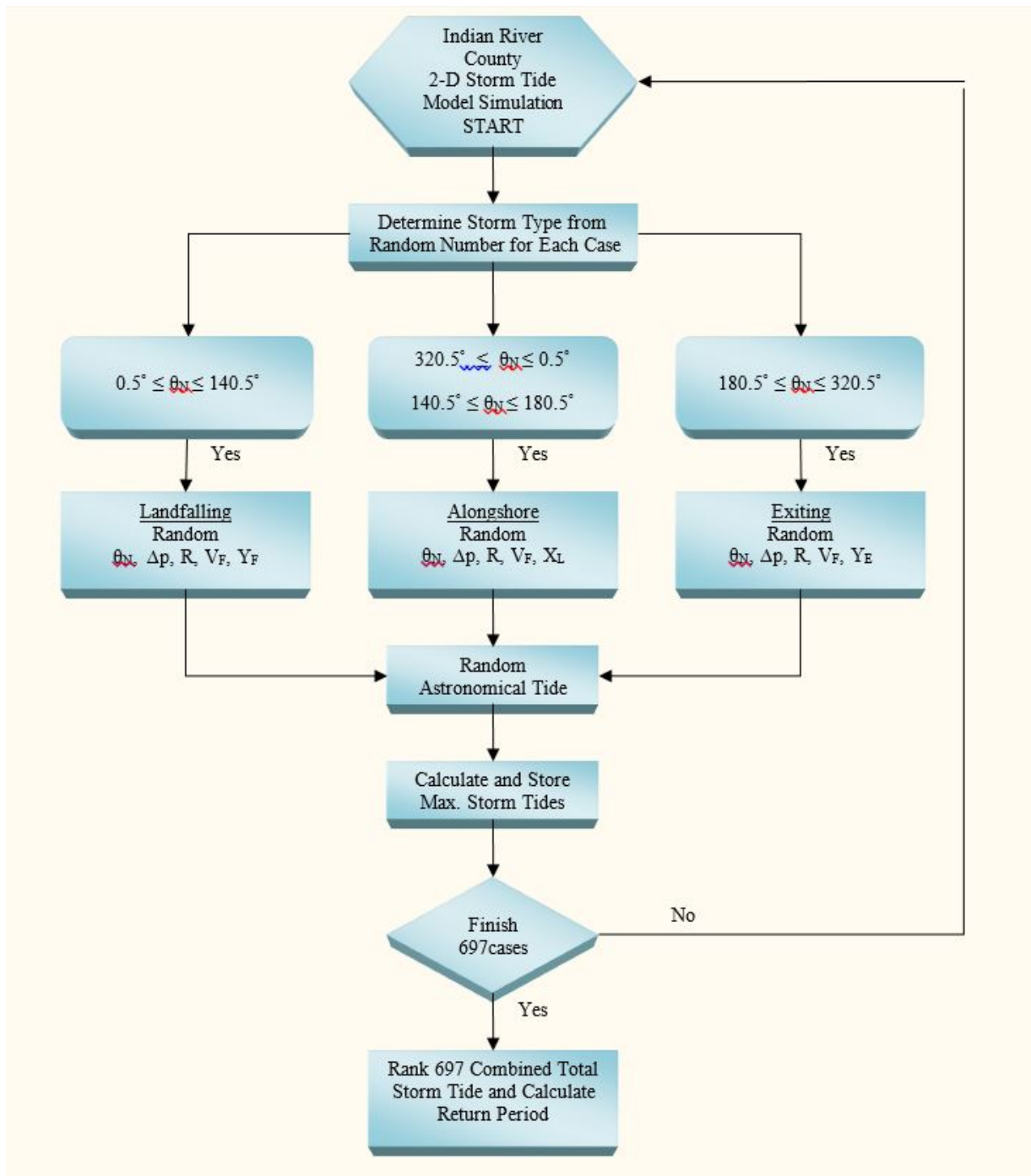


Figure 9 Flow Chart for Two-Dimensional Storm Tide Simulations

### 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 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 697 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,  $\Delta p$ ); Track Direction,  $\theta_N$ ; 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,  $\theta_N$ , and is similar for all other variables.

The approximate piece-wise linear cumulative probability distribution function for track direction,  $\theta_N$ , 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  $\theta_N$  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 Vero Beach 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 (697) 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 697 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 = 697 (associated with the lowest water level) the return period would be:

$$TR_{697} = 1000 / 697 = 1.43 \text{ years}$$

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 Indian River 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.

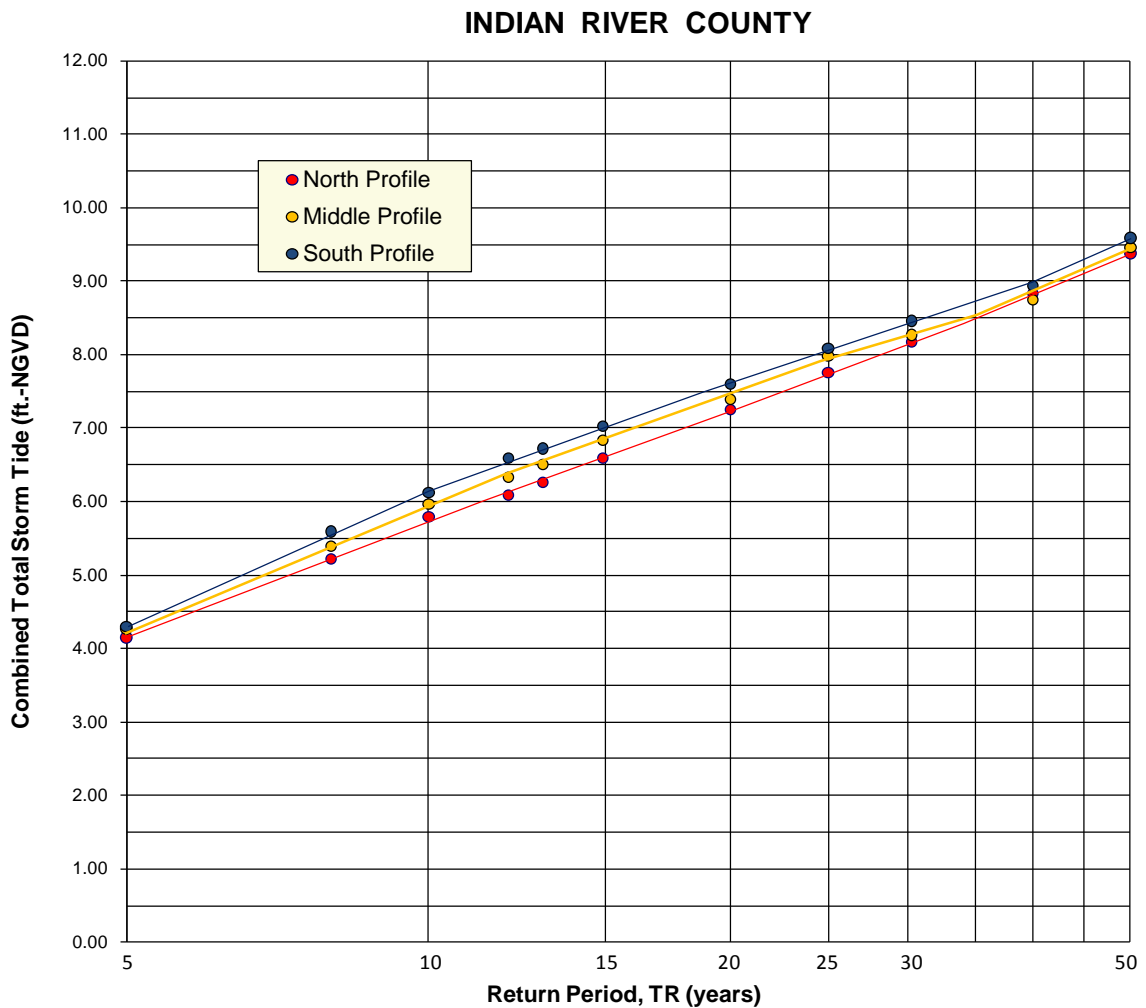


Figure 10 Combined Total Storm Tide Elevation Versus Return Period for Study Area

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

Table I

Combined Total Storm Tide Level\* (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	9.4	8.0	9.5	8.0	9.6	8.1
30	8.2	6.8	8.3	6.8	8.5	7.0
25	7.8	6.4	8.0	6.5	8.1	6.6
20	7.3	5.9	7.4	5.9	7.6	6.1
15	6.6	5.2	6.8	5.3	7.0	5.5
10	5.8	4.4	6.0	4.5	6.1	4.6
5	4.2	2.8	4.3	2.8	4.3	2.8

\*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 Indian River 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. and Chiu, T. Y., "Combined Total Storm Tide Frequency for Indian River County, Florida," Beaches and Shores Resource Center, Florida State University, October 1986.
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  
INDIAN RIVER COUNTY**

#	Date	Name	$\theta_N$ (degrees)	$Y_F$ (n.mi.)	$V_F$ (knots)	$\Delta p$ (in.Hg)	R (n.mi.)	Type
1	9/9/1903		116	114	6.9	-1.1	43	L
2	6/14/1906		229	100	15.3	-1.01	26	E
3	10/8/1906		219	91	16.8	-1.77		E
4	7/31/1915		124	-61	5.3	-0.68		L
5	10/20/1921		248	-84	13.2	-0.74		E
6	10/14/1924		254	103	11.0	-0.80		E
7	11/27/1925		221	-59	13.3	-0.64		E
8	7/22/1926		149	7.6	7.0	-0.97	14	A
9	8/3/1928		138	28	5.3	-1.07		L
10	9/6/1928		120	38	14.2	-2.00	28	L
11	7/25/1933		90	20	3.5	-0.74		L
12	8/31/1933		120	58	14.6	-1.92	13	L
13	10/30/1935		64	105	15.8	-1.18	10	L
14	8/7/1939		120	26	10.1	-0.74		L
15	9/4/1947		76	82	8.2	-1.95	26	L
16	10/9/1947		222	76	10.7	-0.65	13	E
17	9/18/1948		222	49	6.6	-1.45	16	E
18	10/3/1948		233	110	16.6	-1.01	16	E
19	8/23/1949		126	63	12.0	-1.75	23	L
20	8/29/1960	DONNA	210	-112	16.0	-1.30	24	E
21	10/8/1964	ISBELL	225	52	20.0	-1.33	13	E
22	8/25/1979	DAVID	162	1	8.4	-1.21	27	A
23	7/31/1995	ERIN	123	2.2	14.2	-0.92		L
24	10/22/1998	MITCH	251	47	28.0	-0.77		E
25	10/12/1999	IRENE	186	31	8.1	-0.83		E
26	8/9/2004	CHARLEY	200	-110	21.2	-1.27	22	E
27	8/25/2004	FRANCES	106	33.1	7.3	-1.63	30	L
28	9/13/2004	JEANNE	101	30.6	10.8	-1.83	26	L
29	8/23/2005	KATRINA	64	100	6.9	-0.74	8	L
30	10/15/2005	WILMA	227	48	26.5	-1.86		E
31	8/2/1901		113	99	7.7	-0.24		L
32	10/12/1904		251	115	9.4	-0.14		E
33	8/28/1909		97	82	8.0	-0.31		L
34	9/24/1909		233	39.7	10.0	-0.14		E
35	8/23/1910		180	76	9.0	-0.14		A
36	10/3/1912		263	-98	16.1	-0.14		E
37	8/21/1916		181	-68	11.0	-0.14		E
38	11/11/1916		242	123	32.0	-0.21		E
39	9/25/1920		242	-124	34.3	-0.31		E
40	10/15/1921		221	-33	20.0	-0.14		E
41	8/31/1930		230	-103	4.6	-0.18		E
42	5/27/1934		207	-2	15.7	-0.18		E
43	6/12/1936		259	123	21.6	-0.18		E
44	8/20/1936		116	-116	15.8	-0.31		L

#	Date	Name	$\theta_N$ (degrees)	$Y_F$ (n.mi.)	$V_F$ (knots)	$\Delta p$ (in.Hg)	R (n.mi.)	Type
45	7/29/1937		233	-111	13.3	-0.24		E
46	8/24/1937		111	-77	11.4	-0.38		L
47	8/2/1940		57	-117	12.7	-0.18		L
48	10/31/1946		138	89	13.4	-0.24		L
49	9/28/1951	HOW	239	11	15.5	-0.54		E
50	2/2/1952		218	64	29.0	-0.31		E
51	8/28/1953		241	101	14.2	-0.18		E
52	10/7/1953	HAZEL	234	-11	24.0	-0.56		E
53	6/18/1959		240	-56	32.0	-0.14		E
54	10/17/1959	JUDITH	264	43	28.5	-0.42		E
55	8/26/1962	ALMA	183	18	15.0	-0.18		E
56	6/1/1968	ABBY	286	-18	3.7	-0.56		E
57	10/1/1969	JENNY	202	-53	11.9	-0.14		E
58	9/5/1972	DAWN	233	92	10.0	-0.18		E
59	6/24/1974		228	-96	33.1	-0.39		E
60	10/4/1974		171	22	12.1	-0.31		A
61	8/18/1976	DOTTIE	183	47	16.0	-0.21		E
62	8/7/1981	DENNIS	189	-68	11.1	-0.24		E
63	9/25/1984	ISIDORE	119	76	10.9	-0.39		L
64	7/21/1985	BOB	175	1.3	11.0	-0.21		A
65	8/21/1988	CHRIS	169	25	14.2	-0.15		A
66	11/17/1988	KEITH	233	-41	16.6	-0.42		E
67	11/8/1994	GORDON	234	-3	15.3	-0.53		E
68	8/22/1995	JERRY	138	62	7.5	-0.24		L
69	9/19/1999	HARVEY	249	79	27.6	-0.42		E
70	9/11/2001	GABRIELLE	247	-60	5.7	-0.53		E
71	9/1/2002	EDOUARD	69	-106.7	5.6	-0.15		L
72	9/3/2003	HENRI	237	-78	14.8	-0.18		E
73	9/2/2004	IVAN	76	103	8.2	-0.12		L
74	10/5/2005	TAMMY	156	23	11.0	-0.21		A
75	8/24/2006	ERNESTO	192	-42	13.3	-0.39	25	E
76	8/15/2008	FAY	181	-36	4.0	-0.59	33	E

Landfalling Storms = 24 ; Alongshore Storms = 7 ; Exiting Storms = 45

<sup>1</sup> Values are estimated prior to landfall.

**APPENDIX B**

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR  
INDIAN RIVER COUNTY

