

***Inclusion of Tropical Storms for  
the Combined Total Storm Tide Frequency Restudy  
for Duval County, Florida***

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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 Duval County, Florida" (Reference (1)) was submitted to FDEP in July 1991. This study includes 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 Duval 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 2016. 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 75 n. mi. north and 200 n. mi. south from the midpoint of the Duval County shoreline. Accordingly, there were 26 landfalling, 37 exiting and 14 alongshore storms occurring in the years 1900 through 2016. 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 658 storms will occur within the 275 n. mi. segment of the coast comprising the study area. Of the 658 storms, 222 will be landfalling, 316 exiting and 120 alongshore storms.

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

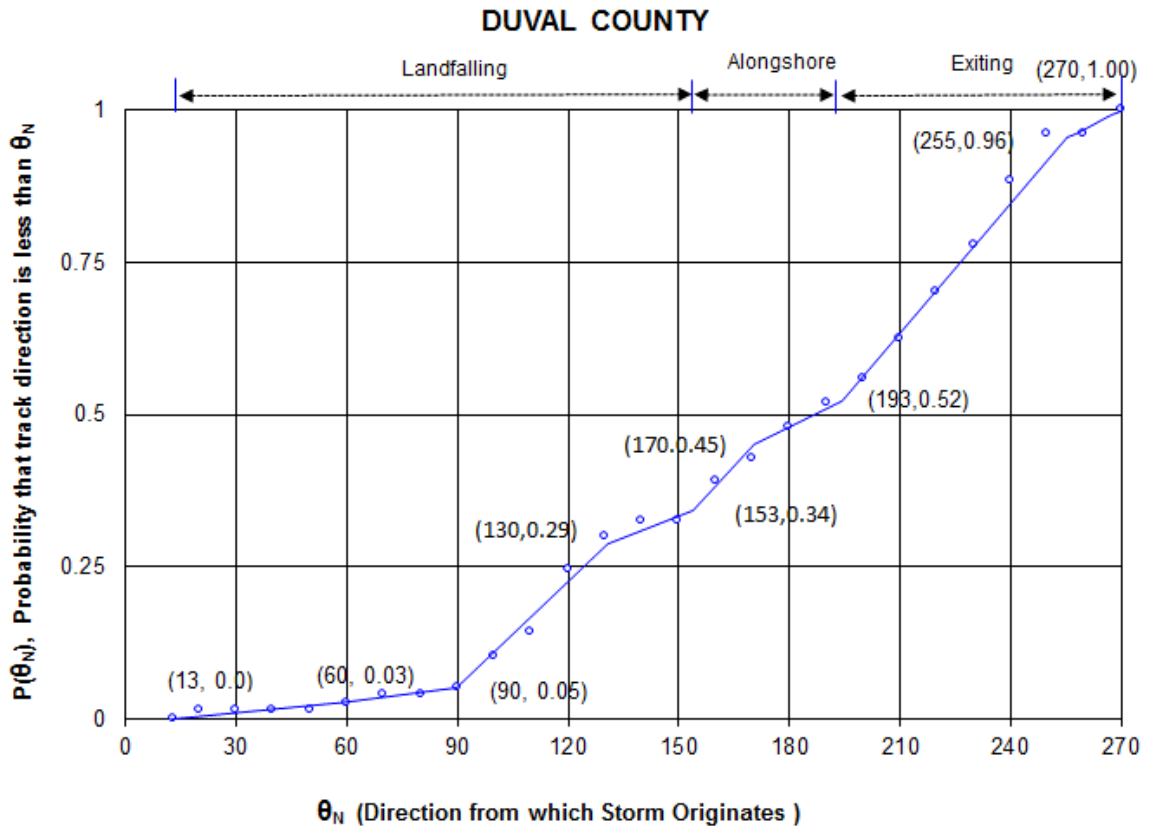


Figure 1: Cumulative Probability Distribution of Storm Track Direction,  $\theta_N$

### 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.

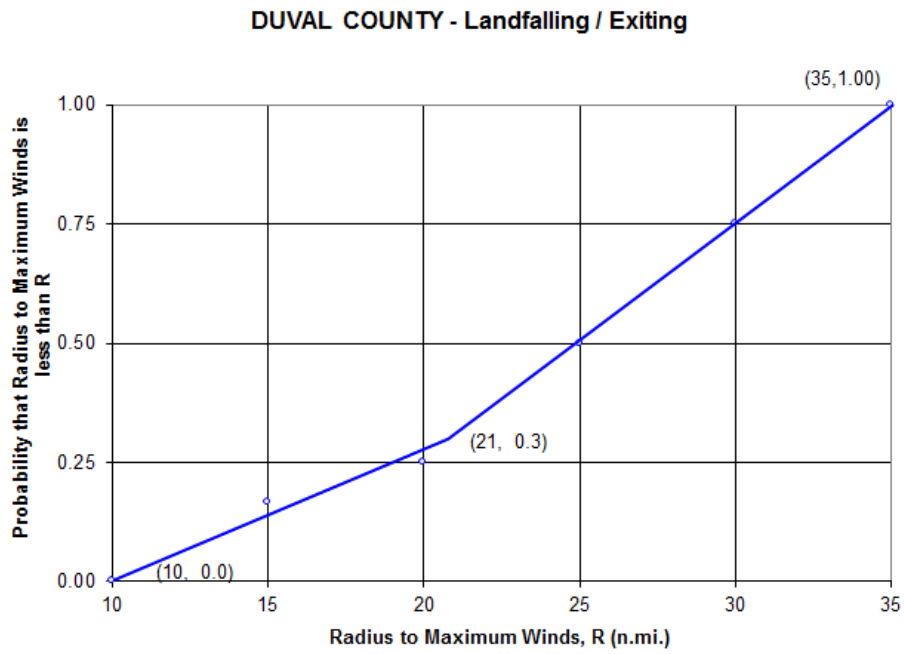


Figure 2: Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Exiting Storms

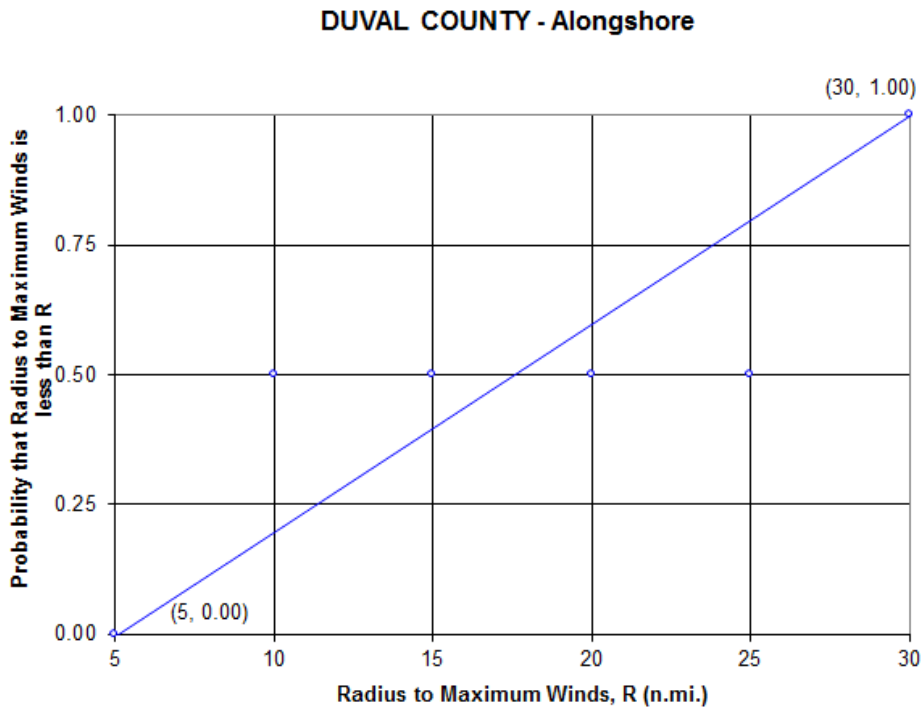


Figure 3: Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

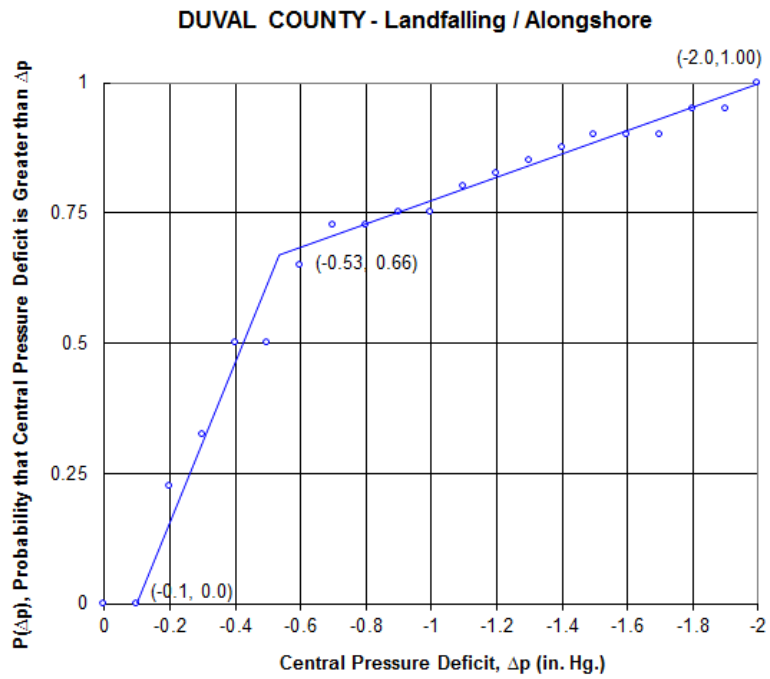


Figure 4: Cumulative Probability Distribution of Central Pressure Deficit,  $\Delta p$  for Landfalling and Alongshore Storms

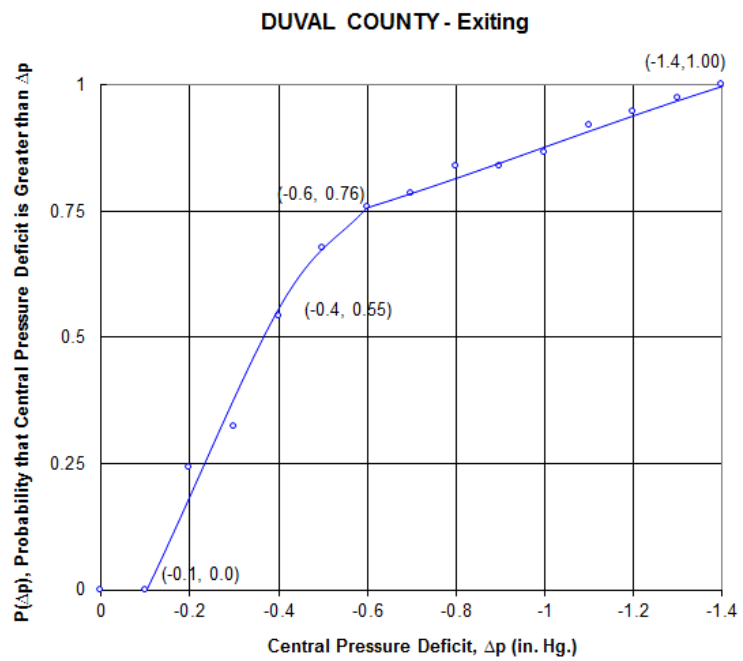


Figure 5: Cumulative Probability Distribution of Central Pressure Deficit,  $\Delta p$  for Exiting Storms



## 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.

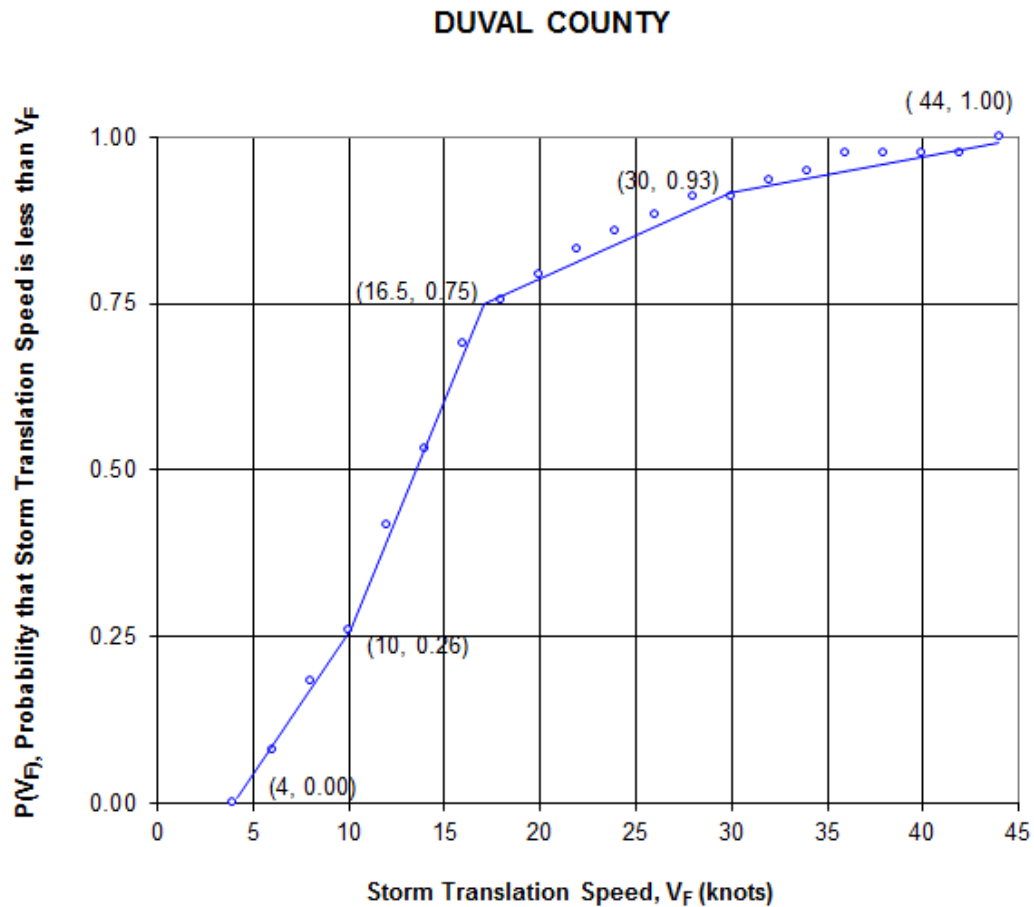


Figure 6: Cumulative Probability Distribution of Translation Speed,  $V_F$

## 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.

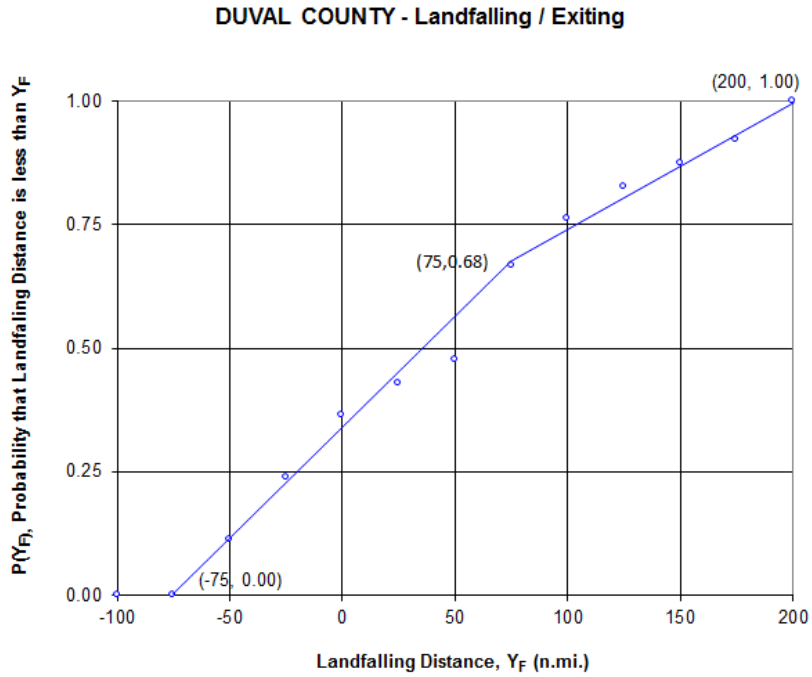


Figure 7: Cumulative Probability Distribution of Landfalling Distance,  $Y_F$ , for Landfalling and Exiting Storms

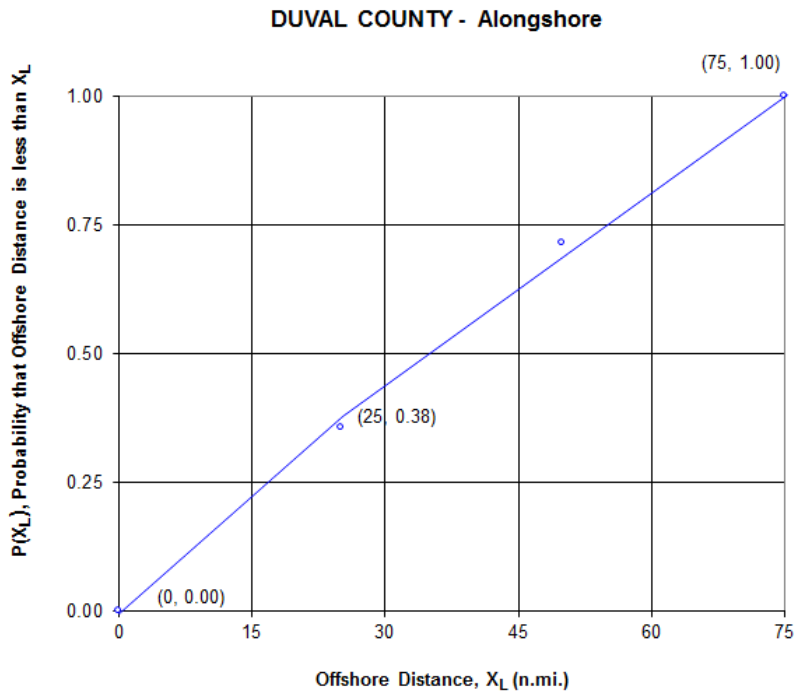


Figure 8: Cumulative Probability Distribution of Offshore Distance,  $X_L$ , for Alongshore Storms

### 3.1 Simulation of a n-Year Sequence of Storm Associated Storm Tides

With the statistical characteristics of historical storms available, the 2-D storm tide model 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.

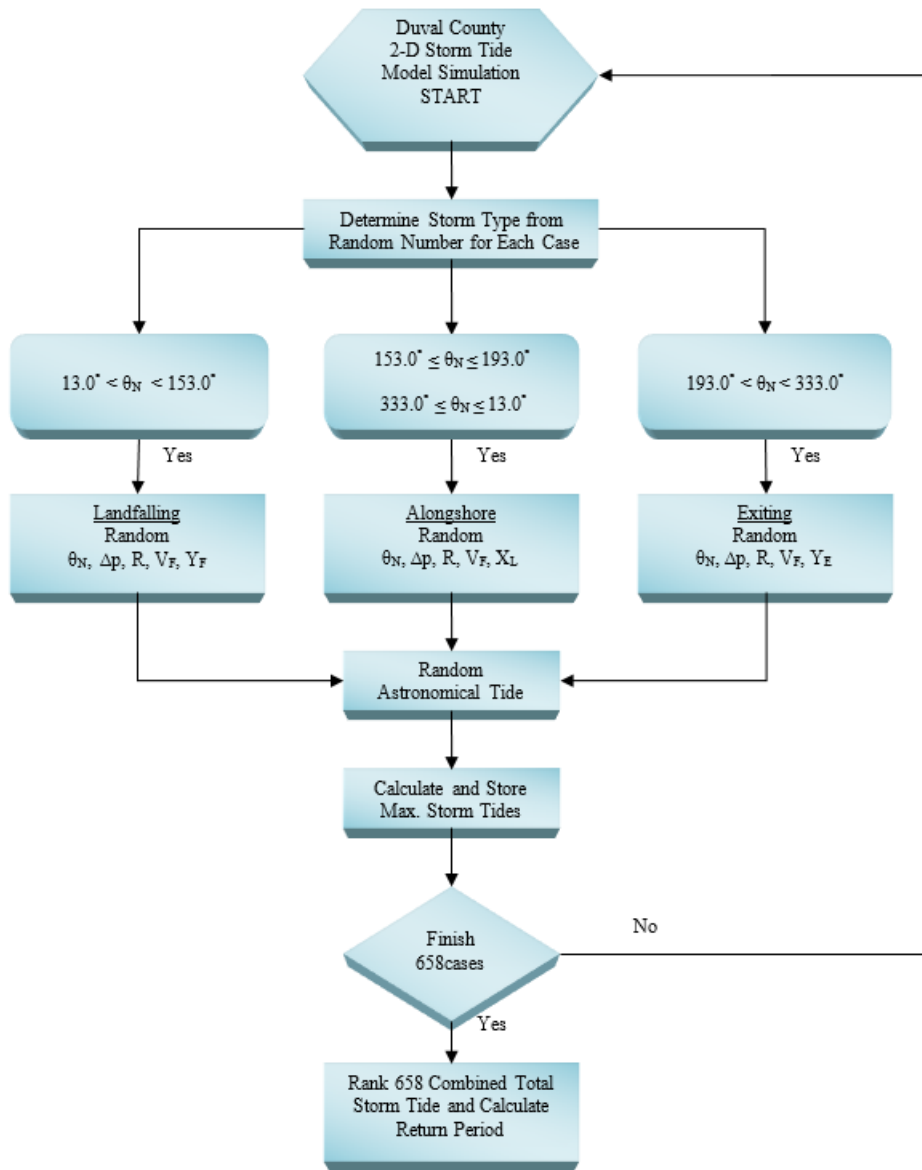


Figure 9: Flow Chart for Two-Dimensional Storm Tide Simulations

### 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 275 n. mi. The simulated storms are given directional distributions according to Figure 1. In an average 1,000-year period, there would be a total of 658 storms.

Selection of Storm Parameters - Each of the five idealized storm parameters, [Radius to Maximum Winds,  $R$ ; Central Pressure,  $P_0$  (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 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  $\theta_N$  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 off Duval 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 (658) 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 658 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 = 658 (associated with the lowest water level) the return period would be:

$$TR_{658} = 1000 / 658 = 1.52 \text{ years}$$

which indicates that the smallest storm tide could be expected to be approximately once every 1.5 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 Duval 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 10. The general locations of three profiles for Duval County are depicted in Figure 11. 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.

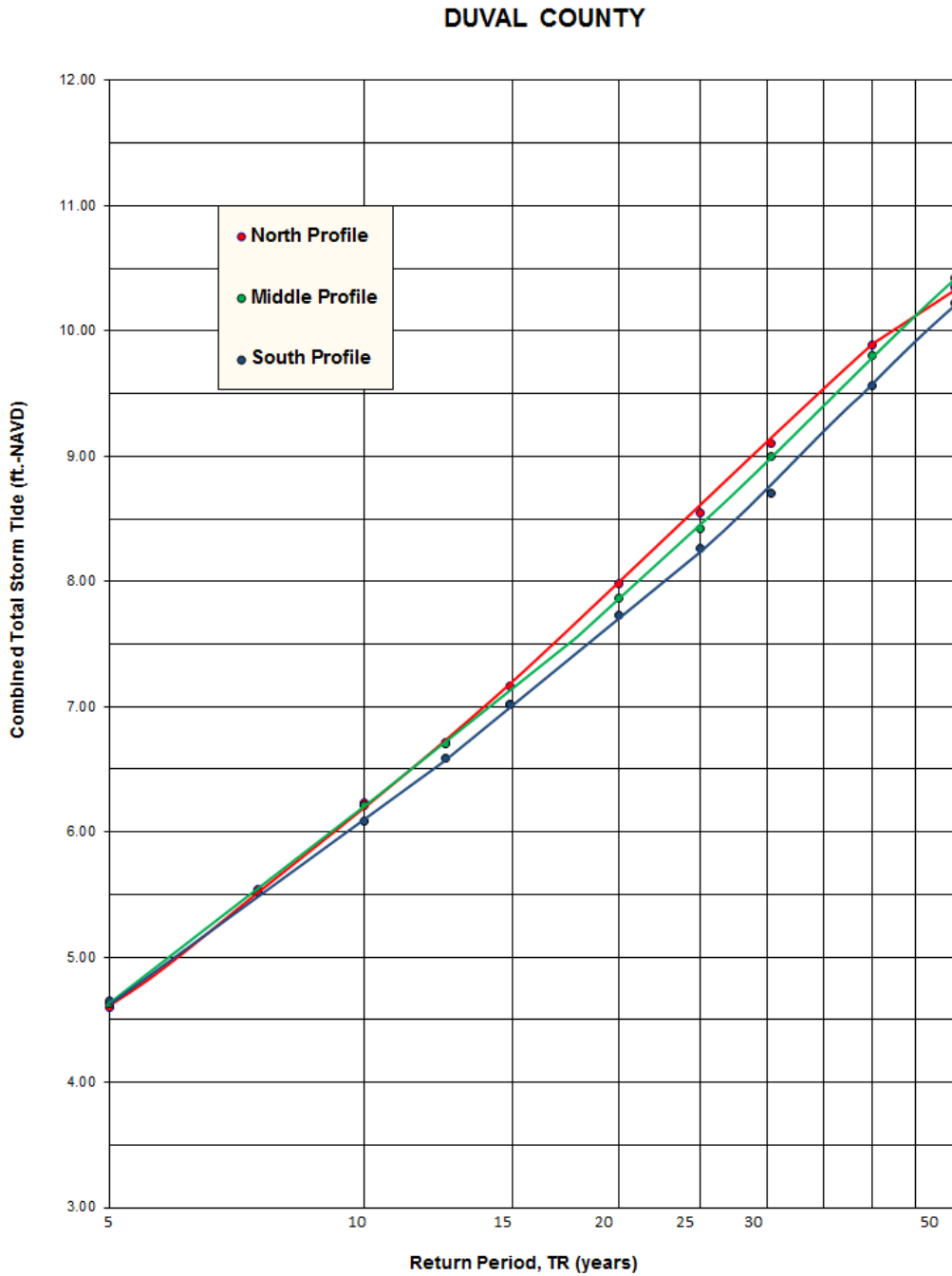


Figure 10: Combined Total Storm Tide Elevation versus Return Period for Study Area

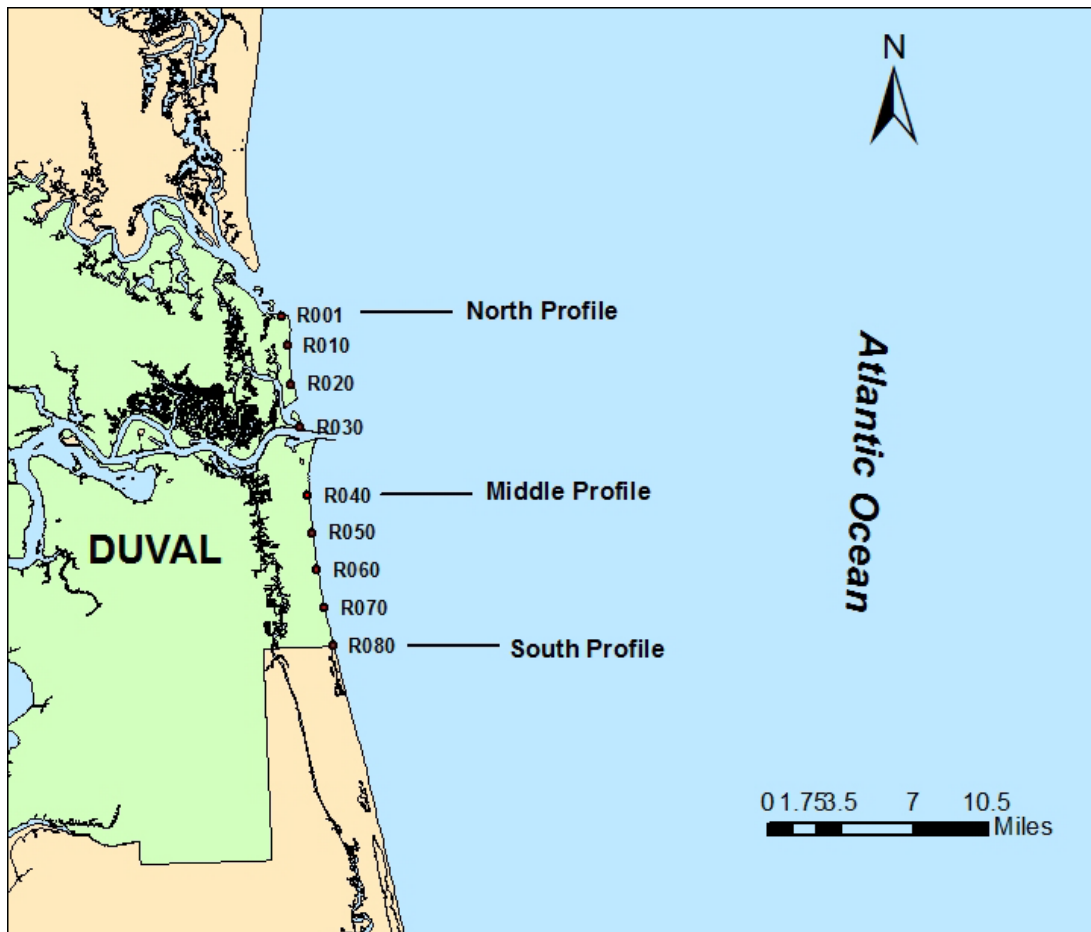


Figure 11: The General Locations of Three Profiles for Duval County



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

Table I: Combined Total Storm Tide Levels\* (ft.-NAVD) for Various Return Periods

Return Period, TR (years)	North Profile	Middle Profile	South Profile
50	10.4	10.4	10.2
30	9.1	9.0	8.7
25	8.6	8.4	8.3
20	8.0	7.9	7.7
15	7.2	7.0	7.0
10	6.2	6.2	6.1
5	4.6	4.6	4.7

\*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 Duval County, Florida," Beaches and Shores Resource Center, Florida State University, July 1991.
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, National Hurricane Center, "Atlantic hurricane database (HURDAT2), 1851 – 2016," <http://www.nhc.noaa.gov/data/#hurdat>

APPENDIX A

Summary of Historical Storms affecting  
Duval County

#	Date	Name	$\theta_N$ (degrees)	$Y_F$ (n.mi.)	$V_F$ (knots)	$\Delta p$ (in.Hg)	R (n.mi.)	Type
1	10/10/1900		231	-16	17.7	-0.18		E
2	10/8/1906		14	16	14.4	-0.38		L
3	6/24/1907		247	-68	25.4	-0.31		E
4	8/28/1909		215	104	12.2	-0.14		E
5	10/9/1910		221	-42	13.2	-0.38		E
6	10/3/1912		263	71	15.7	-0.14		E
7	9/15/1914		113	-13	12.3	-0.54		L
8	7/31/1915		152	77	5.6	-0.68		L
9	5/13/1916		201	-28	11.8	-0.18		E
10	10/2/1916		86	-65	27.7	-0.38		L
11	9/29/1919		103	-51	10.6	-0.24		L
12	9/25/1920		242	53	34.3	-0.31		E
13	10/20/1921		244	89	11.5	-0.97		E
14	11/29/1925		212	110	14.0	-0.74		E
15	7/22/1926		135	65	8.5	-1.12	14	L
16	8/3/1928		111	148	5.6	-1.07		L
17	9/6/1928		207	-10	11.3	-1.07	28	E
18	8/31/1930		221	74	5.3	-0.14		E
19	9/9/1932		241	-40	24.7	-0.31		E
20	8/31/1933		122	184	13.2	-1.92	13	L
21	7/21/1934		52	30	16.3	-0.14		L
22	8/20/1936		117	80	20.2	-0.38		L
23	7/29/1937		227	69	13.1	-0.24		E
24	8/24/1937		106	74	10.8	-0.54		L
25	10/23/1938		232	-64.8	42.6	-0.24		E
26	8/7/1939		115	173	14.3	-0.64		L
27	10/12/1944		194	-29	14.2	-1.10		E
28	6/20/1945		227	50	11.8	-0.38		E
29	9/12/1945		194	12	14.2	-0.77		E
30	10/31/1946		139	176	11.9	-0.18		L
31	10/5/1947		115	-23	21.4	-0.38		L
32	8/23/1949		126	198	11.8	-1.75	23	L
33	8/18/1952	ABLE	159	72	9.6	-1.09		A
34	9/14/1953		231	-30	31.4	-0.24		E
35	10/7/1953	HAZEL	234	173	23.6	-0.56		E
36	6/18/1959		240	121	31.9	-0.14		E
37	7/28/1960	BRENDA	216	-63	14.8	-0.14		E
38	8/29/1960	DONNA	209	71	16.0	-1.30	24	E
39	6/2/1964		235	-3	15.8	-0.14		E
40	8/20/1964	CLEO	180	5	6.0	-0.53	7	A
41	8/28/1964	DORA	99	31	6.2	-1.45	34	L
42	6/1/1968	ABBY	160	0	7.5	-0.38		A
43	10/13/1968	GLADYS	230	38	17.0	-1.04	17	E
44	5/23/1972	ALPHA	98	-35	14.0	-0.65		L

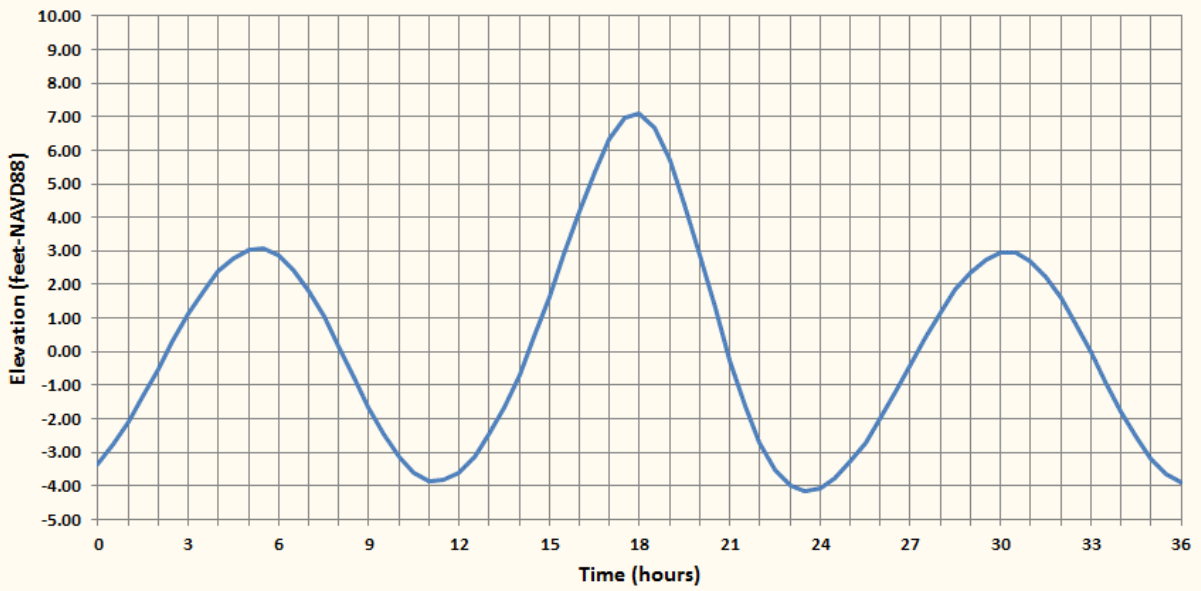
#	Date	Name	$\theta_N$ (degrees)	$Y_F$ (n.mi.)	$V_F$ (knots)	$\Delta p$ (in.Hg)	R (n.mi.)	Type
45	6/24/1974		228	83	32.8	-0.39		E
46	10/24/1975	HALLIE	157	75	4.4	-0.21		A
47	5/21/1976		245	-48	19.1	-0.45		E
48	8/18/1976	DOTTIE	180	70	10.0	-0.50		A
49	6/11/1979		176	74	14	-0.14		A
50	8/25/1979	DAVID	169	23	13.3	-1.27	27	A
51	7/2/1981		175	24	18	-0.14		A
52	8/7/1981	DENNIS	180	29	13.0	-0.30		A
53	6/18/1982		219	10	34.6	-0.42		E
54	9/25/1984	ISIDORE	216	-16	7.4	-0.36		E
55	7/21/1985	BOB	175	46	11.1	-0.27		A
56	10/7/1985	ISABEL	128	-13	6.5	-0.15		L
57	8/21/1988	CHRIS	165	36	26.9	-0.15		A
58	11/17/1988	KEITH	232	142	16.4	-0.42		E
59	8/13/1988		90	-5	6	-0.14		L
60	7/31/1995	ERIN	110	149	15.0	-0.86		L
61	8/22/1995	JERRY	128	166	6.6	-0.24		L
62	10/4/1996	JOSEPHINE	223	-72	42.1	-0.68		E
63	9/11/2001	GABRIELLE	270	109	4.3	-0.53		E
64	9/1/2002	EDOUARD	65	64	5.1	-0.12		L
65	9/20/2002	KYLE	153	39	10.4	-0.12		A
66	9/3/2003	HENRI	237	99	14.5	-0.18		E
67	8/9/2004	CHARLEY	199	80	21.2	-1.27	22	E
68	8/25/2004	FRANCES	115	175	9.5	-1.30	30	L
69	9/13/2004	JEANNE	115	178	9.5	-1.77	26	L
70	10/5/2005	TAMMY	154	1	12.0	-0.36		A
71	8/24/2006	ERNESTO	200	66	12.8	-0.42	25	E
72	5/31/2007	BARRY	200	-45	18.1	-0.36		E
73	8/15/2008	FAY	108	66	6.4	-0.56	33	L
74	5/25/2012	BERYL	99	12	9	-0.59		L
75	6/23/2012	DEBBY	270	53	10.4	-0.45		E
76	6/5/2013	ANDREA	217	-63	22.7	-0.59		E
77	9/28/2016	MATTHEW	176	43	8.7	-1.95		A

Landfalling Storms = 26; Alongshore Storms = 14; Exiting Storms = 37

APPENDIX B

Computed 15 and 25 Year Hydrographs for  
Duval County

**Duval County  
15-Year Hydrograph**



**Duval County  
25-Year Hydrograph**

