INCLUSION OF TROPICAL STORMS
FOR THE COMBINED TOTAL STORM TIDE FREQUENCY RESTUDY
FOR ST. JOHNS COUNTY, FLORIDA

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 St. Johns County, Florida" (Reference (1)) was submitted to FDEP in June 1987. 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 St. Johns 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 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 100 n. mi. north and 200 n. mi. south from the midpoint of the St. Johns County shoreline. Accordingly, there were 26 landfalling, 42 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 725 storms will occur within the 300 n. mi. segment of the coast comprising the study area. Of the 725 storms, 239 will be landfalling, 385 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.
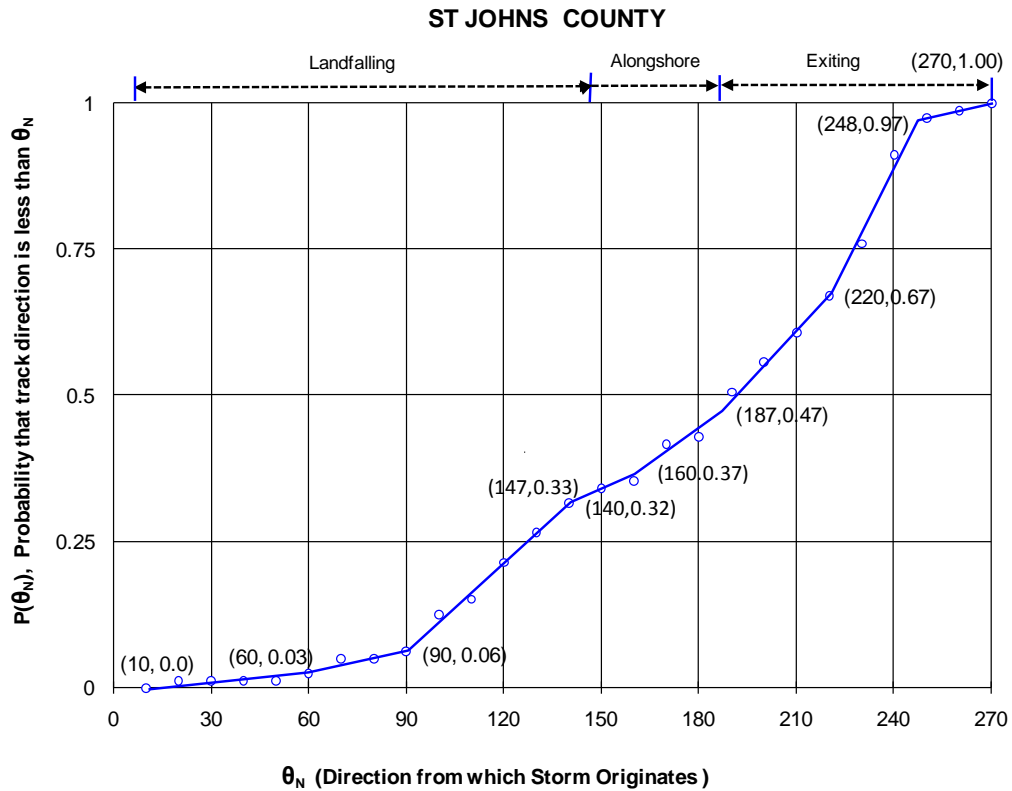
Figure 1 Cumulative Probability Distribution of Storm Track Direction, θ_N

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.

ST JOHNS COUNTY - Landfalling / Exiting
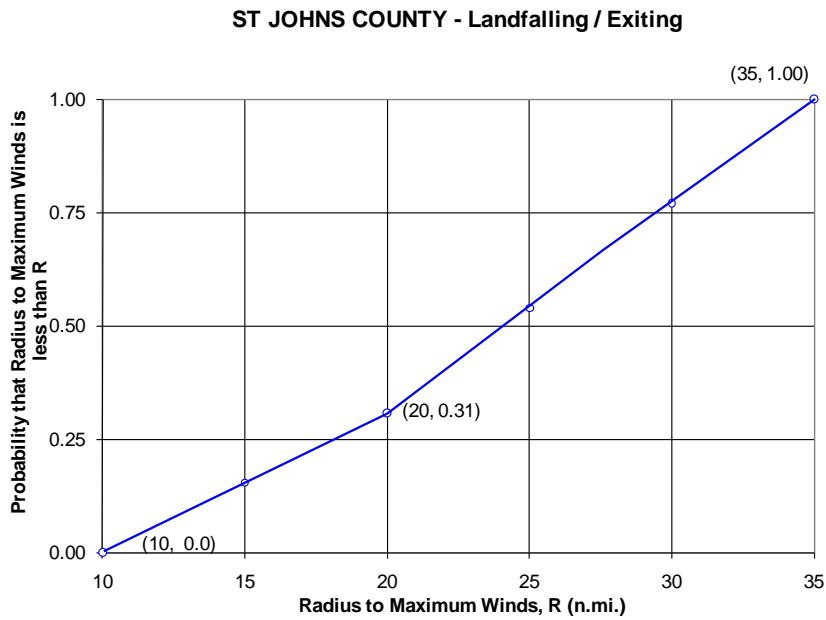
Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Exiting Storms

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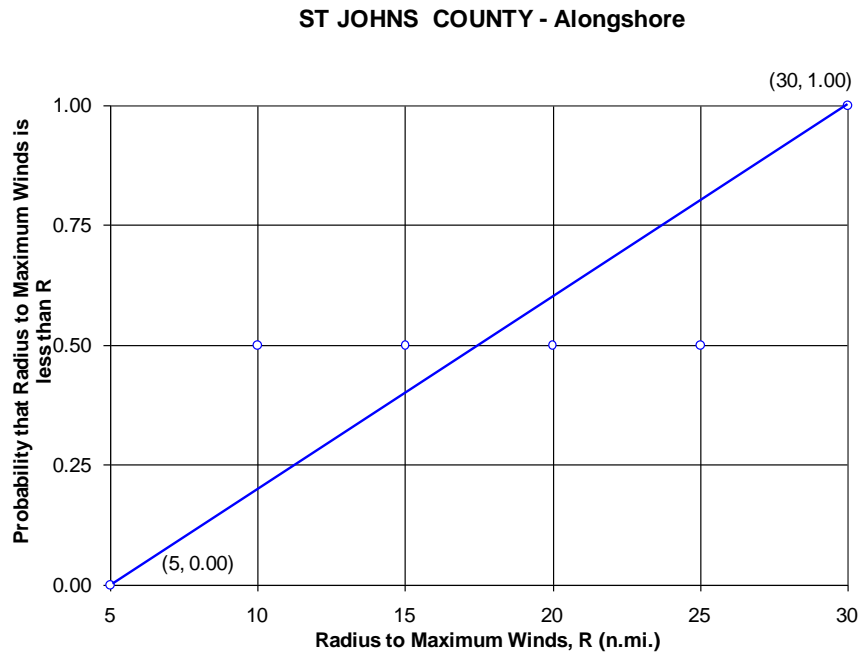
Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms

ST JOHNS COUNTY - Landfalling / Alongshore
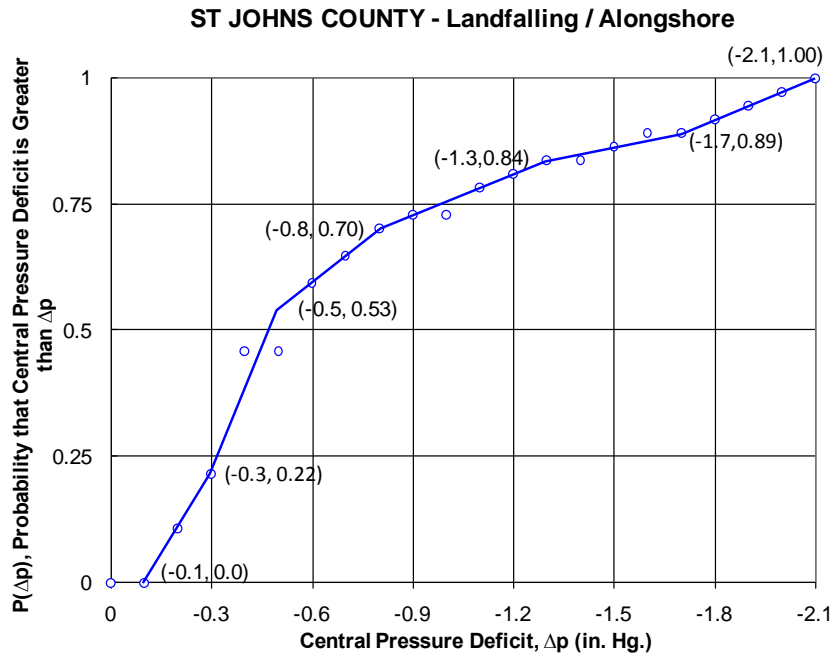
Figure 4 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Landfalling and Alongshore storms

ST JOHNS COUNTY - Exiting
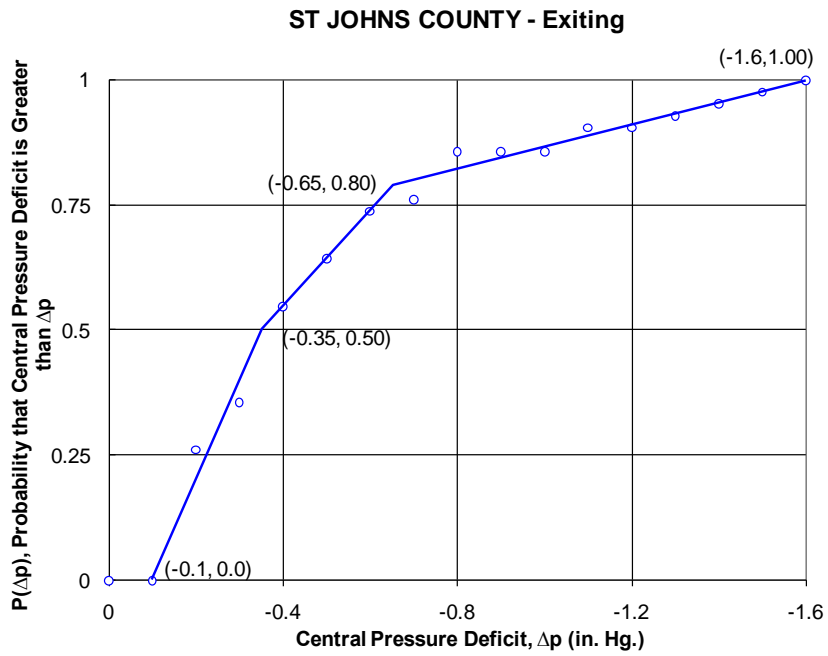
Figure 5 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Exiting storms

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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.

ST JOHNS   COUNTY
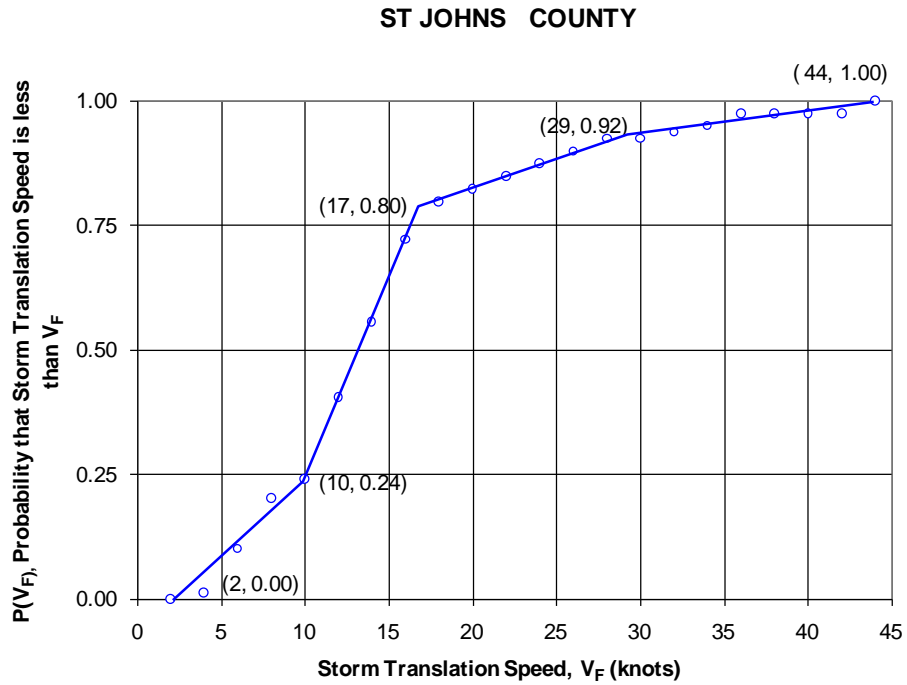
Figure 6 Cumulative Probability Distribution of Translation Speed , V_F

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.

ST JOHNS COUNTY - Landfalling / Exiting

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

ST JOHNS COUNTY - Alongshore
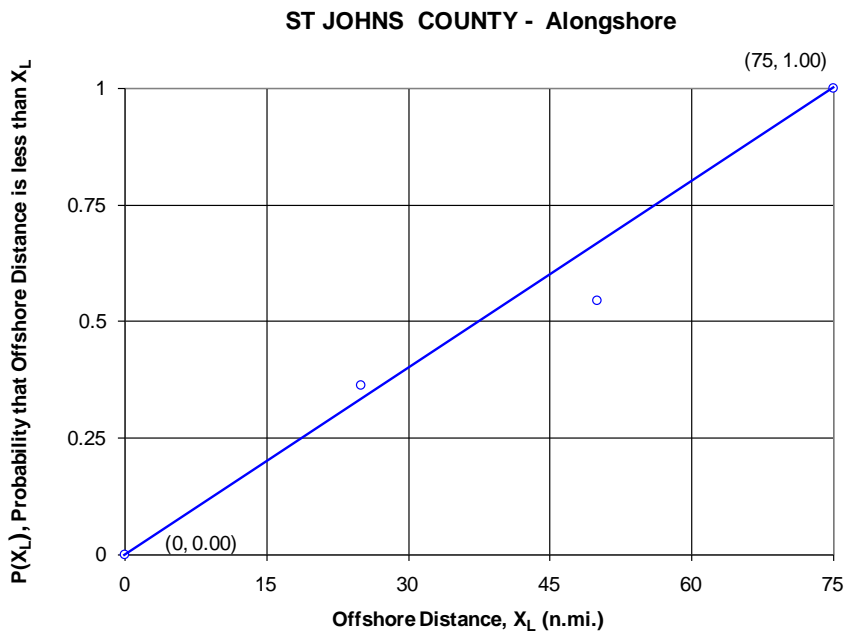
Figure 8 Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

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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.

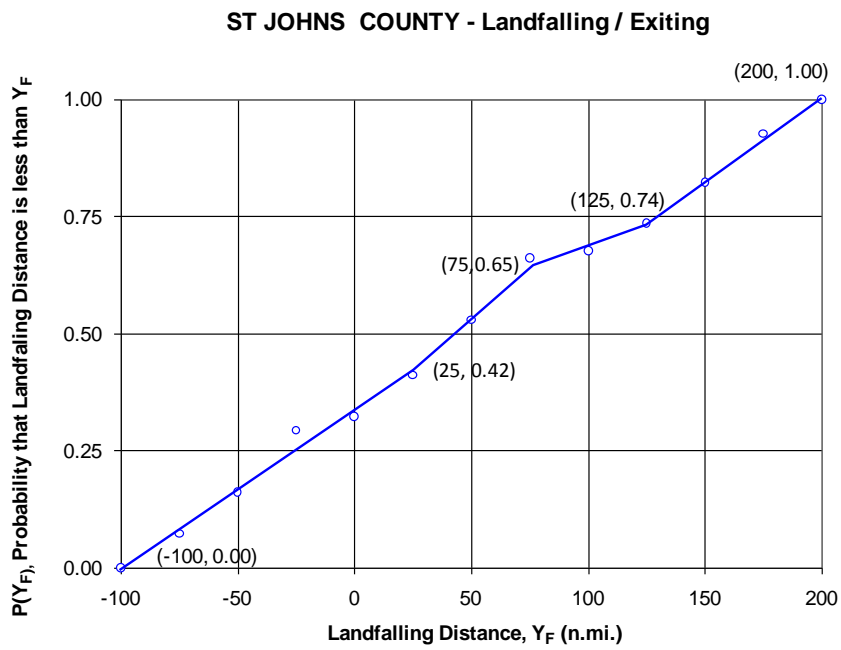The first phase of the simulation comprises the selection of the storm characteristics in accordance with the historical data. In each storm, this involves the following:

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

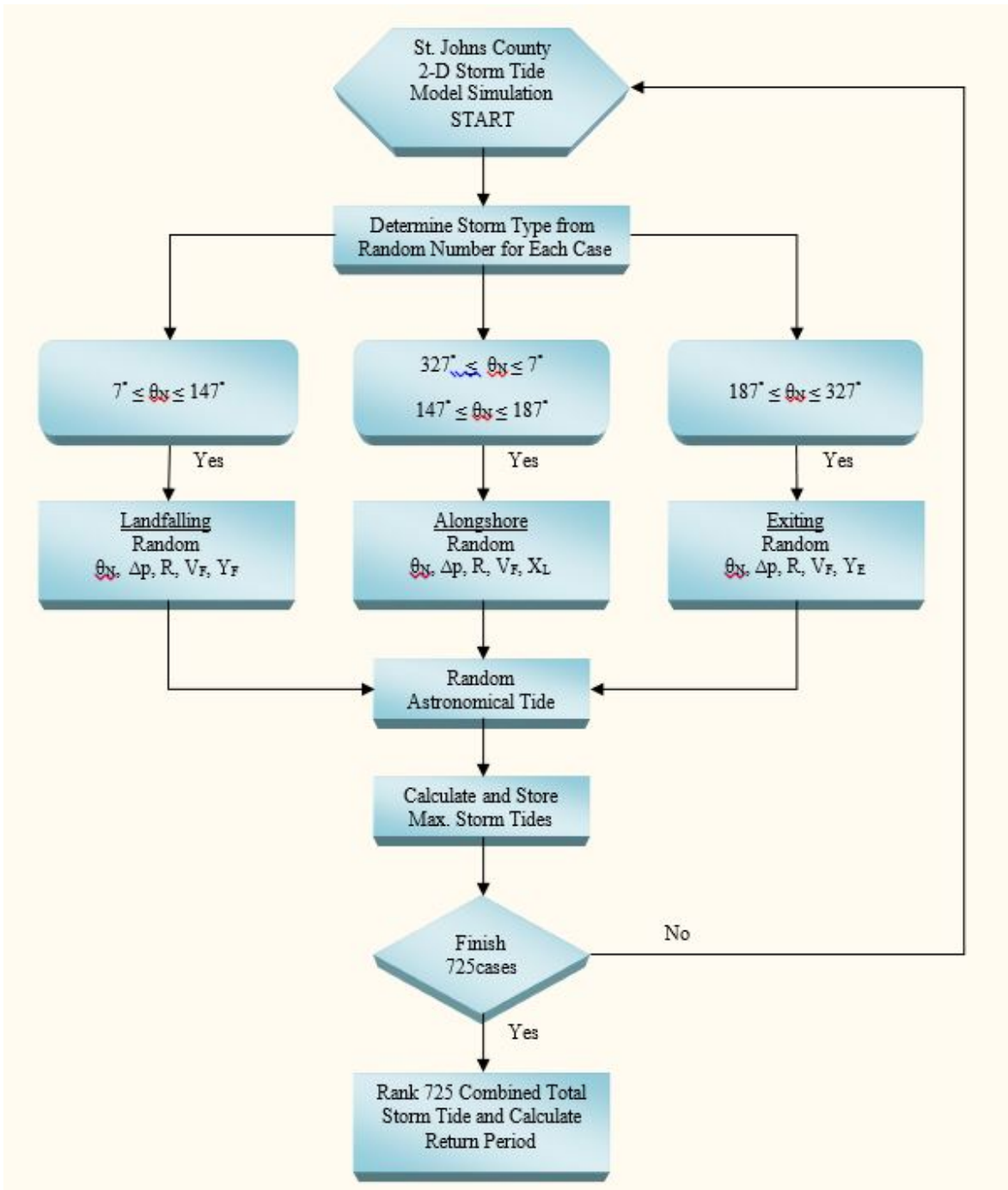To summarize information presented earlier, this phase includes the simulation of the occurrence of 1,000 years of storms along a shoreline segment of 300 n. mi. The simulated storms are given directional distributions according to Figure 5. In an average 1,000 year period, there would be a total of 725 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 St. Johns 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.

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3.3   Computation of Return Periods

With a sufficient number (725) 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 725 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 = 725 (associated with the lowest water level) the return period would be:

$$TR_{725} = 1000 / 725 = 1.38 \text{ years}$$

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 St. Johns 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.

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

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Table I below gives the combined total storm tide values and corresponding return periods for St. Johns 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	11.1	10.0	10.8	9.7	10.5	9.5
30	9.6	8.5	9.5	8.4	9.4	8.4
25	9.1	8.0	9.0	8.0	9.0	8.0
20	8.6	7.5	8.6	7.5	8.4	7.4
15	8.0	6.9	7.9	6.8	7.8	6.8
10	7.0	5.9	6.9	5.8	7.0	6.0
5	5.3	4.2	5.4	4.3	5.4	4.4

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

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 St. Johns 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 St. Johns County, Florida," Beaches and Shores Resource Center, Florida State University, June 1987.

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
ST. JOHNS COUNTY

#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	7/31/1915		139	63.8	5.3	-0.68		L
2	10/20/1921		243	62.7	10.8	-1.09		E
3	11/29/1925		218	50.3	12.7	-0.74		E
4	7/22/1926		143	74.2	8.7	-1.12	14	L
5	8/3/1928		133	131.5	5.9	-1.07		L
6	9/6/1928		120	160.6	14.0	-2.00	28	L
7	7/25/1933		90	157.6	4.3)	-0.70		L
8	8/31/1933		129	176.5	14.4	-1.92	13	L
9	8/7/1939		120	149.9	10.0	-0.74		L
10	10/12/1944		197	-33.9	14.7	-1.04		E
11	6/20/1945		229	8.2	13.8	-0.70		E
12	9/12/1945		196	-25.3	12.5	-0.77		E
13	9/18/1948		221	197.6	6.6	-1.45	16	E
14	8/23/1949		130	174.7	12.4	-1.75	23	L
15	8/18/1952	ABLE	159	(74)	9.6	-1.09		A
16	8/29/1960	DONNA	209	36.5	16.0	-1.30	24	E
17	8/28/1964	DORA	99	4.8	6.2	-1.45	34	L
18	10/13/1968	GLADYS	221	9.3	17.2	-1.42	17	E
19	8/25/1979	DAVID	169	(22.1)	13.3	-1.27	27	A
20	7/31/1995	ERIN	111	132.4	13.9	-0.83		L
21	10/22/1998	MITCH	251	191.5	27.5	-0.77		E
22	8/9/2004	CHARLEY	199	41	21.2	-1.27	22	E
23	8/25/2004	FRANCES	115	160	4.8	-1.57	30	L
24	9/13/2004	JEANNE	101	164	10.6	-1.83	26	L
25	10/10/1900		232	-41.5	17.7	-0.18		E
26	10/8/1906		12	-10.1	12.3	-0.38		L
27	6/24/1907		247	-92.8	25.4	-0.31		E
28	8/28/1909		215	67.4	12.2	-0.14		E
29	9/24/1909		232	191.4	9.8	-0.14		E
30	10/9/1910		221	-65.2	13.2	-0.38		E
31	7/12/1912		90	-82.5	10.4	-0.31		L
32	9/15/1914		114	-39.7	12.3	-0.54		L
33	5/13/1916		201	-48.9	11.8	-0.18		E
34	8/21/1916		188	115.5	11.0	-0.14		E
35	10/2/1916		85	-94.2	25.2	-0.38		L
36	9/25/1920		242	20.2	34.3	-0.31		E
37	10/1/1927		161	(62)	15.9	-0.38		A
38	8/31/1930		229	42.9	4.6	-0.18		E
39	9/9/1932		239	-46.8	23.3	-0.31		E
40	5/27/1934		166	(73.4)	14.4	-0.38		A
41	7/21/1934		65	15.7	16.3	-0.24		L
42	8/20/1936		117	23.4	15.5	-0.31		L
43	7/29/1937		232	34.5	13.1	-0.24		E
44	8/24/1937		111	60.4	11.1	-0.38		L
45	10/23/1938		232	-64.8	42.6	-0.24		E
46	8/2/1940		56	28.5	12.5	-0.18		L

| #	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
47	10/6/1947		104	-42.3	21.4	-0.24		L
48	9/28/1951	HOW	238	158.9	15.3	-0.54		E
49	9/14/1953		231	-64.9	31.4	-0.24		E
50	10/7/1953	HAZEL	234	138.1	23.7	-0.56		E
51	10/17/1959	JUDITH	260	183.3	17.6	-0.42		E
52	7/28/1960	BRENDA	216	-83.1	14.8	-0.14		E
53	8/26/1962	ALMA	197	57.3	14.7	-0.18		E
54	6/2/1964		235	-29.7	15.8	-0.14		E
55	8/20/1964	CLEO	180	(1.8)	6.0	-0.53	7	A
56	6/1/1968	ABBY	160	(3.6)	7.5	-0.38		A
57	10/1/1969	JENNY	201	107.9	11.8	-0.14		E
58	5/23/1972	ALPHA	98	-63.1	14.0	-0.65		L
59	6/24/1974		228	51.1	32.8	-0.39		E
60	5/21/1976		245	-73.5	19.1	-0.45		E
61	8/18/1976	DOTTIE	180	(68.3)	10.0	-0.50		A
62	8/7/1981	DENNIS	189	100.1	11.1	-0.24		E
63	6/18/1982		219	-17.2	34.6	-0.42		E
64	8/8/1984	DIANA	187	(56.2)	4.8	-0.53		A
65	9/25/1984	ISIDORE	216	-40.1	7.4	-0.36		E
66	7/21/1985	BOB	175	(44.5)	11.1	-0.27		A
67	10/7/1985	ISABEL	130	42.2	7.9	-0.15		L
68	8/21/1988	CHRIS	165	(38)	26.9	-0.15		A
69	11/17/1988	KEITH	234	107.7	16.4	-0.42		E
70	11/8/1994	GORDON	233	146.8	15.1	-0.53		E
71	8/22/1995	JERRY	128	159.3	6.6	-0.24		L
72	10/4/1996	JOSEPHINE	223	-92.6	42.2	-0.68		E
73	9/11/2001	GABRIELLE	247	83.8	7.6	-0.53		E
74	9/1/2002	EDOUARD	69	37.3	5.6	-0.15		L
75	9/3/2003	HENRI	237	68.1	14.5	-0.18		E
76	10/5/2005	TAMMY	149	(4)	11.7	-0.36		A
77	8/24/2006	ERNESTO	189	129	11.1	-0.36	25	E
78	5/31/2007	BARRY	200	-62.9	18.1	-0.36		E
79	8/15/2008	FAY	90	40.6	2.0	-0.59	33	L

Landfalling Storms = 26; Alongshore Storms = 11; Exiting Storms = 42

[1] Values are estimated prior to landfall.

APPENDIX B

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR
ST. JOHNS COUNTY

St. Johns County
15-Year Hydrograph
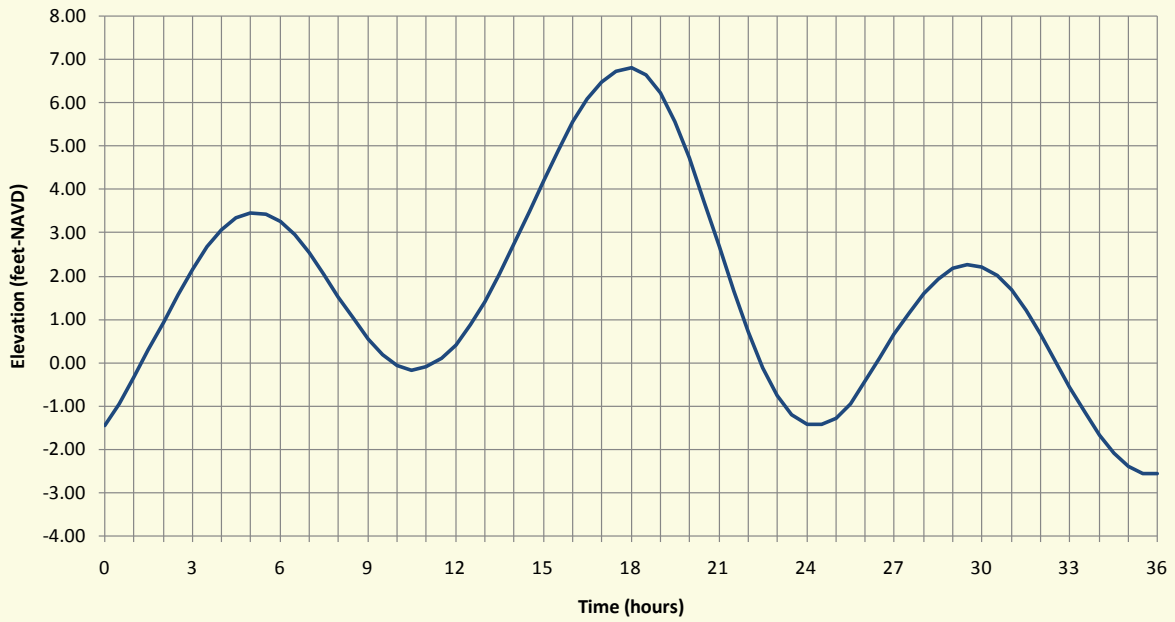
St. Johns County
25-Year Hydrograph

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