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

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June 2012

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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 Lee County, Florida" (Reference (1)) was submitted to FDEP in July, 1990. 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 Lee 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 2010. 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 Lee County shoreline. Accordingly, there were 42 landfalling, 23 exiting and 7 alongshore storms occurring in the years 1900 through 2010. 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 649 storms will occur within the 250 n. mi. segment of the coast comprising the study area. Of the 649 storms, 379 will be landfalling, 207 exiting and 63 alongshore storms.

For purposes of computer use, the cumulative probability distribution of storm track direction (θ_N) is presented in Figure 1.
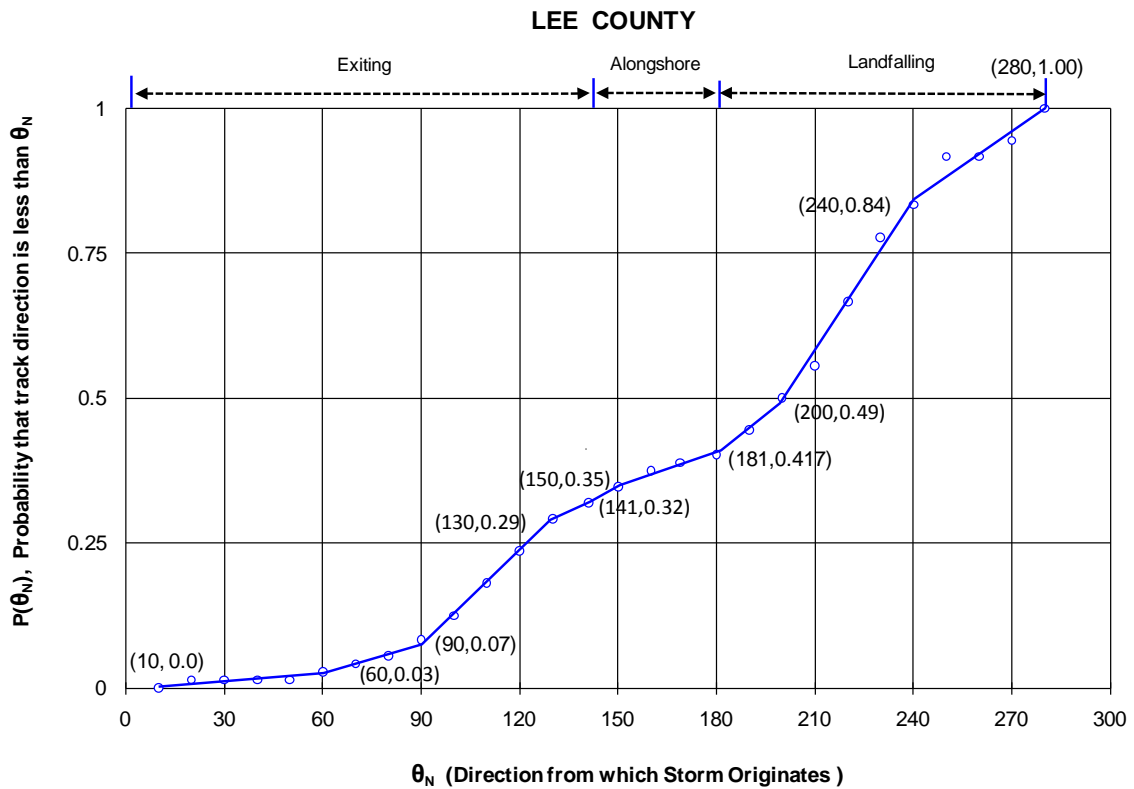
Figure 1 Cumulative Probability Distribution of Storm Track Direction, θ_N

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.

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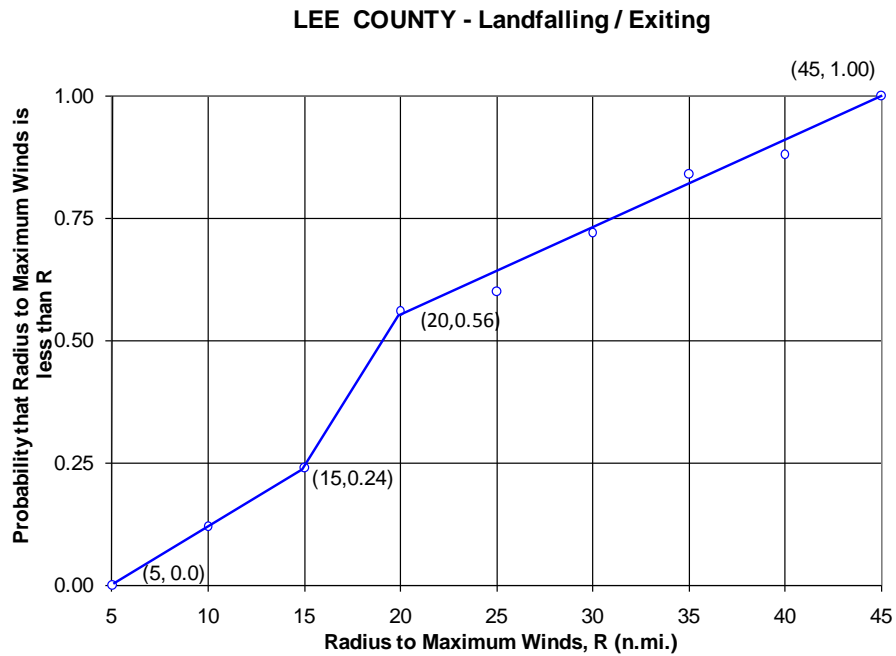
Figure 2 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Landfalling and Exiting Storms

LEE COUNTY - Alongshore
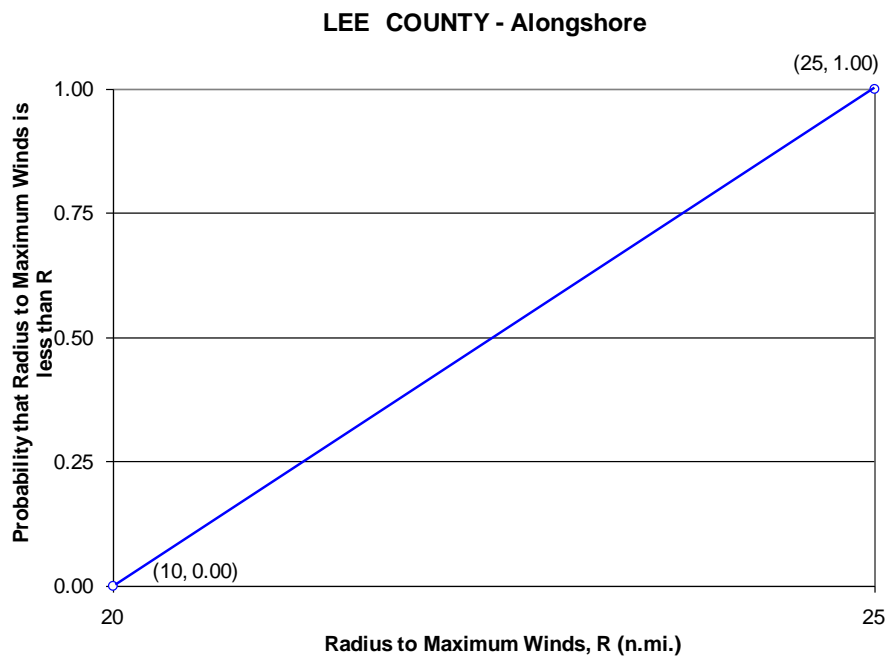
Figure 3 Cumulative Probability Distribution of Radius to the Maximum Wind, R, for Alongshore Storms
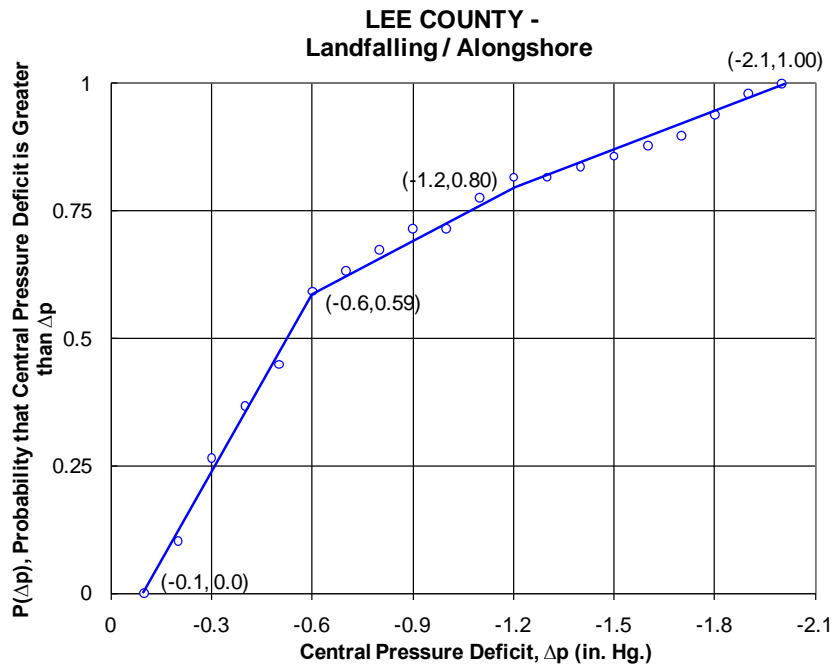
Figure 4 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Landfalling and Alongshore storms
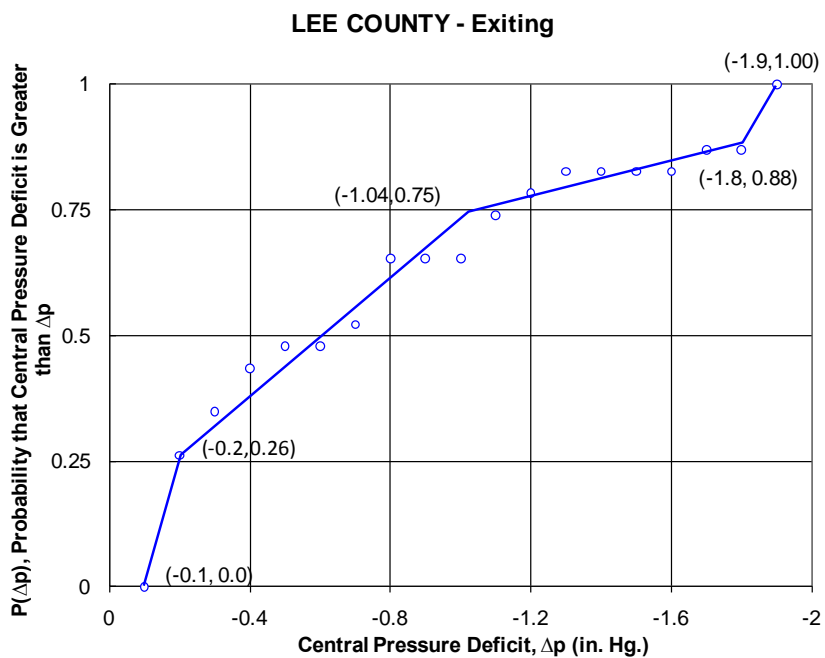
Figure 5 Cumulative Probability Distribution of Central Pressure Deficit, Δp for Exiting storms

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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.

LEE COUNTY
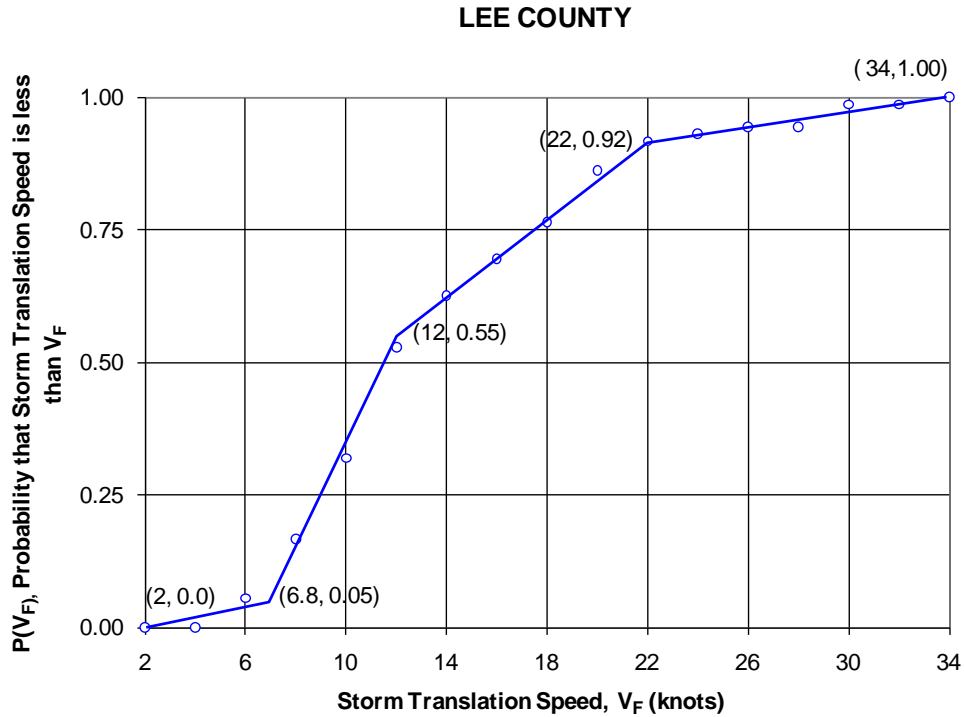
Figure 6 Cumulative Probability Distribution of Translation Speed , V_F

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.

LEE COUNTY - Landfalling / Exiting
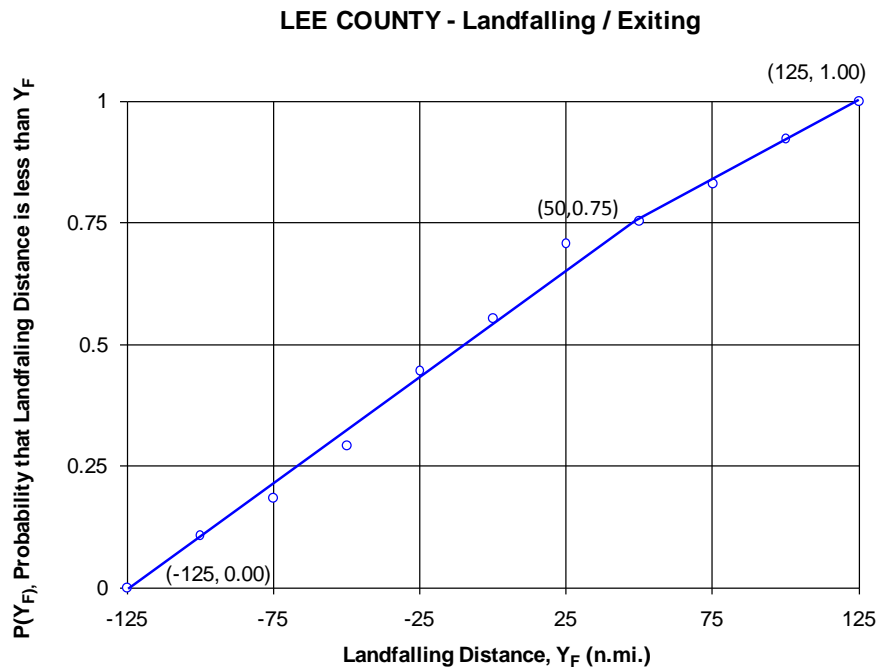
Figure 7 Cumulative Probability Distribution of Landfalling Distance, Y_F, for Landfalling and Exiting Storms

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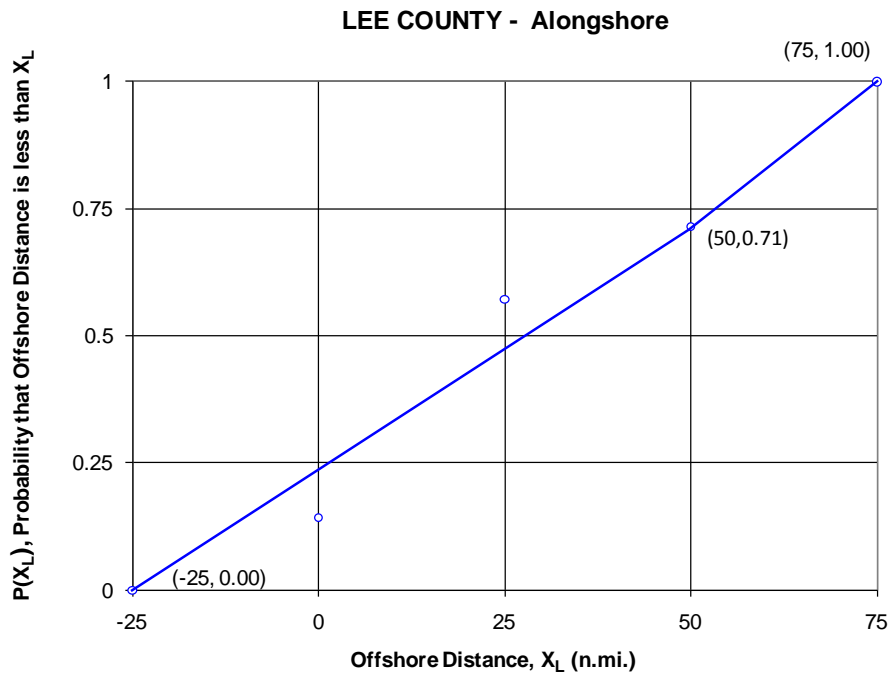
Figure 8 Cumulative Probability Distribution of Offshore Distance, X_L, for Alongshore Storms

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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 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 649 storms.
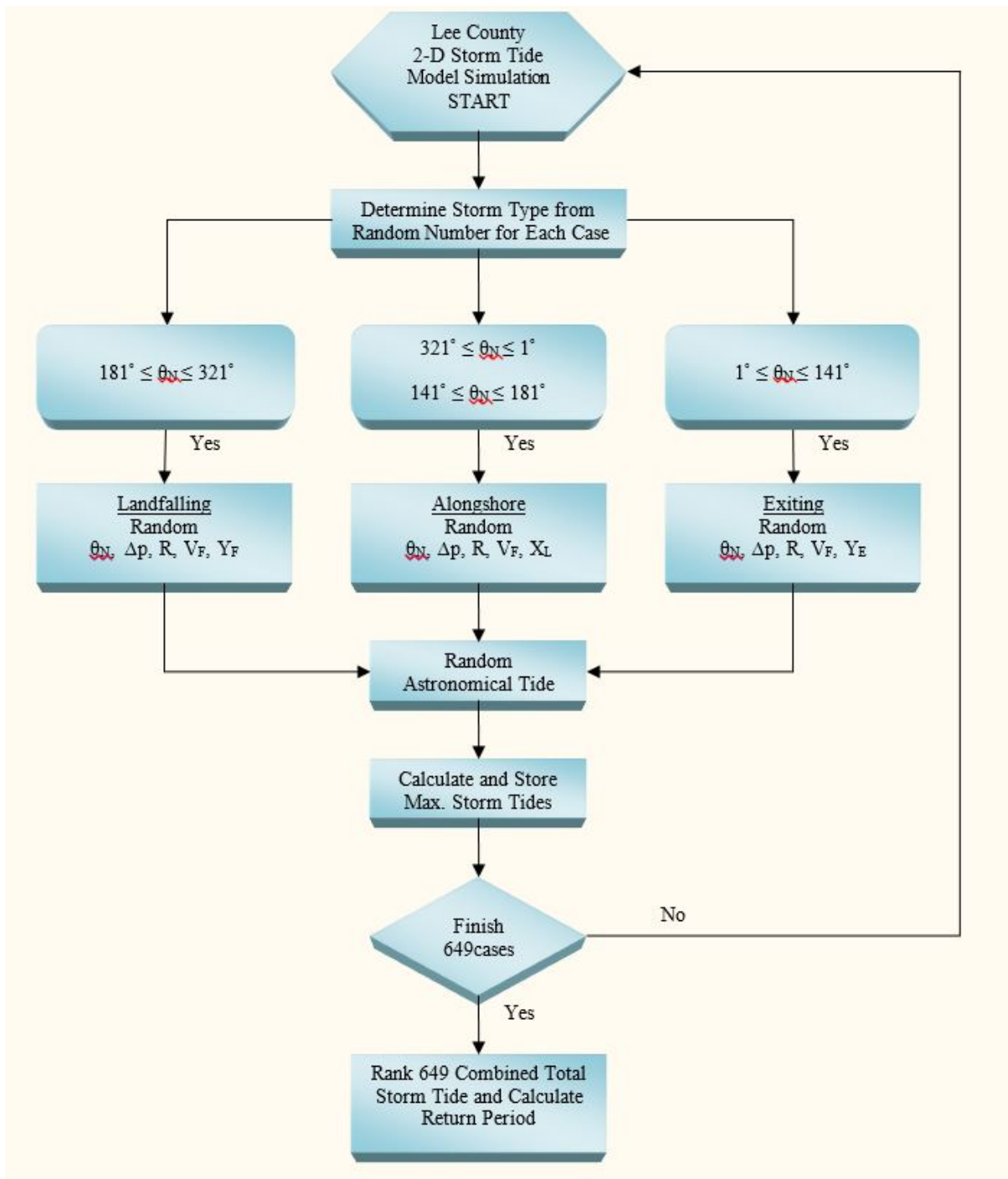
Selection of Storm Parameters - Each of the five idealized storm parameters, [Radius to Maximum Winds, R; Central Pressure, p_o (or Central Pressure Deficit, Δp); Track Direction, θ_N; System Forward Speed, V_F; and Track Position] is determined randomly in accordance with the associated cumulative probability 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 Lee 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 (649) 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 649 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

$$TM = 1000 / M$$

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 = 649 (associated with the lowest water level) the return period would be:

$$TR_{649} = 1000 / 649 = 1.54 \text{ years}$$

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 Lee 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.
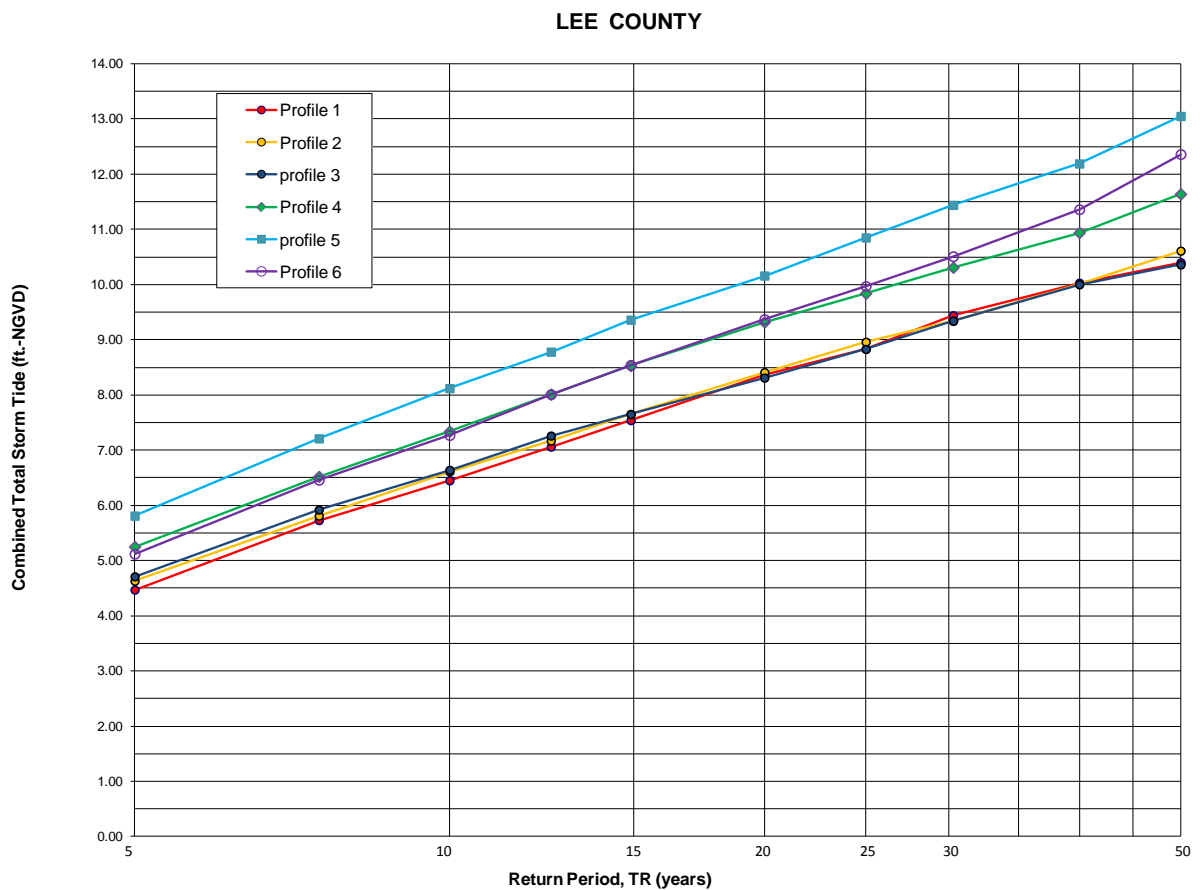
LEE COUNTY

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 Lee County.

Table I

Combined Total Storm Tide Level[*] (ft.) for Various Return Periods

Return Period, TR (years)	Profile 1 NGVD29	Profile 1 NAVD88	Profile 2 NGVD29	Profile 2 NAVD88	Profile 3 NGVD29	Profile 3 NAVD88
50	10.4	9.3	10.6	9.4	10.4	9.2
30	9.4	8.3	9.3	8.1	9.3	8.1
25	8.8	7.7	9.0	7.8	8.8	7.6
20	8.4	7.3	8.4	7.2	8.3	7.1
15	7.5	6.4	7.7	6.5	7.7	6.5
10	6.5	5.4	6.6	5.4	6.6	5.4
5	4.5	3.4	4.6	3.4	4.7	3.5

Return Period, TR (years)	Profile 4 NGVD29	Profile 4 NAVD88	Profile 5 NGVD29	Profile 5 NAVD88	Profile 6 NGVD29	Profile 6 NAVD88
50	11.6	10.4	13.1	11.9	12.4	11.2
30	10.3	9.1	11.4	10.2	10.5	9.3
25	9.8	8.6	10.9	9.7	10.0	8.8
20	9.3	8.1	10.2	9.0	9.4	8.2
15	8.5	7.3	9.4	8.2	8.5	7.3
10	7.3	6.1	8.1	6.9	7.3	6.1
5	5.3	4.1	5.8	4.6	5.1	3.9

[*]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 Lee County, Florida", Beaches and Shores Resource Center, Florida State University, July 1990.

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, "Hurricane Best Track Files (HURDAT), 1851 – 2010", http://www.nhc.noaa.gov/data/hurdat/tracks1851to2010_atl_reanal.txt.

APPENDIX A

SUMMARY OF HISTORICAL STORMS AFFECTING
LEE COUNTY

#	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
1	9/9/1903		119	65	8.2	-0.74	43	E
2	10/9/1910		190	-21	10.2	-1.72	16	L
3	10/20/1921		229	97	10.6	-1.8	18	L
4	10/14/1924		241	-46	6.2	-1.12	19	L
5	11/27/1925		214	3	24.0	-0.64		L
6	9/11/1926		127	6	10.0	-1.86	17	E
7	9/19/1929		125	-68	8.7	-1.22		E
8	8/29/1935		148	19	11.8	-1.51	21	A
9	10/30/1935		72	-88	13.1	-1.18	10	E
10	10/3/1941		128	3	18.0	-1.66	18	E
11	10/12/1944		189	29	16.2	-1.00	27	L
12	10/5/1946		186	83	16.1	-1.00		L
13	9/4/1947		108	-22	6.5	-1.09	34	E
14	10/9/1947		219	-102	12.8	-0.74		L
15	9/18/1948		194	-106	7.2	-1.48	7	L
16	9/1/1950	EASY	214	114	4.8	-1.63	15	L
17	8/29/1960	DONNA	171	-18	11.1	-1.86	20	A
18	10/8/1964	ISBELL	224	-75	18.0	-1.33	10	L
19	8/27/1965	BETSY	99	-82	13.5	-1.80	19	E
20	6/4/1966	ALMA	159	39	17.2	-1.15	23	A
21	9/21/1966	INEZ	83	-117	8.1	-0.74		E
22	10/13/1968	GLADYS	222	123	8.1	-1.07	21	L
23	8/16/1992	ANDREW	97	-54	17.0	-1.83	16	E
24	7/31/1995	ERIN	107	124	14.0	-0.68		E
25	10/12/1999	IRENE	213	-110	8.3	-0.77		L
26	9/11/2001	GABRIELLE	218	46	11.5	-0.89	14	L
27	8/9/2004	CHARLEY	200	3	21.2	-1.95	7	L
28	8/25/2004	FRANCES	119	120	10.3	-1.04	40	E
29	8/23/2005	KATRINA	64	-82	6.9	-0.77	7	E
30	10/15/2005	WILMA	237	-52	22.2	-1.77	41	L
31	8/2/1901		101	27	5.4	-0.24		E
32	6/12/1902		165	75	10.4	-0.38		A
33	10/12/1904		101	18	5.4	-0.24		E
34	10/8/1906		12	-32	13.3	-0.14	35	E
35	9/18/1907		111	-31	11.4	-0.14		E
36	9/24/1909		238	-37	9.4	-0.14		L
37	8/8/1911		152	68	5.7	-0.18		A
38	11/11/1916		244	-102	29.8	-0.21		L
39	10/15/1921		215	-1	18.4	-0.14		L
40	8/7/1928		149	17	10.5	-0.46		A
41	8/29/1930		227	70	7.3	-0.24		L
42	8/26/1932		122	-20	11.5	-0.38		E
43	7/25/1933		90	56	6.2	-0.31		E
44	5/27/1934		212	-72	11.8	-0.24		L
45	6/12/1936		276	-41	19.7	-0.24		L

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| #	Date	Name	θ_N (degrees)	Y_F (n.mi.)	V_F (knots)	Δp (in.Hg)	R (n.mi.)	Type
46	7/27/1936		130	-45	9.3	-0.46		E
47	7/29/1937		222	96	13.4	-0.24		L
48	9/3/1945		132	12	18.0	-0.18		E
49	9/20/1947		193	106	8.2	-0.38		L
50	9/28/1951	HOW	262	13	14.4	-0.46		L
51	2/2/1952		222	-97	29.5	-0.18		L
52	8/28/1953		270	-33	12.5	-0.83		L
53	10/7/1953	HAZEL	233	11	20.0	-0.54		L
54	6/18/1959		241	71	32.7	-0.14		L
55	10/17/1959	JUDITH	260	13	18.1	-0.42		L
56	6/1/1968	ABBY	213	11	13.1	-0.59		L
57	10/1/1969	JENNY	197	-38	9.4	-0.39		L
58	9/12/1970	FELICE	84	-106	9.0	-0.14		E
59	6/24/1974		229	86	20.1	-0.39		L
60	8/18/1976	DOTTIE	222	-92	21.4	-0.21		L
61	7/21/1985	BOB	270	-8	10.7	-0.24		L
62	10/9/1987	FLOYD	247	-115	15.5	-0.59		L
63	11/17/1988	KEITH	246	56	14.6	-0.53		L
64	10/9/1990	MARCO	180	23	7.0	-0.59		A
65	11/8/1994	GORDON	207	-17	7.9	-0.48		L
66	10/22/1998	MITCH	238	-22	19.0	-0.68		L
67	9/19/1999	HARVEY	275	-37	11.6	-0.50	33	L
68	9/3/2003	HENRI	245	94	16.7	-0.24	28	L
69	9/2/2004	IVAN	59	-52	11.5	-0.12		E
70	5/31/2007	BARRY	200	97	28.7	-0.39	17	L
71	8/15/2008	FAY	202	-65	9.7	-0.56	33	L
72	7/22/2010	BONNIE	110	-26	14.3	-0.15	26	E

Landfalling Storms = 48; Alongshore Storms = 8; Exiting Storms = 19

[1] Values are estimated prior to landfall.

APPENDIX B

COMPUTED 15 AND 25 YEAR HYDROGRAPHS FOR
LEE COUNTY

Lee County, Profiles 1 - 3
15-Year Hydrographs
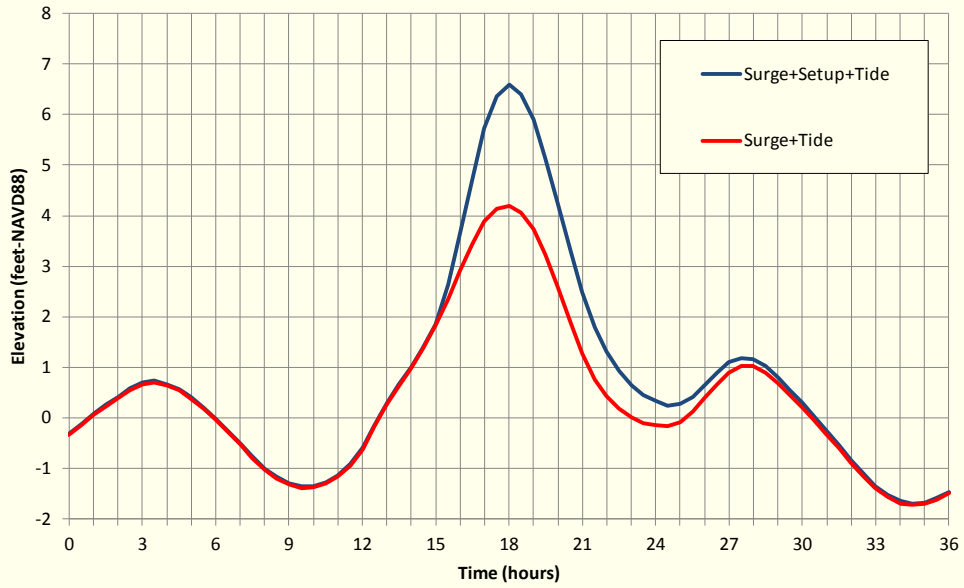
Lee County, Profiles 4 - 6
15-Year Hydrographs

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Lee County, Profiles 1 - 3
25-Year Hydrographs

Lee County, Profiles 4 - 6
25-Year Hydrographs

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