FINAL REPORT

DESIGN STORM SURGE HYDROGRAPHS FOR THE FLORIDA COAST

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16. Abstract

The literature was reviewed for open coast storm surge elevations and hydrograph information for design frequency storms for the Florida coastline. The information and data published by several government agencies, National Oceanic and Atmospheric Administration (NOAA), Federal Emergency Management Administration, FEMA, US Army Corps of Engineers, USACE, and Florida Department of Environmental Protection, FDEP were compiled, compared and assessed. Based on this information recommendations are made regarding 50, 100 and 500 year return interval hurricane storm surge hydrographs for use by the Florida Department of Transportation in estimating design flow conditions at its coastal roadways and bridges.

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A_x, A_y ....terms used in the Generalized Wave Continuity Equation used by ADCIRC

B_x, B_y ....2D depth integrated baroclinic pressure gradient terms in the x and y directions

C ....Chezy coefficient $C = 1.486(h+\eta)^{1/6}/n$

D ....total water depth ($h+\eta$)

D_x, D_y ....2D depth-integrated momentum diffusion/dispersion terms in the x and y directions

E_h ....horizontal eddy viscosity

f ....Darcy-Weisbach friction coefficient

f ....Coriolis parameter = $2\omega\sin\delta$ or = $2\Omega\sin\Psi$

F ....storm forward speed

g ....gravitational constant

h ....still water depth

h ....water depth below sea level datum, usually Mean Sea Level (MSL) or relative to the geoid

H ....total water column thickness ($h + \zeta$)

H(t) ....astronomical tide as a function of time.

n ....Manning's coefficient

p ....barometric/atmospheric pressure

p_s ....atmospheric pressure at the free surface

q_x, q_y ....volumetric transport component per unit width in the x and y directions, respectively

R_{max} ....the radius to maximum winds

S(t) ....storm surge height as a function of time

S_p ....peak storm surge height

$S_{tot}(t)$ ....total storm surge height as a function of time, water level elevation due to storm surge plus water level elevation due to astronomical tide

t ....time

t_0 ....time of landfall (i.e. time of the peak storm surge)

U, V ....depth integrated velocity in x and y direction, respectively

U_G ....gradient wind speed, wind speed 10 m above the water surface

V_F ....storm forward speed

x, y ....horizontal coordinates

Δ ....mass density of water

Ω ....angular speed of earth rotation = 7.27×10^{-5} rad/sec

Ω ....angular speed of earth rotation = 7.27×10^{-5} rad/sec

Ψ ....latitude of site of interest

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β ....Coriolis parameter = $2\Omega\sin\Psi$

δ ....latitude of site of interest (degrees)

η ....storm surge above mean water level, surface elevation above sea level datum

η_{max} ....value of the maximum dynamic wave set-up across the surf zone

$\eta + \gamma$ ....represent the Newtonian tidal potential, astronomical tide, self-attraction and load tide

ρ ....mass density of water

$\overline{\rho}$ ....vertically averaged mass density of water

ρ_0 ....reference mass density of water

θ ....storm angle of motion

τ_{bx}, τ_{by} ....bottom shear stress component in the *x* and y direction, respectively

τ_{bx}, τ_{by} ....bottom shear stress component in the *x* and y direction, respectively

τ_{sx}, τ_{sy} ....surface shear stress component in the *x* and y direction, respectively (e.g. wind stress)

τ_{wx}, τ_{wy} ....wind shear stress component in the *x* and y direction, respectively

ω ....angular speed of earth rotation = 7.28×10^{-5} rad/sec

ζ ....surface elevation relative to the geoid

I. Introduction

Hurricane generated storm surges can produce design flow conditions in coastal waters on the East Coast and Gulf of Mexico Coast of the United States. At this time the procedure used to estimate these flows is to configure and run computer flow models for regions extending from just offshore to inland beyond the point of inundation by the surge. The boundary conditions for these models include runoff discharge from rivers and streams feeding into the system and a water elevation hydrograph at the ocean boundary (i.e. a storm surge hydrograph). The accuracy of the computed flows is quite dependent on the accuracy of the boundary conditions as well as the other parameters in the model. Therefore one key ingredient in the prediction of design flow conditions in coastal waters is the open coast storm surge hydrograph. The design of most structures is based on conditions produced by certain frequency of occurrence events. For bridge piers the most common design storm events have frequencies of 50, 100 and 500 years. In the case of open coast storm surges several government agencies have attempted to predict peak storm surge elevations for different frequency storms along the US East and Gulf Coasts. Far fewer hydrographs associated with these peaks have been published.

Study Objectives

The objectives of this study were to 1) survey the published literature for data and information regarding storm surge predictions for the open coast of Florida, and 2) based on these findings make recommendations to the Florida Department of Transportation (FDOT) regarding storm surge peak values and hydrographs for 50, 100 and 500 year return interval storms for the entire Florida coastline.

Approach

Most, if not all, of the computer models used in analyzing storm surge start with the same basic governing equations. The differences between the models lies in the

1) numerical schemes used to solve the equations,
2) surge generation mechanisms included in the analysis,
3) boundary conditions imposed,
4) types of storms analyzed (real or synthetic),

5) manner in which astronomical tides are treated (or not treated as the case may be) and
6) the methods and procedures used to estimate the different return interval events.

With such a complex problem and so many different solution approaches taken it should not come as a surprise that the results from the various agencies differ from each other, in some cases significantly. Even though a number of papers and reports have been published on these models and the procedures used, many of the details are missing and attempts to obtain more information (through telephone calls and email) were, for the most part, not successful.

Each of the approaches taken has certain advantages and disadvantages. Some of the more recently developed computer models are thought to do a better job in solving the governing equations as a result of more accurate and efficient numerical schemes and methods. To date the solutions using these models have not included one of the important storm surge generation mechanisms, namely wave set-up. Attempts to correct this problem are currently underway.

The approach taken in this study was to collect, compile and analyze as much storm surge information and data as possible including the methods and procedures used to make the predictions. A necessary (but not sufficient) condition was that all of the important physics be included in the model/process. That is, all of the known important storm surge generation mechanisms should be included in the prediction process. The manner in which the statistical analysis to obtain the various return interval events was performed was also deemed important. Other items that were reviewed and considered include: quality of bathymetric and topographic data used; mesh element size; model calibration methods and data; etc.

The study did not uncover a clear cut best approach and data set. This made the recommendation phase of this work more subjective and difficult than anticipated. It is clear that more work is needed in the prediction of design open coast storm surge hydrographs and to a lesser extent design storm surge peak elevations for the coast of Florida. Both the peak elevations and hydrographs recommended in this report are considered by the authors to be the best available at the time.

II. Model Description by Agency

The methods and models for four different agencies are examined in this section. There is one state agency, Florida Department of Environmental Protection (FDEP; formerly Florida Department of Natural Resource, FDNR) and three federal agencies: Federal Emergency Management Agency (FEMA); National Oceanic and Atmospheric Administration (NOAA); and the U.S. Army Corps of Engineers (USACE). The FDEP models were developed by R.G. Dean and T.Y. Chiu. FEMA has used more than one model but the most common one is the "FEMA Coastal Flooding – Hurricane Storm Surge Model" (FEMA Surge) developed by Tetra Tech Inc. NOAA's SLOSH (Sea, Lake and Overland Surges from Hurricanes) model was developed and is used by NOAA and the National Hurricane Center (NHC). The USACE model (ADCIRC) was developed by Luettich, Westerink and Scheffner. A study conducted by Ayres Associates, with funding from several coastal states, utilized ADCIRC results produced by the USACE to obtain storm surge hydrographs and peak elevations for stations along the Eastern and Gulf of Mexico coastline of the United States. This study is referred to here as the Pooled Fund Study.

This section describes each of the models and methods in detail. Of particular interest is the storm parameters included in each model. These parameters are wind stress, bottom stress, dynamic wave setup, topology, astronomical tide, storm speed, size and atmospheric pressure. The extent to which a given model considers these parameters should be an indication of its potential accuracy. That is, a necessary but not sufficient condition for accurate predictions is that all pertinent physics be included in the model.

The FDEP Storm Surge Model

R.G. Dean and T.Y. Chiu developed both a one-dimensional (1-D) and a two-dimensional (2-D) model for use in their work in establishing the location of the Florida Coastal Construction Control Line (CCCL). The storm surge analysis program now covers 25 of the 34 coastal counties in Florida. They used beach and offshore surveys and NOAA and U.S. Geological Survey (USGS) data for the bathymetric and topographic input to their models. Historical hurricane data collected by NOAA for the Atlantic Ocean and Gulf of Mexico (NOAA's

HURDAT data set) were used to synthesize hurricanes with characteristics representative of the more probable and significant hurricanes for the area.

The two-dimensional model uses an implicit finite difference scheme in which the solution to the governing equations is carried out in a fractional time step procedure. The model incorporates the surface (wind) and bottom (friction) shear stresses, the barometric pressure, Coriolis acceleration, the components of slope of the water surface and the boundary conditions. The boundary conditions specify that the water surface displacement on the open-ocean boundaries is equal to the barometric head (due to atmospheric pressure variations). The normal discharge at these boundaries is that necessary to satisfy the volume requirement by the rising and falling water surface encompassed by the boundaries. A no-flow boundary (i.e. flows are zero normal to grid lines) condition is applied where land elevations exist that are higher than the adjacent water elevations. Flooding and "deflooding" of grid blocks is allowed by a simple algorithm. The effects of friction on the ocean bottom and in the overflow zones of the coastal area due to vegetation or buildings are accounted for in an approximate manner.

At each location the 2-D model was configured for that area and calibrated using both astronomical tides and, where data was available, hurricane storm surge. The probability distributions for the hurricane parameters (maximum wind speed, hurricane speed, radius to maximum wind speed, barometric pressure, phase with astronomical tide, etc.) for the storms impacting the study area were established from the NOAA data. The 1-D model was then configured for the area and calibrated using the 2-D model results for the synthetic hurricanes. The 1-D model was sufficiently fast that the number of storms anticipated in 2000 years for that site (approximately 600) was run. This amount of data allowed storm surge elevations to be determined for return intervals up to 500 years. The phase of the astronomical tide were treated as an additional parameter in the Monte Carlo process and thus is included in the statistics for the various return interval events.

The value of the maximum dynamic wave set-up across the surf zone (η_{max}) was computed using the maximum deep water significant wave heights which were estimated by the methods presented in the USACE Shore Protection Manual (1984). Since the value of the deep water significant wave height depends on the wind speed and the wind speed varies with time, the dynamic wave set-up varies with time. Therefore, the value of η_{max} was computed at each time step for the shoreward grid, and added to the corresponding surge value resulting from wind stress, barometric pressure and the effect of astronomical tide to give the combined total storm tide history.

The governing differential equations for the 2-D model are the vertically averaged equations of momentum and the equation of continuity, given by:

Momentum Equations

$$\frac{\partial q_x}{\partial t} + \frac{q_x}{D}\frac{\partial q_x}{\partial x} + \frac{q_y}{D}\frac{\partial q_x}{\partial y} = gD\frac{\partial \eta}{\partial x} - \frac{D}{p}\frac{\partial p}{\partial x} + \frac{\tau_{w_x}}{\rho} - \frac{\tau_{w_x}}{\rho} - \beta q_y \qquad \text{Eq. 1}$$

$$\frac{\partial q_y}{\partial t} + \frac{q_x}{D}\frac{\partial q_y}{\partial x} + \frac{q_y}{D}\frac{\partial q_y}{\partial y} = gD\frac{\partial \eta}{\partial y} - \frac{D}{p}\frac{\partial p}{\partial y} + \frac{\tau_{w_y}}{\rho} - \frac{\tau_{w_y}}{\rho} - \beta q_x \qquad \text{Eq. 2}$$

Continuity Equation

$$\frac{\partial \eta}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \qquad \text{Eq. 3}$$

where

q_x	=	volumetric transport component per unit width in the x direction
q_y	=	volumetric transport component per unit width in the y direction
t	=	time
D	=	total water depth (h+η)
h	=	still water depth
η	=	storm surge above mean water level
x	=	horizontal coordinate, directed offshore
y	=	horizontal coordinate direction according to the left-hand coordinate system
g	=	gravitational constant
Δ	=	mass density of water
p	=	barometric pressure
τ_{w_x}	=	wind shear stress component in the *x* direction
τ_{w_y}	=	wind shear stress component in the *y* direction
τ_{b_x}	=	bottom shear stress component in the *x* direction
τ_{b_y}	=	bottom shear stress component in the *y* direction
f	=	Darcy-Weisbach friction coefficient
β	=	Coriolis parameter = $2\Omega\sin\Psi$
Ω	=	angular speed of earth rotation = 7.27×10^{-5} rad/sec
Ψ	=	latitude of site of interest

The surface and bottom shear stress components are related to the wind speed (W) and discharge components by:

$$\tau_{w_x} = \rho KWW_x \, , \; \tau_{w_y} = \rho KWW_y \qquad \text{Eq. 4}$$

$$\text{and } \tau_{b_x} = \frac{\rho f|q|q_x}{8D^2} \, , \; \tau_{b_y} = \frac{\rho f|q|q_y}{8D^2} \qquad \text{Eq. 5}$$

$$\text{where } |q| = \sqrt{q_x^2 + q_y^2}$$

in which K is an air-sea friction coefficient developed by Van Dorn (1953) and depends on the wind speed (W) as follows:

$$K = \begin{cases} 1.1 \text{x} 10^{-6} & \text{for } W < W_{cr} \\ 1.1\text{x}10^{-6} + 2.5 \text{ x } 10^{-6}(1 - W_{cr}/W)^2 & \text{for } W \geq W_{cr} \end{cases} \qquad \text{Eq. 6}$$

where W_{cr} = 23.6 ft/sec.

The Darcy-Weisbach friction coefficient (f) varies with depth, bottom roughness and vegetation, if present. These studies used the coefficient developed by Christensen and Walton (1980) at the University of Florida.

The hurricane system was described by an idealized hurricane moving at a constant speed at a given angle with the x-axis. The components used to describe the idealized hurricane were forward speed (V_F), angle of motion (θ), gradient wind speed (U_G, wind speed 10 m above the water surface) and atmospheric pressure.

The solutions were started from initial conditions of zero water surface displacement and zero discharge components. The hurricane system was translated along a specified path at a designated speed. At each time step, the hurricane effects were represented by the pressure and wind stress components on each grid cell. These effects were calculated and the finite difference equations were solved to update the values of η, q_x and q_y for each grid cell.

The governing 1-D differential equations in finite difference form are:

$$\eta_{i+1}^{n+1} = \eta_i^{n+1} + \frac{\Delta x}{g(\overline{h+\eta})}\left[\frac{\tau_{w_{x_i}}}{\rho} - \beta q_{y_i}^{n+1}\right] + \frac{p_i^{n+1} - p_{i+1}^{n+1}}{\rho g} \qquad \text{Eq. 7}$$

$$\text{and } q_{y_i}^{n+1} = \frac{1}{BB}\left[q_{y_i}^{n} + \frac{\Delta t}{\rho}\tau_{w_{y_i}}\right], \qquad \text{Eq. 8}$$

where $BB = 1.0 + \frac{f\Delta t\,|\,q_{y_i}^{n}\,|}{8(\overline{h+\eta})^2}$. The remaining variables are as defined previously for the two-dimensional model.

The 1-D model is initiated from a condition of rest ($q_y = 0$) and zero water surface displacement ($\eta = 0$). The only boundary condition required is that at the seaward end ($i = 1$) of each transect where the "barometric tide" is imposed as

$$\eta_1 = \frac{p_\infty - p_1}{\rho g}\ . \qquad \text{Eq. 9}$$

The NOAA Model (SLOSH)

SLOSH (Sea, Lake and Overland Surges from Hurricanes) is a 2-D, depth averaged, finite difference model developed and run by the National Hurricane Center (NHC) of NOAA to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes. This model solves the same governing equations as those presented for the 2-D FDEP model.

Inputs to the SLOSH model are:

- Barometric Pressure
- Storm Size
- Storm Forward Speed
- Storm Track
- Wind Speed

Graphical output from the model displays color coded storm surge heights for a particular area in feet above the model's reference level, the National Geodetic Vertical Datum (NGVD).

The SLOSH model is the basis for the "hazard analysis" portion of coastal hurricane evacuation plans. Hundreds of hypothetical hurricanes are simulated with various Saffir-Simpson Scale categories, forward speeds, landfall directions, and landfall locations. An envelope of high water containing the maximum value a grid cell attains is generated at the end of each model run. These envelopes are combined by the NHC into various composites which depict the possible flooding. Details of the SLOSH model could not be located in the literature.

The FEMA SURGE Model

The Federal Emergency Management Agency (FEMA) Storm Surge Model (FEMA SURGE) was adopted in 1976 for use in Flood Insurance Studies (FIS) based on a recommendation by the National Academy of Sciences (NAS).

The model consists of a meteorological model (or hurricane storm model), a hydrodynamic model and a statistical procedure. The statistical procedure uses synthetic storms to determine the storm surge frequency of occurrence based on the location.

The FEMA studies examined the characteristics of historical storms within the geographic area of the location of interest. An ensemble of synthetic storms statistically representing those that may affect the study area was developed. The distribution and magnitude of the wind velocity and atmospheric pressure of these synthetic storms is described by the meteorological or hurricane storm model. This model provides the wind shear stress and pressure gradient to the hydrodynamic model and the results of the hydrodynamic model gives the storm surge. Dynamic wave set-up and astronomical tides are not explicitly included in the hydrodynamic model. However, the effect of wave set-up can be somewhat accounted for in the calibration process if measured storm surge elevation data is available at the location of interest. In this procedure the astronomical tide is added to the storm surge following the simulation using a range of tidal phases for each storm event to determine the maximum storm surge for the study area.

The hydrodynamic model uses an explicit, 2-D, depth-integrated model with a finite difference scheme to simulate storm surges. Model inputs include:

- offshore bathymetry
- coastline configuration
- boundary conditions
- bottom friction

- other resistance coefficients (e.g. flow drag caused by obstacles protruding through the water column)
- surface wind stress
- atmospheric pressure distribution of the hurricane

The governing equations consist of the continuity equation

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x}\left[U(h+\eta)\right] + \frac{\partial}{\partial y}\left[V(h+\eta)\right] = 0, \qquad \text{Eq. 10}$$

and the momentum equations

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} = -g\frac{\partial \eta}{\partial x} + fV + \frac{\tau_{wx}}{\rho(h+\eta)} - \frac{\tau_{bx}}{\rho(h+\eta)} - \frac{1}{\rho}\frac{\partial p}{\partial x}, \qquad \text{Eq. 11}$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} = -g\frac{\partial \eta}{\partial y} - fU + \frac{\tau_{wy}}{\rho(h+\eta)} - \frac{\tau_{by}}{\rho(h+\eta)} - \frac{1}{\rho}\frac{\partial p}{\partial y}, \qquad \text{Eq. 12}$$

where

x, y	=	horizontal, rectangular coordinates
U, V	=	depth integrated velocity in x and y direction, respectively
t	=	time
η	=	surface elevation above sea level datum
h	=	water depth below sea level datum, usually Mean Sea Level (MSL)
ρ	=	mass density of water
p	=	atmospheric pressure
τ_{wx}, τ_{wy}	=	wind shear stress component in the *x* and y direction, respectively
τ_{bx}, τ_{by}	=	bottom shear stress component in the *x* and y direction, respectively
g	=	gravitational constant
f	=	Coriolis parameter = $2\omega\sin\delta$
ω	=	angular speed of earth rotation = 7.28×10^{-5} rad/sec
δ	=	latitude of site of interest (degrees)

Bottom shear stress is computed using

$$\tau_{bx} = \frac{gU\sqrt{U^2+V^2}}{C^2} \text{ and } \tau_{by} = \frac{gV\sqrt{U^2+V^2}}{C^2} \qquad \text{Eq. 13}$$

where

U, V	=	depth integrated velocity in x and y direction, respectively
C	=	Chezy coefficient $C = 1.486(h+\eta)^{1/6}/n$
n	=	Manning's coefficient

The wind shear stress is computed using

$$\tau_{w_x} = \rho KWW_x, \ \tau_{w_y} = \rho KWW_y \qquad \text{Eq. 14}$$

in which K is an air-sea friction coefficient developed by Van Dorn (1953) and depends on the wind speed (W) as follows:

$$K = \begin{cases} 1.1 \text{x} 10^{-6} & \text{for } W < W_{cr} \\ 1.1 \text{x} 10^{-6} + 2.5 \text{ x } 10^{-6} (1 - W_{cr}/W)^2 & \text{for } W \geq W_{cr} \end{cases} \qquad \text{Eq. 15}$$

where W_{cr} = 23.6 ft/sec.

The momentum and continuity equations are solved at all interior cells which have a water depth greater than zero. The model allows for wetting and drying of grid cells. The normal velocity at the wet-dry cell boundary is zero.

Generally, two grids are used. A coarse, offshore grid where the open boundary conditions are applied and a finer, nearshore and inland grid. Output from the offshore grid serves as the ocean boundary condition for the nearshore grid. Through a series of numerical experiments, the offshore grid is sized so as to minimize the errors in the ocean boundary conditions for the nearshore grid.

Pooled Fund Study

A study with pooled funding from the Departments of Transportation of several coastal states in the U.S. examined available storm surge hydrographs from the USACE, NOAA and FEMA. A synthetic hydrograph used by the USACE was modified in the second phase of this work to obtain a better fit to the hydrographs produced by the USACE ADCIRC model generated data set in the areas investigated in this study. The synthetic hydrograph is a mathematical expression (Eq. 16 and 17) of water height as a function of time with coefficients that depend on the hurricane parameters (peak surge height, storm forward speed and radius to maximum winds). The original expression consisted only of equation 16. The Pooled Fund Study modified the equation to obtain better fits to the falling limb of the hydrograph:

$$S(t) = S_p \left\{ 1 - \exp\left[- \left| \frac{R_{max}/F}{t - t_0} \right| \right] \right\} + H(t), \text{ for } t \leq t_0; \qquad \text{Eq. 16}$$

$$S(t) = S_p \left\{ 1 - \exp\left[- \left| \frac{R_{max}/F}{t - t_0} \right| \right] - 0.14(t - t_0)\exp[-0.18(t - t_0)] \right\} + H(t), \text{ for } t > t_0. \qquad \text{Eq. 17}$$

in which

$S(t)$	=	storm surge height as a function of time
S_p	=	peak storm surge height
t	=	time
R_{max}	=	the radius to maximum winds
F	=	storm forward speed
t_0	=	time of landfall (i.e. time of the peak storm surge)
$H(t)$	=	astronomical tide as a function of time.

The ADCIRC model grid used to generate the data set analyzed in the Pool Study is coarse and the nearshore bathymetry in the model is not as accurate as it should be (according to the engineers at USACE that configured and ran the model and generated the data set).

The Pooled Fund Study produced recommendations for 50, 100 and 500 year return interval storm surge elevations and hydrographs for the U.S. East Coast and Gulf of Mexico shoreline.

US Army Corps of Engineers (ADCIRC model)

The Advanced Circulation (ADCIRC) model for shelves, coasts and estuaries was developed by Luettich, Westerink and Scheffner for the Dredging Research Program of the US Army Corps of Engineers (USACE) during the period from July 1988 through September 1990. Its original purpose was to generate a database of harmonic constituents for tidal elevation and current at specified locations along the US coasts and to use tropical and extra-tropical global boundary conditions to compute frequency indexed storm surge hydrographs for specific locations.

The ADCIRC model (as used in the studies described here) is a two-dimensional, depth-integrated model that outputs the free surface displacement and depth averaged velocity at all nodes in the model mesh. It solves the shallow-water in non-linear form and includes convective acceleration terms, finite amplitude terms and bottom friction in a standard quadratic form. The 2-D equations are discretized in space using the finite element (FE) method and in time using the finite difference (FD) method. Elevation is obtained from the solution of the depth-integrated continuity equation in the Generalized Wave-Continuity Equation (GWCE) form. Velocity is obtained from the solution the 2D depth-integrated momentum equations.

ADCIRC boundary conditions include:

- specified elevation (harmonic tidal constituents or time series)
- specified normal flow (harmonic tidal constituents or time series)
- zero normal flow
- slip or no slip conditions for velocity

- external barrier overflow out of the domain
- internal barrier overflow between sections of the domain
- surface stress (wind and/or wave radiation stress)
- atmospheric pressure
- outward radiation of waves (Sommerfield condition)

ADCIRC can be forced with:

- elevation boundary conditions
- normal flow boundary conditions
- surface stress boundary conditions
- tidal potential
- earth load/self attraction tide

The governing equations consist of

Continuity equation (GWCE form)

$$\frac{\partial^2 \zeta}{\partial t^2} + \tau_0 \frac{\partial \zeta}{\partial t} + \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} - UH \frac{\partial \tau_0}{\partial x} - VH \frac{\partial \tau_0}{\partial y} = 0, \qquad \text{Eq. 18}$$

Momentum equations

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - fV = -\frac{\partial}{\partial x}\left[\frac{p_s}{\rho_0} + g\zeta - g(\eta + \gamma)\right] + \frac{\tau_{sx}}{\rho_0 H} - \frac{\tau_{bx}}{\rho_0 H} + D_x - B_x, \qquad \text{Eq. 19}$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + fU = -\frac{\partial}{\partial y}\left[\frac{p_s}{\rho_0} + g\zeta - g(\eta + \gamma)\right] + \frac{\tau_{sy}}{\rho_0 H} - \frac{\tau_{by}}{\rho_0 H} + D_y - B_y, \qquad \text{Eq. 20}$$

where

U, V	=	depth integrated velocity in x and y direction, respectively
t	=	time
ζ	=	surface elevation relative to the geoid
$\eta + \gamma$	=	represent the Newtonian tidal potential, earth tide, self attraction and load tide
h	=	bathymetric water depth relative to the geoid
H	=	total water column thickness ($h + \zeta$)
x, y	=	horizontal coordinates
g	=	gravitational constant
$\overline{\rho}$	=	vertically averaged mass density of water
ρ_0	=	reference mass density of water
p_s	=	atmospheric pressure at the free surface
τ_0	=	numerical weighting parameter for the GWCE
τ_{sx}, τ_{sy}	=	surface shear stress component in the *x* and y direction, respectively (e.g. wind stress)
τ_{bx}, τ_{by}	=	bottom shear stress component in the *x* and y direction, respectively
f	=	Coriolis parameter = $2\Omega\sin\Psi$
Ω	=	angular speed of earth rotation = 7.27×10^{-5} rad/sec

Ψ	=	latitude of site of interest
A_x, A_y	=	terms for the GWCE

$$A_x = U\frac{\partial H}{\partial t} + H\left\{\begin{array}{l} -U\dfrac{\partial U}{\partial x} - V\dfrac{\partial U}{\partial y} + fV - \dfrac{\partial}{\partial x}\left[\dfrac{p_s}{\rho_0} + g\zeta - g(\eta + \gamma)\right] \\ +\dfrac{\tau_{sx}}{\rho_0 H} - \dfrac{\tau_{bx}}{\rho_0 H} + D_x - B_x + \tau_0 U \end{array}\right\}, \quad \text{Eq. 21}$$

$$A_y = V\frac{\partial H}{\partial t} + H\left\{\begin{array}{l} -U\dfrac{\partial V}{\partial x} - V\dfrac{\partial V}{\partial y} - fU - \dfrac{\partial}{\partial y}\left[\dfrac{p_s}{\rho_0} + g\zeta - g(\eta + \gamma)\right] \\ +\dfrac{\tau_{sy}}{\rho_0 H} - \dfrac{\tau_{by}}{\rho_0 H} + D_y - B_y + \tau_0 V \end{array}\right\}. \quad \text{Eq. 22}$$

B_x, B_y = 2D depth integrated baroclinic pressure gradient terms in the x and y directions. In Cartesian coordinates they are defined as

$$B_x = g\left[\left(\frac{\bar{\rho} - \rho_0}{\rho_0}\right)\frac{\partial \zeta}{\partial x} + \frac{H}{2}\frac{\partial}{\partial x}\left(\frac{\bar{\rho} - \rho_0}{\rho_0}\right)\right], \quad \text{Eq. 23}$$

$$B_y = g\left[\left(\frac{\bar{\rho} - \rho_0}{\rho_0}\right)\frac{\partial \zeta}{\partial y} + \frac{H}{2}\frac{\partial}{\partial y}\left(\frac{\bar{\rho} - \rho_0}{\rho_0}\right)\right]. \quad \text{Eq. 24}$$

D_x, D_y = 2D depth-integrated momentum diffusion/dispersion terms in the x and y directions. In Cartesian coordinates they are defined as

$$D_x = \frac{E_h}{H}\left[\frac{\partial^2 UH}{\partial x^2} + \frac{\partial^2 UH}{\partial y^2}\right], \; D_y = \frac{E_h}{H}\left[\frac{\partial^2 VH}{\partial x^2} + \frac{\partial^2 VH}{\partial y^2}\right]$$

E_h = horizontal eddy viscosity

Bottom shear stress components are expressed by: $\tau_{bx} = U\tau_*$ and $\tau_{by} = V\tau_*$, where τ_* is a quadratic function of depth-averaged velocity:

$\tau_* = C_f \dfrac{\sqrt{U^2 + V^2}}{H}$, and C_f is the drag coefficient ($C_f \sim 0.0025$).

Summary

Table II-1 shown below summarizes information for the models discussed in this section. No evaluation has been made with respect to the computational precision or theoretical accuracy of the models

Table II- 1. Storm Surge Model Summary

Model	Type	Storm Size	Wind Surface Shear Stress	Bottom Shear Stress	Dynamic Wave Set-up	Offshore Topography	Astronomical Tide	Storm Forward Speed	Atmospheric Pressure
ADCIRC (USACE)	2-D, FD/FE[1]	x	x	x		x	x	x	x
SLOSH (NOAA)	2-D	x	x			x		x	x
SURGE (FEMA)	2D	x	x	x	x[5]	x	x[4]	x	x
FDEP Surge	2-D, FD[1]	x	x	x		x		x	x
	1-D[2], FD[1]	x	x	x	x	x	x[3]	x	x

(1) FD = Finite Difference, FE = Finite Element.
(2) 1-D FDEP model is calibrated with the 2-D model.
(3) Astronomical tide is included as one of the parameters in the analysis.
(4) Astronomical tide is added after the surge computation.
(5) Wave-setup is included at a few locations.

III. Peak Storm Surge Height

Peak Storm Surge Heights by Agency
Peak storm surge height predictions published by the various agencies (FDEP, FEMA, NOAA and USACE/ADCIRC) for locations along the Florida coast are presented in Appendix A. FDEP, FEMA and USACE have determined peak heights for several return periods. All three agencies looked at return intervals of 50, 100 and 500 years. FDEP also made predictions for 10, 20 and 200 year return intervals. NOAA made predictions based on the severity of the storm (i.e. the Saffir-Simpson Scale Category: 1, 2, 3, 4, 5). Table A-3 lists the NOAA predictions for category 5 hurricanes.

Figures III-1 through III-9 show the peak storm surge height predictions graphically by agency around the state. The figures are grouped by return interval: 50 year (Figures III-1, III-2 and III-3), 100 year (Figures III-4, III-5 and III-6) and 500 year (Figures III-7, III-8 and III-9). Each group of figures traces the predictions around the coast of Florida in a continuous line from the western most boundary of Escambia County to the northern most boundary of Nassau County. The "boxed" (☐) values are recommended values ("Rec.") and will be discussed later in this section.

The previous section discussed the methodologies and models used by each agency. From Table II-1, the FDEP surge model is the only one to include all the important parameters (wind stress, bottom stress, dynamic wave setup, topology, astronomical tide, storm speed and size and atmospheric pressure). At present the ADCIRC model does not include dynamic wave setup. The FEMA surge model only includes dynamic wave setup in some cases and then only for the 100 year return interval storm. Accordingly, it is believed that the FDEP model more accurately reflects the effects of an actual storm surge event.

General Comparison of Agency Results
A comparison of the peak storm surge heights predicted by the ADCIRC and FDEP models shows the following for the 100 year return interval:

- The maximum difference between the ADCIRC predictions and those from FDEP is 67% with ADCIRC under predicting as compared to FDEP.

- ADCIRC predicts at least 50% less than FDEP in Okaloosa, Bay, Dade, Broward, Palm Beach and Martin counties.
- The best agreement between ADCIRC and FDEP (less than 10% difference) occurs in Pinellas, Manatee, Sarasota and Duval counties.
- The ADCIRC model differs from the FDEP model by an average of approximately 30%.

Comparing the peak storm surge heights predicted by the FEMA and FDEP models shows the following for the 100 year return interval storm:

- The maximum difference between the FEMA predictions and those from FDEP is 55% with FEMA under predicting as compared to FDEP.
- FEMA predicts an average of 33% less than FDEP in Okaloosa, Walton, Bay, Gulf and Franklin counties.
- In Dade, Broward and Palm Beach, Martin and St. Lucie counties, FEMA predicts at least 36% below FDEP with an average difference of 44%.
- The best agreement between FEMA and FDEP (less than 10% difference) occurs in Escambia and Pinellas counties.
- The FEMA model differs from the FDEP model by an average of approximately 26% less than the FDEP model.

Comparing the 500 year return interval peak storm surge heights predicted by the FDEP model and those predicted by NOAA for a category 5 hurricane used shows the following:

- The maximum difference between the NOAA predictions and those from FDEP is 70% with FDEP under predicting as compared to NOAA.
- FDEP predicts an average of 40% less than NOAA in Pinellas, Manatee, Sarasota, Lee and Collier counties.
- In Dade County, FDEP predicts 39% above NOAA.
- The best agreement between NOAA and FDEP (less than 15% difference) occurs in Escambia, Bay, Gulf, St. Lucie, Brevard, St. Johns and Nassau Counties. In Bay, St. Lucie, Brevard, St. Johns and Nassau Counties the difference is less than 10%.

The comparison between the FDEP predictions and the NOAA predictions are not necessarily attributable to model differences. Rather, it may be that the 500 year event is a category 5 hurricane in the counties where agreement is good and the 500 year event is something different in the counties with poor agreement.

Comparison of Agency Results at Specific Locations (50 year surge)
For the 50 year surge (Figures III-1 through III-3), the FDEP peak predictions are equal to or greater than other agency predictions in all but a few locations.

In Figure III-2, FEMA shows a peak at 12.8 feet. This is approximately 1 foot above an interpolated FDEP value and the actual ADCIRC prediction. The peak is also a spike in the trend of the FEMA predictions and may be anomalous.

The ADCIRC 50 year peaks from Charlotte through Lee Counties (Figure III-2) are up to two feet above the FDEP predictions and 4 to 5 ft above the FEMA predictions. A similar situation occurs at the Anclote River in Pinellas County, with FDEP splitting the difference between FEMA (11 feet) and ADCIRC (8.5 feet). Again, the FDEP prediction is believed to be more accurate.

Comparison of Agency Results at Specific Locations (100 year surge)
For the 100 year surge, the ADCIRC peak is as much as 3 feet higher than the FEMA predictions and the interpolated FDEP values for Taylor and Dixie Counties (Figure III-4). In Figure III-5, the FDEP predictions average through the difference between the FEMA and ADCIRC predictions. As before, the FDEP prediction is believed to be more accurate.

The same FEMA peak is anomalously high in Figure III-5 as in Figure III-3 (Highland Pt, Monroe County). Again, this point appears to be a spike in the predictions and is considered to be unreliable.

Comparison of Agency Results at Specific Locations (500 year surge)
The 500 year ADCIRC peak shows the same anomalously high values in Taylor and Dixie Counties (Figure III-7) as it did in the 100 year predictions (Figure III-4). Also as in the 100 year predictions, FEMA and FDEP agree in this region.

In Figure 8, the FDEP prediction is near the average of the FEMA and ADCIRC values as it did in the 50 and 100 year cases. As before, the FDEP prediction is believed to be more accurate.

Since the FDEP model includes all the pertinent parameters for estimating the storm surge, it is believed that this model has produced the most accurate of the published predictions. Also, Figures III-1 through III-9 show that the FDEP predictions are more consistent from location to location. For these reasons, the FDEP predictions are believed to be the more reliable and accurate overall than those from the other agencies.

Location Coverage
Figure III-10 shows the locations of all the FDEP model runs listed in Table A-4. As noted in the model description, the FDEP model was developed for the Coastal Construction Control Line (CCCL) program and has been applied to locations in 25 of the 34 coastal counties in Florida. with sandy beaches. Taylor, Dixie, Levy, Citrus, Hernando, Pasco and Monroe Counties were not examined. Jefferson County is covered by the Wakulla County Study and Santa Rosa County is closely bounded by profiles in the Escambia and Okaloosa County studies.

For most of the counties examined, the FDEP model produced hydrographs to describe the water level with time. No hydrographs are available for Wakulla County and only one hydrograph each is available in Walton, Franklin, Charlotte and Nassau Counties. Nevertheless, the FDEP database is very extensive and provides excellent state-wide coverage.

FEMA conducted Federal Insurance Studies on all the coastal counties in Florida, including those not covered by the FDEP studies (Taylor, Dixie, Levy, Citrus, Hernando, Pasco and Monroe Counties). However, FEMA's concern was the maximum flood level that would be reached and no hydrographs were published.

Recommended Peak Storm Surge Heights
To facilitate analysis and cross-referencing between agency results, each location of interest was assigned a reference number. The reference numbers consist of a county code (the first one or two digits) numbered sequentially around the coast of Florida in a continuous line from Escambia County to Nassau County. The last two digits are the local code numbered sequentially on the same line (West to East in the Panhandle, North to South on the Gulf Coast and South to North on the Atlantic Coast). When sorted by these reference numbers, the results can be examined continuously along the coast. The table below shows the county numbering scheme.

County	Ref Group	County	Ref Group	County	Ref Group
Escambia	100	Citrus	1300	Palm Beach	2500
Santa Rosa	200	Hernando	1400	Martin	2600
Okaloosa	300	Pasco	1500	St. Lucie	2700
Walton	400	Pinellas	1600	Indian River	2800
Bay	500	Manatee	1700	Brevard	2900
Gulf	600	Sarasota	1800	Volusia	3000
Franklin	700	Charlotte	1900	Flagler	3100
Wakulla	800	Lee	2000	St. Johns	3200
Jefferson	900	Collier	2100	Duval	3300
Taylor	1000	Monroe	2200	Nassau	3400
Dixie	1100	Dade	2300		
Levy	1200	Broward	2400		

Table III-1 provides an agency cross-reference and location list. The reference number, the names of the locations of interest, the latitude and longitude of the locations, the FDEP, FEMA, NOAA and ADCIRC reference numbers are all contained in this table. Figure III-10 locates the stations around the state.

The agency reference numbers in Table III-1 and Appendix A do not correspond to numbers assigned by the respective agencies. As with the overall reference numbers, these reference numbers were assigned by this study to facilitate analysis. The FDEP reference numbers correspond directly to the overall numbers. The agency reference numbers are found in Tables A-1 through A-4.

Tables III-2, III-3 and III-4 list the peak surge values for 50, 100 and 500 year return periods, respectively, by reference number and location according to Table III-1. Each table includes the FDEP, FEMA and ADCIRC predictions. Table III-4 (the 500 year return period) also includes the NOAA model predictions. Figures III-1 through III-9 show the contents of Tables III-2, III-3 and III-4 graphically.

The last two columns (Rec. and Rec. Source) of Tables III-2, III-3 and III-4 list the recommended peak surge values for the respective return periods. The "Rec. Source" listing is the agency from which the recommendation was taken.

For the most part, the recommended value is the FDEP value. In several locations where FDEP values were not available (Dixie, Levy and Pasco Counties) FEMA values were used. In others, the peak value was interpolated between adjacent locations and compared to the modeled value of the other agencies. These interpolated cases are labeled "Interp" in the last column of Tables III-2, III-3 and III-4.

Table III- 1. Cross-Reference and Location List

Ref	Location	Latitude (deg N)	Longitude (deg W)	FDEP Ref	FEMA Ref	NOAA Ref	ADCIRC Ref
101	Escambia W, Esc	30.28	87.52	101	1		
102	Pensacola Bay, Esc	30.32	87.27	102	2	1	1
103	Pensacola Bch, Esc	30.35	87.07	103	3		
104	Eglin AFB, Esc	30.38	86.87	104	4		
301	Eglin AFB, Oka	30.40	86.63	301	5		
302	Destin W, Oka	30.39	86.60	302	6	2	2
303	Destin E, Oka	30.38	86.40	303	7		
401	Miramar Bch, Wal	30.37	86.35	401	8		
402	Grayton Bch, Wal	30.33	86.16	402	9		
403	Inlet Bch, Wal	30.29	86.05	403	10		
501	Hollywood Bch, Bay	30.27	85.99	501	11		
502	Panama City, Bay	30.10	85.69	502	12	3	3
503	Mexico Bch, Bay	29.93	85.39	503			4
600	Beacon Hill, Gul	29.92	85.38	600	15		5
601	St Joseph Pt, Gul	29.85	85.41	601			
602	St Joseph Park, Gul	29.76	85.40	602	16		
603	Cape San Blas, Gul	29.68	85.37	603			
604	McNeils, Gul	29.68	85.30	604		4	
605	Indian Pass, Gul	29.68	85.25	605			6
701	St Vincent Is, Fra	29.59	85.05	701	17		
702	West Pass, Fra	29.63	84.93	702	18		7
703	Sikes Cut, Fra	29.68	84.81	703	19		
704	St George Is, Fra	29.75	84.71	704	20		
705	Dog Is, Fra	29.80	84.59	705	21		
706	Alligator Harbor, Fra	29.90	84.35	706	22		8
801	Lighthouse Pt, Wak	29.93	84.29	801			9
802	Shell Pt, Wak	29.96	84.23	802	23		10
803	Goose Creek Bay, Wak	30.00	84.17	803	24	5	11
804	Whale Is, Wak	30.03	84.12	804	25		12
805	Palmetto Is, Wak	30.07	84.06	805			13
806	Little Redfish Pt, Wak	30.10	84.00	806	26		16
1001	Stake Pt, Tay	30.00	83.80		28		17
1002	Deadman Bay, Tay	29.60	83.50		30		18
1101	Horseshoe Bch, Dix	29.40	83.25		32		
1102	Suwannee River, Dix	29.30	83.10		34		19
1201	Cedar Key, Lev	29.15	83.00		37	6	
1202	Waccasassa River, Lev	29.15	82.83		38		20
1301	Crystal River, Cit	28.88	82.64		40		21
1302	Homasassa Bay, Cit	28.75	82.64		41		22
1303	Chassahowitzka Bay, Cit	28.65	82.64		42		23

Table III- 1. Cross-Reference and Location List (continued)

Ref	Location	Latitude (deg N)	Longitude (deg W)	FDEP Ref	FEMA Ref	NOAA Ref	ADCIRC Ref
1401	Little Pine Is Bay, Her	28.50	82.64		45		24
1501	Port Richey, Pas	28.25	82.75		47		
1601	Anclote River, Pin	28.08	82.83	1601	46		25
1602	Hurricane Pass, Pin	27.89	82.85	1602	49		
1603	St Pete Bch, Pin	27.73	82.74	1603	51	7	
1604	Bunces Pass, Pin	27.62	82.72	1604	52		
1701	Tampa Bay, Man	27.54	82.74	1701		8	26
1702	Bradenton Bch, Man	27.46	82.70	1702			31
1703	Longboat Key, Man	27.39	82.64	1703			32
1801	Longboat Key, Sar	27.38	82.64	1801	53	9	33
1802	Venice Inlet, Sar	27.17	82.49	1802			34
1803	Manasota, Sar	26.95	82.38	1803	54		
1901	Manasota, Cha	26.95	82.38	1901			
1902	Don Pedro Is, Cha	26.89	82.33	1902	55		27
1903	Gasparilla Pass, Cha	26.81	82.28	1903			28
2001	Gasparilla Is, Lee	26.79	82.27	2001	56		
2002	Captiva Pass, Lee	26.65	82.25	2002	57		29
2003	Captiva, Lee	26.52	82.19	2003	58		
2004	Sanibel Is, Lee	26.42	82.09	2004	59		35
2005	Ft Myers Bch, Lee	26.43	81.91	2005	60	10	30
2006	Bonita Bch, Lee	26.34	81.85	2006	61		36
2101	Wiggins Pass, Col	26.32	81.84	2101	62		
2102	Doctors Pass, Col	26.19	81.82	2102	63		37
2103	Keewaydin Is, Col	26.06	81.79	2103	64		38
2104	Naples, Col	25.92	81.73	2104	65	11	39
2201	Highland Pt., Mon	25.50	81.20		67		40
2202	Shark Pt, Mon	25.30	81.20		68		41
2203	Key West, Mon	24.70	81.40		69	12	
2204	Big Pine Key, Mon	24.80	80.80		71		
2205	Long Key, Mon	25.10	80.40		72		
2206	Key Largo, Mon	25.25	80.30		75	13	
2207	N Key Largo, Mon	25.10	80.40		76		
2301	Key Biscayne, Dad	25.68	80.16	2301	78		42
2302	Miami Bch, Dad	25.83	80.12	2302	79	14	43
2303	Bakers Haulover, Dad	25.95	80.12	2303	80		44
2401	Hollywood, Bro	26.03	80.11	2401	82		45
2402	Ft Lauderdale, Bro	26.06	80.11	2402	83		
2403	Pompano Bch, Bro	26.22	80.09	2403	84		46
2501	Boca Raton, Pal	26.33	80.07	2501	85		
2502	Boynton Inlet, Pal	26.53	80.05	2502	86		48
2503	Lake Worth Inlet, Pal	26.76	80.04	2503	87		49
2504	Jupiter Inlet, Pal	26.96	80.08	2504	88		50
2601	Blowing Rocks, Mar	27.01	80.09	2601	89		
2602	St. Lucie Inlet, Mar	27.15	80.15	2602	90		51
2603	Jensen Bch, Mar	27.26	80.20	2603	91		
2701	Jensen Bch Park, StL	27.27	80.20	2701			

Table III- 1. Cross-Reference and Location List (continued)

Ref	Location	Latitude (deg N)	Longitude (deg W)	FDEP Ref	FEMA Ref	NOAA Ref	ADCIRC Ref
2702	Ft Pierce Inlet S, StL	27.42	80.27	2702	92		
2703	Ft Pierce Inlet N, StL	27.54	80.32	2703		16	52
2801	Vero Bch, Ind	27.58	80.33	2801			
2802	Indian R Shores, Ind	27.74	80.38	2802	93		
2803	Sebastian Inlet, Ind	27.84	80.44	2803			
2901	Sebastian Bch, Bre	27.91	80.47	2901	96		53
2902	Satellite Bch, Bre	28.18	80.59	2902	97		
2903	Cocoa Bch, Bre	27.58	80.33	2903	99	17	54
2904	Cape Canaveral, Bre	28.50	80.50		100		
2905	N Cape Canaveral, Bre	28.80	80.65		101		
3001	New Smyrne Bch, Vol	28.88	80.79	3001			
3002	Daytona Bch, Vol	29.15	80.97	3002	103	18	55
3003	N. Penisula Rec., Vol	29.43	81.10	3003			
3101	Flagler Bch, Fla	29.44	81.10	3101			
3102	Painters Hill, Fla	29.54	81.16	3102	104		
3103	Marineland, Fla	29.67	81.21	3103			56
3201	Matanzas Inlet, StJ	29.70	81.22	3201	105		
3202	St. Augustine Inlet, StJ	29.96	81.31	3202	106	19	57
3203	Ponte Vedra Bch, StJ	30.23	81.37	3203	107		
3301	Lake Duval, Duv	30.26	81.38	3301			
3302	Manhattan Bch, Duv	30.36	81.40	3302	108		58
3303	Little Talbot Is, Duv	30.48	81.41	3303	109		
3401	Nassau Sound, Nas	30.54	81.44	3401			59
3402	Fernandina Bch, Nas	30.70	81.43	3402		20	
3403	St. Marys Ent., Nas	30.71	81.43	3403			

Table III- 2. 50-year Peak Storm Surge Heights.

Ref	Location	50-yr Peak Storm Surge Height (ft, NGVD)				Rec. Source
		FDEP	FEMA	ADCIRC	Rec.	
101	Escambia W, Esc	9.8	6.8		**9.8**	FDEP
102	Pensacola Bay, Esc	9.7	6.8	6.5	**9.7**	FDEP
103	Pensacola Bch, Esc	9.4	6.8		**9.4**	FDEP
104	Eglin AFB, Esc	9.2	6.8		**9.2**	FDEP
301	Eglin AFB, Oka	9.9			**9.9**	FDEP
302	Destin W, Oka	10.2		5.0	**10.2**	FDEP
303	Destin E, Oka	10.2			**10.2**	FDEP
401	Miramar Bch, Wal	9.8	6.8		**9.8**	FDEP
402	Grayton Bch, Wal	9.4	6.8		**9.4**	FDEP
403	Inlet Bch, Wal	8.9	6.8		**8.9**	FDEP
501	Hollywood Bch, Bay	10.6	4.6		**10.6**	FDEP
502	Panama City, Bay	11.0	4.7	4.6	**11.0**	FDEP
503	Mexico Bch, Bay	10.7		4.7	**10.7**	FDEP
600	Beacon Hill, Gul	10.1	4.8	4.2	**10.1**	FDEP
601	St Joseph Pt, Gul	8.0			**8.0**	FDEP
602	St Joseph Park, Gul	7.7			**7.7**	FDEP
603	Cape San Blas, Gul	9.3			**9.3**	FDEP
604	McNeils, Gul	10.8			**10.8**	FDEP
605	Indian Pass, Gul	11.0		6.0	**11.0**	FDEP
701	St Vincent Is, Fra	10.1	6.0		**10.1**	FDEP
702	West Pass, Fra	10.2	6.3	6.1	**10.2**	FDEP
703	Sikes Cut, Fra	10.2	8.1		**10.2**	FDEP
704	St George Is, Fra	10.5	8.9		**10.5**	FDEP
705	Dog Is, Fra	11.5	9.9		**11.5**	FDEP
706	Alligator Harbor, Fra	12.2	12.5	7.7	**12.2**	FDEP
801	Lighthouse Pt, Wak	13.1		10.9	**13.1**	FDEP
802	Shell Pt, Wak	13.3	13.4	10.9	**13.3**	FDEP
803	Goose Creek Bay, Wak	13.5	13.4	11.0	**13.5**	FDEP
804	Whale Is, Wak	13.9	13.1	11.0	**13.9**	FDEP
805	Palmetto Is, Wak	14.2		11.1	**14.2**	FDEP
806	Little Redfish Pt, Wak	13.9	13.3	12.8	**13.9**	FDEP
1001	Stake Pt, Tay			13.7	**13.6**	Interp
1002	Deadman Bay, Tay			13.7	**13.4**	Interp
1101	Horseshoe Bch, Dix				**13.1**	Interp
1102	Suwannee River, Dix		12.4	12.6	**12.8**	Interp
1201	Cedar Key, Lev		11.8		**12.6**	Interp
1202	Waccasassa River, Lev		12.3	12.0	**12.3**	FEMA
1301	Crystal River, Cit			9.6	**12.0**	Interp
1302	Homasassa Bay, Cit			9.6	**11.7**	Interp
1303	Chassahowitzka Bay, Cit			9.6	**11.5**	Interp
1401	Little Pine Is Bay, Her		11.4	8.5	**11.2**	Interp
1501	Port Richey, Pas		10.9		**10.9**	FEMA
1601	Anclote River, Pin	9.5	10.9	8.5	**9.5**	FDEP

Table III- 2. 50-year Peak Storm Surge Heights (continued).

Ref	Location	50-yr Peak Storm Surge Height (ft, NGVD)				Rec. Source
		FDEP	FEMA	ADCIRC	Rec.	
1602	Hurricane Pass, Pin	8.5	8.2		**8.5**	FDEP
1603	St Pete Bch, Pin	9.9	8.1		**9.9**	FDEP
1604	Bunces Pass, Pin	8.5	7.8		**8.5**	FDEP
1701	Tampa Bay, Man	11.0		9.9	**11.0**	FDEP
1702	Bradenton Bch, Man	11.1		10.5	**11.1**	FDEP
1703	Longboat Key, Man	11.3		10.9	**11.3**	FDEP
1801	Longboat Key, Sar	11.4	8.6	10.9	**11.4**	FDEP
1802	Venice Inlet, Sar	11.3		10.6	**11.3**	FDEP
1803	Manasota, Sar	11.7	8.6		**11.7**	FDEP
1901	Manasota, Cha	11.7			**11.7**	FDEP
1902	Don Pedro Is, Cha	11.5		10.9	**11.5**	FDEP
1903	Gasparilla Pass, Cha	11.4		12.6	**11.4**	FDEP
2001	Gasparilla Is, Lee	10.7	8.2		**10.7**	FDEP
2002	Captiva Pass, Lee	10.6	8.7	12.8	**10.6**	FDEP
2003	Captiva, Lee	10.6	8.9		**10.6**	FDEP
2004	Sanibel Is, Lee	11.6	8.9	13.6	**11.6**	FDEP
2005	Ft Myers Bch, Lee	12.9	10.8	13.4	**12.9**	FDEP
2006	Bonita Bch, Lee	12.9	10.1	13.1	**12.9**	FDEP
2101	Wiggins Pass, Col	13.1			**13.1**	FDEP
2102	Doctors Pass, Col	12.2		12.3	**12.2**	FDEP
2103	Keewaydin Is, Col	11.5		12.2	**11.5**	FDEP
2104	Naples, Col	11.5		12.2	**11.5**	FDEP
2201	Highland Pt., Mon		12.8	11.9	**11.6**	Interp
2202	Shark Pt, Mon		10.9	11.9	**11.7**	Interp
2203	Key West, Mon		5.5		**11.7**	Interp
2204	Big Pine Key, Mon		5.5		**11.8**	Interp
2205	Long Key, Mon		5.9		**11.9**	Interp
2206	Key Largo, Mon		6.6		**12.0**	Interp
2207	N Key Largo, Mon		7.0		**12.1**	Interp
2301	Key Biscayne, Dad	12.1	7.5	4.4	**12.1**	FDEP
2302	Miami Bch, Dad	10.8	6.9	4.5	**10.8**	FDEP
2303	Bakers Haulover, Dad	11.4	6.4	3.9	**11.4**	FDEP
2401	Hollywood, Bro	11.4		4.0	**11.4**	FDEP
2402	Ft Lauderdale, Bro	11.2			**11.2**	FDEP
2403	Pompano Bch, Bro	10.9		3.9	**10.9**	FDEP
2501	Boca Raton, Pal	9.9			**9.9**	FDEP
2502	Boynton Inlet, Pal	9.9	6.3	4.0	**9.9**	FDEP
2503	Lake Worth Inlet, Pal	9.7	6.3	4.1	**9.7**	FDEP
2504	Jupiter Inlet, Pal	9.8	6.3	4.0	**9.8**	FDEP
2601	Blowing Rocks, Mar	10.3	6.2		**10.3**	FDEP
2602	St. Lucie Inlet, Mar	10.8	6.1	4.6	**10.8**	FDEP
2603	Jensen Bch, Mar	11.1	6.2		**11.1**	FDEP
2701	Jensen Bch Park, StL	10.4			**10.4**	FDEP
2702	Ft Pierce Inlet S, StL	10.8	6.3		**10.8**	FDEP

Table III- 2. 50-year Peak Storm Surge Heights (continued).

Ref	Location	50-yr Peak Storm Surge Height (ft, NGVD)				Rec. Source
		FDEP	FEMA	ADCIRC	Rec.	
2703	Ft Pierce Inlet N, StL	11.1		5.5	**11.1**	FDEP
2801	Vero Bch, Ind	10.2			**10.2**	FDEP
2802	Indian R Shores, Ind	10.0	6.4		**10.0**	FDEP
2803	Sebastian Inlet, Ind	9.9			**9.9**	FDEP
2901	Sebastian Bch, Bre	10.2	6.5	6.3	**10.2**	FDEP
2902	Satellite Bch, Bre	9.8	6.7		**9.8**	FDEP
2903	Cocoa Bch, Bre	9.4	6.5	4.6	**9.4**	FDEP
2904	Cape Canaveral, Bre		6.6		**9.4**	Interp
2905	N Cape Canaveral, Bre		7.0		**9.5**	Interp
3001	New Smyrne Bch, Vol	9.5			**9.5**	FDEP
3002	Daytona Bch, Vol	8.8	7.2	5.1	**8.8**	FDEP
3003	N. Penisula Rec., Vol	9.2			**9.2**	FDEP
3101	Flagler Bch, Fla	8.7			**8.7**	FDEP
3102	Painters Hill, Fla	9.4	7.1		**9.4**	FDEP
3103	Marineland, Fla	9.8		9.1	**9.8**	FDEP
3201	Matanzas Inlet, StJ	9.2	7.2		**9.2**	FDEP
3202	St. Augustine Inlet, StJ	9.6	7.7	9.4	**9.6**	FDEP
3203	Ponte Vedra Bch, StJ	10.4	7.9		**10.4**	FDEP
3301	Lake Duval, Duv	10.5			**10.5**	FDEP
3302	Manhattan Bch, Duv	10.5		10.8	**10.5**	FDEP
3303	Little Talbot Is, Duv	10.6	8.9		**10.6**	FDEP
3401	Nassau Sound, Nas	11.1		9.9	**11.1**	FDEP
3402	Fernandina Bch, Nas	11.6			**11.6**	FDEP
3403	St. Marys Ent., Nas	11.9			**11.9**	FDEP

Table III- 3. 100-year Peak Storm Surge Heights.

Ref	Location	100-yr Peak Storm Surge Height (ft, NGVD)				Rec. Source
		FDEP	FEMA	ADCIRC	Rec.	
101	Escambia W, Esc	11.4	10.5		**11.4**	FDEP
102	Pensacola Bay, Esc	11.0	10.5	7.6	**11.0**	FDEP
103	Pensacola Bch, Esc	10.8	10.5		**10.8**	FDEP
104	Eglin AFB, Esc	10.7	10.5		**10.7**	FDEP
301	Eglin AFB, Oka	11.2	7.7		**11.2**	FDEP
302	Destin W, Oka	11.4	7.5	5.7	**11.4**	FDEP
303	Destin E, Oka	11.4	7.7		**11.4**	FDEP
401	Miramar Bch, Wal	11.4	8.0		**11.4**	FDEP
402	Grayton Bch, Wal	11.2	8.0		**11.2**	FDEP
403	Inlet Bch, Wal	10.5	8.0		**10.5**	FDEP
501	Hollywood Bch, Bay	11.9	5.3		**11.9**	FDEP
502	Panama City, Bay	12.2	5.5	5.3	**12.2**	FDEP
503	Mexico Bch, Bay	12.0		5.3	**12.0**	FDEP
600	Beacon Hill, Gul	11.7	5.7	4.8	**11.7**	FDEP
601	St Joseph Pt, Gul	9.3			**9.3**	FDEP
602	St Joseph Park, Gul	8.8	7.0		**8.8**	FDEP
603	Cape San Blas, Gul	11.1			**11.1**	FDEP
604	McNeils, Gul	12.4			**12.4**	FDEP
605	Indian Pass, Gul	12.6		7.2	**12.6**	FDEP
701	St Vincent Is, Fra	12.0	6.5		**12.0**	FDEP
702	West Pass, Fra	12.1	6.9	7.2	**12.1**	FDEP
703	Sikes Cut, Fra	12.3	8.8		**12.3**	FDEP
704	St George Is, Fra	12.6	9.5		**12.6**	FDEP
705	Dog Is, Fra	13.0	10.7		**13.0**	FDEP
706	Alligator Harbor, Fra	14.7	13.5	9.5	**14.7**	FDEP
801	Lighthouse Pt, Wak	14.7		13.3	**14.7**	FDEP
802	Shell Pt, Wak	15.1	15.0	13.3	**15.1**	FDEP
803	Goose Creek Bay, Wak	15.3	15.1	13.4	**15.3**	FDEP
804	Whale Is, Wak	15.3	14.9	13.4	**15.3**	FDEP
805	Palmetto Is, Wak	15.5		13.5	**15.5**	FDEP
806	Little Redfish Pt, Wak	15.2	15.1	15.2	**15.2**	FDEP
1001	Stake Pt, Tay		14.7	16.6	**14.9**	Interp
1002	Deadman Bay, Tay		14.3	17.7	**14.6**	Interp
1101	Horseshoe Bch, Dix		13.7		**14.3**	Interp
1102	Suwannee River, Dix		14.0	16.3	**14.0**	Interp
1201	Cedar Key, Lev		13.1		**13.7**	Interp
1202	Waccasassa River, Lev		13.6	14.3	**13.3**	Interp
1301	Crystal River, Cit		13.5	11.2	**13.0**	Interp
1302	Homasassa Bay, Cit		13.0	11.2	**12.7**	Interp
1303	Chassahowitzka Bay, Cit		12.5	11.1	**12.4**	Interp
1401	Little Pine Is Bay, Her		12.6	9.9	**12.1**	Interp
1501	Port Richey, Pas		12.7		**11.8**	Interp
1601	Anclote River, Pin	11.5	12.7	9.9	**11.5**	FDEP

Table III- 3. 100-year Peak Storm Surge Heights (continued).

Ref	**Location**	**100-yr Peak Storm Surge Height (ft, NGVD)**				**Rec. Source**
		FDEP	**FEMA**	**ADCIRC**	**Rec.**	
1602	Hurricane Pass, Pin	10.1	9.7		**10.1**	FDEP
1603	St Pete Bch, Pin	11.5	9.6		**11.5**	FDEP
1604	Bunces Pass, Pin	9.9	9.2		**9.9**	FDEP
1701	Tampa Bay, Man	12.3		12.3	**12.3**	FDEP
1702	Bradenton Bch, Man	12.5		13.4	**12.5**	FDEP
1703	Longboat Key, Man	12.8		14.0	**12.8**	FDEP
1801	Longboat Key, Sar	12.9	10.0	14.0	**12.9**	FDEP
1802	Venice Inlet, Sar	12.6		13.5	**12.6**	FDEP
1803	Manasota, Sar	13.1	10.0		**13.1**	FDEP
1901	Manasota, Cha	13.1			**13.1**	FDEP
1902	Don Pedro Is, Cha	12.9	11.0	13.9	**12.9**	FDEP
1903	Gasparilla Pass, Cha	12.7		15.6	**12.7**	FDEP
2001	Gasparilla Is, Lee	12.5	9.3		**12.5**	FDEP
2002	Captiva Pass, Lee	12.2	9.9	15.6	**12.2**	FDEP
2003	Captiva, Lee	12.2	10.0		**12.2**	FDEP
2004	Sanibel Is, Lee	13.4	10.0	16.7	**13.4**	FDEP
2005	Ft Myers Bch, Lee	14.8	12.4	16.6	**14.8**	FDEP
2006	Bonita Bch, Lee	14.7	12.5	16.1	**14.7**	FDEP
2101	Wiggins Pass, Col	15.2	11.0		**15.2**	FDEP
2102	Doctors Pass, Col	14.1	11.0	15.2	**14.1**	FDEP
2103	Keewaydin Is, Col	13.1	10.0	14.8	**13.1**	FDEP
2104	Naples, Col	12.9	10.0	14.9	**12.9**	FDEP
2201	Highland Pt., Mon		16.7	14.0	**13.0**	Interp
2202	Shark Pt, Mon		14.3	14.0	**13.2**	Interp
2203	Key West, Mon		8.4		**13.3**	Interp
2204	Big Pine Key, Mon		8.3		**13.5**	Interp
2205	Long Key, Mon		8.8		**13.6**	Interp
2206	Key Largo, Mon		9.4		**13.7**	Interp
2207	N Key Largo, Mon		9.9		**13.9**	Interp
2301	Key Biscayne, Dad	14.0	6.6	5.1	**14.0**	FDEP
2302	Miami Bch, Dad	13.6	6.9	5.2	**13.6**	FDEP
2303	Bakers Haulover, Dad	13.5	7.3	4.5	**13.5**	FDEP
2401	Hollywood, Bro	13.6	6.4	4.5	**13.6**	FDEP
2402	Ft Lauderdale, Bro	13.1	6.5		**13.1**	FDEP
2403	Pompano Bch, Bro	12.5	6.2	4.3	**12.5**	FDEP
2501	Boca Raton, Pal	11.6	6.2		**11.6**	FDEP
2502	Boynton Inlet, Pal	11.5	7.1	4.4	**11.5**	FDEP
2503	Lake Worth Inlet, Pal	11.1	7.1	4.6	**11.1**	FDEP
2504	Jupiter Inlet, Pal	11.2	7.1	4.6	**11.2**	FDEP
2601	Blowing Rocks, Mar	11.2	7.0		**11.2**	FDEP
2602	St. Lucie Inlet, Mar	11.6	7.2	5.3	**11.6**	FDEP
2603	Jensen Bch, Mar	11.9	7.0		**11.9**	FDEP
2701	Jensen Bch Park, StL	11.4			**11.4**	FDEP
2702	Ft Pierce Inlet S, StL	12.1	7.0		**12.1**	FDEP

Table III- 3. 100-year Peak Storm Surge Heights (continued).

Ref	Location	100-yr Peak Storm Surge Height (ft, NGVD)				Rec. Source
		FDEP	FEMA	ADCIRC	Rec.	
2703	Ft Pierce Inlet N, StL	12.3		6.4	**12.3**	FDEP
2801	Vero Bch, Ind	11.5			**11.5**	FDEP
2802	Indian R Shores, Ind	11.3	9.5		**11.3**	FDEP
2803	Sebastian Inlet, Ind	11.2			**11.2**	FDEP
2901	Sebastian Bch, Bre	11.6	9.5	7.4	**11.6**	FDEP
2902	Satellite Bch, Bre	11.1	9.9		**11.1**	FDEP
2903	Cocoa Bch, Bre	10.7	9.4	5.0	**10.7**	FDEP
2904	Cape Canaveral, Bre		9.8		**10.9**	Interp
2905	N Cape Canaveral, Bre		10.2		**11.0**	Interp
3001	New Smyrne Bch, Vol	11.2			**11.2**	FDEP
3002	Daytona Bch, Vol	10.6	8.0	5.6	**10.6**	FDEP
3003	N. Penisula Rec., Vol	11.3			**11.3**	FDEP
3101	Flagler Bch, Fla	10.7			**10.7**	FDEP
3102	Painters Hill, Fla	11.8	8.3		**11.8**	FDEP
3103	Marineland, Fla	12.6		10.2	**12.6**	FDEP
3201	Matanzas Inlet, StJ	12.3	8.4		**12.3**	FDEP
3202	St. Augustine Inlet, StJ	12.3	9.0	10.5	**12.3**	FDEP
3203	Ponte Vedra Bch, StJ	13.1	9.3		**13.1**	FDEP
3301	Lake Duval, Duv	13.2			**13.2**	FDEP
3302	Manhattan Bch, Duv	13.2	11.0	12.3	**13.2**	FDEP
3303	Little Talbot Is, Duv	13.1	9.9		**13.1**	FDEP
3401	Nassau Sound, Nas	13.2		11.0	**13.2**	FDEP
3402	Fernandina Bch, Nas	13.7			**13.7**	FDEP
3403	St. Marys Ent., Nas	13.9			**13.9**	FDEP

Table III- 4. 500-year Peak Storm Surge Heights.

Ref	Location	500-yr Peak Storm Surge Height (ft, NGVD)					Rec. Source
		FDEP	FEMA	NOAA	ADCIRC	Rec.	
101	Escambia W, Esc	15.3	11.0			**15.3**	FDEP
102	Pensacola Bay, Esc	14.3	11.0	12.7	10.2	**14.3**	FDEP
103	Pensacola Bch, Esc	13.9	11.0			**13.9**	FDEP
104	Eglin AFB, Esc	13.8	11.0			**13.8**	FDEP
301	Eglin AFB, Oka	13.0				**13.0**	FDEP
302	Destin W, Oka	13.7		11.0	7.5	**13.7**	FDEP
303	Destin E, Oka	13.7				**13.7**	FDEP
401	Miramar Bch, Wal	14.2	10.8			**14.2**	FDEP
402	Grayton Bch, Wal	14.1	10.8			**14.1**	FDEP
403	Inlet Bch, Wal	13.6	10.8			**13.6**	FDEP
501	Hollywood Bch, Bay	14.8	6.9			**14.8**	FDEP
502	Panama City, Bay	15.1	7.4	14.6	6.9	**15.1**	FDEP
503	Mexico Bch, Bay	15.0			6.9	**15.0**	FDEP
600	Beacon Hill, Gul	16.3	7.1		6.1	**16.3**	FDEP
601	St Joseph Pt, Gul	12.6				**12.6**	FDEP
602	St Joseph Park, Gul	11.9				**11.9**	FDEP
603	Cape San Blas, Gul	16.0				**16.0**	FDEP
604	McNeils, Gul	16.9		14.7		**16.9**	FDEP
605	Indian Pass, Gul	17.0			9.8	**17.0**	FDEP
701	St Vincent Is, Fra	14.7	7.6			**14.7**	FDEP
702	West Pass, Fra	15.1	8.0		9.9	**15.1**	FDEP
703	Sikes Cut, Fra	15.4	10.0			**15.4**	FDEP
704	St George Is, Fra	16.0	10.8			**16.0**	FDEP
705	Dog Is, Fra	16.4	12.2			**16.4**	FDEP
706	Alligator Harbor, Fra	18.7	15.2		13.5	**18.7**	FDEP
801	Lighthouse Pt, Wak	17.3			18.9	**17.3**	FDEP
802	Shell Pt, Wak	17.3	17.5		18.9	**17.3**	FDEP
803	Goose Creek Bay, Wak	17.8	18.2		19.0	**17.8**	FDEP
804	Whale Is, Wak	18.1	17.9		19.0	**18.1**	FDEP
805	Palmetto Is, Wak	18.3			19.1	**18.3**	FDEP
806	Little Redfish Pt, Wak	17.9	18.4		20.6	**17.9**	FDEP
1001	Stake Pt, Tay				23.3	**17.7**	Interp
1002	Deadman Bay, Tay				26.9	**17.5**	Interp
1101	Horseshoe Bch, Dix					**17.2**	Interp
1102	Suwannee River, Dix		17.0		25.1	**17.0**	FEMA
1201	Cedar Key, Lev		15.5	21.4		**15.5**	FEMA
1202	Waccasassa River, Lev		16.0		19.6	**16.0**	FEMA
1301	Crystal River, Cit				14.9	**15.9**	Interp
1302	Homasassa Bay, Cit				14.8	**15.8**	Interp
1303	Chassahowitzka Bay, Cit				14.8	**15.6**	Interp
1401	Little Pine Is Bay, Her		14.7		13.2	**15.5**	Interp
1501	Port Richey, Pas		16.5			**15.4**	Interp
1601	Anclote River, Pin	15.3	16.5		13.2	**15.3**	FDEP

Table III- 4. 500-year Peak Storm Surge Heights (continued).

Ref	Location	500-yr Peak Storm Surge Height (ft, NGVD)					Rec. Source
		FDEP	FEMA	NOAA	ADCIRC	Rec.	
1602	Hurricane Pass, Pin	13.4	13.6			**13.4**	FDEP
1603	St Pete Bch, Pin	14.7	12.7	20.3		**14.7**	FDEP
1604	Bunces Pass, Pin	13.1	11.8			**13.1**	FDEP
1701	Tampa Bay, Man	15.0		25.5	18.1	**15.0**	FDEP
1702	Bradenton Bch, Man	15.0			20.4	**15.0**	FDEP
1703	Longboat Key, Man	15.7			21.3	**15.7**	FDEP
1801	Longboat Key, Sar	16.0	12.6	18.8	21.3	**16.0**	FDEP
1802	Venice Inlet, Sar	15.6			20.4	**15.6**	FDEP
1803	Manasota, Sar	15.5	12.6			**15.5**	FDEP
1901	Manasota, Cha	15.5				**15.5**	FDEP
1902	Don Pedro Is, Cha	15.0			20.8	**15.0**	FDEP
1903	Gasparilla Pass, Cha	15.0			22.5	**15.0**	FDEP
2001	Gasparilla Is, Lee	15.4	11.7			**15.4**	FDEP
2002	Captiva Pass, Lee	14.7	12.2		22.1	**14.7**	FDEP
2003	Captiva, Lee	14.9	12.3			**14.9**	FDEP
2004	Sanibel Is, Lee	16.2	12.3		24.1	**16.2**	FDEP
2005	Ft Myers Bch, Lee	17.4	15.5	22.6	24.0	**17.4**	FDEP
2006	Bonita Bch, Lee	17.9	14.4		23.2	**17.9**	FDEP
2101	Wiggins Pass, Col	18.9				**18.9**	FDEP
2102	Doctors Pass, Col	17.5			22.0	**17.5**	FDEP
2103	Keewaydin Is, Col	16.3			21.0	**16.3**	FDEP
2104	Naples, Col	15.1		21.7	21.0	**15.1**	FDEP
2201	Highland Pt., Mon		17.8		19.0	**15.5**	Interp
2202	Shark Pt, Mon		14.0		19.0	**15.8**	Interp
2203	Key West, Mon		7.3	10.8		**16.2**	Interp
2204	Big Pine Key, Mon		7.1			**16.5**	Interp
2205	Long Key, Mon		7.5			**16.9**	Interp
2206	Key Largo, Mon		8.2	11.0		**17.3**	Interp
2207	N Key Largo, Mon		8.6			**17.6**	Interp
2301	Key Biscayne, Dad	18.0	7.6		6.7	**18.0**	FDEP
2302	Miami Bch, Dad	17.7	7.8	10.8	6.8	**17.7**	FDEP
2303	Bakers Haulover, Dad	17.6	8.4		5.8	**17.6**	FDEP
2401	Hollywood, Bro	16.9	7.4		5.8	**16.9**	FDEP
2402	Ft Lauderdale, Bro	17.2	7.1			**17.2**	FDEP
2403	Pompano Bch, Bro	17.1	7.1		5.4	**17.1**	FDEP
2501	Boca Raton, Pal	14.6	7.1			**14.6**	FDEP
2502	Boynton Inlet, Pal	15.0	8.4		5.4	**15.0**	FDEP
2503	Lake Worth Inlet, Pal	15.0	8.4		5.7	**15.0**	FDEP
2504	Jupiter Inlet, Pal	15.4	8.4		6.0	**15.4**	FDEP
2601	Blowing Rocks, Mar	12.6	8.8			**12.6**	FDEP
2602	St. Lucie Inlet, Mar	13.0	9.1		7.0	**13.0**	FDEP
2603	Jensen Bch, Mar	13.5	8.8			**13.5**	FDEP
2701	Jensen Bch Park, StL	13.3				**13.3**	FDEP

Table III- 4. 500-year Peak Storm Surge Heights (continued).

Ref	Location	500-yr Peak Storm Surge Height (ft, NGVD)					Rec. Source
		FDEP	**FEMA**	**NOAA**	**ADCIRC**	**Rec.**	
2702	Ft Pierce Inlet S, StL	13.9	8.7			**13.9**	FDEP
2703	Ft Pierce Inlet N, StL	14.7		13.6	8.5	**14.7**	FDEP
2801	Vero Bch, Ind	13.9				**13.9**	FDEP
2802	Indian R Shores, Ind	13.4	9.7			**13.4**	FDEP
2803	Sebastian Inlet, Ind	13.4				**13.4**	FDEP
2901	Sebastian Bch, Bre	14.2	9.8		10.0	**14.2**	FDEP
2902	Satellite Bch, Bre	13.7	10.1			**13.7**	FDEP
2903	Cocoa Bch, Bre	13.3	9.8	14.6	6.0	**13.3**	FDEP
2904	Cape Canaveral, Bre		9.9			**14.0**	Interp
2905	N Cape Canaveral, Bre		10.6			**14.7**	Interp
3001	New Smyrne Bch, Vol	15.4				**15.4**	FDEP
3002	Daytona Bch, Vol	15.8	10.8	13.1	6.8	**15.8**	FDEP
3003	N. Penisula Rec., Vol	15.7				**15.7**	FDEP
3101	Flagler Bch, Fla	15.2				**15.2**	FDEP
3102	Painters Hill, Fla	16.7	10.8			**16.7**	FDEP
3103	Marineland, Fla	18.3			12.8	**18.3**	FDEP
3201	Matanzas Inlet, StJ	16.3	11.0			**16.3**	FDEP
3202	St. Augustine Inlet, StJ	16.9	11.7	17.0	13.1	**16.9**	FDEP
3203	Ponte Vedra Bch, StJ	18.9	12.2			**18.9**	FDEP
3301	Lake Duval, Duv	17.8				**17.8**	FDEP
3302	Manhattan Bch, Duv	17.9	12.0		15.6	**17.9**	FDEP
3303	Little Talbot Is, Duv	17.8	12.7			**17.8**	FDEP
3401	Nassau Sound, Nas	18.8			13.6	**18.8**	FDEP
3402	Fernandina Bch, Nas	19.9		19.1		**19.9**	FDEP
3403	St. Marys Ent., Nas	20.2				**20.2**	FDEP

Table III- 5. Summary of Recommended Peak Storm Surge Heights.

Ref	Location	Latitude (deg N)	Longitude (deg W)	Peak Storm Surge Height (ft, NGVD)		
				50-yr	100-yr	500-yr
101	Escambia W, Esc.	30.28	87.52	9.8	11.4	15.3
102	Pensacola Bay, Esc.	30.32	87.27	9.7	11.0	14.3
103	Pensacola Bch, Esc.	30.35	87.07	9.4	10.8	13.9
104	Eglin AFB, Esc.	30.38	86.87	9.2	10.7	13.8
301	Eglin AFB, Oka.	30.40	86.63	9.9	11.2	13.0
302	Destin W, Oka.	30.39	86.60	10.2	11.4	13.7
303	Destin E, Oka.	30.38	86.40	10.2	11.4	13.7
401	Miramar Bch, Wal.	30.37	86.35	9.8	11.4	14.2
402	Grayton Bch, Wal.	30.33	86.16	9.4	11.2	14.1
403	Inlet Bch, Wal.	30.29	86.05	8.9	10.5	13.6
501	Hollywood Bch, Bay	30.27	85.99	10.6	11.9	14.8
502	Panama City, Bay	30.10	85.69	11.0	12.2	15.1
503	Mexico Bch, Bay	29.93	85.39	10.7	12.0	15.0
600	Beacon Hill, Gulf	29.92	85.38	10.1	11.7	16.3
601	St Joseph Pt, Gulf	29.85	85.41	8.0	9.3	12.6
602	St Joseph Park, Gulf	29.76	85.40	7.7	8.8	11.9
603	Cape San Blas, Gulf	29.68	85.37	9.3	11.1	16.0
604	McNeils, Gulf	29.68	85.30	10.8	12.4	16.9
605	Indian Pass, Gulf	29.68	85.25	11.0	12.6	17.0
701	St Vincent Is, Fra.	29.59	85.05	10.1	12.0	14.7
702	West Pass, Fra.	29.63	84.93	10.2	12.1	15.1
703	Sikes Cut, Fra.	29.68	84.81	10.2	12.3	15.4
704	St George Is, Fra.	29.75	84.71	10.5	12.6	16.0
705	Dog Is, Fra.	29.80	84.59	11.5	13.0	16.4
706	Alligator Hbr, Fra.	29.90	84.35	12.2	14.7	18.7
801	Lighthouse Pt, Wak.	29.93	84.29	13.1	14.7	17.3
802	Shell Pt, Wak.	29.96	84.23	13.3	15.1	17.3
803	Goose Creek Bay, Wak.	30.00	84.17	13.5	15.3	17.8
804	Whale Is, Wak.	30.03	84.12	13.9	15.3	18.1
805	Palmetto Is, Wak.	30.07	84.06	14.2	15.5	18.3
806	Little Redfish Pt, Wak.	30.10	84.00	13.9	15.2	17.9
1001	Stake Pt, Tay.	30.00	83.80	13.6	14.9	17.7
1002	Deadman Bay, Tay.	29.60	83.50	13.4	14.6	17.5
1101	Horseshoe Bch, Dix.	29.40	83.25	13.1	14.3	17.2
1102	Suwannee River, Dix.	29.30	83.10	12.8	14.0	17.0
1201	Cedar Key, Levy	29.15	83.00	12.6	13.7	15.5
1202	Waccasassa River, Levy	29.15	82.83	12.3	13.3	16.0
1301	Crystal River, Cit.	28.88	82.64	12.0	13.0	15.9
1302	Homasassa Bay, Cit.	28.75	82.64	11.7	12.7	15.8
1303	Chassahowitzka Bay, Cit.	28.65	82.64	11.5	12.4	15.6
1401	Little Pine Is Bay, Her.	28.50	82.64	11.2	12.1	15.5
1501	Port Richey, Pas.	28.25	82.75	10.9	11.8	15.4
1601	Anclote River, Pin.	28.08	82.83	9.5	11.5	15.3

Table III- 5. Summary of Recommended Peak Storm Surge Heights (continued).

Ref	Location	Latitude (deg N)	Longitude (deg W)	Peak Storm Surge Height (ft, NGVD)		
				50-yr	100-yr	500-yr
1602	Hurricane Pass, Pin.	27.89	82.85	8.5	10.1	13.4
1603	St Pete Bch, Pin.	27.73	82.74	9.9	11.5	14.7
1604	Bunces Pass, Pin.	27.62	82.72	8.5	9.9	13.1
1701	Tampa Bay, Man.	27.54	82.74	11.0	12.3	15.0
1702	Bradenton Bch, Man.	27.46	82.70	11.1	12.5	15.0
1703	Longboat Key, Man.	27.39	82.64	11.3	12.8	15.7
1801	Longboat Key, Sar.	27.38	82.64	11.4	12.9	16.0
1802	Venice Inlet, Sar.	27.17	82.49	11.3	12.6	15.6
1803	Manasota, Sar.	26.95	82.38	11.7	13.1	15.5
1901	Manasota, Cha	26.95	82.38	11.7	13.1	15.5
1902	Don Pedro Is, Char.	26.89	82.33	11.5	12.9	15.0
1903	Gasparilla Pass, Char.	26.81	82.28	11.4	12.7	15.0
2001	Gasparilla Is, Lee	26.79	82.27	10.7	12.5	15.4
2002	Captiva Pass, Lee	26.65	82.25	10.6	12.2	14.7
2003	Captiva, Lee	26.52	82.19	10.6	12.2	14.9
2004	Sanibel Is, Lee	26.42	82.09	11.6	13.4	16.2
2005	Ft Myers Bch, Lee	26.43	81.91	12.9	14.8	17.4
2006	Bonita Bch, Lee	26.34	81.85	12.9	14.7	17.9
2101	Wiggins Pass, Col.	26.32	81.84	13.1	15.2	18.9
2102	Doctors Pass, Col.	26.19	81.82	12.2	14.1	17.5
2103	Keewaydin Is, Col.	26.06	81.79	11.5	13.1	16.3
2104	Naples, Col.	25.92	81.73	11.5	12.9	15.1
2201	Highland Pt., Mon.	25.50	81.20	11.6	13.0	15.5
2202	Shark Pt, Mon.	25.30	81.20	11.7	13.2	15.8
2203	Key West, Mon.	24.70	81.40	11.7	13.3	16.2
2204	Big Pine Key, Mon.	24.80	80.80	11.8	13.5	16.5
2205	Long Key, Mon.	25.10	80.40	11.9	13.6	16.9
2206	Key Largo, Mon.	25.25	80.30	12.0	13.7	17.3
2207	N. Key Largo, Mon.	25.10	80.40	12.1	13.9	17.6
2301	Key Biscayne, Dade	25.68	80.16	12.1	14.0	18.0
2302	Miami Bch, Dade	25.83	80.12	10.8	13.6	17.7
2303	Bakers Haulover, Dade	25.95	80.12	11.4	13.5	17.6
2401	Hollywood, Bro.	26.03	80.11	11.4	13.6	16.9
2402	Ft Lauderdale, Bro.	26.06	80.11	11.2	13.1	17.2
2403	Pompano Bch, Bro.	26.22	80.09	10.9	12.5	17.1
2501	Boca Raton, Palm.	26.33	80.07	9.9	11.6	14.6
2502	Boynton Inlet, Palm.	26.53	80.05	9.9	11.5	15.0
2503	Lake Worth Inlet, Palm.	26.76	80.04	9.7	11.1	15.0
2504	Jupiter Inlet, Palm.	26.96	80.08	9.8	11.2	15.4
2601	Blowing Rocks, Mar.	27.01	80.09	10.3	11.2	12.6
2602	St. Lucie Inlet, Mar.	27.15	80.15	10.8	11.6	13.0
2603	Jensen Bch, Mar.	27.26	80.20	11.1	11.9	13.5
2701	Jensen Bch Park, StL.	27.27	80.20	10.4	11.4	13.3

Table III- 5. Summary of Recommended Peak Storm Surge Heights (continued).

Ref	Location	Latitude (deg N)	Longitude (deg W)	Peak Storm Surge Height (ft, NGVD)		
				50-yr	100-yr	500-yr
2702	Ft Pierce Inlet S, StL.	27.42	80.27	10.8	12.1	13.9
2703	Ft Pierce Inlet N, StL.	27.54	80.32	11.1	12.3	14.7
2801	Vero Bch, Ind.	27.58	80.33	10.2	11.5	13.9
2802	Indian R Shores, Ind.	27.74	80.38	10.0	11.3	13.4
2803	Sebastian Inlet, Ind.	27.84	80.44	9.9	11.2	13.4
2901	Sebastian Bch, Bre.	27.91	80.47	10.2	11.6	14.2
2902	Satellite Bch, Bre.	28.18	80.59	9.8	11.1	13.7
2903	Cocoa Bch, Bre.	27.58	80.33	9.4	10.7	13.3
2904	Cape Canaveral, Bre.	28.50	80.50	9.4	10.9	14.0
2905	N Cape Canaveral, Bre.	28.80	80.65	9.5	11.0	14.7
3001	New Smyrne Bch, Vol.	28.88	80.79	9.5	11.2	15.4
3002	Daytona Bch, Vol.	29.15	80.97	8.8	10.6	15.8
3003	N. Penisula Rec., Vol.	29.43	81.10	9.2	11.3	15.7
3101	Flagler Bch, Flag.	29.44	81.10	8.7	10.7	15.2
3102	Painters Hill, Flag.	29.54	81.16	9.4	11.8	16.7
3103	Marineland, Flag.	29.67	81.21	9.8	12.6	18.3
3201	Matanzas Inlet, StJ.	29.70	81.22	9.2	12.3	16.3
3202	St. Augustine Inlet, StJ.	29.96	81.31	9.6	12.3	16.9
3203	Ponte Vedra Bch, StJ.	30.23	81.37	10.4	13.1	18.9
3301	Lake Duval, Duv.	30.26	81.38	10.5	13.2	17.8
3302	Manhattan Bch, Duv.	30.36	81.40	10.5	13.2	17.9
3303	Little Talbot Is, Duv.	30.48	81.41	10.6	13.1	17.8
3401	Nassau Sound, Nas.	30.54	81.44	11.1	13.2	18.8
3402	Fernandina Bch, Nas.	30.70	81.43	11.6	13.7	19.9
3403	St. Marys Ent., Nas.	30.71	81.43	11.9	13.9	20.2

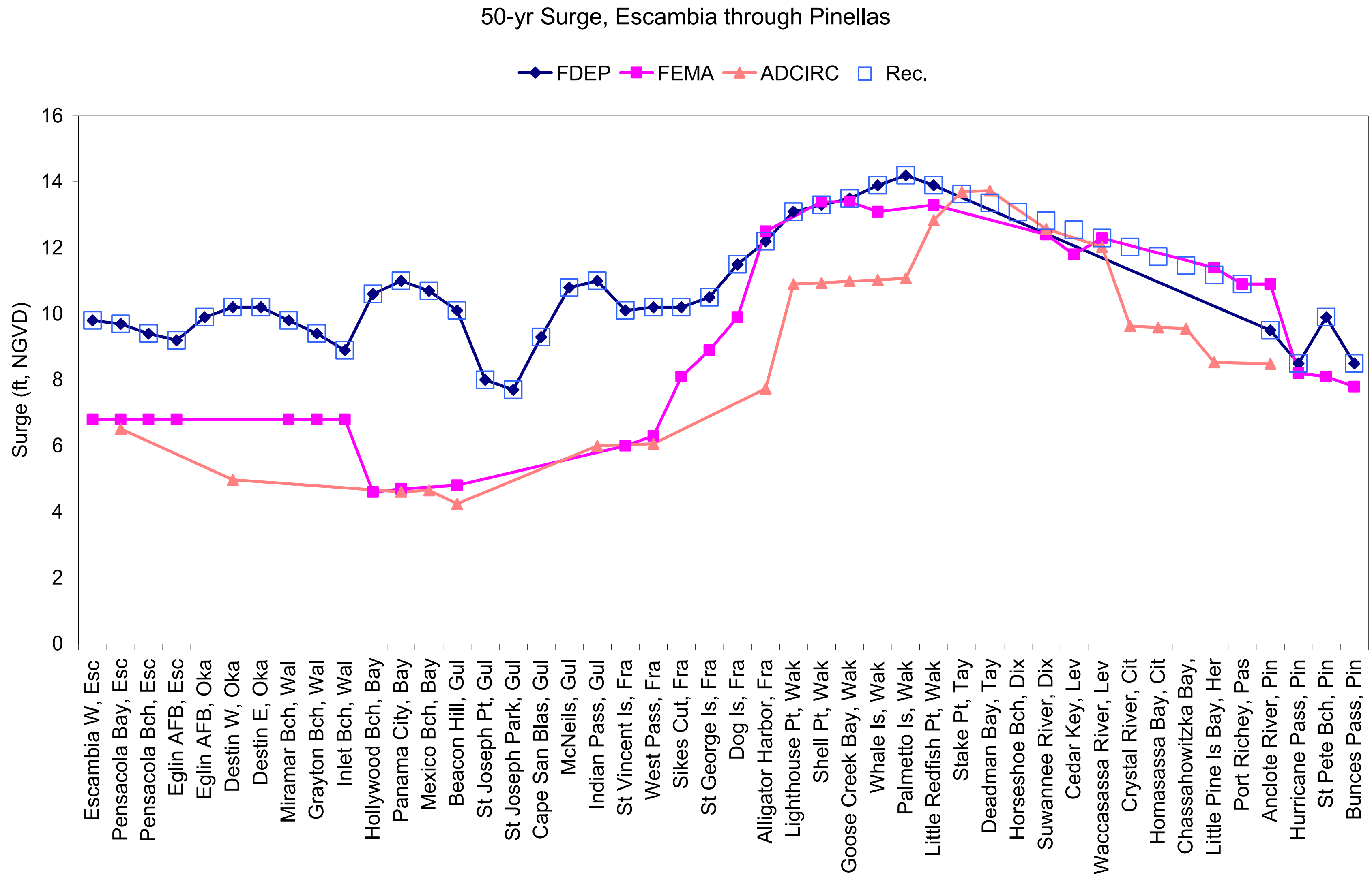

Figure III- 1. Peak 50-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Escambia to Pinellas counties. Recommended (Rec.) values are indicated by a box (☐).

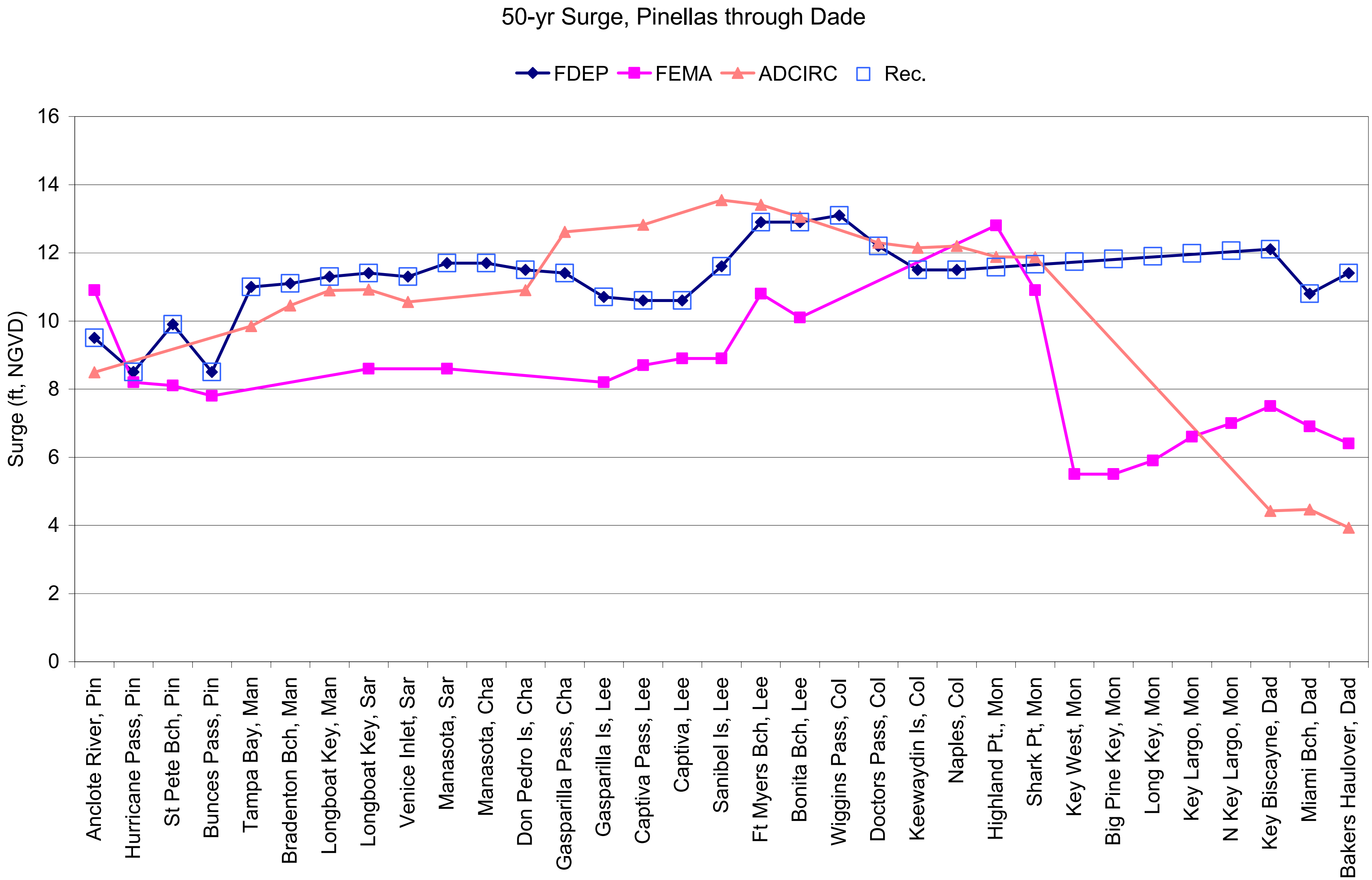

Figure III- 2. Peak 50-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Pinellas to Dade counties. Recommended (Rec.) values are indicated by a box (☐).

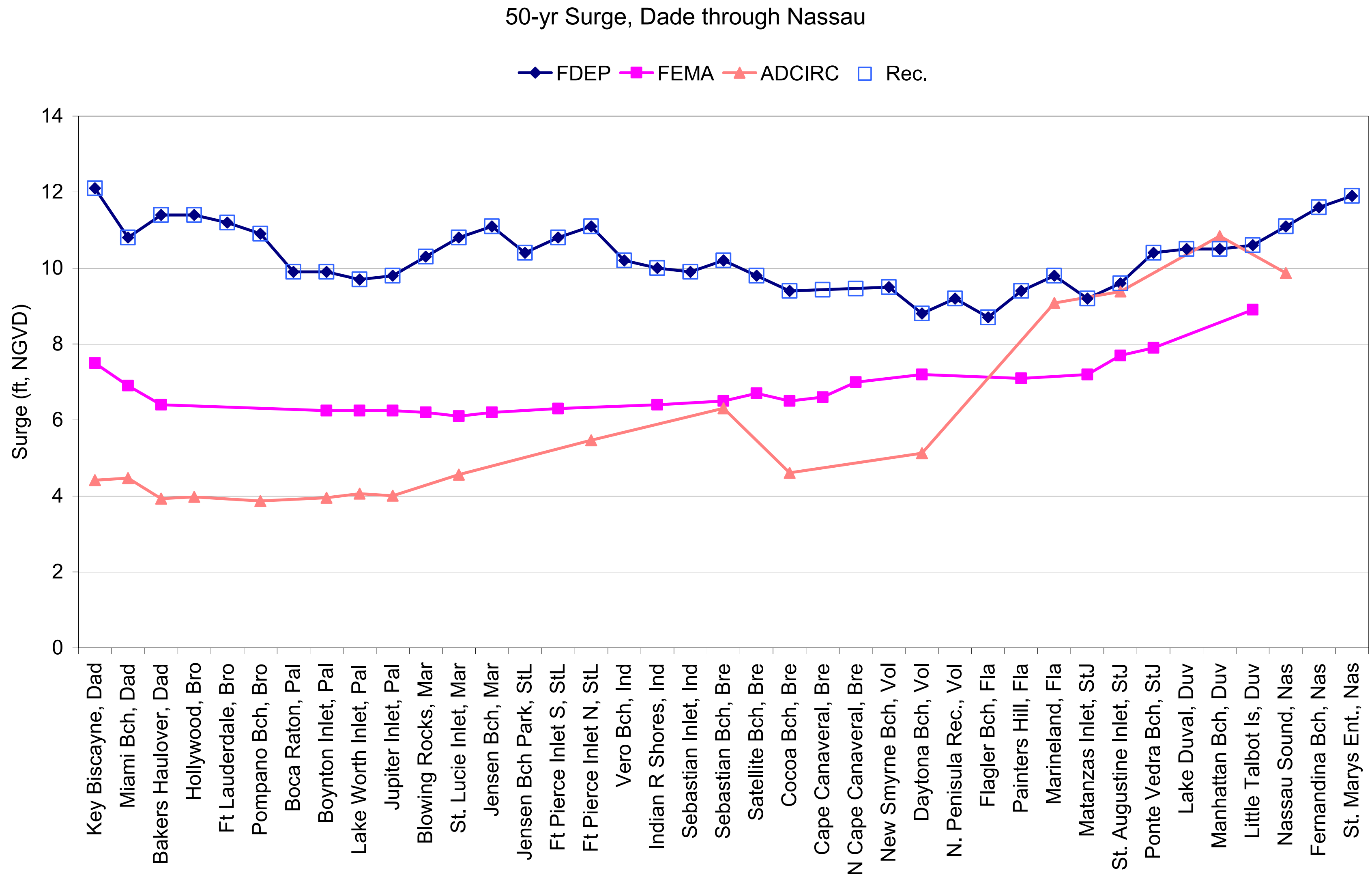

Figure III- 3. Peak 50-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Dade to Nassau counties. Recommended (Rec.) values are indicated by a box (☐).

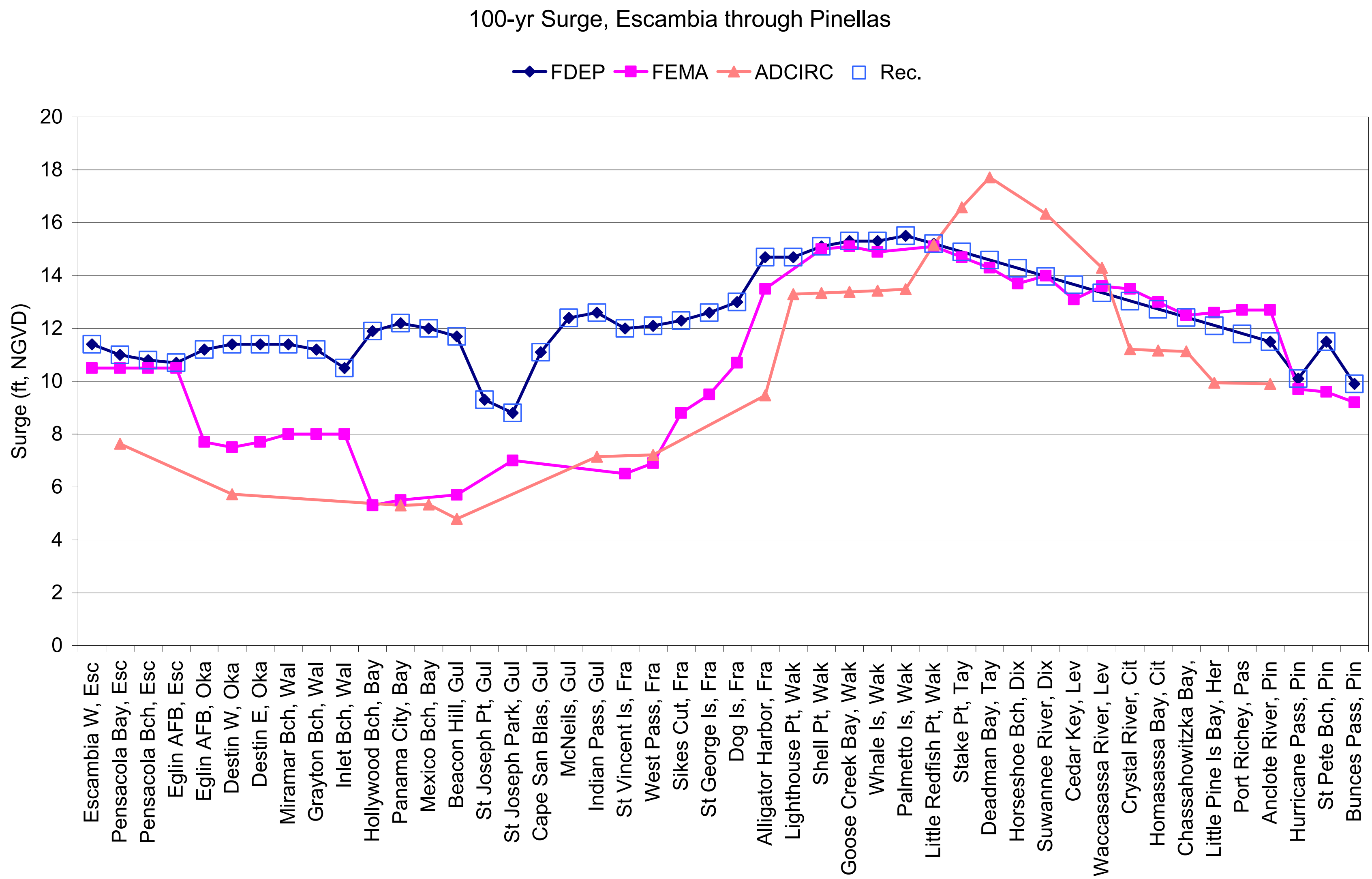

Figure III- 4. Peak 100-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Escambia to Pinellas counties. Recommended (Rec.) values are indicated by a box (☐).

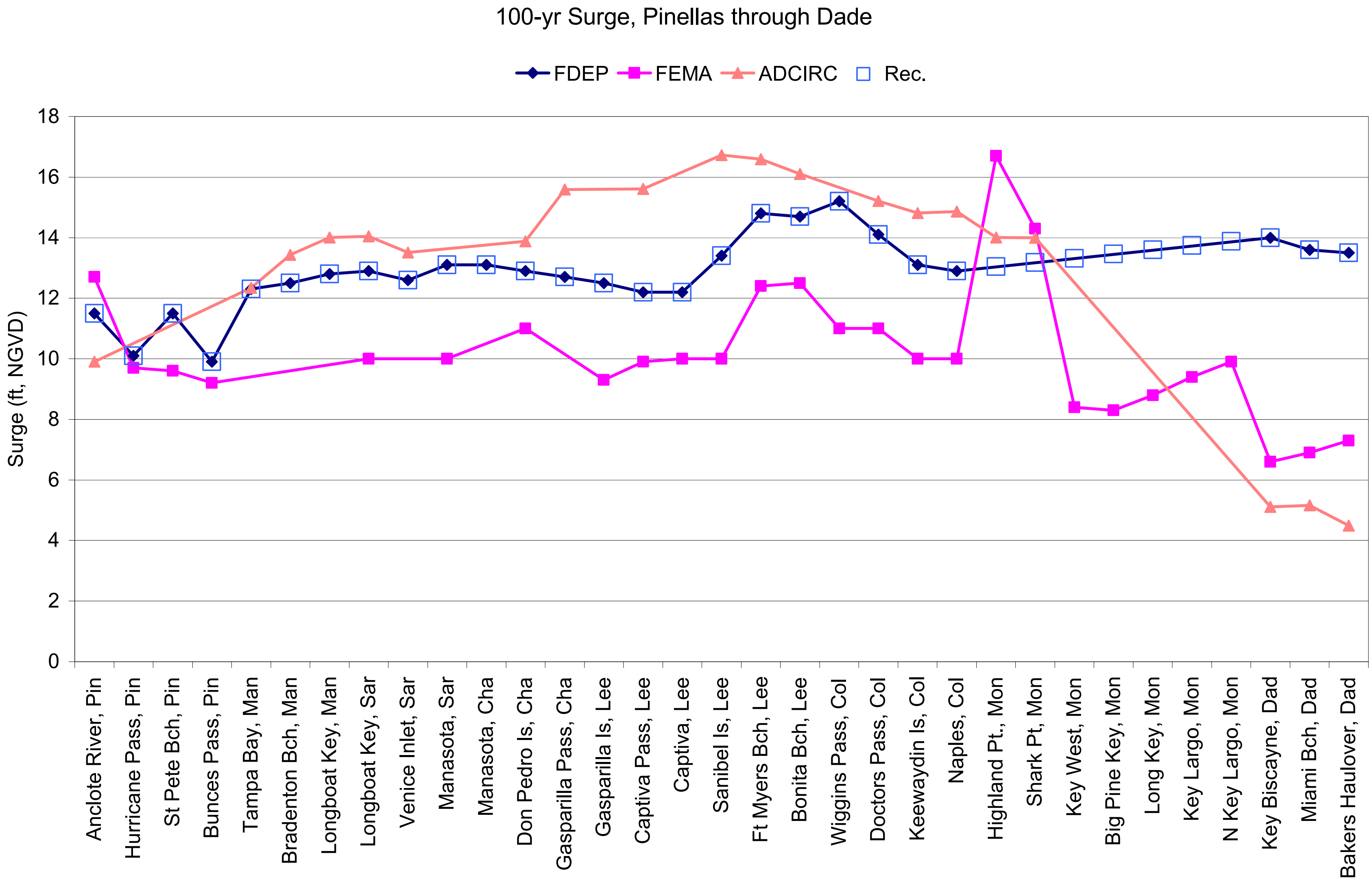

Figure III- 5. Peak 100-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Pinellas to Dade counties. Recommended (Rec.) values are indicated by a box (☐).

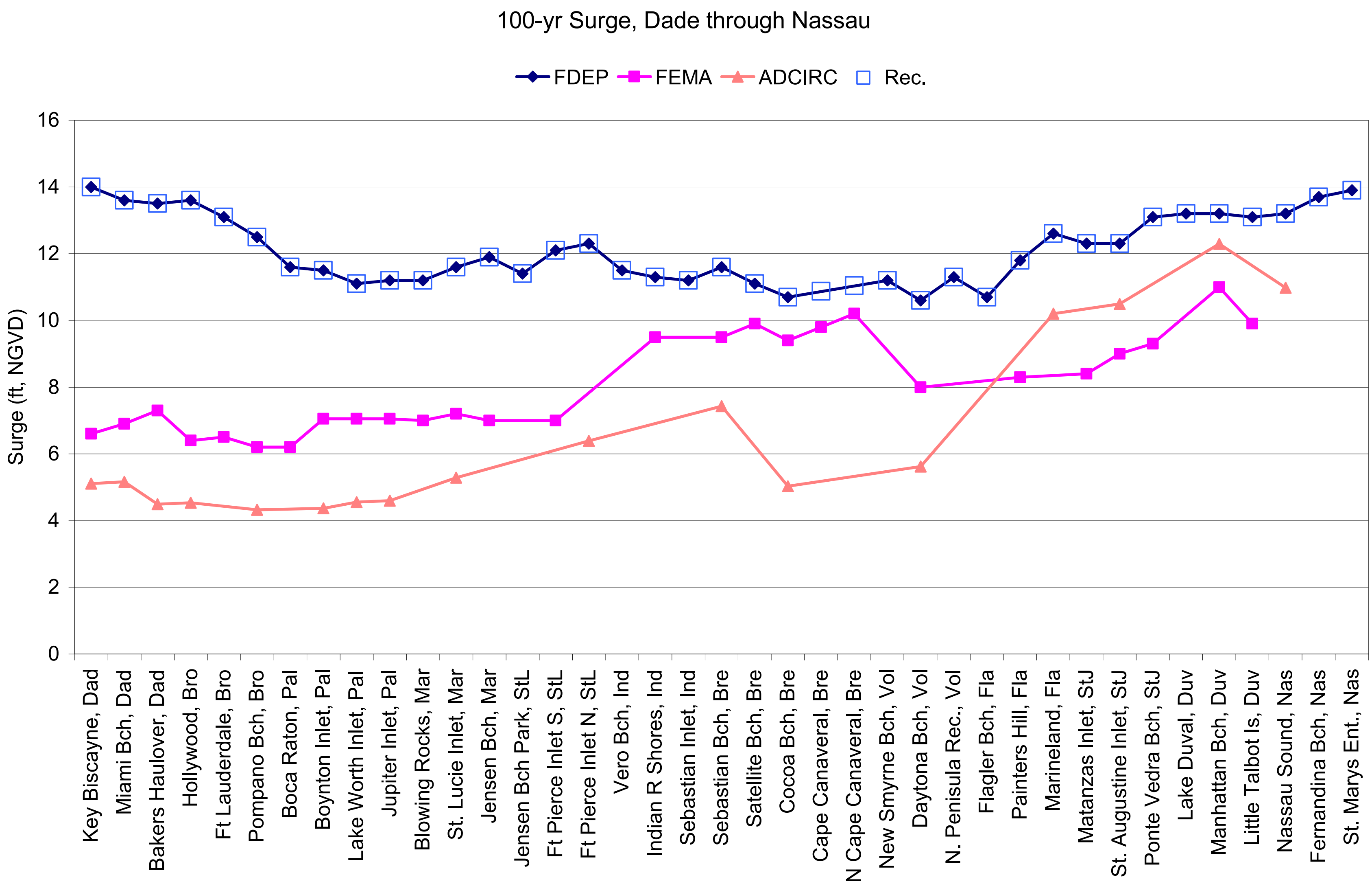

Figure III- 6. Peak 100-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Dade to Nassau counties. Recommended (Rec.) values are indicated by a box (☐).

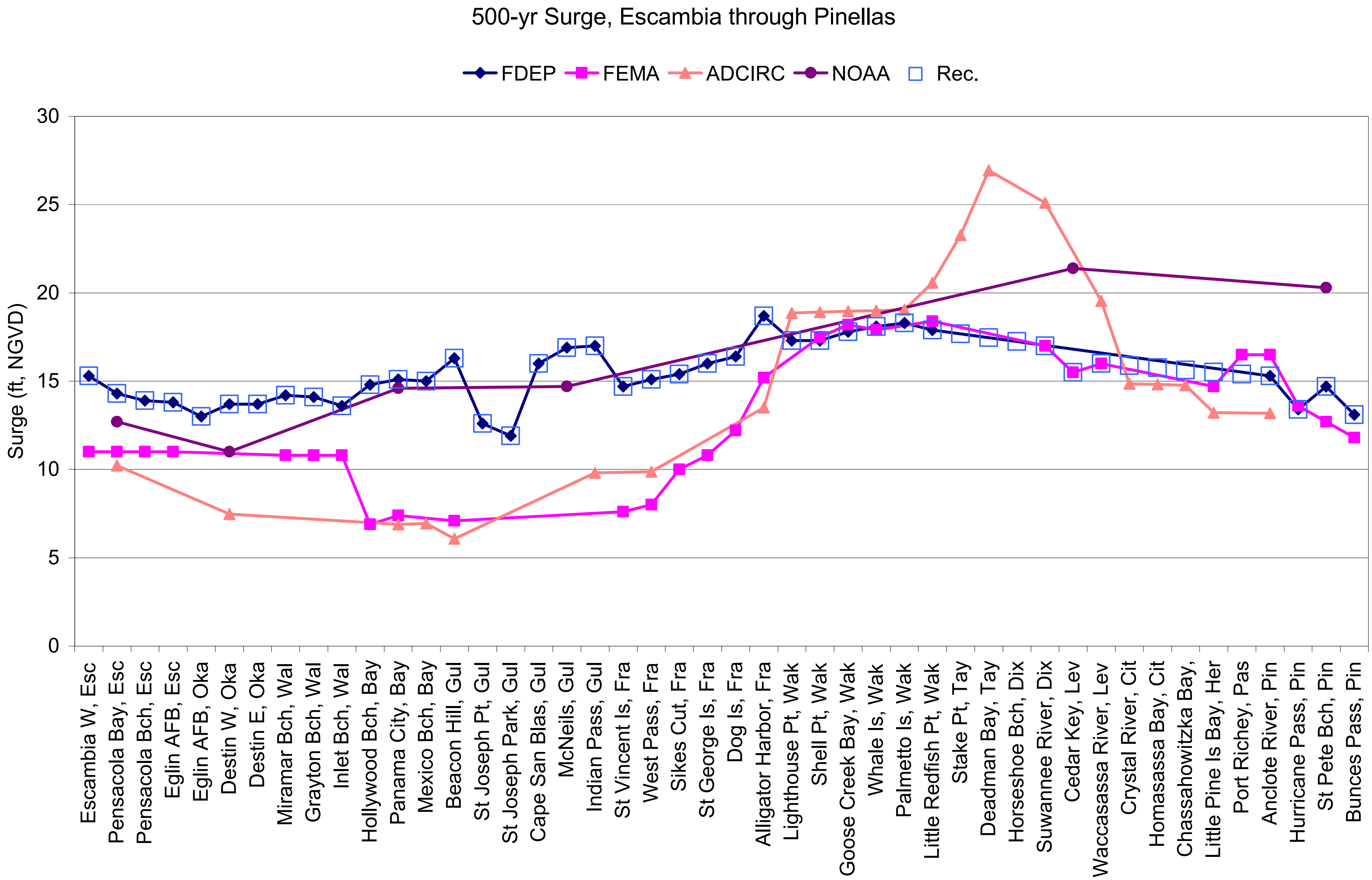

Figure III- 7. Peak 500-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Escambia to Pinellas counties. The NOAA prediction is for a Category 5 hurricane. Recommended (Rec.) values are indicated by a box (☐).

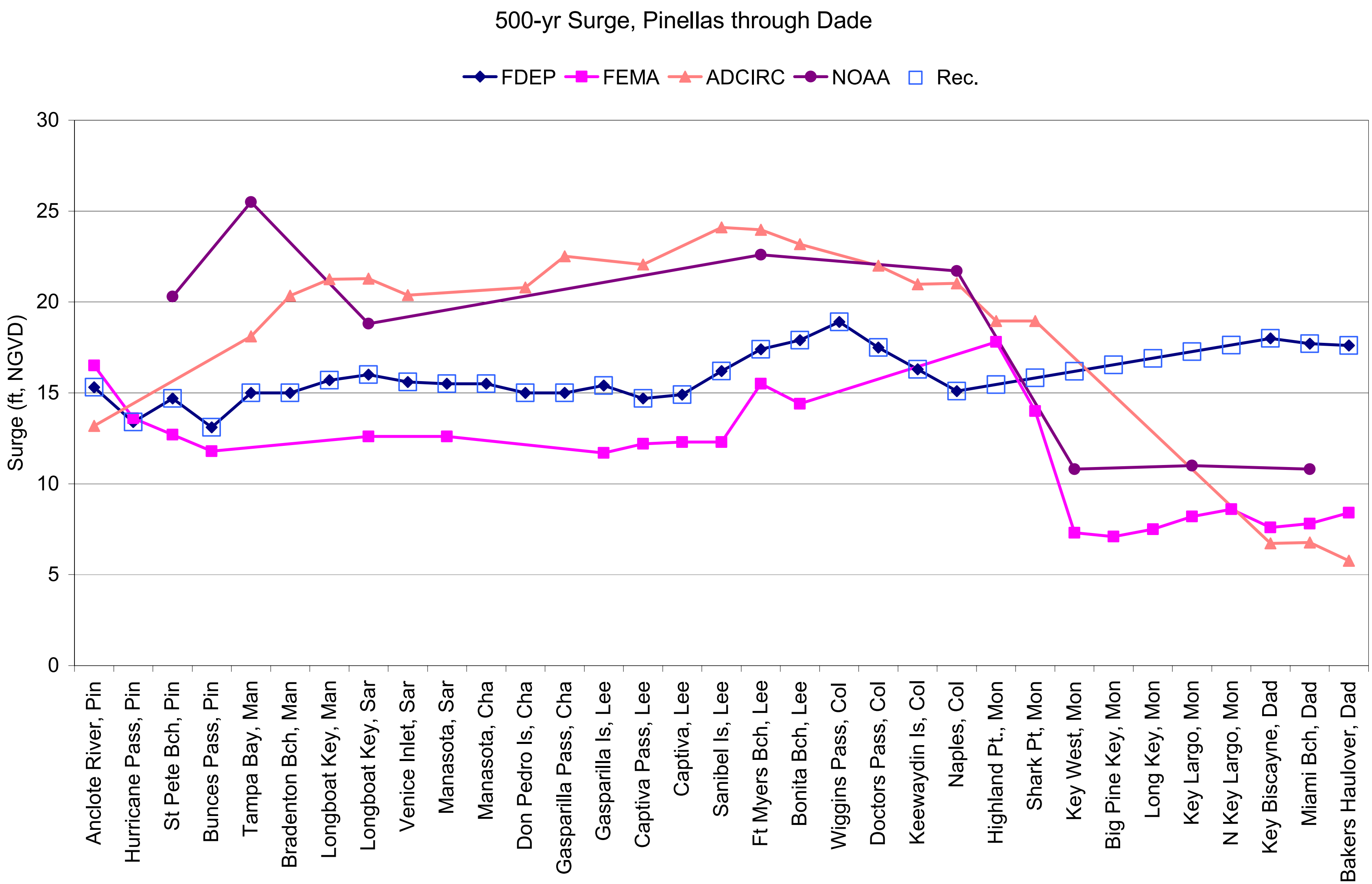

Figure III- 8. Peak 500-year Storm Surge Heights predicted by FDEP, FEMA and ADCIRC for Pinellas to Dade counties. The NOAA prediction is for a Category 5 hurricane. Recommended (Rec.) values are indicated by a box (☐).

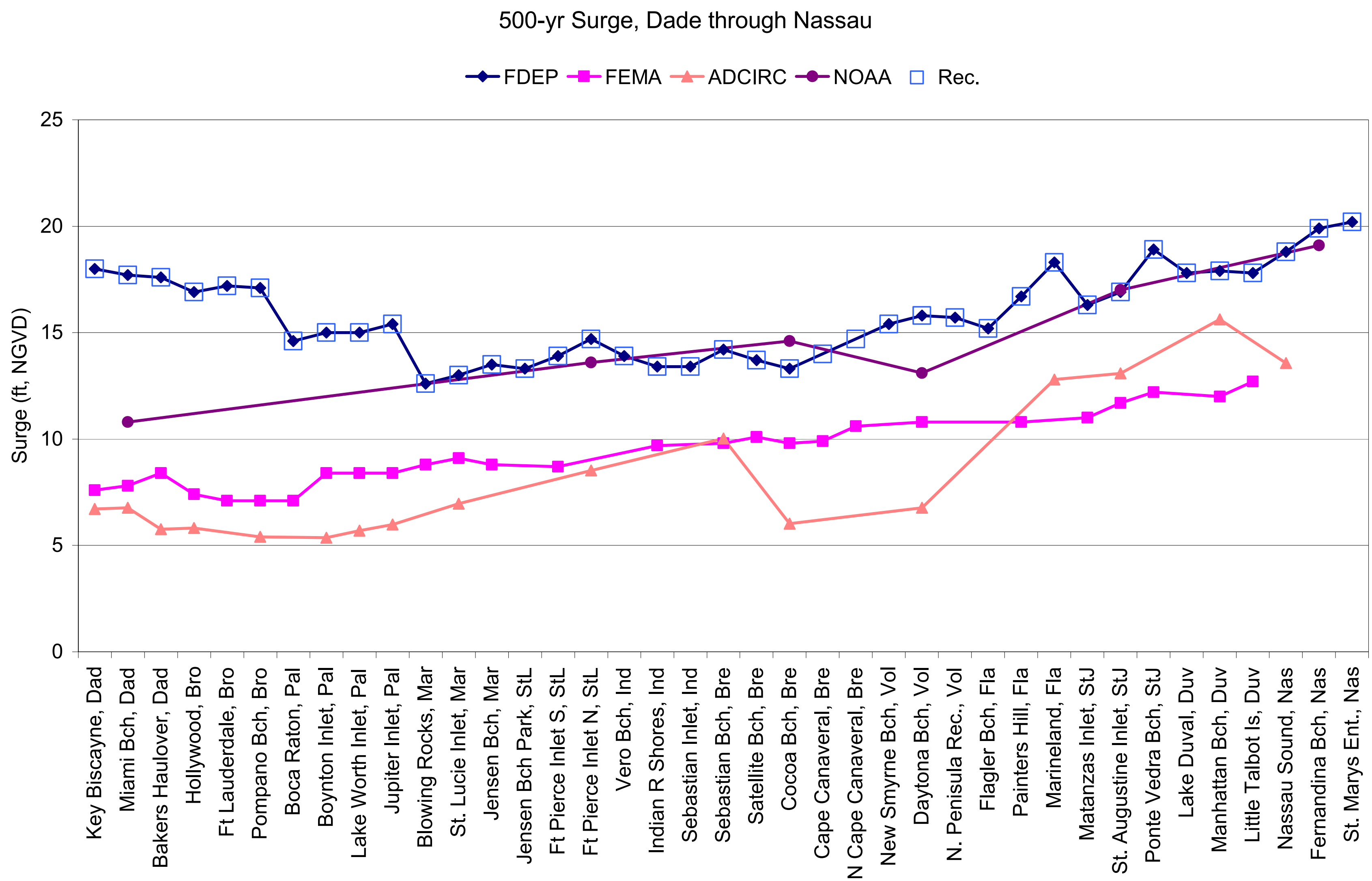

Figure III- 9. Peak 500-year Storm Surge Heights predicted by FDEP, FEMA, ADCIRC for Dade to Nassau counties. The NOAA prediction is for a Category 5 hurricane. Recommended (Rec.) values are indicated by a box (☐).

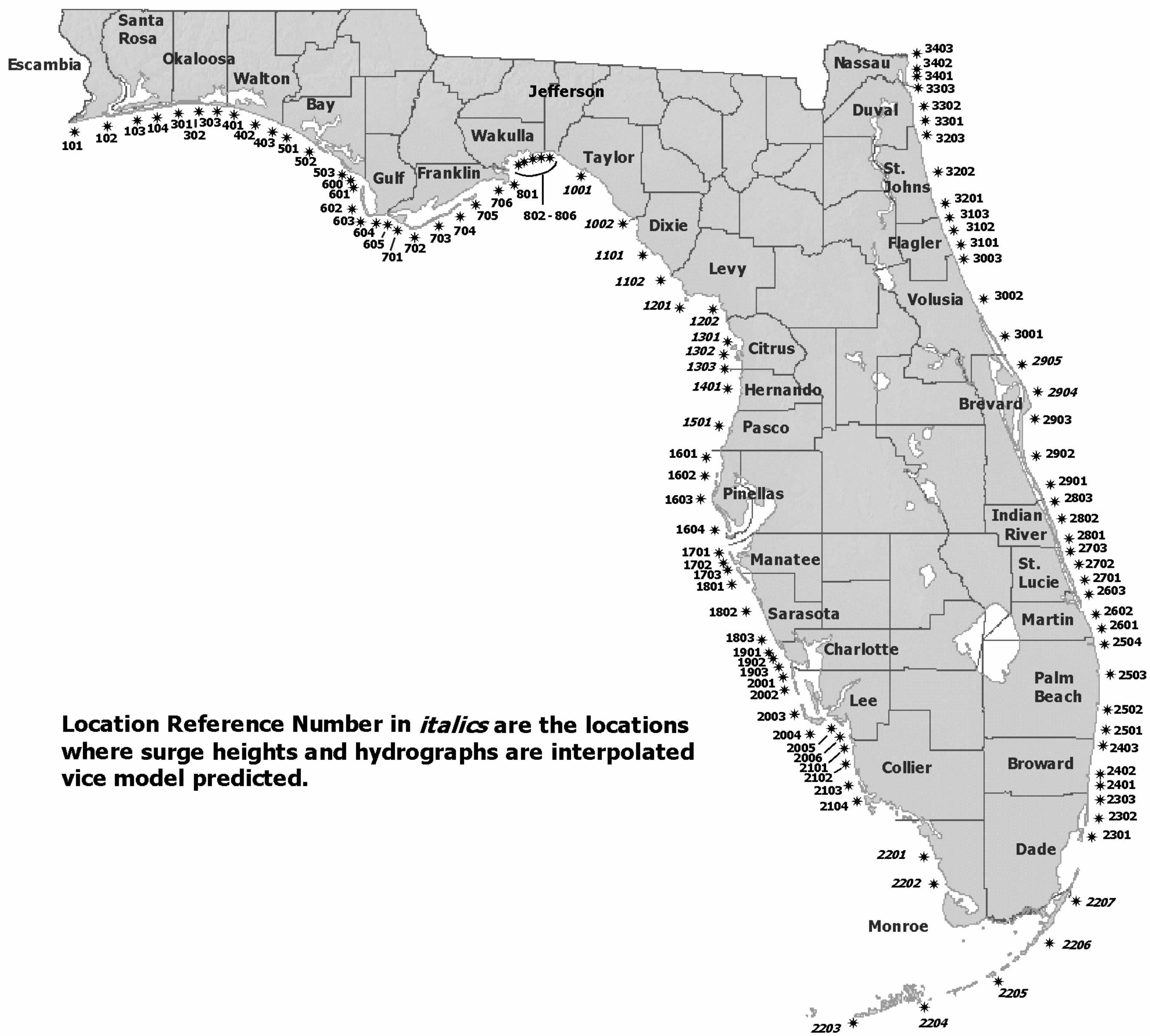

Figure III- 10. Storm Surge Peak and Hydrograph Locations.

IV. Storm Surge Hydrographs

Discussion of Available Hydrographs

The FDEP, NOAA and USACE (Pooled Fund Study) studies have provided storm surge hydrographs (plots of storm surge height as a function of time) around the state. As previously noted, NOAA modeled a category 5 hurricane. FDEP modeled various storms and determined the storm surge return period for each location. From these the FDEP publishes the hydrograph with its peak value closest to their 100 year value. According to the Pooled Fund Study, the USACE (ADCIRC) hydrographs can be reliably reproduced using equations 16 and 17 and the data contained in Table A-4 of Appendix A. Recall that the USACE (Pooled Fund Study) hydrographs do not include astronomical tide and wave setup which will impact the shape of the hydrograph as well as its amplitude

Figures B-1 through B-4 in Appendix B show plots of the NOAA category 5 hurricane hydrographs at various locations around Florida. Figures B-5 through B-20 show plots of the 100 year storm surge hydrographs modeled by the FDEP and Pooled Fund Study (reproduced by the synthetic storm surge model). The NOAA hydrographs tend to have very steep, possibly unrealistic slopes indicating (possibly) that wave set-up was not included in their analyses. As discussed in section III, the Pooled Fund Study peak storm surge heights are smaller (on average) than the FDEP peaks. The synthetic hydrographs also tend to have shorter durations than the FDEP hydrographs; again this is most likely due to the exclusion of wave set-up in the analysis.

A storm surge hydrograph and predicted astronomical tide for Hurricane Opal (1995) was obtained from the NOAA/NWS Co-Ops web site and compared with Leadon et al (1998). This hydrograph was taken at the Panama City Beach pier and had a peak offshore surge height of 8.3 ft. The NWS Service Assessment of Hurricane Opal (1996) reported a radius to maximum wind of 54 nm and a storm forward speed of 20 kts. Using these parameters and equations 16 and 17, a synthetic hydrograph was developed (including the predicted astronomical tide). Figure IV- 1 shows this synthetic hydrograph plotted against the measured hydrograph. While the surge prior to the peak is reproduced well; the surge following the peak is much too steep.

NOAA published a storm surge hydrograph for Hurricane Hugo (1989) measured in Winyah Bay, South Carolina. Garcia et al (1990) reported a radius to maximum wind of 13 nm and a storm forward speed of 19 kts. Using a peak storm surge height of 9.5 ft (from the hydrograph), the synthetic hydrograph was computed. Figure IV- 2 shows the Hurricane Hugo synthetic hydrograph plotted against the measured hydrograph. Agreement between the hydrographs is not very good.

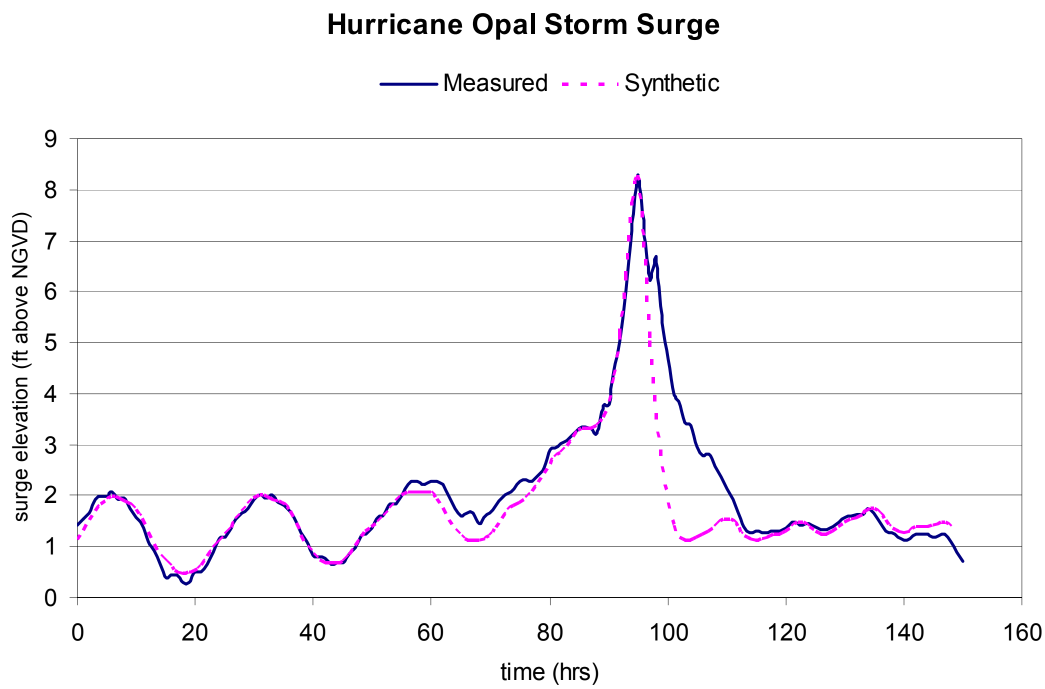

Figure IV- 1. Measured vs. Synthetic Storm Surge Hydrographs for Hurricane Opal.

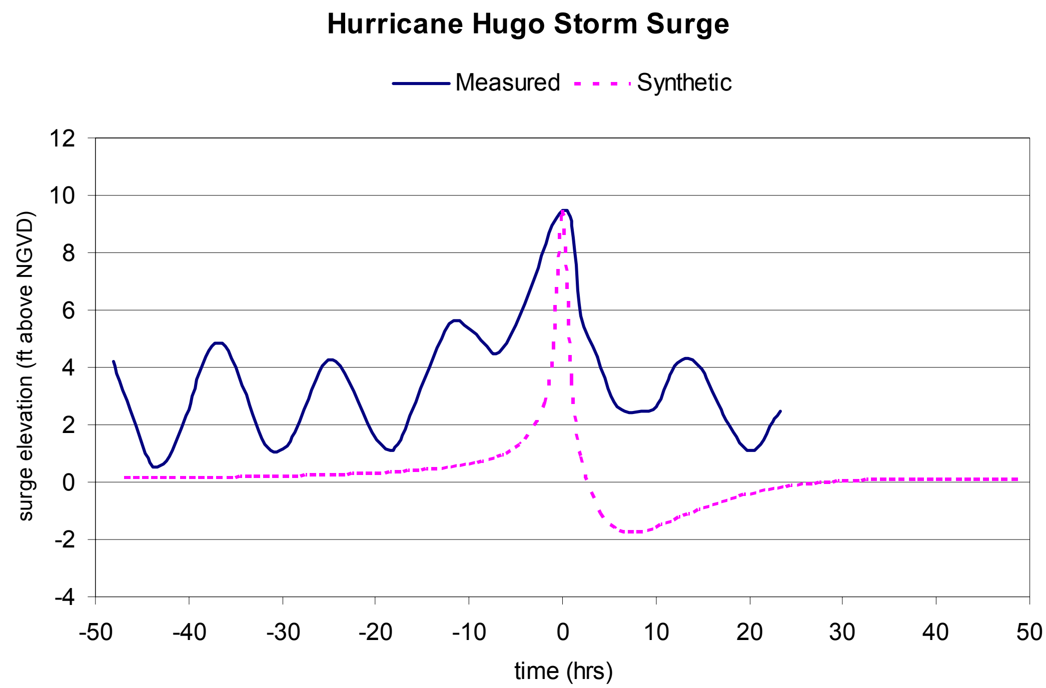

Figure IV- 2. Measured vs. Synthetic Storm Surge Hydrographs for Hurricane Hugo.

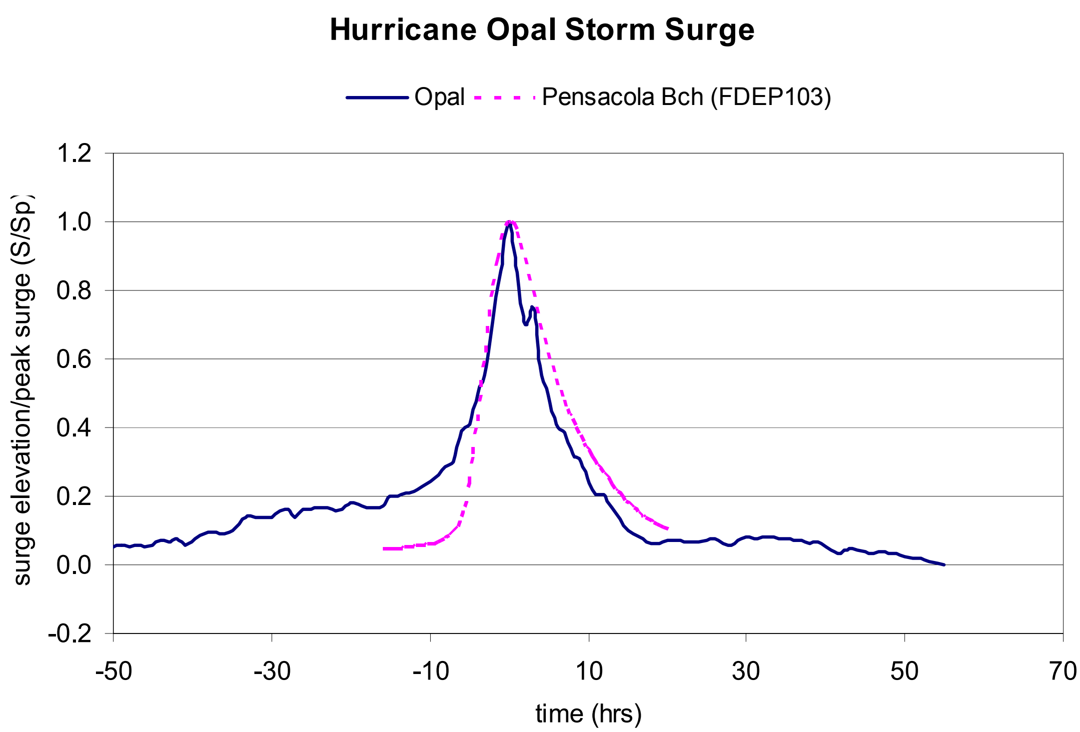

Figure IV- 3. Measured (Hurricane Opal) vs. Modeled (FDEP, Pensacola) Hydrographs, surge height is normalized by peak storm surge height.

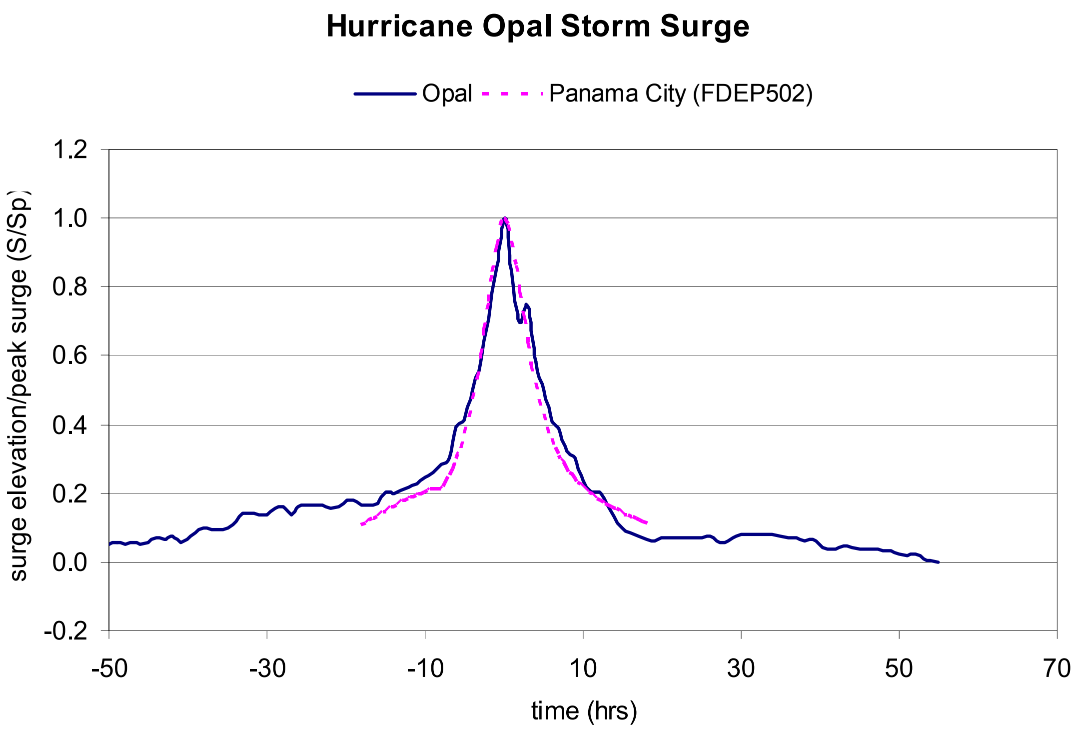

Figure IV- 4. Measured (Hurricane Opal) vs. Modeled (FDEP, Pensacola) Hydrographs, surge height is normalized by peak storm surge height.

Figures IV- 3 and IV- 4 show the 100 year FDEP surge hydrographs (without astronomical tide) for Pensacola Beach and Panama City, respectively, plotted against the measured hydrograph (minus the predicted astronomical tide) for Hurricane Opal. As previously noted, the Hurricane Opal hydrograph was taken at the Panama City Beach pier, several hundred feet offshore and outside of the surf zone. Wave set-up would not be significant in this area. This is indicated by the difference in the measured and the predicted peak storm surge heights (8.3 ft for the Hurricane Opal hydrograph; 10.8 ft and 12.2 ft predicted for Pensacola Beach and Panama City, respectively). Therefore, the hydrographs are normalized by their respective peaks for comparison. In both figures there is very good agreement between the measured hydrograph and the model. Figure IV- 3 shows particularly good agreement. It should be recalled that the measured hydrograph was at Panama City Beach, while Opal's eye made landfall just east of Pensacola.

Overall, the FDEP hydrographs were evaluated to be superior and more reliable for use in design applications. However, as with the peak storm surge values, the FDEP hydrographs were not available throughout Florida. Neither has the FDEP published 50 or 500 year return period hydrographs. Where FEMA peaks could be used to supplement the FDEP predictions in section III, no FEMA model hydrographs have been published. These circumstances require some approximations and interpolations to be made to provide design hydrographs to cover the entire Florida coast and 50 and 500 year return interval conditions.

An additional problem exists due to the method used by the FDEP studies to determine the peak storm surge height. The peak height is obtained from an ensemble of model runs. The model results are collected and the peak is interpolated for a given return interval. Hence, the 50, 100 or 500 year return interval may or may not have an actual model run (and therefore a hydrograph) associated with it. The published hydrographs are for the model runs with the peak value close to (but not necessarily exactly equal to) that tabulated for the 100 year return interval. Therefore, in addition to developing hydrographs for locations not analyzed by FDEP and the 50 and 500 year return interval conditions, the existing hydrographs need to be slightly modified so as to yield the predicted 100 year return interval peak storm surge height.

Correction of Surge Hydrograph to Predicted 100 year Peak Storm Surge Height

The procedure for correcting the existing 100 year FDEP hydrograph to the predicted 100 year peak storm surge height was as follows:

- When available, the astronomical tide (H) was removed from the total surge record (S_{tot}) so that the tidal range was not included in the correction:

$$S(t) = S_{tot}(t) - H(t).$$

- The correction factor (CF) was determined from the ratio of the tabulated 100 year peak storm surge (S_{p-100}) to the published hydrograph peak storm surge:

$$CF = \frac{S_{p-100} - H(t_0)}{S(t_0)}, \text{ where } S(t_0) = S_{tot}(t_0) - H(t_0).$$

- The correction factor was then applied to the storm surge (with astronomical tide removed) and the astronomical tide added to the result:

$$S_{tot-corr}(t) = CF \times S(t) + H(t).$$

The result is the modeled hydrograph corrected to the predicted 100 year peak storm surge height.

Hydrographs in Areas without Coverage

The FDEP has not published hydrographs for Wakulla County and only one hydrograph for Walton, Franklin, Charlotte and Nassau Counties. Peak storm surge heights have been published for these locations (6 in Wakulla and Franklin Counties and 3 in Walton, Charlotte and Nassau Counties). No FDEP studies were conducted in Taylor, Dixie, Levy, Citrus, Hernando, Pasco and Monroe Counties and no FDEP model hydrographs exist for these locations.

Figure IV- 5 compares hydrographs in Okaloosa and Walton Counties bordering the missing locations in Walton County (locations 401 and 402 in Figure III- 10). The hydrograph in Okaloosa County has a longer record (36 hours) and includes an astronomical tide while that in Walton County has a shorter record (14 hours) and no published astronomical tide. The record length and availability of an astronomical tide make the Okaloosa County hydrograph a better source for the hydrographs for the missing locations.

Figure IV- 6 compares hydrographs in Gulf and Franklin Counties bordering four of the five missing locations in Franklin County (locations 701, 702, 703 and 704 in Figure III- 10). The hydrographs are similar but with a significant difference on the flood side. This difference is likely due to bathymetry and the behavior of the storm due to its path. It is reasonable to expect that the locations with a more westerly geographic aspect (701 and 702) would be similar to the Gulf County hydrograph and those with a more easterly aspect would be similar to that from Franklin County.

Model hydrographs for Franklin and Pinellas counties are compared in Figure IV- 7. These locations border Wakulla, Taylor, Dixie, Levy, Citrus, Hernando, and Pasco Counties. The hydrographs are symmetric and have similar shapes though separated by a significant distance. It is reasonable that the hydrographs in the missing counties would also be similar (locations 706, 801 through 806, 1001, 1002, 1101, 1102, 1201, 1202, 1301, 1302, 1303, 1401 and 1501 in Figure III- 10).

Figure IV- 8 compares model hydrographs in Sarasota, Charlotte and Lee Counties bordering missing locations 1901 and 1903 (Figure III- 10). All three hydrographs are similar and it was decided that the missing hydrographs would be similar to those nearest their locations (location 1803 for missing location 1901 and location 1902 for missing location 1903).

Figure IV- 9 compares model hydrographs in Collier and Dade Counties, from southern Collier County on the Gulf coast to southern Dade County on the Atlantic coast. The hydrographs are similar and it is reasonable to assume that the missing hydrographs in Monroe County would also be similar (locations 2201, 2202, 2203, 2204, 2205, 2206 and 2207 in Figure III- 10).

No hydrographs exist for northern Brevard County; however Figure IV- 10 shows the hydrographs for southern Volusia County. These are also similar, indicating that the nearby northern Brevard County locations (2904 and 2905 in Figure III- 10) should have the same shape.

Figure IV- 11 compares hydrographs for northern Duval and northern Nassau Counties bordering the missing locations in Nassau County (3401 and 3402 in Figure III- 10). The shape of the Duval County hydrograph is more consistent with the shape of the majority of hydrographs in this geographic region and so was used as the source hydrograph for the missing locations.

Utilizing the similarities noted above, the locations where hydrographs were needed were paired with source hydrographs to be interpolated according to the peak storm surge height of the location of interest. Table IV- 1 shows the locations requiring storm surge hydrographs paired with source locations evaluated according to the above discussion.

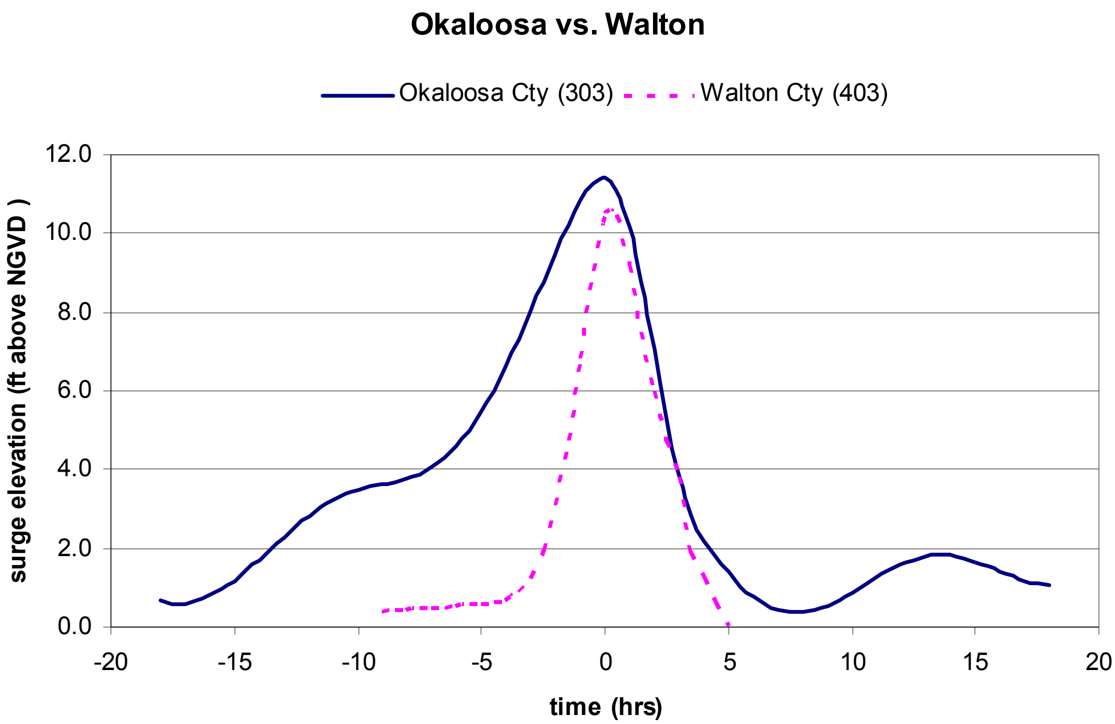

Figure IV- 5. 100 year Storm Surge Hydrographs for Okaloosa County (Ref 303) and Walton County (Ref 303).

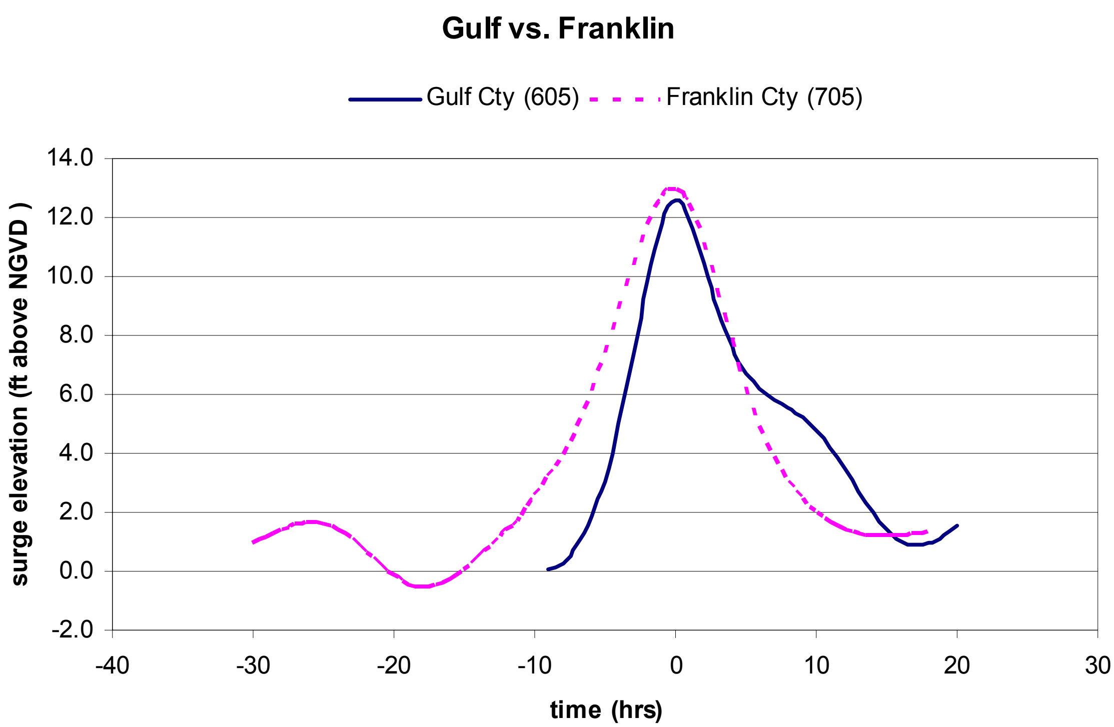

Figure IV- 6. 100 year Storm Surge Hydrographs for Gulf County (Ref 605) and Franklin County (Ref 705).

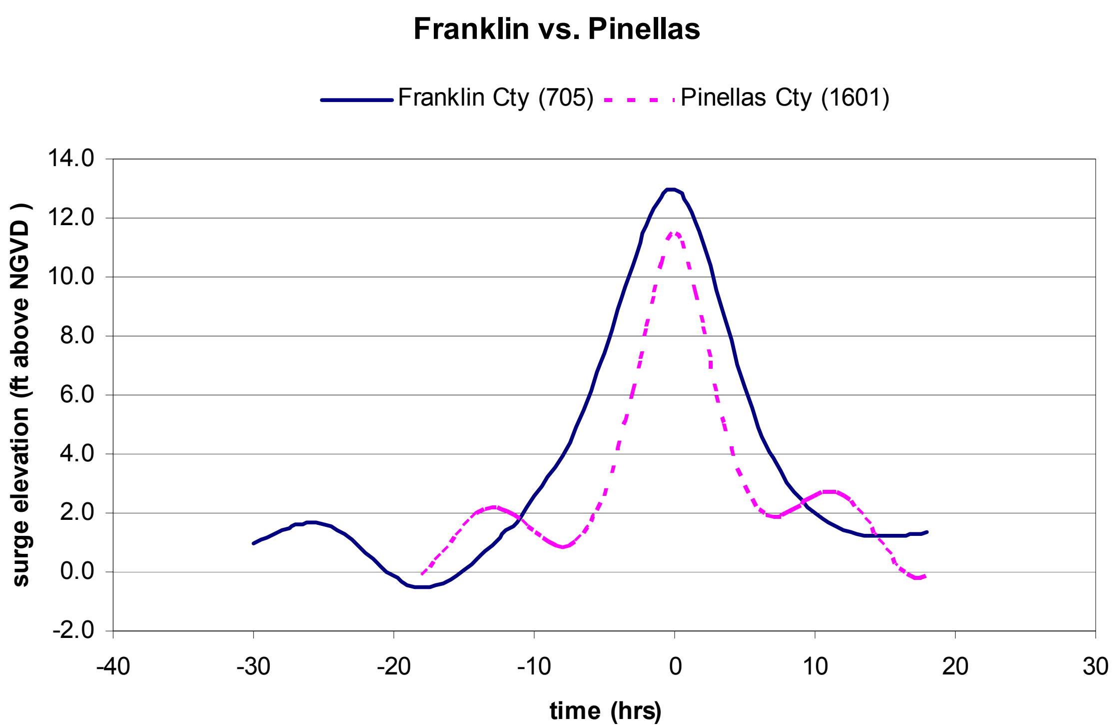

Figure IV- 7. 100 year Storm Surge Hydrographs for Franklin County (Ref 705) and Pinellas County (Ref 1601).

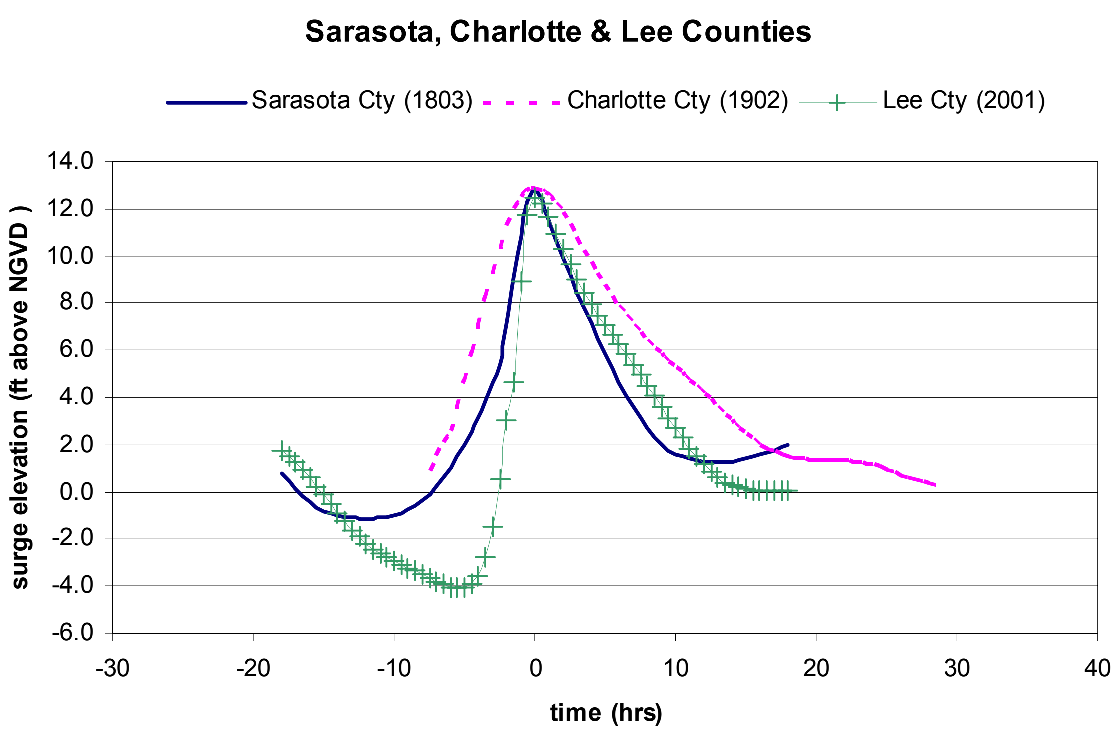

Figure IV- 8. 100 year Storm Surge Hydrographs for Sarasota (Ref 1803), Charlotte (Ref 1902) and Lee (Ref 2001) Counties.

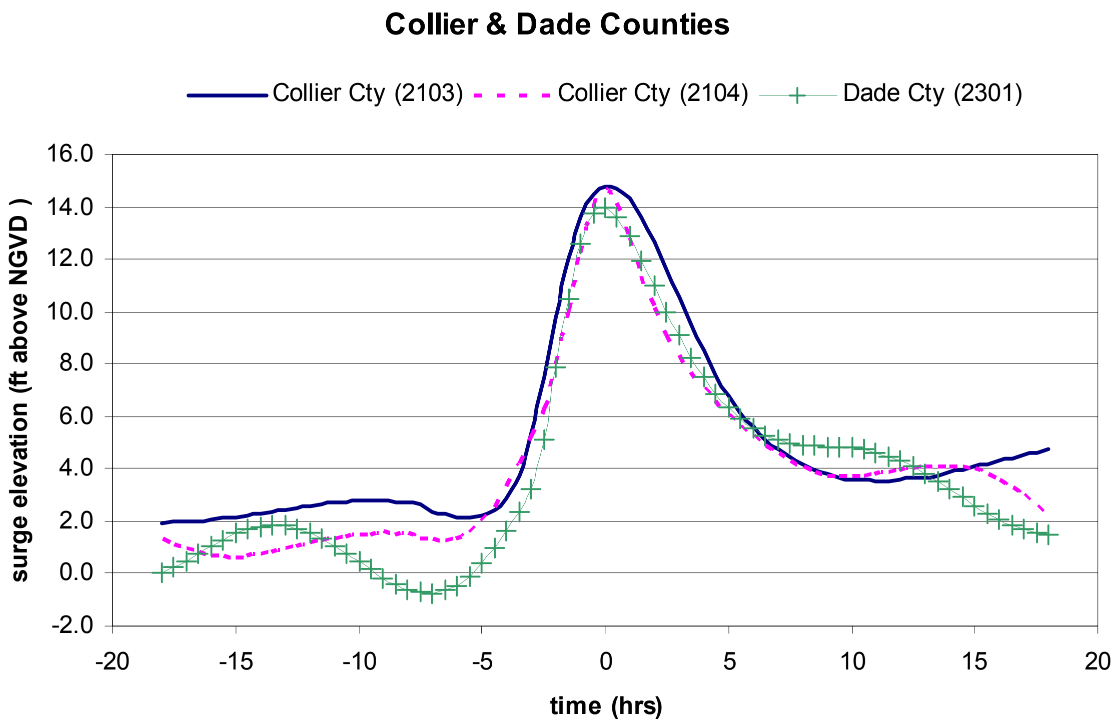

Figure IV- 9. 100 year Storm Surge Hydrographs for Collier & Dade Counties (Ref 2103, 2104 and 2301).

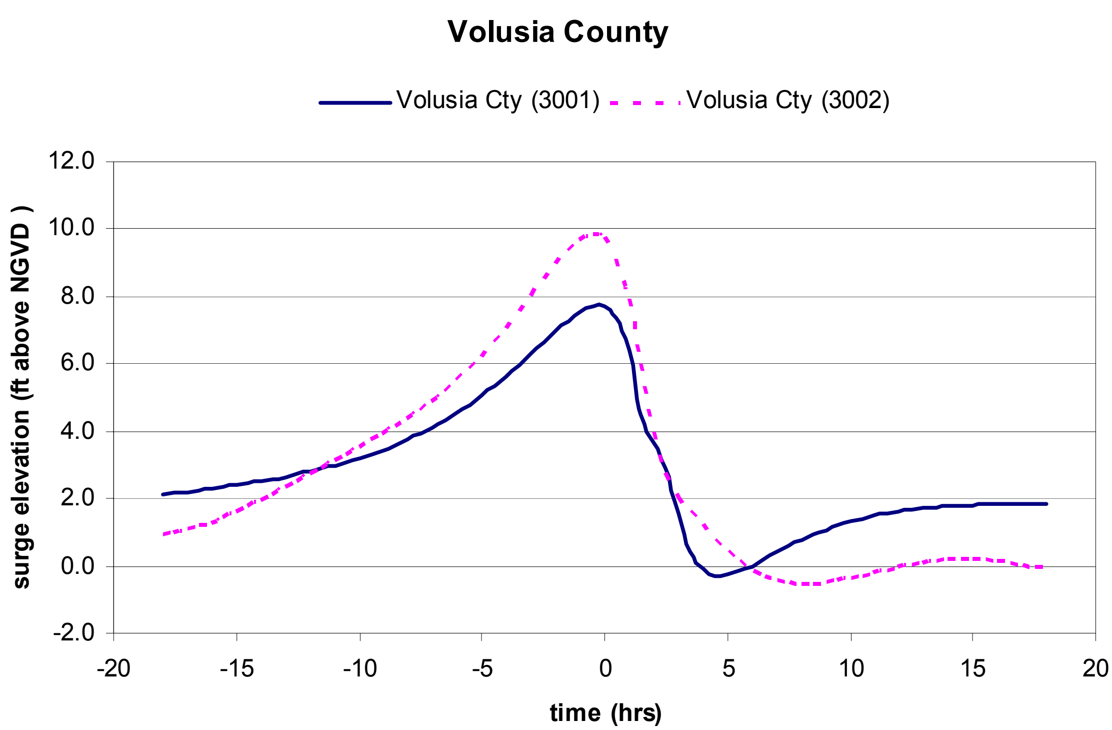

Figure IV- 10. 100 year Storm Surge Hydrographs for Volusia County (Ref 3001 and 3002).

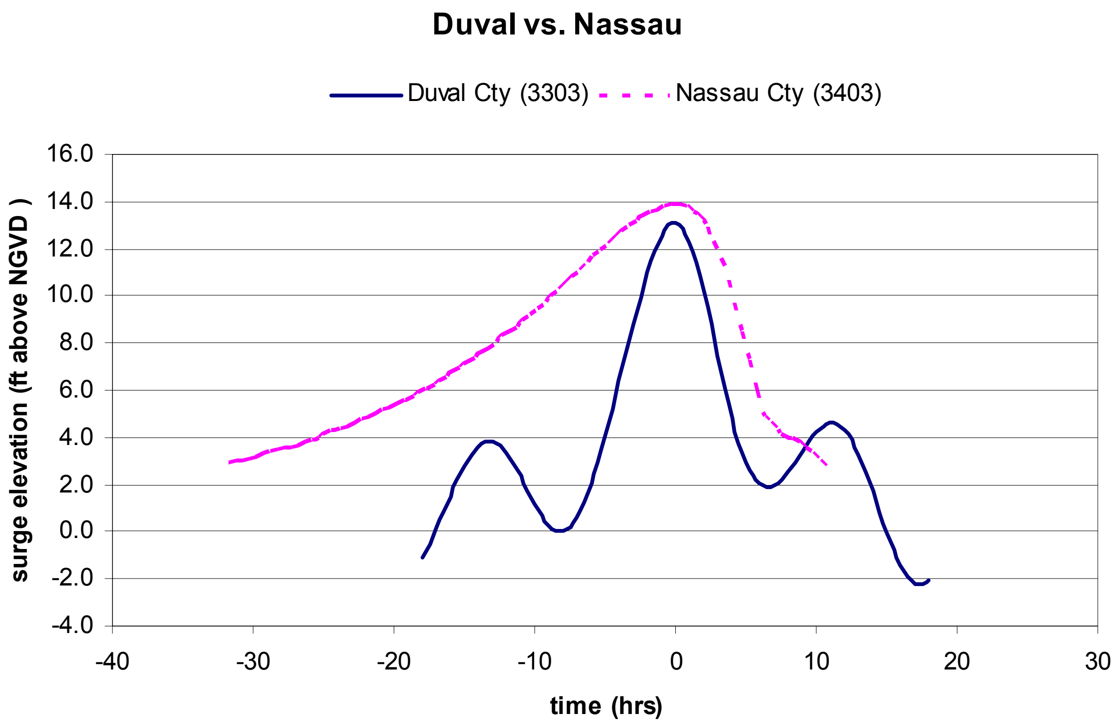

Figure IV- 11. 100 year Storm Surge Hydrographs for Duval (Ref 3303) and Nassau Counties (Ref 3403).

The procedure for interpolating the source hydrographs to develop hydrographs for locations where none have been published is similar to that used to correct the original hydrographs to match the modeled 100 year peak storm surge height. Existing hydrographs are modified by applying the peak storm surge height at the required location to similarly shaped hydrographs nearby.

- When available, the astronomical tide (H) was removed from the total surge tide ($S_{tot-source}$) of the source hydrograph so that the tidal range was not modified:

$$S_{source}(t) = S_{tot-source}(t) - H(t).$$

- The interpolation factor (F) was determined from the ratio of the peak storm surge of the source location (source) to the peak storm surge of the required location (req) :

$$F = \frac{S_{p-source} - H(t_0)}{S_{p-req} - H(t_0)}.$$

- The interpolation factor was then applied to the storm surge (with astronomical tide removed) and the astronomical tide was added back to the result:

$$S_{tot-req}(t) = F \times S_{source}(t) + H(t).$$

Table IV- 1. Locations without Storm Surge Hydrographs and Source Locations

Ref	Location	Source Ref	Source Location
401	Miramar Bch, Wal.	303	Destin E, Oka.
402	Grayton Bch, Wal.	303	Destin E, Oka.
701	St Vincent Is, Fra.	605	Indian Pass, Gulf
702	West Pass, Fra.	605	Indian Pass, Gulf
703	Sikes Cut, Fra.	705	Dog Is, Fra.
704	St George Is, Fra.	705	Dog Is, Fra.
706	Alligator Harbor, Fra.	705	Dog Is, Fra.
801	Lighthouse Pt, Wak.	705	Dog Is, Fra.
802	Shell Pt, Wak.	705	Dog Is, Fra.
803	Goose Creek Bay, Wak.	705	Dog Is, Fra.
804	Whale Is, Wak.	705	Dog Is, Fra.
805	Palmetto Is, Wak.	705	Dog Is, Fra.
806	Little Redfish Pt, Wak.	705	Dog Is, Fra.
1001	Henderson River, Tay.	1601	Anclote River, Pin.
1002	Deadman Bay, Tay.	1601	Anclote River, Pin.
1101	Horseshoe Bch, Dix.	1601	Anclote River, Pin.
1102	Suwannee River, Dix.	1601	Anclote River, Pin.
1201	Cedar Key, Lev.	1601	Anclote River, Pin.
1202	Waccasassa River, Lev.	1601	Anclote River, Pin.
1301	Crystal River, Cit.	1601	Anclote River, Pin.
1302	Homasassa Bay, Cit.	1601	Anclote River, Pin.
1303	Chassahowitzka Bay, Cit.	1601	Anclote River, Pin.
1401	Piithlachascotee R., Her.	1601	Anclote River, Pin.
1501	Port Richey, Pas.	1601	Anclote River, Pin.
1901	Manasota, Cha.	1803	Manasota, Sar.
1903	Gasparilla Pass, Cha.	1902	Don Pedro Is, Cha.
2201	Bird Key, Mon.	2103	Keewaydin Is, Col.
2202	Highland Pt., Mon.	2103	Keewaydin Is, Col.
2203	Key West, Mon.	2103	Keewaydin Is, Col.
2204	Big Pine Key, Mon.	2301	Key Biscayne, Dad.
2205	Long Key, Mon.	2301	Key Biscayne, Dad.
2206	Key Largo, Mon.	2301	Key Biscayne, Dad.
2207	N Key Largo, Mon.	2301	Key Biscayne, Dad.
2904	Cape Canaveral, Bre.	3001	New Smyrne Bch, Vol.
2905	N Cape Canaveral, Bre.	3001	New Smyrne Bch, Vol.
3401	Nassau Sound, Nas.	3303	Little Talbot Is, Duv.
3402	Fernandina Bch, Nas.	3303	Little Talbot Is, Duv

Development of 50 and 500 year Storm Surge Hydrographs from the 100 year Hydrograph

To develop storm surge hydrographs with peaks surge heights for 50 and 500 year return intervals, the 100 year FDEP hydrographs were modified by increasing (or decreasing) the water elevation while maintaining the hydrograph shape.

- When available, the astronomical tide (H) was removed from the total surge tide (S_{tot}) so that the tidal range was not included in the modification:

  $$S(t) = S_{tot}(t) - H(t).$$

- The modification factor (MF) was determined from the ratio of the 50 or 500 year peak storm surge to the hydrograph surge peak:

  50 year: $MF_{50} = \dfrac{S_{p-50} - H(t_0)}{S(t_0)}$, where $S(t_0) = S_{tot}(t_0) - H(t_0)$, and

  500 year: $MF_{500} = \dfrac{S_{p-500} - H(t_0)}{S(t_0)}$.

- The modification factor was then applied to the storm surge (with astronomical tide removed) and the time series, and the surge at each time step was associated with the new time series:

  $S_{50}(t) = MF_{50} \times S(t)$, $t_{50} = MF_{50} \times t_{orig}$ → [t_{50}, S_{50}], and

  $S_{500}(t) = MF_{500} \times S(t)$, $t_{500} = MF_{500} \times t_{orig}$ → [t_{500}, S_{500}].

- The 50 and 500 year storm surge was then interpolated to the original time series and the astronomical tide was added to the result:

  [t_{50}, S_{50}] → [t_{orig}, S_{50}^{int}] → $S_{tot-50}(t) = S_{50}^{int}(t) + H(t)$, and

  [t_{500}, S_{500}] → [t_{orig}, S_{500}^{int}] → $S_{tot-500}(t) = S_{500}^{int}(t) + H(t)$

This procedure provides hydrographs with 50 and 500 year return period peak elevations without unrealistically increasing the slopes of the hydrographs.

Hydrograph Steepness

Variations in actual storm conditions (e.g. storm size, storm forward speed, wind speed) can influence the storm duration for any given peak storm surge height. Therefore, it is prudent to consider a range of hydrographs for the design peak storm surge height. This can be done by dilating and/or contracting the storm time line of the storm surge hydrograph. To illustrate how this can be done the timeline for the 100 year storm surge was subjected to 60% dilation and 30% contraction as follows:

- When available, the astronomical tide (H) was removed from the total surge tide (S_{tot}) so that the tidal range was not included in the modification:

  $$S(t) = S_{tot}(t) - H(t).$$

- The time series (t) corresponding to the surge was multiplied by 0.7 and 1.6 to give alternate timelines: $t_{70\%} = 0.7t$ and $t_{160\%} = 1.6t$. Note, the time series must be referenced to t = 0, at the time of peak storm surge.
- The surge elevation series was then associated with the modified timeline and the new time-surge elevation series was interpolated to find the new surge height at the time steps on the original timeline:

  $[t_{70\%}, S_{orig}] \rightarrow [t_{orig}, S_{70\%}]$ and

  $[t_{130\%}, S_{orig}] \rightarrow [t_{orig}, S_{160\%}]$.

  This is required to reintegrate the astronomical tide which is associated with the original timeline.
- The astronomical tide removed in the first step is then add to the new surge height at each of the original time steps:

  $S_{tot-70\%}(t) = S_{70\%}(t) + H(t)$, and

  $S_{tot-160\%}(t) = S_{160\%}(t) + H(t)$.

Hydrograph Plots

Figures IV- 12 through IV- 48 show plots of the recommended hydrographs. Each figure shows three locations. For each location, the left hand plot shows storm surge hydrographs with peak elevations for 50, 100 and 500 year return periods. The right hand plots show hydrographs with the 100 year return period peak elevation and a normal timeline, a timeline contracted to 70% of normal [dur(-)] and a timeline dilated to 160% of normal [dur(+)]. Hydrographs for locations without FDEP model runs are indicated by "Interpolated" in the left hand plot title. The reference numbers on each plot correspond to the numbered locations in Figure III-10.

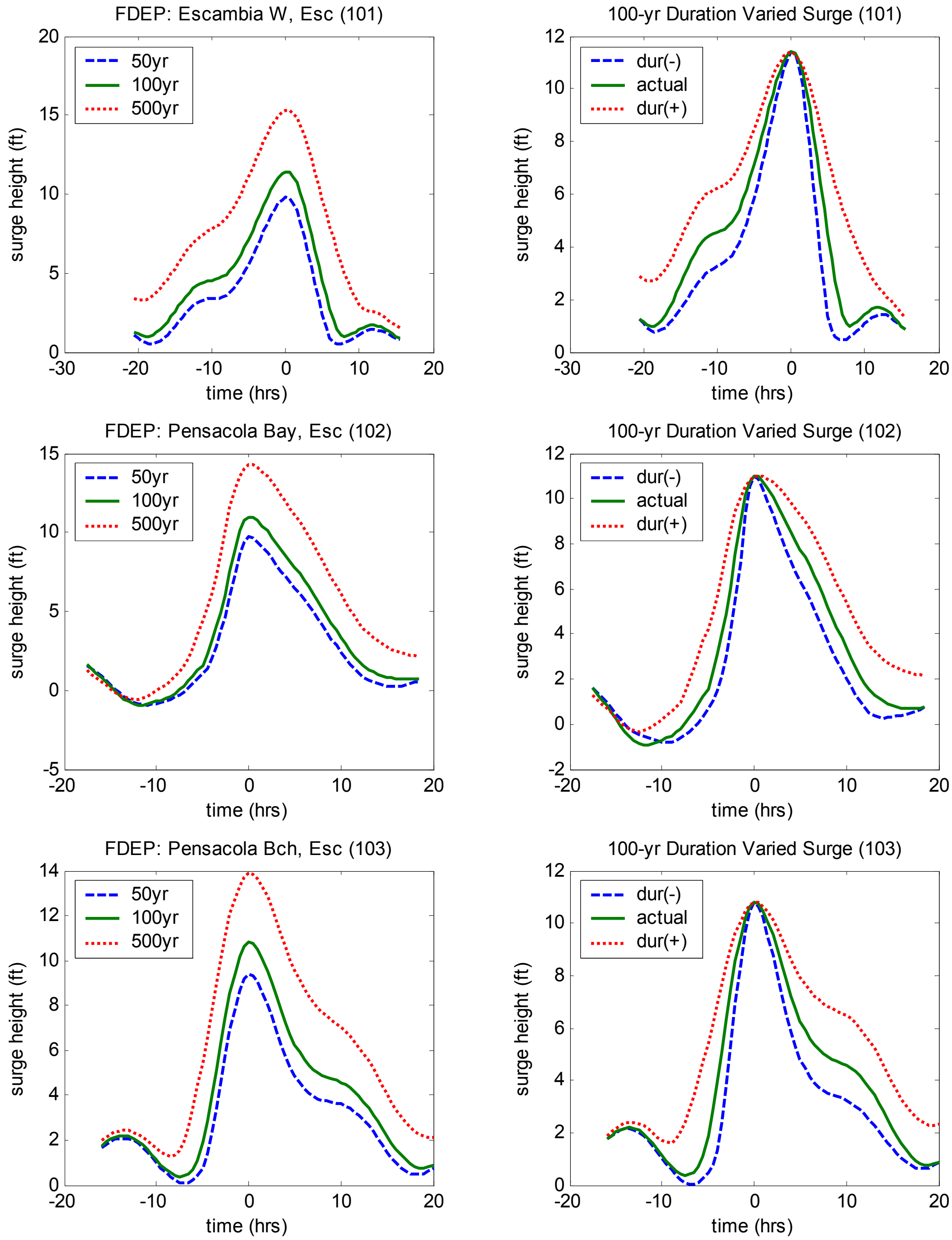

Figure IV- 12. Hydrograph plots for Escambia County.

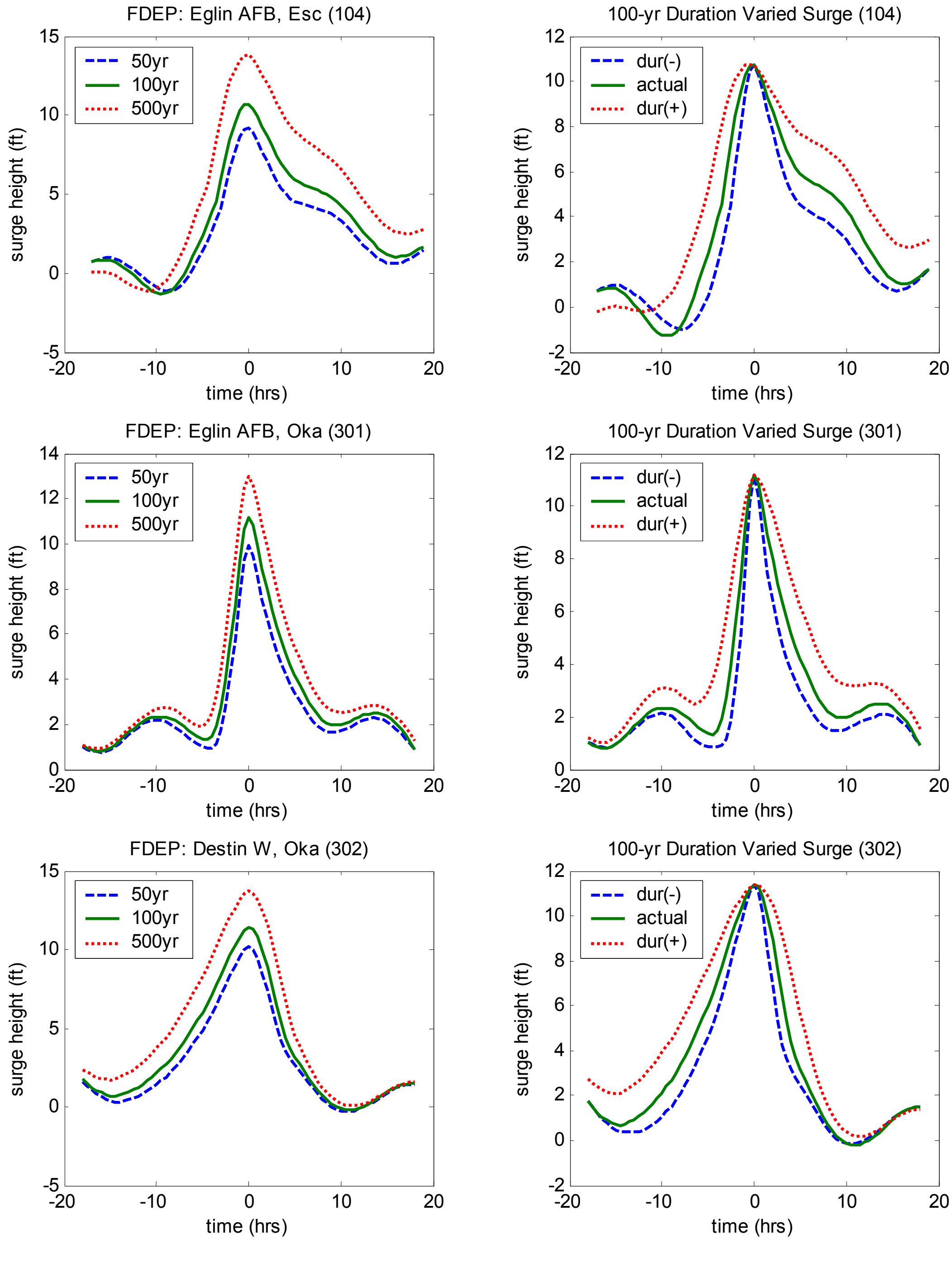

Figure IV- 13. Hydrograph plots for Escambia and Okaloosa Counties.

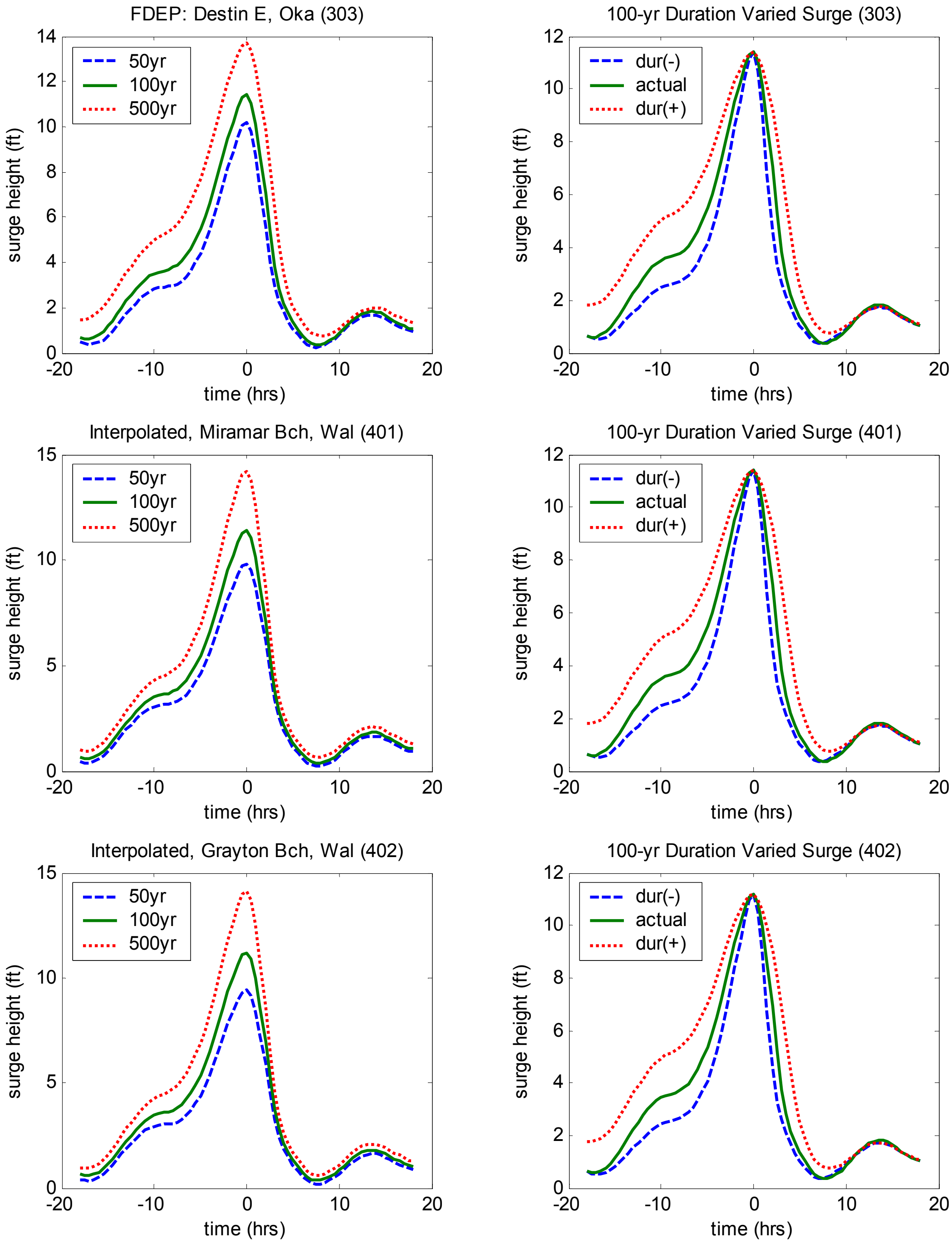

Figure IV- 14. Hydrograph plots for Okaloosa and Walton Counties.

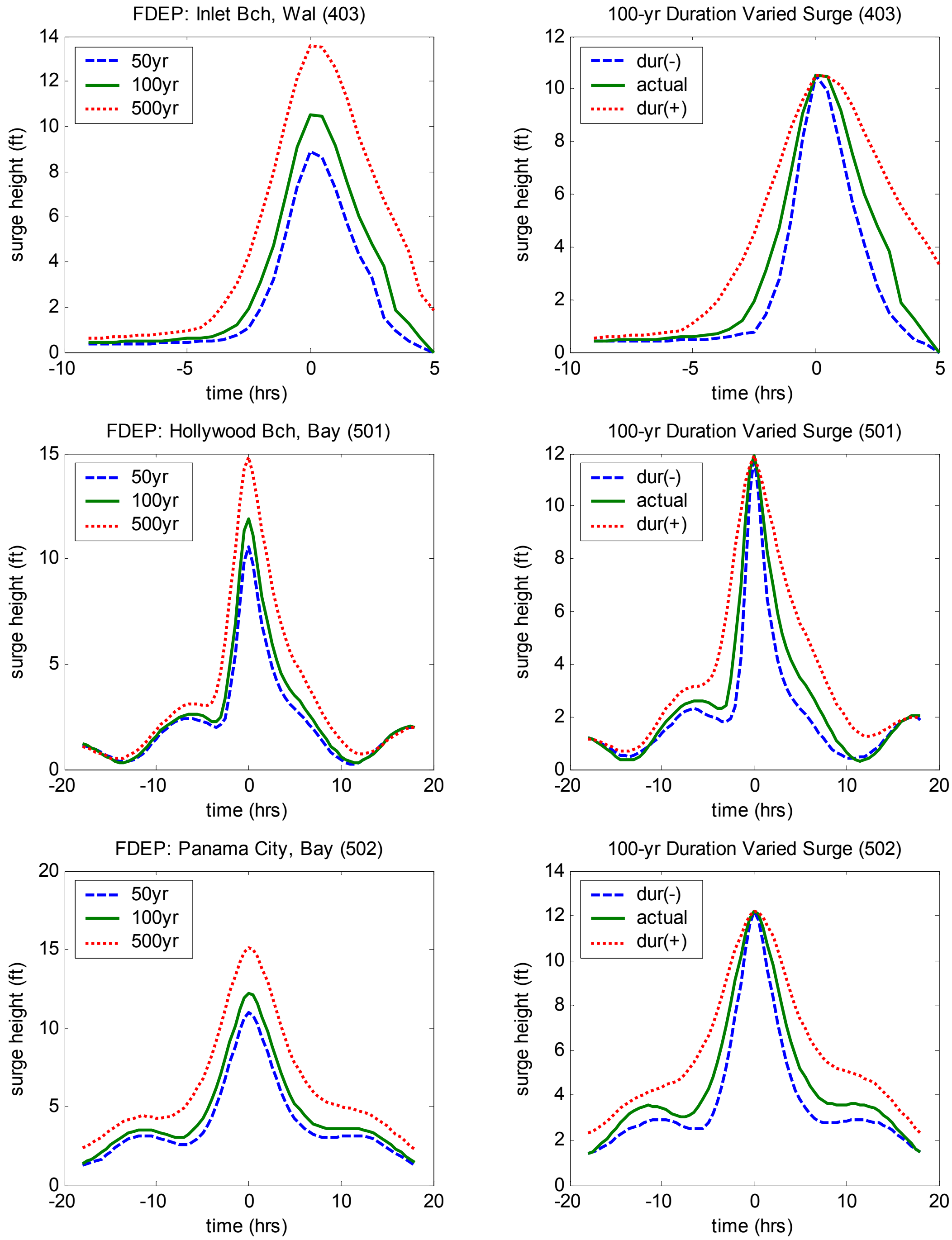

Figure IV- 15. Hydrograph plots for Walton and Bay Counties. (Note: the Walton County, 403, hydrograph did not have an associated astronomical tide.)

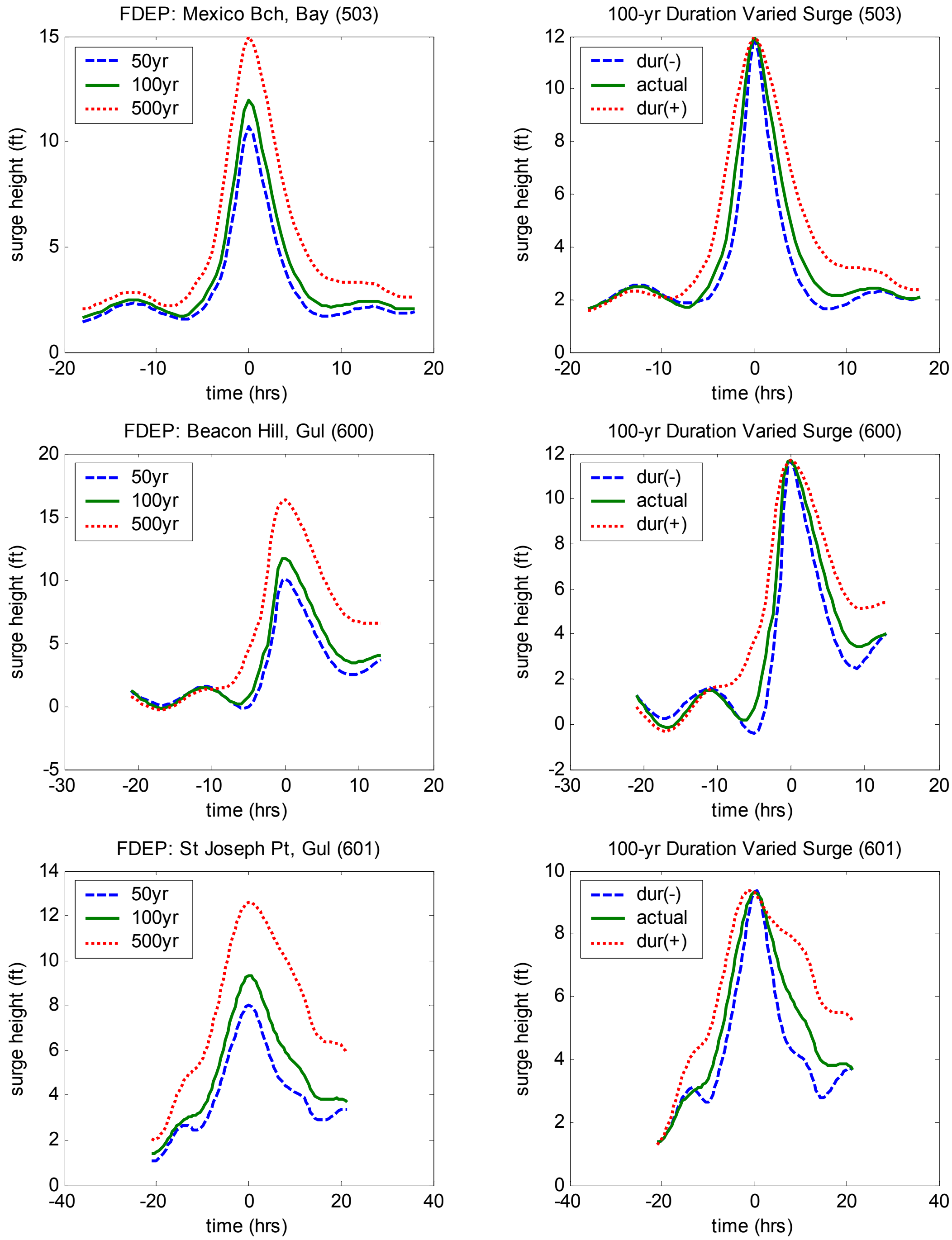

Figure IV- 16. Hydrograph plots for Bay and Gulf Counties.

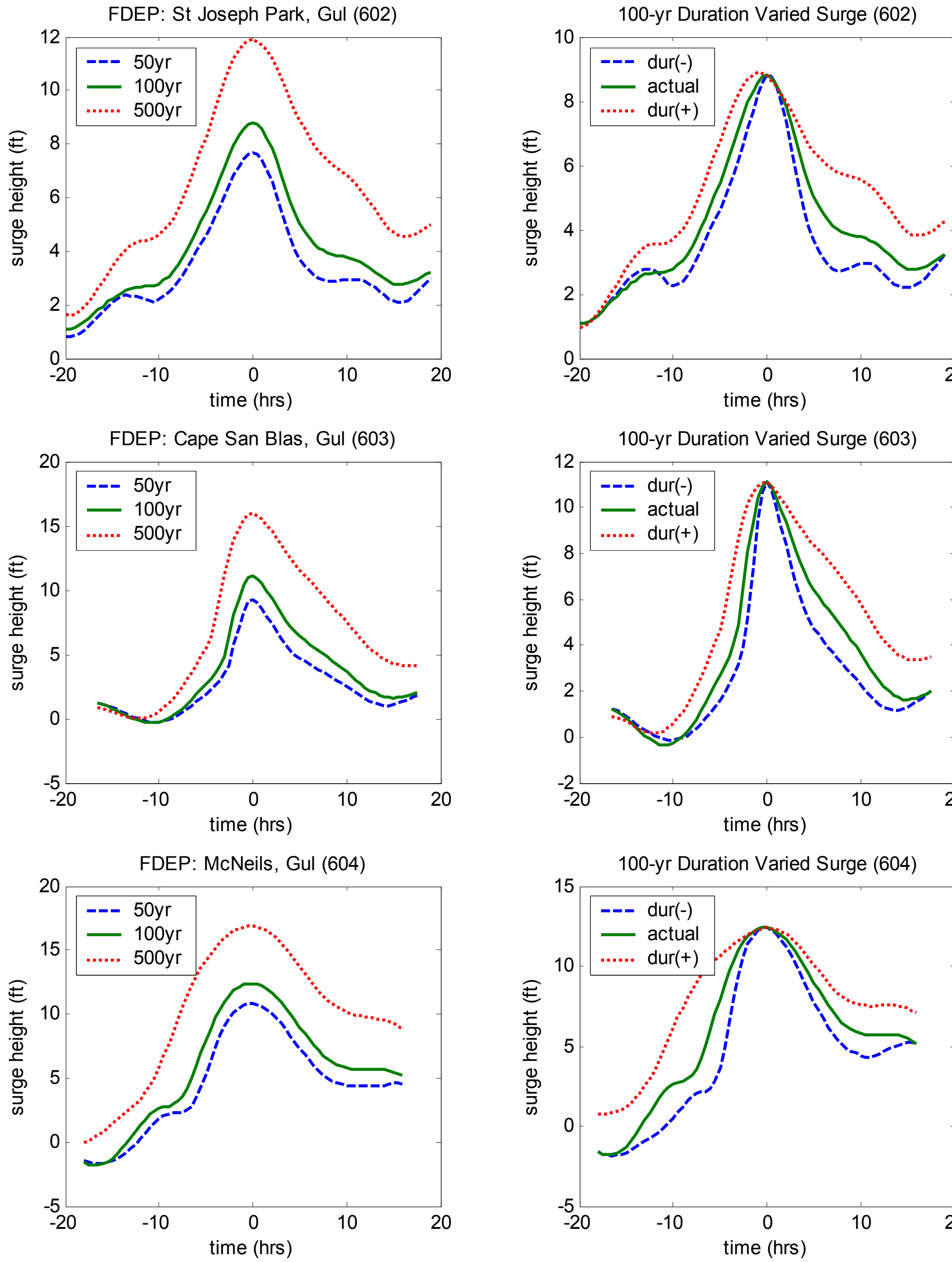

Figure IV- 17. Hydrograph plots for Gulf County.

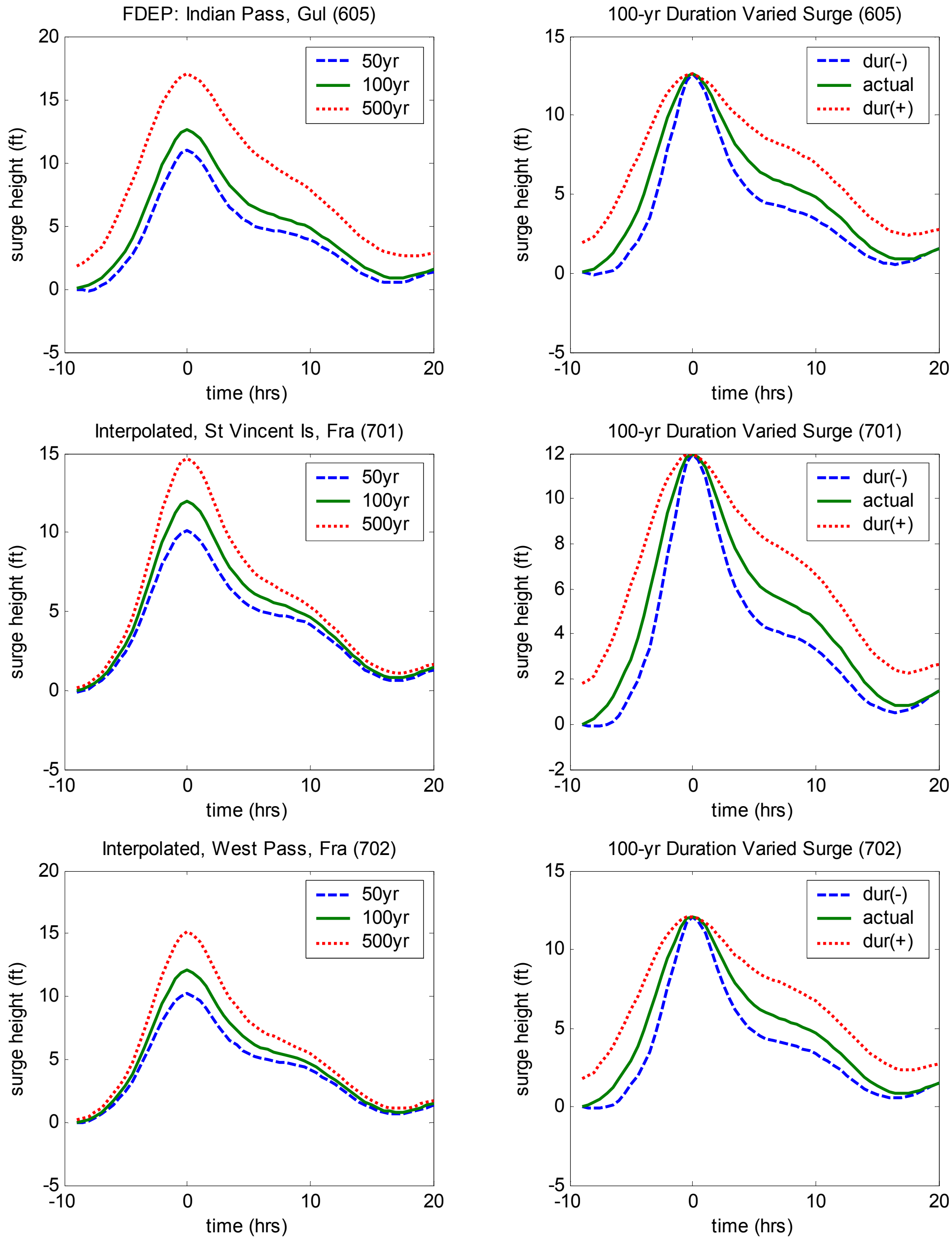

Figure IV- 18. Hydrograph plots for Gulf and Franklin Counties.

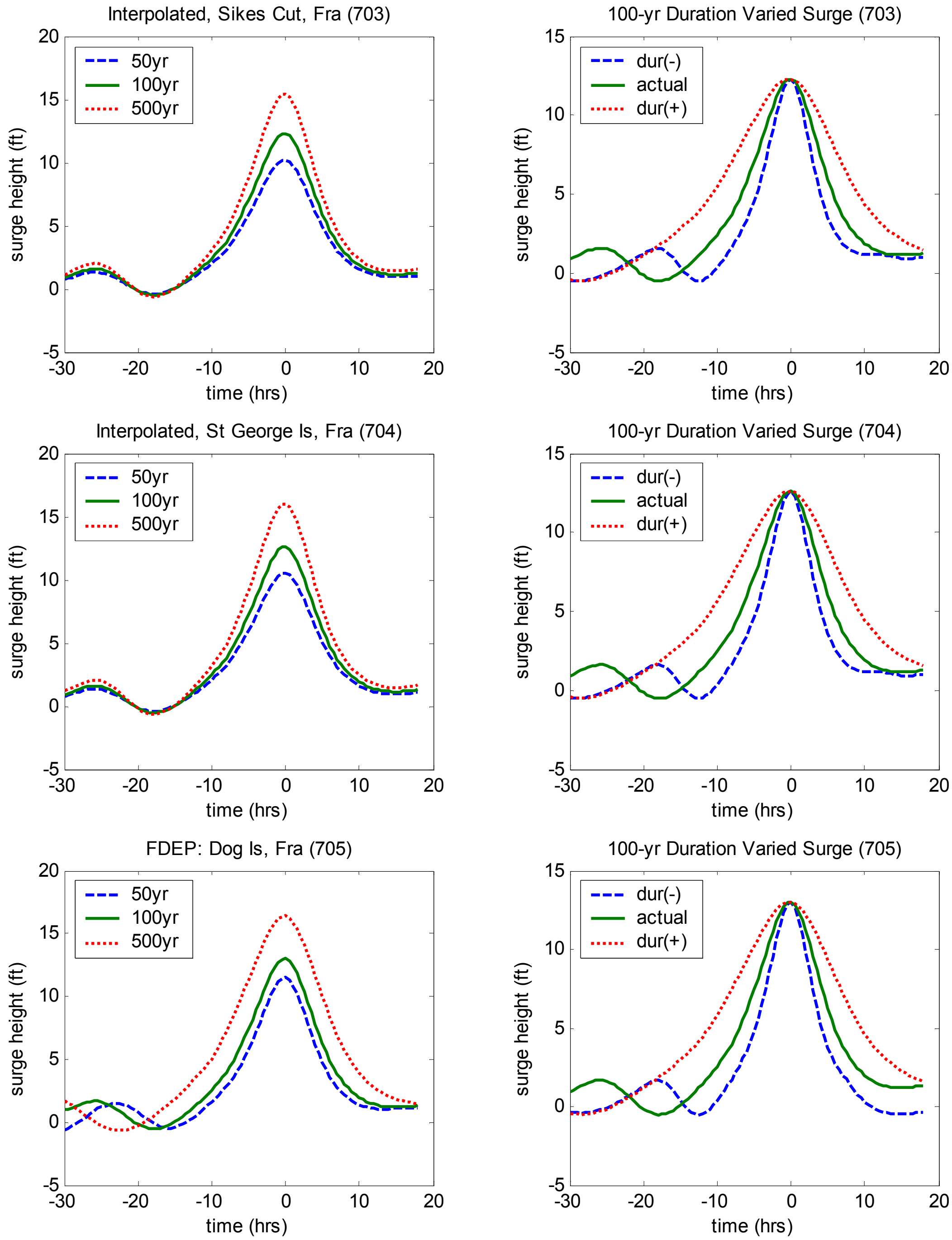

Figure IV- 19. Hydrograph plots for Franklin County. (Note: the Franklin County, 705, hydrograph does not have an associated astronomical tide, though it is included in the total surge plotted here.)

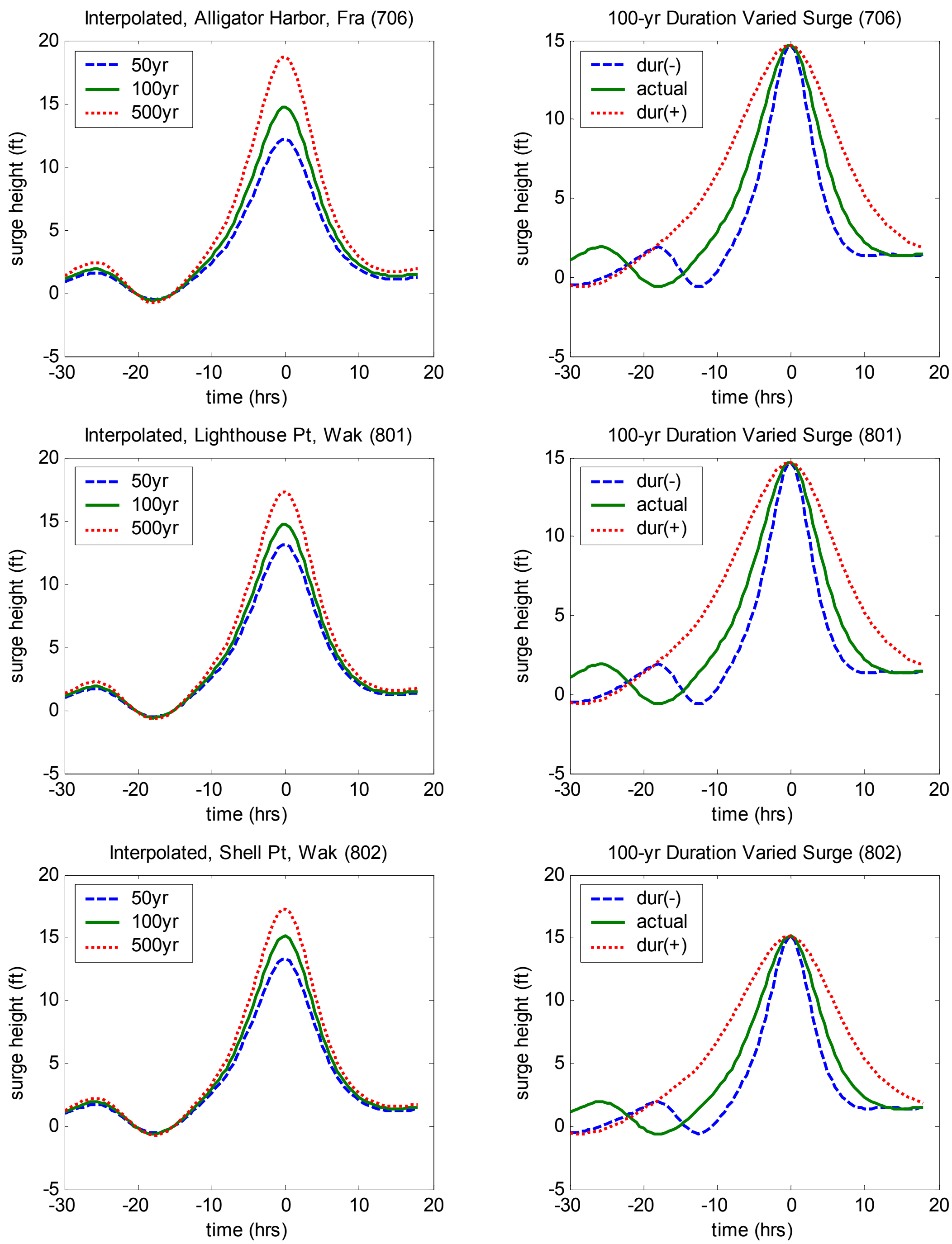

Figure IV- 20. Hydrograph plots for Franklin and Wakulla Counties.

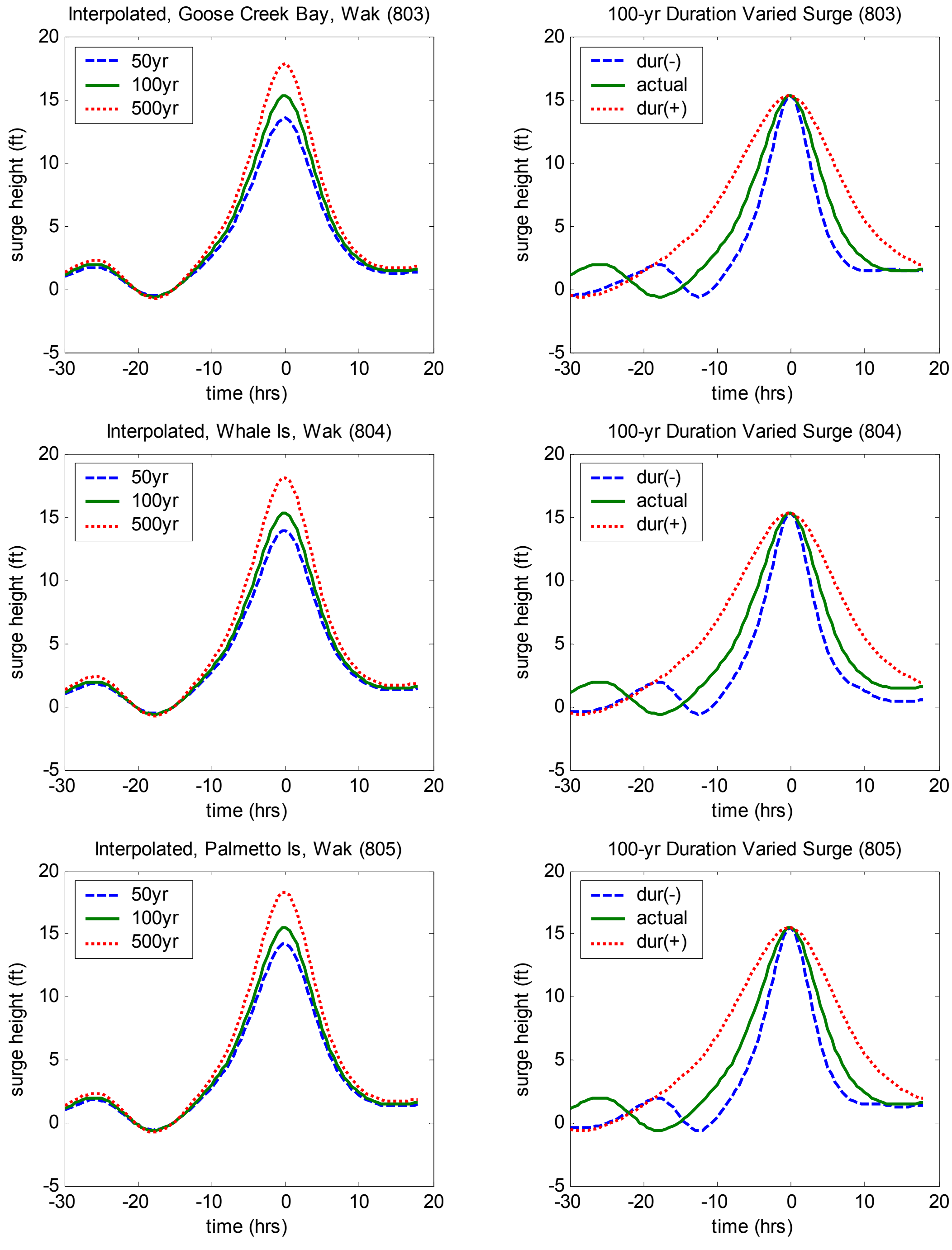

Figure IV- 21. Hydrograph plots for Wakulla County. (Note: the Wakulla County, 804, hydrograph does not have an associated astronomical tide, though it is included in the total surge plotted here.)

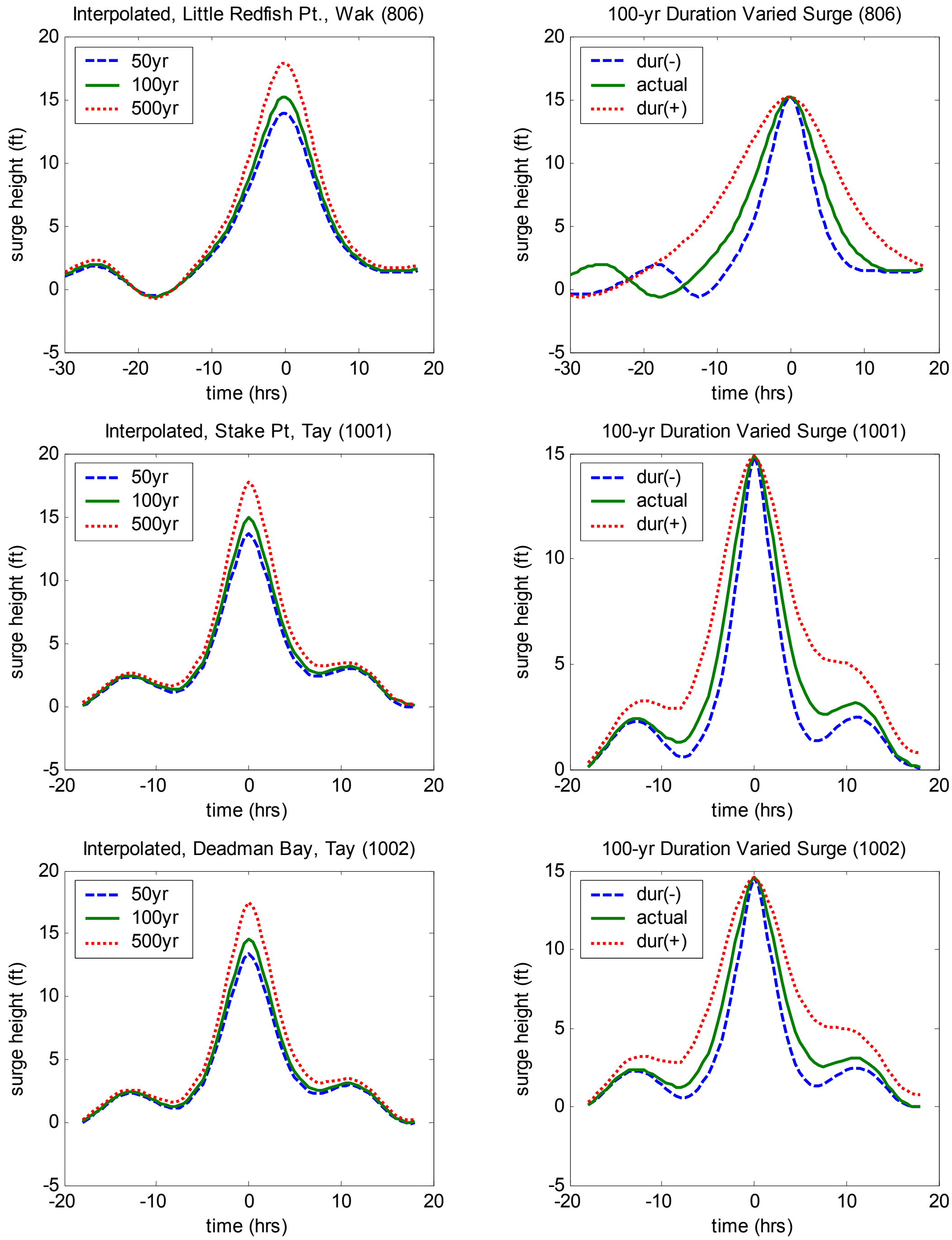

Figure IV- 22. Hydrograph plots for Wakulla and Taylor Counties.

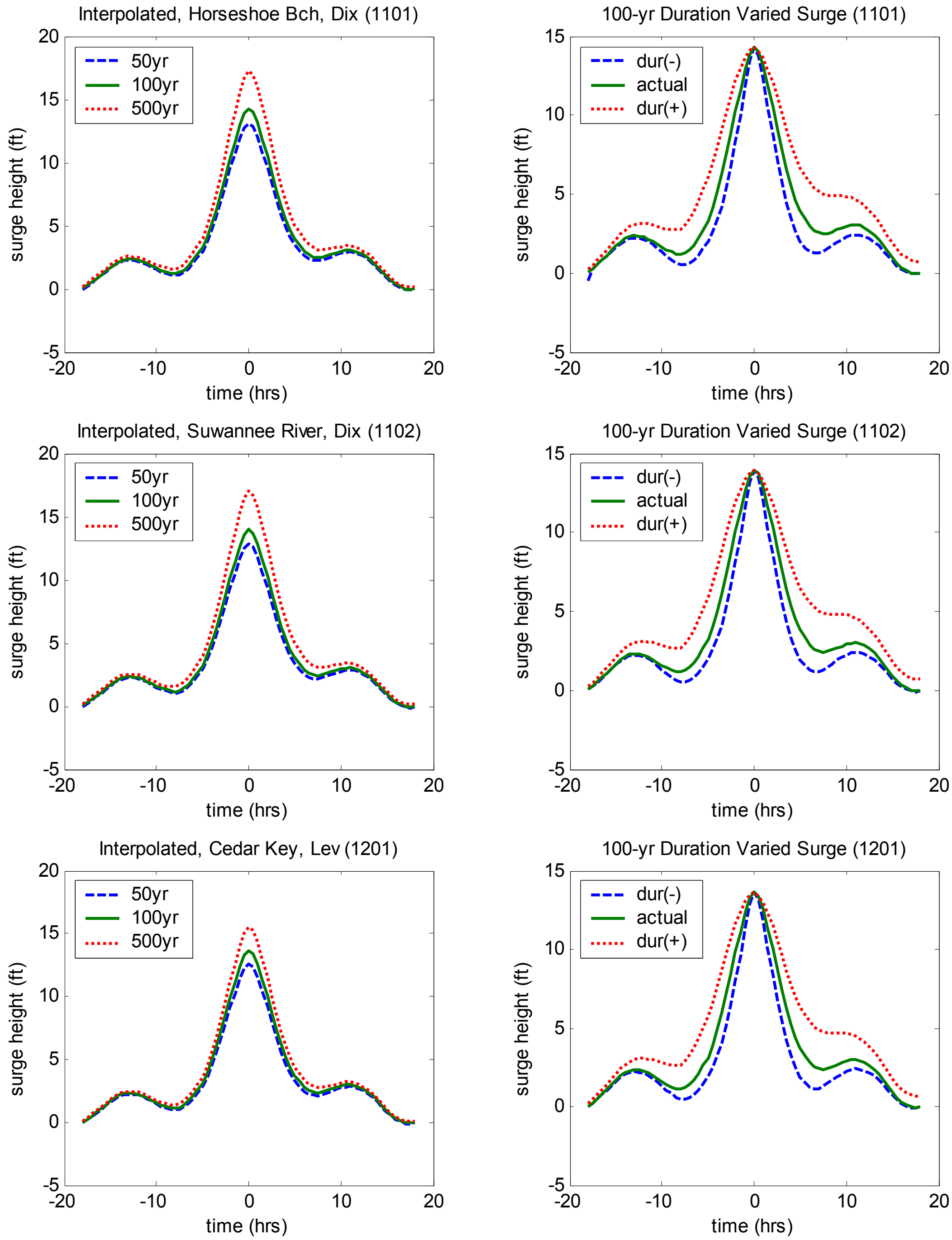

Figure IV- 23. Hydrograph plots for Dixie and Levy Counties.

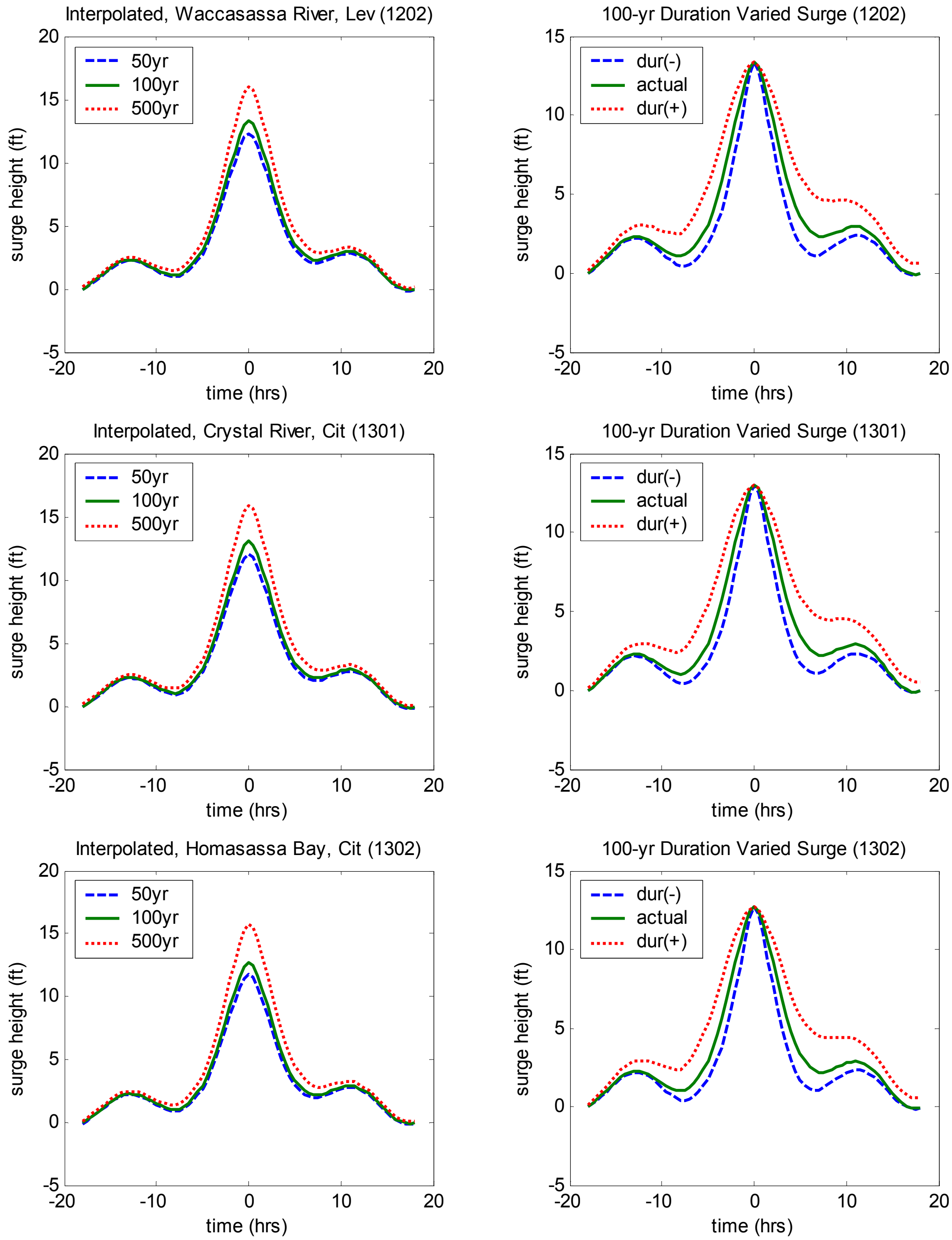

Figure IV- 24. Hydrograph plots for Levy and Citrus Counties.

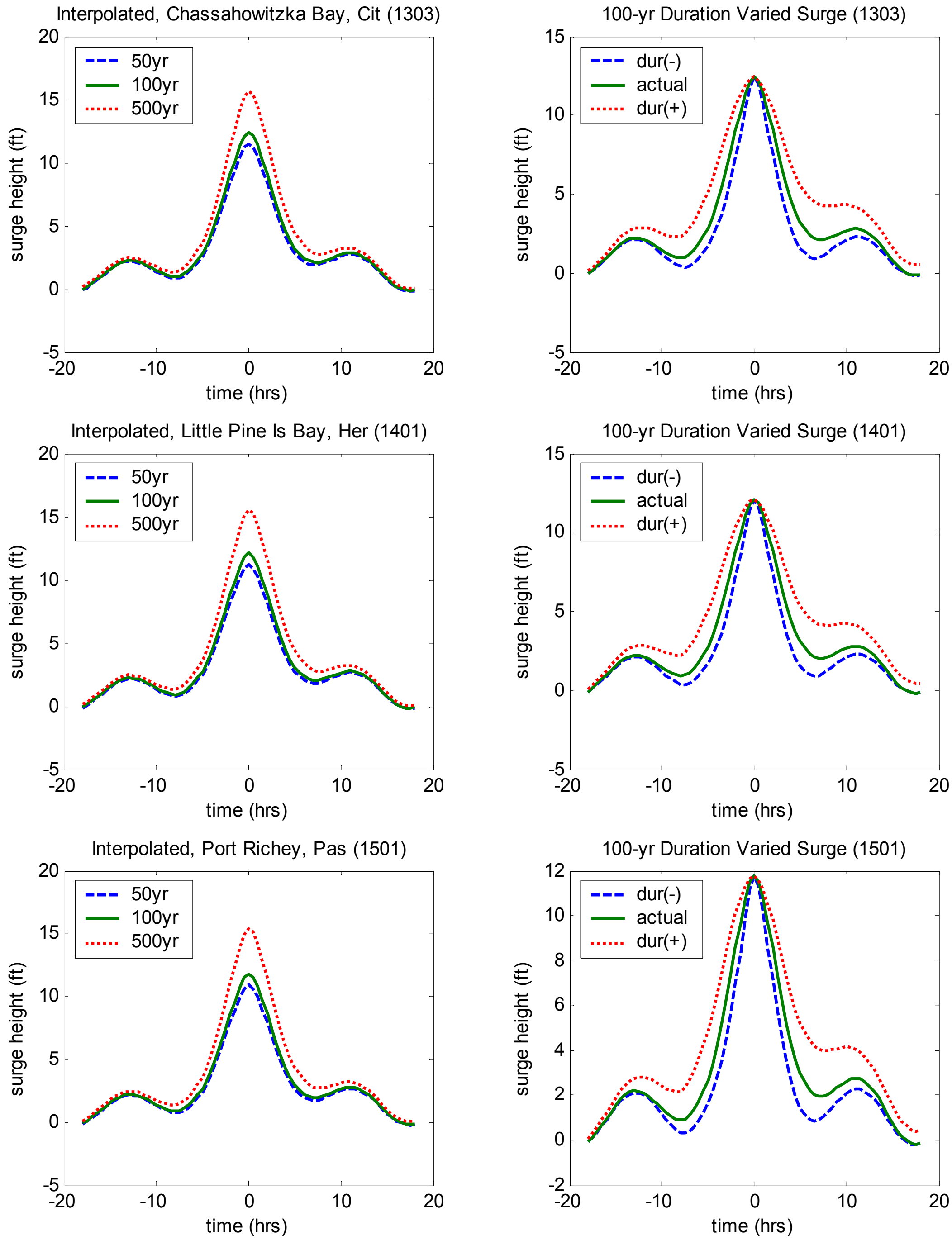

Figure IV- 25. Hydrograph plots for Citrus, Hernando and Pasco Counties.

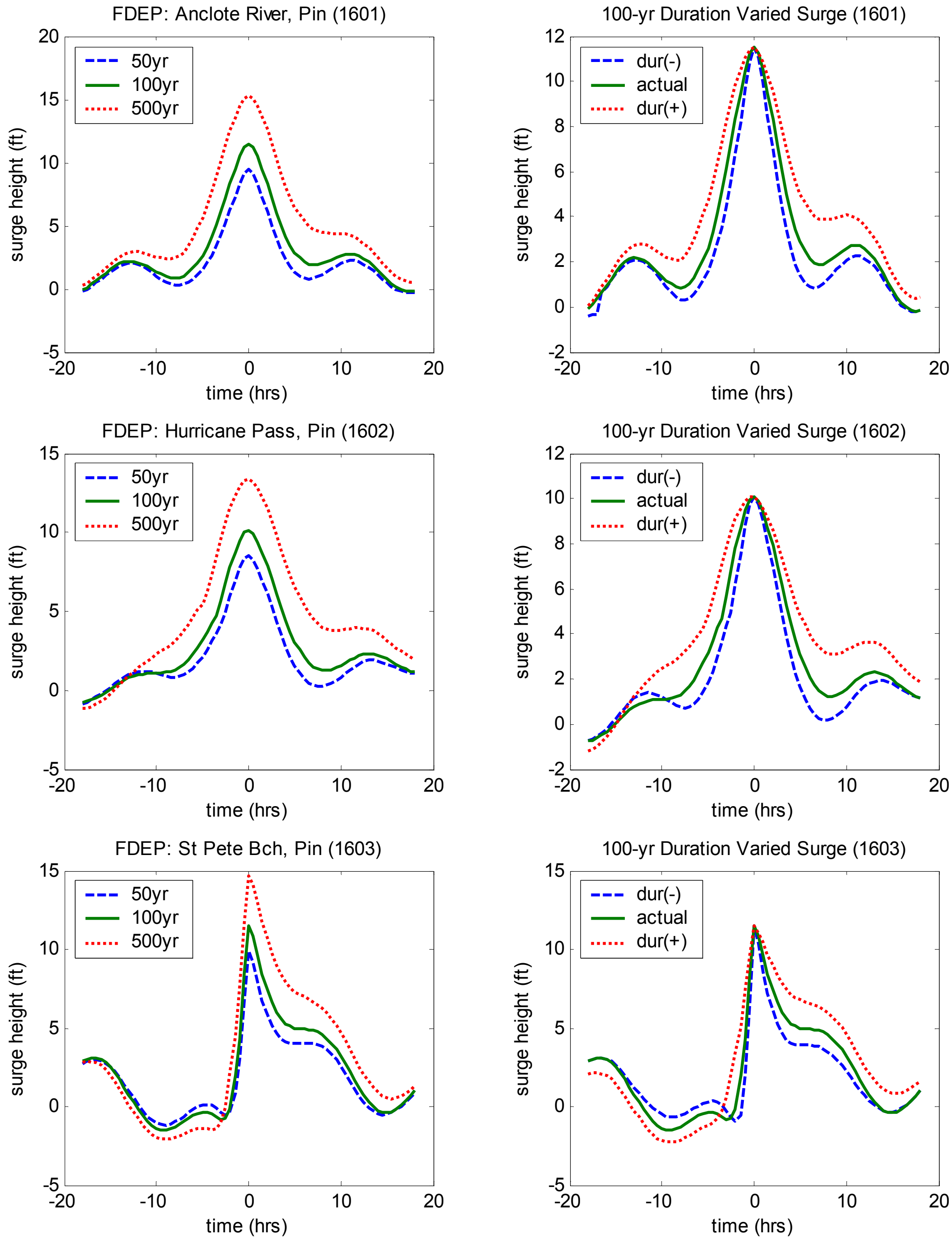

Figure IV- 26. Hydrograph plots for Pinellas County.

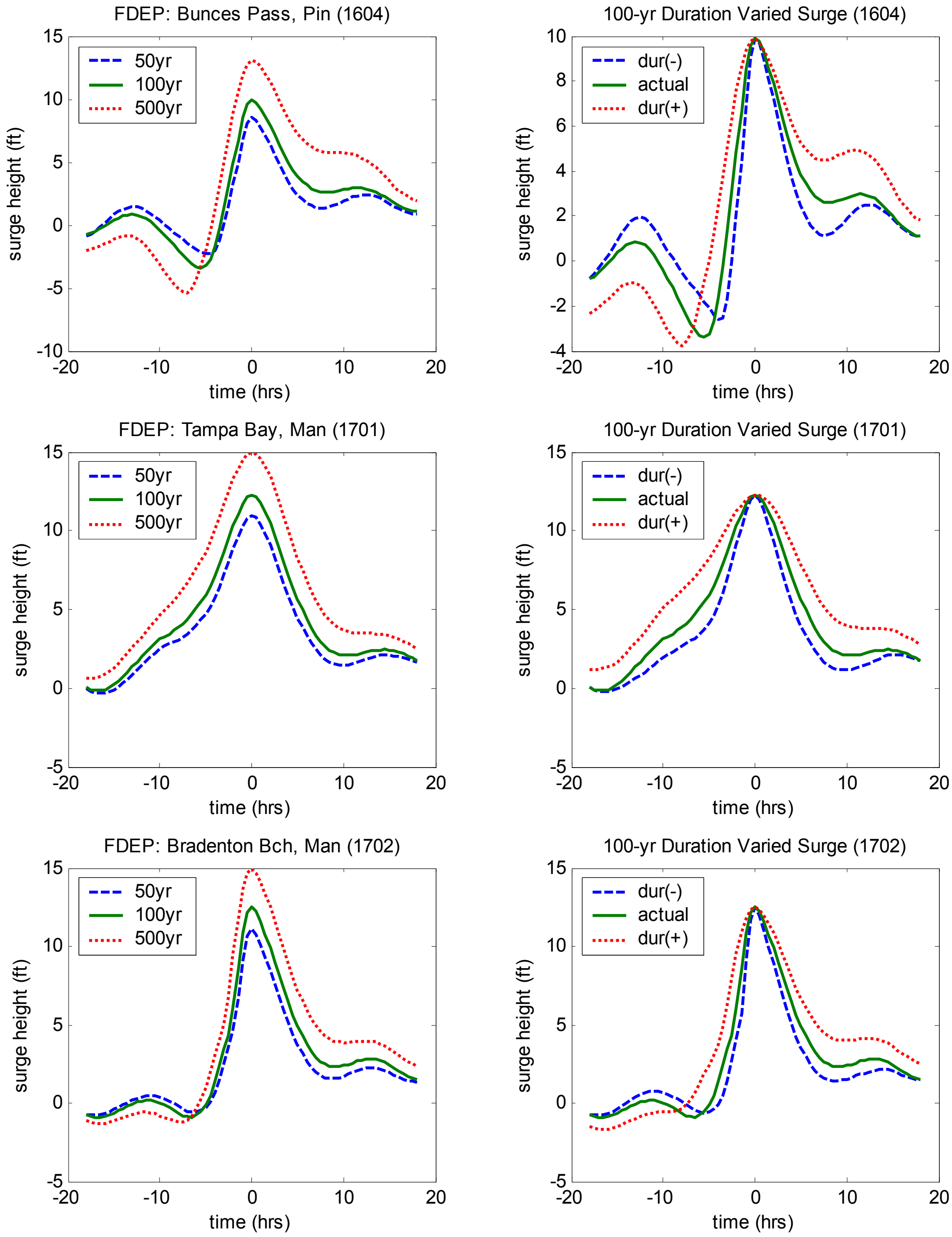

Figure IV- 27. Hydrograph plots for Pinellas and Manatee Counties.

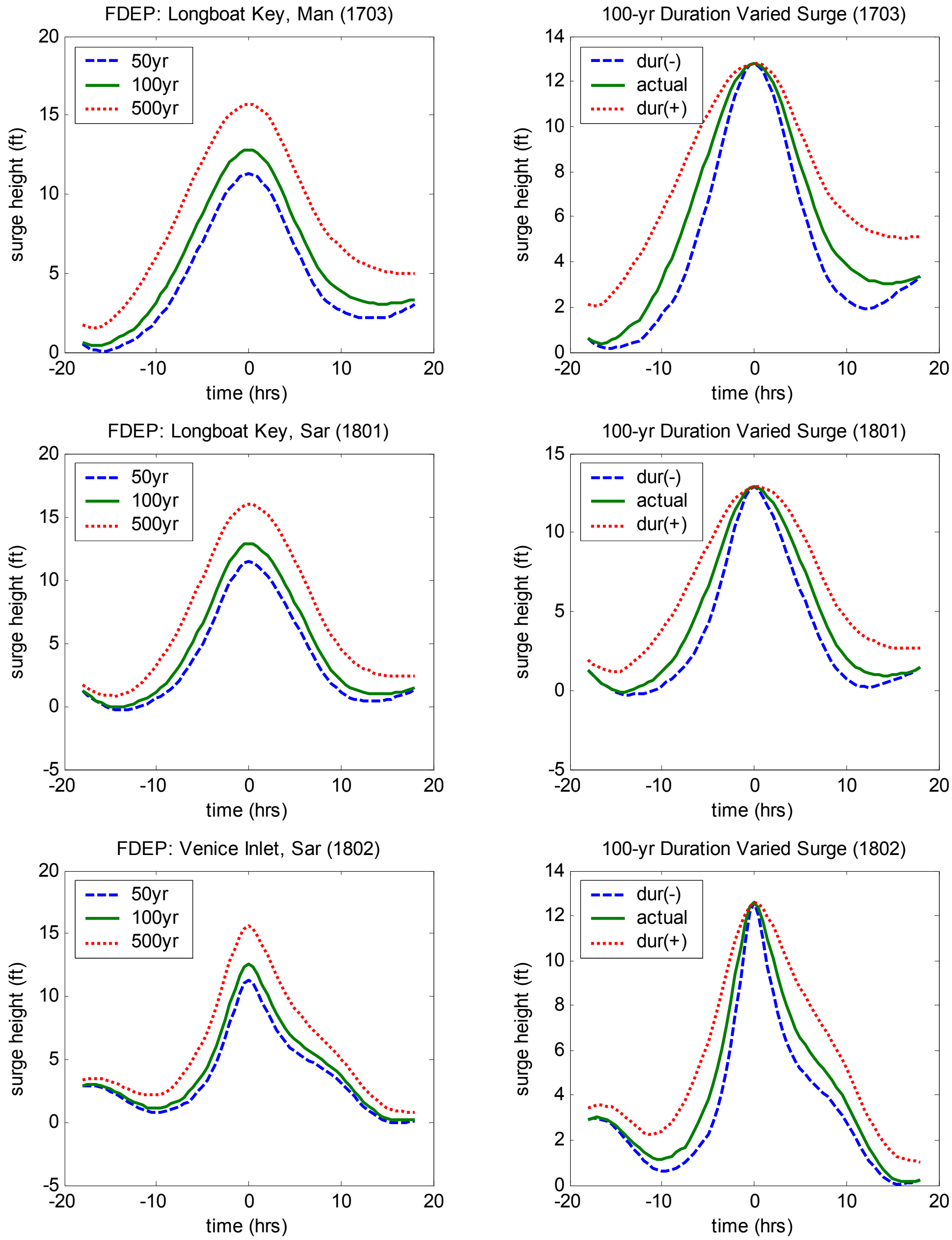

Figure IV- 28. Hydrograph plots for Manatee and Sarasota Counties.

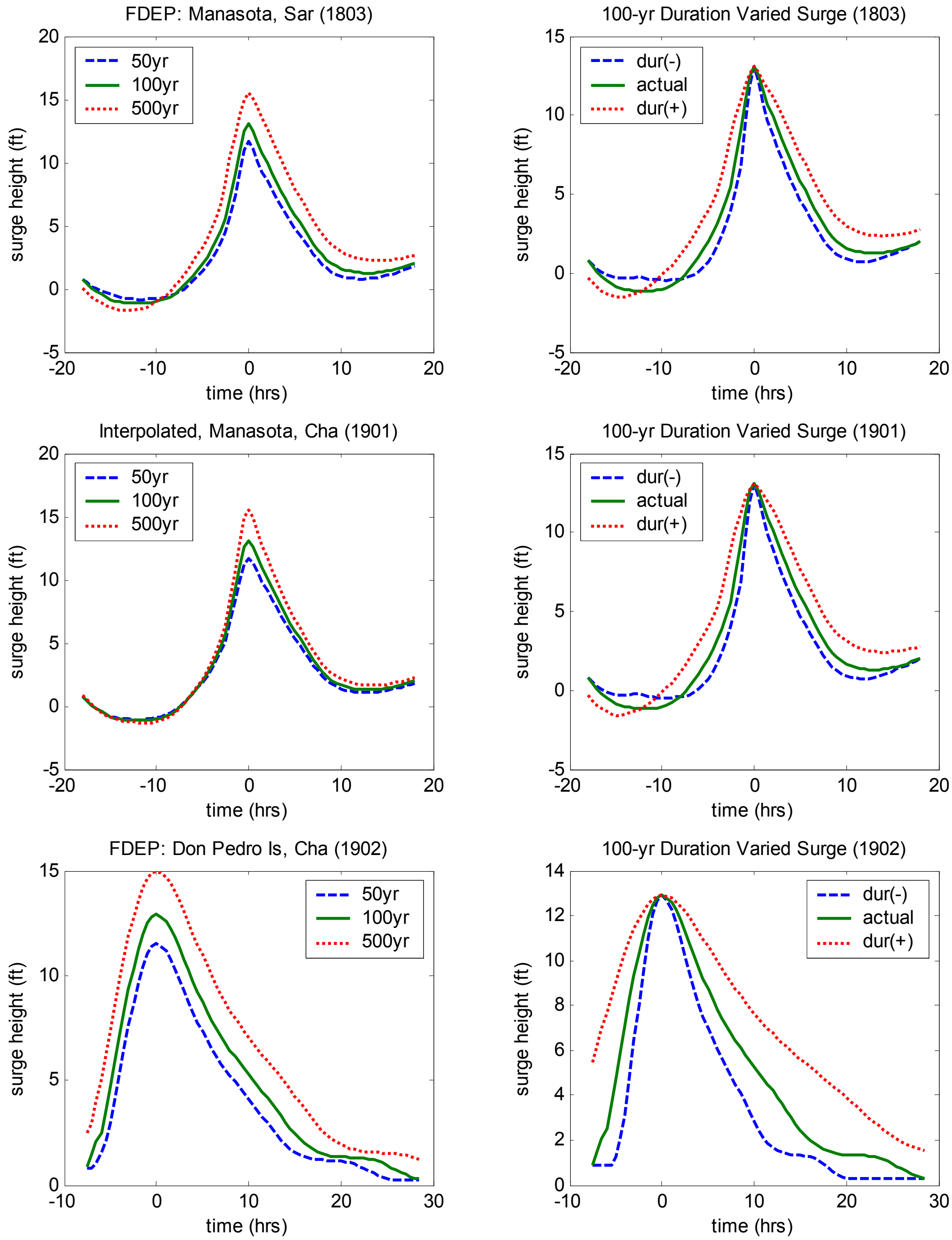

Figure IV- 29. Hydrograph plots for Sarasota and Charlotte Counties.

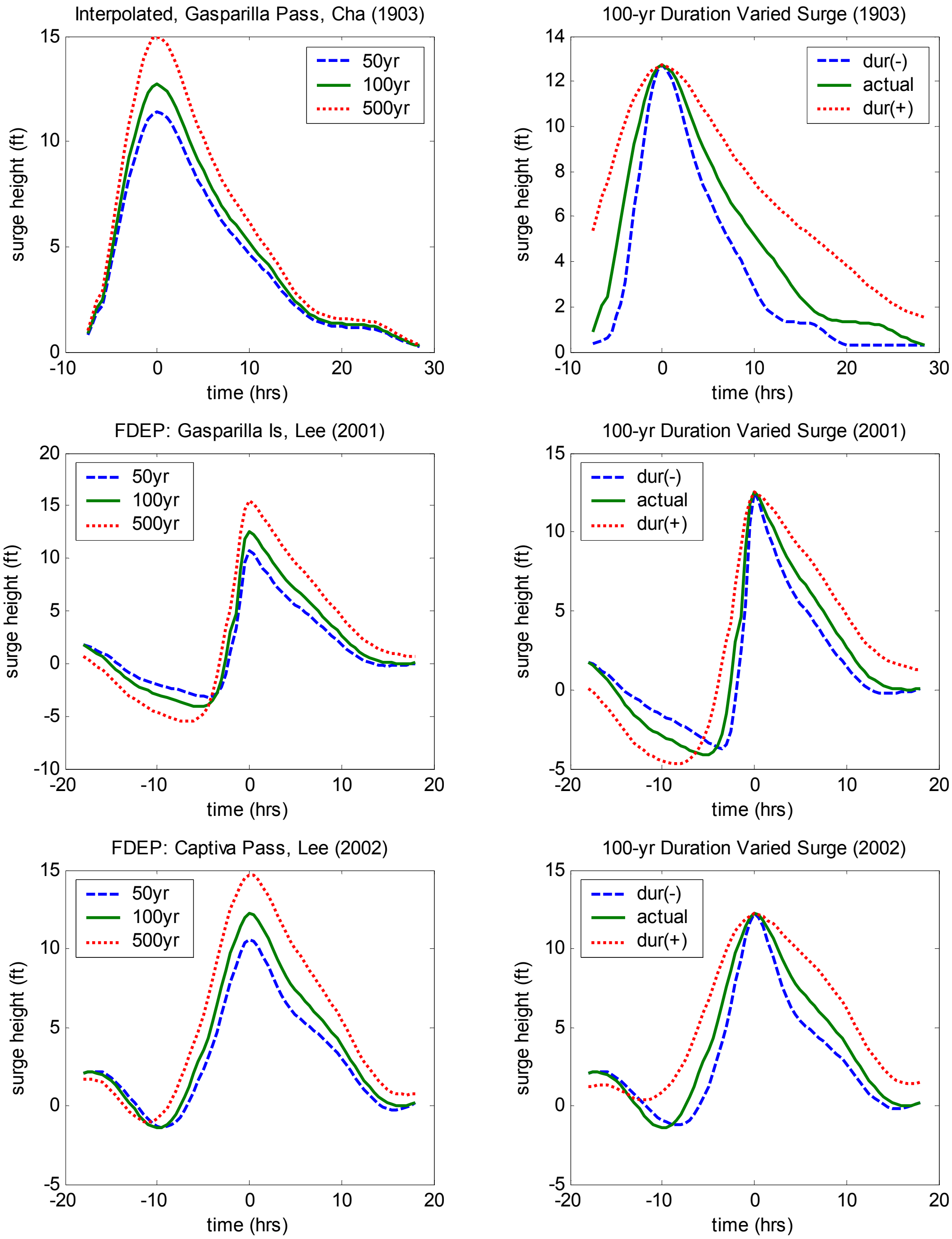

Figure IV- 30. Hydrograph plots for Charlotte and Lee Counties.

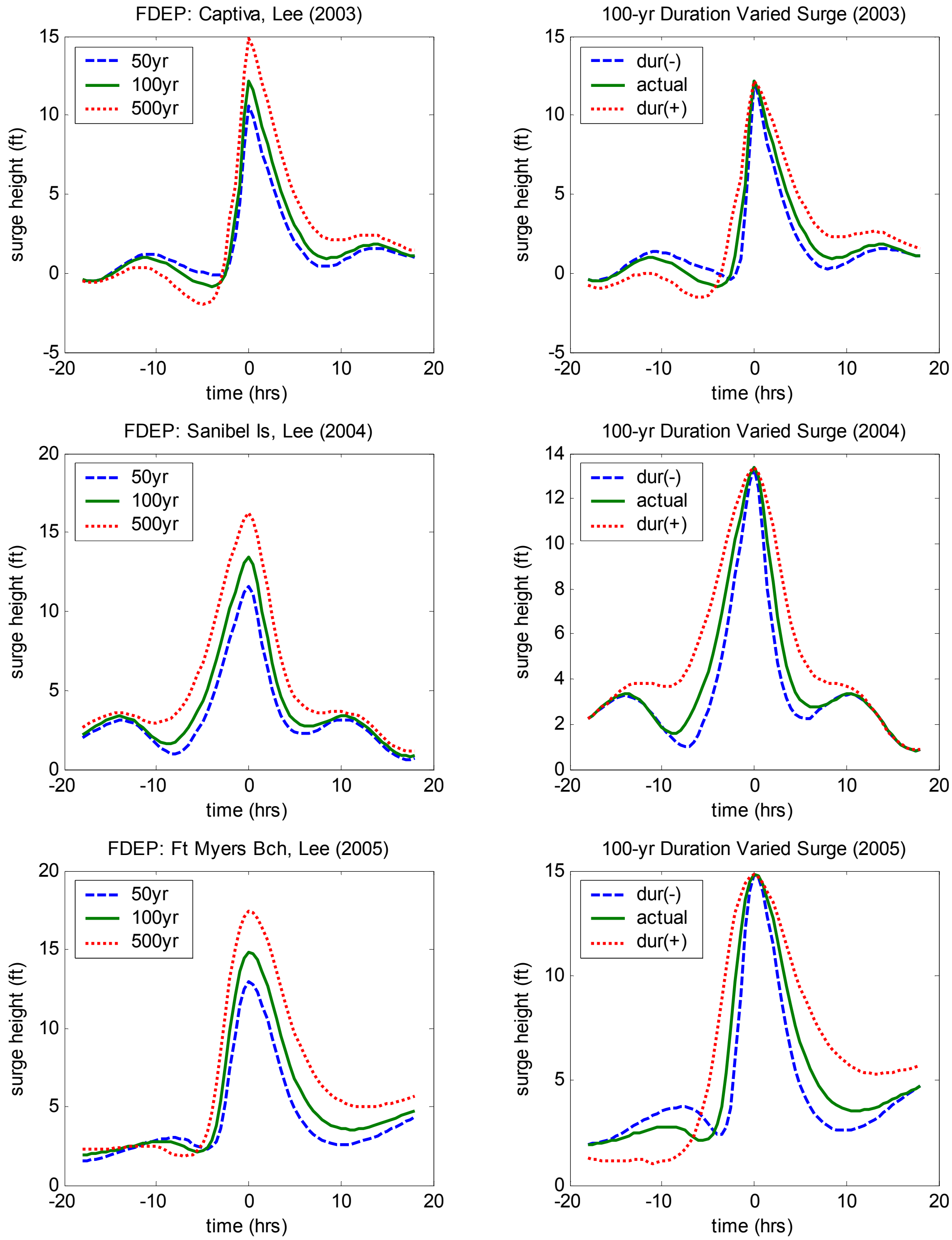

Figure IV- 31. Hydrograph plots for Lee County.

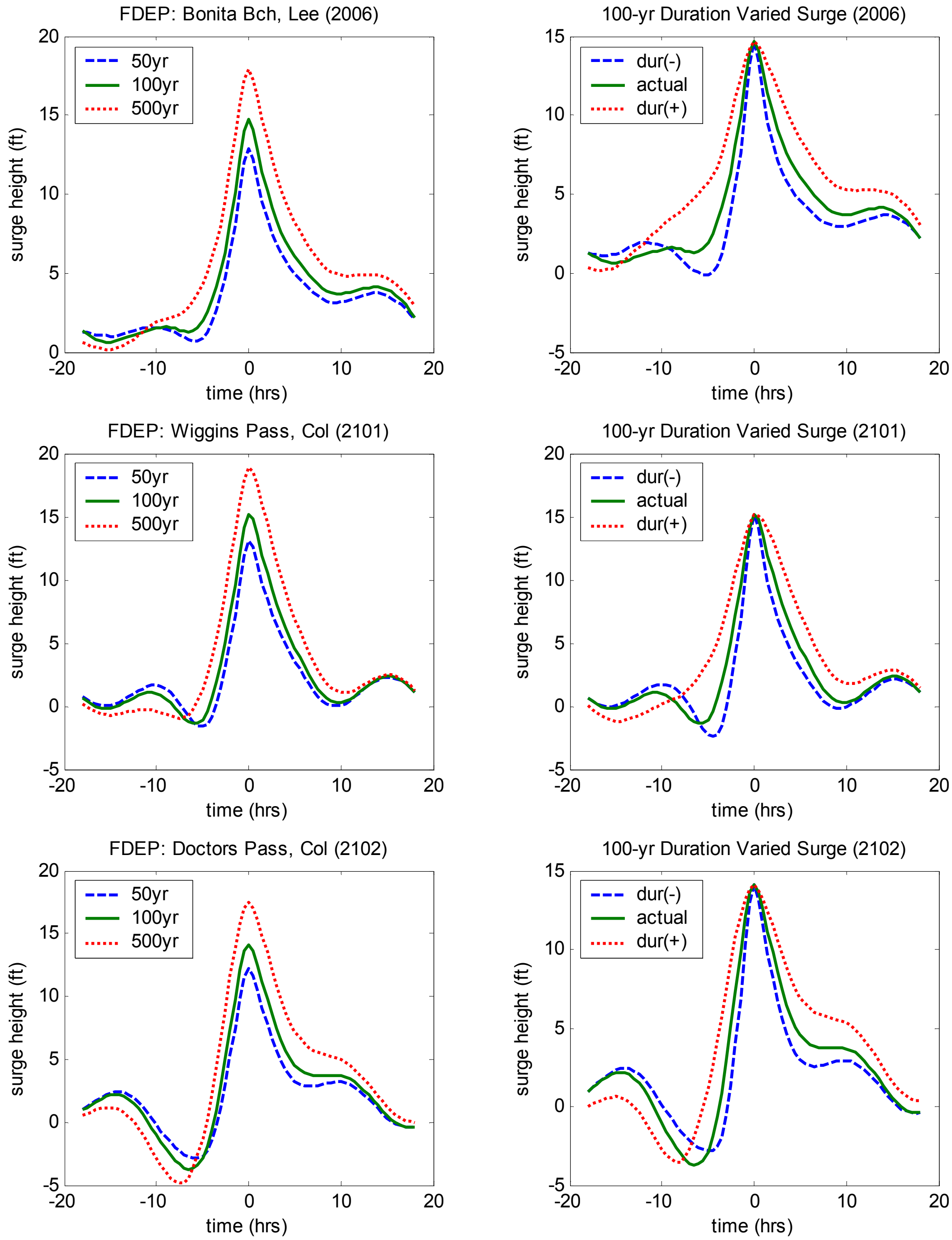

Figure IV- 32. Hydrograph plots for Lee and Collier Counties.

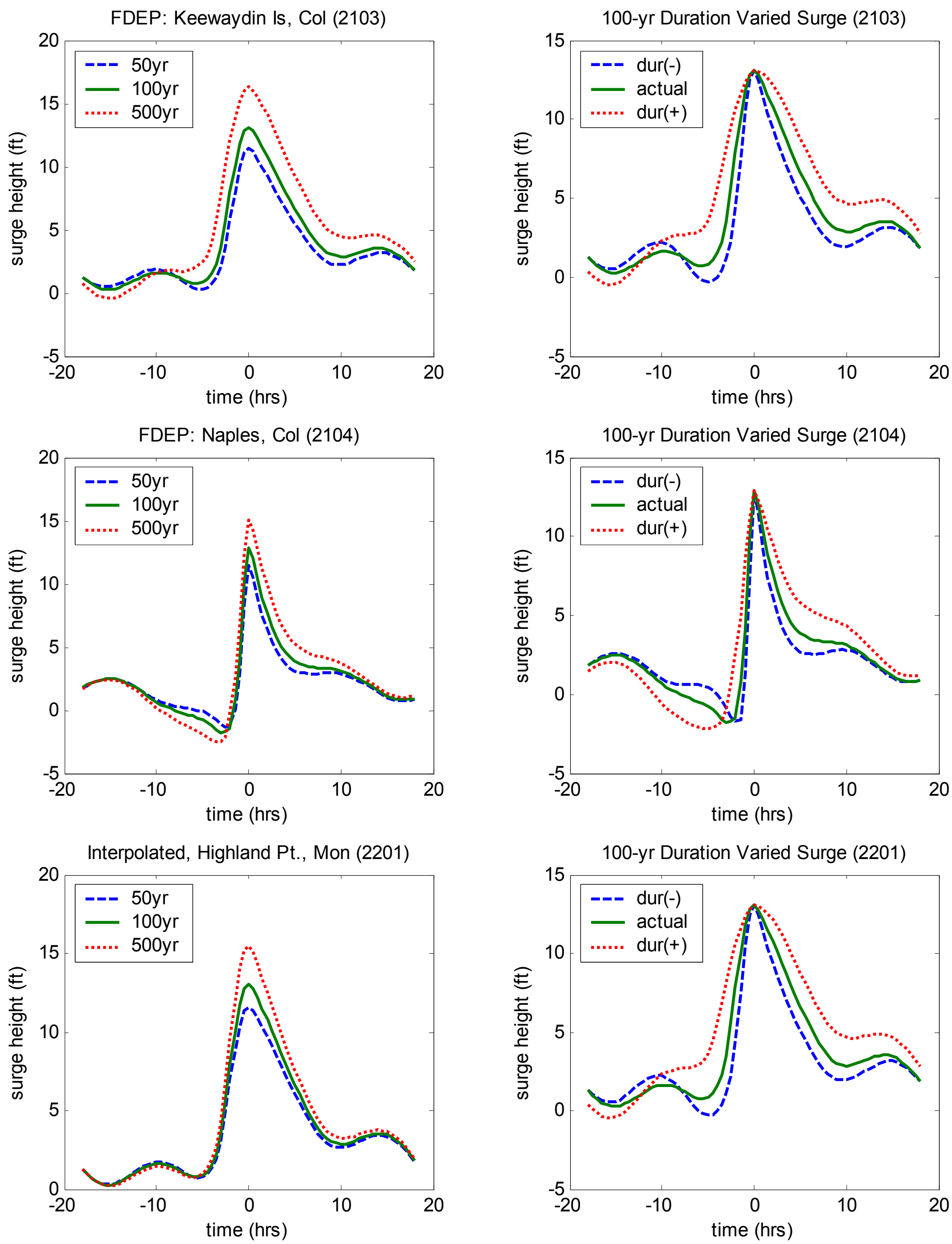

Figure IV- 33. Hydrograph plots for Collier and Monroe Counties.

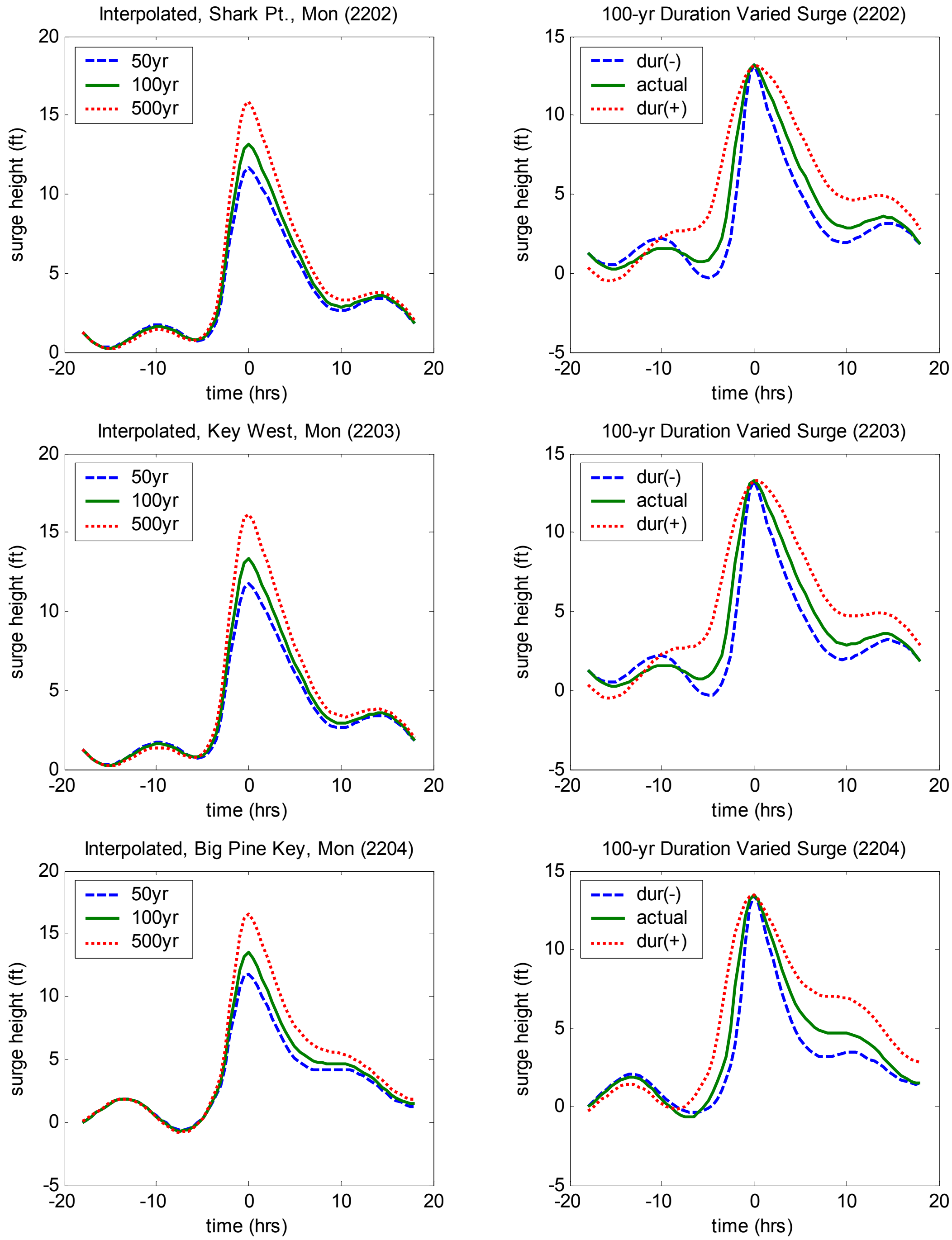

Figure IV- 34. Hydrograph plots for Monroe County.

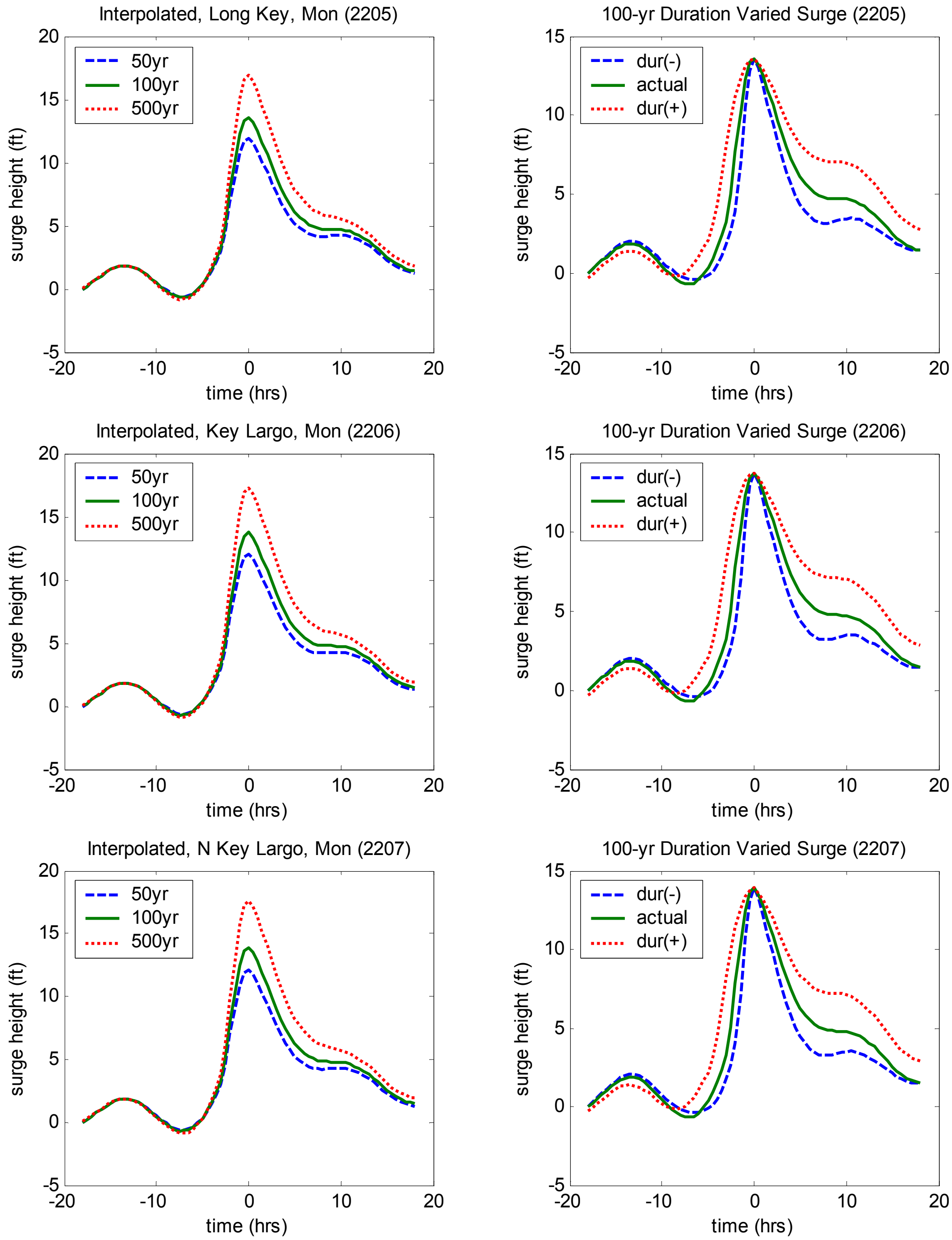

Figure IV- 35. Hydrograph plots for Monroe County.

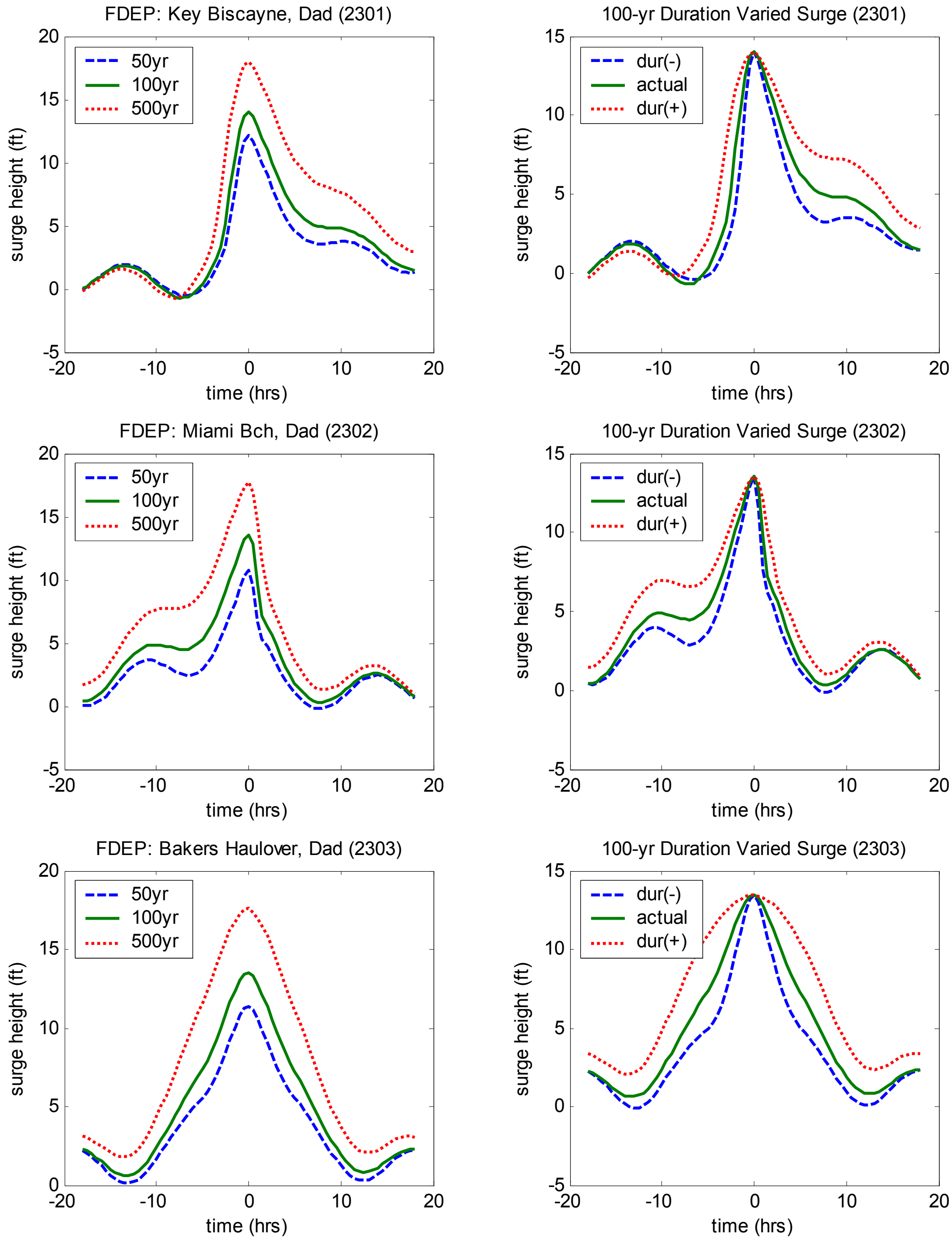

Figure IV- 36. Hydrograph plots for Dade County.

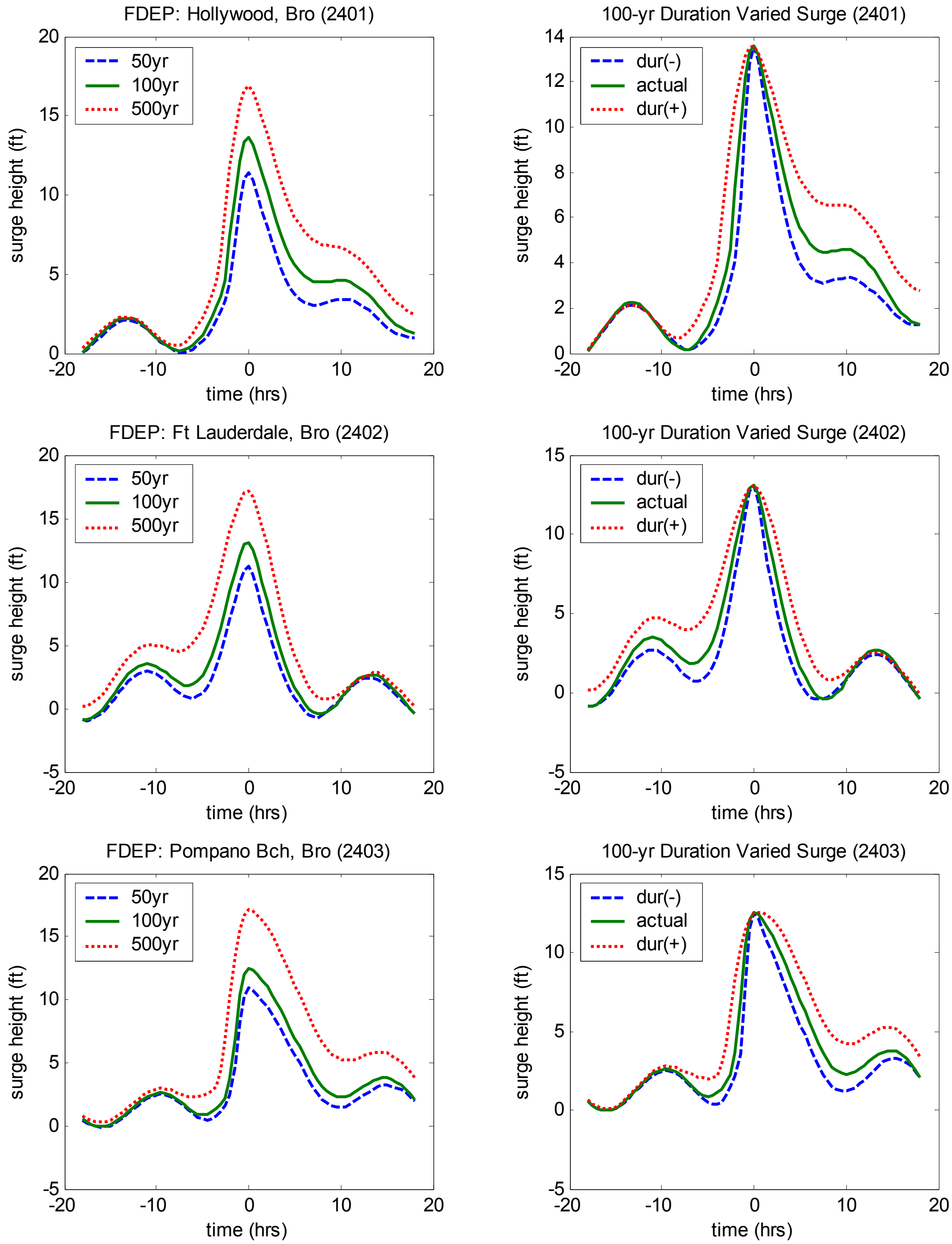

Figure IV- 37. Hydrograph plots for Broward County.

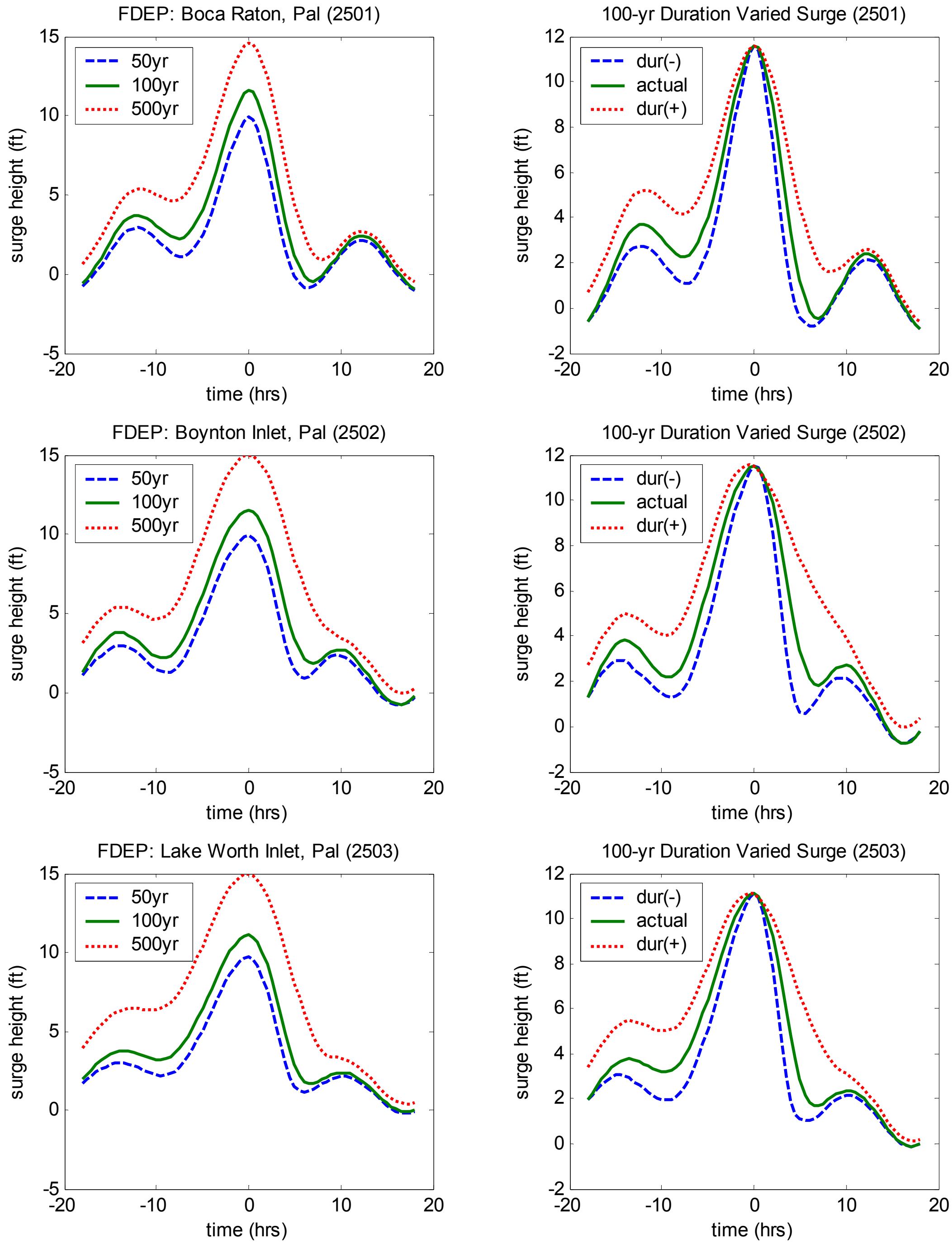

Figure IV- 38. Hydrograph plots for Palm Beach County.

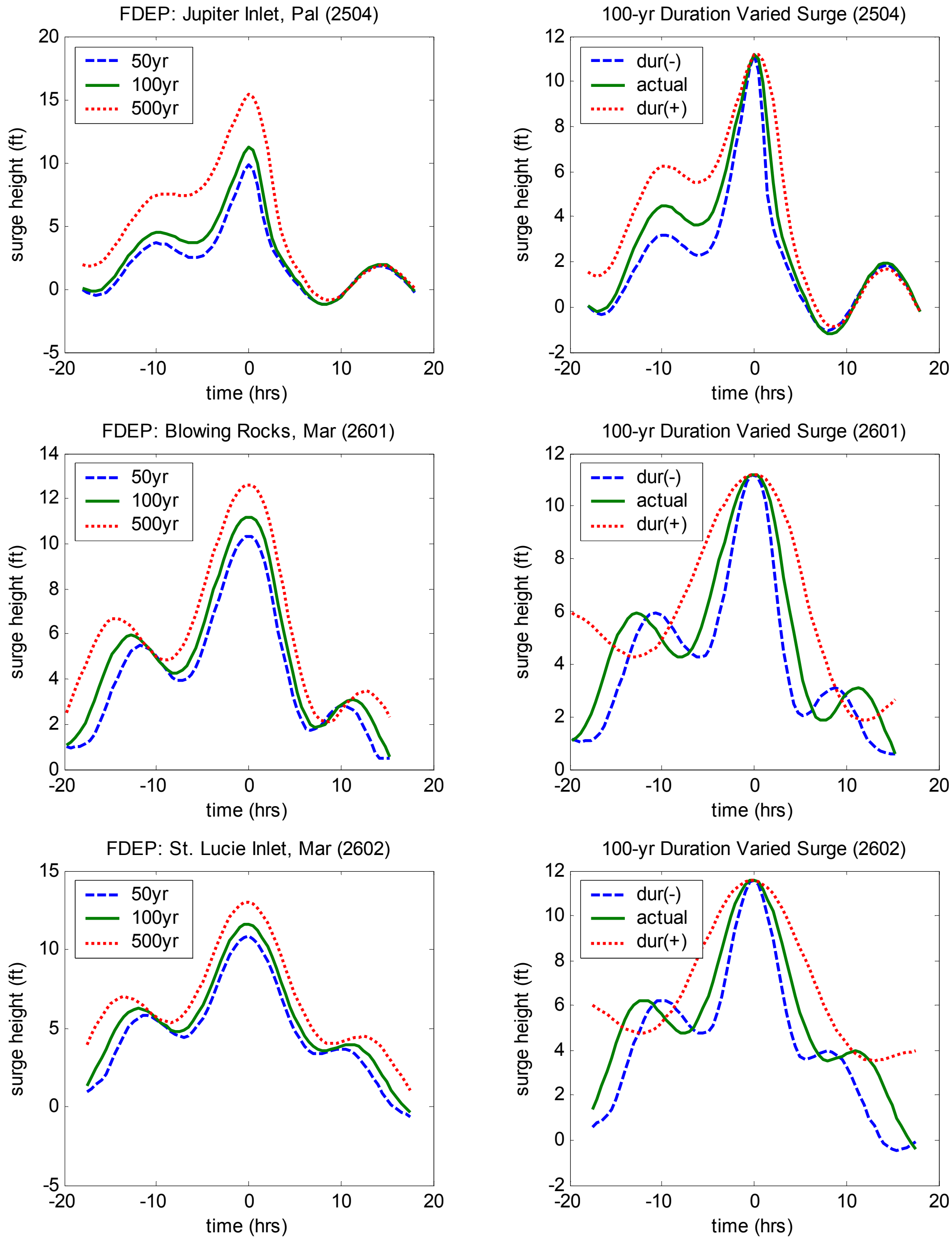

Figure IV- 39. Hydrograph plots for Palm Beach and Martin Counties. (Note: the Martin County, 705, hydrograph does not have an associated astronomical tide, though it is included in the total surge plotted here.)

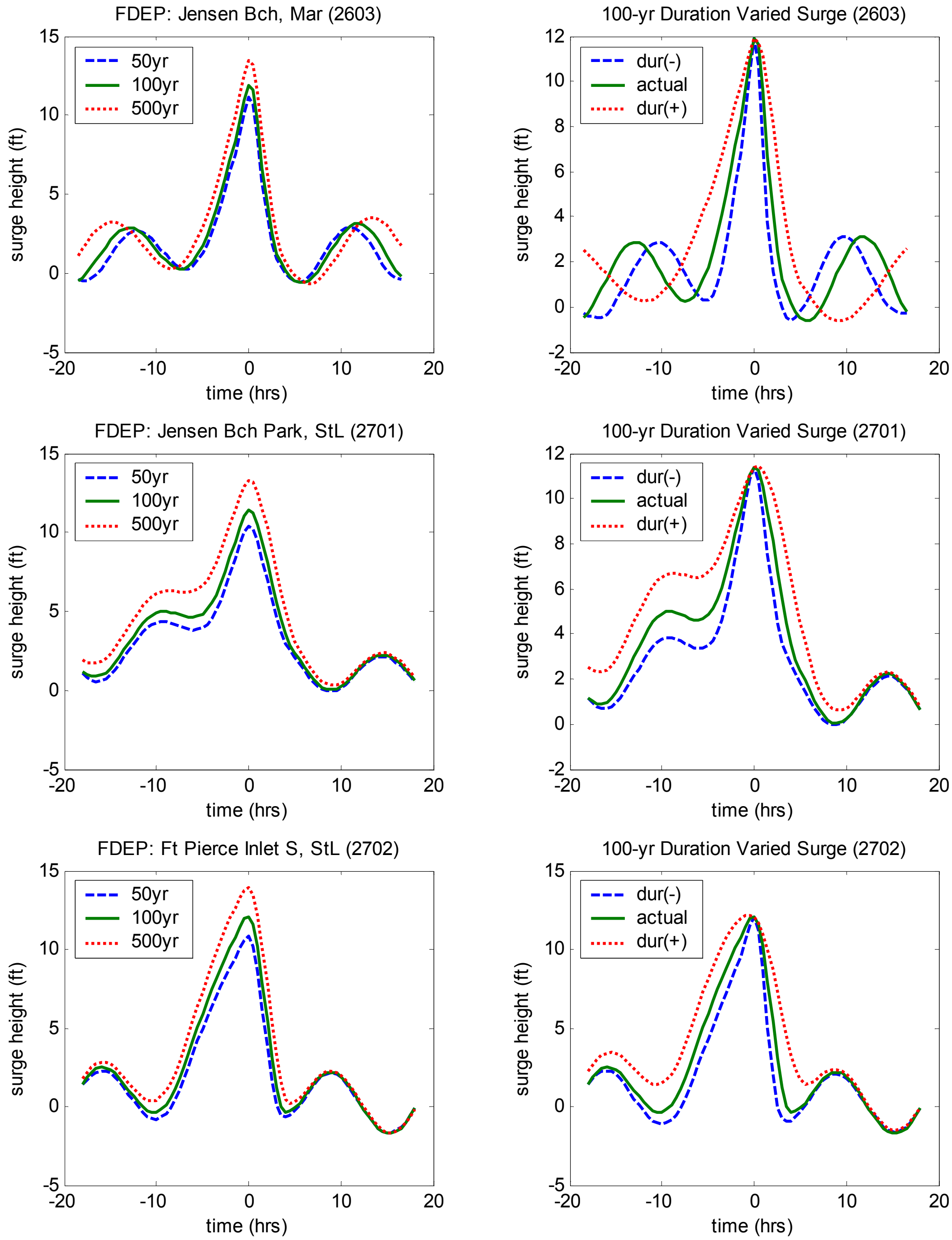

Figure IV- 40. Hydrograph plots for Martin and St. Lucie Counties.

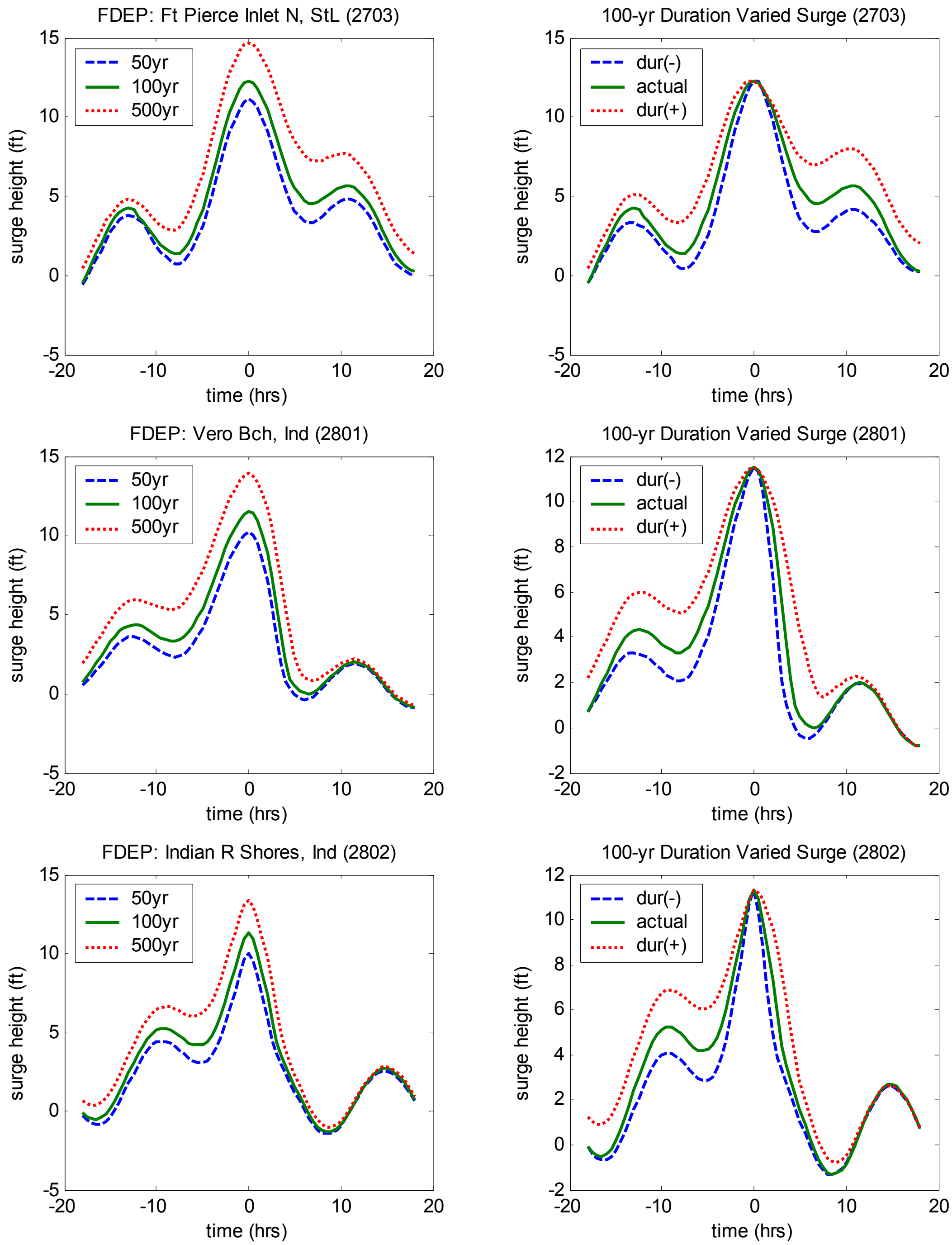

Figure IV- 41. Hydrograph plots for St Lucie and Indian River Counties.

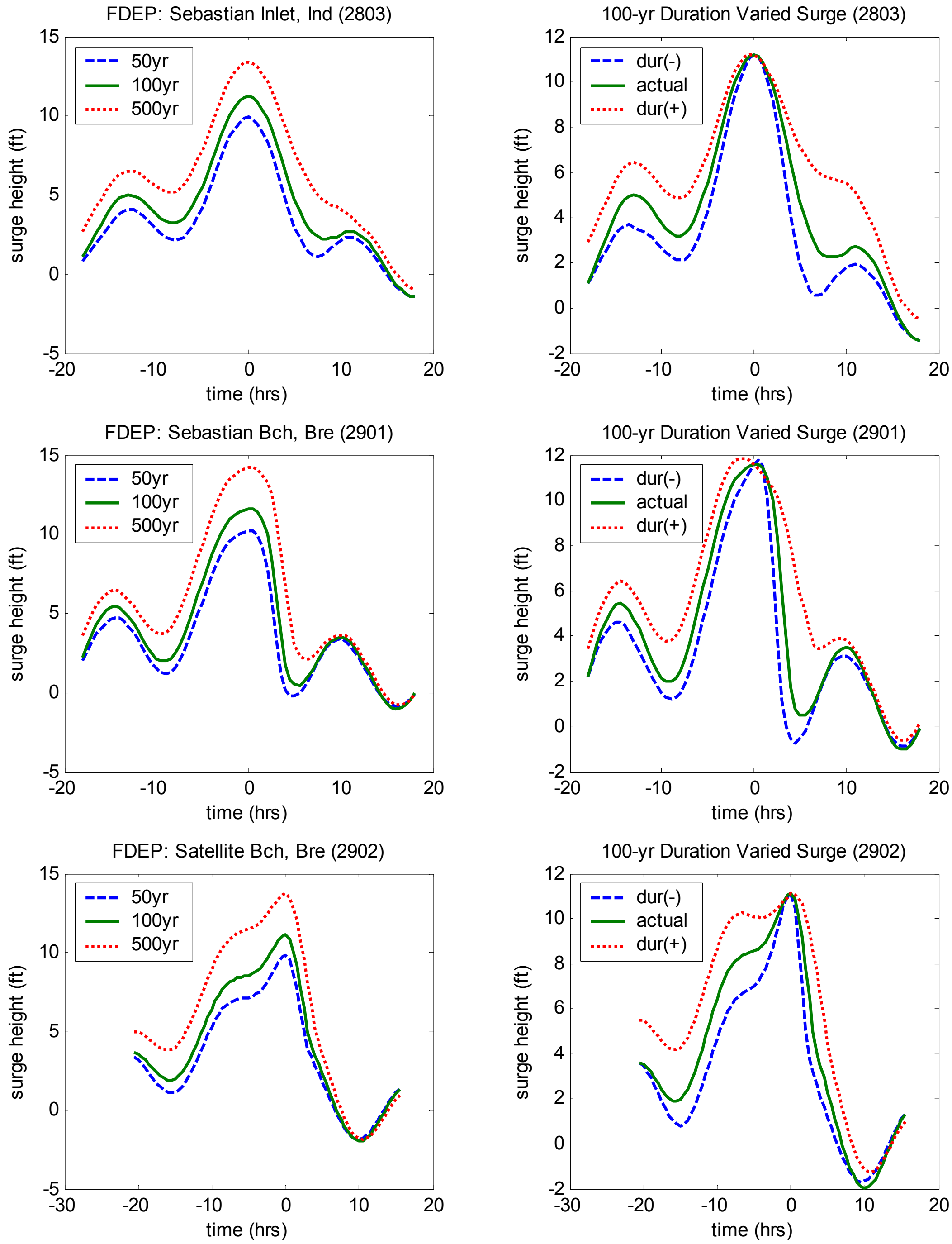

Figure IV- 42. Hydrograph plots for Indian River and Brevard Counties.

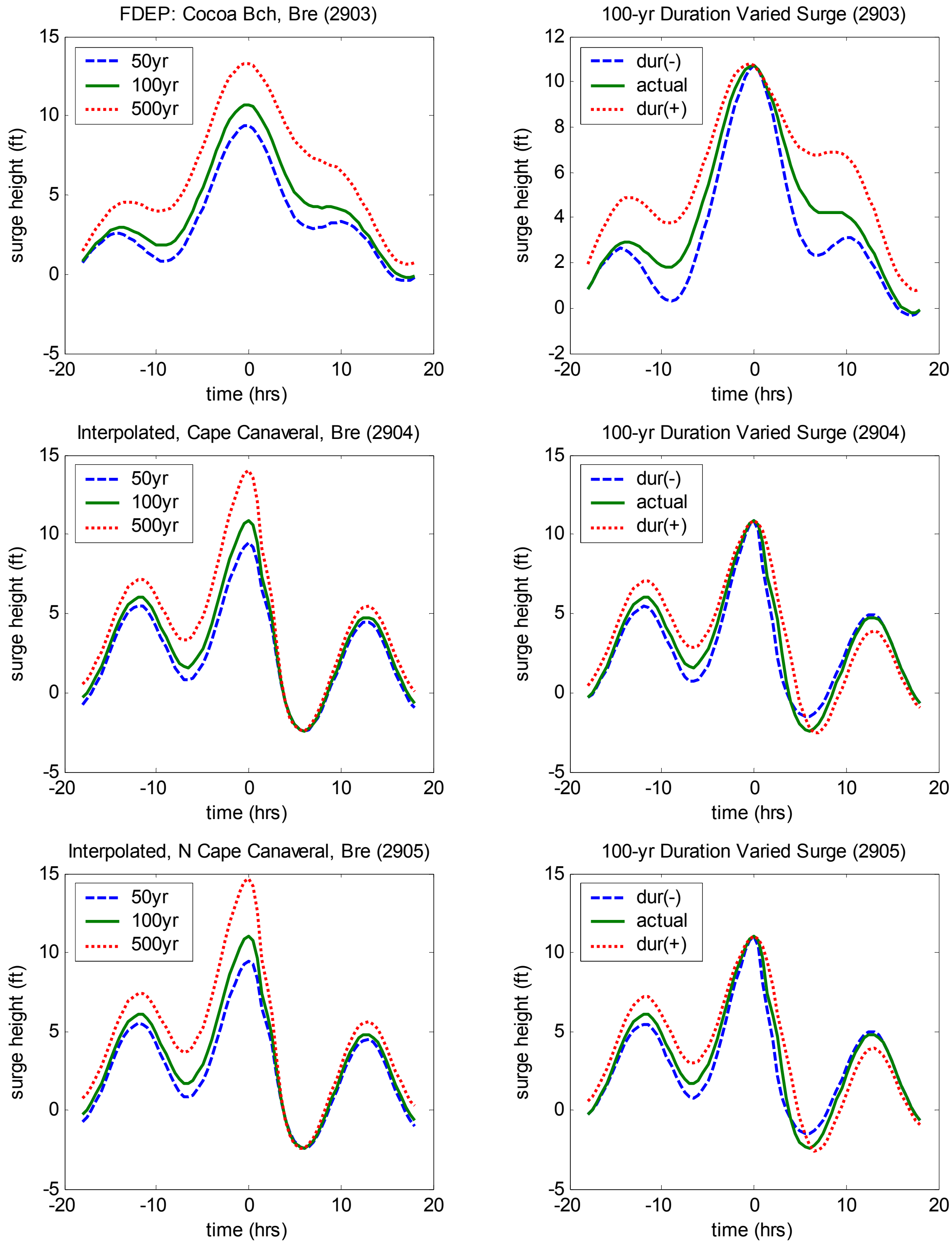

Figure IV- 43. Hydrograph plots for Brevard County.

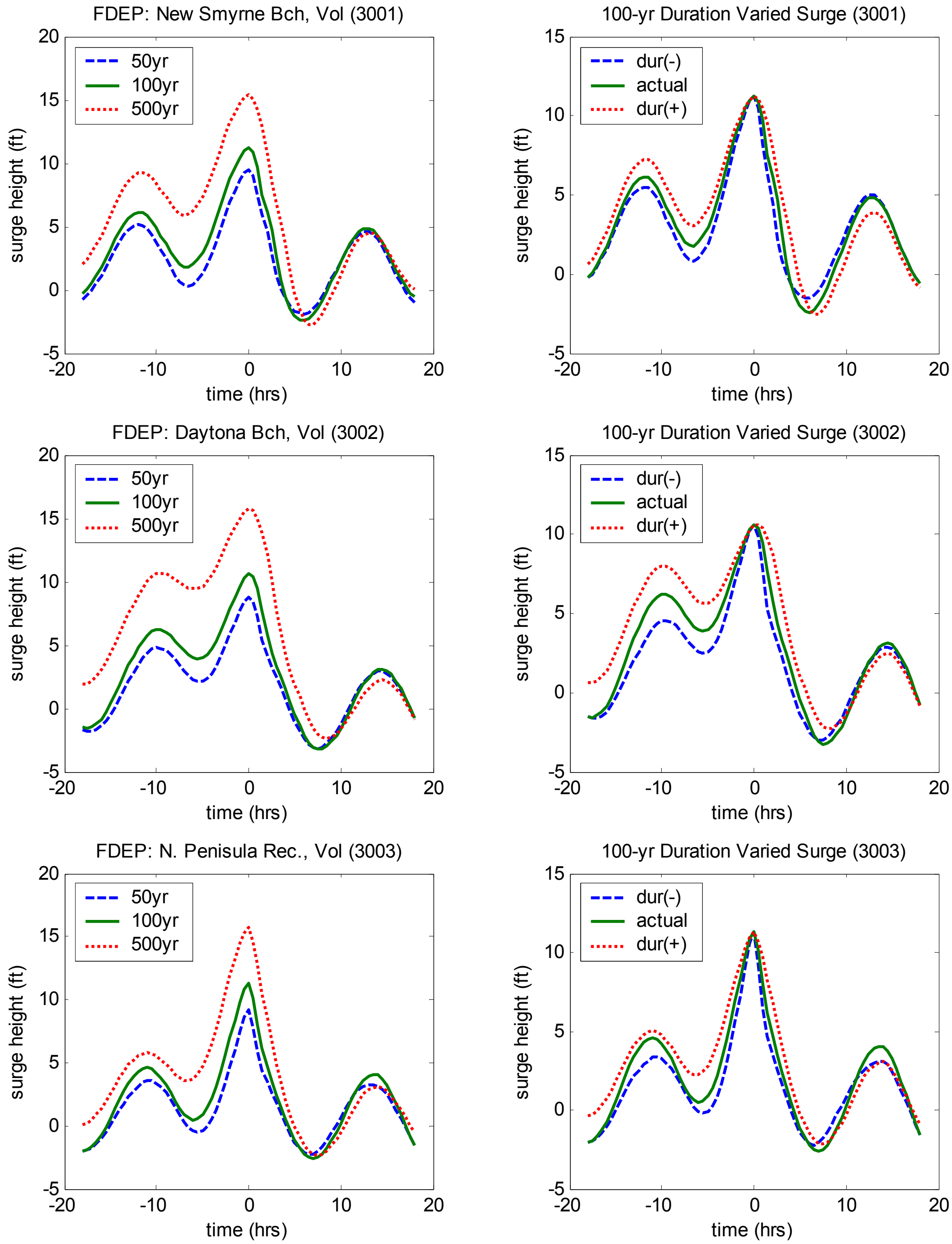

Figure IV- 44. Hydrograph plots for Volusia County.

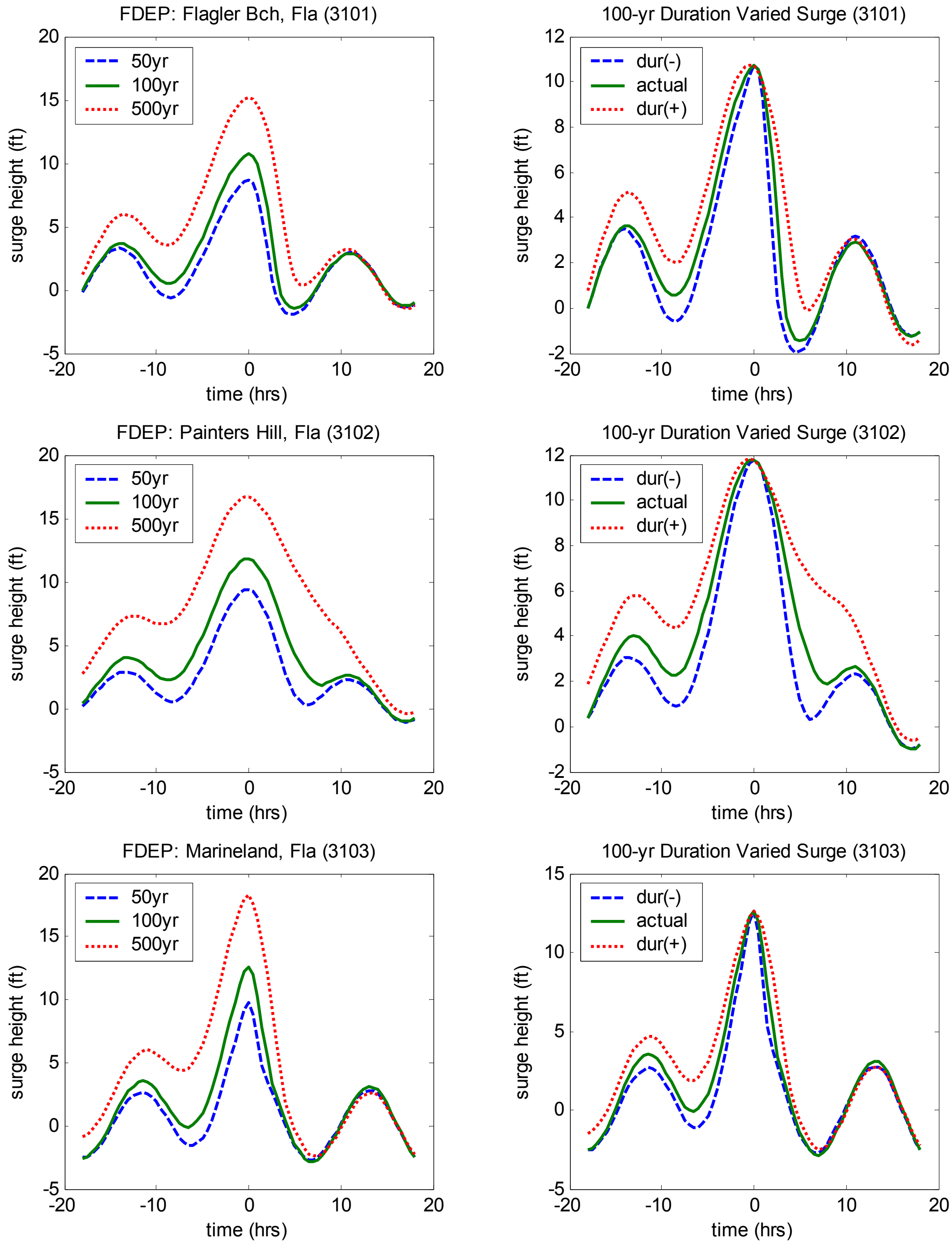

Figure IV- 45. Hydrograph plots for Flagler County.

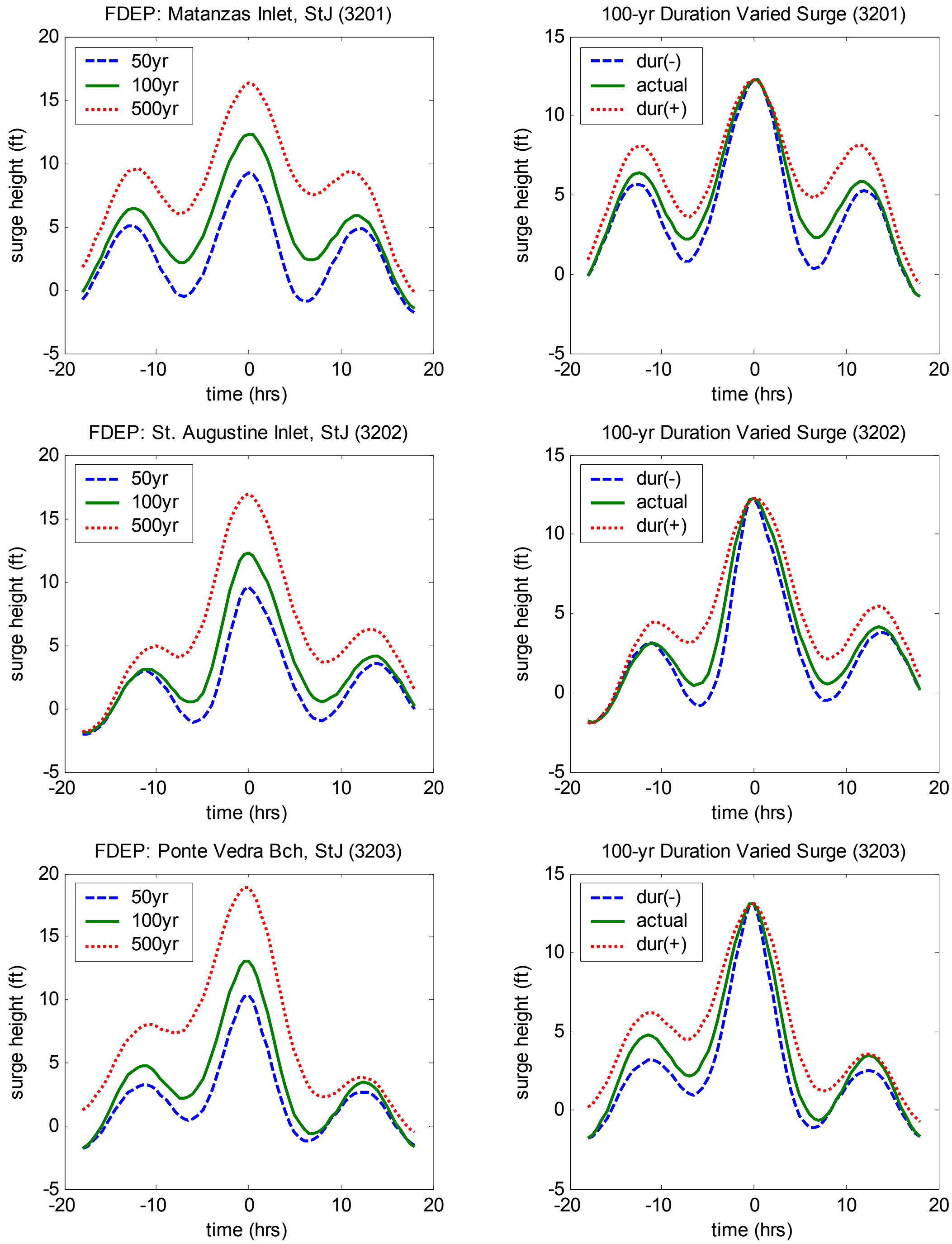

Figure IV- 46. Hydrograph plots for St. Johns County.

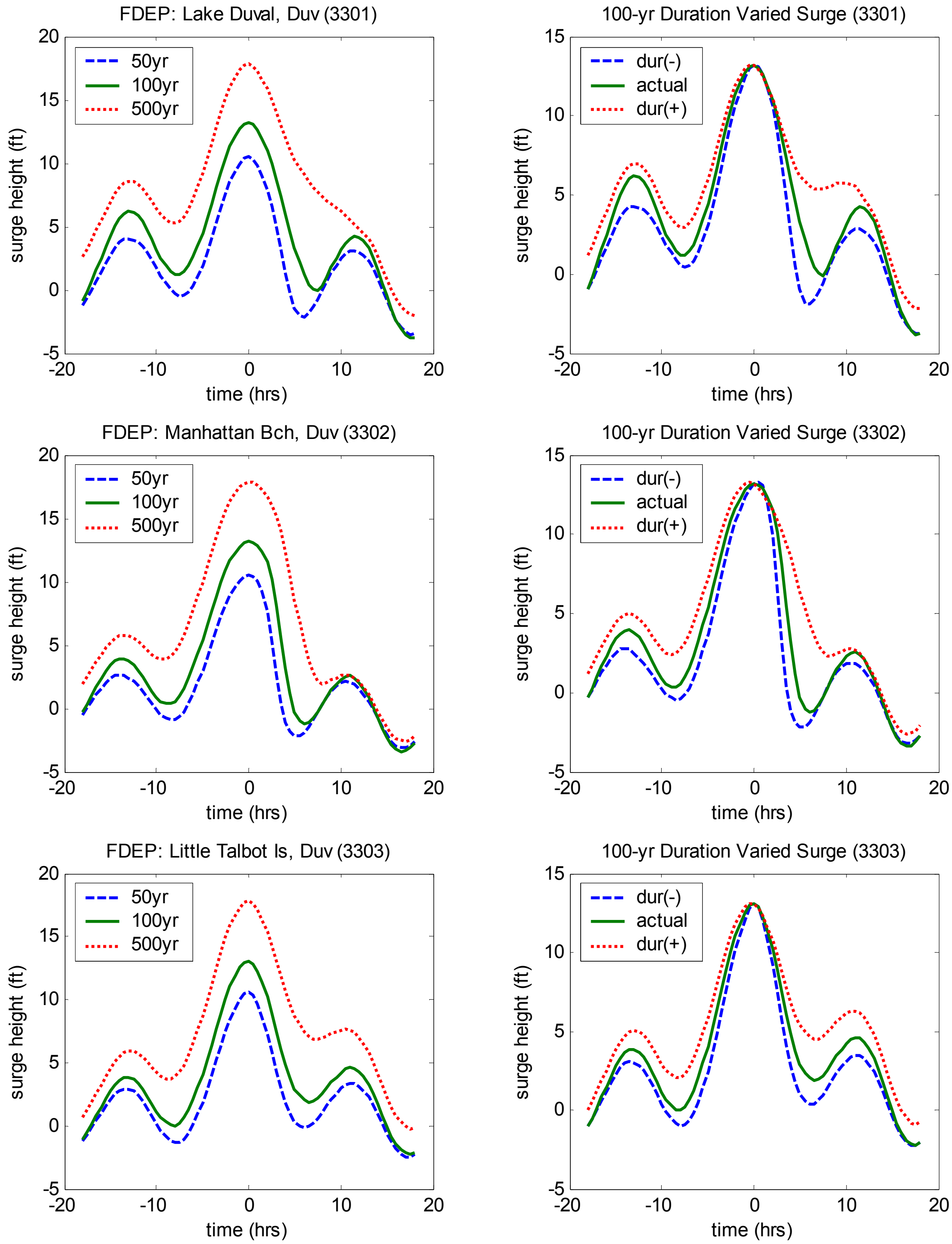

Figure IV- 47. Hydrograph plots for Duval County.

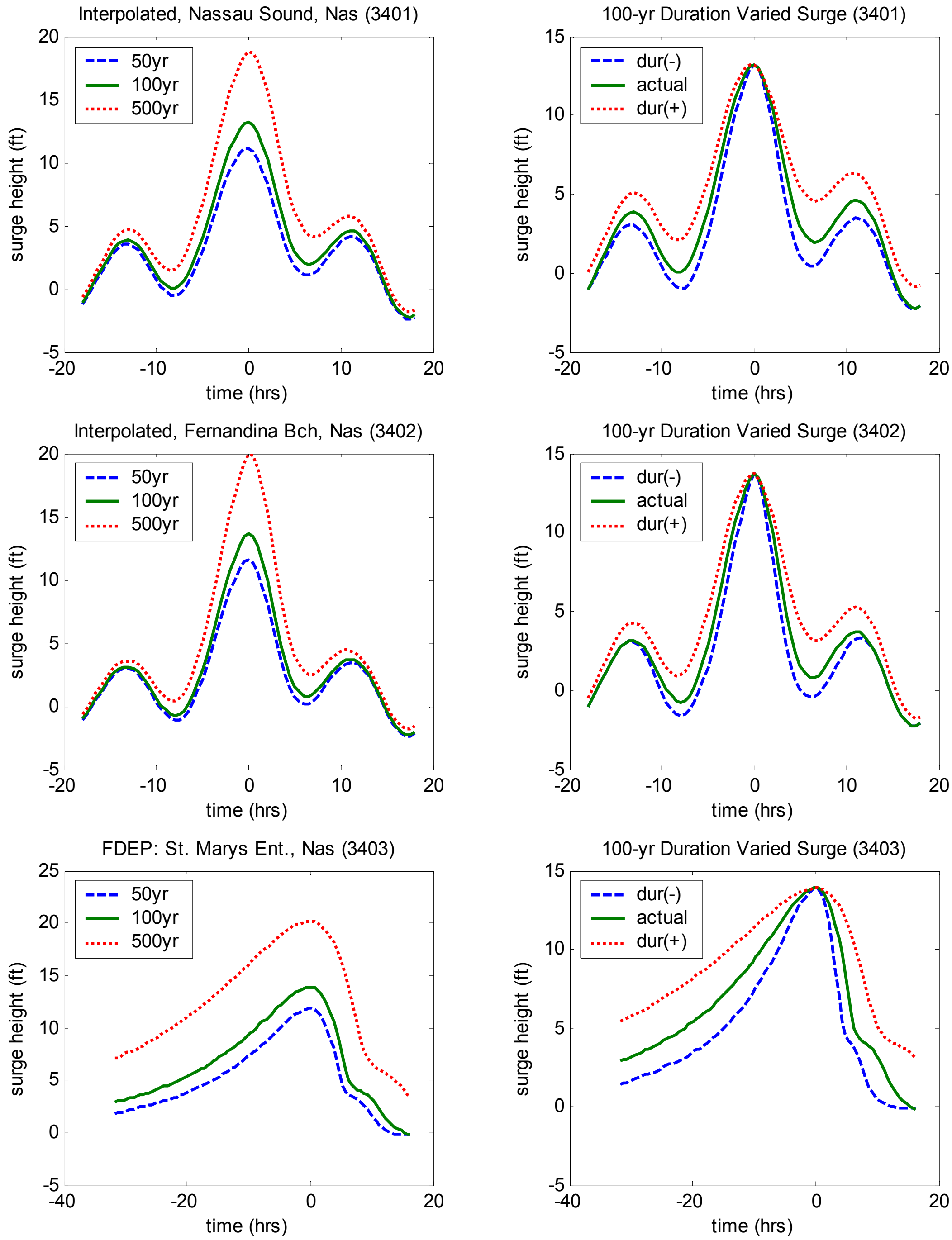

Figure IV- 48. Hydrograph plots for Nassau County.

Appendix A
Summary of Agency Results:
Peak Storm Surge Heights

Table A-1. Peak Storm Surge Heights by Return Period, Florida Department of Environmental Protection (FDEP).

Ref	County	Location	Latitude (deg N)	Longitude (deg W)	Profile	Storm Surge Peak (ft, NGVD)					
						10-yr	20-yr	50-yr	100-yr	200-yr	500-yr
101	Escambia	Escambia W	30.28	87.52	1	4.3	7.3	9.8	11.4	12.9	15.3
102		Pensacola Bay	30.32	87.27	2	4.3	7.4	9.7	11	12.4	14.3
103		Pensacola Bch	30.35	87.07	3	4.2	7.1	9.4	10.8	12.2	13.9
104		Eglin AFB	30.38	86.87	4	4.1	6.9	9.2	10.7	12	13.8
301	Okaloosa	Eglin AFB	30.40	86.63	WEST	5.3	7.8	9.9	11.2	12.1	13
302		Destin W	30.39	86.60	MIDDLE	5.6	8	10.2	11.4	12.4	13.7
303		Destin E	30.38	86.40	EAST	5.8	8.2	10.2	11.4	12.4	13.7
401	Walton	Miramar Bch	30.37[a]	86.35[a]	WEST	4	6.9	9.8	11.4	12.7	14.2
402		Grayton Bch	30.33[a]	86.16[a]	MIDDLE	3.8	6.5	9.4	11.2	12.5	14.1
403		Inlet Bch	30.29[a]	86.05[a]	EAST	3.8	6.2	8.9	10.5	11.9	13.6
501	Bay	Hollywood Bch	30.27	85.99	WEST	5.2	8	10.6	11.9	13.1	14.8
502		Panama City	30.10	85.69	MIDDLE	5.7	8.6	11	12.2	13.4	15.1
503		Mexico Bch	29.93	85.39	EAST	5.8	8.5	10.7	12	13.3	15
600	Gulf	Beacon Hill	29.92	85.38	0	3.7	6.9	10.1	11.7	13.6	16.3
601		St Joseph Pt	29.85	85.41	1	3.7	5.8	8	9.3	10.5	12.6
602		St Joseph Park	29.76	85.40	2	3.5	5.5	7.7	8.8	10.1	11.9
603		Cape San Blas	29.68	85.37	3	3.4	6.2	9.3	11.1	12.4	16
604		McNeils	29.68	85.30	4	4.2	7.9	10.8	12.4	14	16.9
605		Indian Pass	29.68	85.25	5	4.4	7.9	11	12.6	14.3	17
701	Franklin	St Vincent Is	29.59[a]	85.05[a]	6	2.1	6.1	10.1	12	13.4	14.7
702		West Pass	29.63[a]	84.93[a]	5	2.2	6.1	10.2	12.1	13.5	15.1
703		Sikes Cut	29.68[a]	84.81[a]	4	2.4	6.2	10.2	12.3	13.8	15.4
704		St George Is	29.75[a]	84.71[a]	3	2.5	6.3	10.5	12.6	14.3	16
705		Dog Is	29.80[a]	84.59[a]	2	2.7	6.5	11.5	13	14.7	16.4
706		Alligator Harbor	29.90[a]	84.35[a]	1	3.2	7.3	12.2	14.7	16.3	18.7
801	Wakulla	Lighthouse Pt	29.93[a]	84.29[a]	6	9	10.9	13.1	14.7	15.9	17.3
802		Shell Pt	29.96[a]	84.23[a]	5	9.2	11	13.3	15.1	16.1	17.3
803		Goose Creek Bay	30.00[a]	84.17[a]	4	8.9	11	13.5	15.3	16.1	17.8
804		Whale Is	30.03[a]	84.12[a]	3	9.3	11.4	13.9	15.3	16.6	18.1
805		Palmetto Is	30.07[a]	84.06[a]	2	9.5	11.7	14.2	15.5	17	18.3
806		Little Redfish Pt.	30.10[a]	84.00[a]	1	9.5	11.5	13.9	15.2	16.7	17.9

[a] Estimated position

Table A-1. Peak Storm Surge Heights by Return Period, FDEP (continued).

Ref	County	Location	Latitude (deg N)	Longitude (deg W)	Profile	Storm Surge Peak (ft, NGVD)					
						10-yr	20-yr	50-yr	100-yr	200-yr	500-yr
1601	Pinellas	Anclote River	28.08[a]	82.83[a]	1	3.2	6.2	9.5	11.5	13.1	15.3
1602		Hurricane Pass	27.89[a]	82.85[a]	2	3.4	5.7	8.5	10.1	12	13.4
1603		St Pete Bch	27.73[a]	82.74[a]	3	4.3	7.3	9.9	11.5	12.7	14.7
1604		Bunces Pass	27.62[a]	82.72[a]	4	3.6	6.1	8.5	9.9	11.3	13.1
1701	Manatee	Tampa Bay	27.54	82.74	NORTH	5.3	8.3	11	12.3	13.7	15
1702		Bradenton Bch	27.46	82.70	MIDDLE	5.5	8.4	11.1	12.5	13.8	15
1703		Longboat Key	27.39	82.64	SOUTH	5.7	8.7	11.3	12.8	14.1	15.7
1801	Sarasota	Longboat Key	27.38	82.64	NORTH	5.7	8.7	11.4	12.9	14.4	16
1802		Venice Inlet	27.17	82.49	MIDDLE	6	8.8	11.3	12.6	14	15.6
1803		Manasota	26.95	82.38	SOUTH	6.8	9.3	11.7	13.1	14.2	15.5
1901	Charlotte	Manasota	26.95	82.38	NORTH	6.8	9.3	11.7	13.1	14.2	15.5
1902		Don Pedro Is	26.89	82.33	MIDDLE	6.8	9.3	11.5	12.9	14	15
1903		Gasparilla Pass	26.81	82.28	SOUTH	6.7	9	11.4	12.7	13.8	15
2001	Lee	Gasparilla Is	26.79	82.27	1	4.1	7.5	10.7	12.5	13.8	15.4
2002		Captiva Pass	26.65	82.25	2	4.4	7.5	10.6	12.2	13.5	14.7
2003		Redfish Pass	26.52	82.19	3	4.6	7.5	10.6	12.2	13.5	14.9
2004		Sanibel Is	26.42	82.09	4	5.3	8.9	11.6	13.4	14.4	16.2
2005		Ft Myers Bch	26.43	81.91	5	6.5	9.8	12.9	14.8	15.9	17.4
2006		Bonita Bch	26.34	81.85	6	6.5	9.6	12.9	14.7	16.1	17.9
2101	Collier	Wiggins Pass	26.32	81.84	1	7.1	10	13.1	15.2	16.9	18.9
2102		Doctors Pass	26.19	81.82	2	6.8	9.4	12.2	14.1	15.7	17.5
2103		Keewaydin Is	26.06	81.79	3	7.1	9.4	11.5	13.1	14.5	16.3
2104		Marco Is	25.92	81.73	4	7.1	9.4	11.5	12.9	13.9	15.1
2301	Dade	Key Biscayne	25.68[a]	80.16[a]	SOUTH	8.2	9.8	12.1	14	15.8	18
2302		Miami Bch	25.83[a]	80.12[a]	MIDDLE	8.1	9.5	10.8	13.6	15.4	17.7
2303		Bakers Haulover	25.95[a]	80.12[a]	NORTH	8	9.3	11.4	13.5	15.3	17.6
2401	Broward	Hollywood	26.03	80.11	SOUTH	7.7	9	11.4	13.6	15.4	16.9
2402		Ft Lauderdale	26.06	80.11	MIDDLE	7.8	8.9	11.2	13.1	14.8	17.2
2403		Pompano Bch	26.22	80.09	NORTH	7.7	9	10.9	12.5	14.3	17.1

[a] Estimated position

Table A-1. Peak Storm Surge Heights by Return Period, FDEP (continued).

Ref	County	Location	Latitude (deg N)	Longitude (deg W)	Profile	Storm Surge Peak (ft, NGVD)					
						10-yr	20-yr	50-yr	100-yr	200-yr	500-yr
2501	Palm Beach	Boca Raton	26.33	80.07	4	5.7	7.7	9.9	11.6	12.8	14.6
2502		Boynton Inlet	26.53	80.05	3	5.6	7.7	9.9	11.5	12.7	15
2503		Lake Worth Inlet	26.76	80.04	2	5.7	7.6	9.7	11.1	12.5	15
2504		Jupiter Inlet	26.96	80.08	1	5.9	7.9	9.8	11.2	13	15.4
2601	Martin	Blowing Rocks	27.01[a]	80.09[a]	SOUTH	6.7	8.6	10.3	11.2	11.9	12.6
2602		St. Lucie Inlet	27.15[a]	80.15[a]	MIDDLE	7.1	9	10.8	11.6	12.3	13
2603		Jensen Bch	27.26[a]	80.20[a]	NORTH	7.5	9.5	11.1	11.9	12.6	13.5
2701	St. Lucie	Jensen Bch Park	27.27	80.20	SOUTH	5.9	8.8	10.4	11.4	12.2	13.3
2702		Ft Pierce Inlet S	27.42	80.27	MIDDLE	6	9.1	10.8	12.1	12.9	13.9
2703		Ft Pierce Inlet N	27.54	80.32	NORTH	6	9.2	11.1	12.3	13.3	14.7
2801	Indian River	Vero Bch	27.58[a]	80.33[a]	SOUTH	7.3	8.7	10.2	11.5	12.6	13.9
2802		Indian R Shores	27.74[a]	80.38[a]	MIDDLE	7.1	8.5	10	11.3	12.2	13.4
2803		Sebastian Inlet	27.84[a]	80.44[a]	NORTH	6.9	8.4	9.9	11.2	12.2	13.4
2901	Brevard	Sebastian Bch	27.91[a]	80.47[a]	SOUTH	6.8	8.3	10.2	11.6	12.6	14.2
2902		Satellite Bch	28.18[a]	80.59[a]	MIDDLE	6.6	8	9.8	11.1	12.3	13.7
2903		Cocoa Bch	27.58[a]	80.33[a]	NORTH	6.1	7.5	9.4	10.7	12	13.3
3001	Volusia	New Smyrne Bch	28.88	80.79	SOUTH	5.9	7.4	9.5	11.2	12.9	15.4
3002		Daytona Bch	29.15	80.97	MIDDLE	5	6.7	8.8	10.6	12.9	15.8
3003		N. Penisula Rec.	29.43	81.10	NORTH	4.8	6.5	9.2	11.3	13.2	15.7
3101	Flagler	Flagler Bch	29.43	81.10	SOUTH	4.7	6.1	8.7	10.7	12.7	15.2
3102		Painters Hill	29.54	81.16	MIDDLE	4.9	6.4	9.4	11.8	13.9	16.7
3103		Marineland	29.67	81.21	NORTH	5	6.7	9.8	12.6	15.1	18.3
3201	St. Johns	Matanzas Inlet	29.70	81.22	SOUTH	3.6	5.1	9.2	12.3	14.5	16.3
3202		St. Augustine Inlet	29.96	81.31	MIDDLE	3.6	5.4	9.6	12.3	14.5	16.9
3203		Ponte Vedra Bch	30.23	81.37	NORTH	3.2	5.5	10.4	13.1	15.4	18.9
3301	Duval	Lake Duval	30.26	81.38	SOUTH	5	6.9	10.5	13.2	15.3	17.8
3302		Manhattan Bch	30.36	81.40	MIDDLE	4.9	6.9	10.5	13.2	15.3	17.9
3303		Little Talbot Is	30.48	81.41	NORTH	5.3	7.1	10.6	13.1	15.1	17.8
3401	Nassau	Nassau Sound	30.54[a]	81.44[a]	SOUTH	4.8	7.6	11.1	13.2	15.2	18.8
3402		Fernandina Bch	30.70[a]	81.43[a]	MIDDLE	5	8	11.6	13.7	15.9	19.9
3403		St. Marys Ent.	30.70[a]	81.43[a]	NORTH	5	8.3	11.9	13.9	16.3	20.2

[a] Estimated position

Table A-2. Peak Storm Surge Heights by Return Period, Federal Emergency Management Agency (FEMA).

Ref	Transect #	Location	County	Storm Surge Peak (ft, NGVD)			FIS Report[c] Date
				50-yr	100-yr	500-yr	
1	1	Perdido Key	Escambia	6.8	10.5[a]	11	2/23/2000
2	8	Pensacola Bay Inlet	Escambia	6.8	10.5[a]	11	
3	12	Pensacola Bch	Escambia	6.8	10.5[a]	11	
4	17	Eglin AFB	Escambia	6.8	10.5[a]	11	
5	1		Okaloosa	-	7.7[a]	-	6/5/1997
6	2		Okaloosa	-	7.5[a]	-	
7	5		Okaloosa	-	7.7[a]	-	
8	1	Miramar Bch	Walton	6.8	8	10.8	3/7/2000
9	6	Grayton Bch	Walton	6.8	8	10.8	
10	8	Inlet Bch	Walton	6.8	8	10.8	
11	1	West, N, E Bay	Bay	4.6	5.3	6.9	1/3/1986
12	8	(Panama City)	Bay	4.7	5.5	7.4	
13	9	(Panama City)	Bay	4.3	5	6.8	
14	15	(Panama City)	Bay	4.2	4.8	6.2	
15	22	St. Joseph Bay	Bay	4.8	5.7	7.1	
16	-		Gulf	-	7	-	12/15/1982
17	2	St Vincent Is	Franklin	6	6.5	7.6	1/18/1983
18	5	St George Is	Franklin	6.3	6.9	8	
19	10	St George Is	Franklin	8.1	8.8	10	
20	13	East Pass	Franklin	8.9	9.5	10.8	
21	14	Dog Island	Franklin	9.9	10.7	12.2	
22	40	Lighthouse Pt	Franklin	12.5	13.5	15.2	
23	1		Wakulla	13.4	15	17.5	6/17/1986
24	4		Wakulla	13.4	15.1	18.2	
25	6		Wakulla	13.1	14.9	17.9	
26	8		Wakulla	13.3	15.1	18.4	
27	2	Peary Is Creek	Taylor	-	15.1	-	8/16/1995
28	4	Eaglenest Pt	Taylor	-	14.7	-	
29	5	Adams Bch	Taylor	-	15.1	-	
30	6	Cedar Is	Taylor	-	14.3	-	
31	9	Dallus Creek	Taylor	-	14	-	
32	1		Dixie	12.2	13.7[b]	16.7	5/2/1983
33	4		Dixie	11.9	13.5[b]	16.3	
34	6		Dixie	12.4	14[b]	17	
35	11		Dixie	11.9	13.5[b]	16.3	
36	1		Levy	11.6	12.9	15.4	9/1/1983
37	4		Levy	11.8	13.1	15.5	
38	6		Levy	12.3	13.6	16	
39	11		Levy	12.7	13.8	16	

[a] Value includes additional 2.5 feet to account for dynamic wave setup
[b] Value includes the effects of dynamic wave setup
[c] Flood Insurance Study (FIS) published by the FEMA by county

Table A-2. Peak Storm Surge Heights by Return Period, FEMA (continued).

Ref	Transect #	Location	County	Storm Surge Peak (ft, NGVD)			FIS Report[c] Date
				50-yr	100-yr	500-yr	
40	-		Citrus	-	13.5	-	2/5/1984
41	-		Citrus	-	13	-	
42	-		Citrus	-	12.5	-	
43	1		Hernando	11	12.2[b]	14.3	10/17/1983
44	3		Hernando	10.9	12.1[b]	14.2	
45	9		Hernando	11.4	12.6[b]	14.7	
46	1	St Joseph Sound	Pasco	10.9	12.7	16.5	9/30/1992
47	-	Port Richey	Pasco	10.9	12.7	16.5	
48	-	Pass-a-Grille Beach	Pinellas	8.7	10.4	13.4	5/6/1996
49	14	Indian Rocks Beach	Pinellas	8.2	9.7	13.6	
50	-	Belleair Beach	Pinellas	8.3	9.9	12.8	
51	-	Clearwater Beach	Pinellas	8.1	9.6	12.7	
52	-	Passage Key	Manatee	7.8	9.2	11.8	7/15/1992
53	6		Sarasota	8.6	10	12.6	9/3/1992
54	6		Sarasota	8.6	10	12.6	
55	-	Open Coast	Charlotte	-	11	-	6/16/1993
56	1	Gasparilla Island	Lee	8.2	9.3	11.7	7/20/1998
57	4	Cayo Costa Is	Lee	8.7	9.9	12.2	
58	5	Captiva Pass	Lee	8.9	10	12.3	
59	7	Sanibel Is	Lee	8.9	10	12.3	
60	19	Estero Is	Lee	10.8	12.4	15.5	
61	22	Bonita Bch	Lee	10.1	12.5	14.4	
62	1		Collier	-	11	-	6/3/1986
63	10		Collier	-	11	-	
64	20		Collier	-	10	-	
65	38		Collier	-	10	-	
66	110	Bird Key	Monroe	10.1	13.7[b]	14.4	2/15/2002
67	109	Highland Point	Monroe	12.8	16.7[b]	17.8	
68	106	Middle Cape	Monroe	10.9	14.3[b]	14	
69	1	Key West	Monroe	5.5	8.4[b]	7.3	
70	33	Bahia Honda Key	Monroe	5.1	8[b]	6.8	
71	43	Fat Deer Key	Monroe	5.5	8.3[b]	7.1	
72	53	Long Key	Monroe	5.9	8.8[b]	7.5	
73	63	Lower Matecumbe Key	Monroe	6.1	9[b]	7.7	
74	73	Upper Matecumbe Key	Monroe	6.4	9.3[b]	8	
75	83	Key Largo	Monroe	6.6	9.4[b]	8.2	
76	94	N Key Largo	Monroe	7	9.9[b]	8.6	
77	103	Palo Alto Key	Monroe	7.2	9.3[b]	12	

[a] Value includes additional 2.5 feet to account for dynamic wave setup
[b] Value includes the effects of dynamic wave setup
[c] Flood Insurance Study (FIS) published by the FEMA by county

Table A-2. Peak Storm Surge Heights by Return Period, FEMA (continued).

Ref	Transect #	Location	County	Storm Surge Peak (ft, NGVD)			FIS Report[c] Date
				50-yr	100-yr	500-yr	
78	29		Dade	7.5	6.6	7.6	3/2/1994
79	20		Dade	6.9	6.9	7.8	
80	10		Dade	6.4	7.3	8.4	
81	1		Dade	6.2	8	9	
82	4	Hollywood	Broward	-	6.4	7.4	10/2/1997
83	12	Ft Lauderdale	Broward	-	6.5	7.1	
84	26	Lighthouse Pt	Broward	-	6.2	7.1	
85	30	Deerfield Bch	Broward	-	6.2	7.1	
86	-		Palm Beach	6.25	7.05	8.4	4/15/1982
87	-		Palm Beach	6.25	7.05	8.4	
88	-		Palm Beach	6.25	7.05	8.4	
89	36		Martin	6.2	7	8.8	7/5/1983
90	25	St Lucie Inlet	Martin	6.1	7.2	9.1	
91	2		Martin	6.2	7	8.8	
92	-		St. Lucie	6.3	7	8.7	2/17/1982
93	1		Indian River	6.4	9.5[b]	9.7	5/4/1989
94	15		Indian River	6	9.1[b]	9.2	
95	26		Indian River	5.9	9[b]	8.8	
96	131	Sebastian Bch	Brevard	6.5	9.5[b]	9.8	11/19/1997
97	101	Satellite Bch	Brevard	6.7	9.9[b]	10.1	
98	83	Patrick AFB	Brevard	6.8	10[b]	10.3	
99	54	Cocoa Bch	Brevard	6.5	9.4[b]	9.8	
100	35	Cape Canaveral	Brevard	6.6	9.8[b]	9.9	
101	27		Brevard	7	10.2[b]	10.6	
102	6	Ardon Is	Brevard	7.1	10.1[b]	10.5	
103	-		Volusia	7.2	8	10.8	4/15/2002
104	1-6		Flagler	7.1	8.3	10.8	2/5/1986
105	75		St. Johns	7.2	8.4	11	9/18/1985
106	4		St. Johns	7.7	9	11.7	
107	1		St. Johns	7.9	9.3	12.2	
108	-		Duval	-	11	12	4/17/1989
109	-		Nassau	8.9	9.9	12.7	2/15/1984

[a] Value includes additional 2.5 feet to account for dynamic wave setup
[b] Value includes the effects of dynamic wave setup
[c] Flood Insurance Study (FIS) published by the FEMA by county

Table A-3. Peak Storm Surge Heights for a Category 5 Hurricane, National Atmospheric and Oceanic Administration (NOAA) (See Figure A-1 for locations)

Reference Number	Location	County	Peak Storm Surge Height (ft, NGVD)
1	Pensacola Beach	Escambia	12.7
2	Ft. Walton Beach	Walton	11
3	Panama City Beach	Bay	14.6
4	St. George Island	Franklin	14.7
5	Wakulla Beach	Wakulla	26.6
6	Cedar Key	Levy	21.4
7	Clearwater Beach	Pinellas	20.3
8	Tampa Bay	Pinellas	25.5
9	Sarasota	Sarasota	18.8
10	Ft. Myers	Lee	22.6
11	Naples	Collier	21.7
12	Key West	Monroe	10.8
13	Key Largo	Monroe	11
14	Miami Beach	Dade	10.8
15	West Palm Beach	Palm Beach	12.4
16	Ft. Pierce	St. Lucie	13.6
17	Cocoa Beach	Brevard	14.6
18	Daytona Beach	Volusia	13.1
19	St. Augustine	St. Johns	17
20	Fernandina Beach	Nassau	19.1
21	Hugo, Customs House	S. Carolina	12.5
22	Hugo, Winyah Bay	S. Carolina	9.5

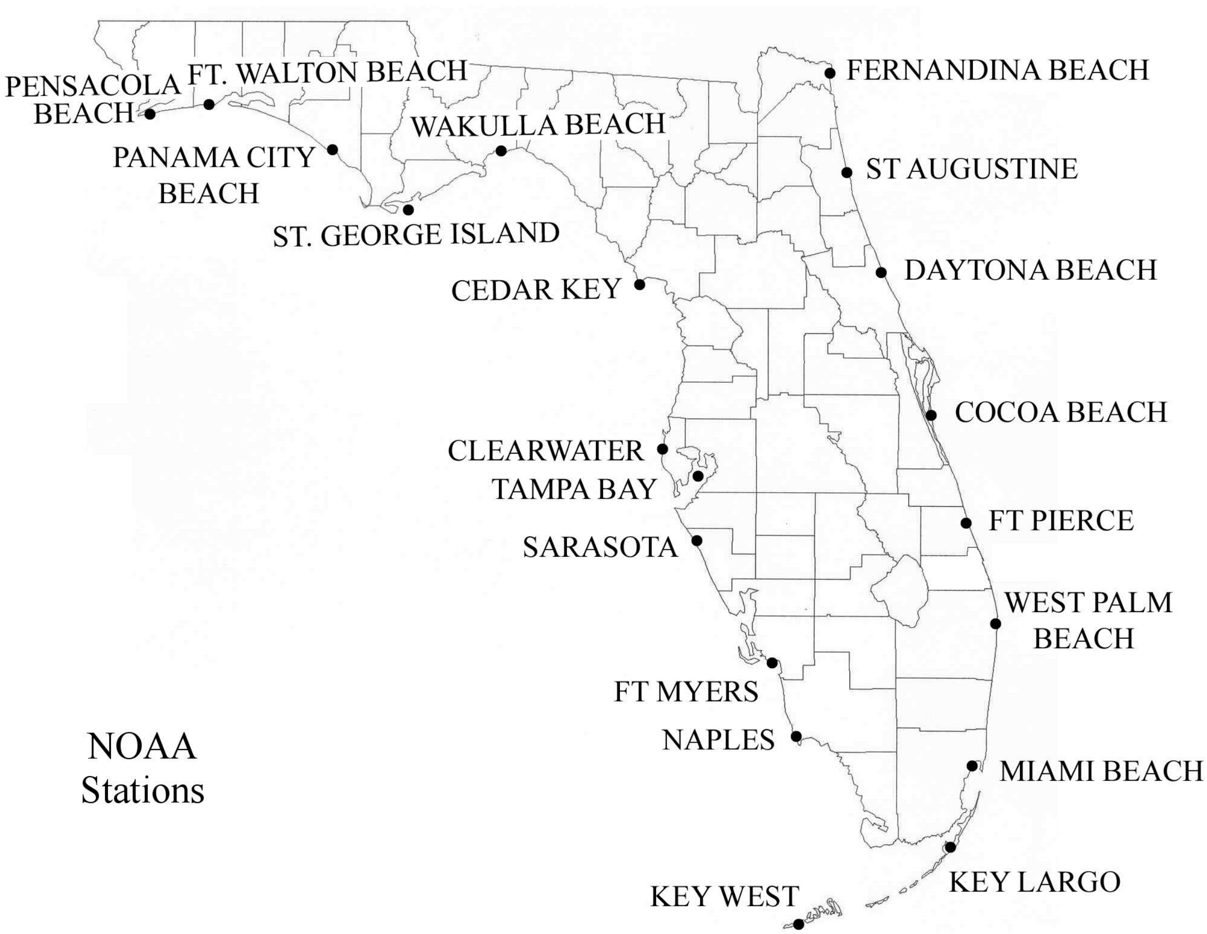

Figure A- 1. Locations of NOAA Stations.

Table A-4. Peak Storm Surge Height Results by Return Period, US Army Corps of Engineers, ADCIRC Model. Results are for use in the synthetic hydrograph recommended by the Pooled Fund Study. (See Figure A-2 for locations by reference number)

Ref	Lat (N)	Long (W)	ADCIRC Sta #	Storm Surge Peak (ft, NGVD)			Radius to Max Wind (nm)	Forward Speed (kts)	Tide Amp (ft)	Tide Period (hr)	Waterway
				50-yr	100-yr	500-yr					
1	30.3114	87.3072	502	5.87	6.99	9.58	23.1	10.4	0.65	25	Pensacola Bay
2	30.3819	86.5144	499	4.26	5.02	6.76	23.2	10.47	0.71	25	Choctawhatchee Bay (Destin)
3	30.1172	85.7347	495	3.84	4.53	6.13	23.3	10.53	0.77	25	West, N, E Bay
4	30.0656	85.6314	495	3.84	4.53	6.13	22	10.61	0.81	25	(Panama City)
5	29.8808	85.3739	494	3.35	3.9	5.18	21.5	10.7	0.89	25	St. Joseph Bay
6	29.6722	85.2281	491	5.05	6.2	8.86	21	10.77	0.95	12.5	Apalachicola Bay
7	29.6197	85.1133	491	5.05	6.2	8.86	20.5	10.85	1.01	12.5	
8	29.7667	84.6767	488	6.66	8.4	12.43	20	10.92	1.07	12.5	
9	29.9639	84.3319	486	9.77	12.17	17.74	19.8	11	1.13	12.5	Ochlockonee Bay
10	30.0133	84.3628	486	9.77	12.17	17.74	19.68	11.06	1.17	12.5	Dickerson/Levy Bay
11	30.0094	84.3592	486	9.77	12.17	17.74	19.56	11.12	1.22	12.5	Oyster Bay
12	30.0394	84.3083	486	9.77	12.17	17.74	19.44	11.18	1.26	12.5	
13	30.0539	84.2814	486	9.77	12.17	17.74	19.52	11.24	1.31	12.5	Walker Creek
14	30.0736	84.2494	486	9.77	12.17	17.74	19.4	11.3	1.36	12.5	Goose Creek Bay
15	30.0769	84.1992	486	9.77	12.17	17.74	19.38	11.36	1.4	12.5	St. Marks River
16	30.0781	83.9947	485	11.48	13.81	19.22	19.26	11.42	1.36	12.5	Aucilla River
17	29.9714	83.7864	484	12.37	15.25	21.94	19.14	11.48	1.33	12.5	Henderson River
18	29.6603	83.4242	483	12.46	16.43	25.65	19.02	11.54	1.28	12.5	Deadman River
19	29.2942	83.1753	480	11.32	15.09	23.85	18.9	11.6	1.25	12.5	Suwannee River
20	29.1414	82.825	478	10.82	13.09	18.34	18.88	11.66	1.21	12.5	Waccasassa River
21	28.895	82.7128	477	8.46	10.04	13.68	18.6	11.73	1.17	12.5	Crystal River
22	28.7503	82.7	477	8.46	10.04	13.68	18.4	11.84	1.13	12.5	Homasassa Bay
23	28.6956	82.6494	477	8.46	10.04	13.68	18.2	11.92	1.09	12.5	Chassahowitzka Bay
24	28.2761	82.7494	475	7.48	8.89	12.17	18	12	1.05	12.5	Piithlachascotee River
25	28.1781	82.805	475	7.48	8.89	12.17	17.9	12.04	1.01	12.5	Anchlote River
26	27.5506	82.7639	208	9.12	11.61	17.38	17.8	12.08	0.73	12.5	Tampa Bay
27	26.8914	82.3478	467	10.14	13.12	20.04	17.7	12.12	0.76	12.5	Lemon Bay
28	26.7092	82.2647	466	11.81	14.79	21.71	17.6	12.16	0.8	12.5	Charlotte Harbor
29	26.6094	82.2289	466	12	14.79	21.25	17.5	12.2	0.82	12.5	

Table A-5. Peak Storm Surge Height Results by Return Period, USACE/ADCIRC (continued).

Ref	Lat (N)	Long (W)	ADCIRC Sta #	Storm Surge Peak (ft, NGVD)			Radius to Max Wind (nm)	Forward Speed (kts)	Tide Amp (ft)	Tide Period (hr)	Waterway
				50-yr	100-yr	500-yr					
30	26.4469	81.9878	464	12.56	15.74	23.12	17.4	12.24	0.85	12.5	
31	27.4428	82.6972	471	9.58	12.56	19.48	17.3	12.28	0.87	12.5	Longboat Pass (Sarasota Bay)
32	27.3269	82.5942	470	10	13.12	20.37	17.2	12.32	0.89	12.5	New Pass
33	27.2906	82.575	470	10	13.12	20.37	17.14	12.36	0.92	12.5	Big Sarasota Bay
34	27.0009	82.475	469	9.61	12.56	19.42	17.07	12.4	0.95	12.5	Venice Inlet
35	26.4706	81.9731	464	12.56	15.74	23.12	17	12.4	0.99	12.5	Estero Bay
36	26.3961	81.8942	463	12.04	15.09	22.17	16.9	12.34	1.01	12.5	
37	26.0931	81.8086	462	11.25	14.17	20.96	16.8	12.28	1.04	12.5	Gordon Pass
38	25.97	81.7556	461	11.05	13.71	19.88	16.7	12.22	1.1	12.5	Big Marco Pass
39	25.9	81.7286	461	11.05	13.71	19.88	16.6	12.16	1.15	12.5	Caxambas Bay
40	25.5411	81.2247	457	10.73	12.86	17.81	16.5	12.08	1.15	12.5	First Bay
41	25.3564	81.1544	457	10.73	12.86	17.81	16.5	12	1.14	12.5	Highland Point
42	25.6567	80.2161	443	3.28	3.97	5.58	17	9.5	1.14	12.5	Miami
43	25.7514	80.1311	443	3.28	3.97	5.58	17.27	9.53	1.19	12.5	Bakers Haulover Inlet
44	25.9	80.1172	442	2.69	3.25	4.53	17.54	9.57	1.24	12.5	
45	26.0922	80.1028	442	2.69	3.25	4.53	17.81	9.6	1.29	12.5	Turning Basin
46	26.2547	80.0806	441	2.53	2.98	4.07	18.08	9.64	1.34	12.5	Hillsboro Bay
47	26.3364	80.065	441	2.53	2.98	4.07	18.08	9.67	1.38	12.5	Boca Raton Inlet
48	26.5456	80.0361	440	2.53	2.95	3.94	18.62	9.7	1.42	12.5	S. Lake Worth Inlet
49	26.7728	80.0264	439	2.59	3.08	4.23	18.89	9.74	1.47	12.5	Lake Worth Inlet
50	26.9442	80.0653	438	2.49	3.08	4.46	19.06	9.77	1.52	12.5	Loxahatchee River
51	27.1644	80.1472	437	2.98	3.71	5.38	19.33	9.81	1.58	12.5	St. Lucie River
52	27.4731	80.2833	436	3.84	4.76	6.89	19.6	9.85	1.63	12.5	Ft. Pierce Inlet
53	27.8608	80.4417	435	4.62	5.74	8.33	19.87	9.9	1.69	12.5	Sebastian Inlet
54	28.4092	80.5797	432	2.76	3.18	4.17	20.14	9.95	1.85	12.5	Cape Canaveral
55	29.0769	80.9111	430	3.12	3.61	4.76	20.5	10	2.01	12.5	Ponce de Leon Inlet
56	29.7072	81.2208	427	6.95	8.07	10.66	21.1	10.25	2.13	12.5	Matanzas Inlet
57	29.9136	81.2797	426	7.12	8.23	10.82	21.7	10.5	2.26	12.5	St. Augustine Inlet
58	30.4114	81.3944	424	8.46	9.91	13.25	22.4	10.75	2.38	12.5	St. Johns River
59	30.5611	81.4147	424	7.12	8.23	10.82	23	11	2.75	12.5	Nassau Sound

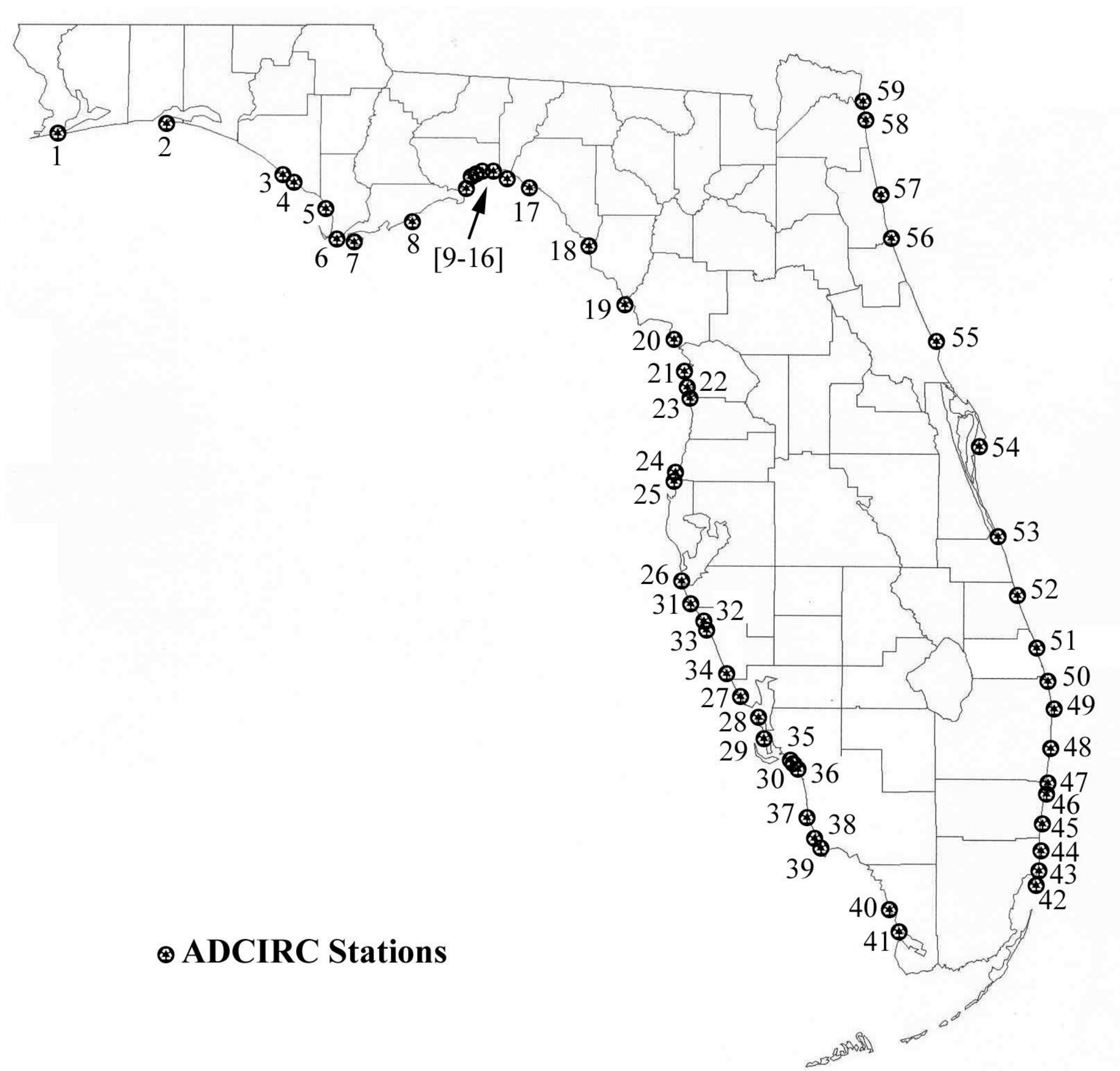

Figure A- 2. Locations of ADCIRC Stations.

Appendix B
Storm Surge Hydrographs

NOAA Category 5 Storm Surge Hydrographs

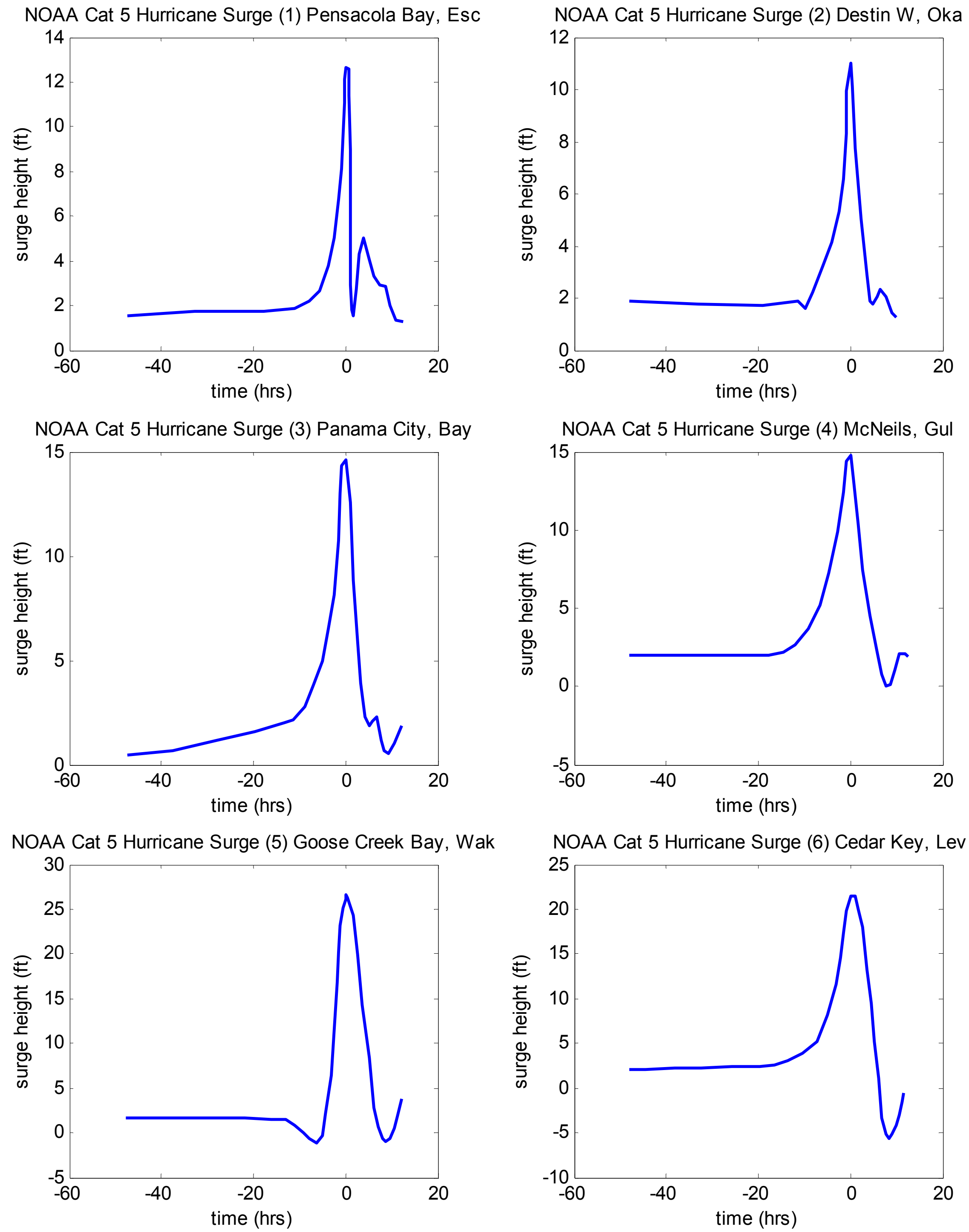

Figure B- 1. NOAA Category 5 Hurricane Storm Surge Hydrographs; Pensacola Bay to Cedar Key.

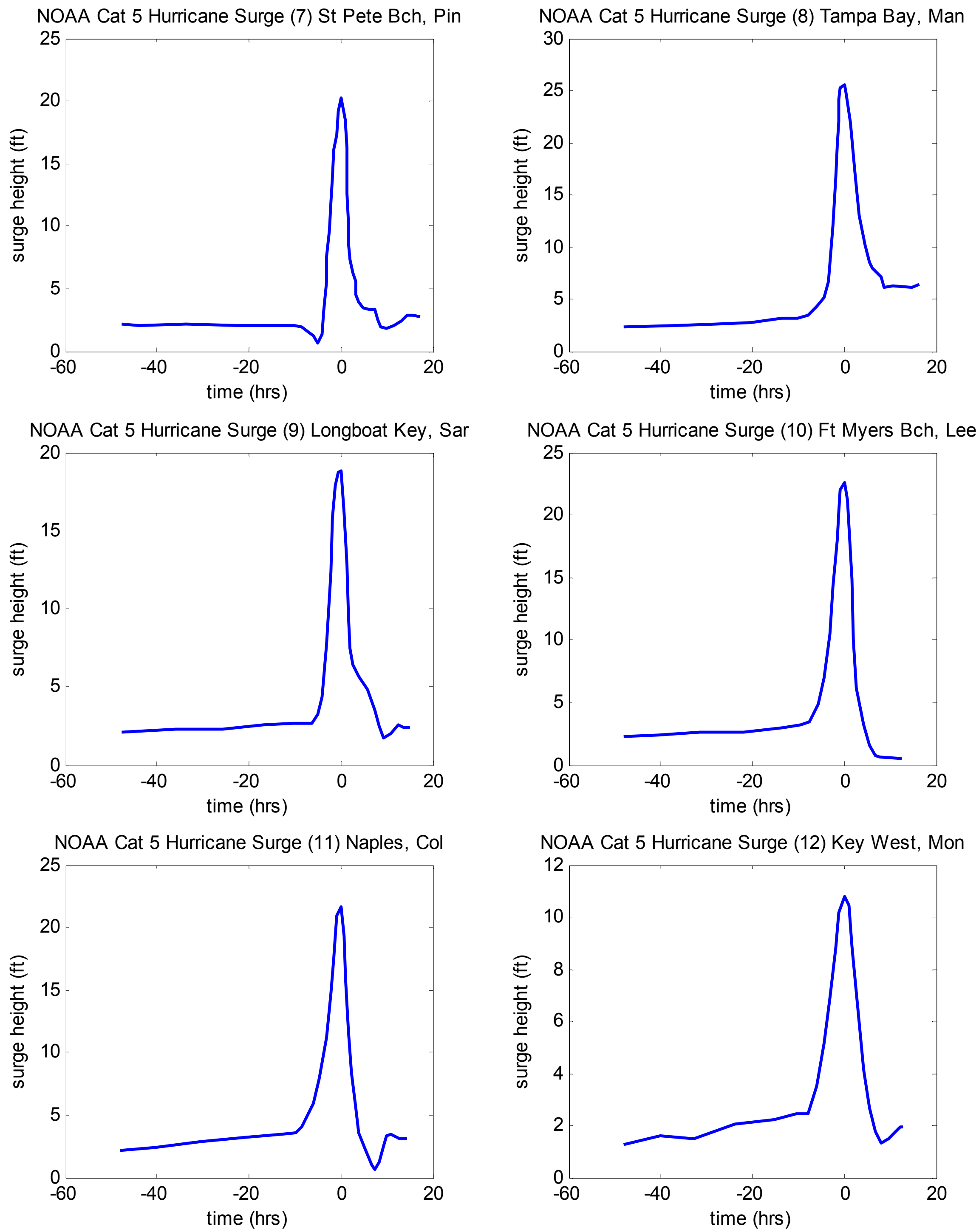

Figure B- 2. NOAA Category 5 Hurricane Storm Surge Hydrographs; St. Petersburg to Key West.

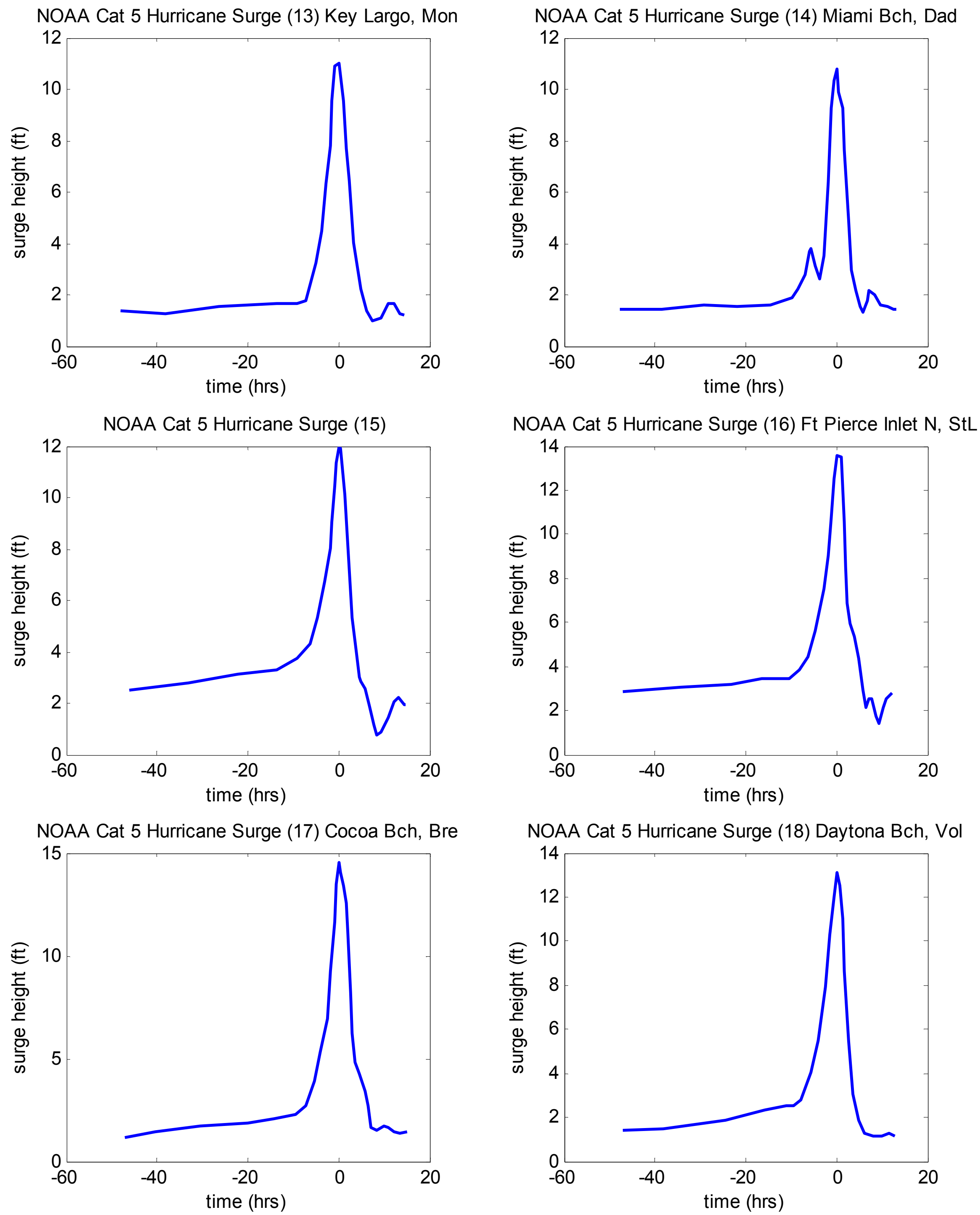

Figure B- 3. NOAA Category 5 Hurricane Storm Surge Hydrographs; Key Largo to Daytona Beach.

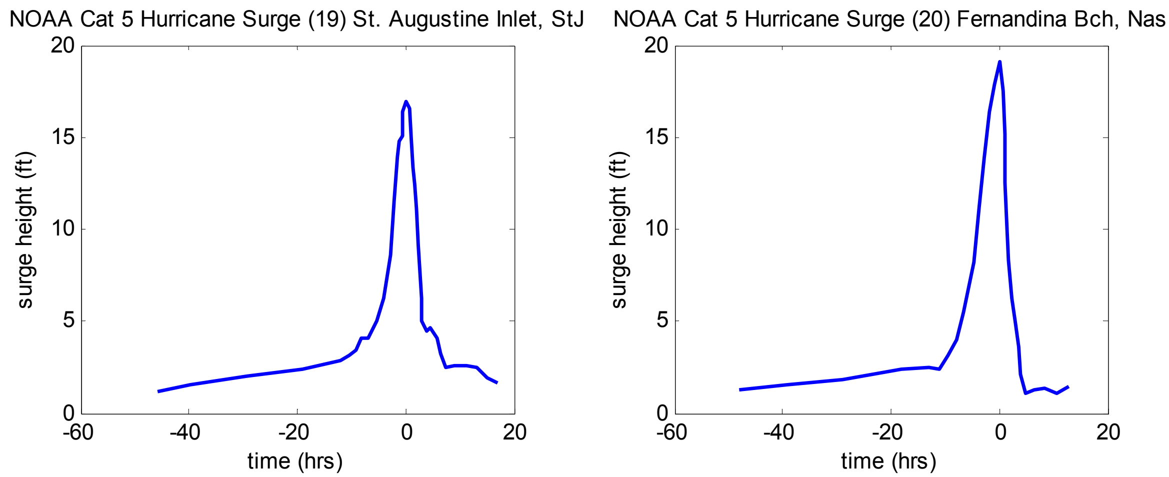

Figure B- 4. NOAA Category 5 Hurricane Storm Surge Hydrographs; St. Augustine Inlet and Fernandina Beach.

Comparison of FDEP and Pooled Fund Study Synthetic Hydrographs

The following plots compare the FDEP model hydrographs for a 100 year storm surge and the hydrographs constructed using the synthetic hydrograph equations developed by the Pooled Fund Study (Eq. 16 and 17). Input parameters (S_p, R_{max}, F) for the synthetic hydrographs were obtained from the FDOT's Drainage Handbook: Hydrology and are listed in Table A-4.

The Pooled Fund Study recommended using the astronomical tide at four phases with respect to the time of landfall: high tide, low tide, maximum flood and maximum ebb. The following figures show the results for high and low tide at each location (left and right hand plots respectively). Again, the astronomical tide parameters were obtained from the Drainage Handbook and are listed in Table A-4.

Where corresponding FDEP hydrographs did not exist, the Modified FDEP hydrographs were used. These are indicated on the plots.

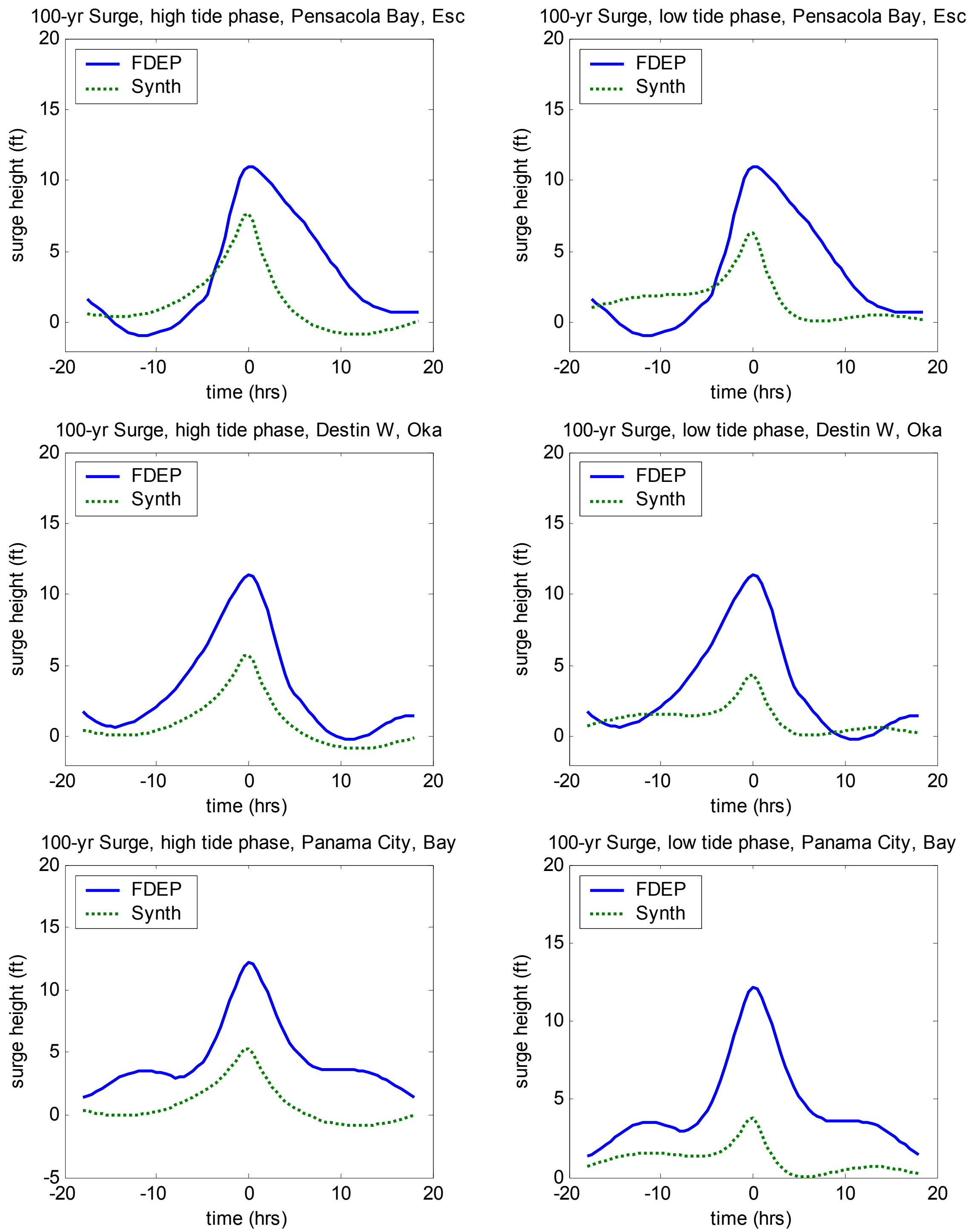

Figure B- 5. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Pensacola Bay to Panama City.

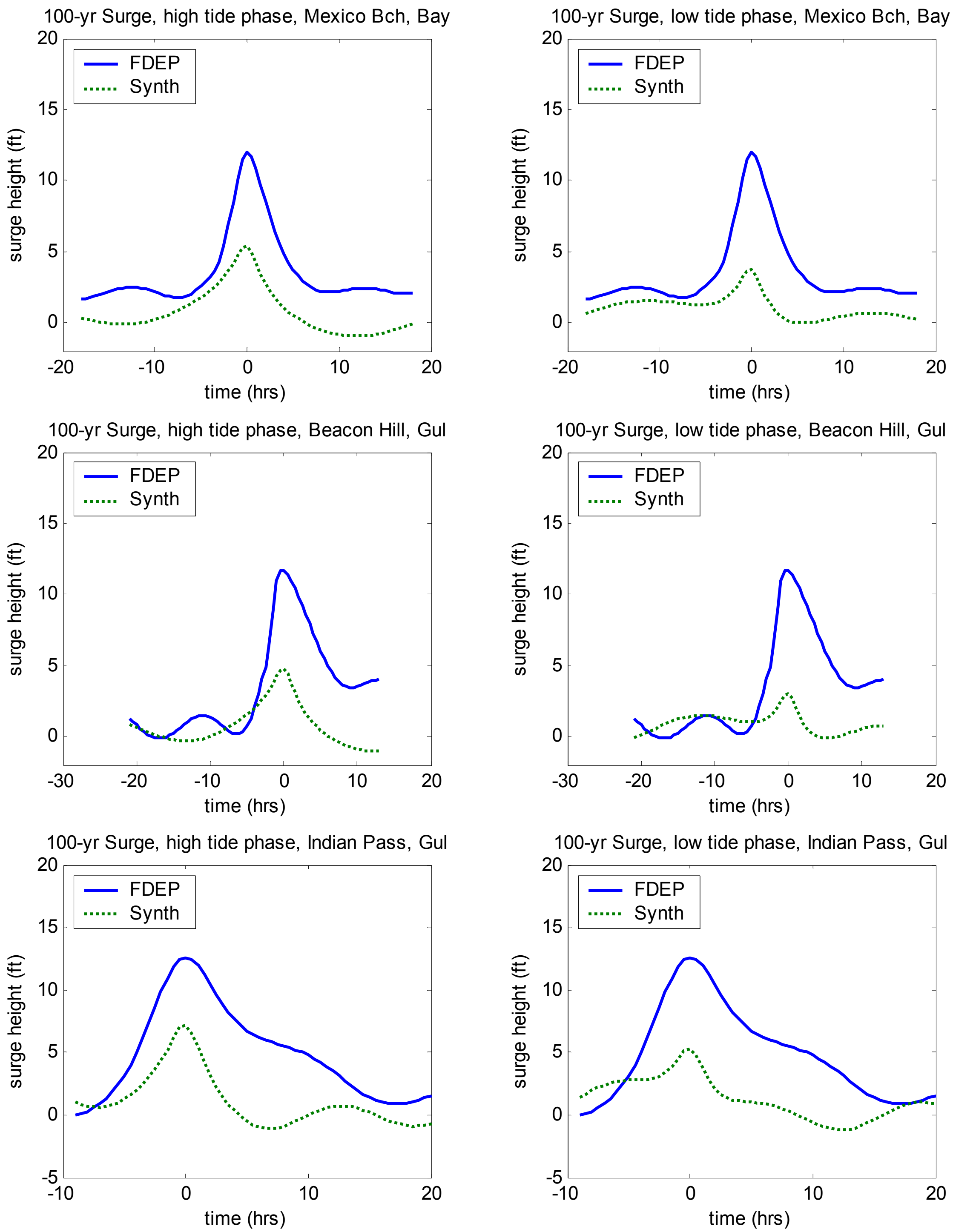

Figure B- 6. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Mexico Beach, Bay County to Indian Pass, Gulf County.

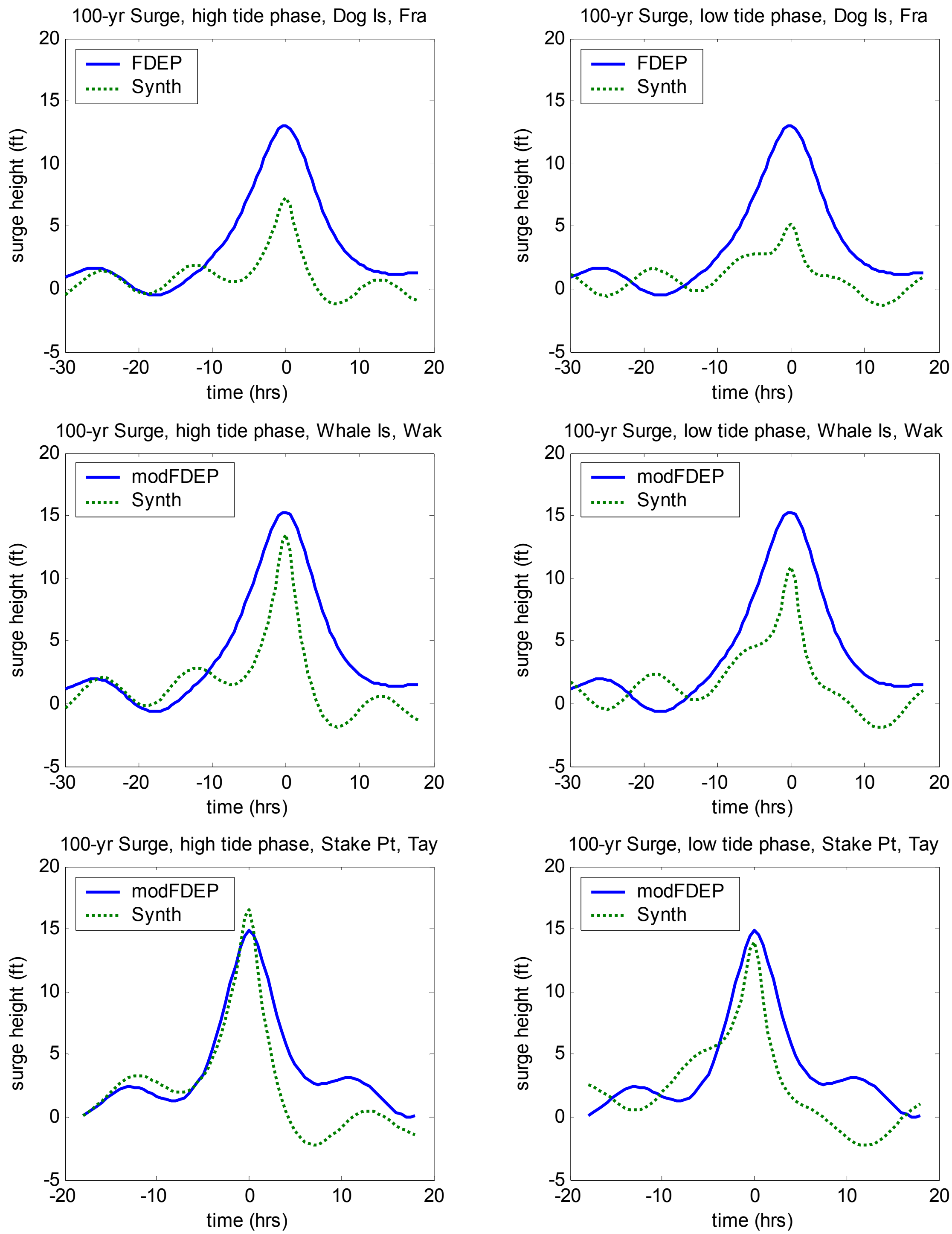

Figure B- 7. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Dog Island, Franklin County to Stake Point, Taylor County.

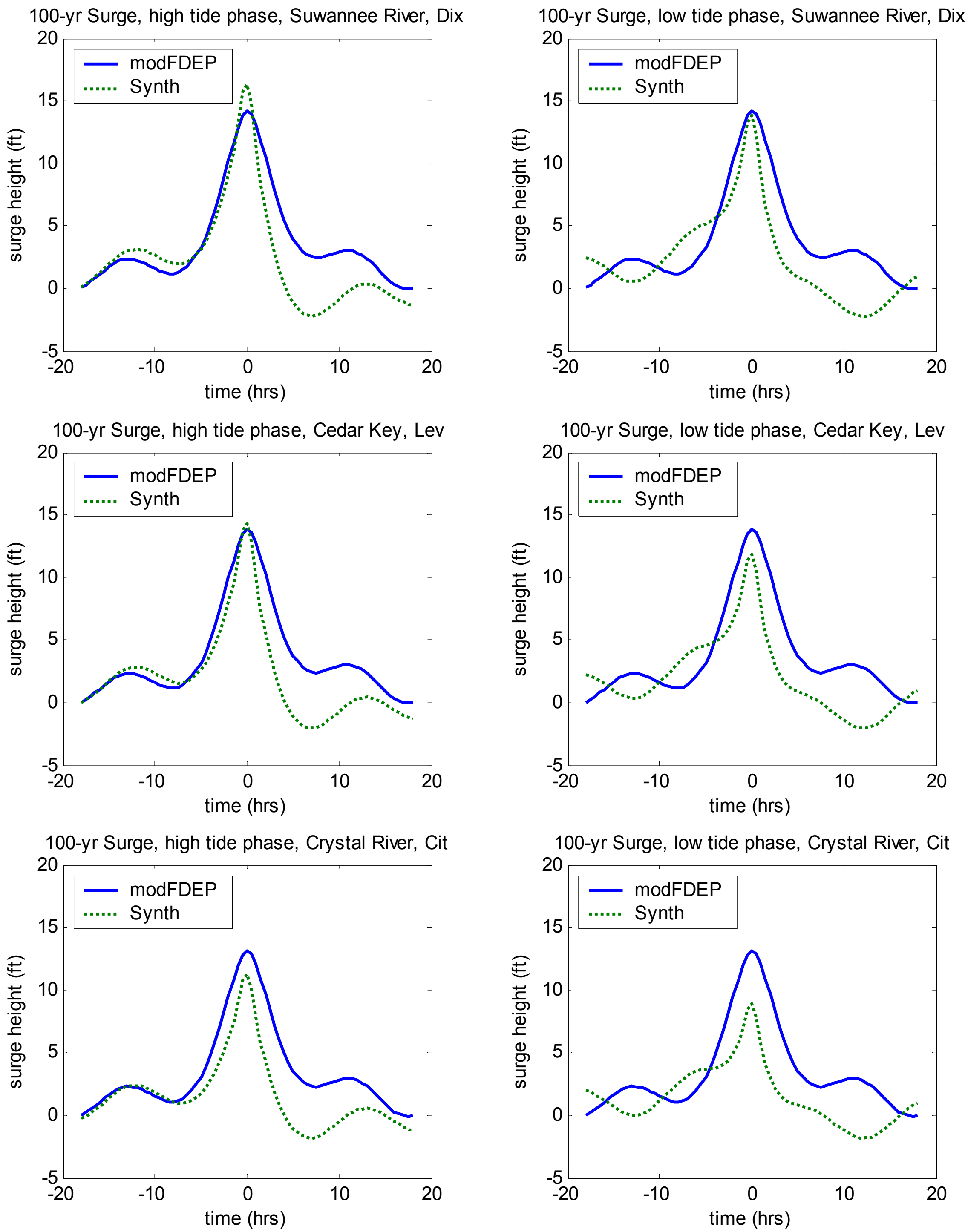

Figure B- 8. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Suwannee River, Dixie County to Stake Crystal River, Citrus County.

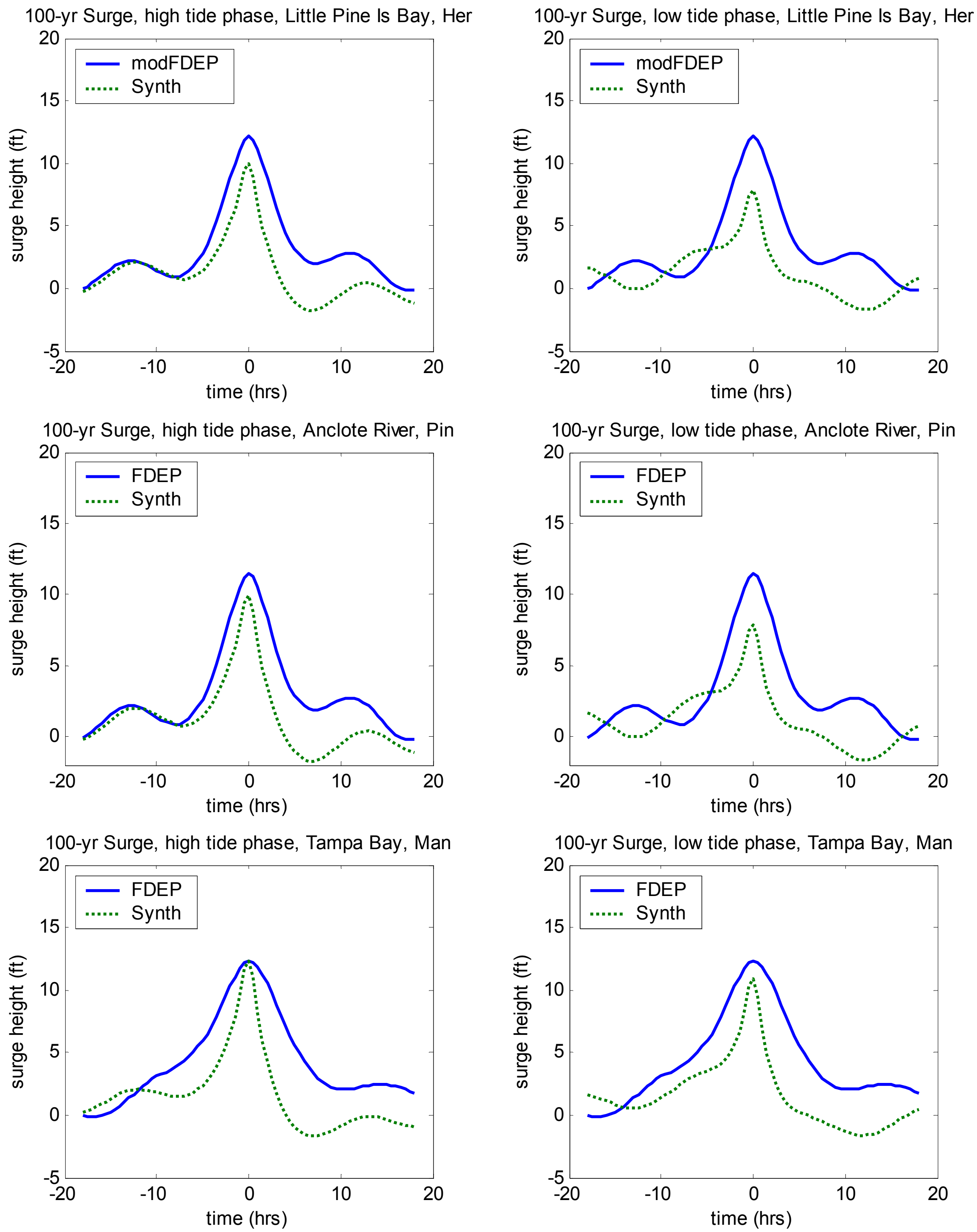

Figure B- 9. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Little Pine Island Bay, Hernando County to Tampa Bay.

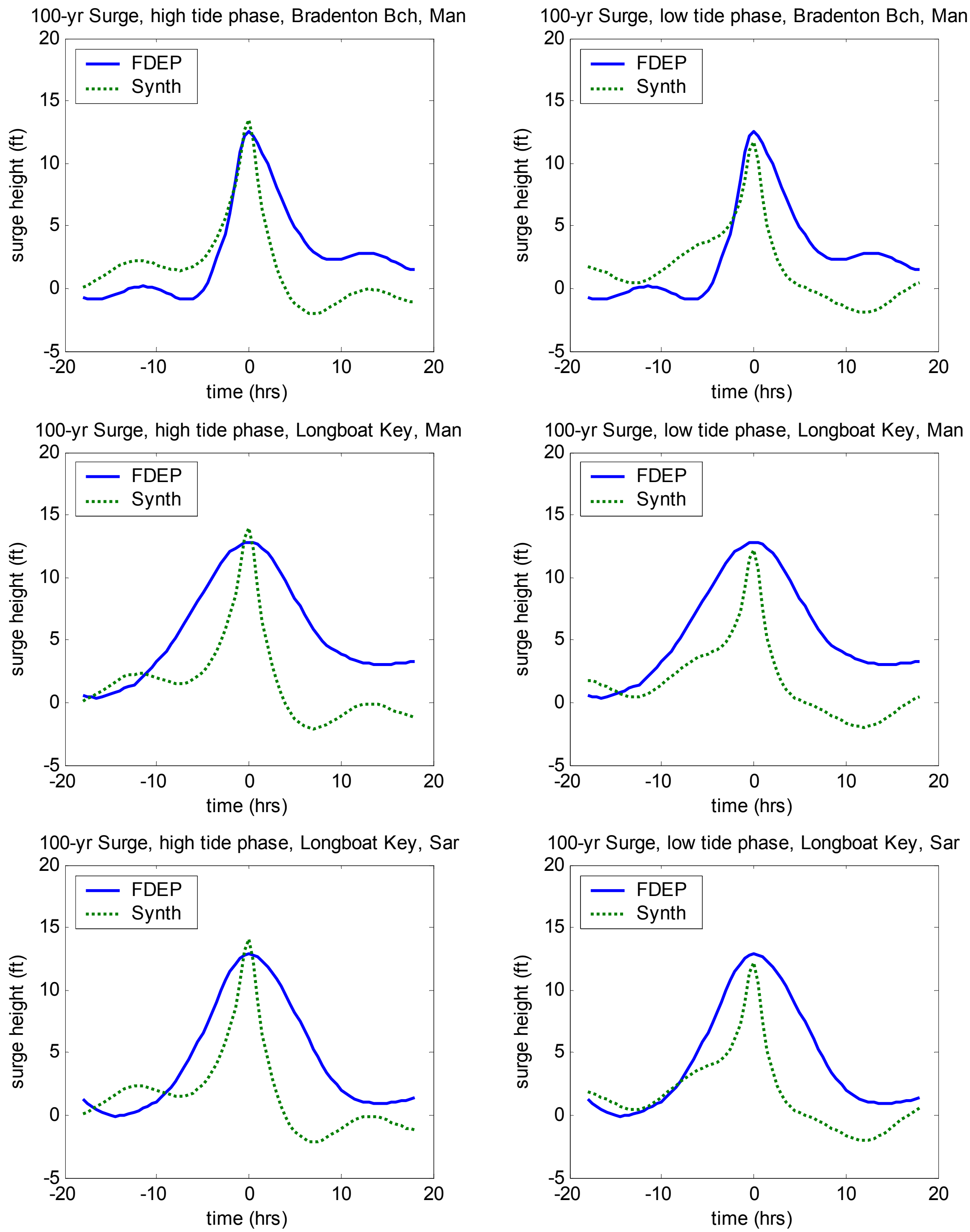

Figure B- 10. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Bradenton Beach, Manatee County to Longboat Key, Sarasota County.

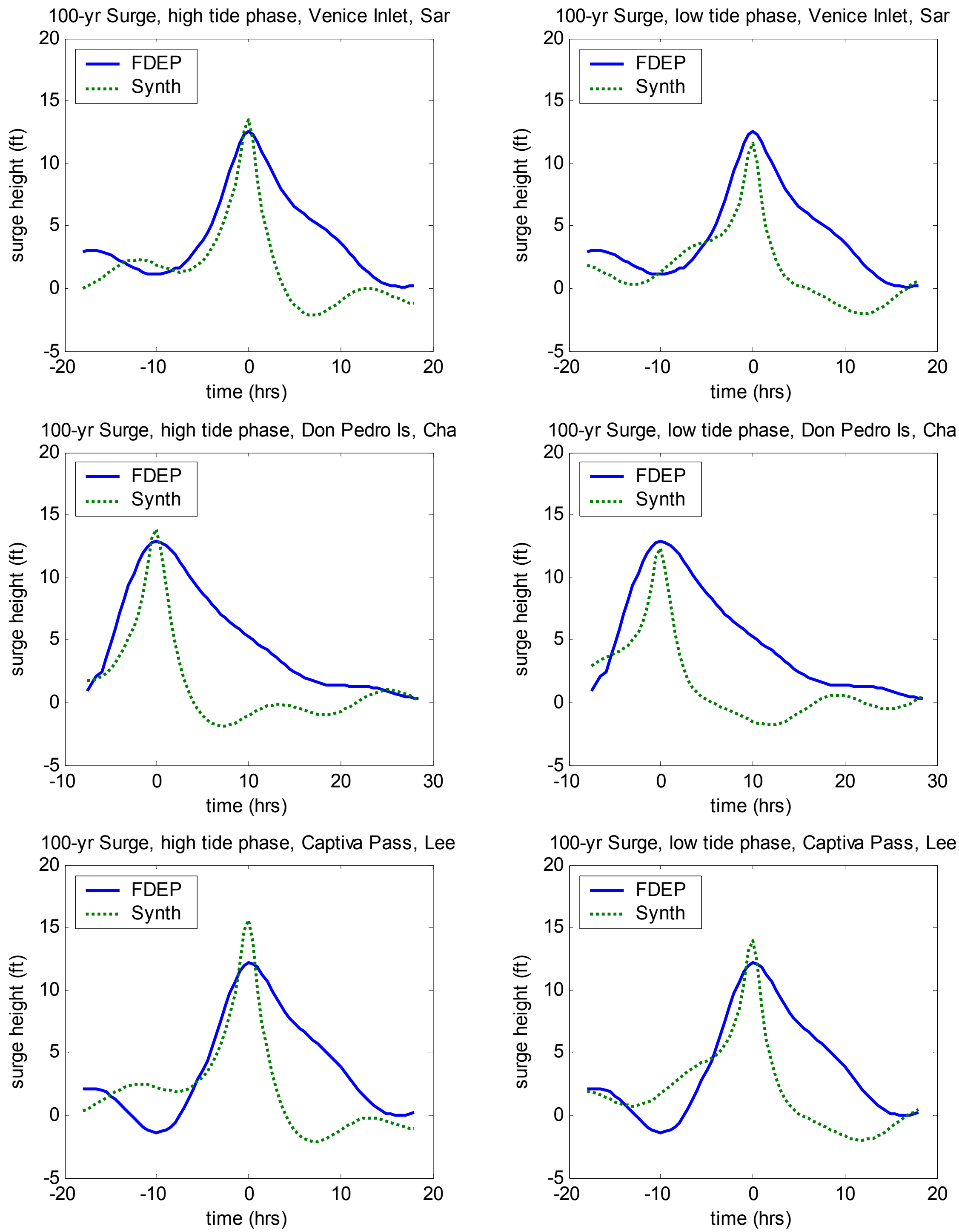

Figure B- 11. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Venice Inlet, Sarasota County to Captiva Pass, Lee County.

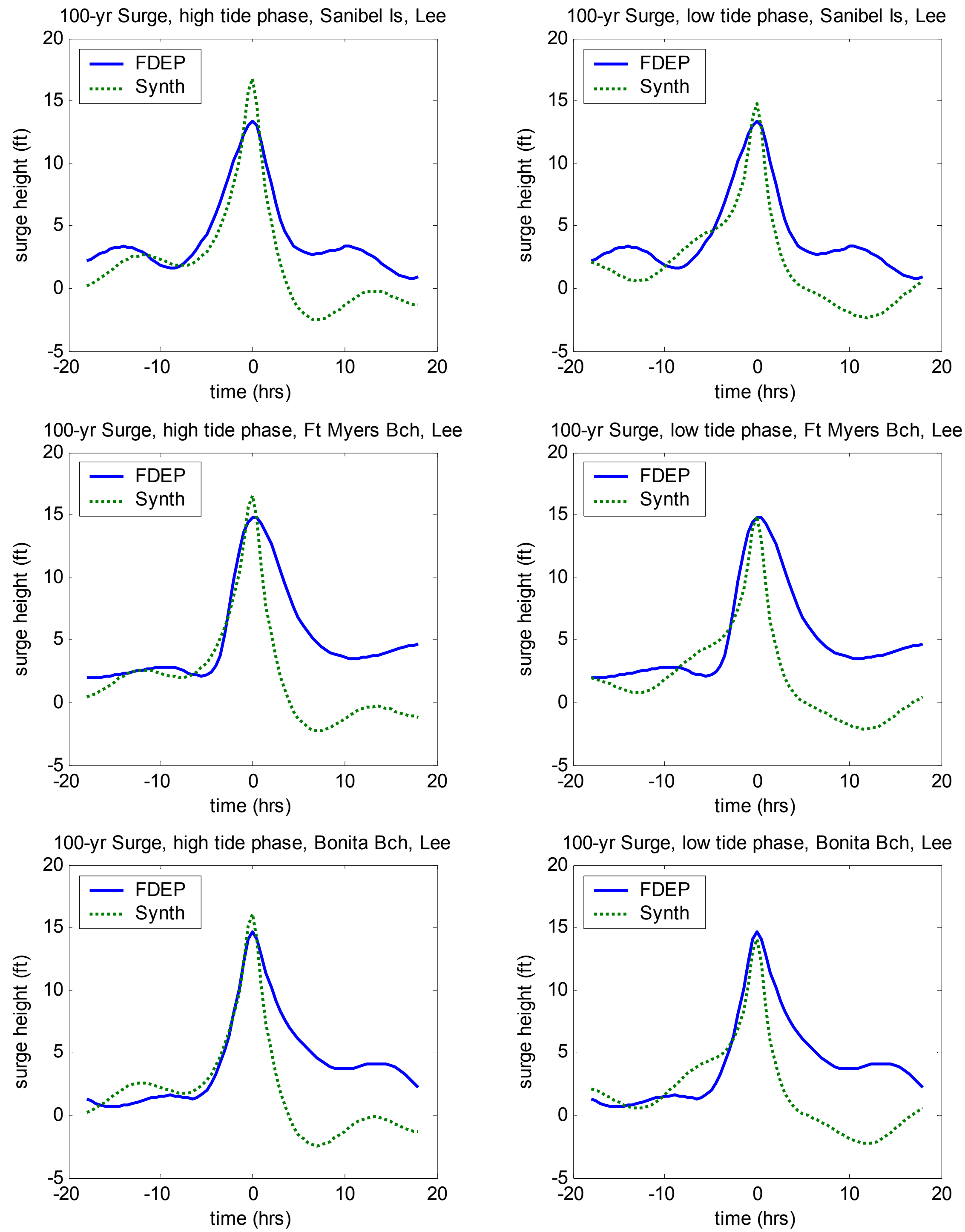

Figure B- 12. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Sanibel Island, Lee County to Bonita Point, Lee County.

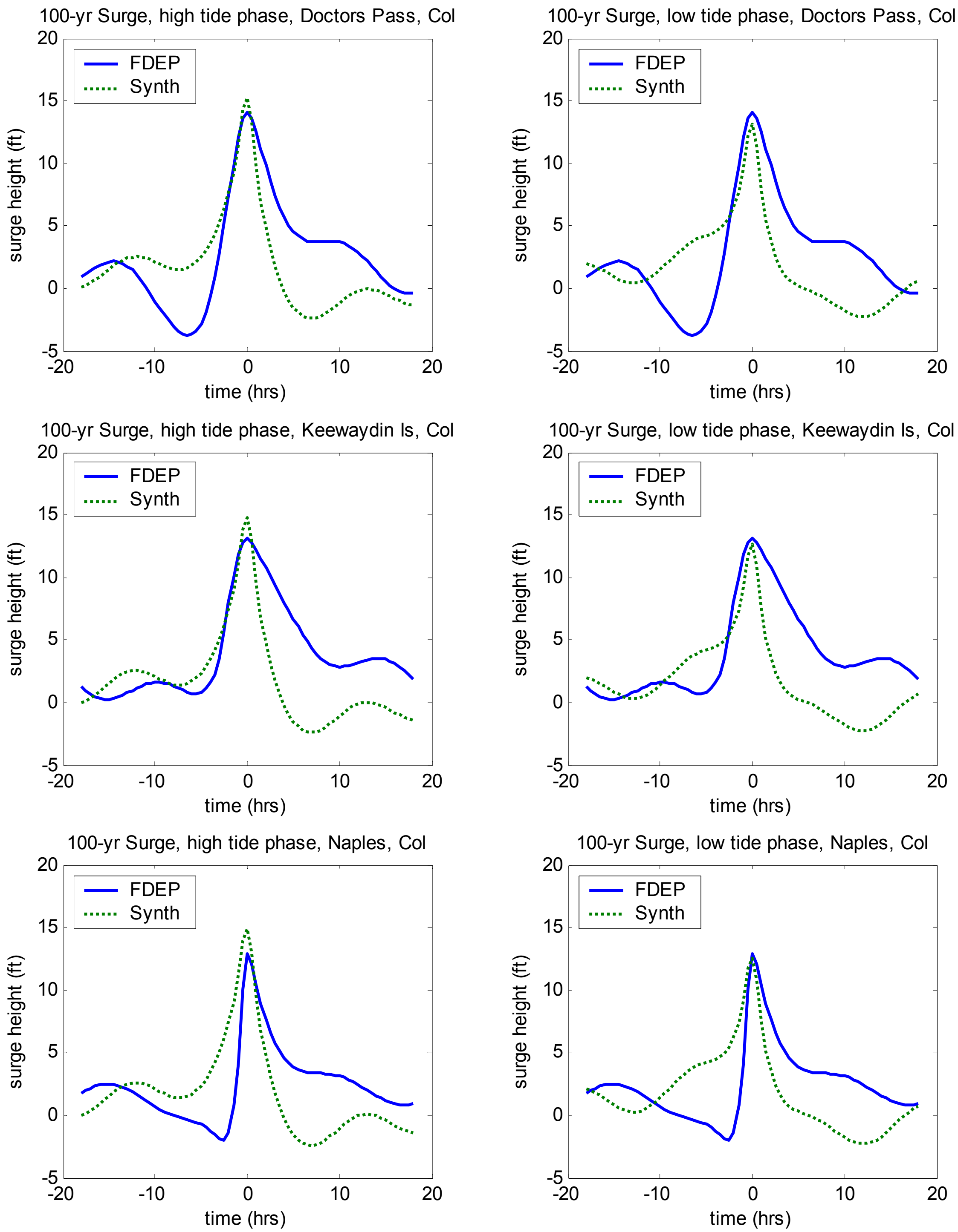

Figure B- 13. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Doctors Pass, Collier County to Naples.

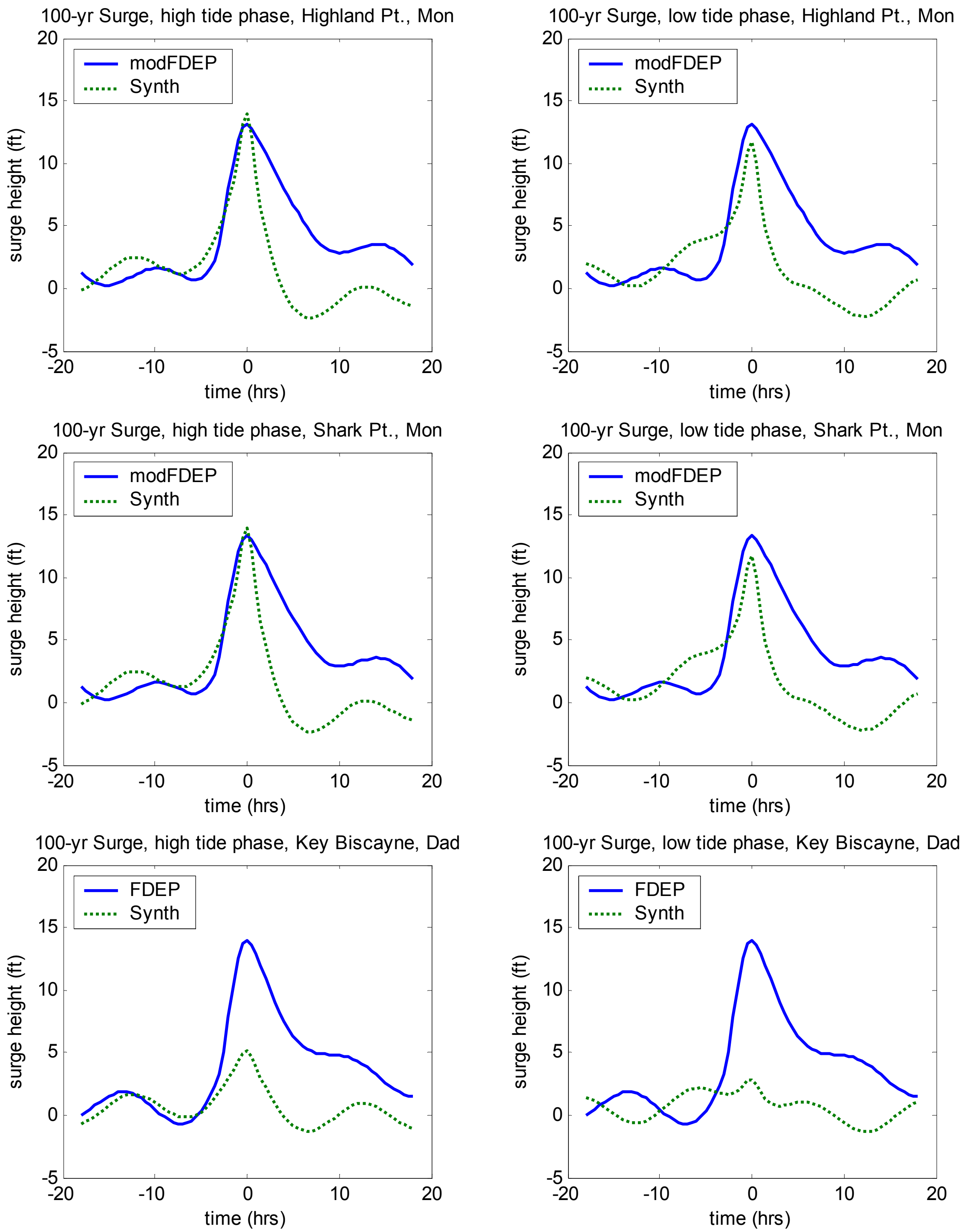

Figure B- 14. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Highland Point, Monroe County to Key Biscayne.

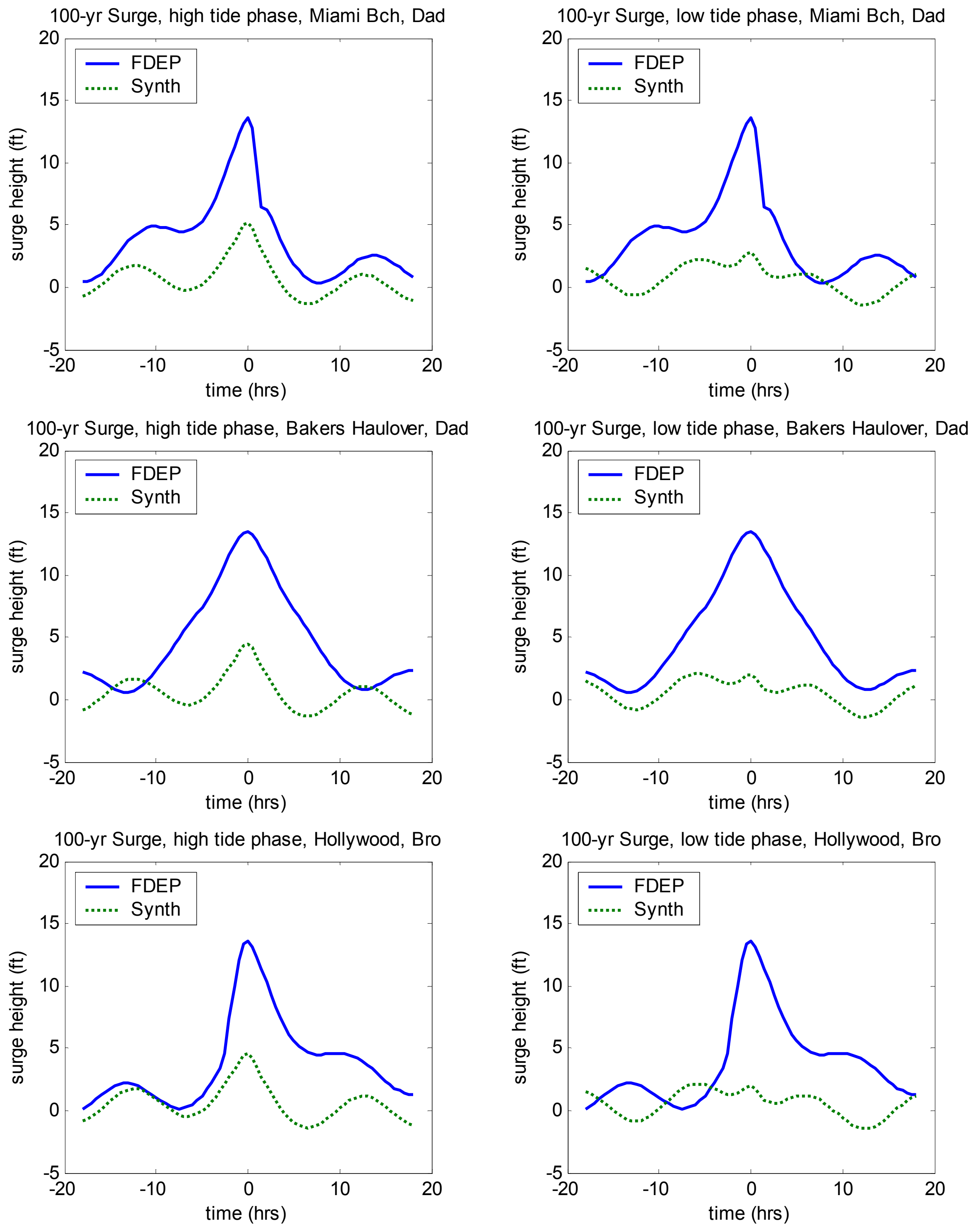

Figure B- 15. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Miami Beach to Hollywood, Broward County.

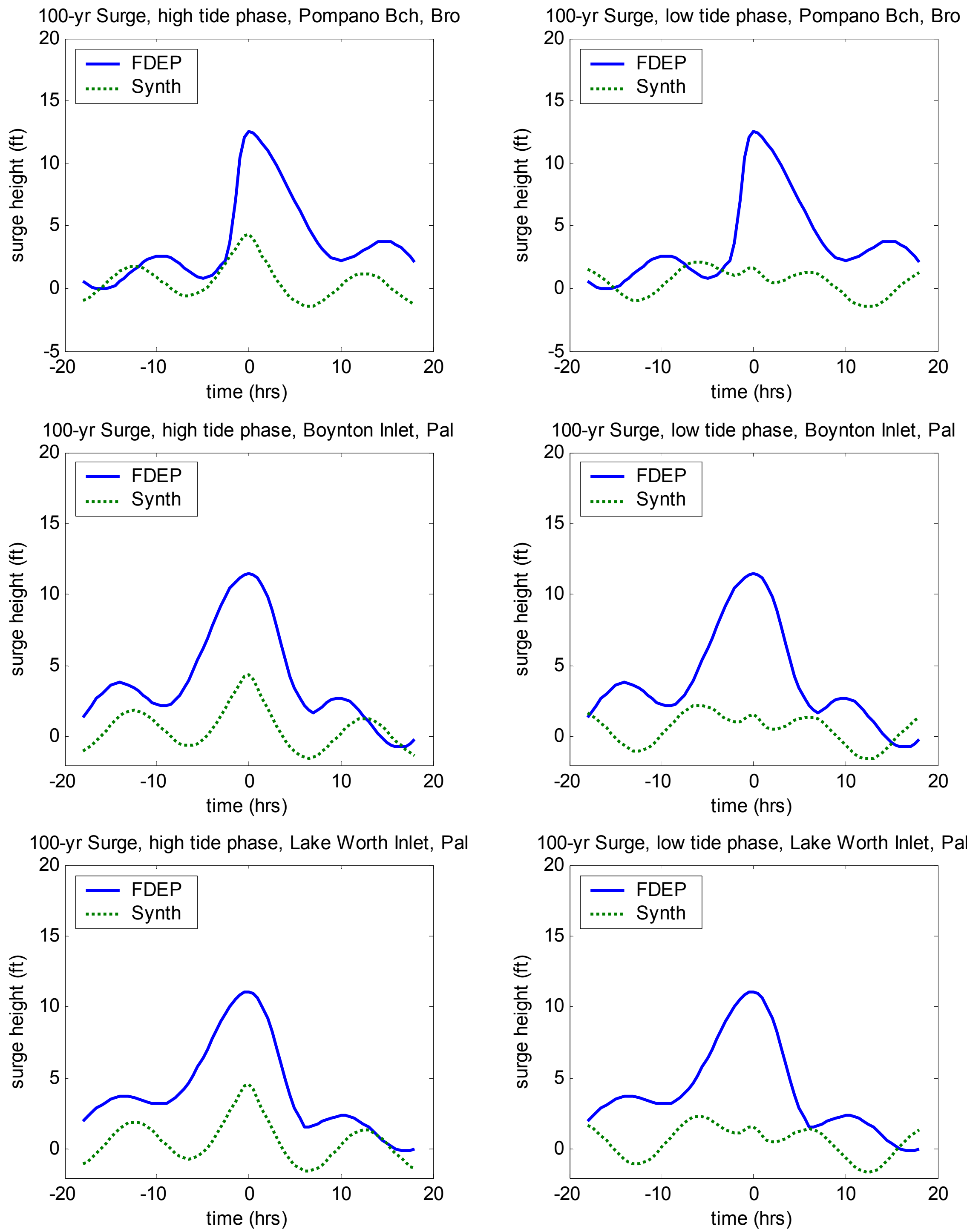

Figure B- 16. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Pompano Beach, Broward County to Lake Worth Inlet, Palm Beach County.

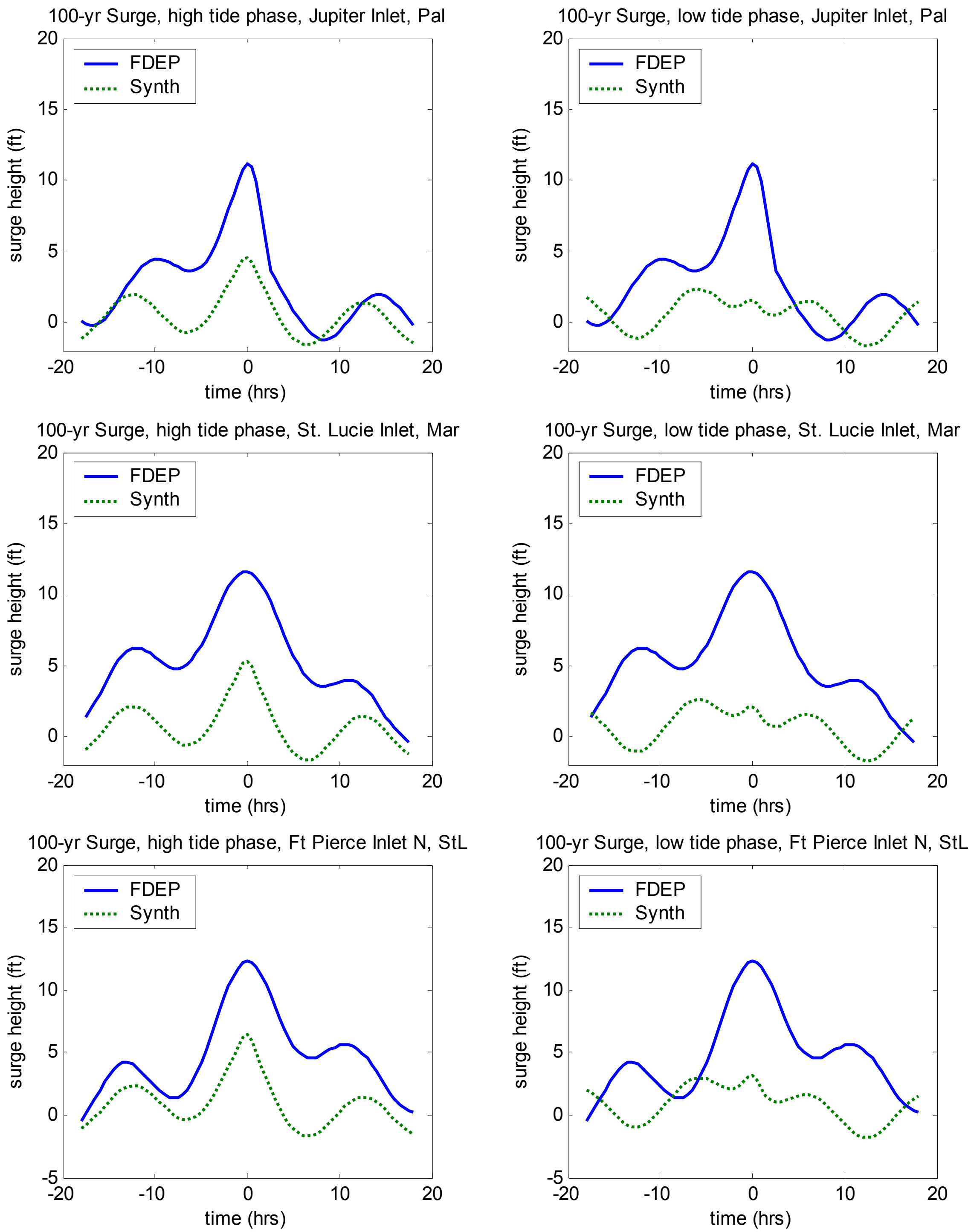

Figure B- 17. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Jupiter Inlet, Palm Beach County to Fort Pierce Inlet, St. Lucie County.

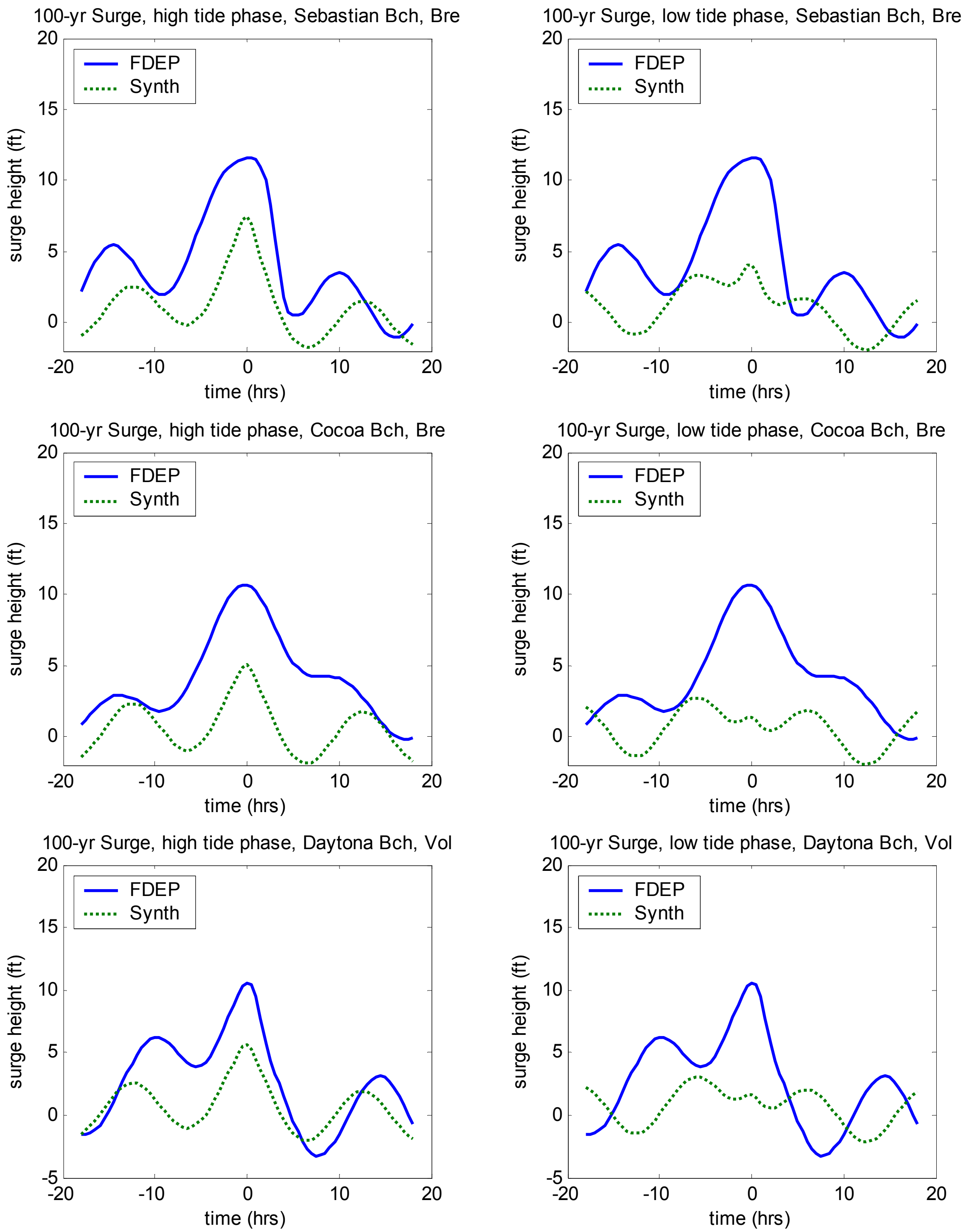

Figure B- 18. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Sebastian Beach, Brevard County to Daytona Beach, Volusia County.

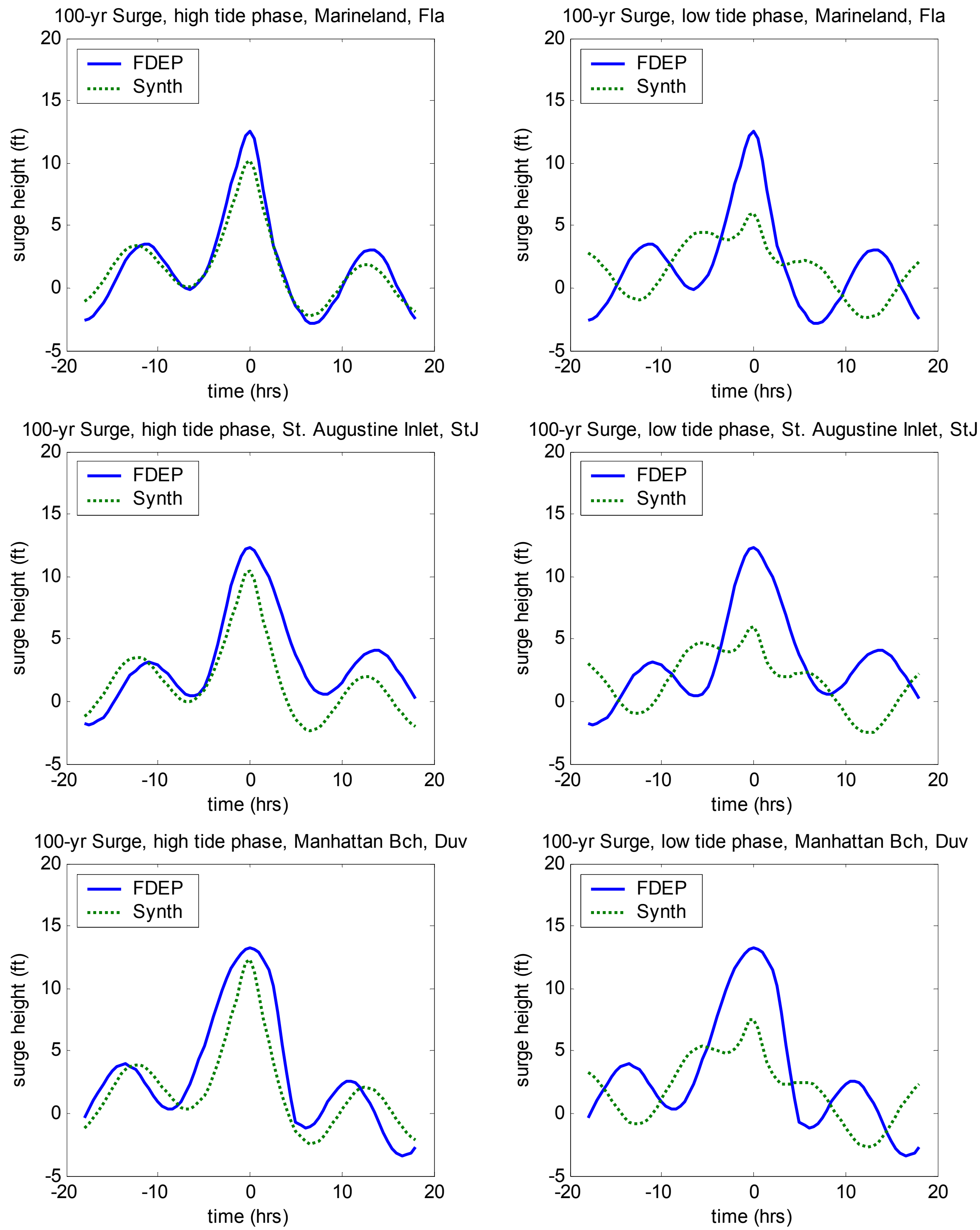

Figure B- 19. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Marineland, Flagler County to Manhattan Beach, Duval County.

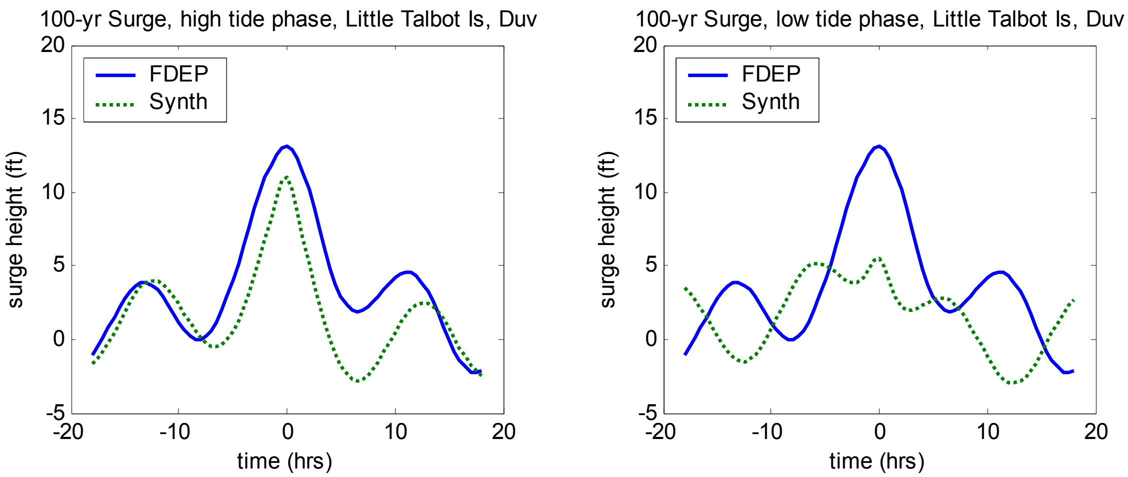

Figure B- 20. Comparison of FDEP and Pooled Fund Study Synthetic hydrographs for a 100 year storm surge; Little Talbot Island, Duval County

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Dade County, May 1981
Duval County, July 1991
Escambia County, January 1986
Flagler County, September 1987
Franklin County, September 1983
Gulf County, August 1985
Indian River County, October 1986
Lee County, July 1990
Manatee County, March 1987
Martin, July 1984
Nassau, September 1982
Okaloosa, January 1991
Palm Beach, April 1992
Pinellas, March 1995 (addendum 2000)
St. Johns, June 1987
St. Lucie, March 1988
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City of Neptune Beach, Duval County, FL, April 1989
Collier County, FL, June 1986
Dade County, FL, March 1994
Dixie County, FL, May 1983
Escambia County, FL, February 2000
Flagler County, FL, February 1986
Franklin County, FL, January 1983
Indian River County, FL, May 1989
Hernando County, FL, October 1983
Lee County, FL, July 1998
Levy County, FL September 1983
Manatee County, FL, July 1992
Martin County, FL, July 1983
Monroe County, FL, February 2002
Nassau County, FL, May 1988
Okaloosa County, FL, June 1997
Palm Beach County, FL, April 1982
Pasco County, FL, September 1992
Pinellas County, FL, May 1996
Santa Rosa County, FL, January 2000
Sarasota County, FL, September 1992
St. Johns County, FL, September 1985
St. Lucie County, FL, August 1991
Taylor County, FL, August 1995
Volusia County, FL, April 2002
Wakulla County, FL, June 1986
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