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Coastal Engineering Considerations in Bridge Design

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Coastal Infrastructure

- 29% of the nation's population within the country's coastline counties, 76% in Florida
- 60,000 coastal road miles nationwide with approximately 18,000 road miles in Florida – 30%
- 31% of Florida's ~6,600 bridges tidally influenced
- 55% of total bridge length tidally influenced

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Let's begin…

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{dy}+w\frac{\partial u}{\partial z}\right)=$$

$$\rho g_x-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[2\mu\frac{\partial u}{\partial x}+\lambda\nabla\cdot\mathbf{V}\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{dy}+w\frac{\partial v}{\partial z}\right)=$$

$$\rho g_y-\frac{\partial p}{\partial y}+\frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y}+\lambda\nabla\cdot\mathbf{V}\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{dy}+w\frac{\partial w}{\partial z}\right)=$$

$$\rho g_z-\frac{\partial p}{\partial z}+\frac{\partial}{\partial z}\left[2\mu\frac{\partial w}{\partial z}+\lambda\nabla\cdot\mathbf{V}\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]$$

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Outline

- Tides
- Sea Level Rise
- Hurricane Storm Surge
- Waves and Wave Forces
- FEMA
- Shoreline/Abutment Protection

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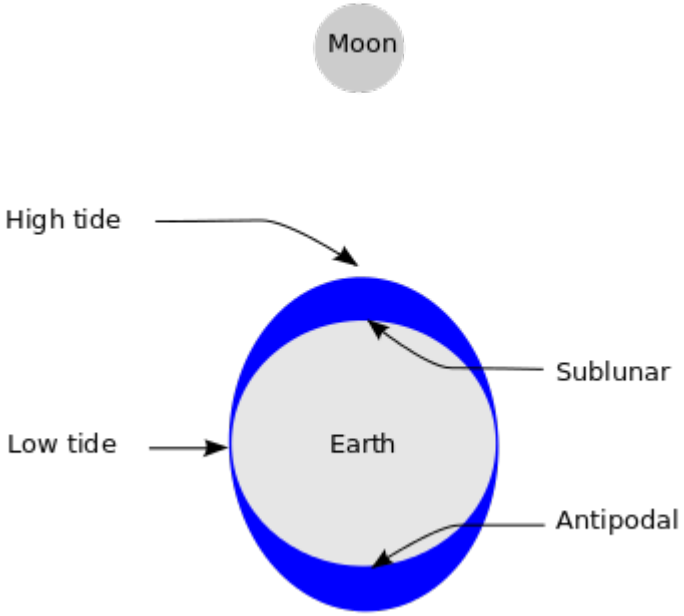
Tides

- Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth.



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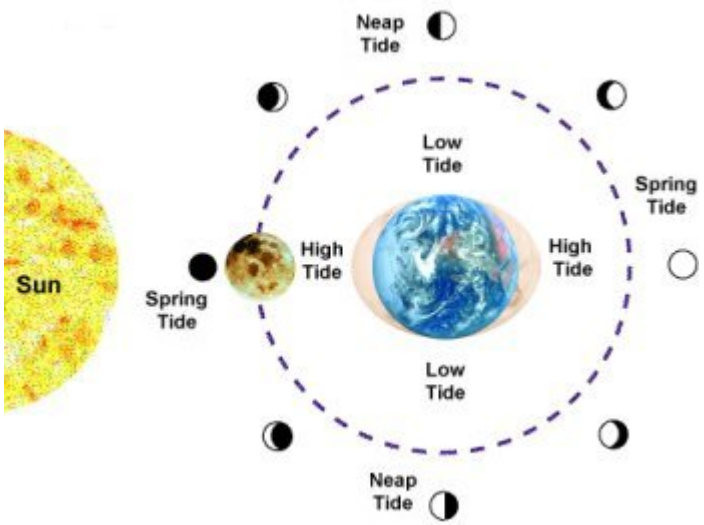
Spring and Neap Tides

- Spring tides
  - Full moon and new moon
  - Larger tidal range
- Neap tides
  - Moon's quarter phases
  - Smaller difference between high and low tides



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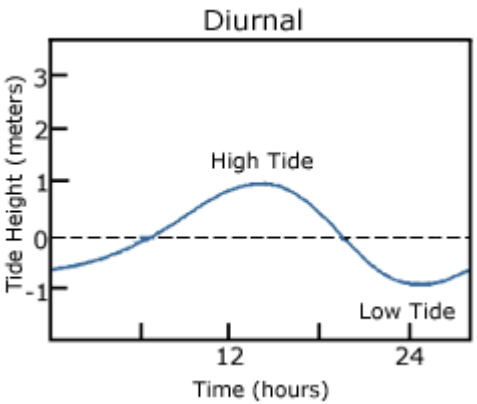
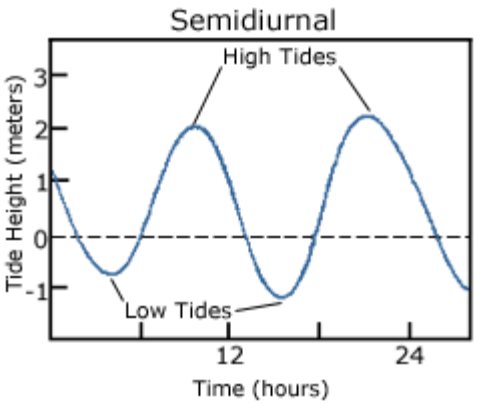
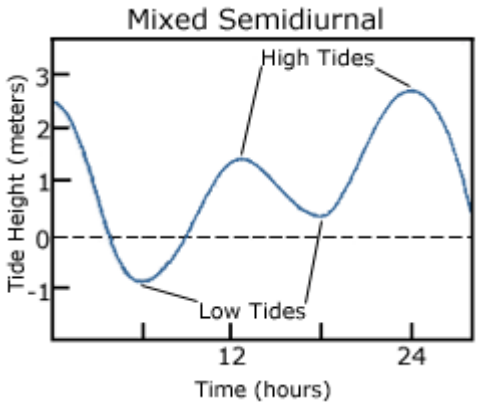
Types of Tides

- Diurnal – one high tide and one low tide per day
- Semidiurnal - two high tides and two low tides per day
- Mixed - two unequal high tides and two unequal low tides per tidal day







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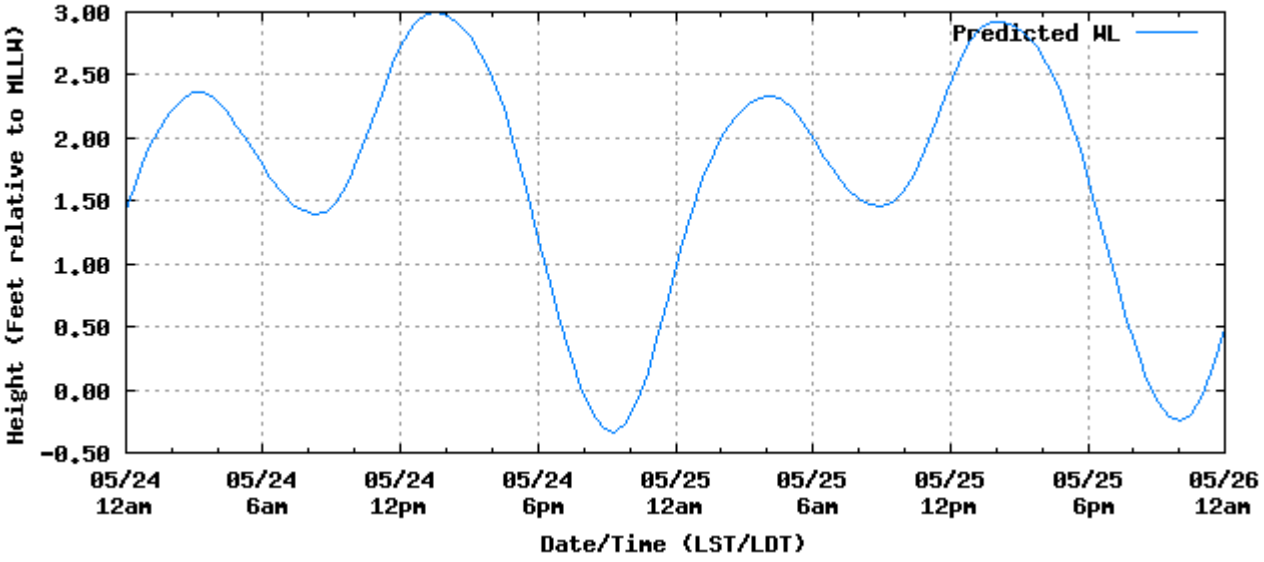
Tidal Datums

- Mean High Water (MHW)
- Mean Low Water (MLW)
- Mean Lower Low Water (MLLW)



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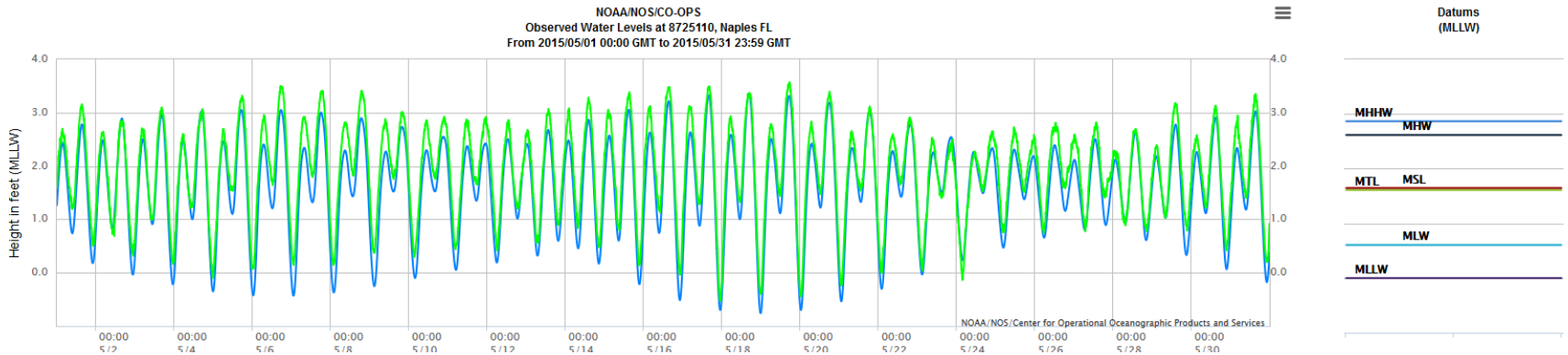

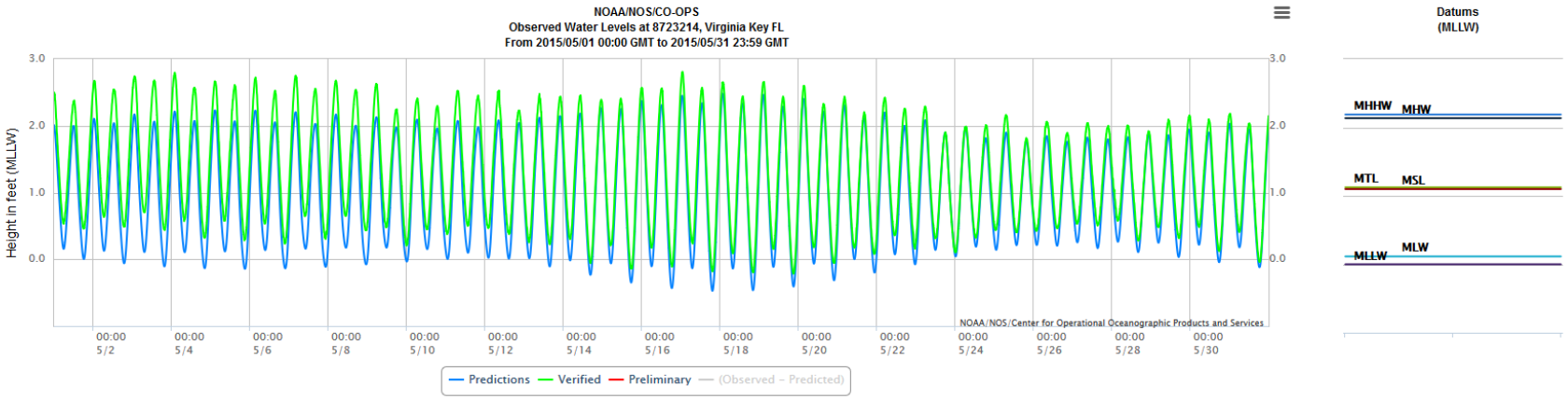

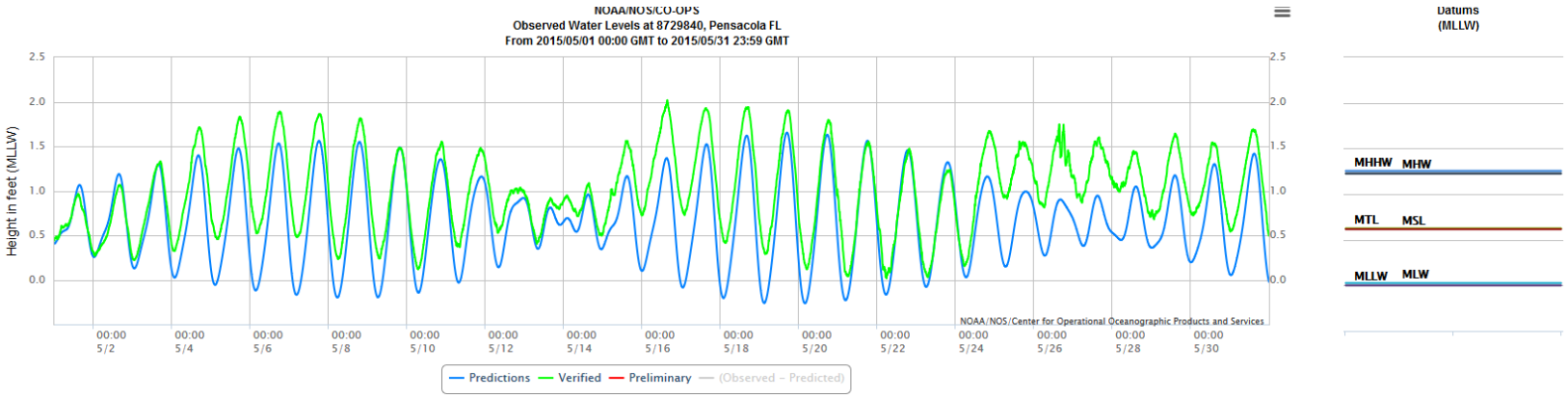

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Tidal Datums

- MHW – clearances
  - Navigation
  - Aggressive waterways
- Sources
  - NOAA: http://co-ops.nos.noaa.gov/map/
  - FDEP: http://labins.org/map/index.html

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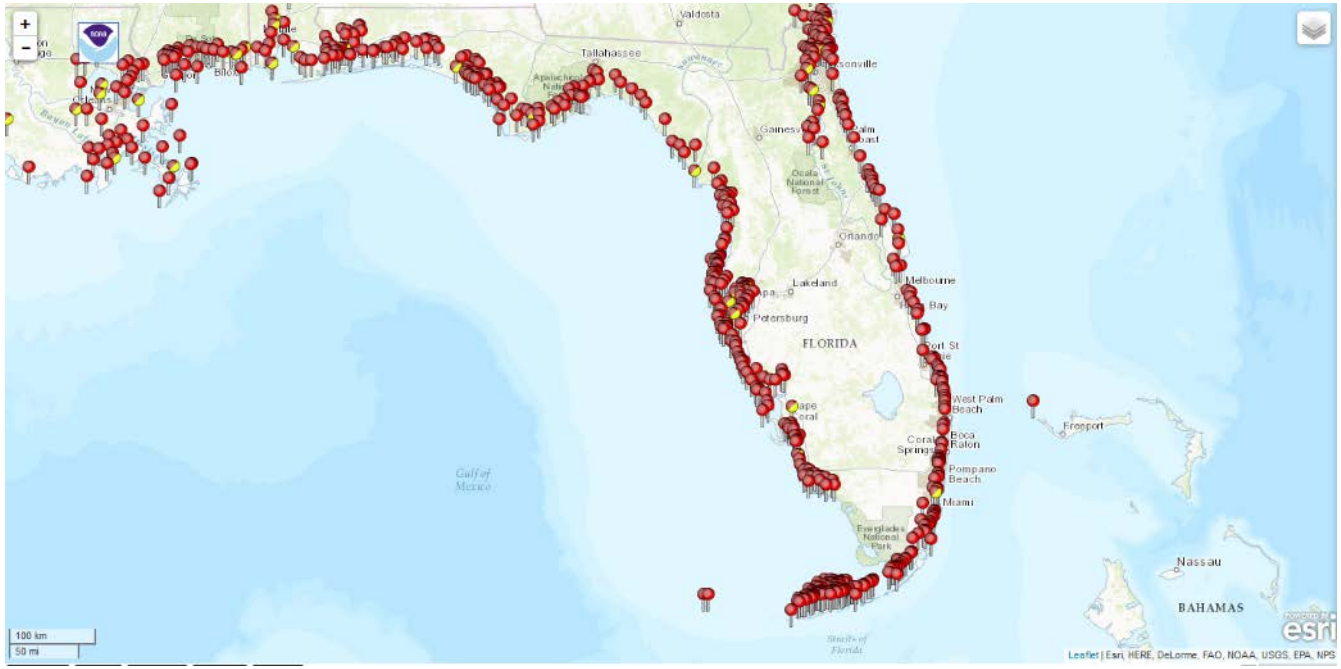

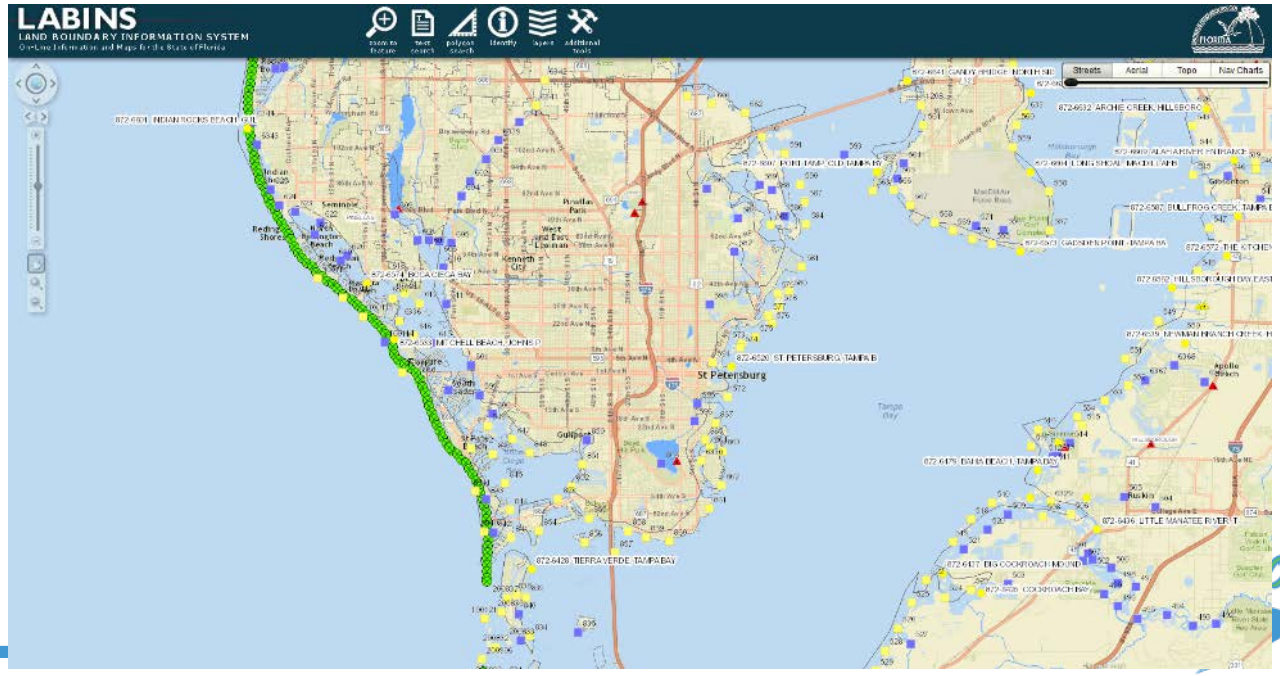

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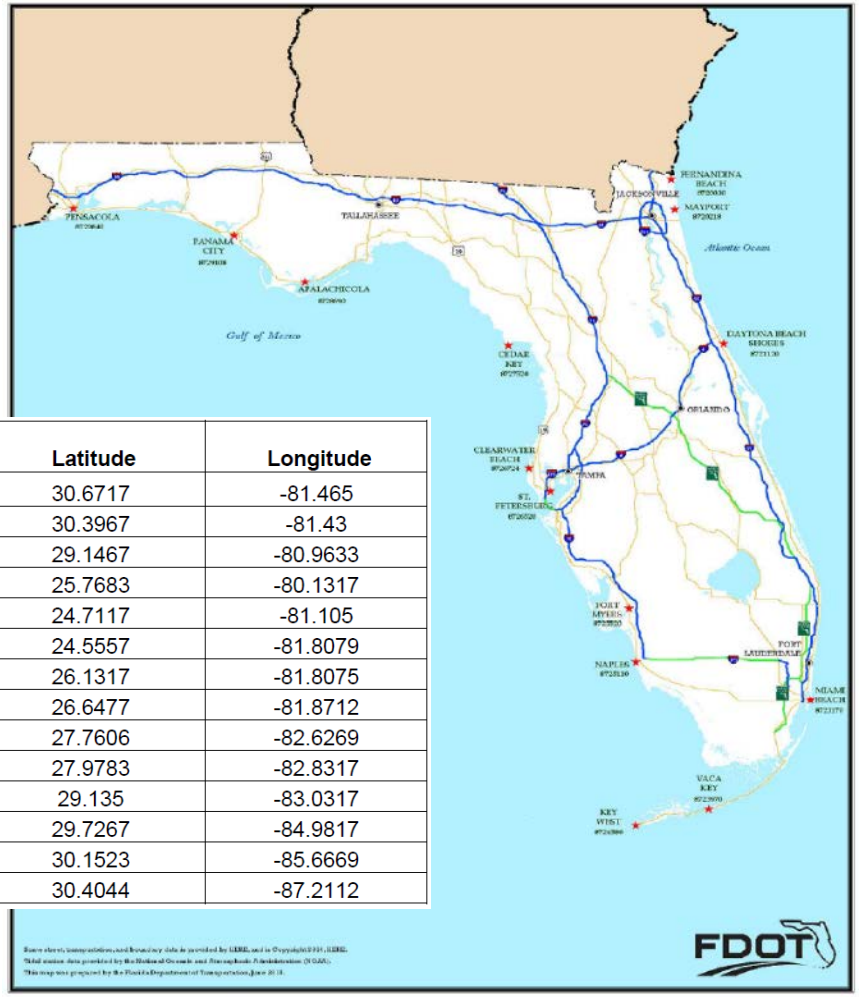
Sea Level Rise

- The design of coastal projects (including new construction, reconstruction and projects rebuilding drainage systems) must include a sea level rise analysis to assess impacts to design.
- The sea level rise data based on historical tidal records:
  - Gathered by National Water Level Observation Network (NWLON)
  - Managed by the National Oceanic and Atmospheric Administration (NOAA)

Station ID	Station Name	MSL Trends (mm/yr)	+/- 95% CI (mm/yr)	Latitude	Longitude
8720030	Fernandina Beach, FL	2.01	0.18	30.6717	-81.465
8720218	Mayport, FL	2.44	0.27	30.3967	-81.43
8721120	Daytona Beach Shores, FL	2.32	0.63	29.1467	-80.9633
8723170	Miami Beach, FL	2.39	0.43	25.7683	-80.1317
8723970	Vaca Key, FL	3.18	0.49	24.7117	-81.105
8724580	Key West, FL	2.31	0.15	24.5557	-81.8079
8725110	Naples, FL	2.4	0.48	26.1317	-81.8075
8725520	Fort Myers, FL	2.63	0.51	26.6477	-81.8712
8726520	St. Petersburg, FL	2.54	0.26	27.7606	-82.6269
8726724	Clearwater Beach, FL	2.99	0.64	27.9783	-82.8317
8727520	Cedar Key, FL	1.89	0.18	29.135	-83.0317
8728690	Apalachicola, FL	1.76	0.69	29.7267	-84.9817
8729108	Panama City, FL	1.6	0.67	30.1523	-85.6669
8729840	Pensacola, FL	2.19	0.23	30.4044	-87.2112



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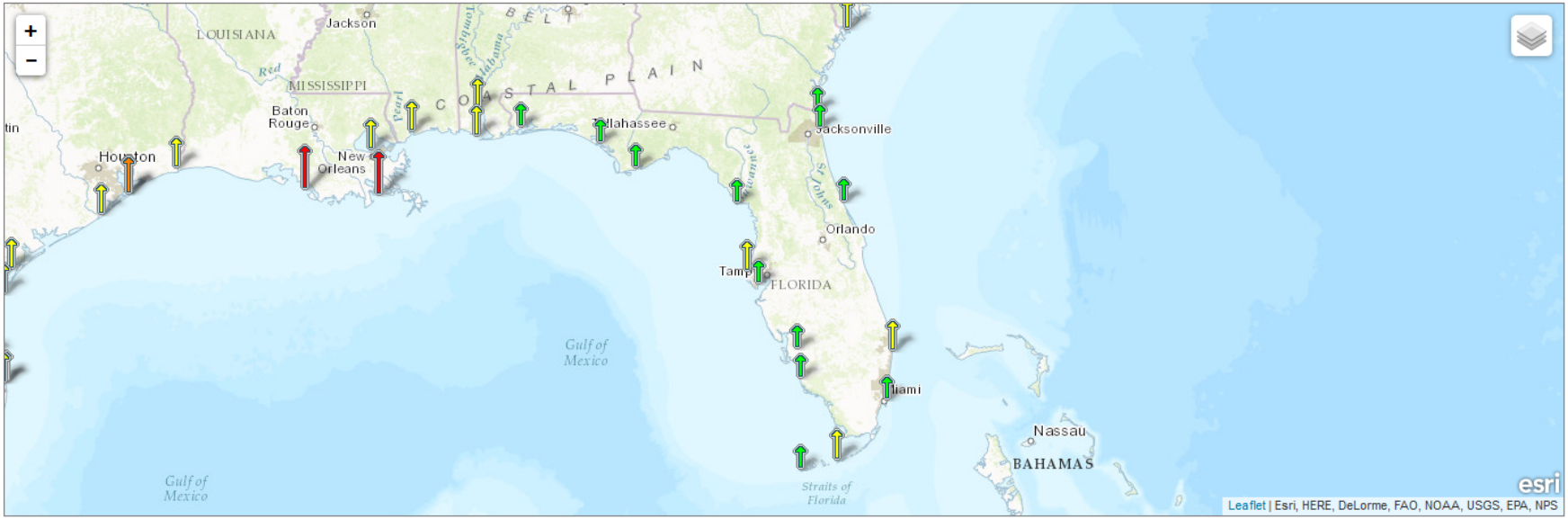
Sea Level Trends

East Coast | West Coast | Gulf Coast | Alaska | Hawaii | Global

View in Google Earth

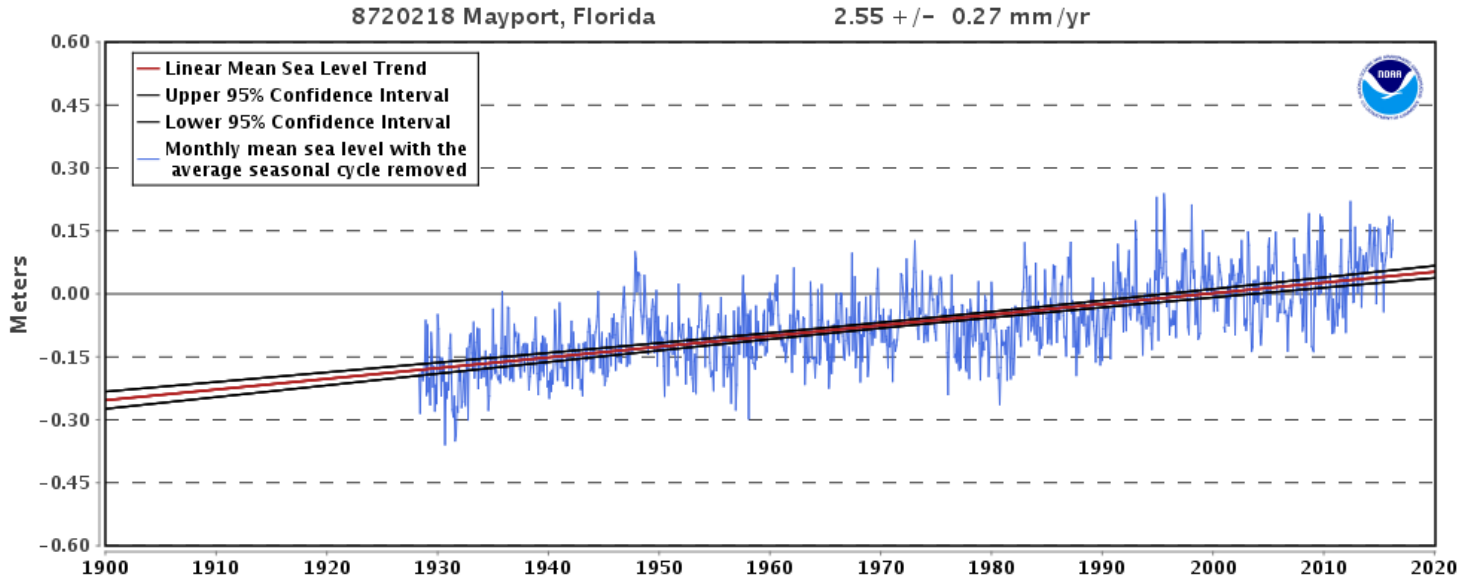


The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

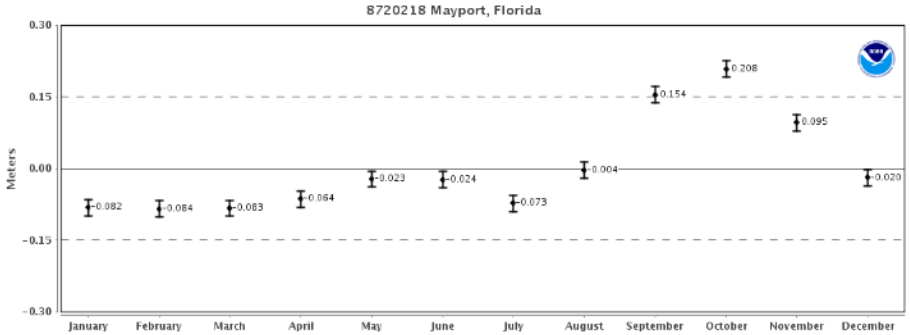
Sea Level Trends
mm/yr (feet/century)

15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)

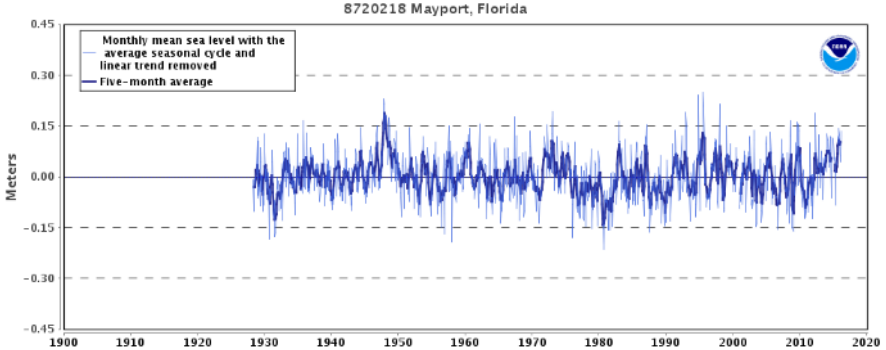
Mean Sea Level Trend
8720218 Mayport, Florida



Average Seasonal Cycle
8720218 Mayport, Florida



Interannual Variation
8720218 Mayport, Florida



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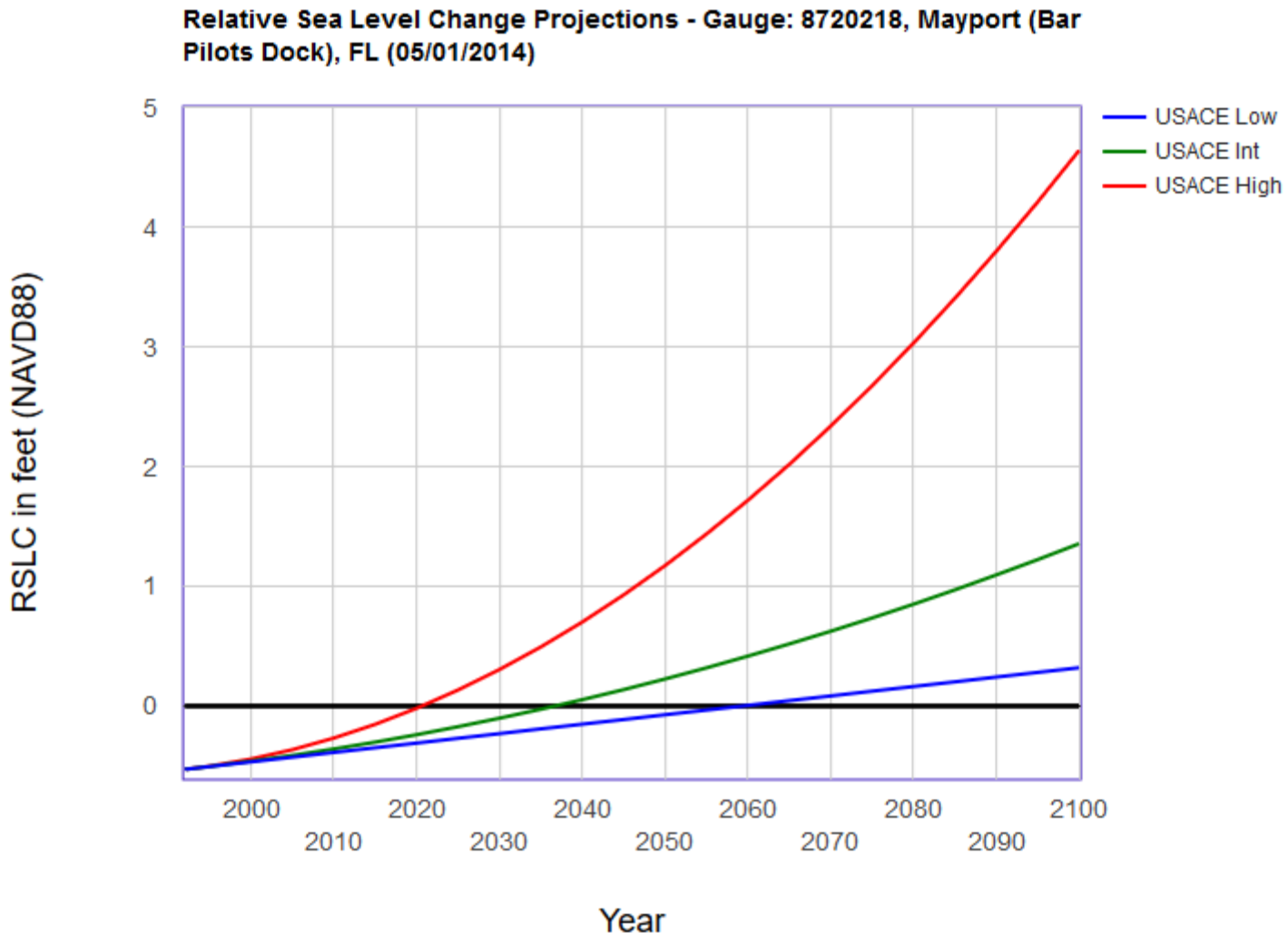
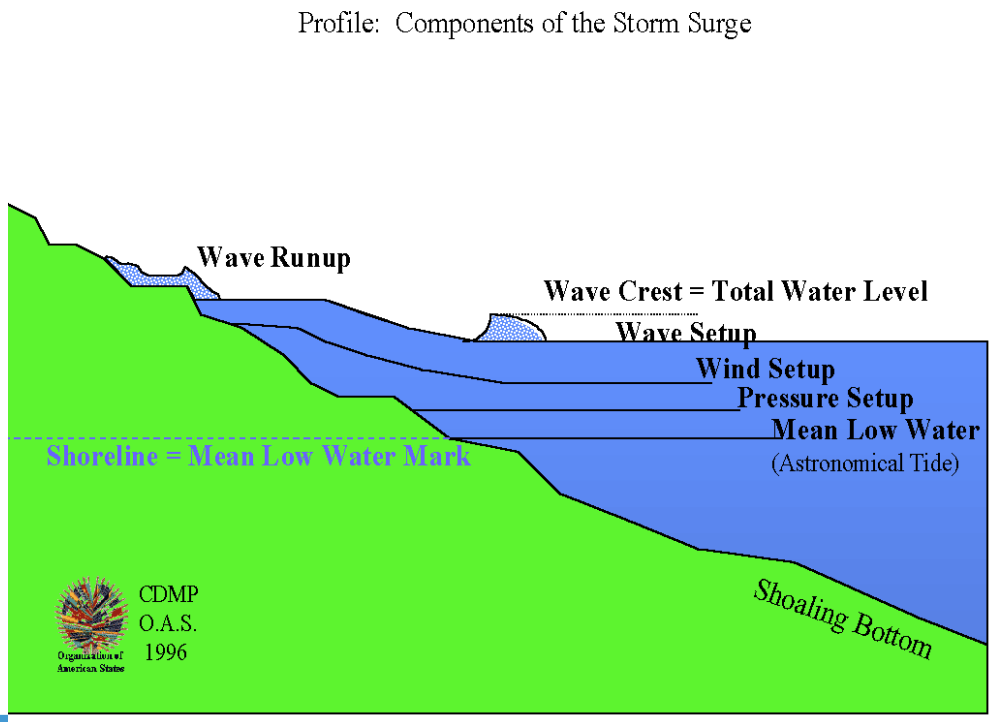
8720218, Mayport (Bar Pilots Dock), FL
NOAA's Published Rate: 0.00787 feet/yr

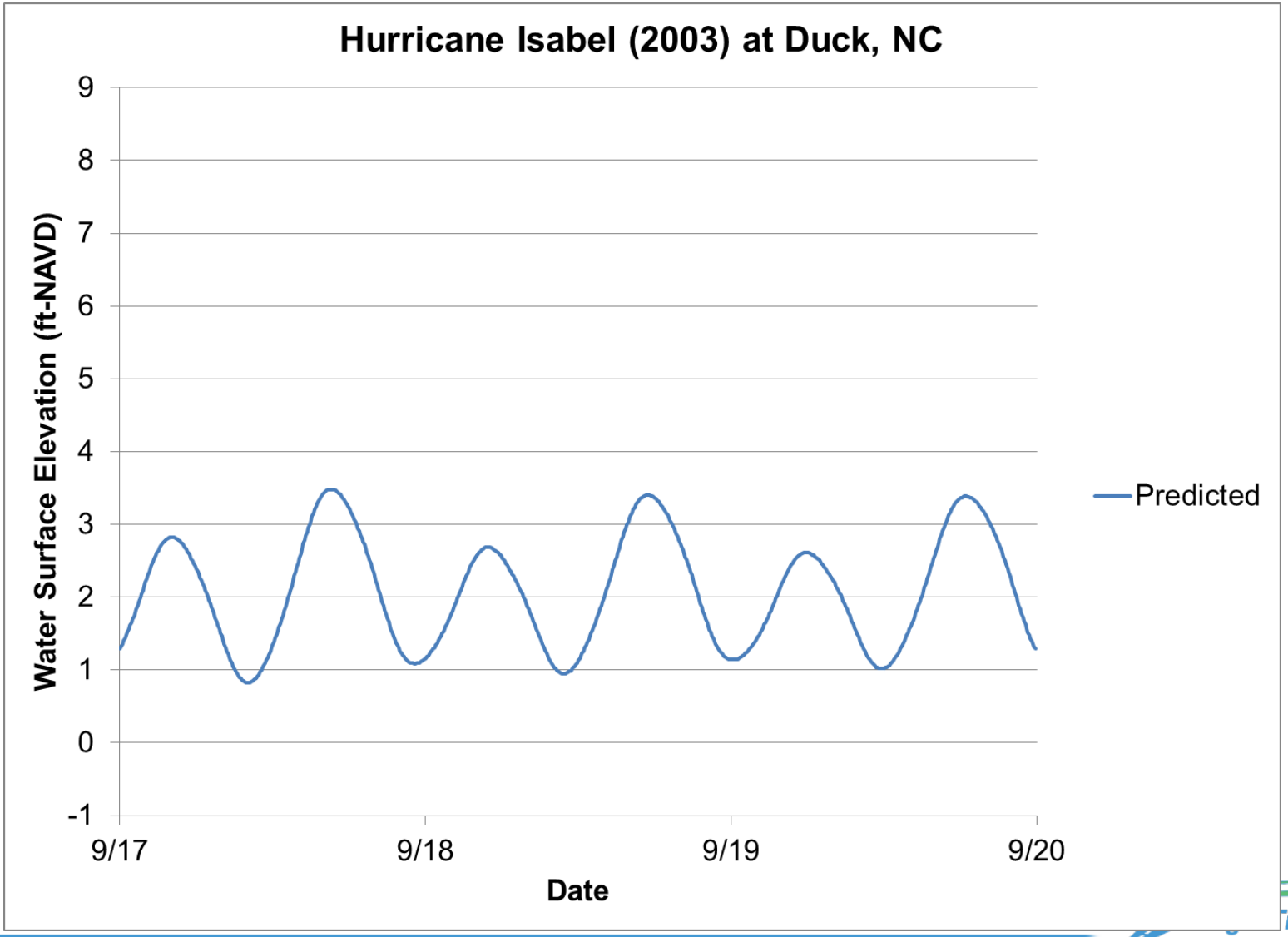


Hurricane Storm Surge

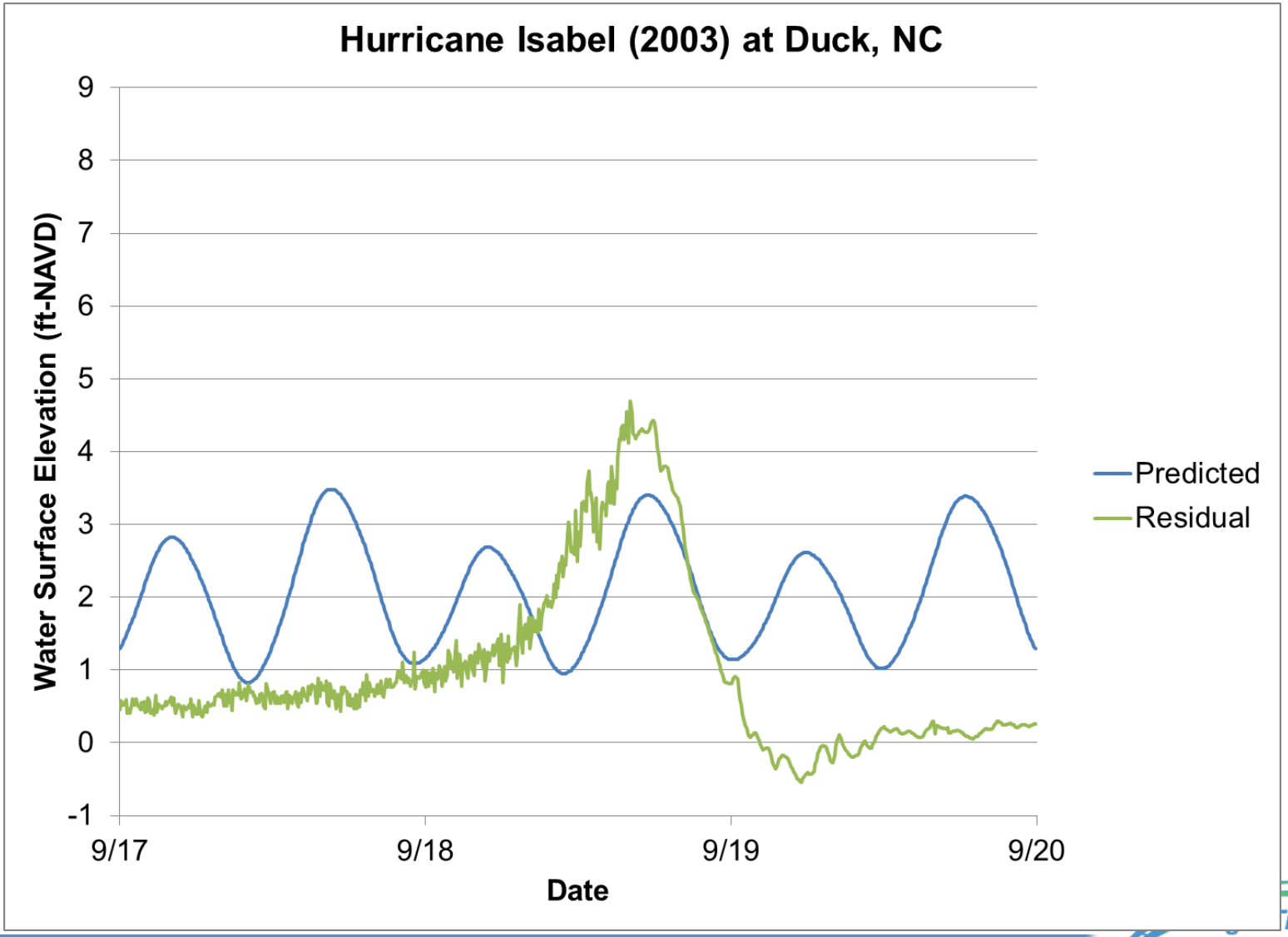
- The rise in water level above the normal astronomical tide level due to the action of a storm
- Components:
  - Wind set-up
  - Atmospheric pressure Reduction
  - Wave set-up
- Storm Tide



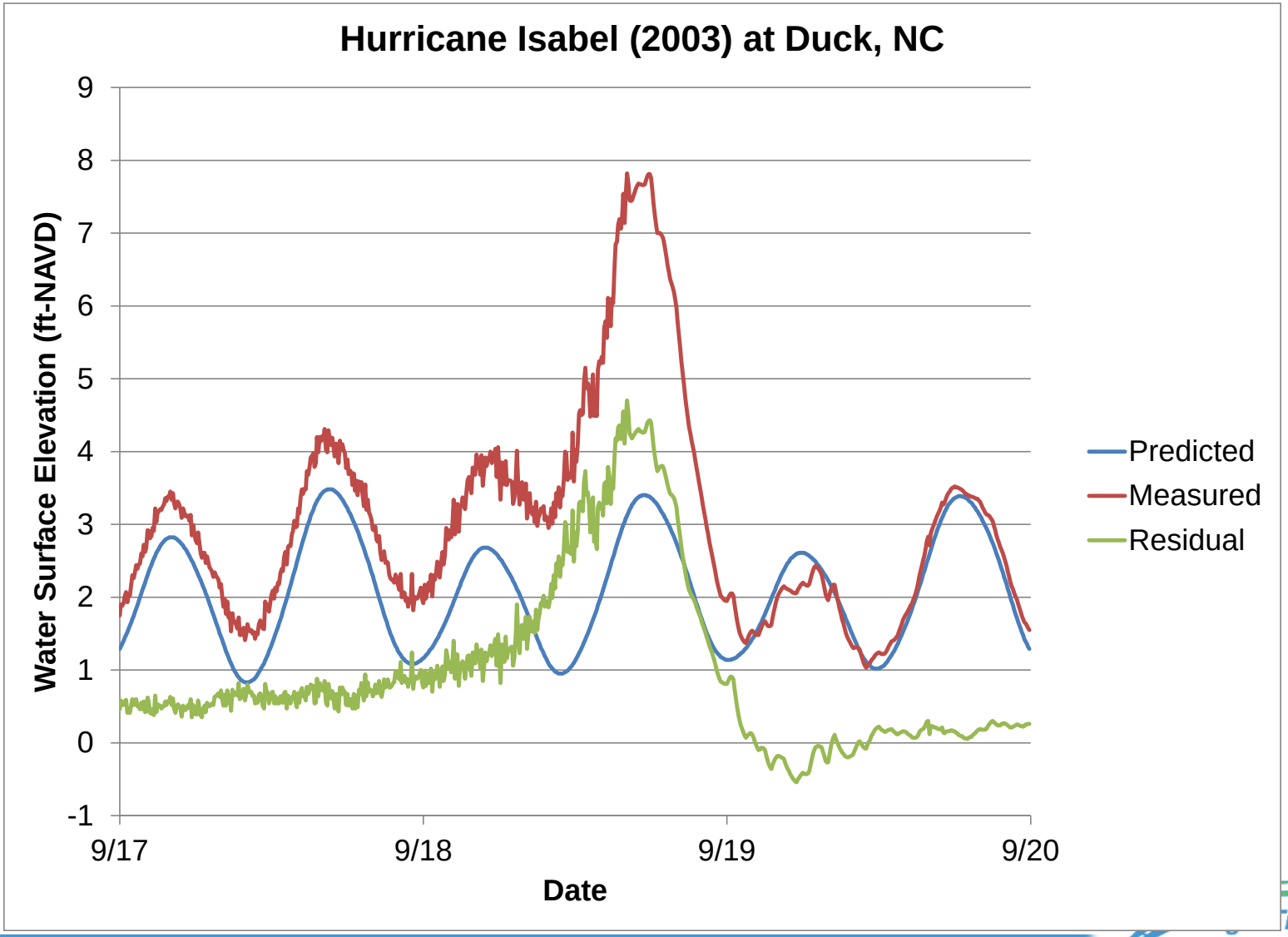
Storm Tide Hydrograph



Storm Tide Hydrograph



Storm Tide Hydrograph



Hydrodynamic Modeling

- Storm surge boundary conditions
- Measured at tide gages
- Synthetic hydrographs
  - FEMA BFE
- Florida DEP hydrographs

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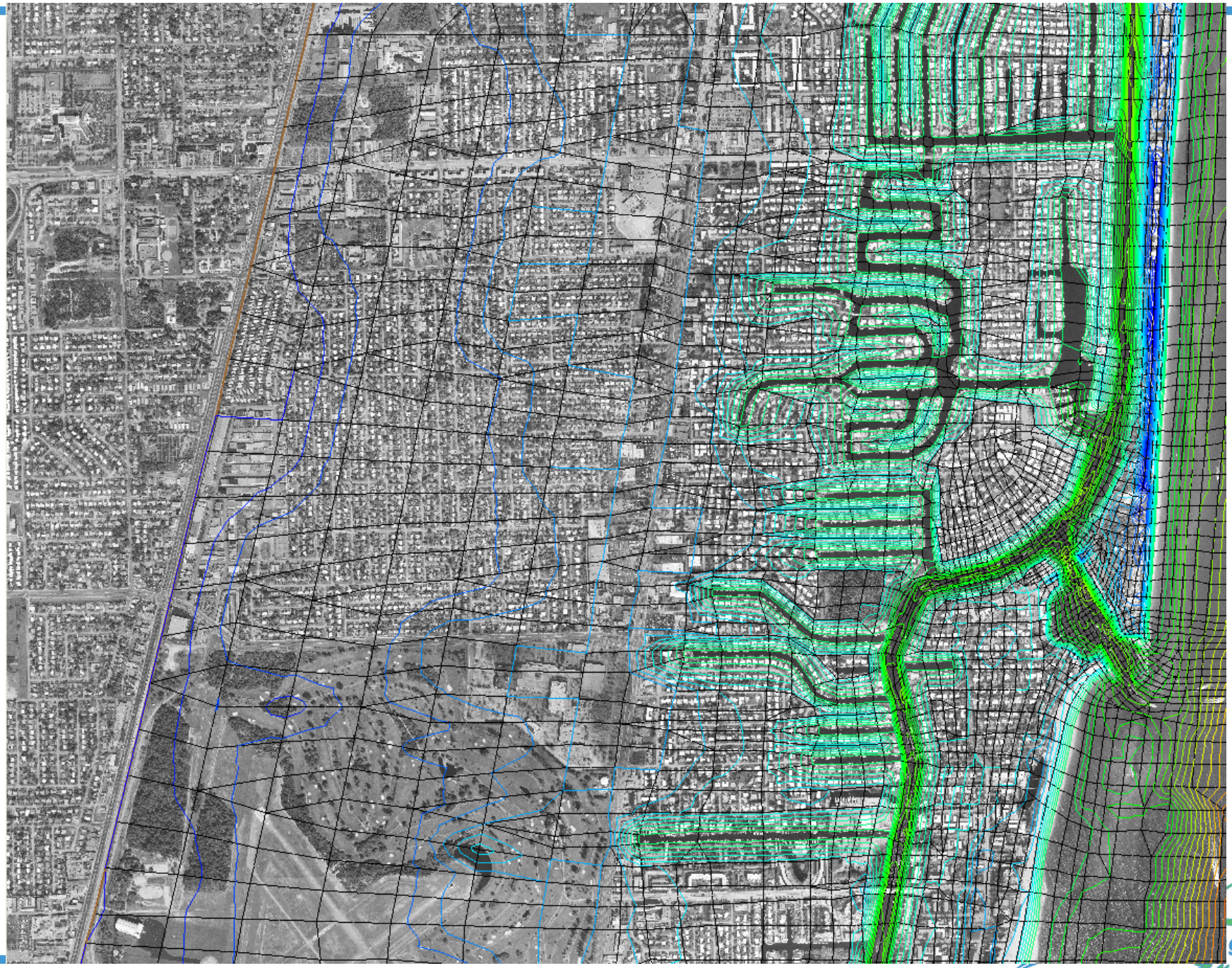
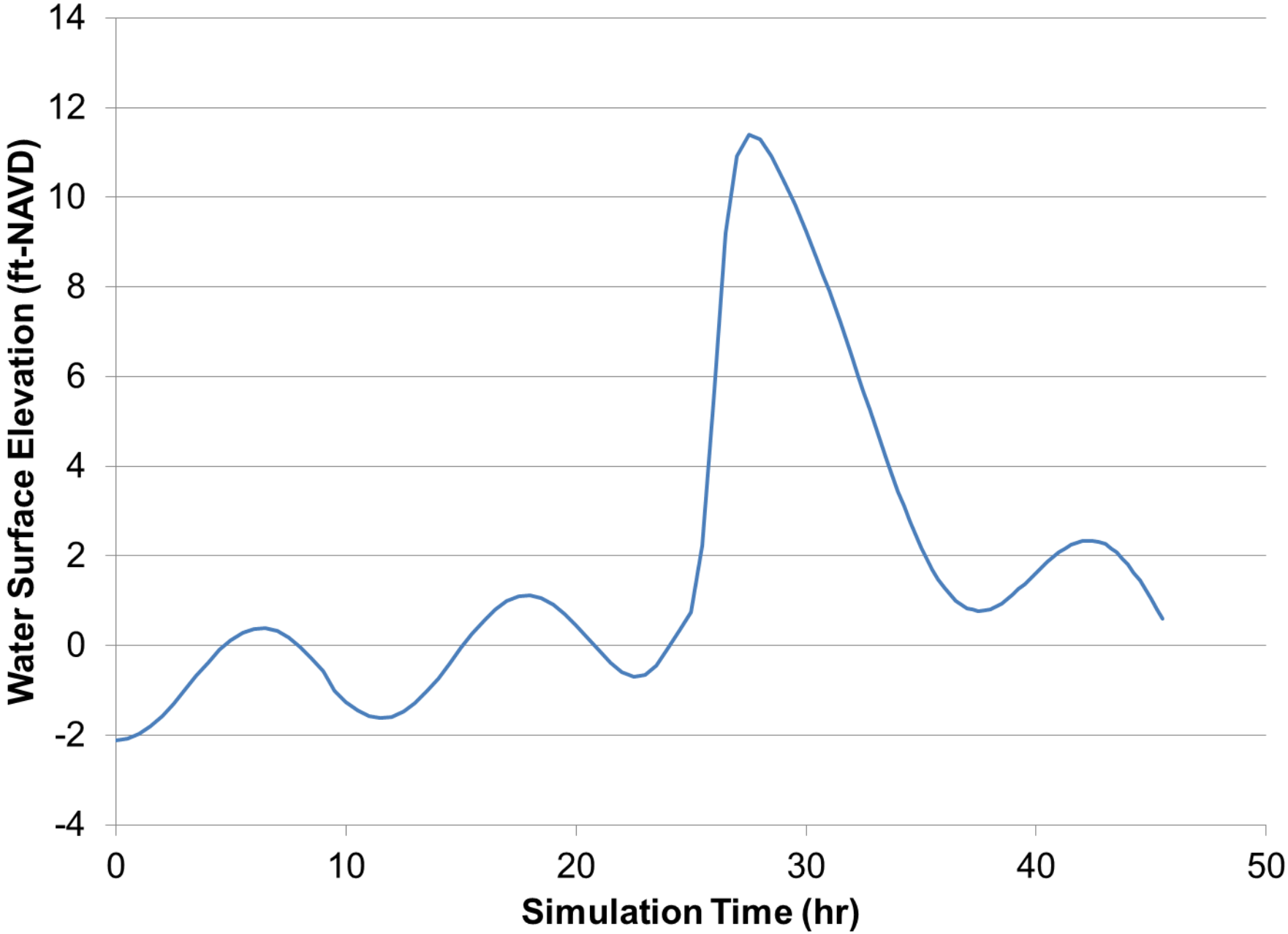
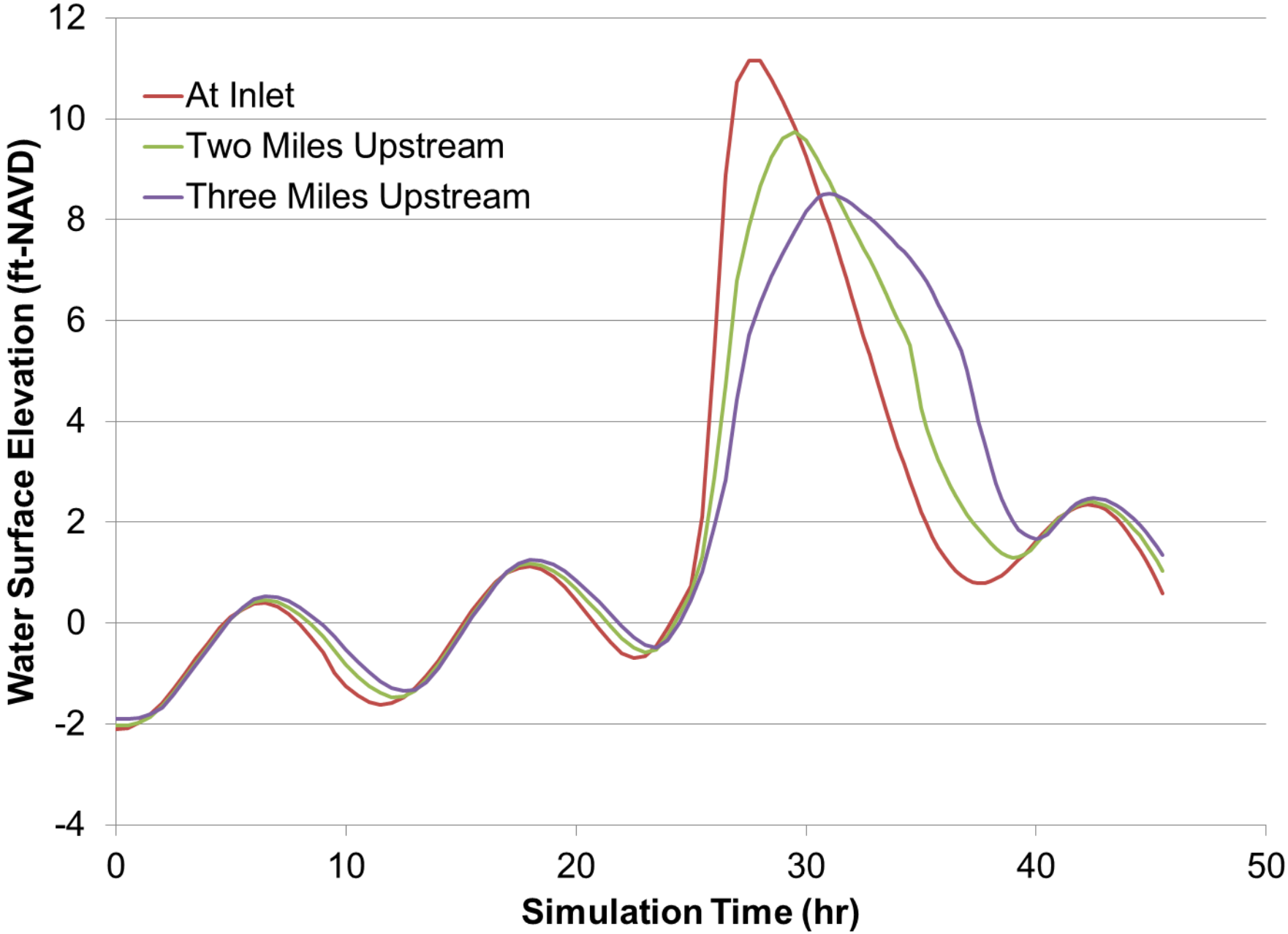



Water Surface Elevation (ft-NAVD)
14
12
10
8
6
4
2
0
-2
-4
0
10
20
30
40
50
Simulation Time (hr)


At Inlet
Two Miles Upstream
Three Miles Upstream
Water Surface Elevation (ft-NAVD)
Simulation Time (hr)
12
10
8
6
4
2
0
-2
-4
0
10
20
30
40
50

Pensacola

I-10 Bridge
US-98 Bridge
Brosnaham Island
Pace
Caroline St
Bagdad
Noriegas Island
N Palafox Rd
W 9 Mile Rd
E 9 Mile Rd
Blackwater Bay
Escambia Bay
Avalon Blvd
Brent
Bellview
Youngs Har
Bayou Texar
West Pensacola
Pensacola
Pensacola Bay
East Bay
Santa Ro
Santa Rosa Island
Lillian
Lillian Hwy
Warrington
Butcherpen Cove
Bayou Grande
Gulf Breeze
S Blue Angel Pkwy
Sorrento Rd
Robertson Island
Big Lagoon
De Luna Dr

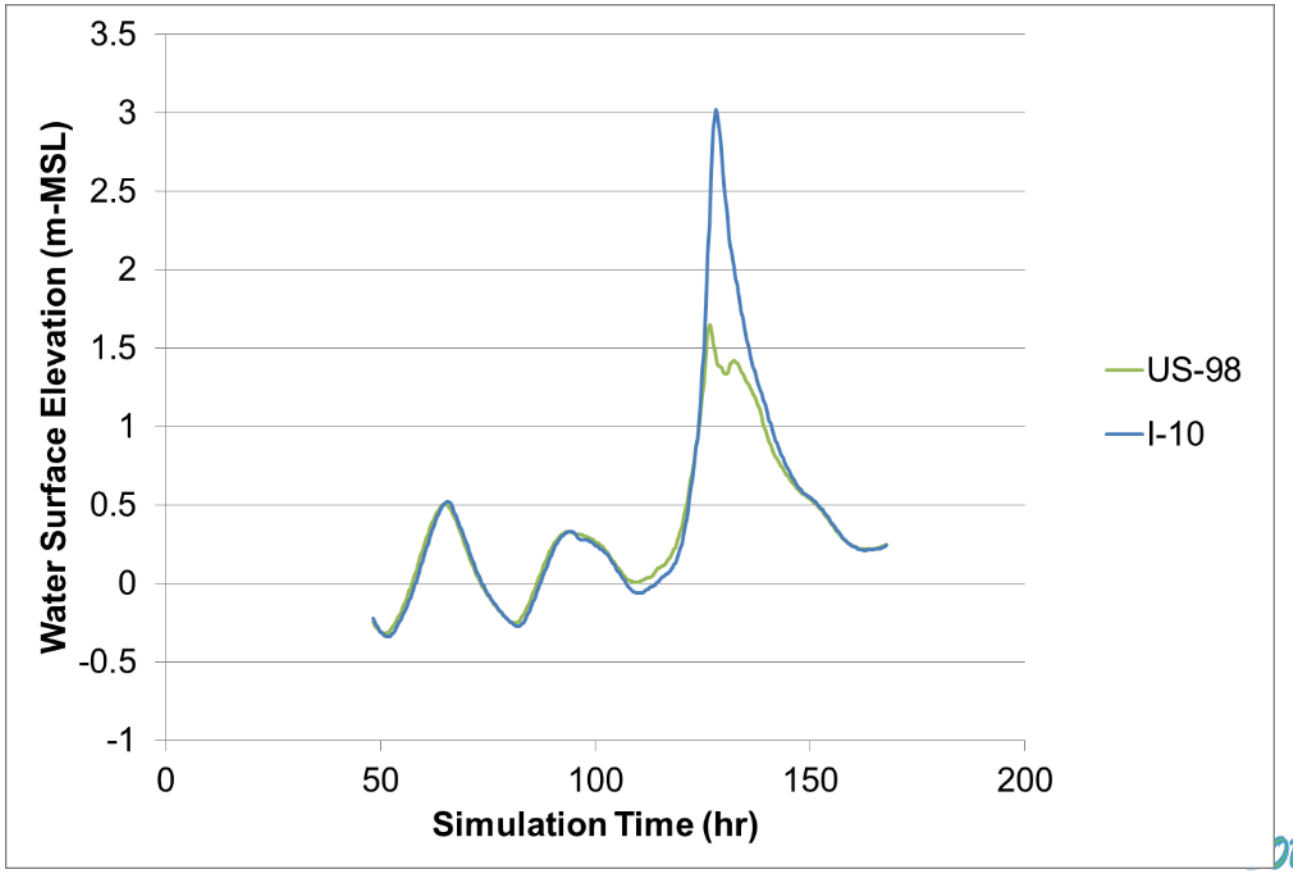
Hurricane Ivan – Case Study

Hurricane Ivan – Case Study

Hurricane Ivan Hindcast

- ADCIRC
- SWAN
- Boundary conditions
  - Tidal potentials
  - Hurricane Ivan meteorological hindcast
    - Spatially and temporally varying
    - Wind and pressure fields
  - “Blanked” the wind for interior waterways

Hurricane Ivan Hindcast



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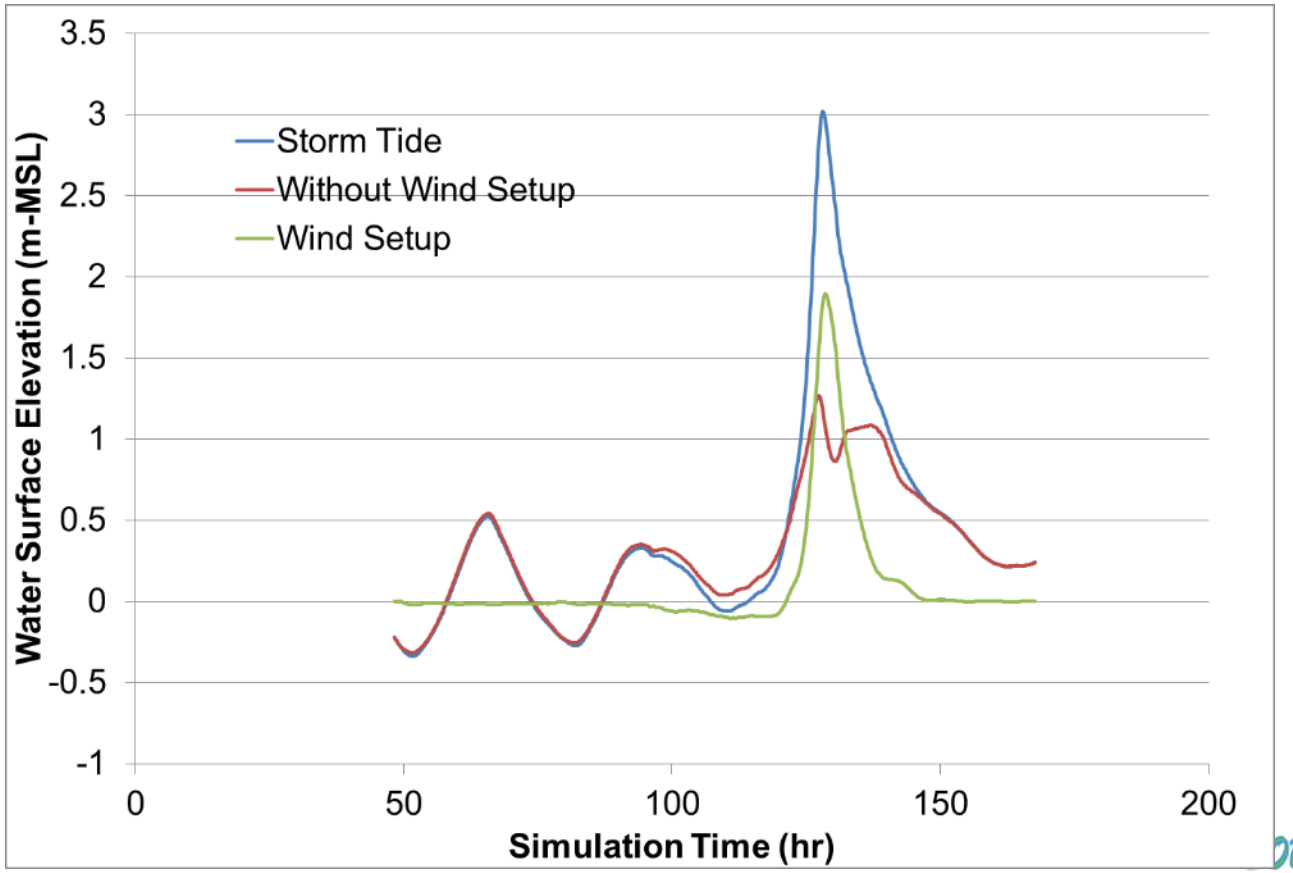
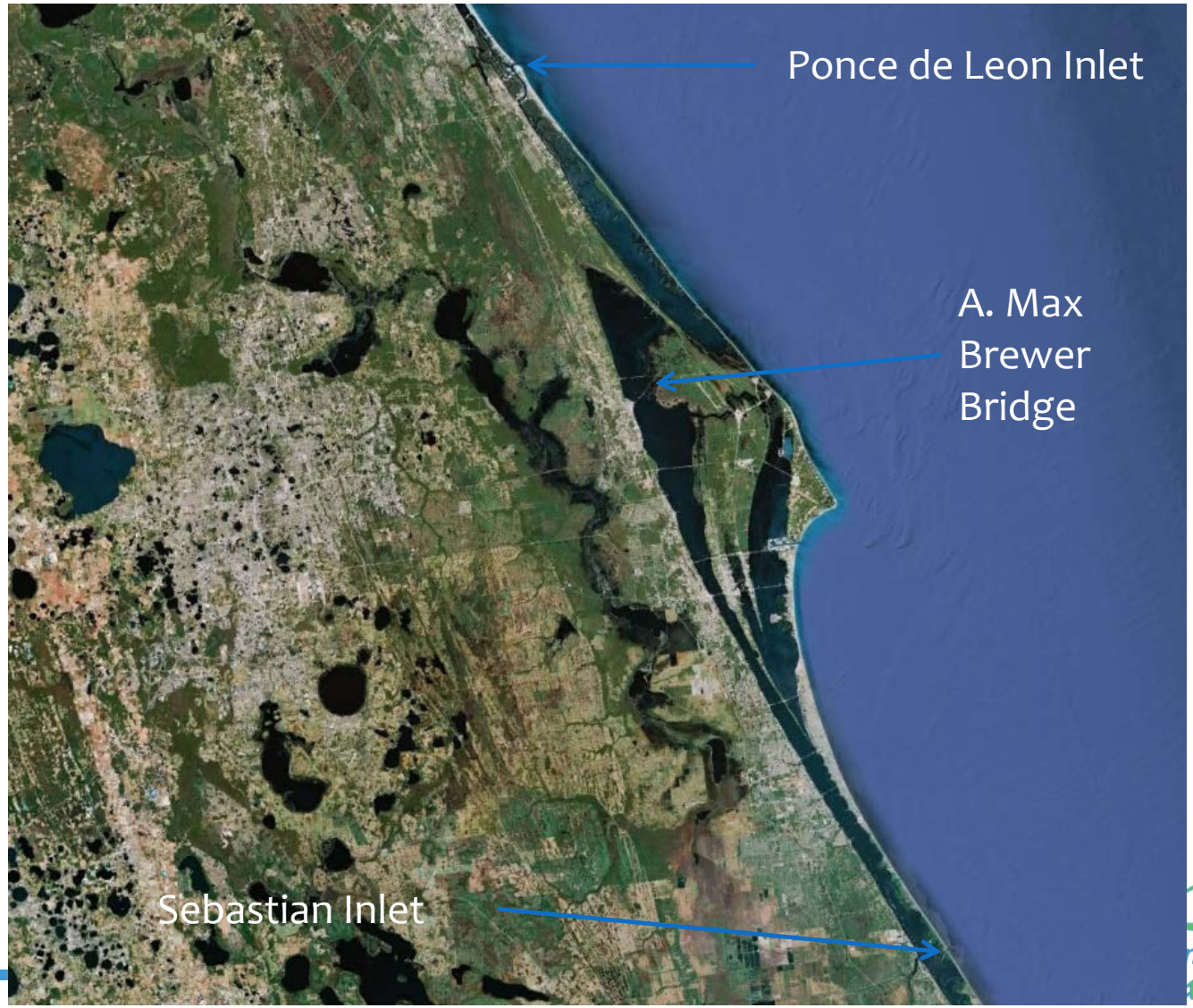
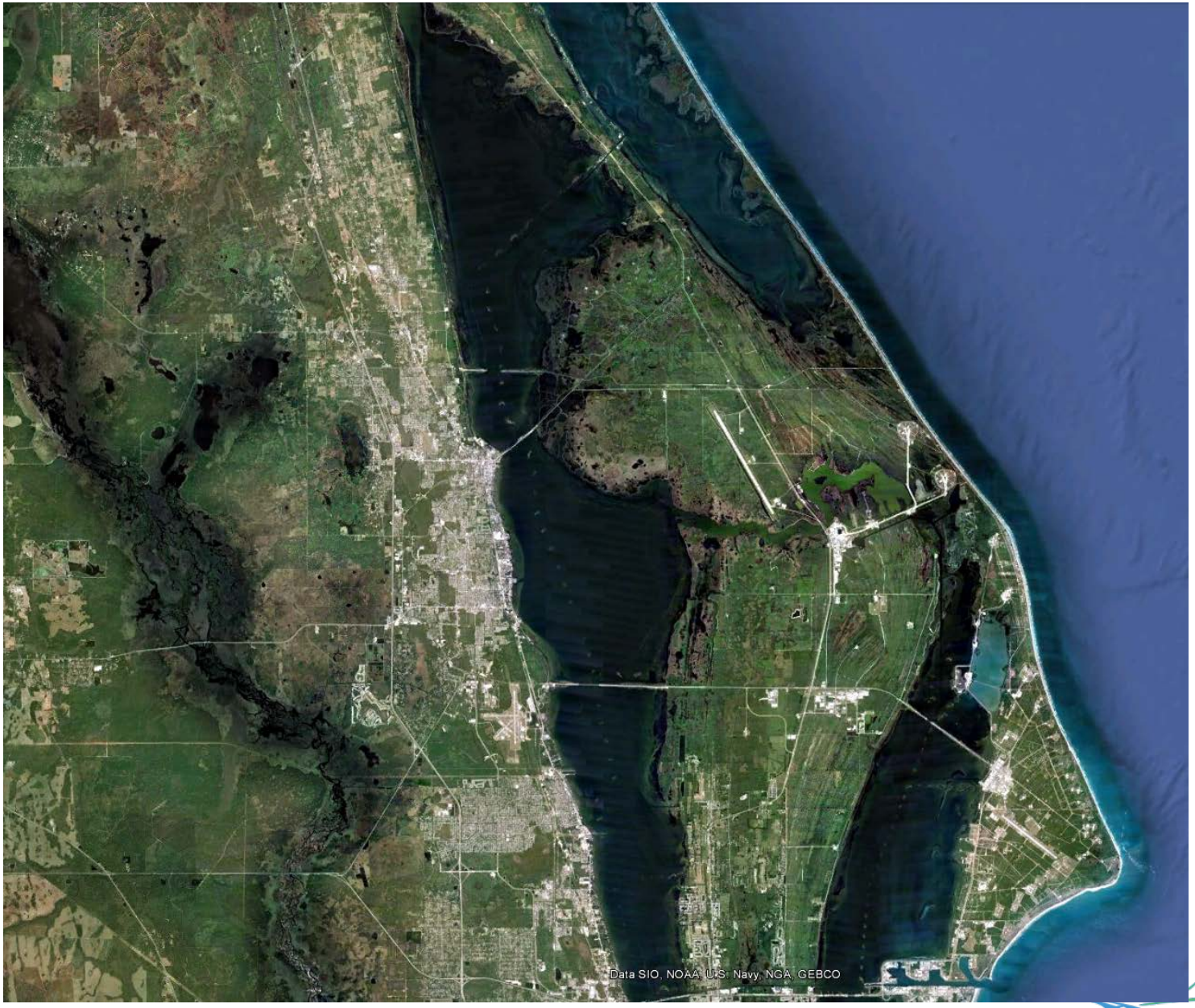
Surge at I-10


Storm Tide
Without Wind Setup
Wind Setup
Water Surface Elevation (m-MSL)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
Simulation Time (hr)

Indian River Lagoon - Case Study



Indian River Lagoon - Case Study



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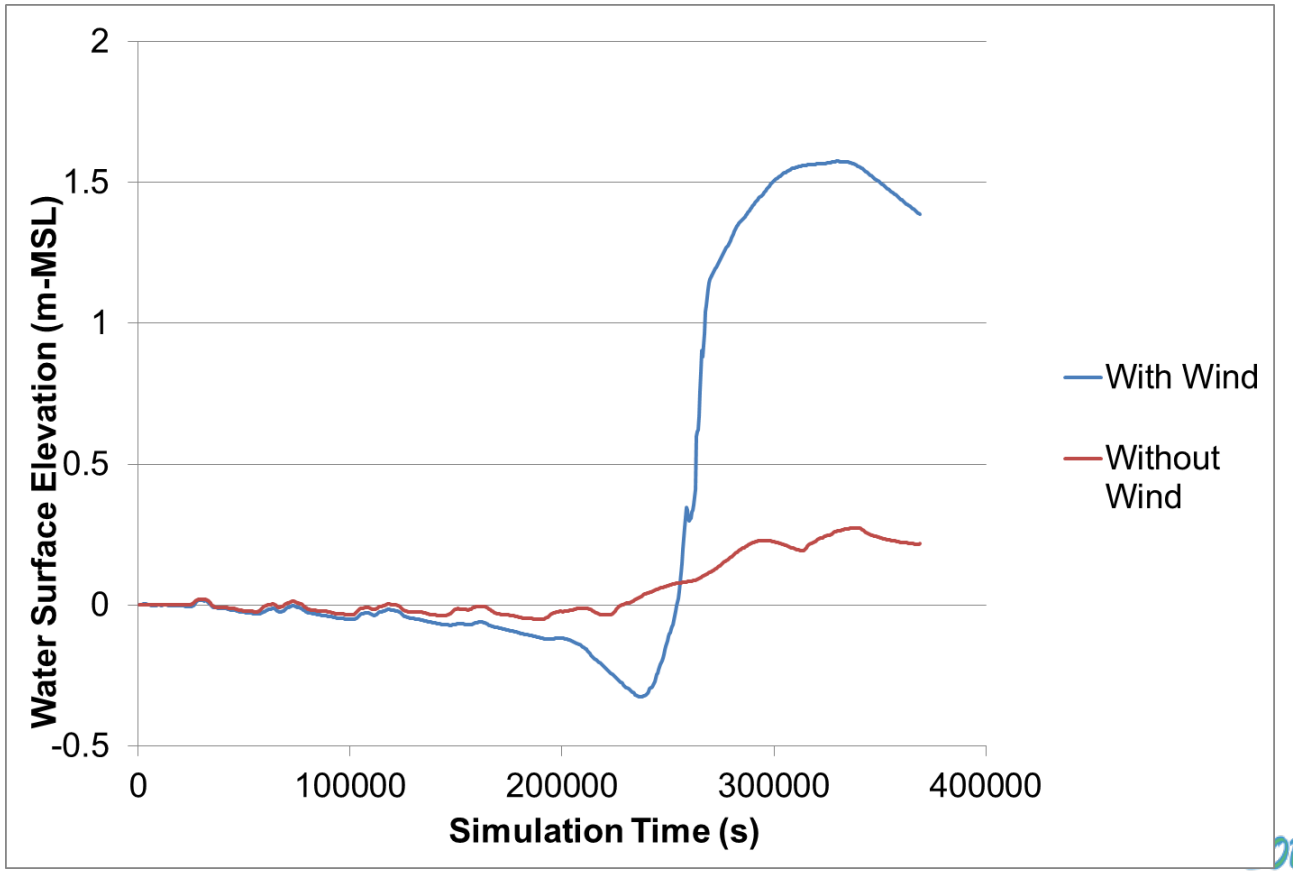
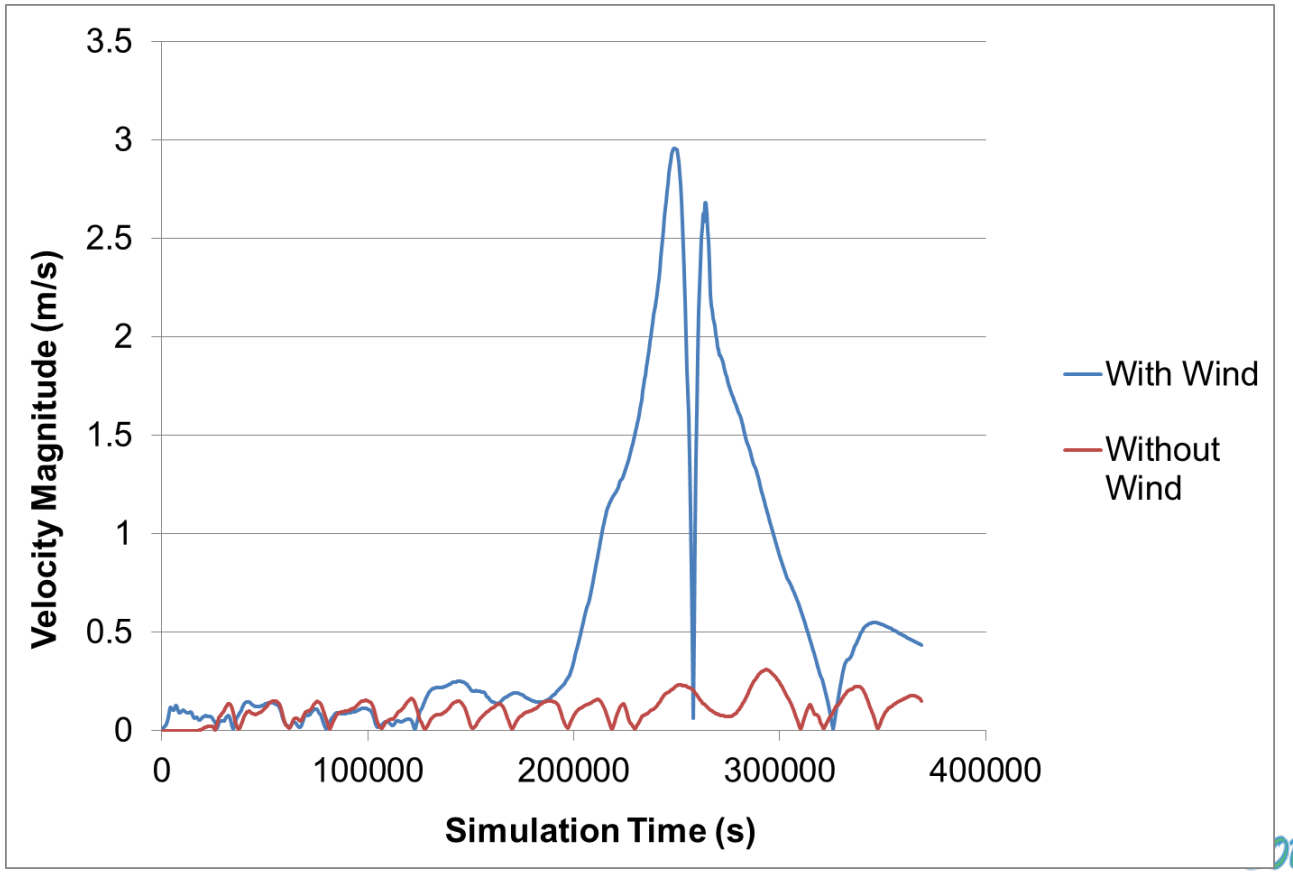
Design Simulation

- ADCIRC
- Boundary conditions
  - Open coast - FDEP storm surge
  - Temporally varying spatially constant wind boundary condition
    - Magnitude and direction from Hurricane Frances (2004)
    - Amplified to match 100- and 500-year wind speeds
    - Very conservative!

Surge at A. Max Brewer Bridge



Velocities at A. Max Brewer Bridge



Wave Climate and Forces

- Design waves generated by hurricane winds
  - Open coast
  - Interior waterways
- Wave loading
  - Superstructures
  - Substructures
- Erosion
  - Shorelines – coastal roadways
  - Abutments

Wave Induced Damage

- Storm surge and wave damage in Gulf of Mexico states
  - I-10, Escambia Bay (Pensacola, FL)
  - US-90, Biloxi Bay (Biloxi, MS)
  - US-90, Saint Louis Bay (Bay Saint Louis, MS)
  - I-10, Lake Pontchartrain (New Orleans, LA)

Bridge Failures

I10 Bridges over Lake Pontchartrain
New Orleans, LA

Bridge Failures

Pensacola, FL

Bay Saint Louis, MS

Biloxi, MS

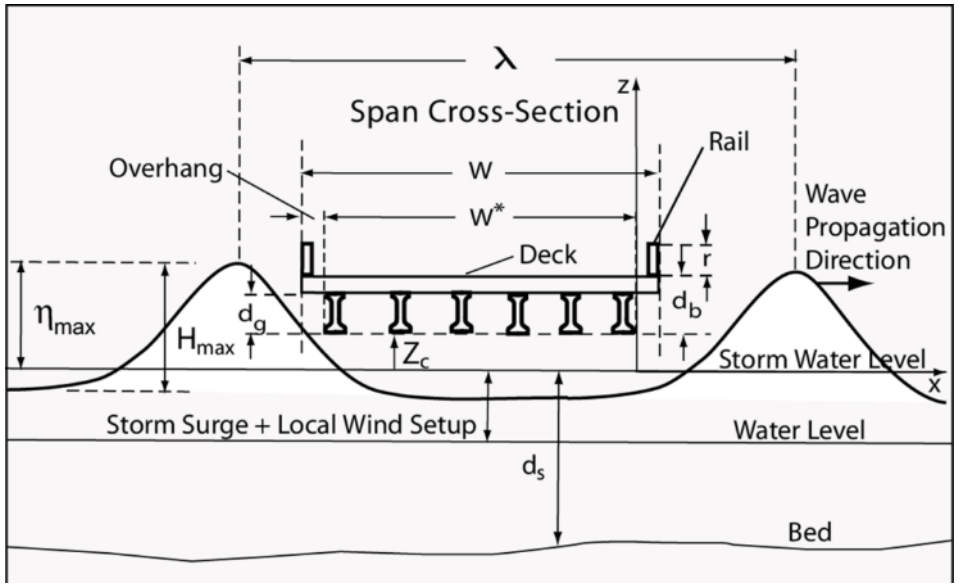
Biloxi, MS

Bridge Failures

- Bridge failures attributed to storm surge and wave loading on bridge superstructures
- FHWA-AASHTO study to develop methods for predicting surge/wave forces and moments on bridge superstructures
  - Resulted in AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms

Information Needed for Surge/Wave Force Prediction

- Met/Ocean Conditions
  - Water elevation
  - Water depth
  - Wave parameters
    - Significant wave height
    - Peak period
    - Maximum wave height
- Structure parameters
  - Bridge dimensions
  - Span low chord elevation



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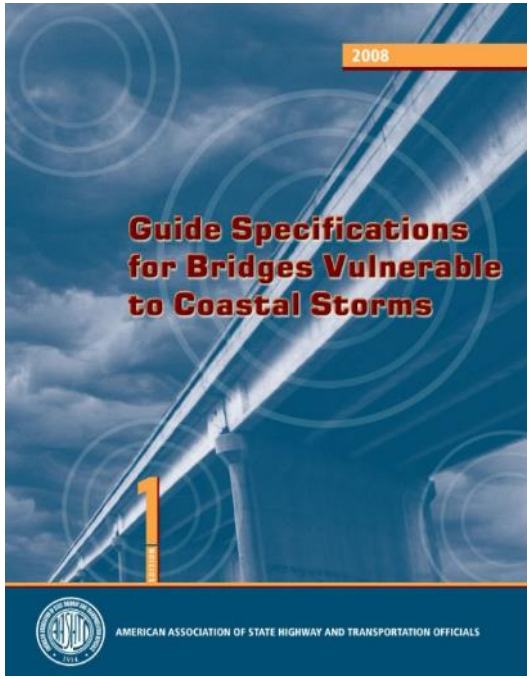
Met/Ocean Conditions

- Three levels of analysis identified in the AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms:

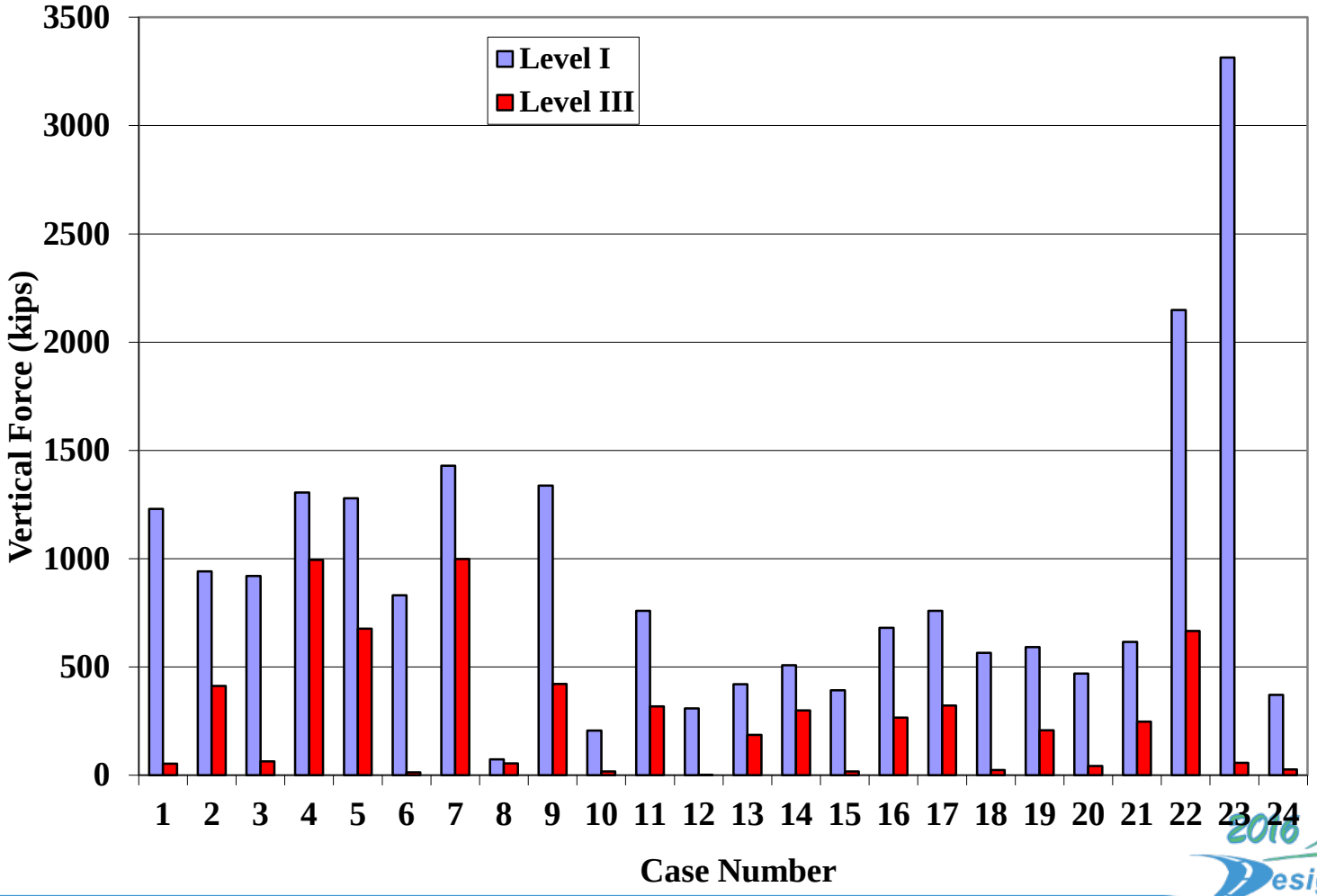


Met/Ocean Conditions

- Three levels of analysis:
  - Level I – Use existing information, FEMA/other storm surge elevation, empirical equations for computing wave heights and periods
  - Level II – Use improved methods to refine storm surge and wave conditions (may employ computer models for surge and/or waves)
  - Level III – More detailed analysis that typically includes hurricane hindcasting

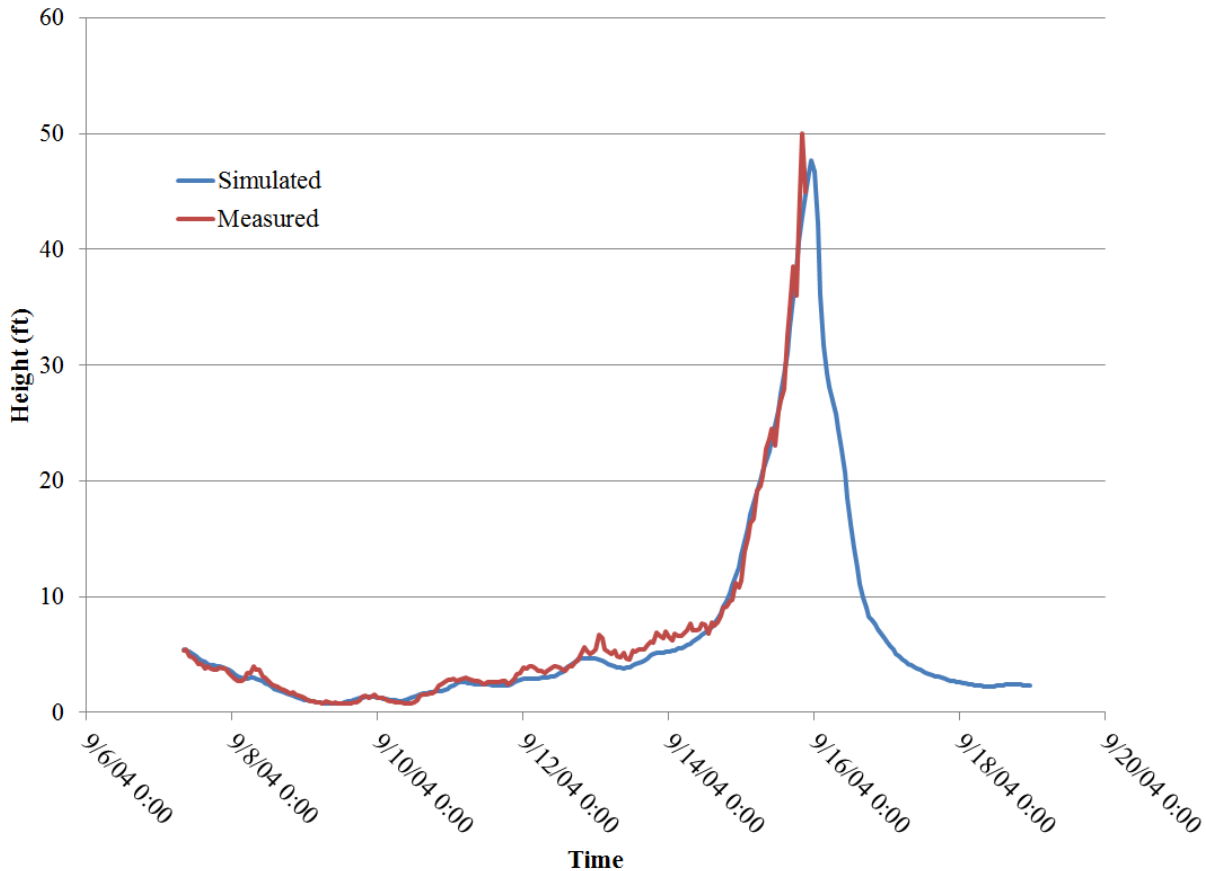
Level of Analyses Comparisons

Example Florida Pilot Study Results



Wave Modeling

NDBC Gage 42042 During Hurricane Ivan



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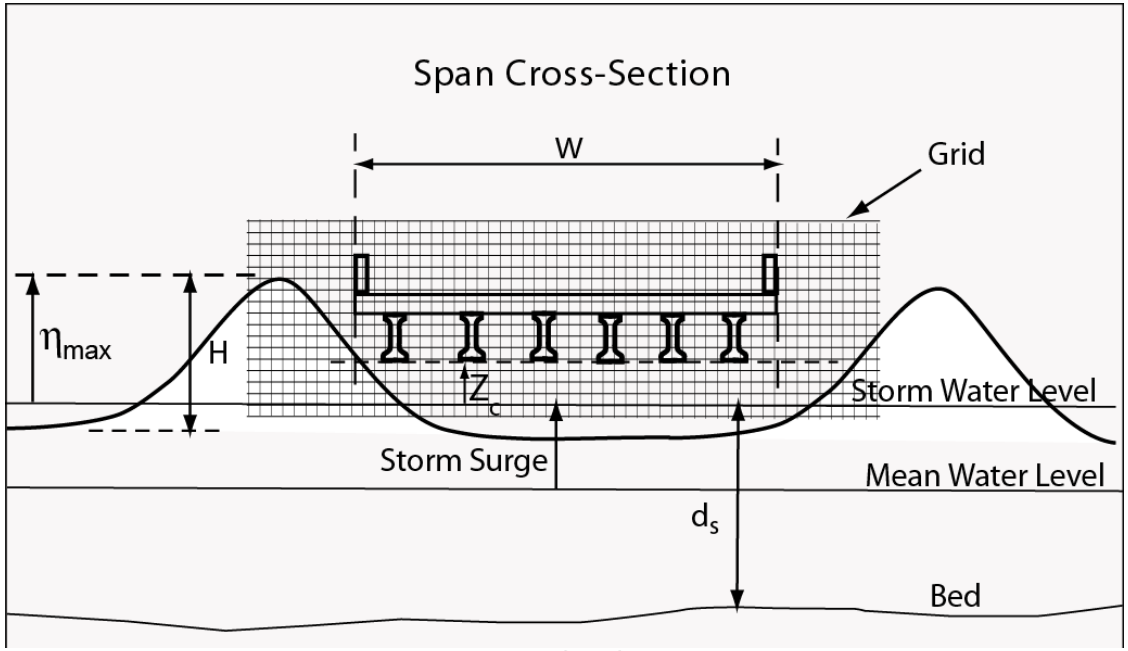
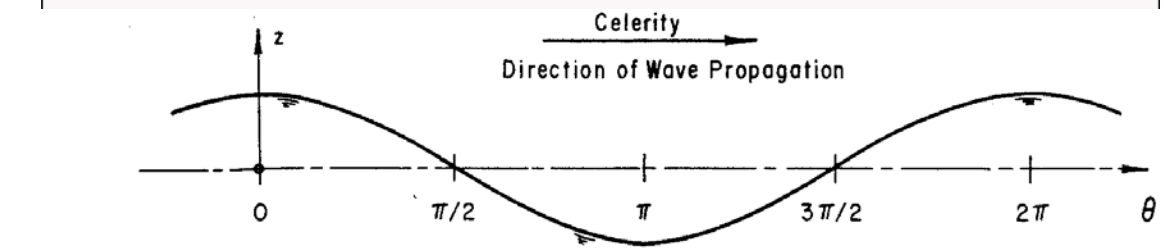
Definition Sketch





Velocity	u = +; w = 0	u = 0; w = +	u = −; w = 0	u = 0; w = −	u = +; w = 0
Acceleration	$a_x = 0$; $a_z = -$	$a_x = +$; $a_z = 0$	$a_x = 0$; $a_z = +$	$a_x = -$; $a_z = 0$	$a_x = 0$; $a_z = -$

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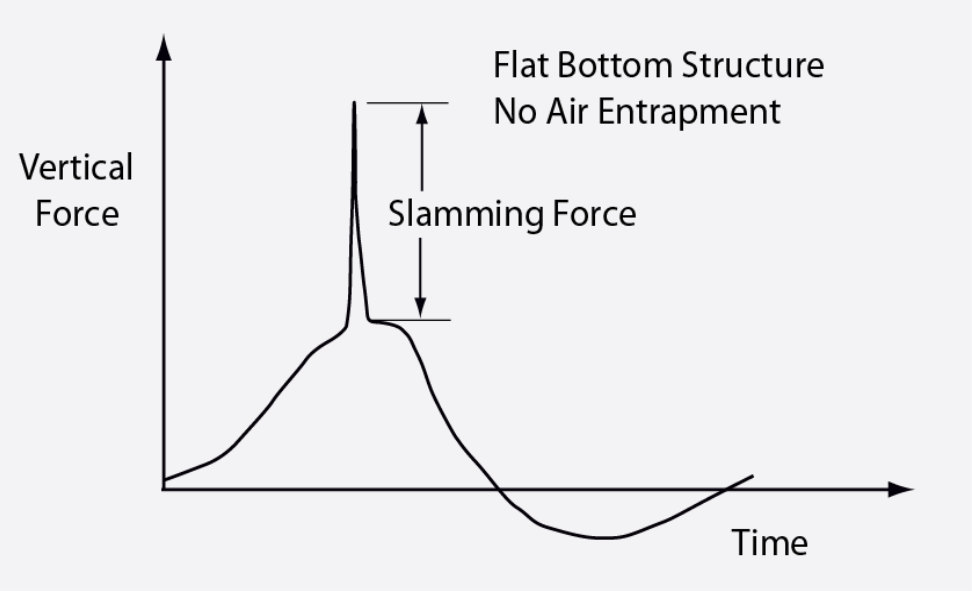
Wave Forces

- Quasi Static Force
  - Buoyancy
  - Added mass
  - Change in added mass
  - Drag force
- Slamming force
  - Different for slab and beam bridges
- Load Factors
  - Extremely critical - strength limit state - 1.75
  - Critical - extreme event limit state 1.0



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Wave Force Takeaways

- What's critical?
  - Owner decides criticality of the bridge
- Get High!
  - One foot above maximum wave crest elevation
  - The higher the better (in general)
- Don't Float!
  - Flat slabs reduce buoyancy forces
  - Venting – height of diaphragm

FEMA

- Flood maps and FIS are resources for determining surge or riverine dominance for stage
  - Surge may dominate design stage, but runoff may dictate scour conditions
  - Storage
- Regulated Floodways - No-rise Certification
  - In areas subject to storm surge, “normal” construction will not increase BFE’s
    - Surge vs. riverine flood thinking
  - Still need to check backwater effects for riverine flooding

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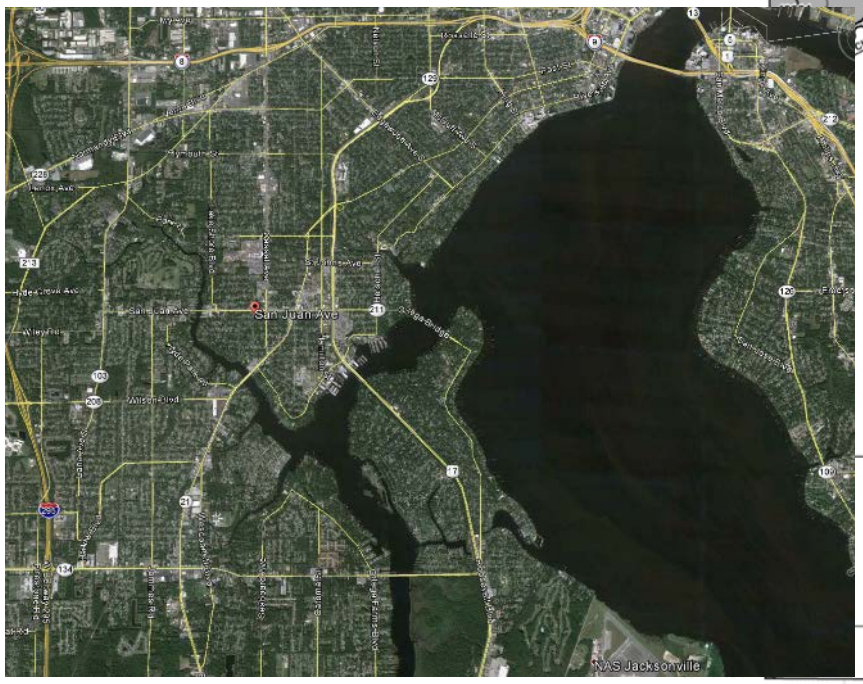
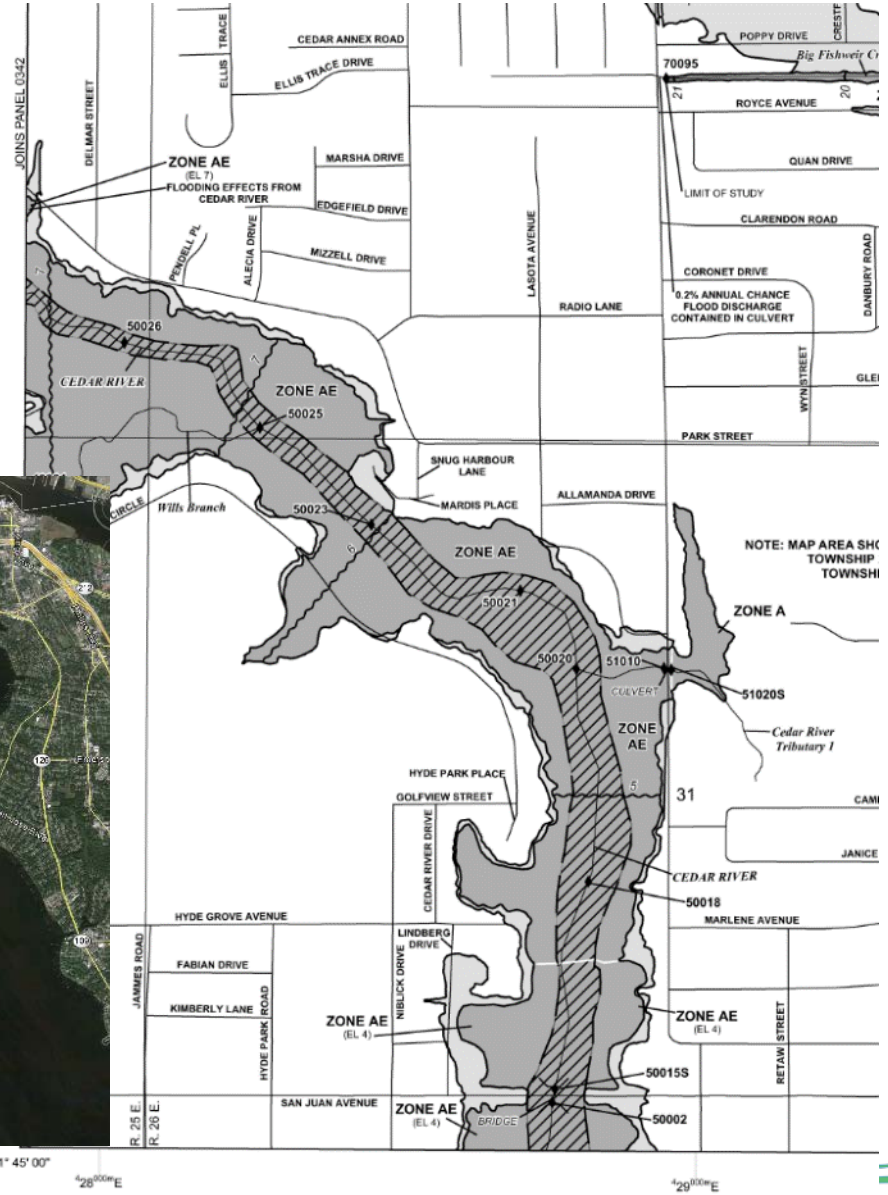
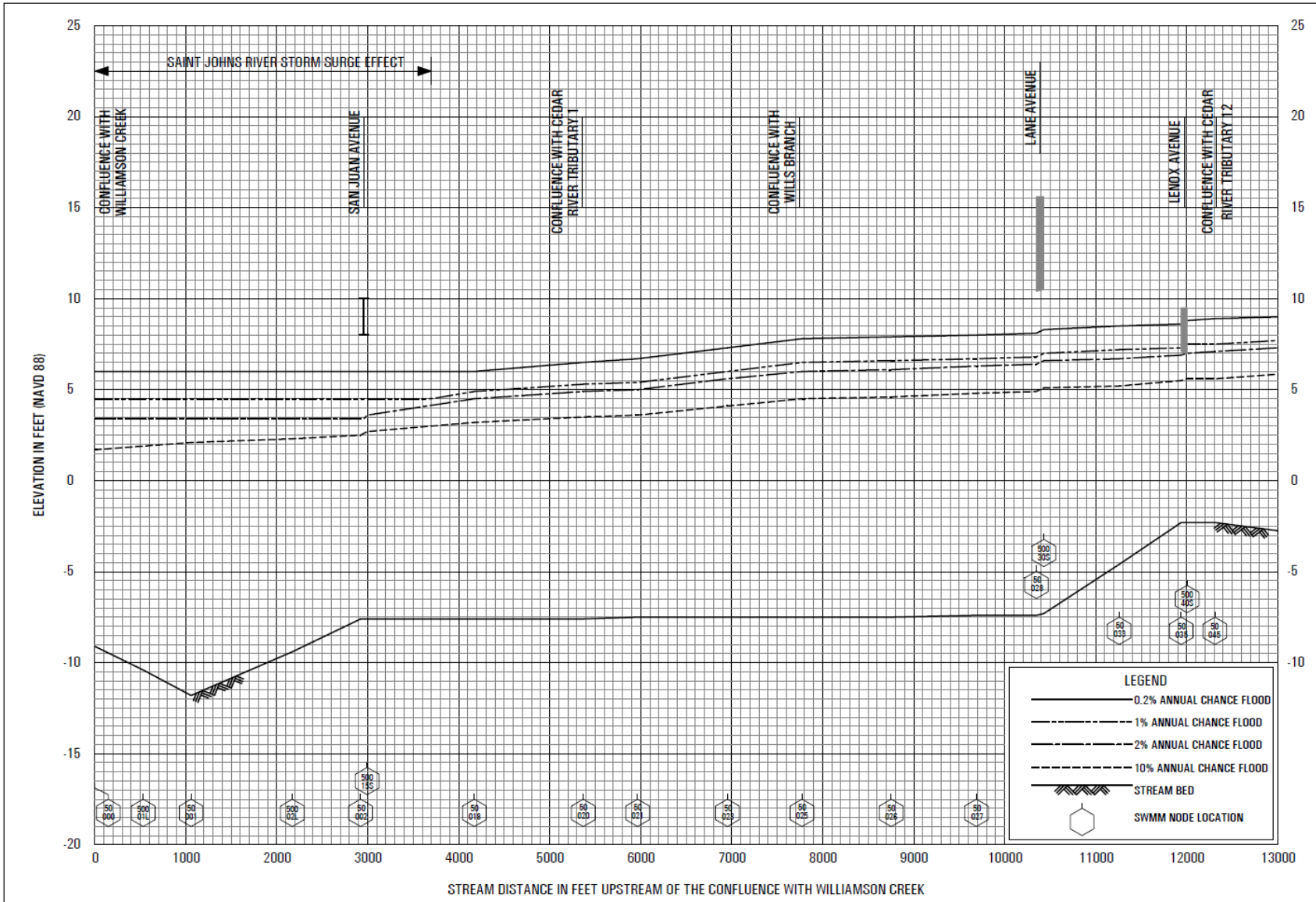
- Cedar River


San Juan Ave
NAS Jacksonville


JOINS PANEL 0342
DELMAR STREET
ELLIS TRACE
CEDAR ANNEX ROAD
ELLIS TRACE DRIVE
POPPY DRIVE
Big Fishweir Cr
70095
ROYCE AVENUE
QUAN DRIVE
LIMIT OF STUDY
CLARENDON ROAD
ZONE AE
(EL 7)
FLOODING EFFECTS FROM CEDAR RIVER
MARSHA DRIVE
EDGEFIELD DRIVE
MIZZELL DRIVE
PENDELL PL
ALECIA DRIVE
LASOTA AVENUE
RADIO LANE
CORONET DRIVE
0.2% ANNUAL CHANCE FLOOD DISCHARGE CONTAINED IN CULVERT
DANBURY ROAD
WYN STREET
50026
CEDAR RIVER
ZONE AE
50025
PARK STREET
SNUG HARBOUR LANE
MARDIS PLACE
ALLAMANDA DRIVE
Wills Branch
50023
ZONE AE
50021
NOTE: MAP AREA SHO
TOWNSHIP
TOWNSHI
ZONE A
50020
51010
CULVERT
51020S
ZONE AE
Cedar River Tributary 1
HYDE PARK PLACE
GOLFVIEW STREET
31
CAMI
JANICE
CEDAR RIVER DRIVE
CEDAR RIVER
50018
HYDE GROVE AVENUE
MARLENE AVENUE
JAMMES ROAD
LINDBERG DRIVE
FABIAN DRIVE
KIMBERLY LANE
HYDE PARK ROAD
NIBLICK DRIVE
ZONE AE
(EL 4)
ZONE AE
(EL 4)
RETAW STREET
50015S
SAN JUAN AVENUE
ZONE AE
(EL 4)
BRIDGE
50002
R. 25 E.
R. 26 E.
81° 45' 00"
E
E



FLOOD PROFILES

CEDAR RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

DUVAL COUNTY, FL

(ALL JURISDICTIONS)

26P

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Shoreline/Abutment Protection

- Shoreline erosion
  - Coastal highways
- Abutment protection
  - Bank and Shore riprap
  - Coastal riprap
- Designing protection for waves
  - Height, Period, Slope
  - USACE Coastal Engineering Manual
  - Take a regional view

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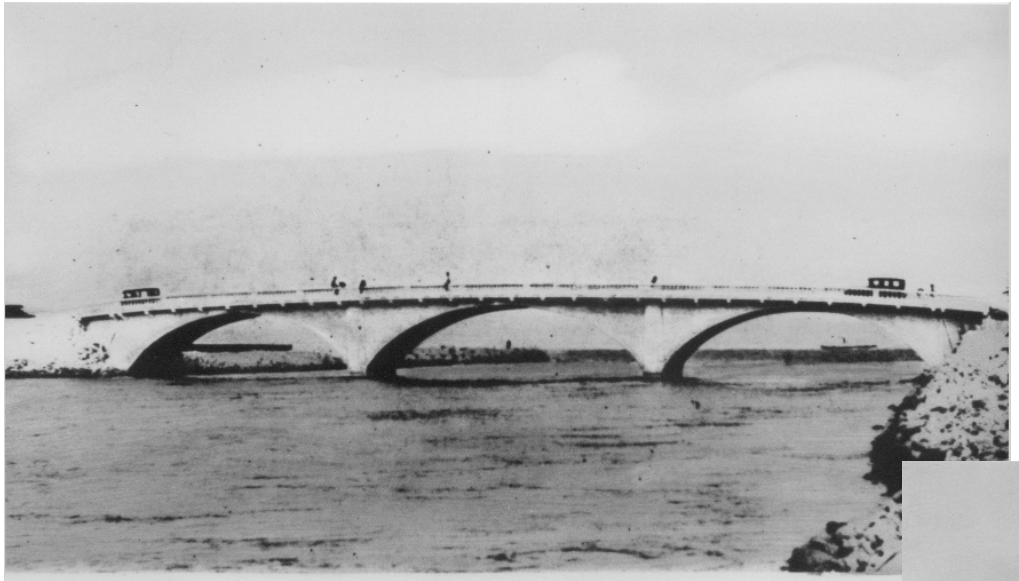
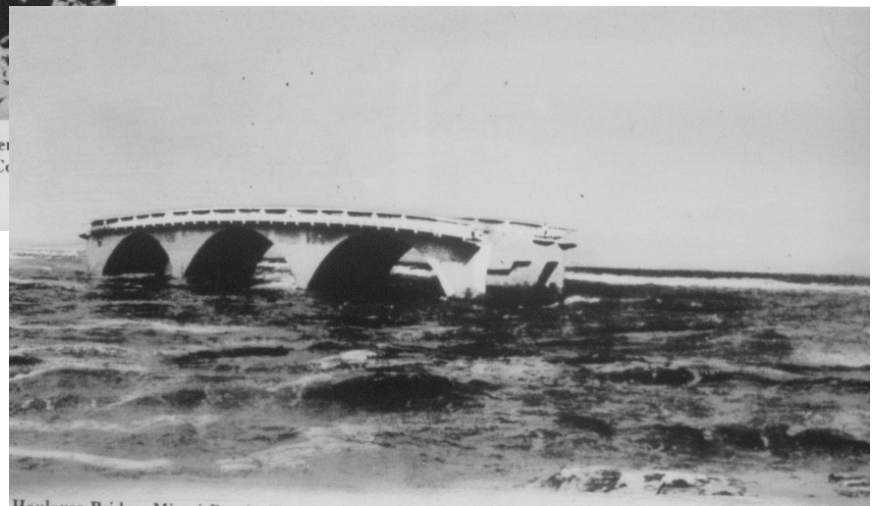
Baker's Haulover Bridge



aker's Haulover Bridge, Miami Beach, Florida, before the storm. Three spans of 61, 70 and 61 feet, total le
Of Luten design, erected by Luten Bridge Company for the Board of Commissioners of Dade C
Miami, Florida, in 1924. Ocean vessel visible under right span.



Haulover Bridge, Miami Beach, Florida, after the storm. The roadway and shore protected by rock jetties an
sheet piling visible through the left span on page 4, have all been washed away to a width of 800 feet
but leaving the bridge standing in its original location, with no damage.

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Questions/Comments?

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