2023 COASTAL MASTER PLAN
*COMMITTED TO OUR COAST*

# TECHNICAL MODELING WORKSHOP

**STUART BROWN, ERIC WHITE, ZACH COBELL, AND DAVID JOHNSON**

**JUNE 16, 2020**

## OVERVIEW

- Outline for today's webinar
  - Introduction – 1:00 pm
  - ICM - 1:10 pm
  - Break - 2:30 pm
  - Storm Surge and Waves Modeling - 2:35 pm
  - Risk Assessment - 3:05 pm

- Additional opportunities for information
  - Follow-up webinars on models and the modeling process (through early 2021)
    - Survey after today's webinar requesting feedback on topics to cover
  - Future webinars on model outputs, project selection, etc. (2021-2023)

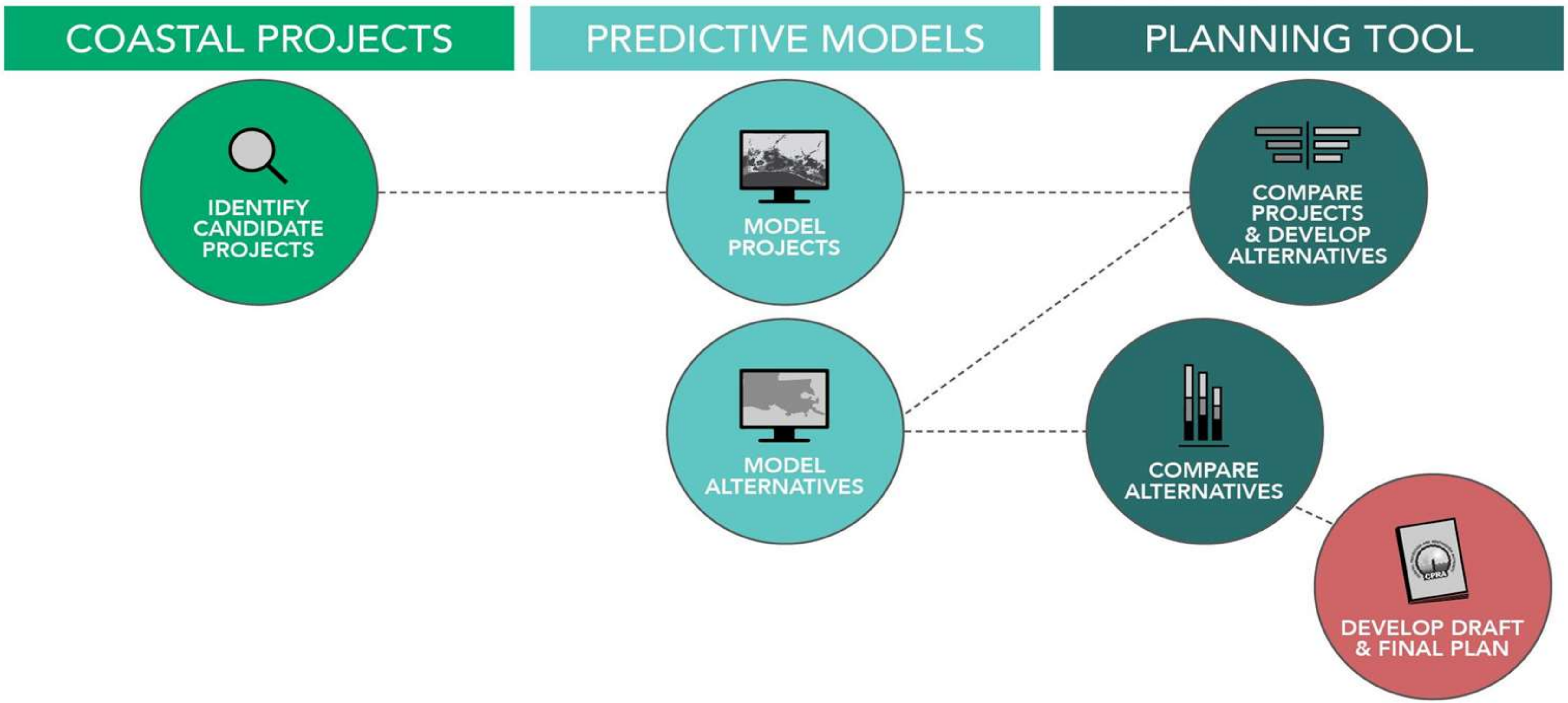
# INTRODUCTION

# WHAT IS THE COASTAL MASTER PLAN?

- Required by law to be updated every six years
- Built on world class science and engineering
- Incorporates extensive public input and review
- Advances a comprehensive and integrated approach to protection and restoration
- Identifies investments that will pay off, not just for us, but for our children and grandchildren


2007, 2012, AND 2017 COASTAL MASTER PLANS

# PROCESS FOR PLAN DEVELOPMENT



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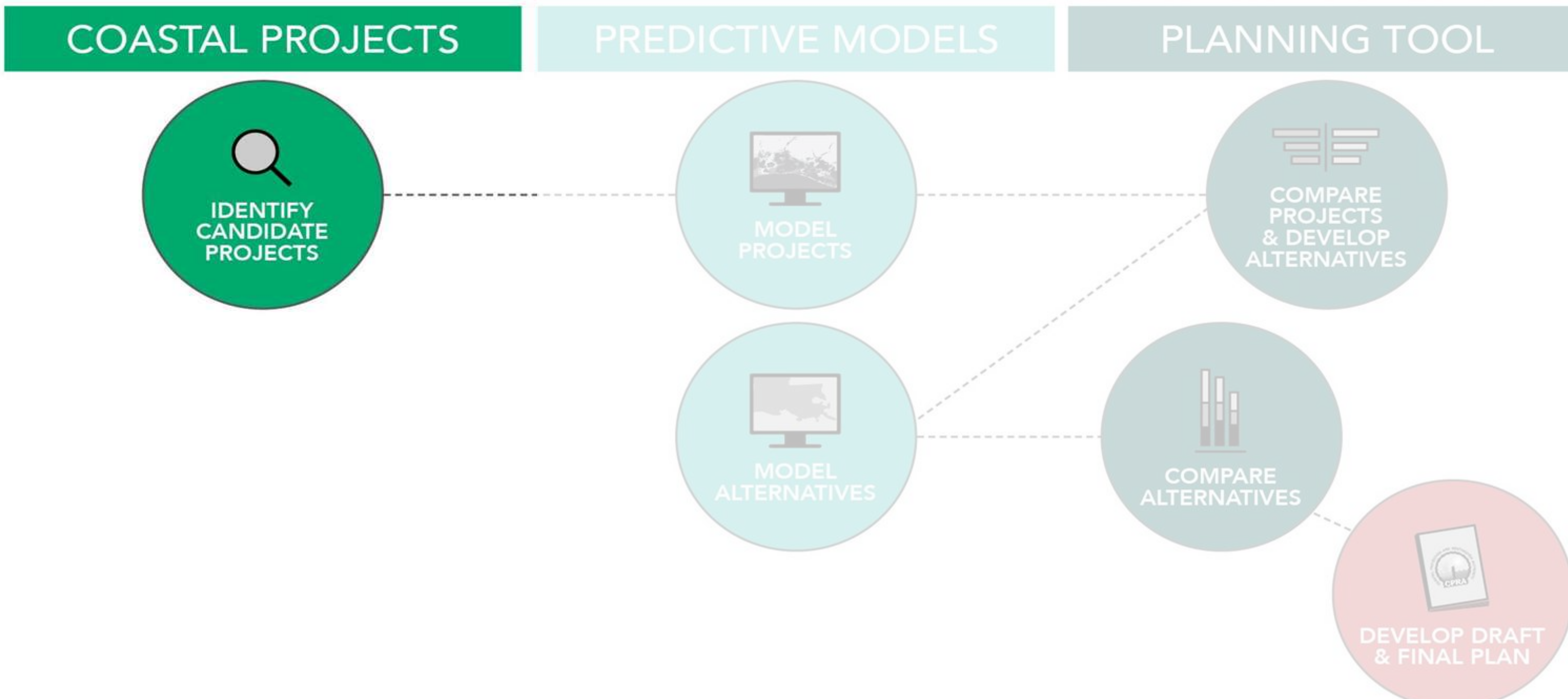
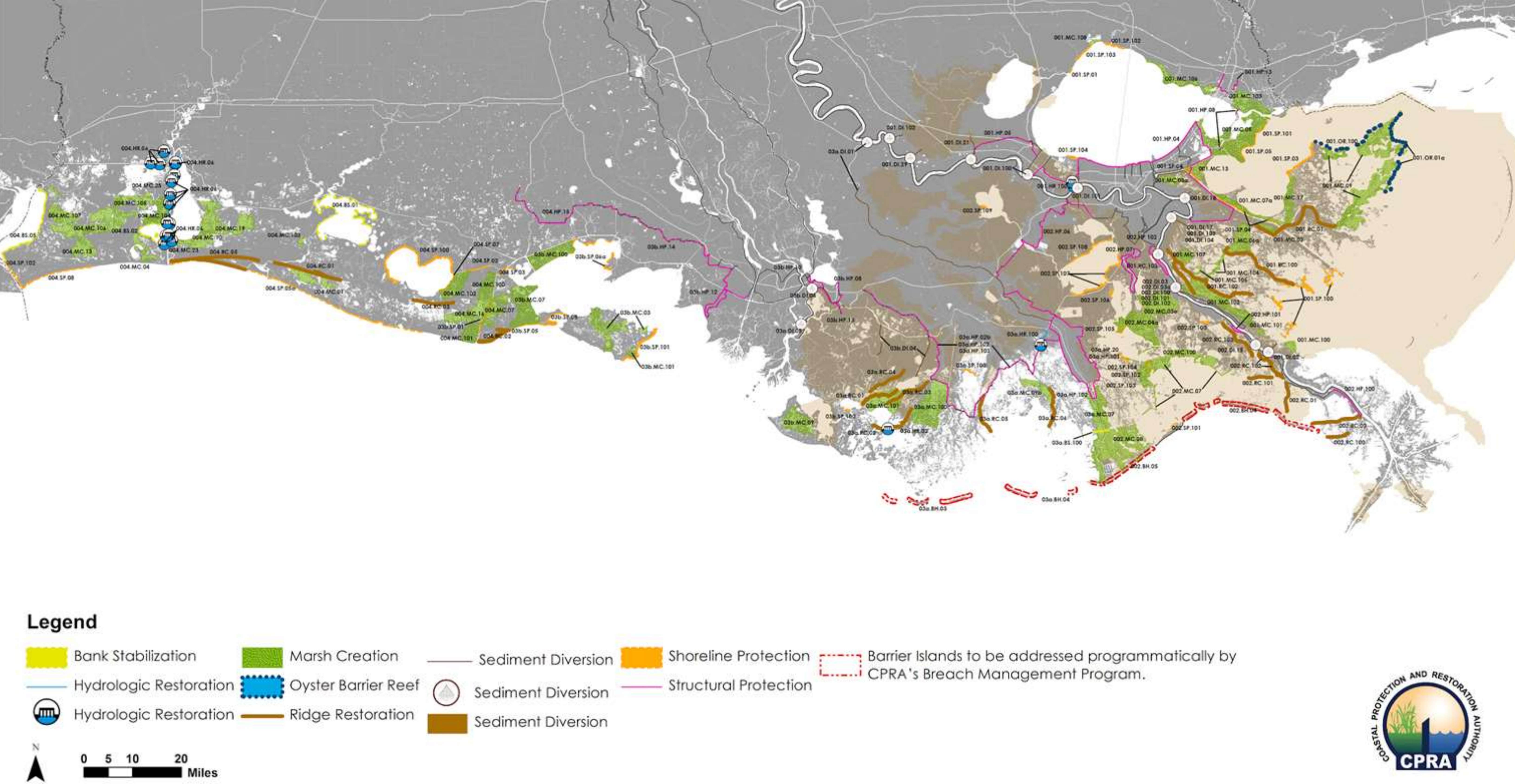
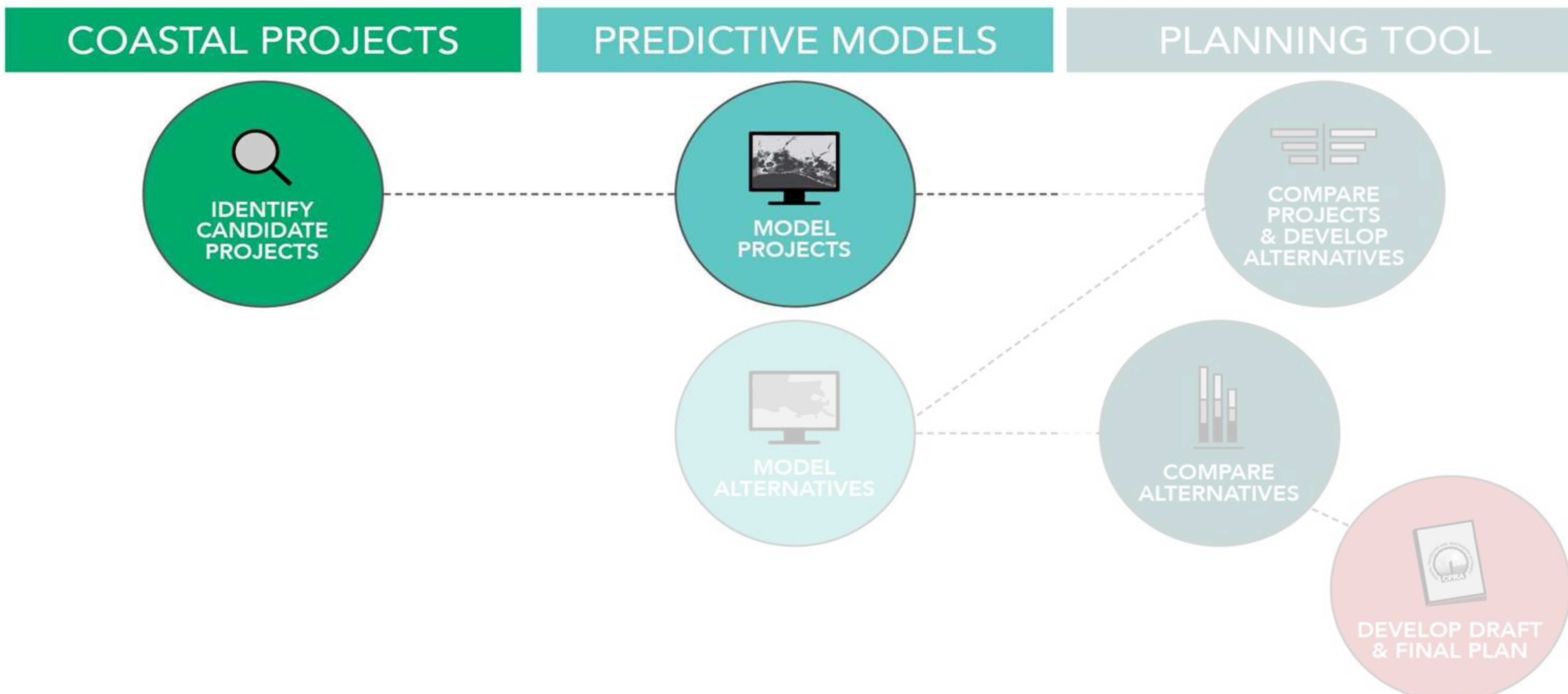


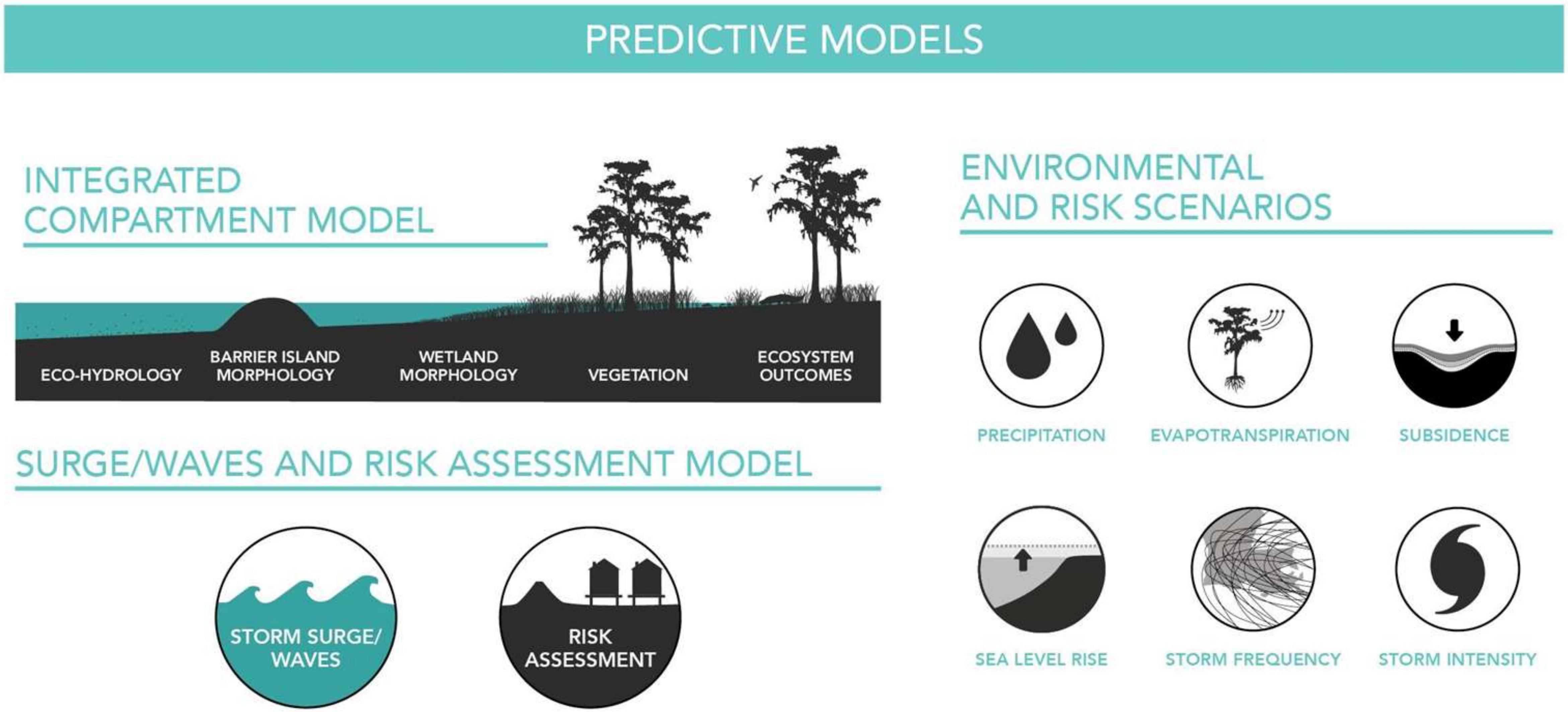



# 2017 MASTER PLAN CANDIDATE PROJECTS

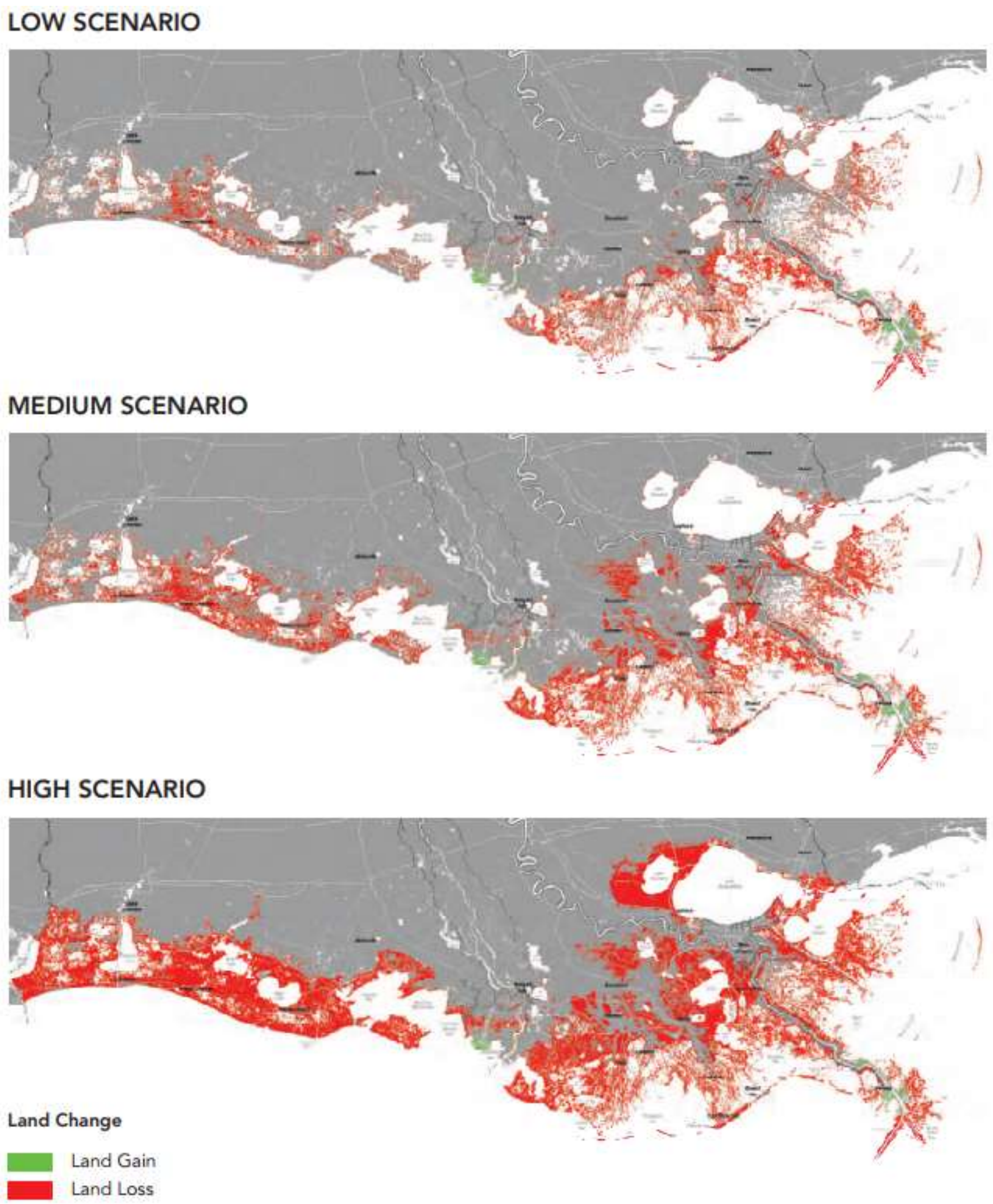
# PROCESS FOR PLAN DEVELOPMENT

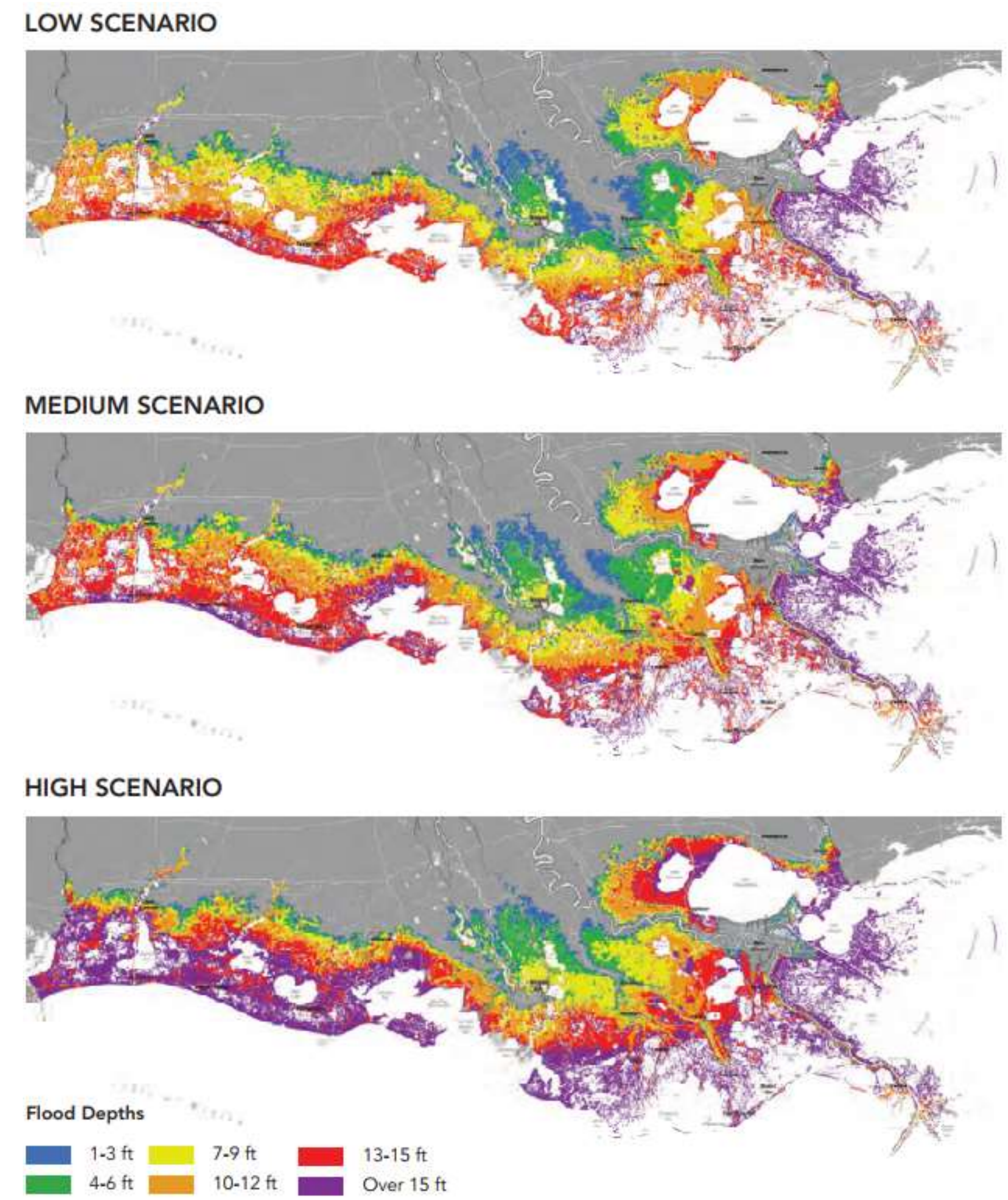


# PREDICTIVE MODELS

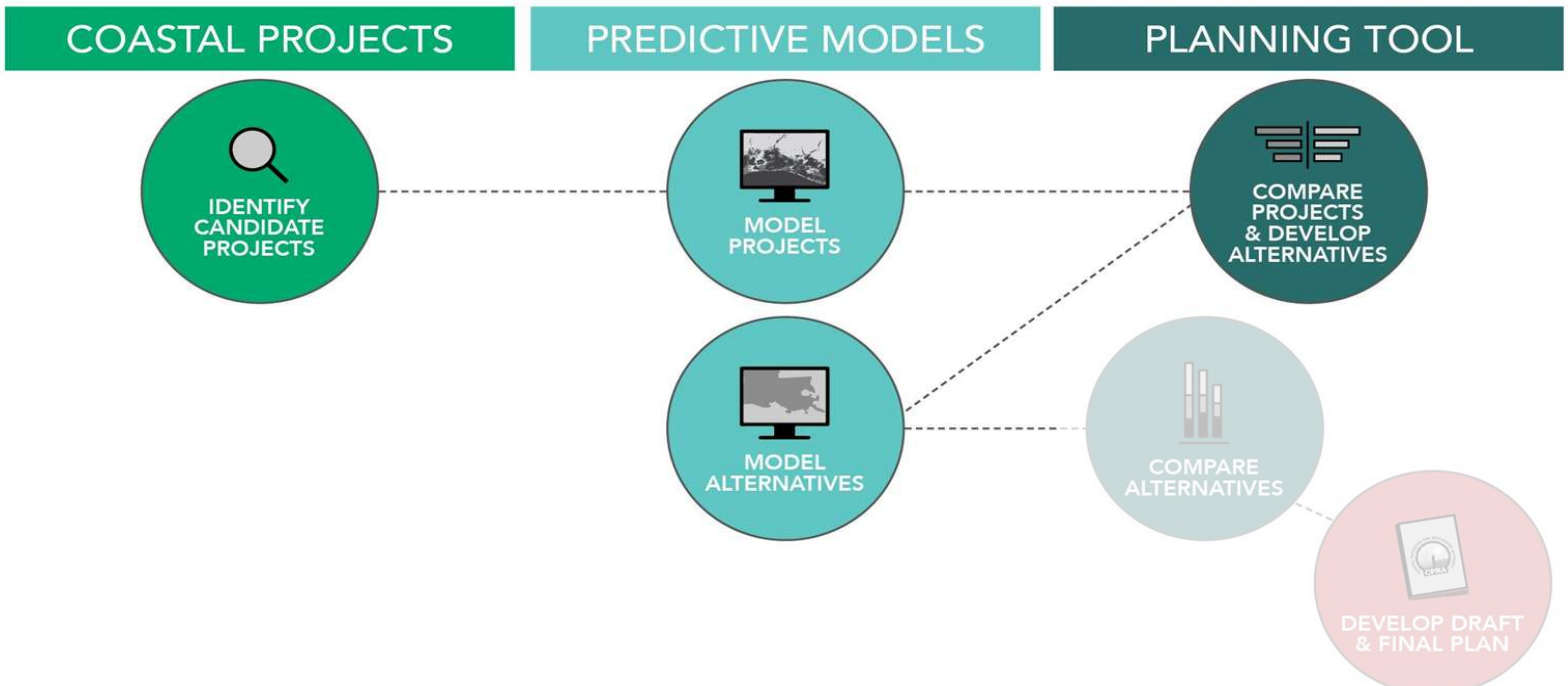


# 2017 FWOA PROJECTED FUTURE CONDITIONS



# PROCESS FOR PLAN DEVELOPMENT



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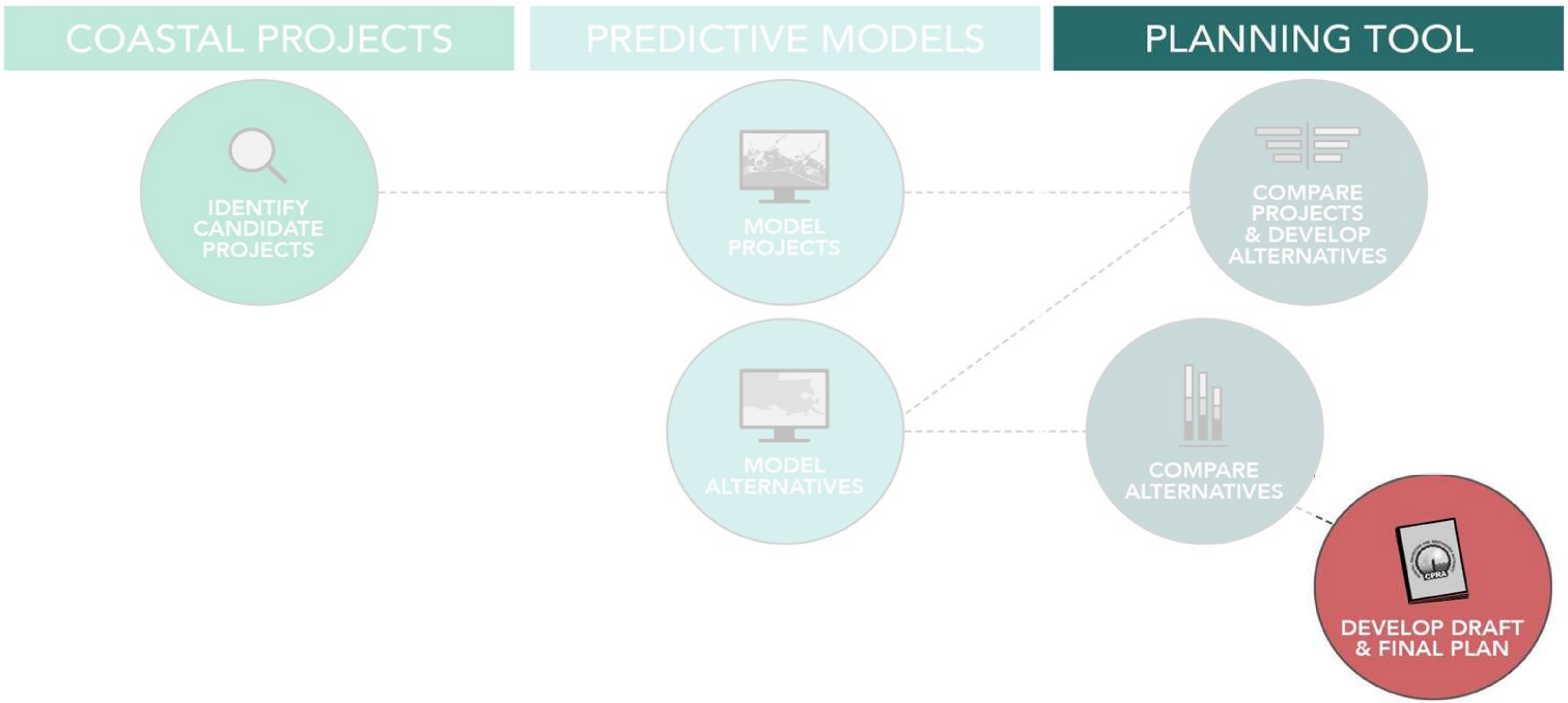
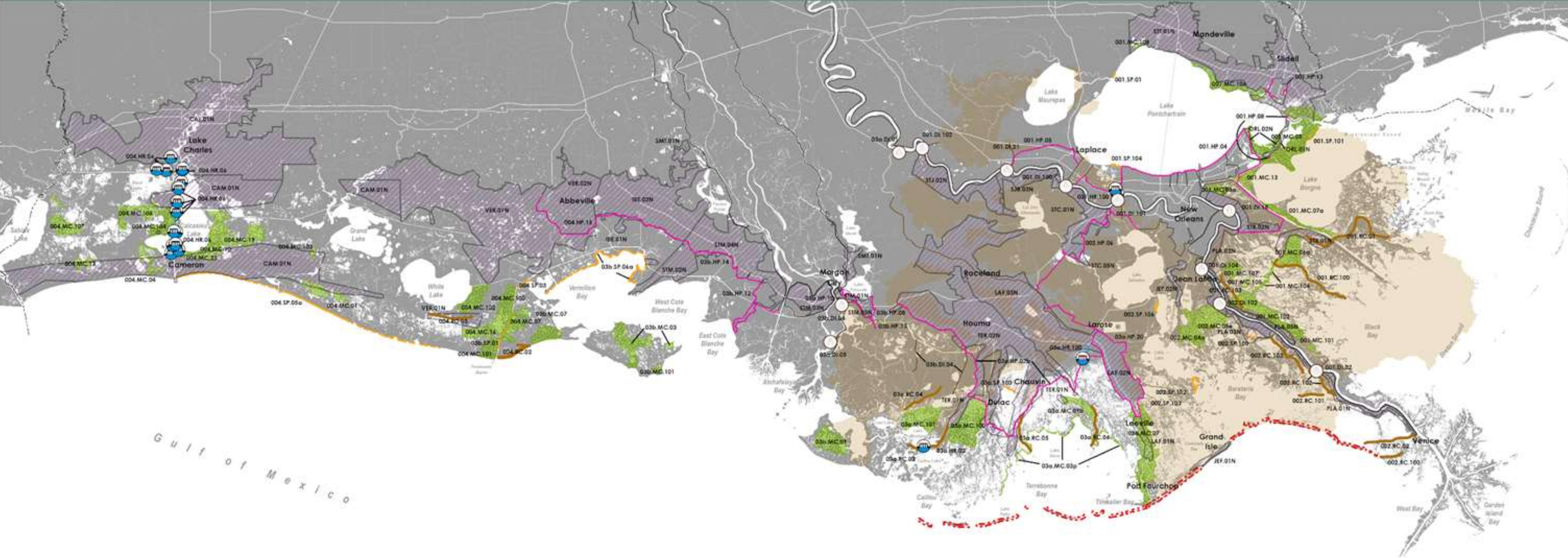





**Legend**

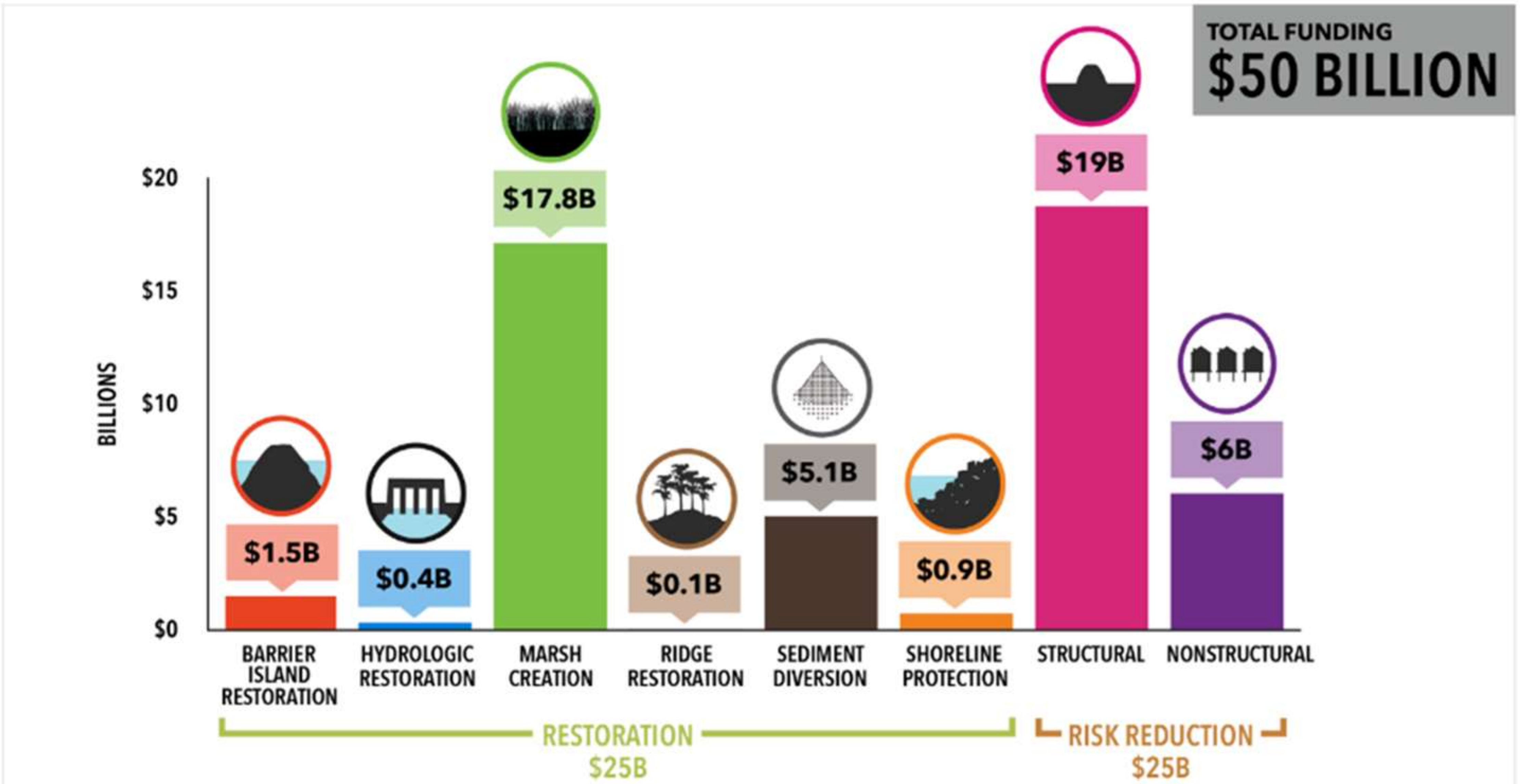
- Bank Stabilization
- Hydrologic Restoration
- Hydrologic Restoration
- Marsh Creation
- Oyster Barrier Reef
- Ridge Restoration
- Sediment Diversion
- Sediment Diversion
- Sediment Diversion
- Shoreline Protection
- Structural Protection
- Barrier Islands to be addressed programmatically by CPRA's Breach Management Program.

N

0 5 10 20 Miles

# 2017 MASTER PLAN SELECTED PROJECTS

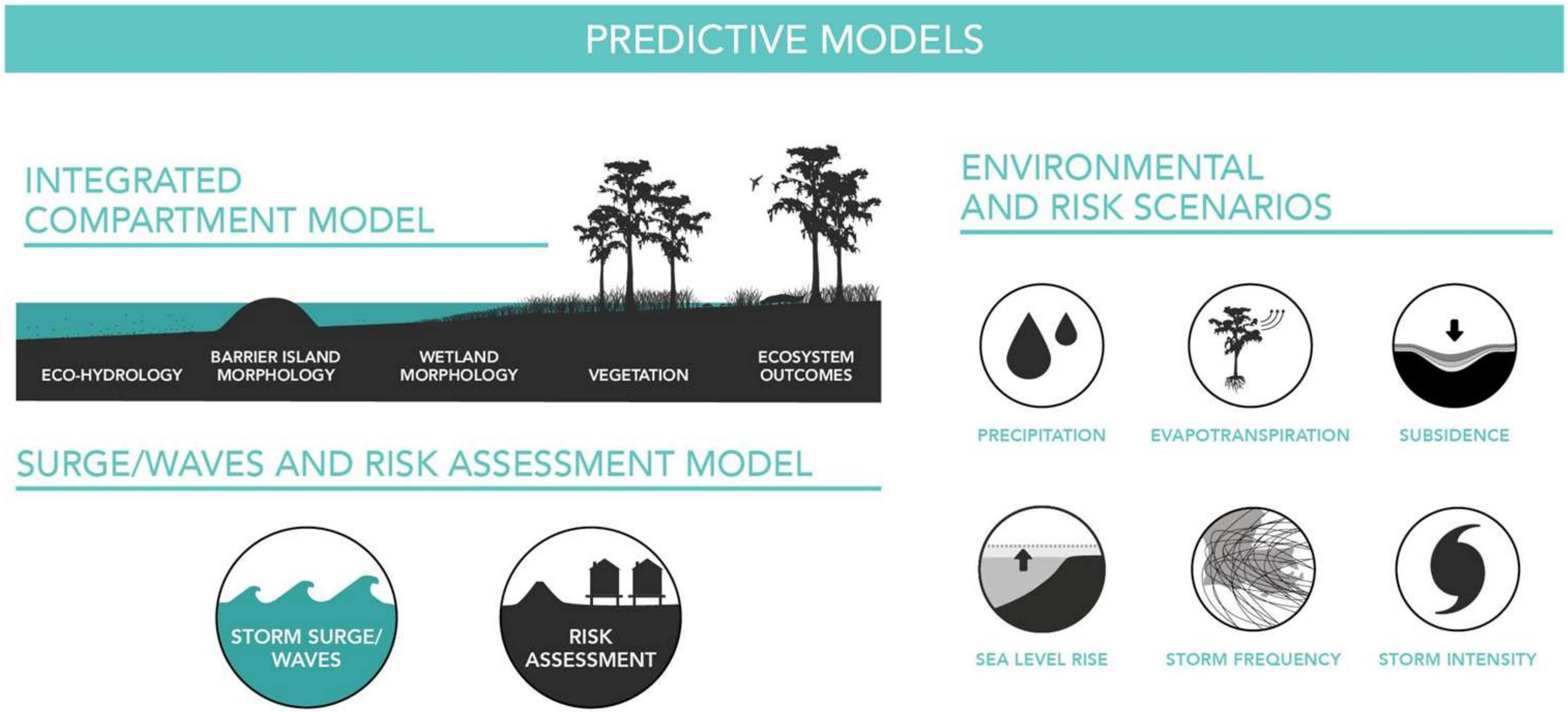
# 2017 COASTAL MASTER PLAN






~26,000 structures mitigated for $6B over 50 years

# PREDICTIVE MODELS

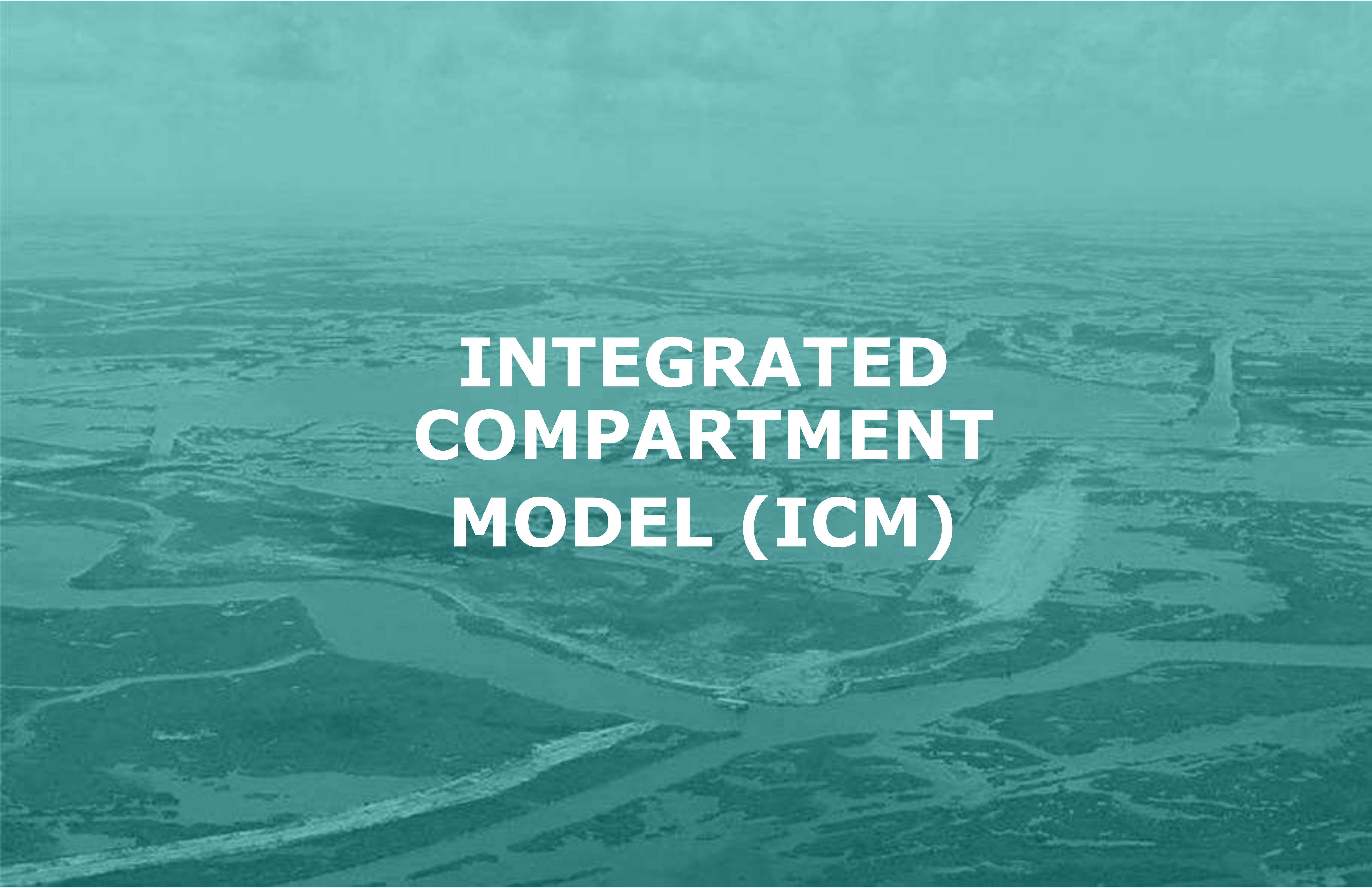


# ACKNOWLEDGEMENTS

# ACKNOWLEDGEMENTS


- Master Plan Team
  - Stuart Brown, Elizabeth Jarrell, Sam Martin, Eric White, Krista Jankowski, Ashley Cobb, Catherine Fitzpatrick, David Lindquist, Denise Reed; former members: Mandy Green, Rachelle Sanderson
- Model Improvement Teams (by organization)
  - **Abt :** Karim Belhadjali, Claire Lay; **Aptim :** Zhifei Dong; **Audubon :** Katie Percy, Erik Johnson, Karen Profita, Nicole Michel, Lindsay Nakashima; **CPRA :** Angelina Freeman, Summer Langlois, Darin Lee, Tommy McGinnis, Leigh Anne Sharp; Jon Bridgeman (former member); **Dynamic Solutions :** Shaye Sable; **LSU :** Megan La Peyre, Kristin DeMarco, Elizabeth Robinson (formerly CPRA); **Moffatt & Nichol :** Kevin Hanegan, Jonathan Wang, Chris Turnipseed; **Purdue University :** David Johnson, Nathan Geldner; **RAND :** Jordan Fischbach, Chuck Stelzner, Mike Wilson, David Groves, Tina Panis; **UNO :** Maddie Foster-Martinez, Meg O'Connell; **USGS :** Brady Couvillion, Don Schoolmaster, Ann Hijuelos, Laura D'Acunto, Gregg Snedden, Hongqing Wang; **ULL :** Jenneke Visser (retired), Scott Duke-Sylvester; **The Water Institute of the Gulf :** Yushi Wang, Scott Hemmerling, Alex McCorquodale, Hugh Roberts, Zach Cobell, Melissa Baustian, Ioannis Georgiou, Mike Miner, Soupy Dalyander, Martjin Bregman, Christine Demyers, Brett McMann, Diana Di Leonardo, Harris Bienn; **Tulane :** Ehab Meselhe, Kelin Hu, Nazmul Azim Beg, Chia-Yu Wu
- PM-TAC Members
  - Jen Irish, Courtney Harris, Wim Kimmerer, Sam Brody, Matt Kirwan, Mark Stacey


QUESTIONS



# INTEGRATED COMPARTMENT MODEL (ICM)

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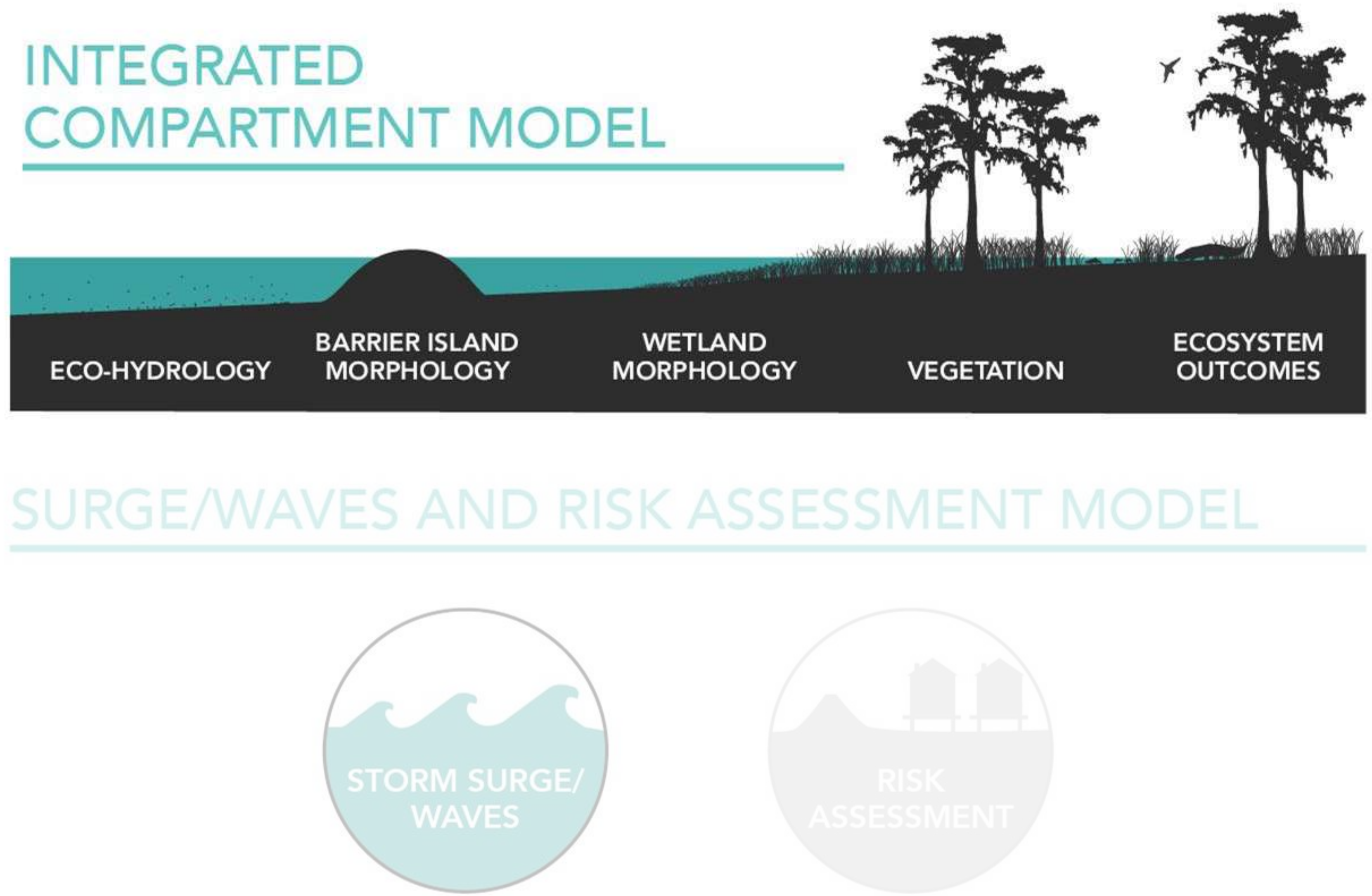
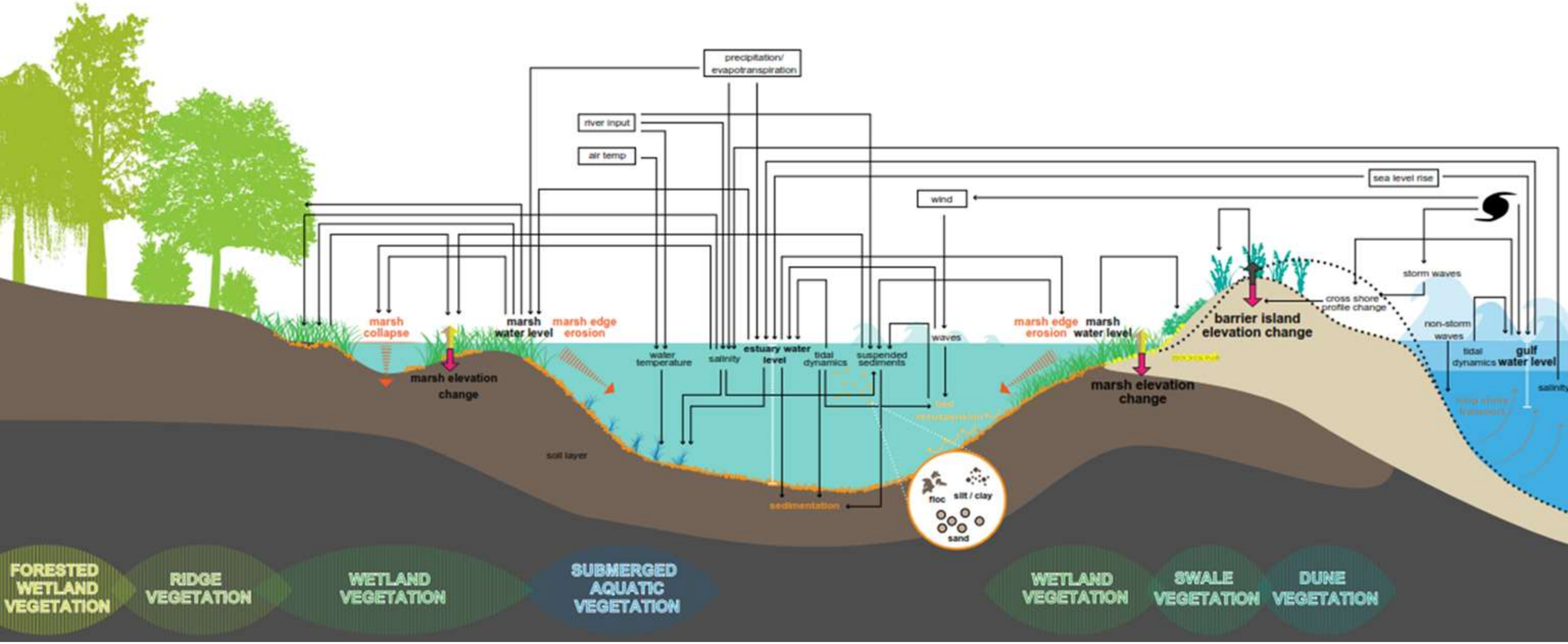
## PREDICTIVE MODELS






# ICM CONCEPTUAL MODEL

# ICM SUBROUTINES

## MODEL PROVENANCE

### ICM-Hydro

**Source Code:**

Fortran

**Original Developers:**

Alex McCorquodale

Ehab Meselhe

**Additional Developers:**

Eric White

Yushi Wang

**Original Theoretical Documentation:**

Meselhe et al. (2013)

### ICM-LAVegMod

**Source Code:**

Python2/3

**Original Developers:**

Scott Duke-Sylvester

Jenneke Visser

**Additional Developer:**

Maddie Foster-Martinez

**Original Theoretical Documentation:**

Visser et al. (2013)

Visser & Duke-Sylvester (2017)

### ICM-Morph

**Source Code:**

Fortran (previously Python2/arcpy)

**Original Developers:**

Brady Couvillion

**Additional Developer:**

Eric White

**Original Theoretical Documentation:**

Couvillion et al. (2013)

# ICM SUBROUTINES

## MODEL PROVENANCE

**ICM-Barrier Island**

**Source Code:**

Fortran

**Original Developers:**

Ioannis Georgiou

Soupy Dalyander

Maddie Foster-Martinez

**Original Theoretical Documentation:**

forthcoming

**ICM-HSI**

**Source Code:**

Python2/3

**Original Developers:**

Ann Hijuelos

**Additional Developers:**

David Lindquist

Shaye Sable

Eric White

**Original Theoretical Documentation:**

2017 Master Plan Technical Appendices

**ICM Control Code**

**Source Code:**

Python 2/3

**Original Developer:**

Eric White

**Original Theoretical Documentation:**

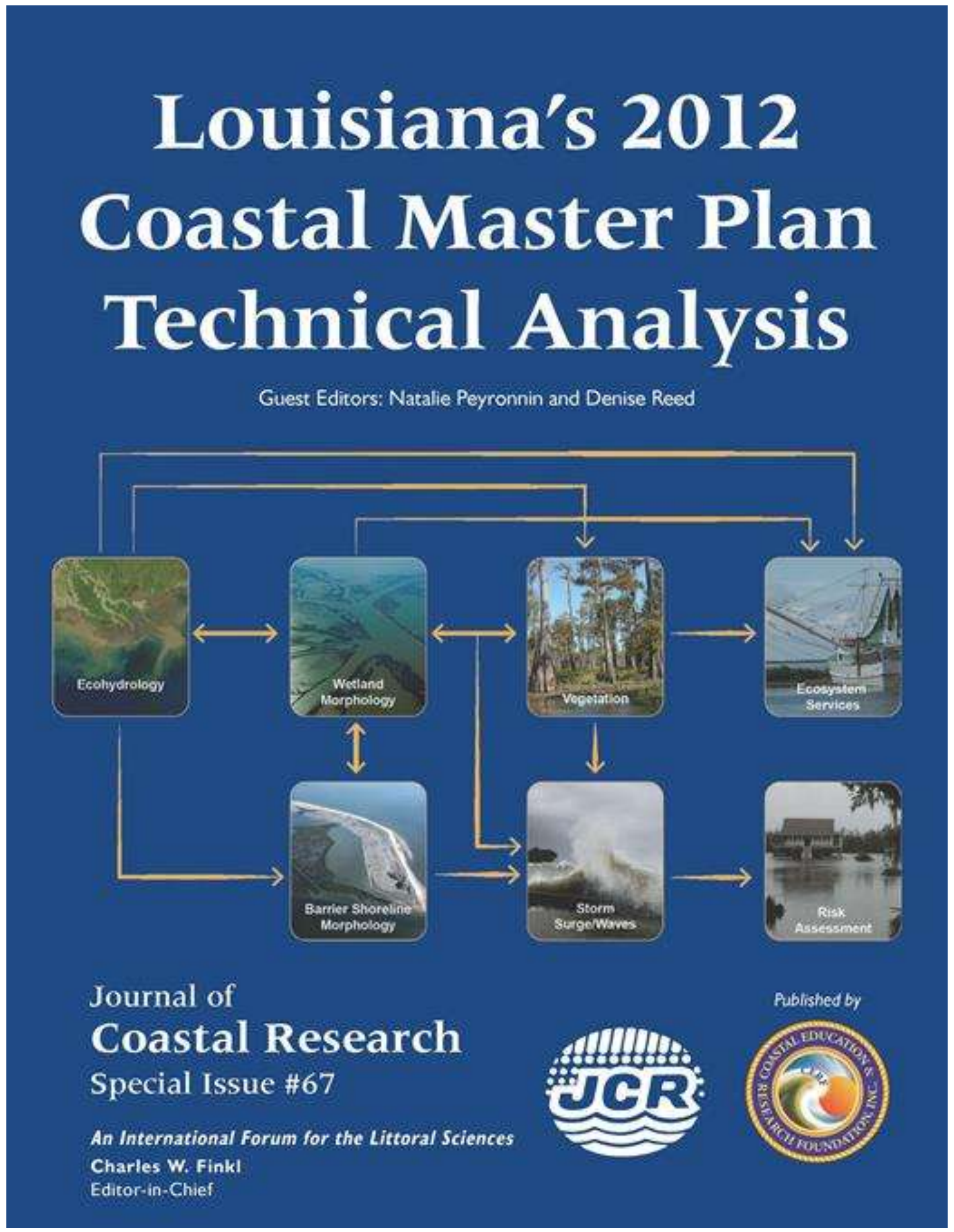
2017 Master Plan Technical Appendix

**Source code for all ICM subroutines is publicly available on GitHub**

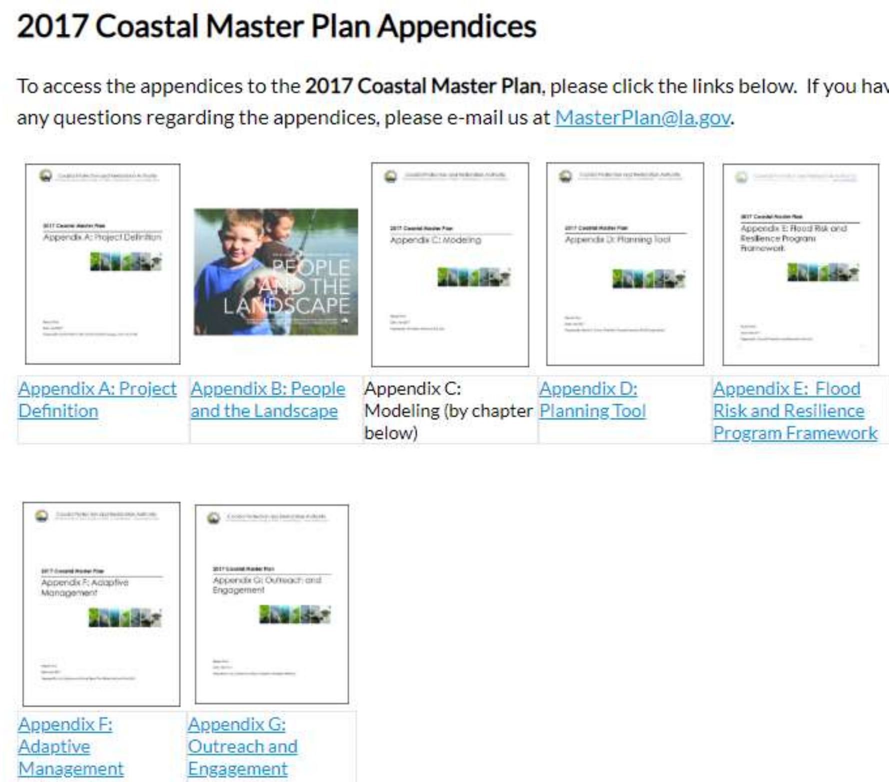
https://github.com/CPRA-MP

# ICM THEORETICAL DOCUMENTATION

## TECHNICAL REPORTS & PEER REVIEWED LITERATURE




Models for 2012 Master Plan were peer reviewed and published in a dedicated issue of JCR.



2017 Coastal Master Plan Appendices

To access the appendices to the **2017 Coastal Master Plan**, please click the links below. If you have any questions regarding the appendices, please e-mail us at MasterPlan@la.gov.

| | | | | |
|---|---|---|---|---|
| Appendix A: Project Definition | Appendix B: People and the Landscape | Appendix C: Modeling (by chapter below) | Appendix D: Planning Tool | Appendix E: Flood Risk and Resilience Program Framework |
| Appendix F: Adaptive Management | Appendix G: Outreach and Engagement | | | |

Updates to models for 2017 Master Plan were documented primarily through technical appendices to the plan.

Reed et al, (2020). *Geomorphology*. https://doi.org/10.1016/j.geomorph.2019.106991

White et al., (2019). *Water*. https://doi.org/10.3390/w11102028

White et al., (2019). *Wetlands*. ttps://doi.org/10.1007/s13157-019-01151-0

White et al., (2018). *Water*. https://doi.org/10.3390/w10081015

Baustian et al., (2018).*Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2017.10.005

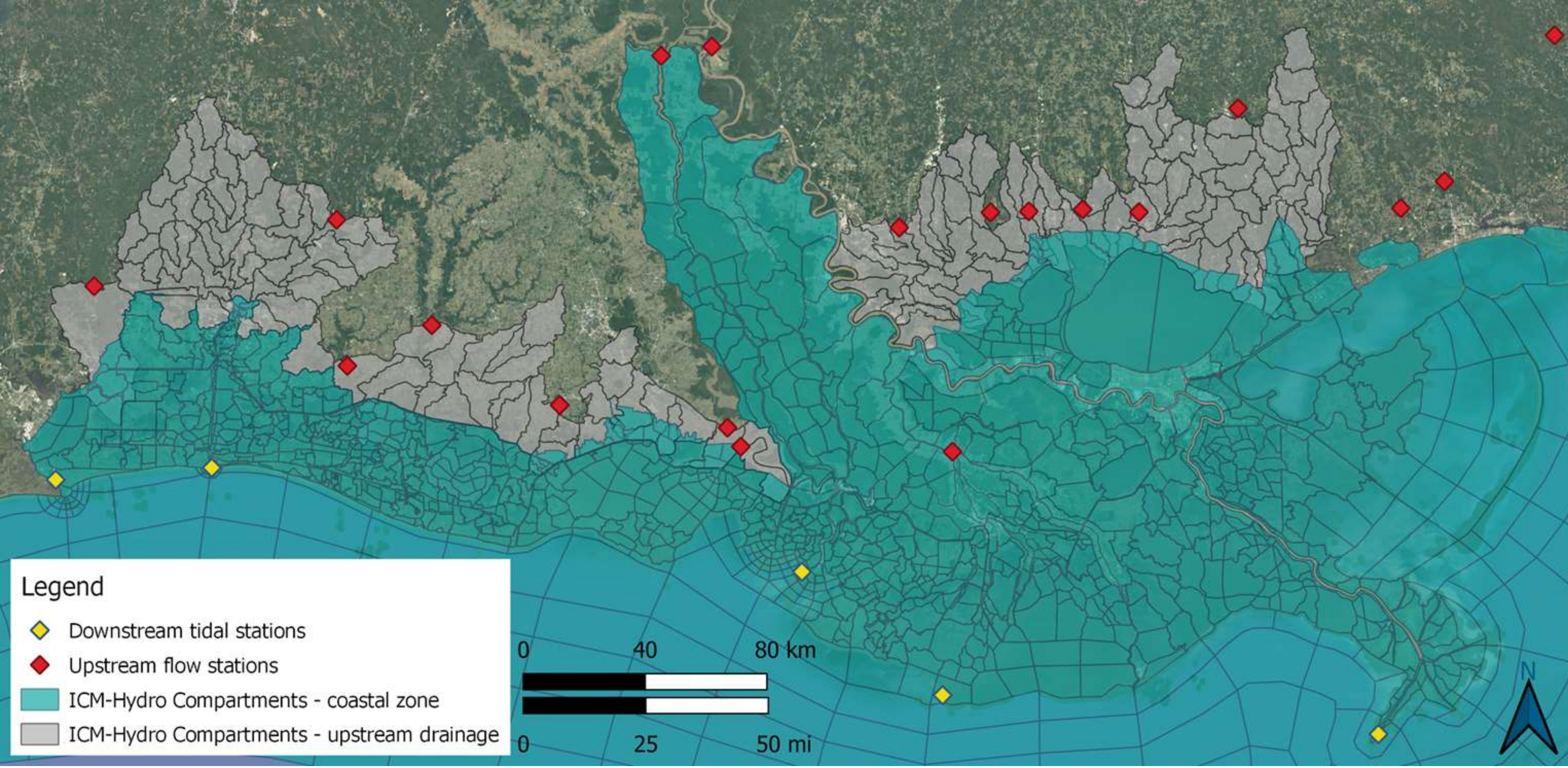
Visser & Duke-Sylvester. (2017). *Sustainability*. http://dx.doi.org/10.3390/su9091625

Hijuelos et al., (2016). *Estuaries and Coasts*. https://doi.org/10.1007/s12237-016-0199-5

Couvillion et al., (2013). *Journal of Coastal Research*. https://doi.org/10.2112/SI_67_3

Meselhe et al., (2013). *Journal of Coastal Research*. https://doi.org/10.2112/SI_67_2.1

Peer reviewed articles based on ICM tools and analyses.

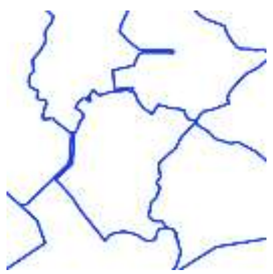



# ICM-HYDRO MODEL DOMAIN

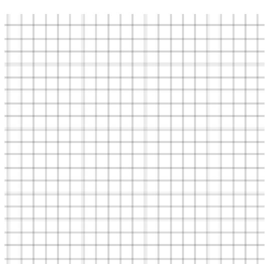
## COMPARTMENT DELINEATION FOR 2023 MASTER PLAN ICM-HYDRO

# COMPARTMENT CONCEPTUALIZATION & SPATIAL RESOLUTION

**Legend**

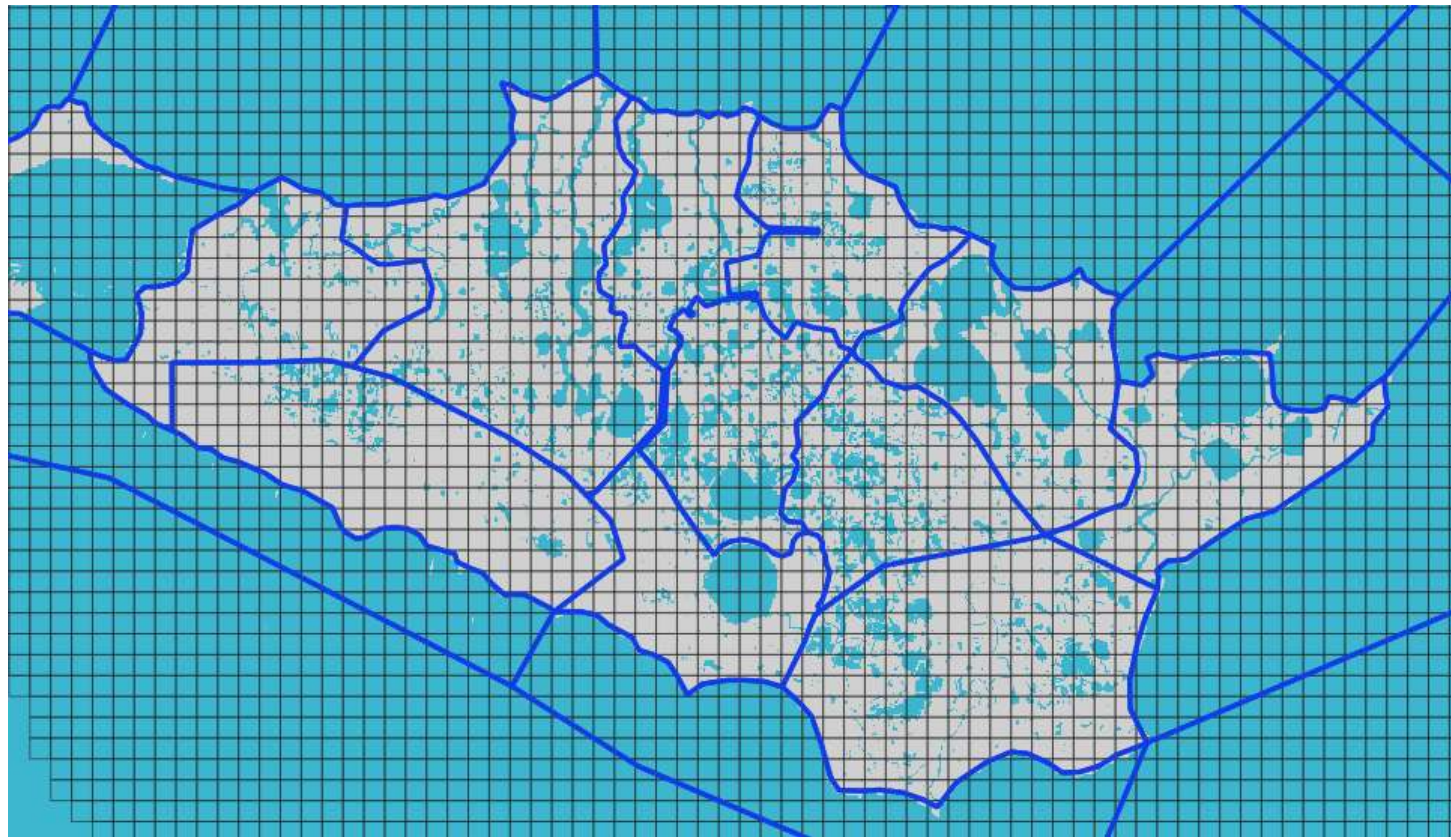


**ICM-Hydro:**
irregularly sized *compartment*



**ICM-LAVegMod & ICM-HSI:**
500-m *grid cell*

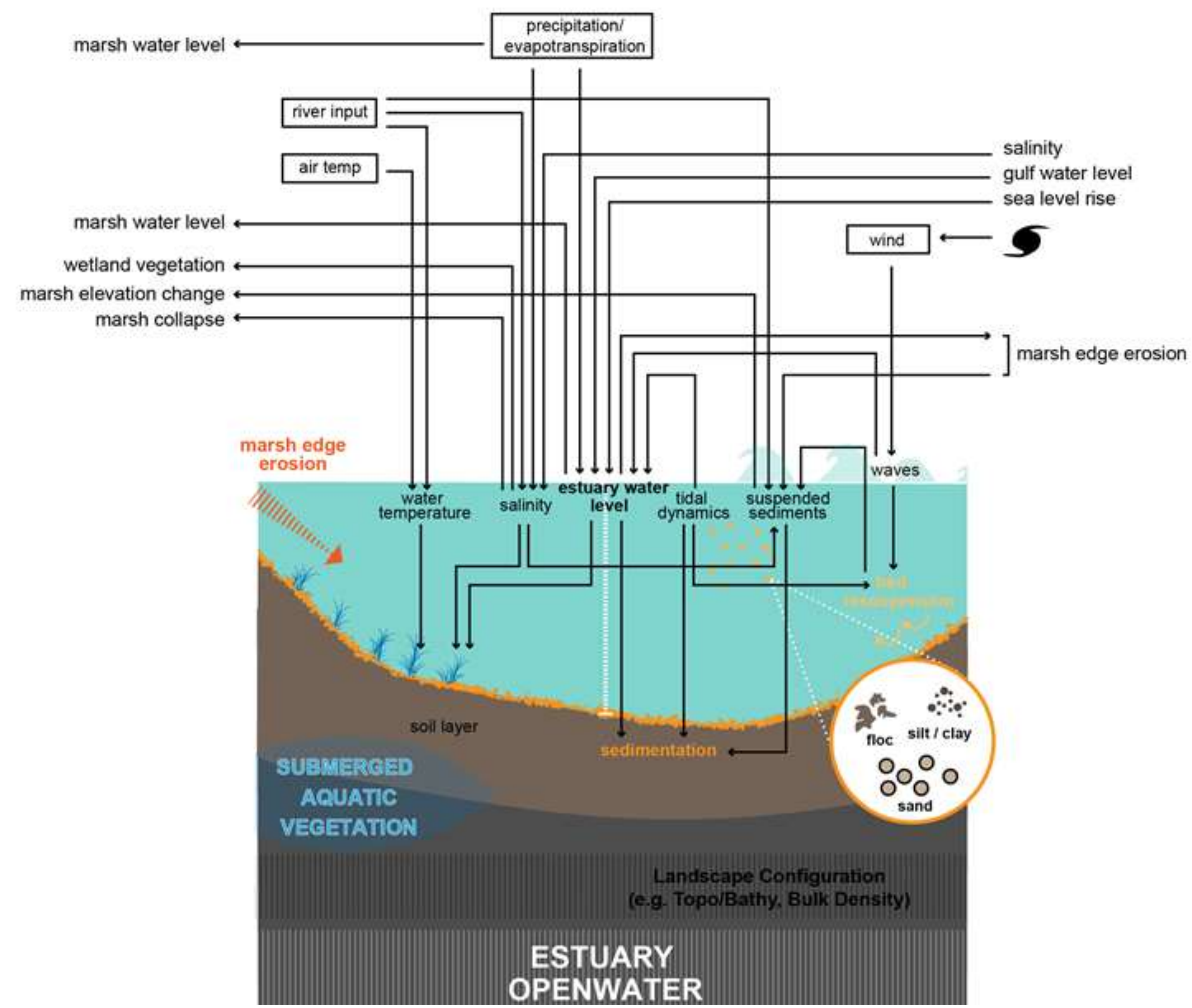
**ICM-Morph:**
30-m *pixel*



ICM resolution for Marsh Island in Vermilion Bay. Irregular polygons in dark blue are ICM-Hydro compartments; Orthogonal grid in black is the ICM-LAVegMod and ICM-HSI 500x500-m grid cells; Gray and teal landscape is the 30-m raster resolution of ICM-Morph.

# ICM-HYDRO CONCEPTUAL MODEL

- Hydrodynamics
- Precipitation/Evapotranspiration
- Water quality*
  - Salinity
  - Temperature
- Sediment deposition
- Bed resuspension/erosion
- Sediment transport and distribution throughout estuary

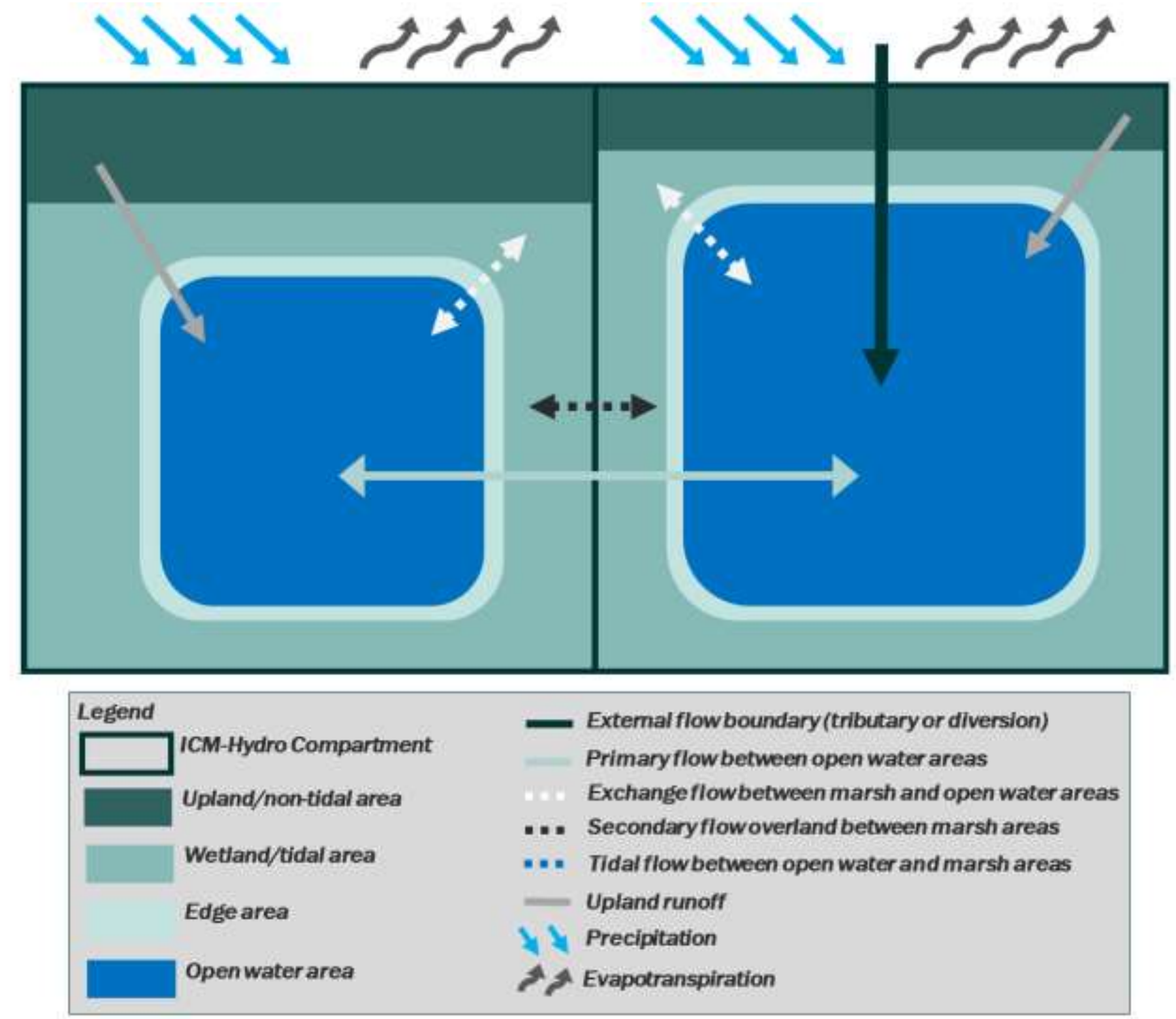



Conceptual model of estuarine and open water processes.

*ICM-Hydro has algorithms for modeling water quality nutrients but these will not be utilized for the 2023 Master Plan*

# ICM-HYDRO SPATIAL REPRESENTATION OF ESTUARY

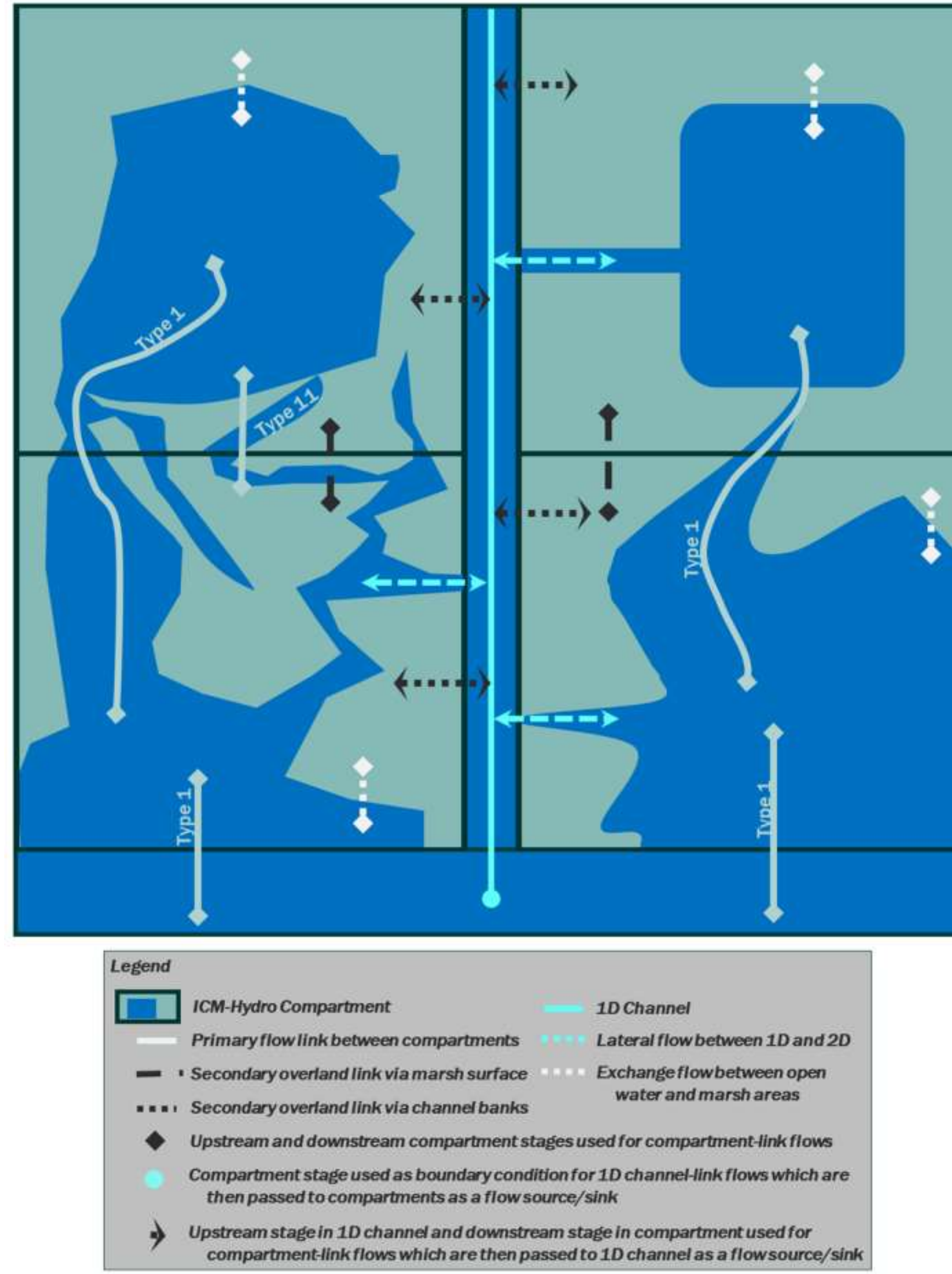
- ICM-Hydro is a link-node mass balance model that uses a reduced spatial complexity to represent coastal hydrodynamics.
- Each node (compartment) can contain:
  - Open water
  - Marsh
  - Marsh edge
  - Upland area that is non-tidal
- Compartments are assumed uniformly mixed in both the vertical and horizontal.




Schematic of ICM-Hydro spatial representation of estuarine landscape and water balance.

# ICM-HYDRO SCHEMATIC DIAGRAM OF HYDRAULIC CONNECTION TYPES

- Compartments are connected via links capturing hydraulic connections
- Various link types represent the predominant flow mechanisms within coastal Louisiana
- New for 2023: 1D open channel flow routing algorithm for channelized flows such as rivers and navigational channels




Schematic of ICM-Hydro hydraulic connection types.

# ICM-HYDRO HYDRAULIC CONNECTION TYPES

- 1D open channel flow
  - Dynamic wave routing for irregular cross-sections
- Rectangular cross-section open channel flow within compartments
  - Assumed normal flow (Manning's equation)
  - Entrance, exit and structure losses can be applied
- Bridge/culverts
  - Orifice equation, 2-way flow
- Weirs
  - Free outfall or submerged
- Tide gates
  - Orifice equation, 1-way flow

# ICM-HYDRO HYDRAULIC CONNECTION TYPES cont.

- Pumps
  - Pump rate assigned based on upstream drainage area/rainfall rate
- Overland flow links
  - Marsh flow connection
  - Ridge/levee barriers
- Rectangular cross-section open channel flow with operational control rules:
  - Downstream salinity
  - Differential stage
  - Downstream stage
  - Time of day
  - Observed open/close record
  - Both downstream stage and salinity
- Regime channels in delta outlets

# ICM-HYDRO WATER QUALITY CONSTITUENT MASS BALANCE

## MASS BALANCE FOR SEDIMENT & SALINITY ROUTING

$$\frac{\partial C_{k,j}}{\partial t} = -\frac{C_{k,j}\eta'_j}{y_j} + \frac{\sum_i \sum_{trib} \sum_{div} \left[C_{k,j,i,trib,div} Q_{i,trib,div}\right]}{y_j A_{s,j}} + \frac{f_{dis} \sum_i \lambda_i \frac{A_i}{L_i}(C_{k,j} - C_{k,nb})}{y_j A_{s,j}} + \frac{\sum_l S_{r,k,j,l}}{y_j A_{s,j}}$$

*Volume Change from P / ET* — *Advection* — *Diffusion* — *Source/Sink*

**Terms**

- $\partial C/\partial t$ = rate of change of concentration in a cell
- $C_{k,j}$ = concentration of constituent k in subcompartment j
- η'=rate of change of water surface elevation (e.g., precip/ET) (dh/dt)
- Q = water discharge
- $A_{s,j}$ = subcompartment water surface area
- $S_{r,k,j,l}$ = subcompartment sources/sink
- $y_j$= subcompartment water depth
- t = time
- $f_{dis}$ = calibration factor
- $\lambda_i$ =diffusivity in link i
- $A_i$= link cross-sectional area
- $L_i$ = effective link length

**Subscripts**

- k = species (sediment class)
- j = number of subcompartment
- i = number of link
- trib = tributary
- div = diversion
- nb = neighboring subcompartment
- dis = dispersivity
- r = source-sink
- S = surface
- l = source/sink index
- Q = water discharge

# ICM-HYDRO SEDIMENT DISTRIBUTION

- Mass in to each compartment
  - Flows
    - Tributary inflows
    - Sediment diversions
    - Connections to neighboring compartments
  - Marsh edge erosion sediment load
    - Constant rate over a year, but rate changes inter-annually based on amount of edge within a compartment at the start of each year
  - Bareground elevation loss
    - Constant rate over a year, but rate changes inter-annually based on amount of bareground lowered in ICM-LAVegMod and ICM-Morph subroutines within a compartment at the start of each year
  - Inundation-induced loss to open water
    - Constant rate over a year, but rate changes inter-annually based on amount of vegetated land that is lost and converted to open water due to inundation stress in ICM-LAVegMod and ICM-Morph subroutines within a compartment at the start of each year

# ICM-HYDRO SEDIMENT DISTRIBUTION

- Mass out of each compartment:
  - Flows to neighboring compartments

- Sources and sinks within each compartment
  - Resuspension of bed material
    - Critical shear stresses calculated from flow & wave velocities
    - Separate routines for cohesive (silt & clay) and sand particles
  - Deposition of bed material
    - Settling velocities calculated for particle class
    - Flocculation of clay modeled
  - Marsh surface deposition
    - Non-uniform deposition in marsh; particles with higher fall-velocities deposit in near-edge zone (30 m)

- Procedure for sediment deposition and resuspension, also applied during storm events

# ICM-HYDRO SEDIMENT DEPOSITION/RESUSPENSION: NEAR BED SHEAR STRESS

- Resuspension if bed shear is greater than critical shear for sediment class
- Deposition if bed shear is less than critical shear for sediment class

$$\tau_{bed} = C_f \rho_w {U_{bed}}^2$$

$$U_{bed} = \mathrm{U} + U_{tide} + U_{wind} + U_{orb}$$

- Orbital velocity at bed from Linear Wave Theory:

$$U_{orb} = \frac{gH_sT}{2L\cosh\left(\frac{2\pi d}{L}\right)}$$

- $H_s$ = significant wave height
- T = wave period
- L = wavelength
- d = water depth

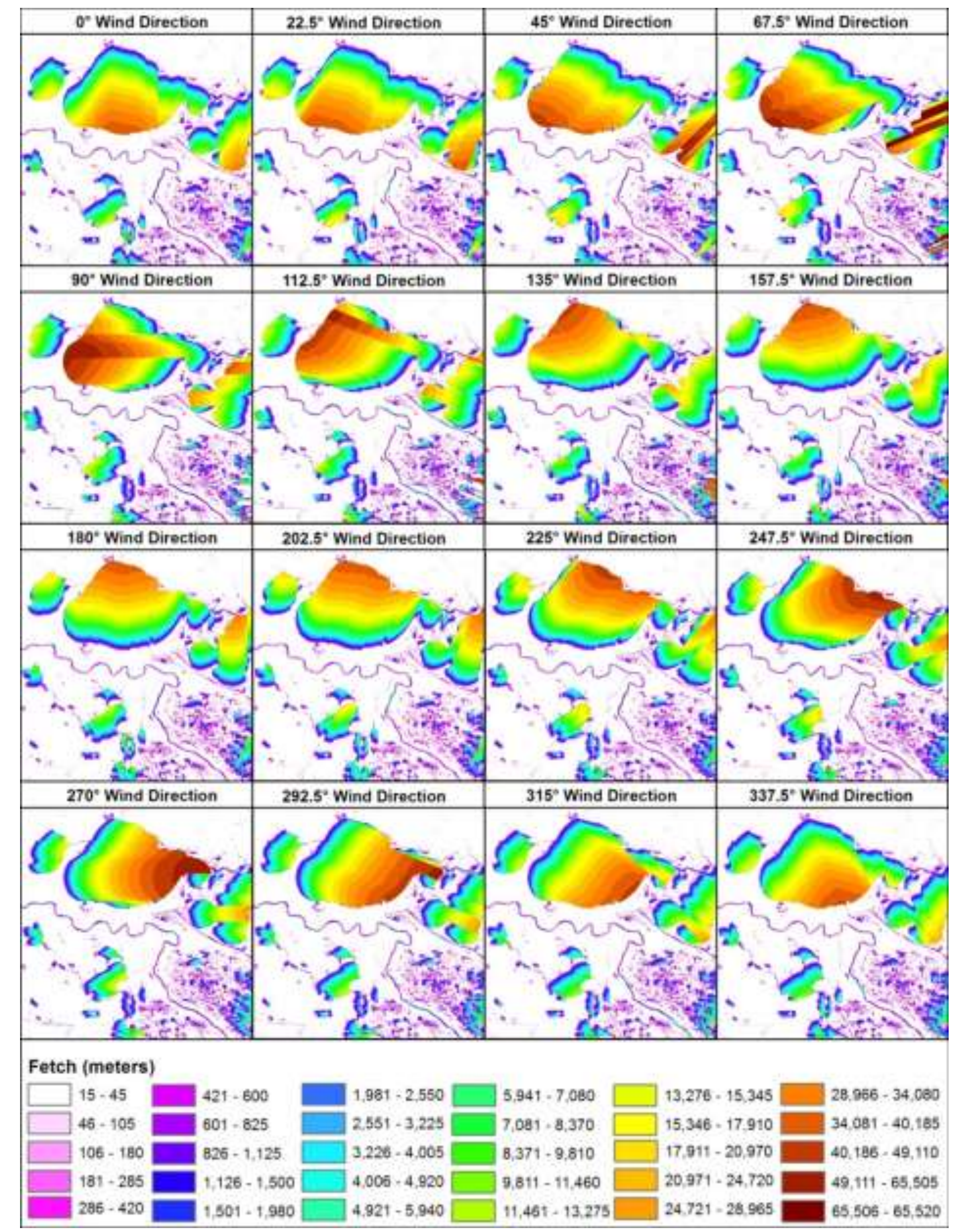
# ICM-HYDRO SEDIMENT DEPOSITION/RESUSPENSION: WAVE MODEL

- Wave energy and frequency from Young and Verhagen (1996) wave model:

$$E = E_{lim}\left\{\tanh A_1 \tanh\left(\frac{B_1}{\tanh A_1}\right)\right\}^n \left(\frac{{U_{10}}^2}{g}\right)^2$$

$$\frac{1}{T} = f = f_{lim}\left\{\tanh A_2 \tanh\left(\frac{B_2}{\tanh A_2}\right)\right\}^m \left(\frac{g}{U_{10}}\right)$$

- $A_1$ and $A_2$ are empirical functions of water depth
- $B_1$ and $B_2$ are empirical functions of fetch
- $U_{10}$ is wind velocity at 10 meters above surface
- Wind timeseries input to model
- Fetch in 16 directions are pre-calculated and considered static throughout model run



Calculated fetch for 16 wind directions for a portion of coastal Louisiana including Lake Pontchartrain and parts of the Breton and Barataria basins. From 2017 Technical Appendix C3-3.2 (Allison, et al., 2017).

# ICM-HYDRO SEDIMENT DEPOSITION/RESUSPENSION: FINES SETTLING

- Silt
  - **Representative $D_{50}$ = 0.03 mm**
- Clay
  - **Representative $D_{50}$ = 0.001 mm**
  - **Flocculated**
  - **Unflocculated**

$$v_{d,k} = w_{s,k}\left(1 - \frac{\tau_{bed}}{\tau_{d,k}}\right)$$

$w_{s,k}$ = settling velocity for class k;

k = subscript indicating the class of cohesive sediment;

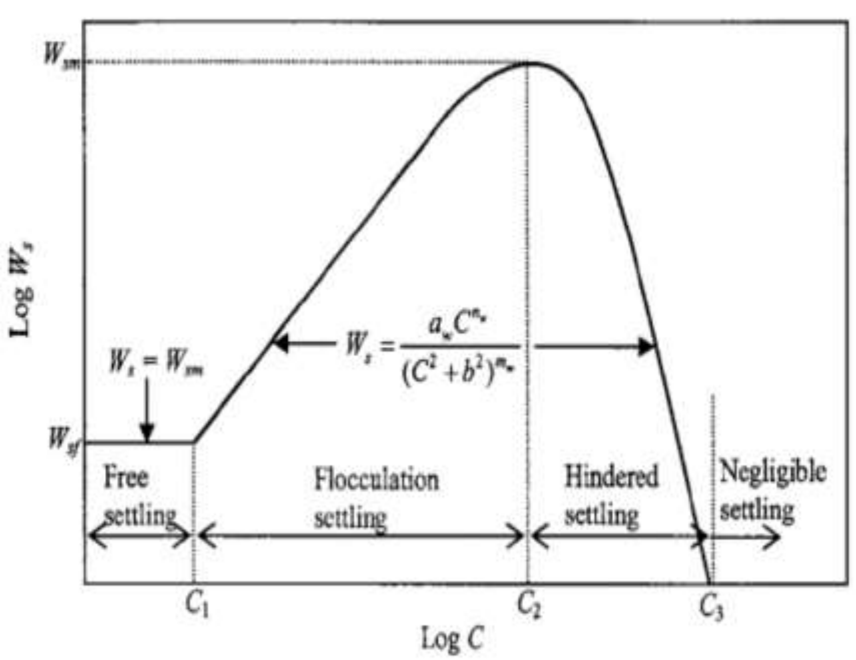
$\tau_{bed}$ = bed shear stress;

$\tau_{d,k}$ = critical shear stress for initiation of deposition of class k.

| ***USDA*** | Clay | | Silt | | Sand | | | | | Gravel | | | Cob-bles | Stones | Boulders |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | fine | co. | fine | co. | v.fi. | fi. | med. | co. | v. co. | fine | medium | coarse | | | |
| millimeters: | | 0.0002 | .002 mm | .02 | .05 | .1 | .25 | .5 | 1 | 2 mm | 5 | 20 | 76 | 250 mm | 600 mm |
| U.S. Standard Sieve No. *(opening)*: | | | | | 300 | 140 | 60 | 35 | 18 | 10 | 4 | *(3/4")* | *(3")* | *(10")* | *(25")* |

# ICM-HYDRO SEDIMENT DEPOSITION/RESUSPENSION: CLAY FLOCCULATION

- Free/Flocculated/Hindered settling methodology from McAnally et al., (2007)
    - Flocculation calculated as function of salinity and  concentration of fine sediment
- Flocculation sediment properties from field studies in FL by Mehta (1991)
    - Ongoing work at LSU to update these parameters fines with local data

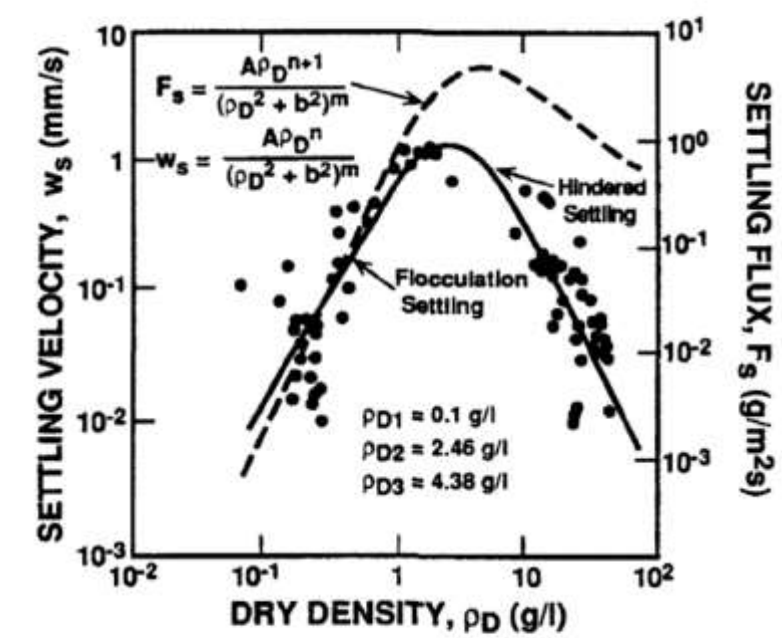



McAnally et al., (2007) - Flocculation settling conceptual curve

$$P_{floc} = \begin{cases} \dfrac{C_{sal}}{C_{sal,max}} P_{floc,max} & C_{sal} < C_{sal,max} \\ P_{floc,max} & C_{sal} \geq C_{sal,max} \end{cases}$$

$$w_{s,floc} = \begin{cases} w_s & C_{clay} < C_1 \\ a\dfrac{{C_{clay}}^{n}}{\left({C_{clay}}^{2} + b^2\right)^{m}} & C_1 < C_{clay} < C_3 \\ negligible & C_3 < C_{clay} \end{cases}$$

McAnally et al., (2007) - Flocculation settling curve logic




Mehta, (1991) - Flocculation sediment parameterization

# ICM-HYDRO SEDIMENT DEPOSITION/RESUSPENSION: SAND FLUX

- Dimensionless shear stress determines resuspension or deposition:

$$\vartheta_{cr} = \frac{\tau_{cr}}{(\rho_s - \rho_w) g D_{50}}$$

- Dimensionless shear stress for initiation of sand motion (van Rijn, 2007):

$$\vartheta_{cr} = \begin{cases} 0.115 {D_*}^{-0.5} & D_* < 4 \\ 0.14 {D_*}^{-0.64} & 4 \leq D_* < 10 \end{cases}$$

- Sediment flux (van Rijn, 2007):

$$q_s = \alpha_s \rho_s u D_{50} {M_e}^{2.4} {D_*}^{-0.6} \qquad M_e = \frac{(u_e - u_{cr})}{\sqrt{g D_{50} \left(\frac{\rho_s}{\rho_w} - 1\right)}} \qquad D_* = D_{50} \left[\frac{g\left(\frac{\rho_s}{\rho_w} - 1\right)}{\upsilon^2}\right]^{1/3}$$

**$u_e$, and $u_{cr}$ are various flow and wave velocity terms that are functions of sediment grain size**

# ICM-HYDRO OUTPUT VARIABLES USED IN OTHER ICM SUBROUTINES

| | | | |
|---|---|---|---|
| **Mean Salinity** *Annual* | **Mean Water Surface Elevation** *Annual* | **Maximum 14-day Salinity** *Annual* | **Tidal Prism Volume** *Annual* |
| | **Mean Salinity** *Growing Season* | **Water Level Variability** *Growing Season* | |
| **Mineral Sediment Deposition** *Monthly* | **Maximum Water Surface Elevation** *Monthly* | **Mean Salinity** *Monthly* | **Mean Temperature** *Monthly* |

# ICM-HYDRO OUTPUT VARIABLES USED IN OTHER ICM SUBROUTINES

**Mean Salinity**
***Annual***

**Mean Water Surface Elevation**

**Maximum 14-day Salinity**

**Tidal Prism Volume**
***Annual***

**Quick pause for any clarifying questions?**

**Mineral Sediment Deposition**
***Monthly***

**Surface Elevation**
***Monthly***

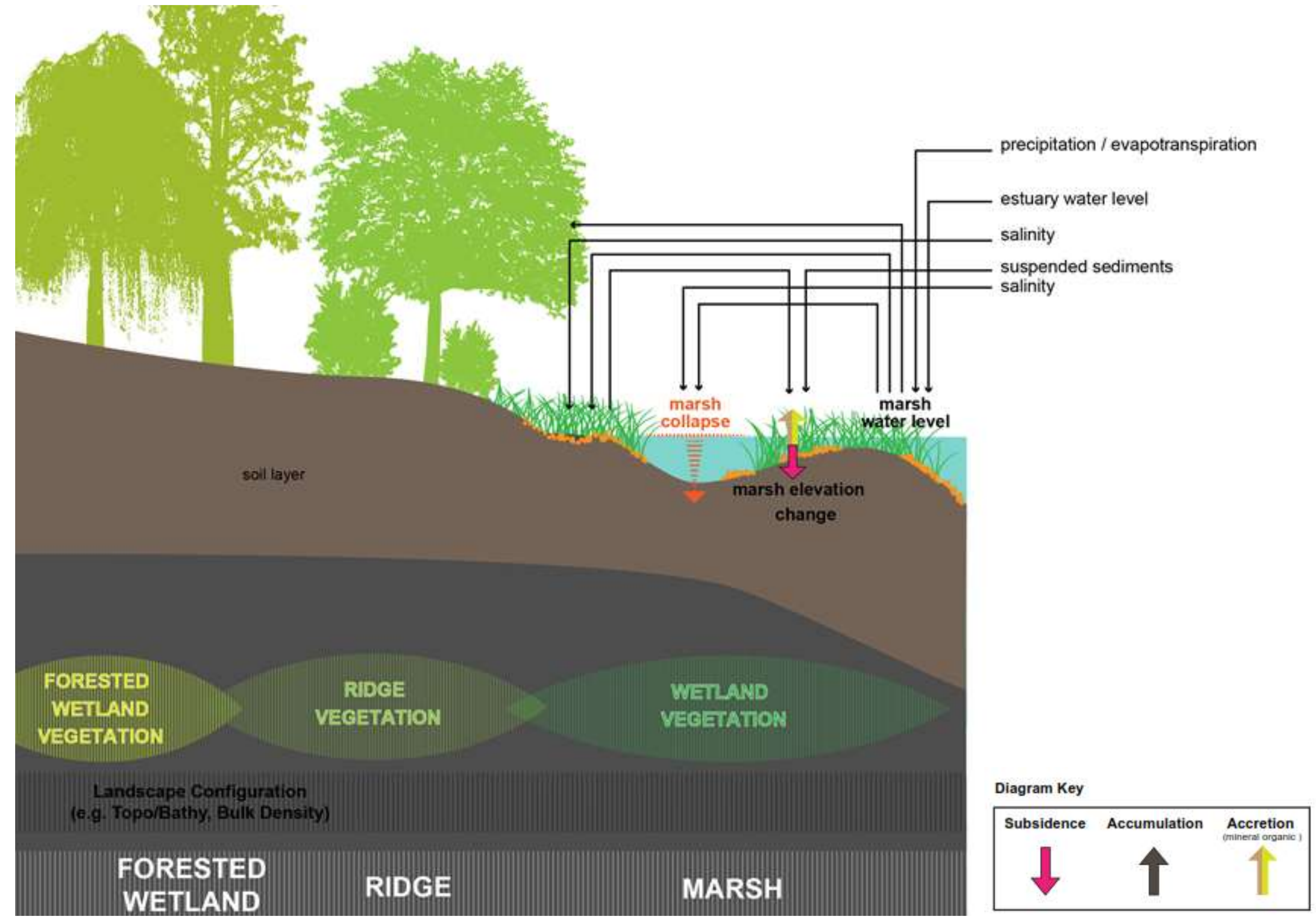
***Monthly***

**Mean Temperature**
***Monthly***

# WETLAND PROCESSES AND VEGETATION

## ICM-LAVEGMOD & ICM-MORPH

- Coastal vegetation
- Wetland elevation change
  - Mineral sediment deposition
  - Organic matter accretion
- Wetland area change
  - Salinity stress
  - Inundation stress
  - Marsh edge erosion
  - Subsidence




Conceptual Diagram of Wetland and Vegetation Processes from the 2017 ICM.

# ICM-LAVEGMOD & ICM-MORPH

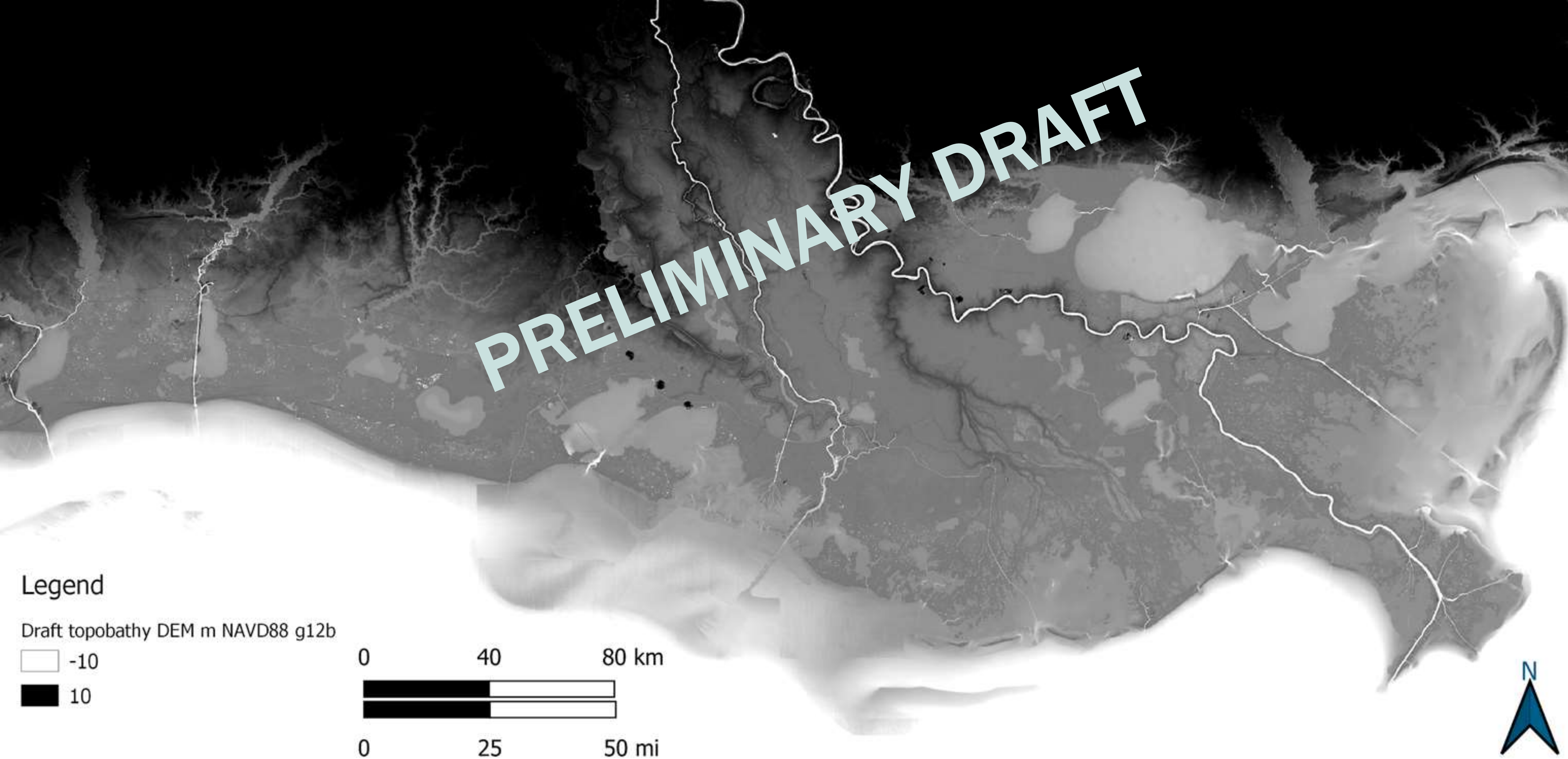
PRIMARY MODEL FEATURES

## ICM-LAVegMod

- 500-m x 500-m regular grid
- Species coverage (%) calculated for each grid cell
- 33 species in 7 habitat types
  - 6 bottomland hardwood forest species
  - 3 swamp forest species
  - 2 fresh floating marsh species
  - 5 fresh attached marsh species
  - 9 intermediate marsh species
  - 4 brackish marsh species
  - 4 saline marsh species
- Submerged vegetation in open water

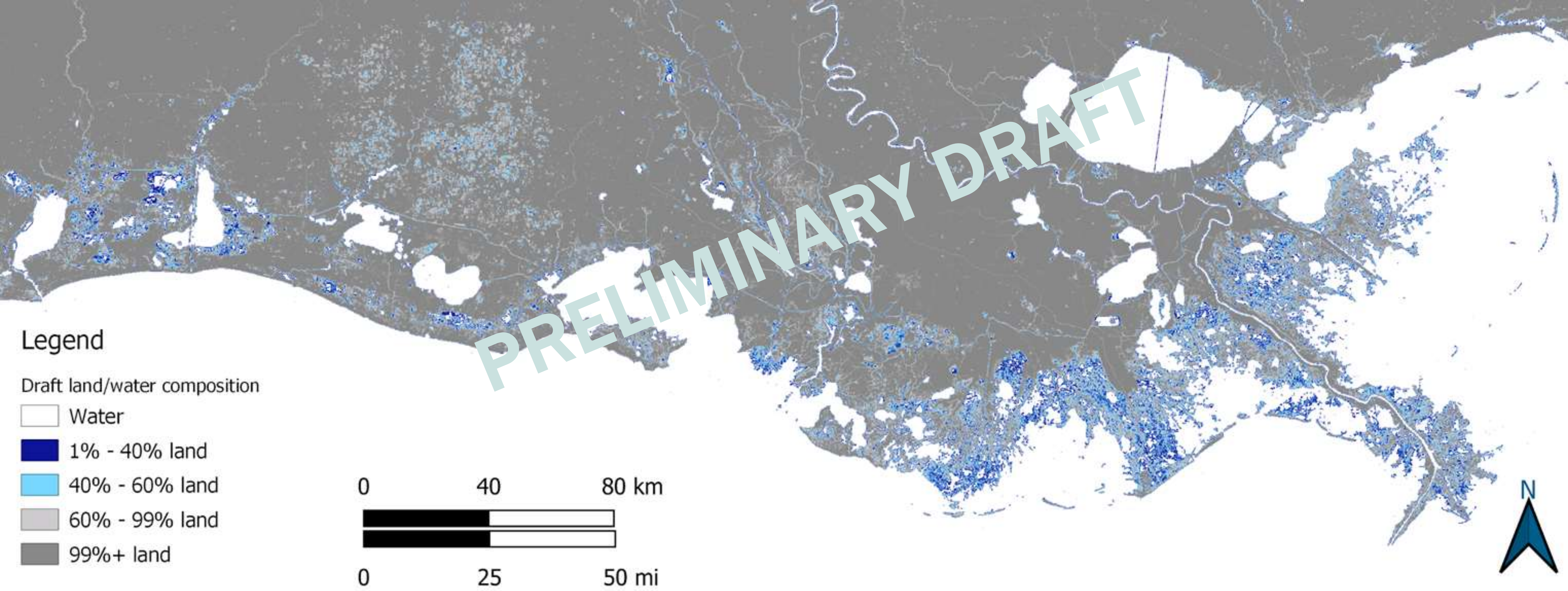
## ICM-Morph

- 30-m resolution (or whatever resolution topobathy DEM is used)
- Relative elevation model
- Marsh elevation increases from:
  - From mineral sediment deposition
  - From organic accretion
- Marsh elevation decreases from:
  - Persistent vegetation loss
  - Subsidence
- Open water bottom increases from:
  - Mineral sediment deposition
- Open water bottom decreases from:
  - Sediment erosion
  - Subsidence
- Marsh area expands due to edge erosion



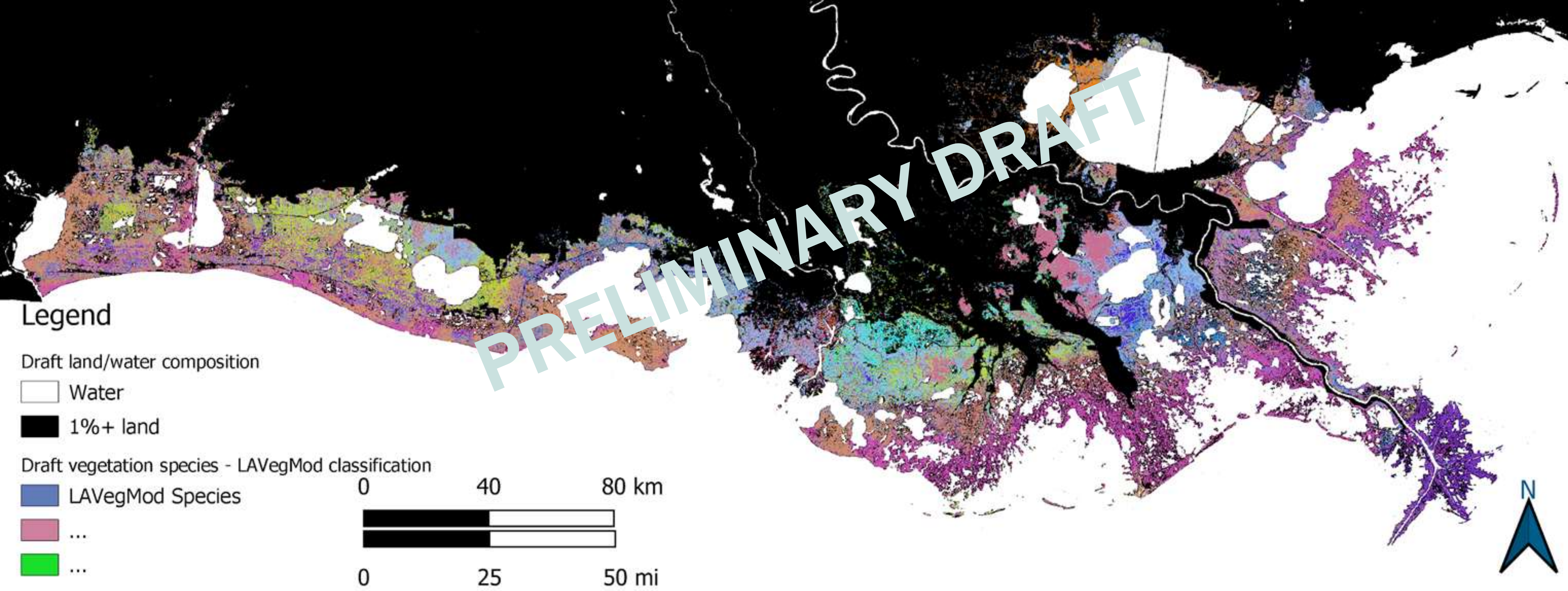

# EXISTING CONDITIONS (2018) TOPOBATHYMETRIC DEM

MOST RECENT TBDEM FROM LIDAR & BATHYMETRIC SURVEYS - FINAL MAP STILL UNDER REVIEW AND REVISIONS




# EXISTING CONDITIONS (2018) LAND/WATER COMPOSITION

**2018 LANDSCAPE CLASSIFIED BY % LAND - FINAL MAP STILL UNDER REVIEW AND REVISIONS**




# EXISTING CONDITIONS (2018) VEGETATION CLASSIFICATION

**2018 LANDSCAPE CLASSIFIED BY LAVEGMOD SPECIES - FINAL MAP STILL UNDER REVIEW AND REVISIONS**

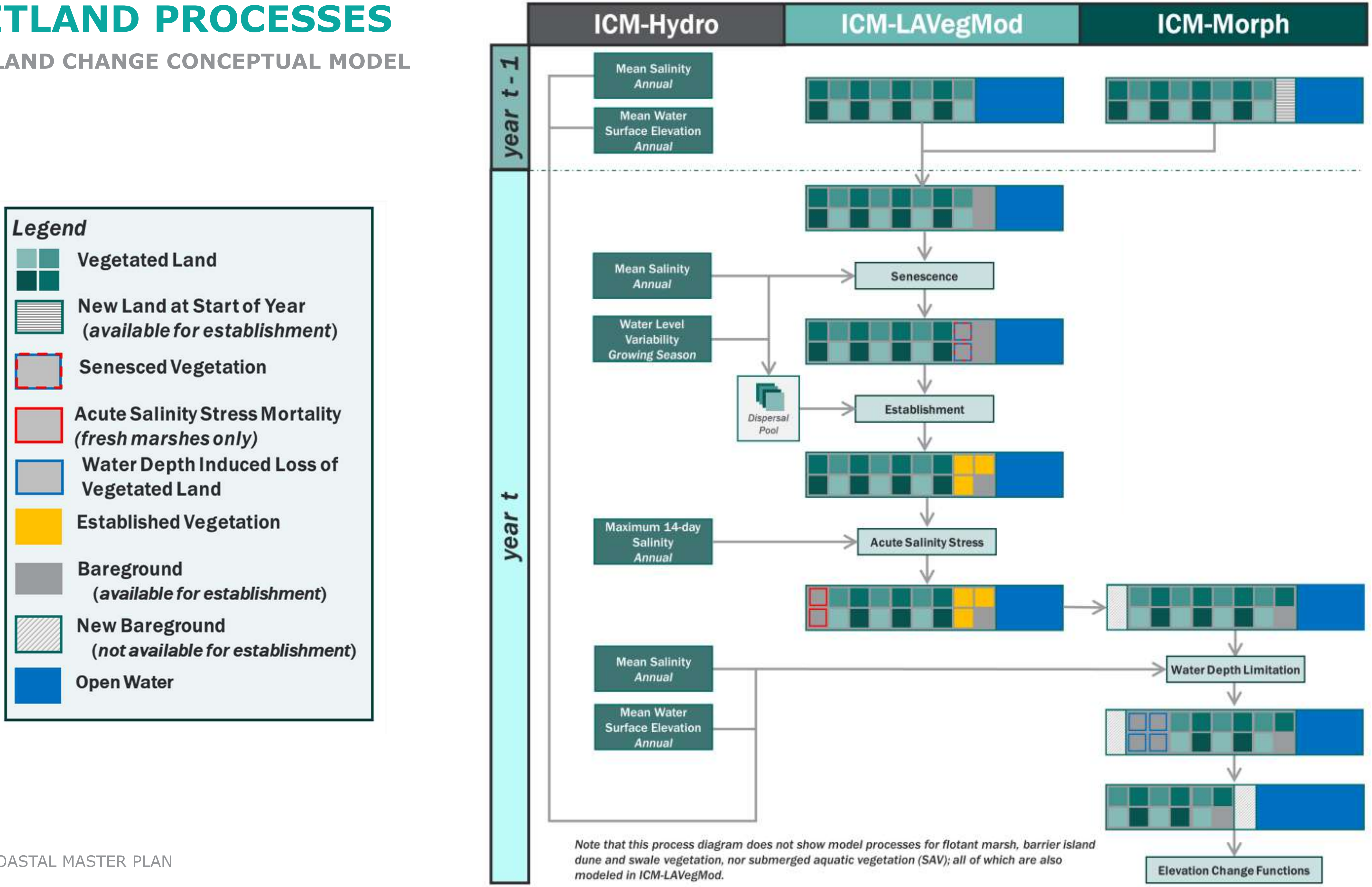
# WETLAND PROCESSES AND VEGETATION

## HABITATS AND SPECIES FOR NON-BARRIER ISLAND REGIONS

| Habitat | Species |
|---|---|
| Bottomland Hardwood Forest | *Quercus laurifolia, Quercus lyrata, Quercus nigra, Quercus texana, Quercus virginiana, Ulmus americana* |
| Swamp Forest | *Nyssa aquatica,Salix nigra, Taxodium distichum* |
| Fresh Floating Marsh | *Eleocharis baldwinii, Panicum hemitomon* |
| Fresh Attached Marsh | *Colocasia esculenta, Morella cerífera, Panicum hemitomon, Sagittaria latifolia, Zizaniopsis miliacea* |
| Intermediate Marsh | *Cladium mariscus, Eleocharis cellulosa, Iva frutescens, Paspalum vaginatum, Phragmites australis, Polygonum punctatum, Sagittaria lancifolia, Schoenoplectus californicus, Typha domingensis* |
| Brackish Marsh | *Schoenoplectus americanus, Schoenoplectus robustus, Spartina cynosuroides, Spartina patens* |
| Saline Marsh | *Avicennia germinans, Distichlis spicata, Juncus roemerianus, Spartina alterniflora* |

# WETLAND PROCESSES

## ICM LAND CHANGE CONCEPTUAL MODEL

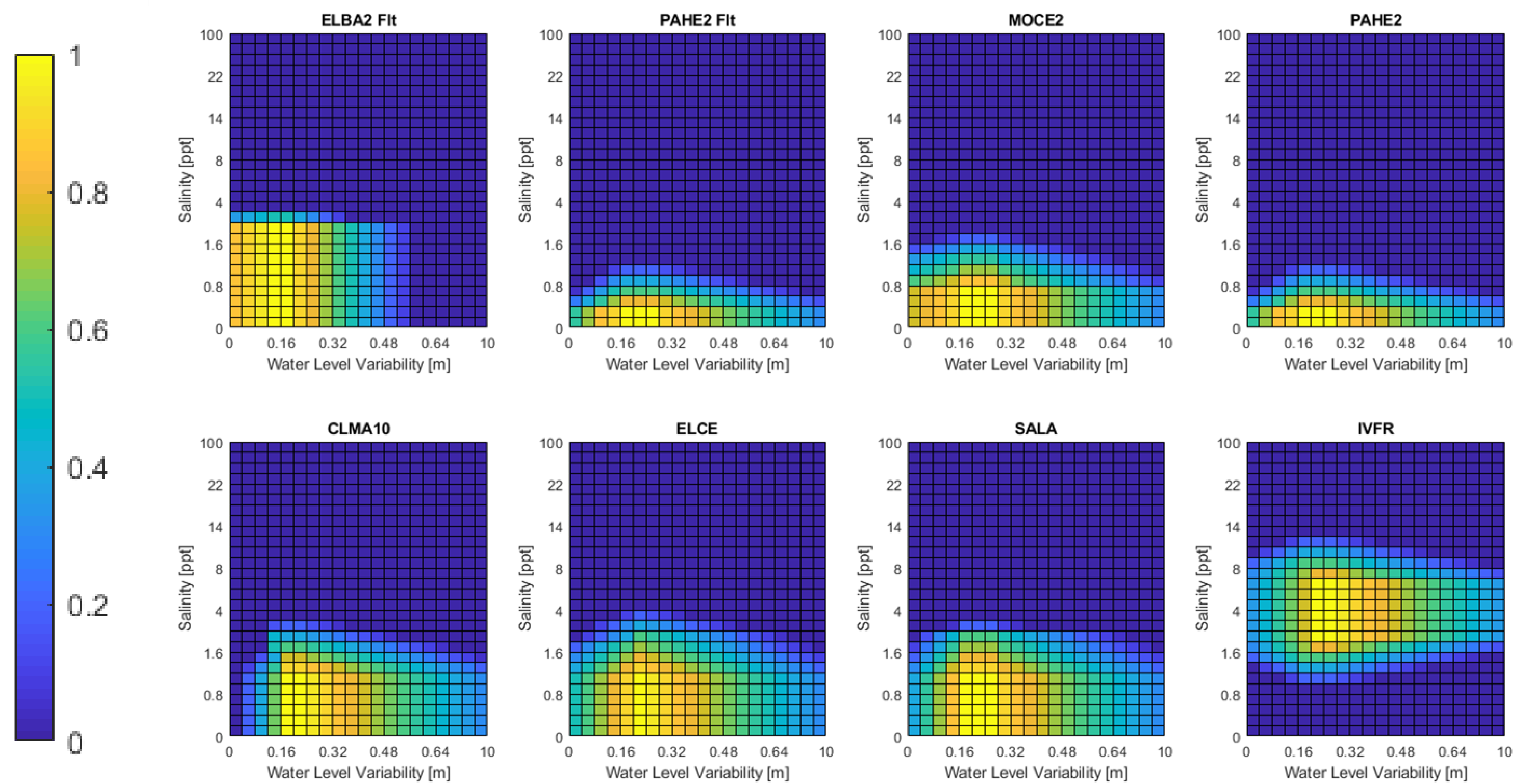



*Note that this process diagram does not show model processes for flotant marsh, barrier island dune and swale vegetation, nor submerged aquatic vegetation (SAV); all of which are also modeled in ICM-LAVegMod.*

# ESTABLISHMENT TABLES FOR SPECIES WITH LIMITED DISPERSAL

- 19 emergent marsh species have limited dispersal distance

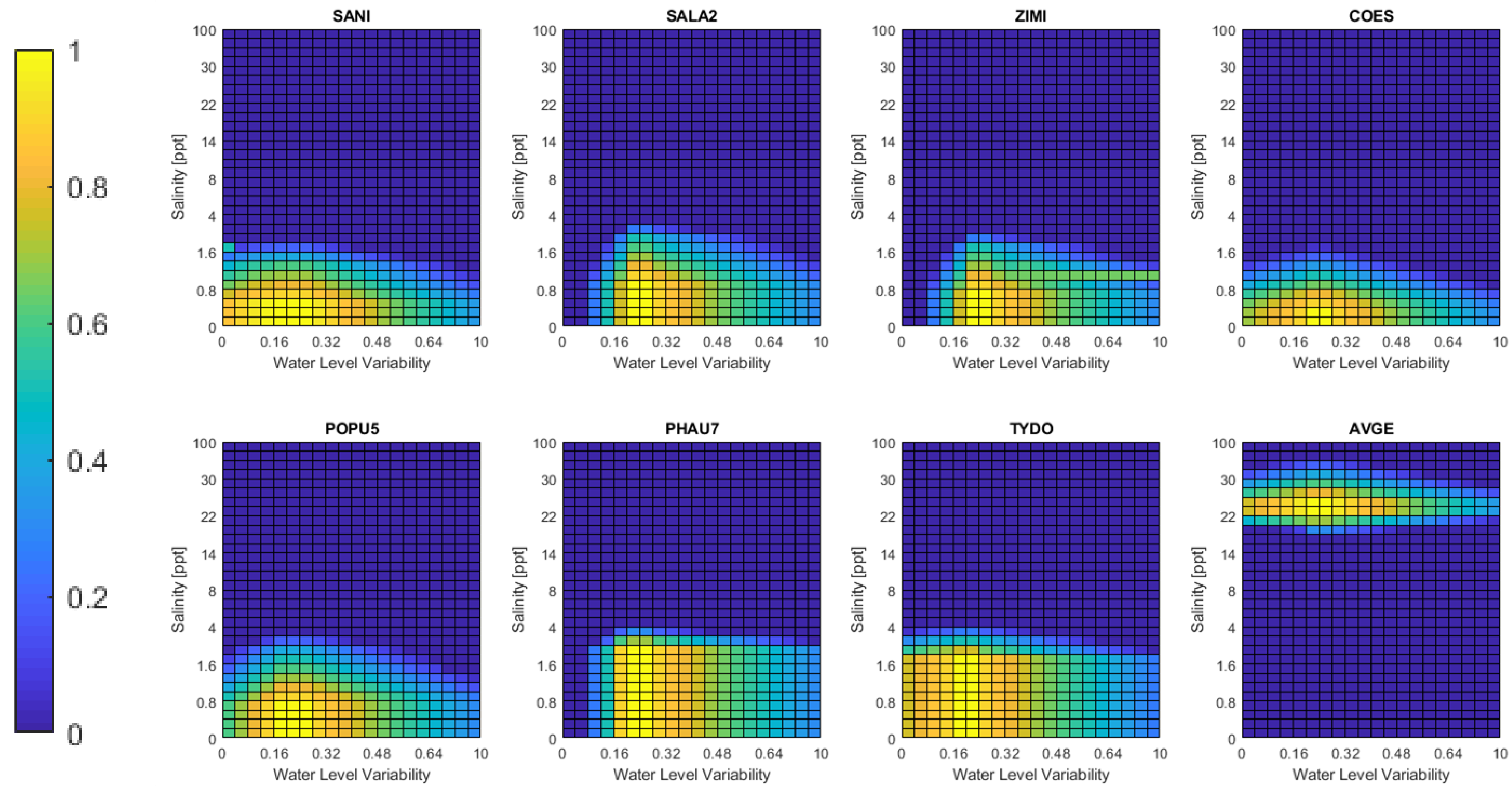
- These species will only establish if preferred/niche conditions are met AND the species is already present nearby




Establishment tables for vegetation species with a maximum allowable dispersal distance.

# ESTABLISHMENT TABLES FOR SPECIES WITH UNLIMITED DISPERSAL

- 8 emergent marsh species are not limited by a dispersal distance criteria
- These species will freely establish if preferred/niche conditions are met regardless of previous presence in the vicinity

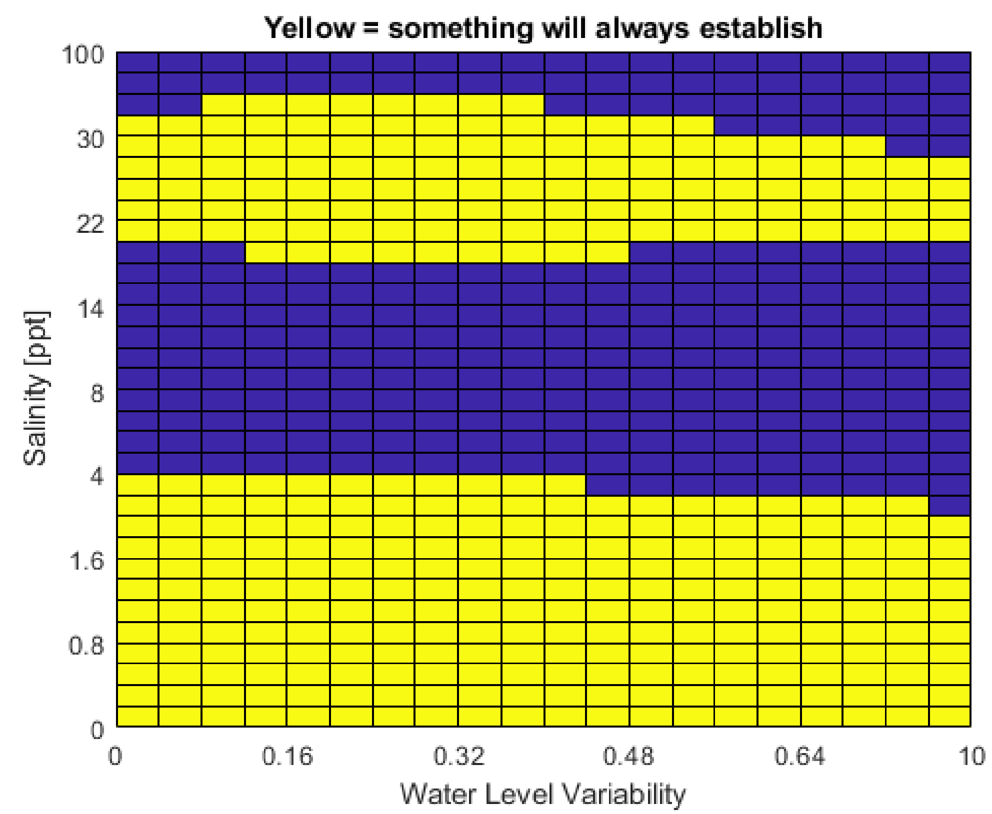



Establishment tables for vegetation species with a no limit to establishment based on dispersal distance.

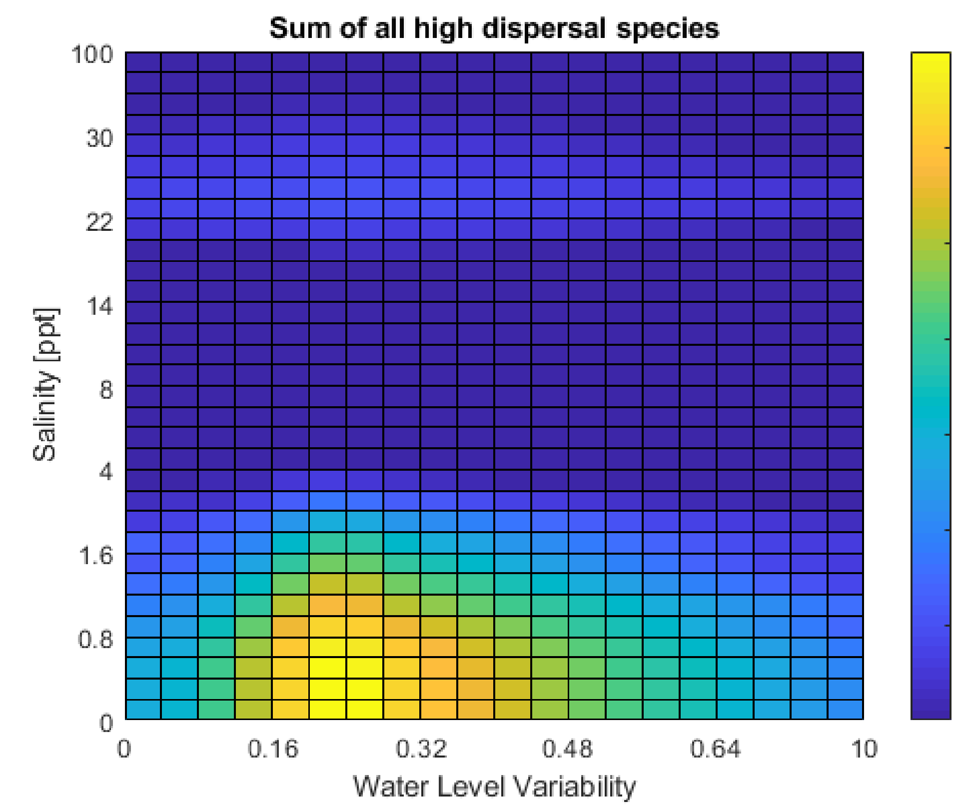
# SALINITY CONDITIONS AND DISPERSAL DISTANCE

- Establishment will always occur if salinity is lower than ~3 ppt or greater than ~20 ppt (yellow area)

- Otherwise (blue area), only nearby species will be able to establish




Salinity zones where vegetation species will always establish (yellow), or where only nearby vegetation species can move in (blue).

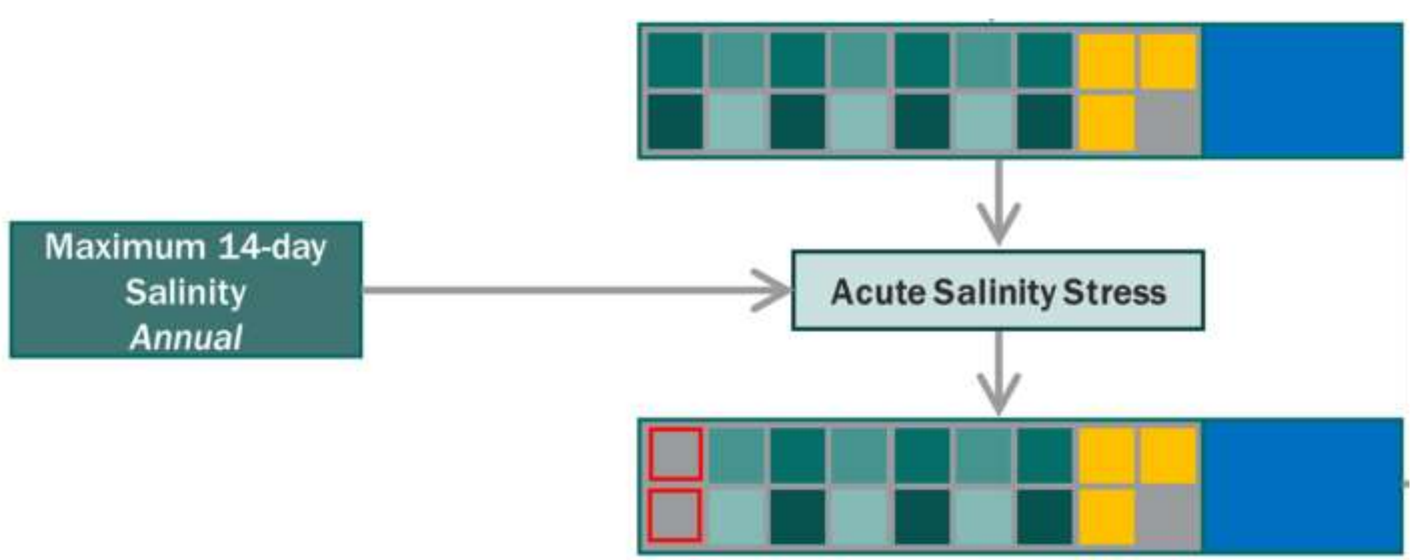



Sum of establishment probability for all species with no dispersal distance limitations.

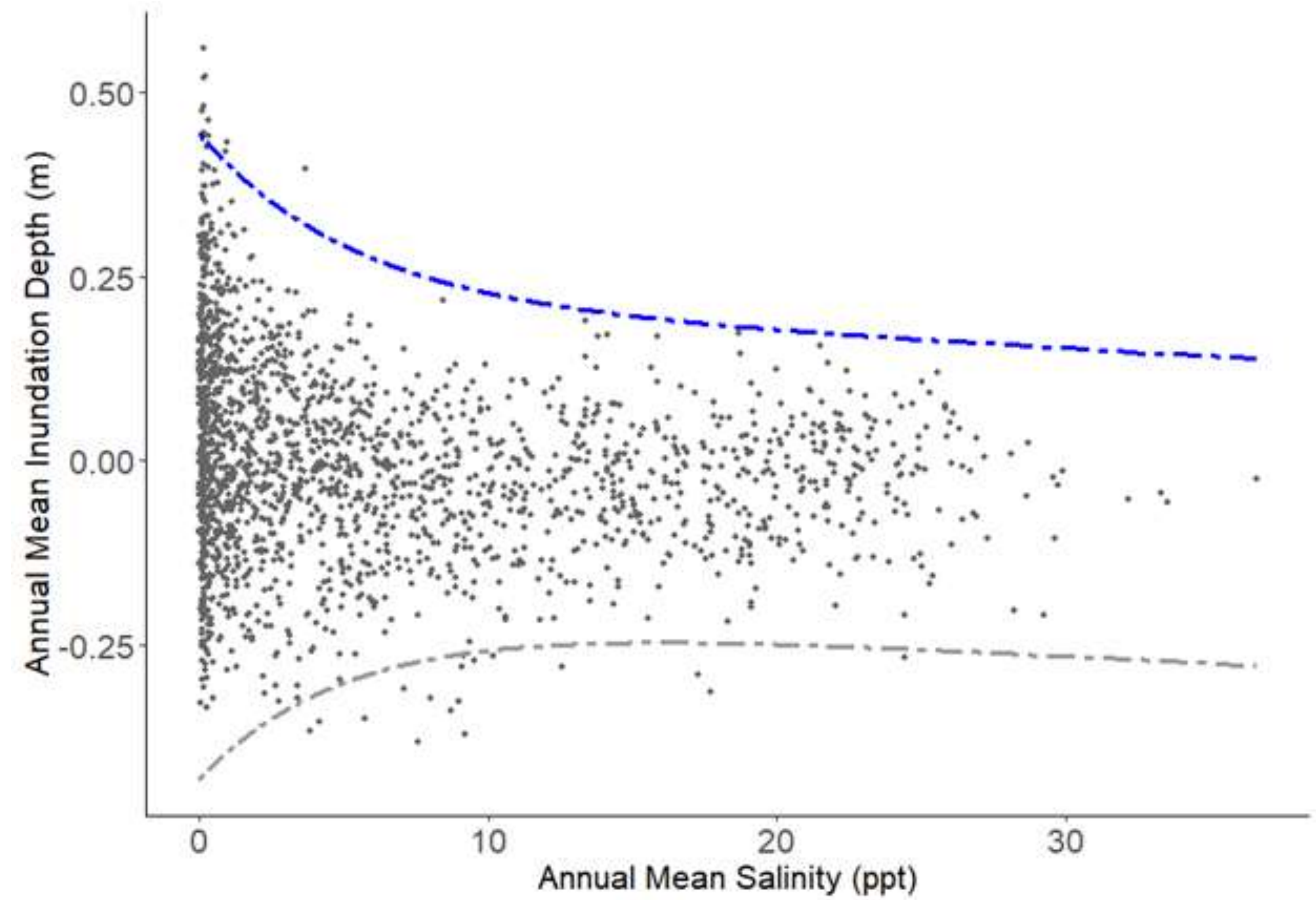
# ADDITIONAL MORTALITY FUNCTIONS

Fresh marshes are subject to a short-term/acute salinity shock stressor

All attached marshes are subject to a water depth limitation (varies by salinity)



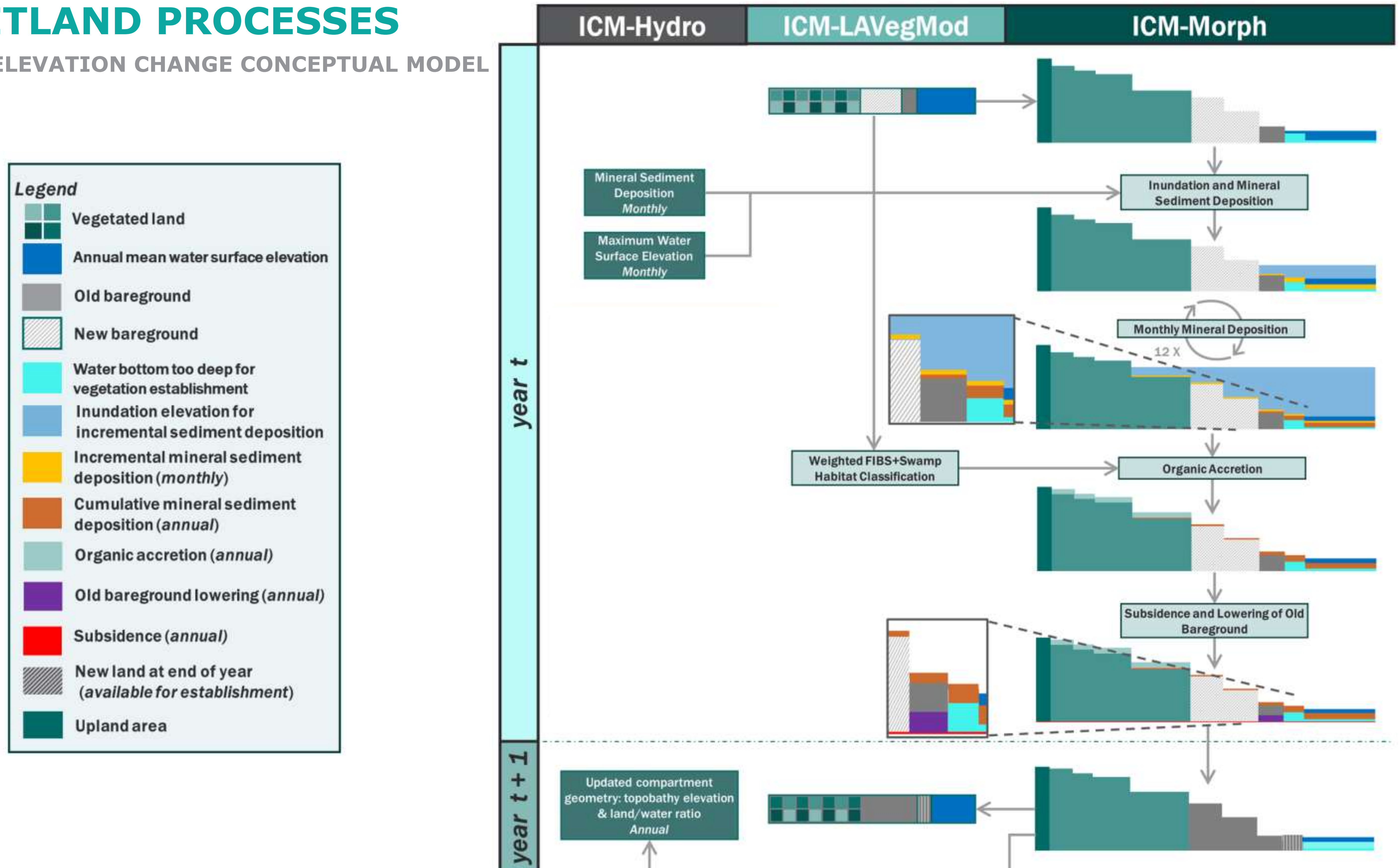

Acute salinity stress is determined from the maximum two-week mean salinity experienced during the year.




Salinity-inundation depth relationship used to define water depth limitation on vegetation (from CRMS data analysis). Lines are the 0.5th (gray) and 99.5th percentiles.

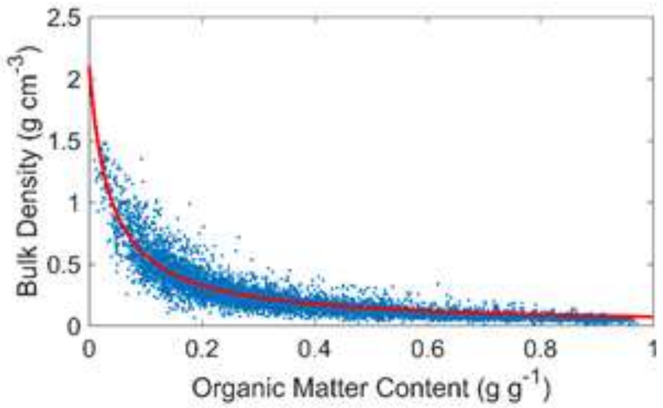
# WETLAND PROCESSES

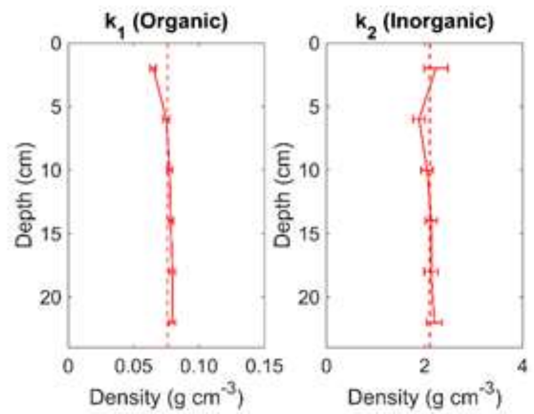
## ICM ELEVATION CHANGE CONCEPTUAL MODEL

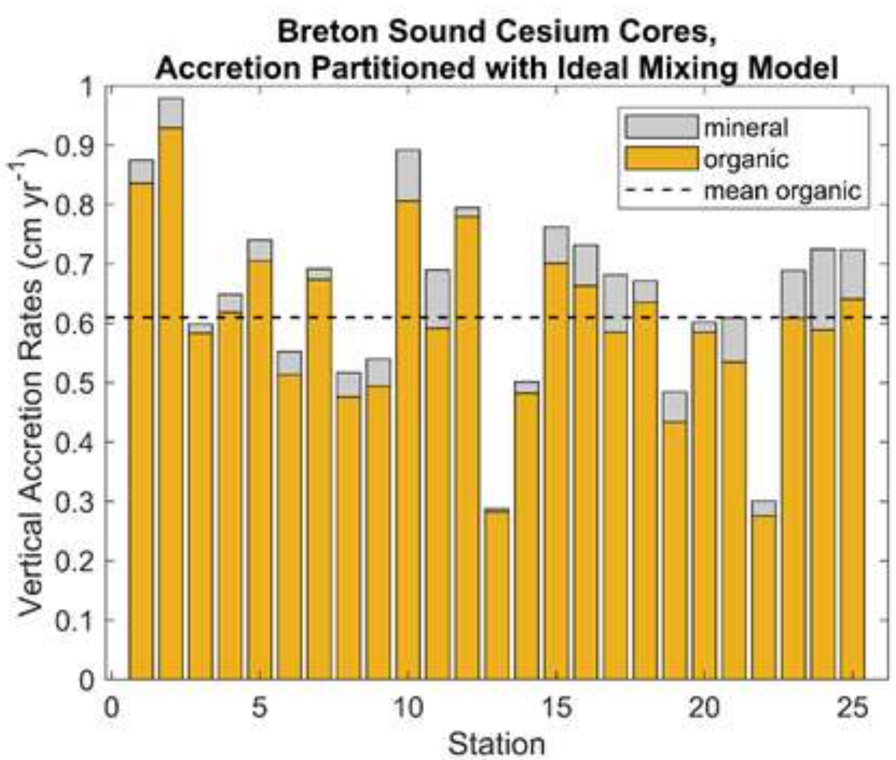


# WETLAND PROCESSES

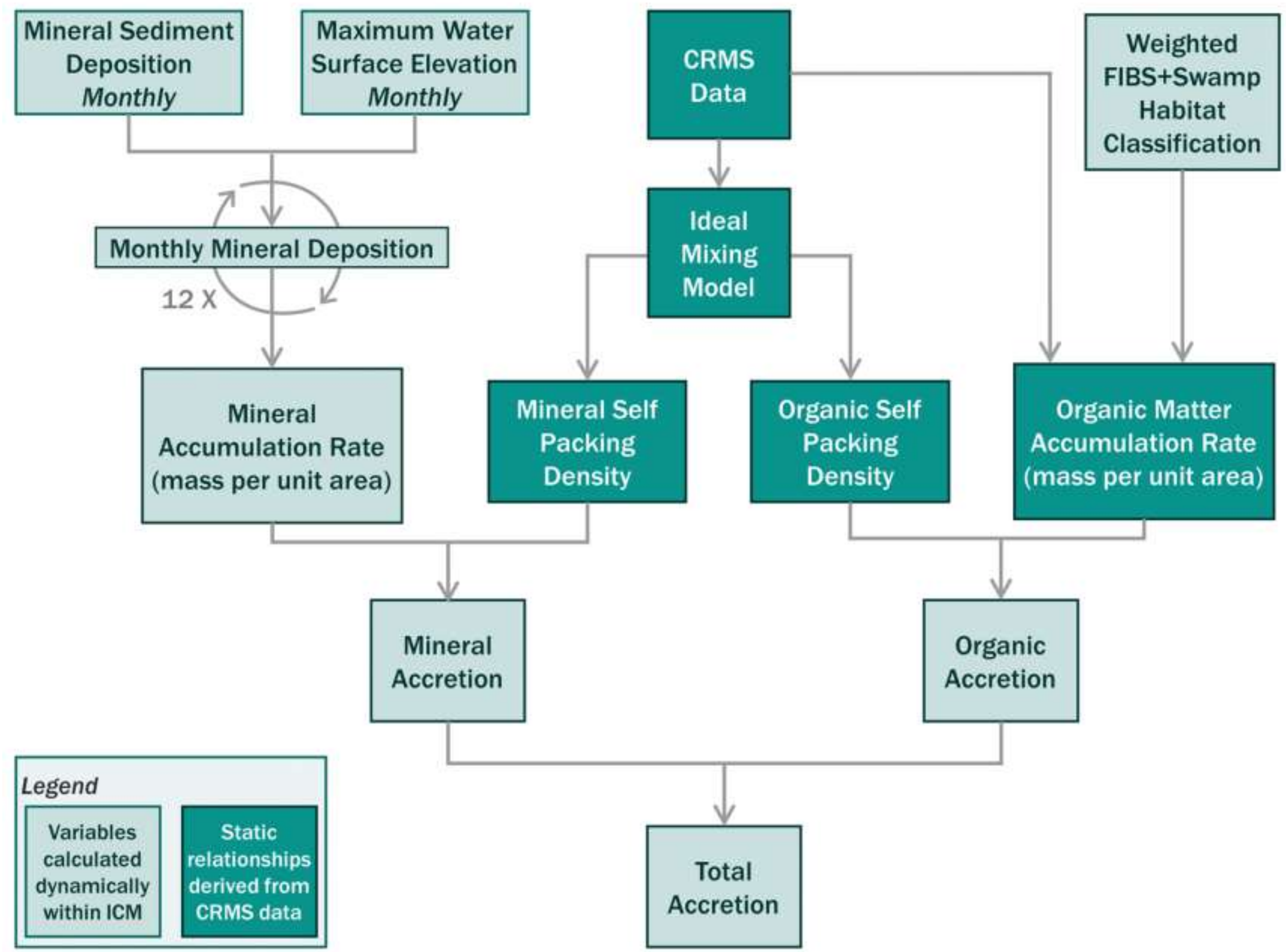
## VERTICAL ACCRETION MODEL



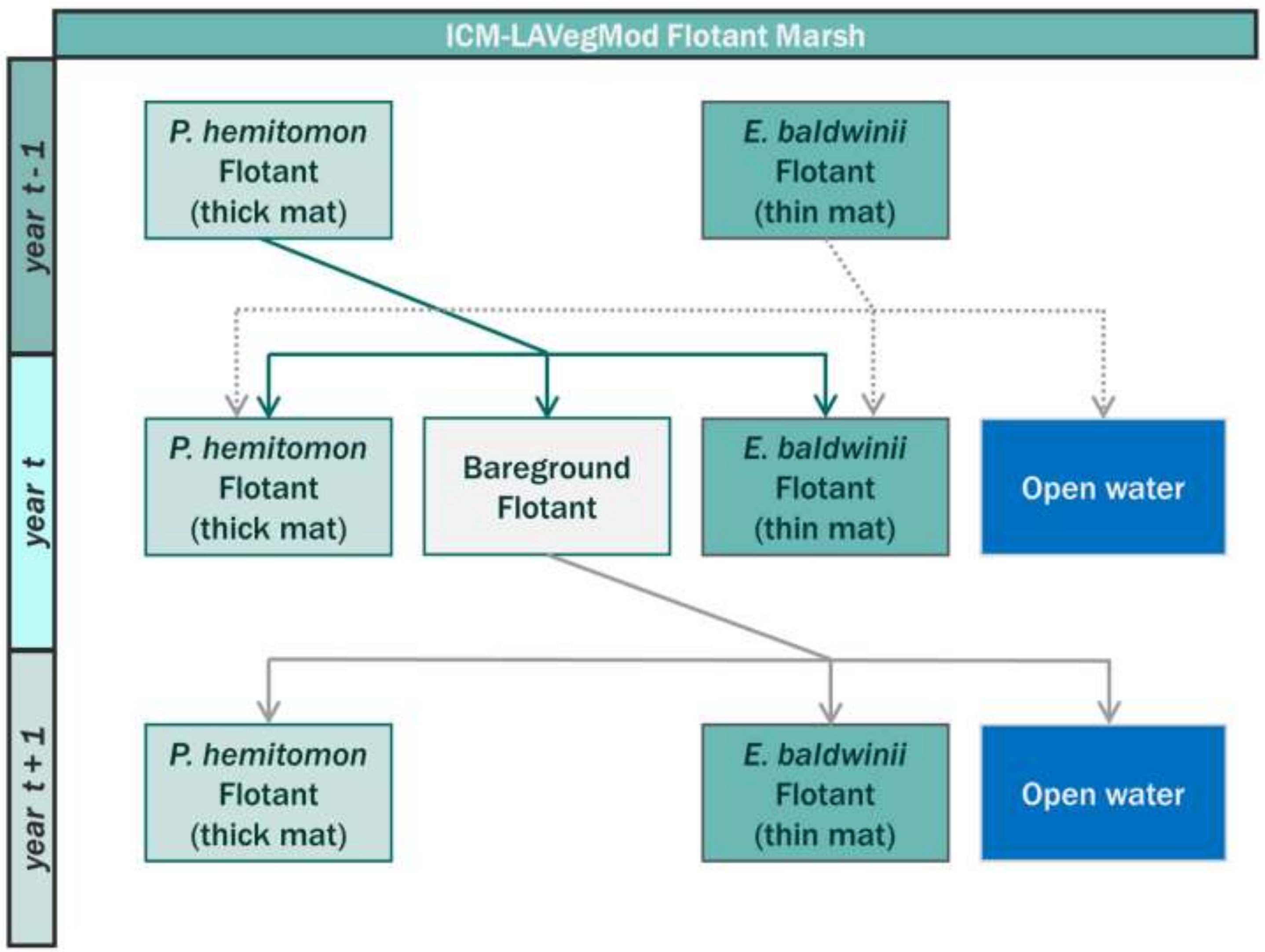




- CRMS bulk density vs. organic matter - DRAFT - relationship currently being updated with additional data (top left).
- Ideal mixing model self-packing densities from CRMS data (top right).
- Sample mineral and organic accretion from ideal mixing model application (bottom).

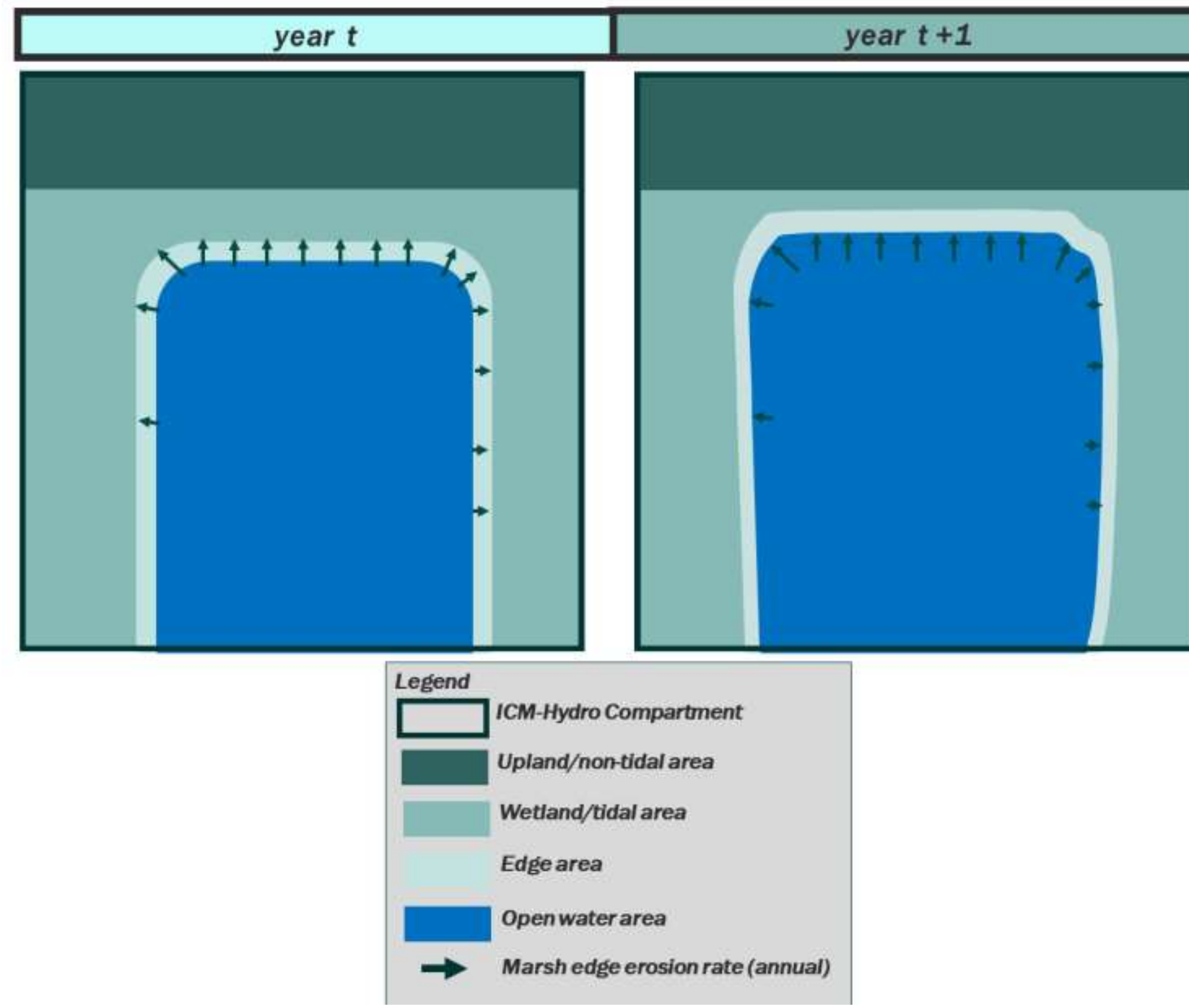



Process and conceptual diagram for vertical accretion functions in ICM.

# ADDITIONAL WETLAND PROCESSES AND VEGETATION FUNCTIONS: FLOTANT MARSH AND EDGE EROSION

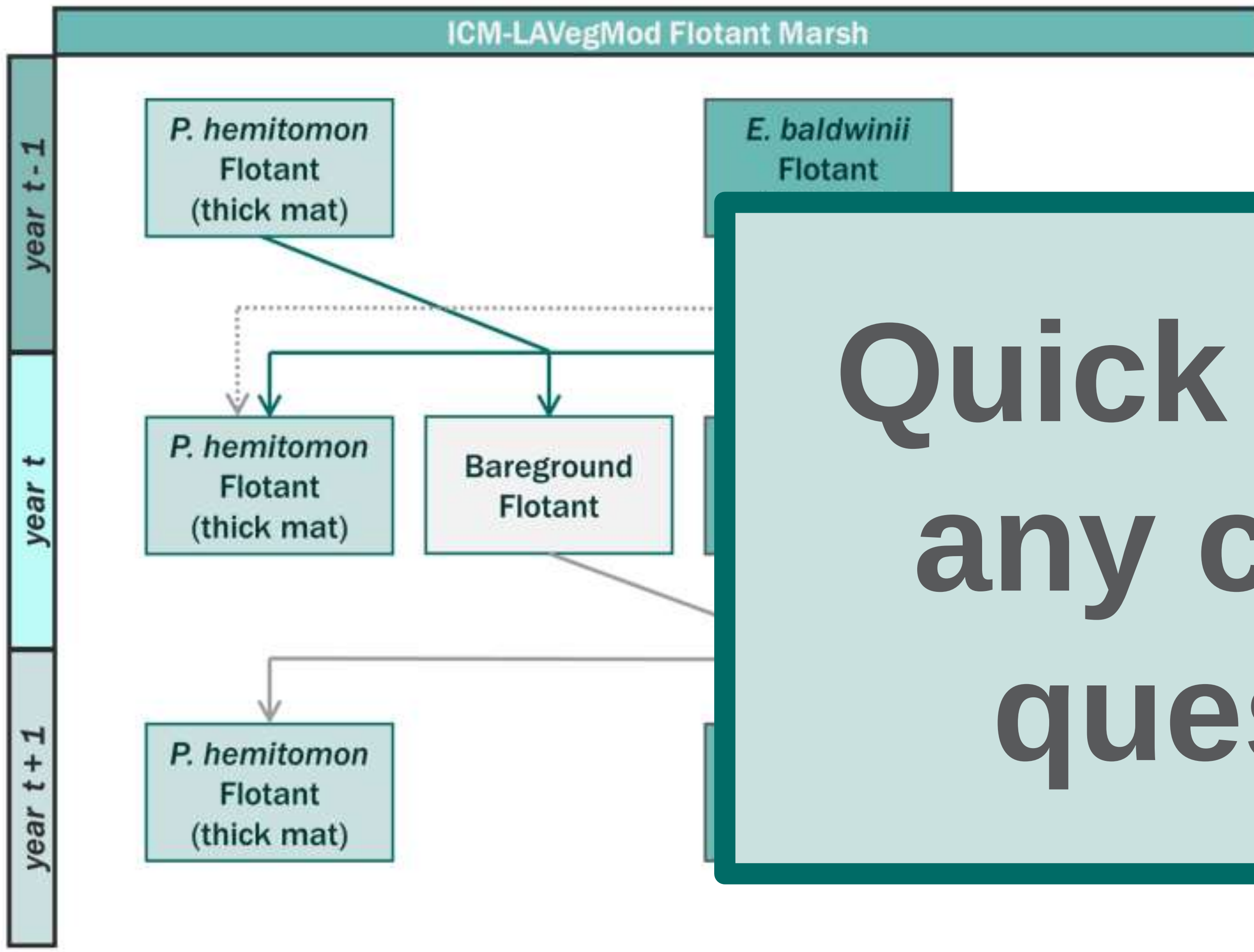



Schematic of flotant marsh functions in ICM-LAVegMod.

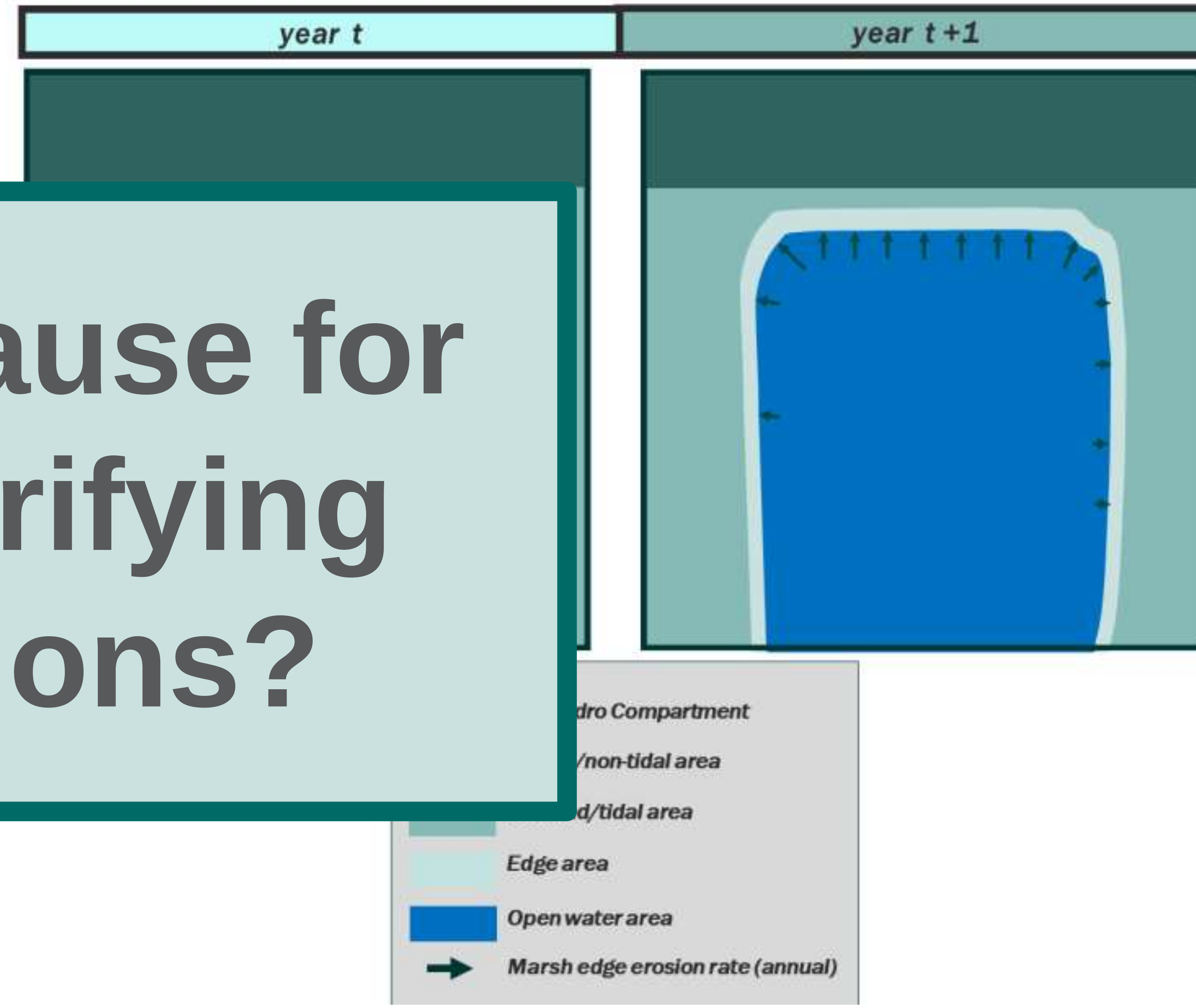



Schematic of marsh edge erosion - rates derived from historic satellite imagery.

# ADDITIONAL WETLAND PROCESSES AND VEGETATION FUNCTIONS: FLOTANT MARSH AND EDGE EROSION




Schematic of flotant marsh functions in ICM-LAVegMod.

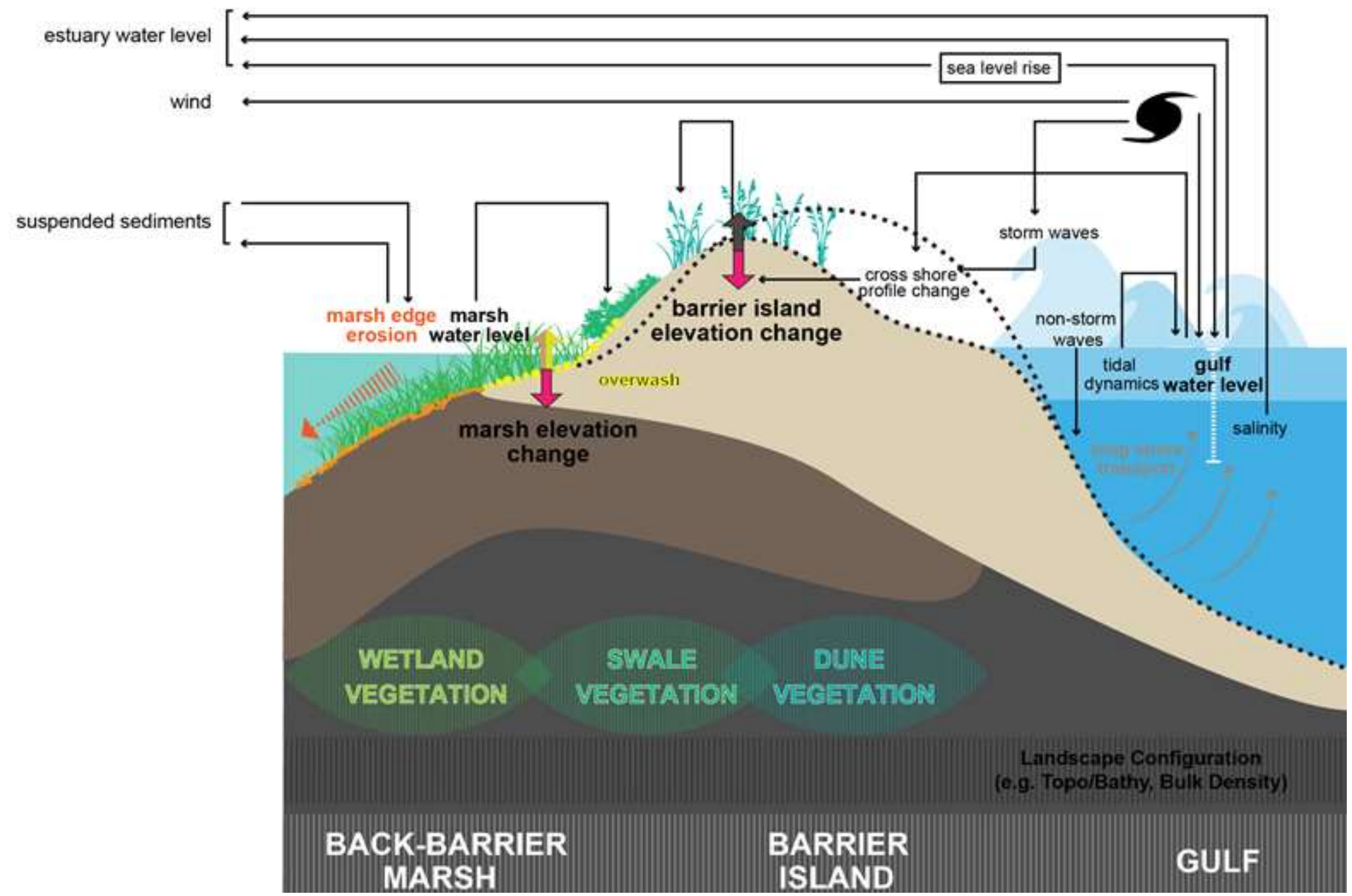



Schematic of marsh edge erosion - rates derived from historic satellite imagery.

**Quick pause for any clarifying questions?**

# ICM-BARRIER ISLAND MODEL

- Barrier island processes modeled in two parts for 2023
  - Barrier Island Tidal Inlet Model (ICM-BITI)
  - Barrier Island Digital Elevation Model (ICM-BIDEM)
- Both components are empirical, non-process-based models
  - Simplification over past modeling in 2017 Master Plan

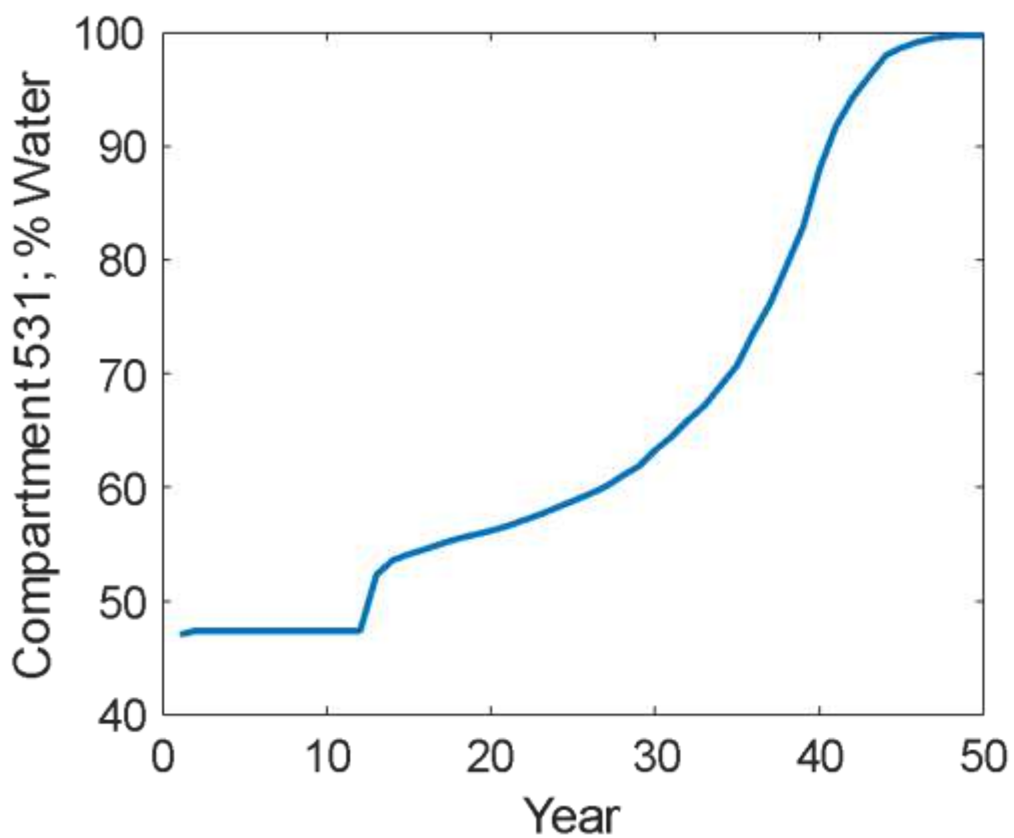



Conceptual model of barrier island processes from the 2017 ICM.

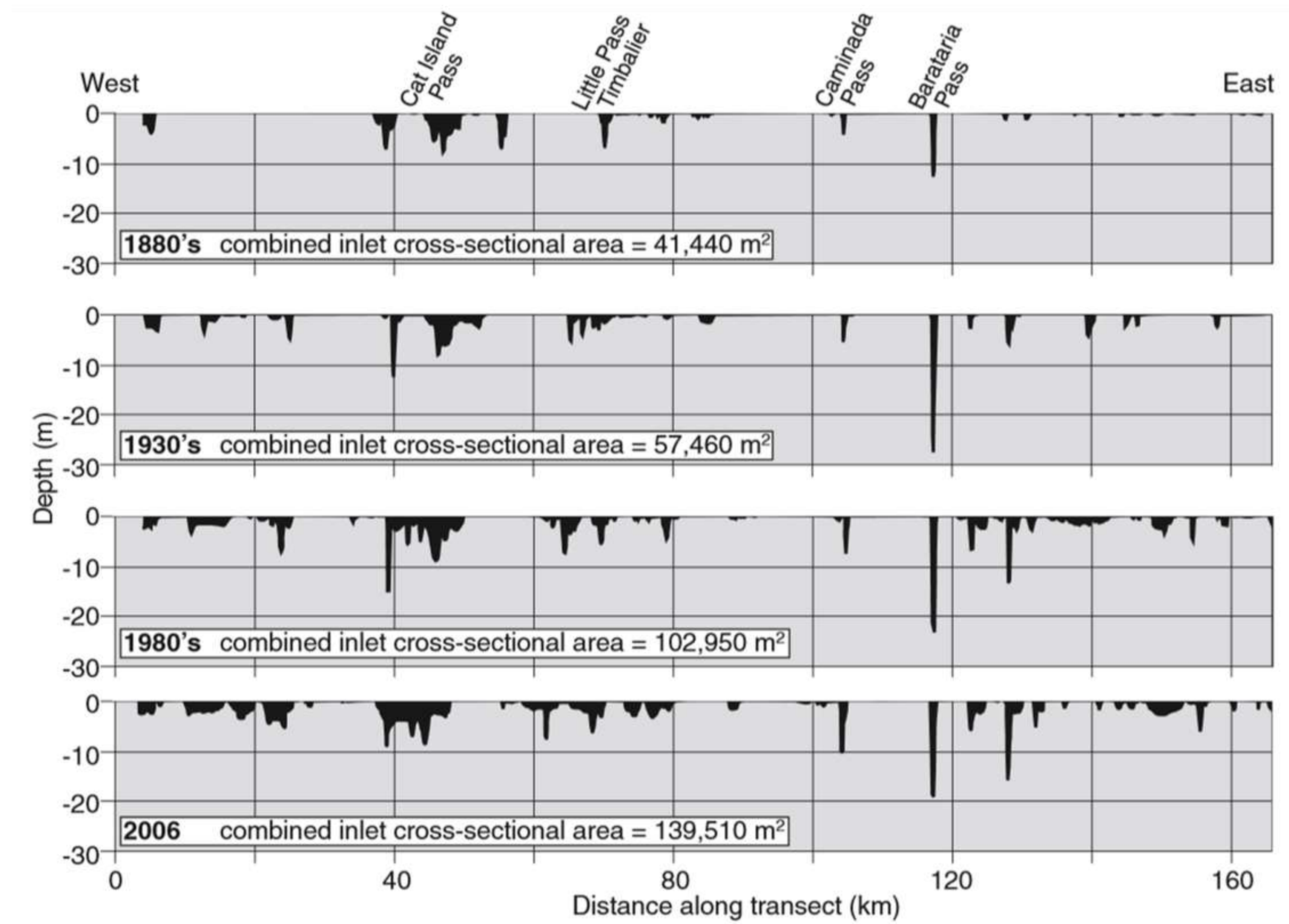
# BARRIER ISLAND TIDAL INLET MODEL

**ICM-BITI**

## Tidal inlet cross-sectional area will change proportional to change in basin tidal prism.




Change in % water in one ICM-Hydro compartment from 2017 ICM.

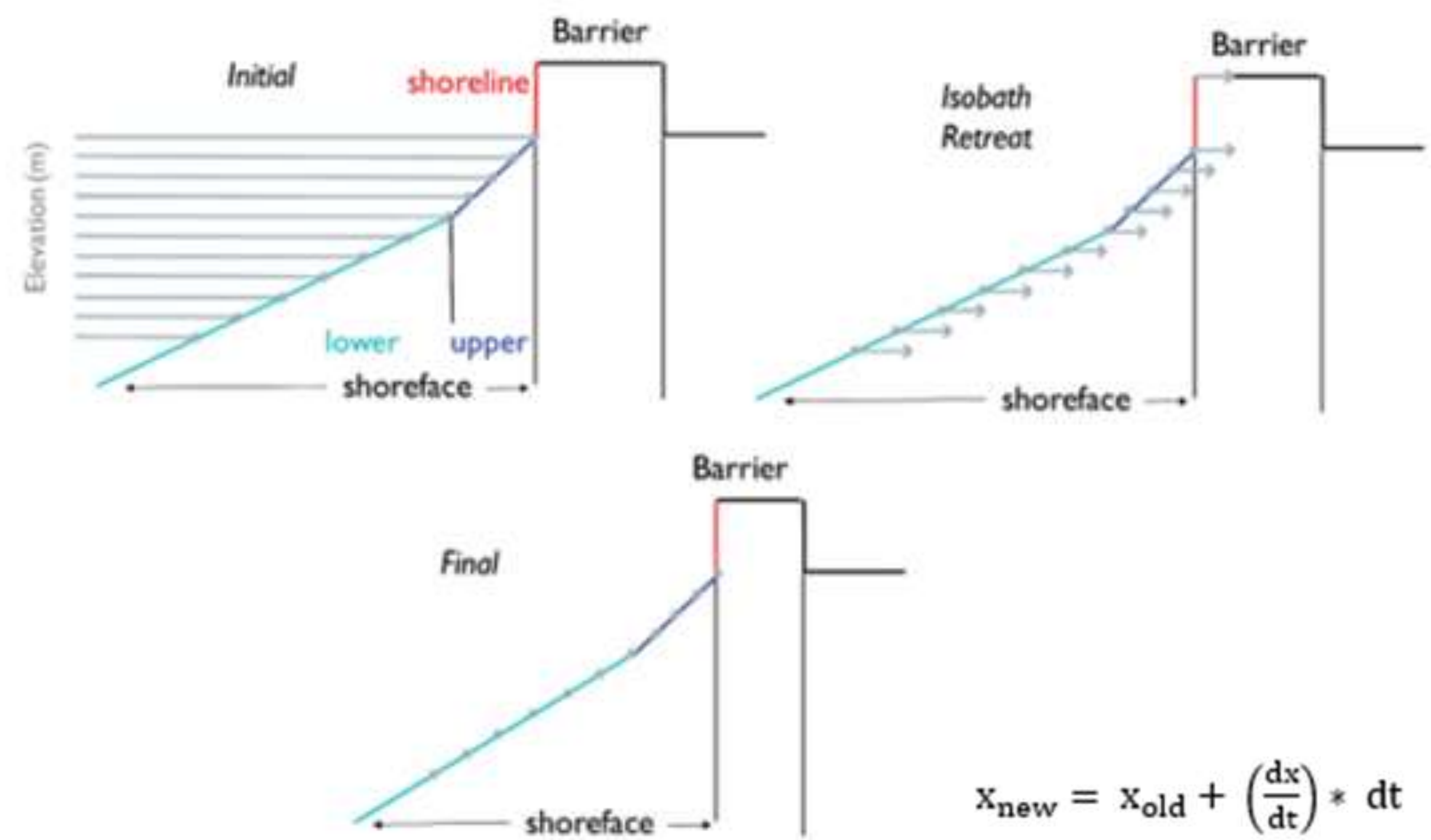



Historical trends in tidal inlet cross-sectional area for Raccoon Point to Sandy Point (1880–2006). Figure from Miner et al., (2009).

# BARRIER ISLAND DIGITAL ELEVATION MODEL

## ICM-BI-DEM

- ICM-BI-DEM evolves the shoreline and shoreface using historic rates.
- Each depth and profile has a unique retreat rate (dx/dt).
- Shoreface slope will change over time as a function of these retreat rates.




$$x_{new} = x_{old} + \left(\frac{dx}{dt}\right) * dt$$

Conceptual model of ICM-BI-DEM empirical processes.

# BARRIER ISLAND DIGITAL ELEVATION MODEL

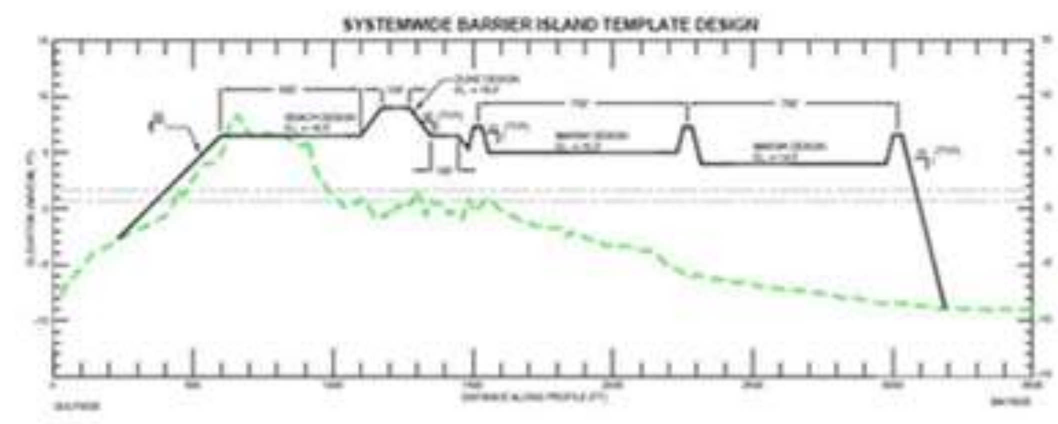
**ICM-BI-DEM**

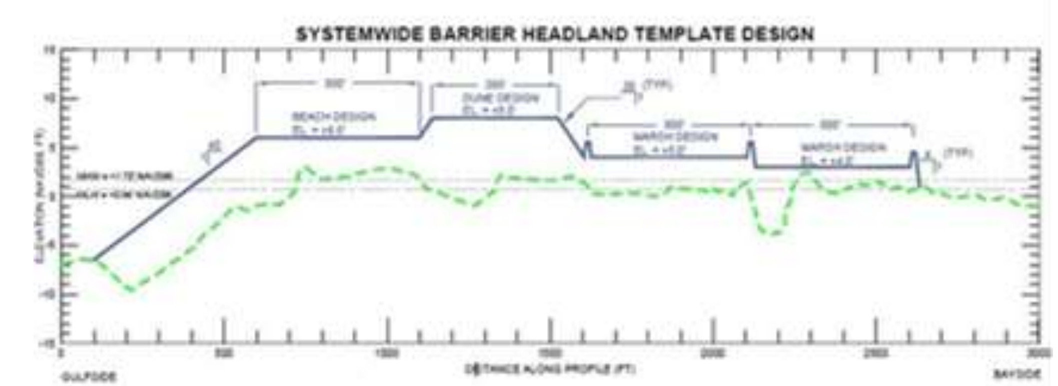
- A maintenance restoration module is added that simulates restoring a barrier island if a critical minimum width threshold is reached.

- This will be applied automatically in the model, in concordance with the Barrier Island System Management (BISM) program

- Exact details on thresholds which will trigger maintenance events are still being decided.

- End result is a model that systematically maintains the integrity of barrier islands over time, without focusing on individual ‘projects’.




Barrier island restoration templates for assumed maintenance. Figure from CEC (2015).

# ECOSYSTEM OUTCOMES: HABITAT SUITABILITY INDICES

# HABITAT SUITABILITY INDICES (HSIs)

## ECOSYSTEM OUTCOMES: NO FEEDBACK INTO LANDSCAPE MODEL SUBROUTINES

Input data feeds into HSIs

Calculations performed annually

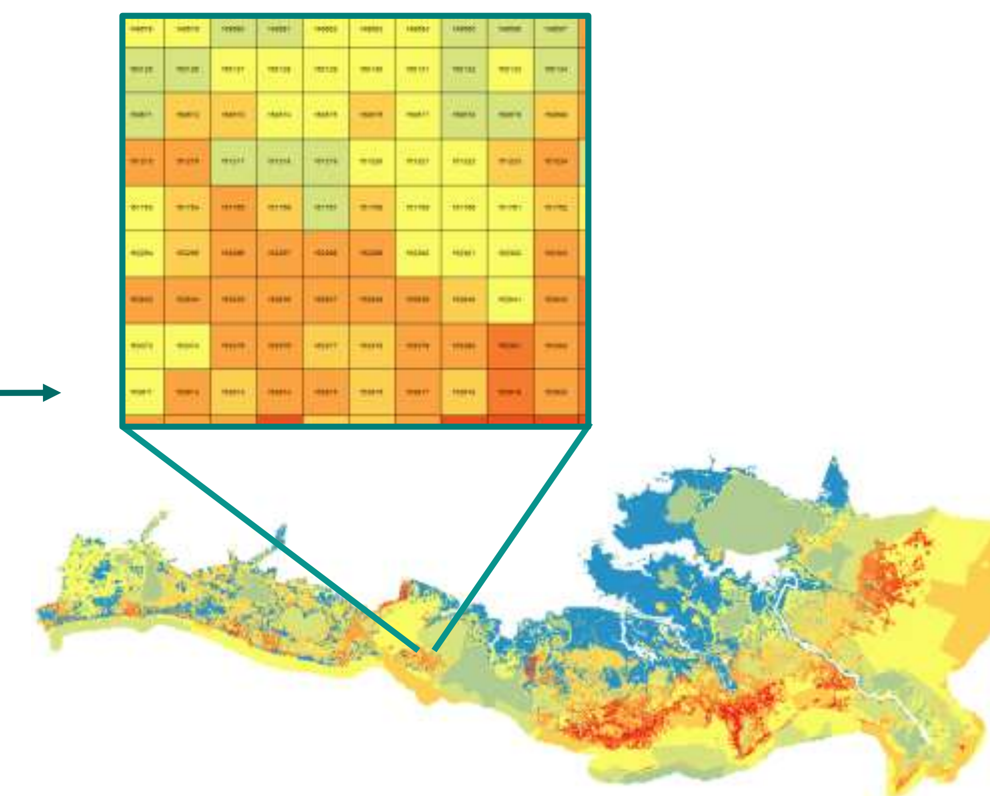
HSI scores (0-1) generated per 500-m grid cell per species

Hydrology

Morphology

Vegetation

HSI

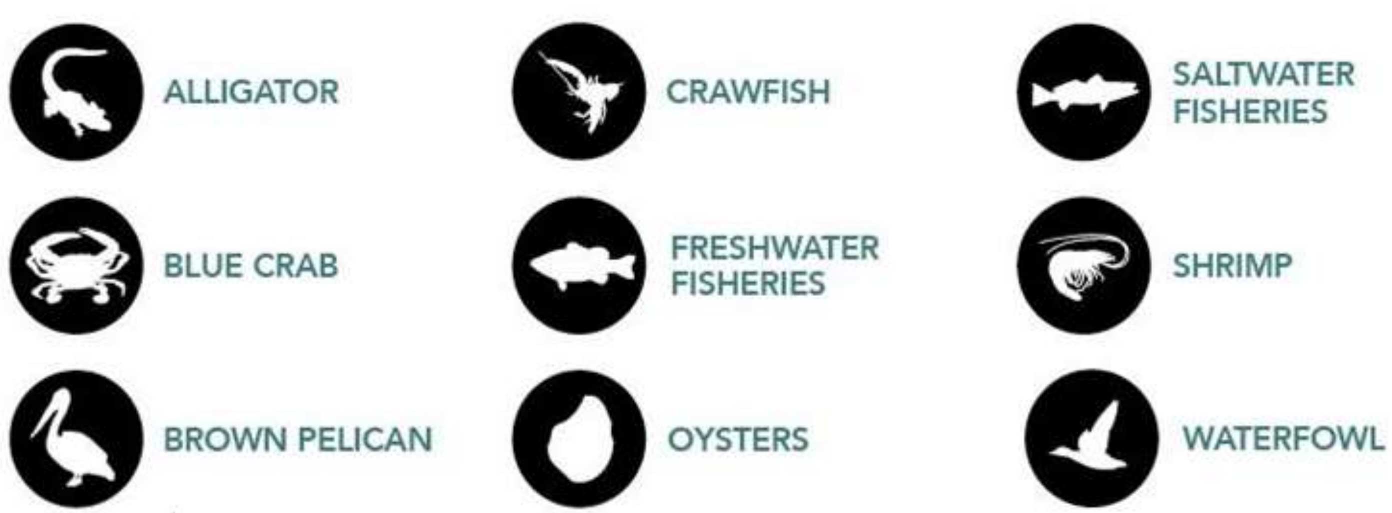


HSI map at bottom right indicates a higher habitat suitability (warmer colors) in more saline environments and a higher suitability in marsh areas as compared to open water areas.

# HABITAT SUITABILITY INDICES: MODELED SPECIES

**HSIs developed from literature review and expert opinion:**

- American Alligator
- Bald Eagle[+^]
- Brown Pelican
- Crayfish
- Eastern Oyster
- Gadwall
- Mottled Duck
- Seaside Sparrow[+]




**HSIs developed from statistical models, literature review and expert opinion:**

- Blue Crab (juvenile)
- Brown Shrimp
  - Small juvenile
  - Large juvenile
- Gulf Menhaden
  - Juvenile
  - Adult
- Largemouth Bass
- Spotted Seatrout
  - Juvenile
  - Adult
- White Shrimp
  - Small juvenile
  - Large juvenile

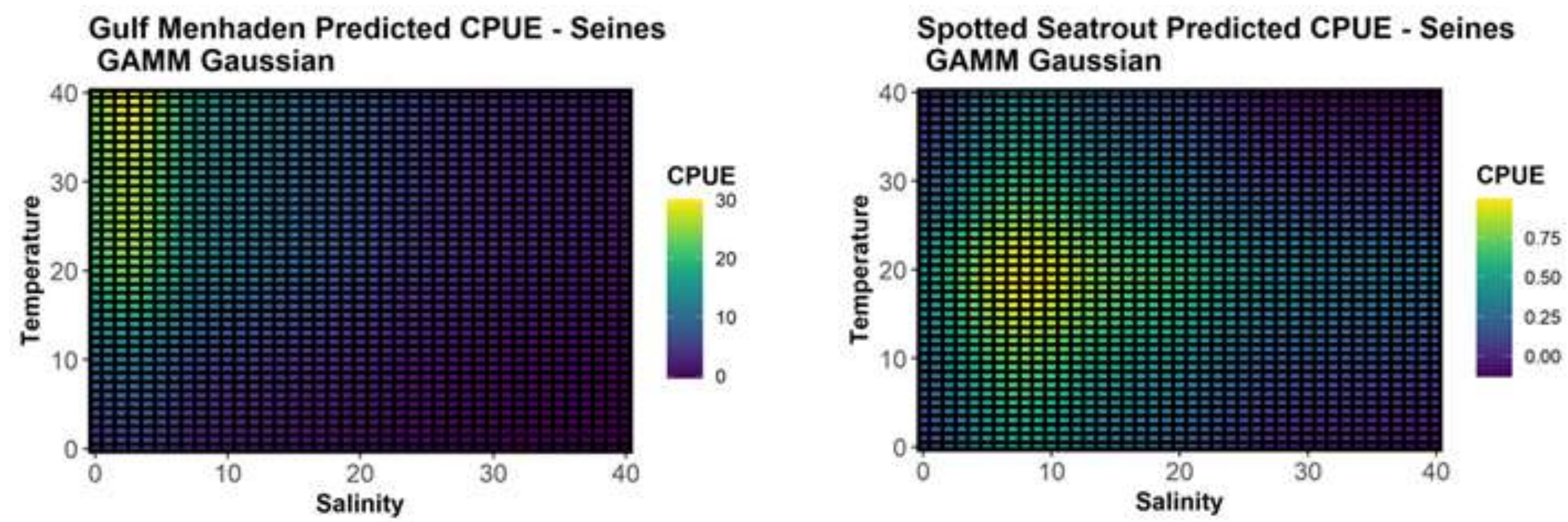
*[+]new for 2023*
*[^]different grid size*

# HABITAT SUITABILITY INDICES: STATISTICAL WATER QUALITY MODELS

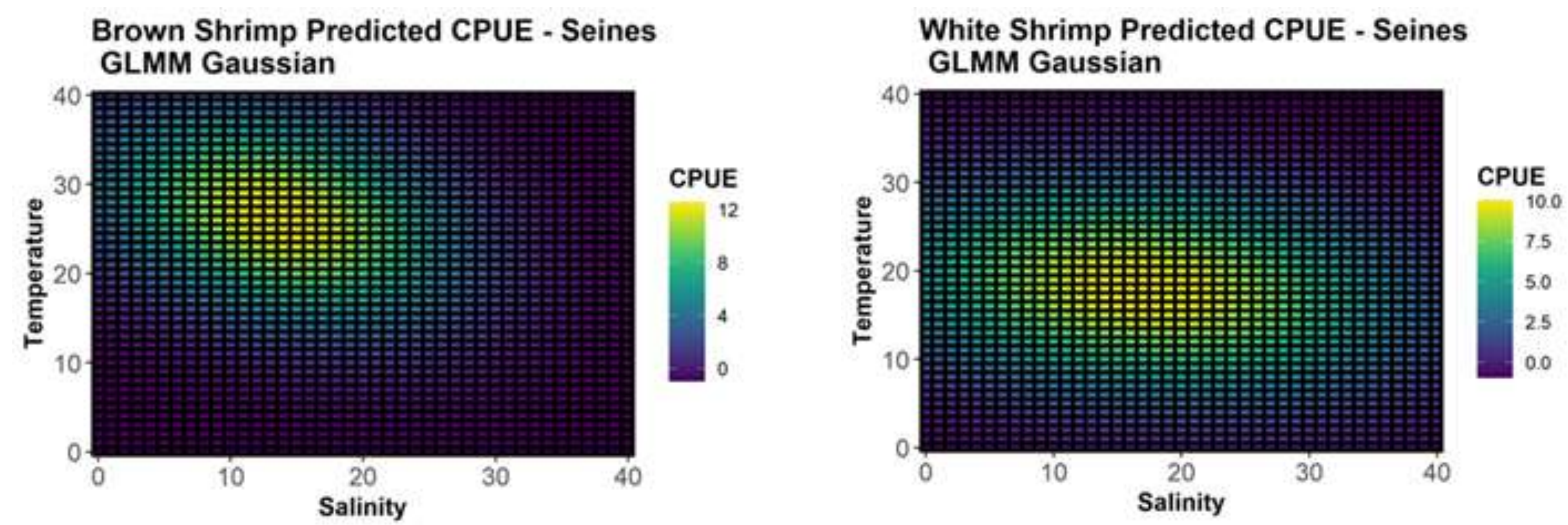
**MODELING CATCH PER UNIT EFFORT**

<u>Salinity-temperature models</u>

- Dept. Wildlife & Fisheries data used to develop statistical models for Catch Per Unit Effort (CPUE)
- Statistical model varied by species
  - Generalized linear mixed model
  - Generalized additive mixed models
- Error distribution model also varied by species
  - Gaussian distribution
  - Poisson distribution


Sample CPUE/salinity/temperature relationship from generalized additive mixed models (GAMM) with a Gaussian error distribution. *Final model will be limited to extent of environmental conditions in LDWF dataset.*

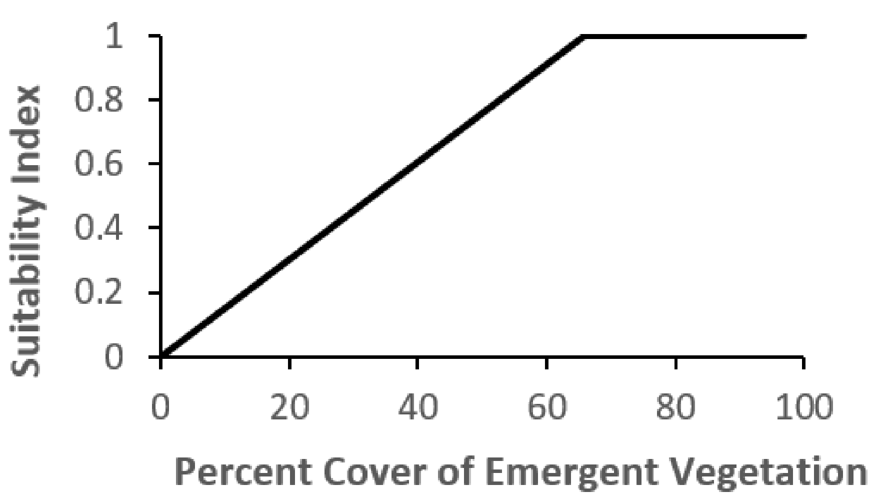



Sample CPUE/salinity/temperature relationship from generalized linear mixed models (GLMM) with a Gaussian error distribution. *Final model will be limited to extent of environmental conditions in LDWF dataset.*

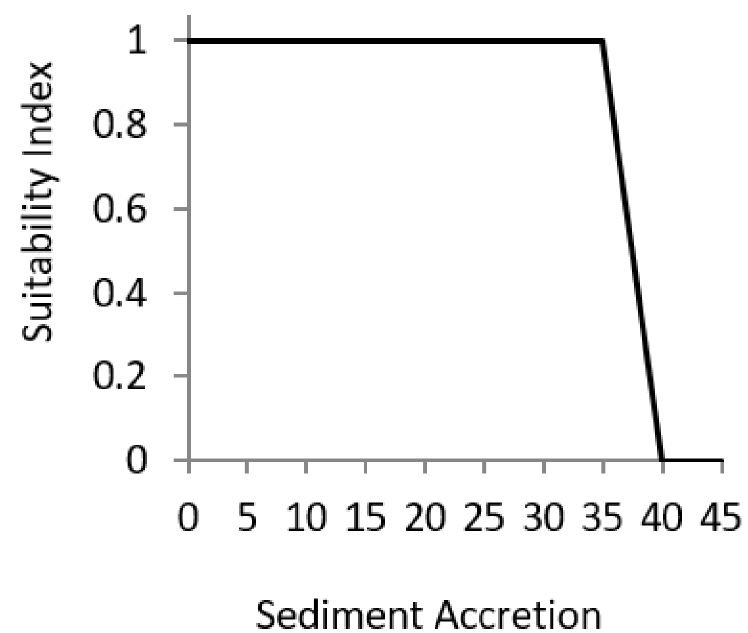
# HABITAT SUITABILITY INDICES: LITERATURE-REVIEW BASED INDICES


**Several species do not have enough observational data available to develop statistical models**

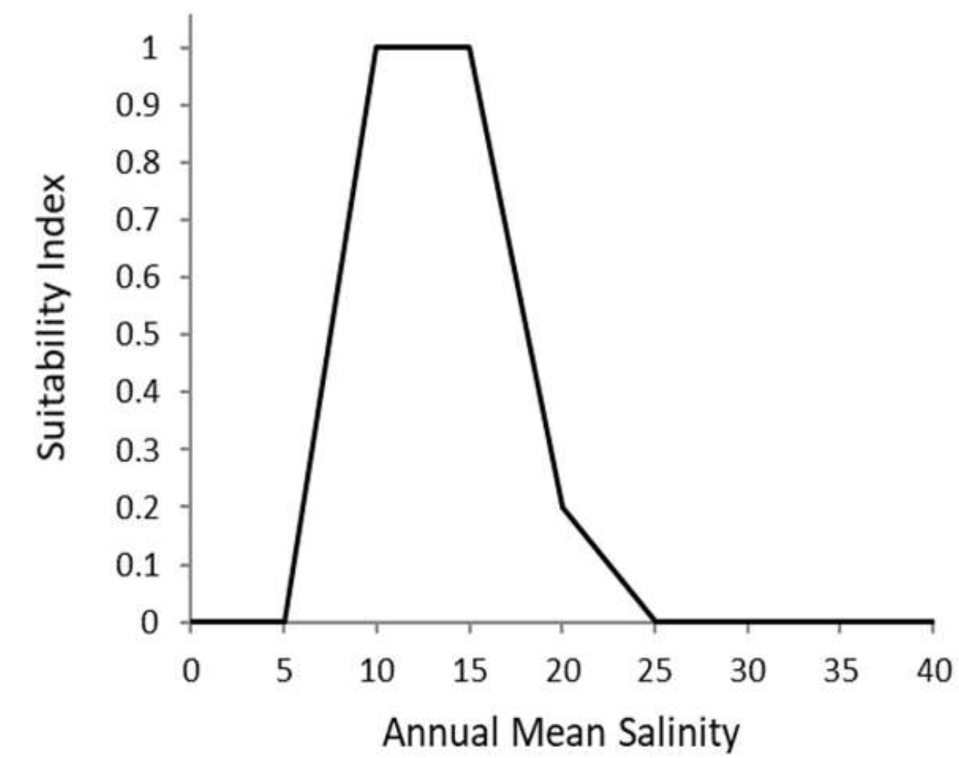
**Literature reviews were conducted to develop suitability indices for these species.**




Suitability index with marsh vegetation for seaside sparrow.



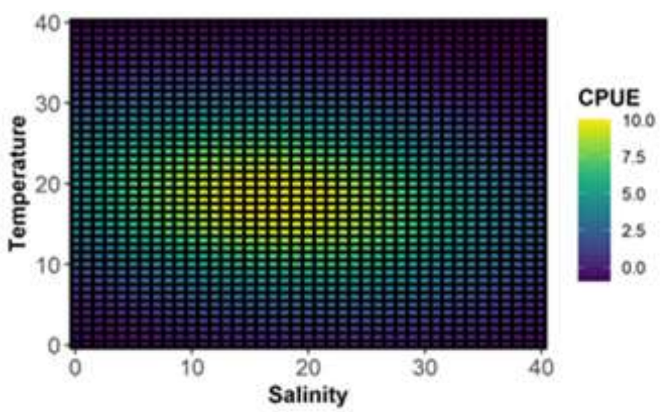

Suitability index with respect to annual sediment deposition (in mm) for eastern oyster.



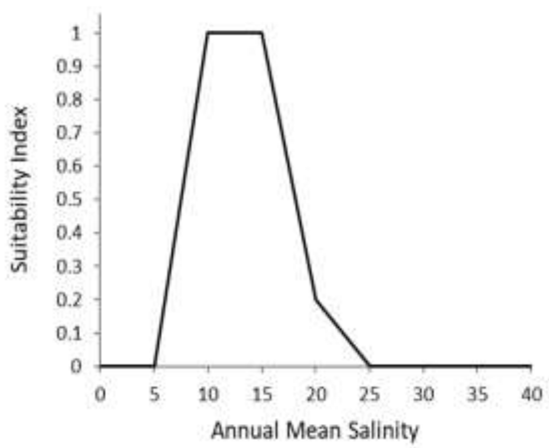

Suitability index with respect to annual mean salinity (in ppt) for eastern oyster.

# HABITAT SUITABILITY INDICES

Water quality suitability indices (salinity, temperature)




or

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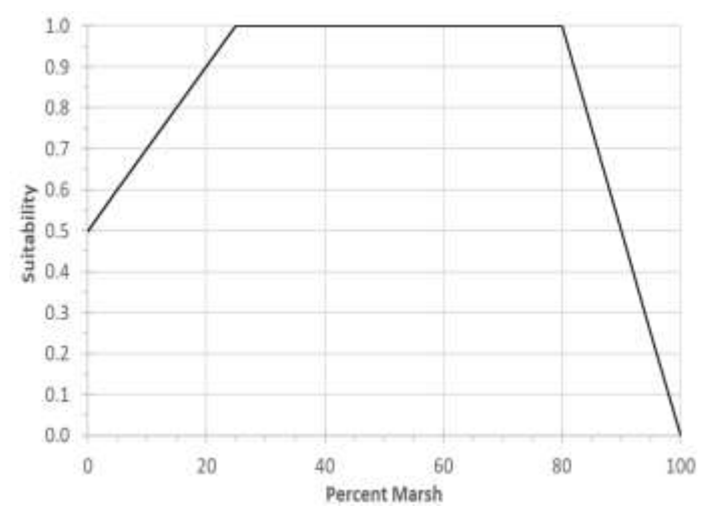
Landscape suitability indices (% water, marsh type, etc.)

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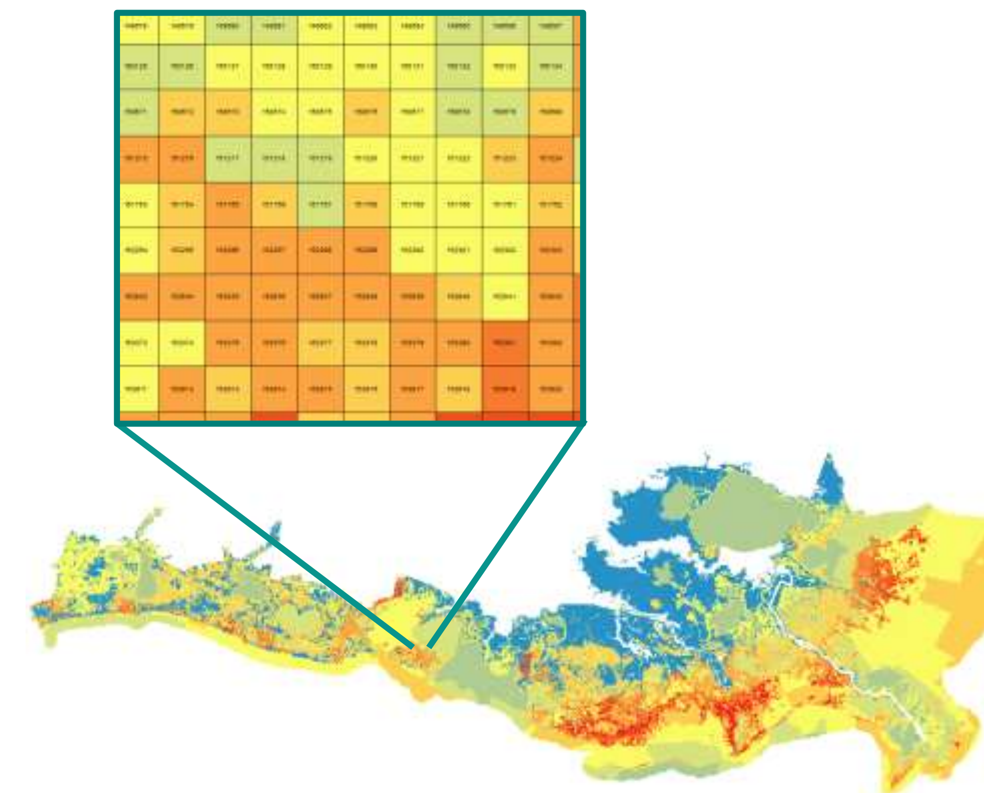
HSI



Final HSI value is determined by combining water quality suitability (either derived statistically or via literature review) and landscape suitability.

# BOUNDARY CONDITIONS & LANDSCAPE DATA

## DATASETS USED FOR MODEL HINDCAST (CALIBRATION/VALIDATION): 2006-2018

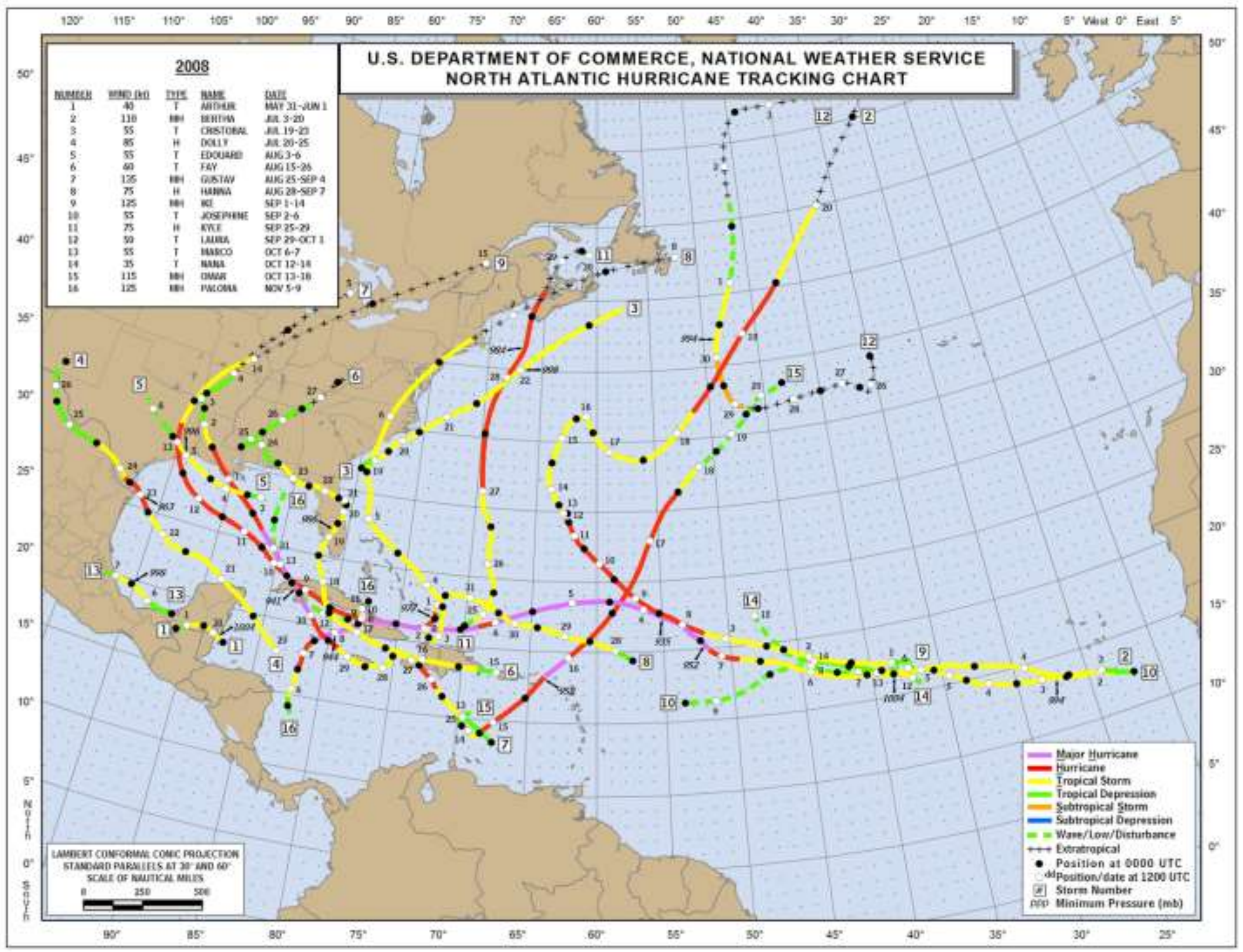
- Timeseries Boundary Conditions
  - Riverine flow input
    - 2006 through end of 2018
    - Rating curves developed in 2017 used for filling missing data
  - Updated sediment rating curves
  - Tidal water levels
    - 2006 through end of 2018
    - Tidal signal decomposed for:
      - Astronomic
      - Seasonal
      - Storm surge
      - Subsidence
      - ESLR
      - Subtidal residual

- Landscape Data
  - Topobathy DEM
    - Latest LiDAR & bathymetric surveys
    - NGOM2 effort
  - Vegetation base map
    - 2018 landscape conditions
  - Land/water/floating base map
    - 2018 landscape conditions
  - Marsh edge erosion rates
    - 2006-2018 imagery

# BOUNDARY CONDITIONS & LANDSCAPE DATA

## STORMS IN THE ICM

- Match synthetic storms to historic tropical cyclones.
- Match based on angle, landfall location, pressure, speed, radius of winds.




Historic tropical cyclones in 2008 hurricane season, NOAA (2008).


Synthetic storm tracks updated for the new JPM-OS methodology.

# MODEL CALIBRATION AND VALIDATION

- Calibration Period: 2010-2018; Validation Period: 2006-2009
- Hydrology
  - Mean water level (daily & monthly comparisons)
    - CRMS and USGS stations
  - Mean tidal range (daily tidal amplitude comparisons)
  - Mean flowrate
    - Limited USGS data
  - Mean salinity (daily & monthly comparisons)
    - CRMS and USGS stations
- Suspended Sediment
  - LDEQ & USGS observation stations
  - Limited data available (all discrete samples); Morphology model's accretion patterns used to fine-tune sediment distribution deposition and resuspension parameters

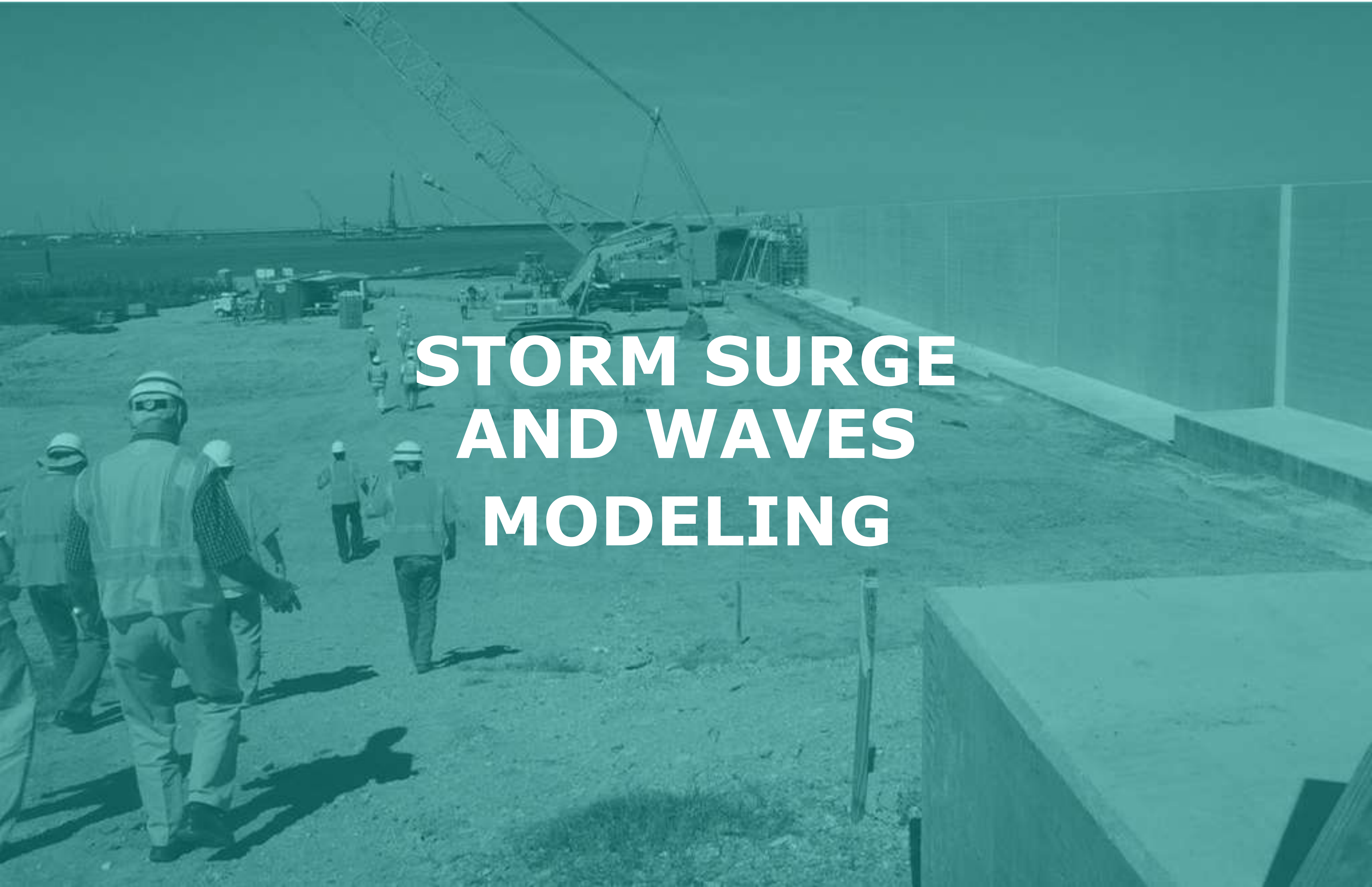
# ADDITIONAL WEBINARS

## OPPORTUNITY FOR MORE DETAILED INFORMATION

- Modeling 101
- ICM Subroutines
  - ICM-Hydro
  - ICM-Morph
  - ICM-LAVegMod
  - ICM- BI
  - ICM- HSIs
- Future Conditions/Scenarios
- Calibration/Validation
- Uncertainty
- Asset Valuation
- Nonstructural Project Definition
- Modeling Projects
- Storm Selection

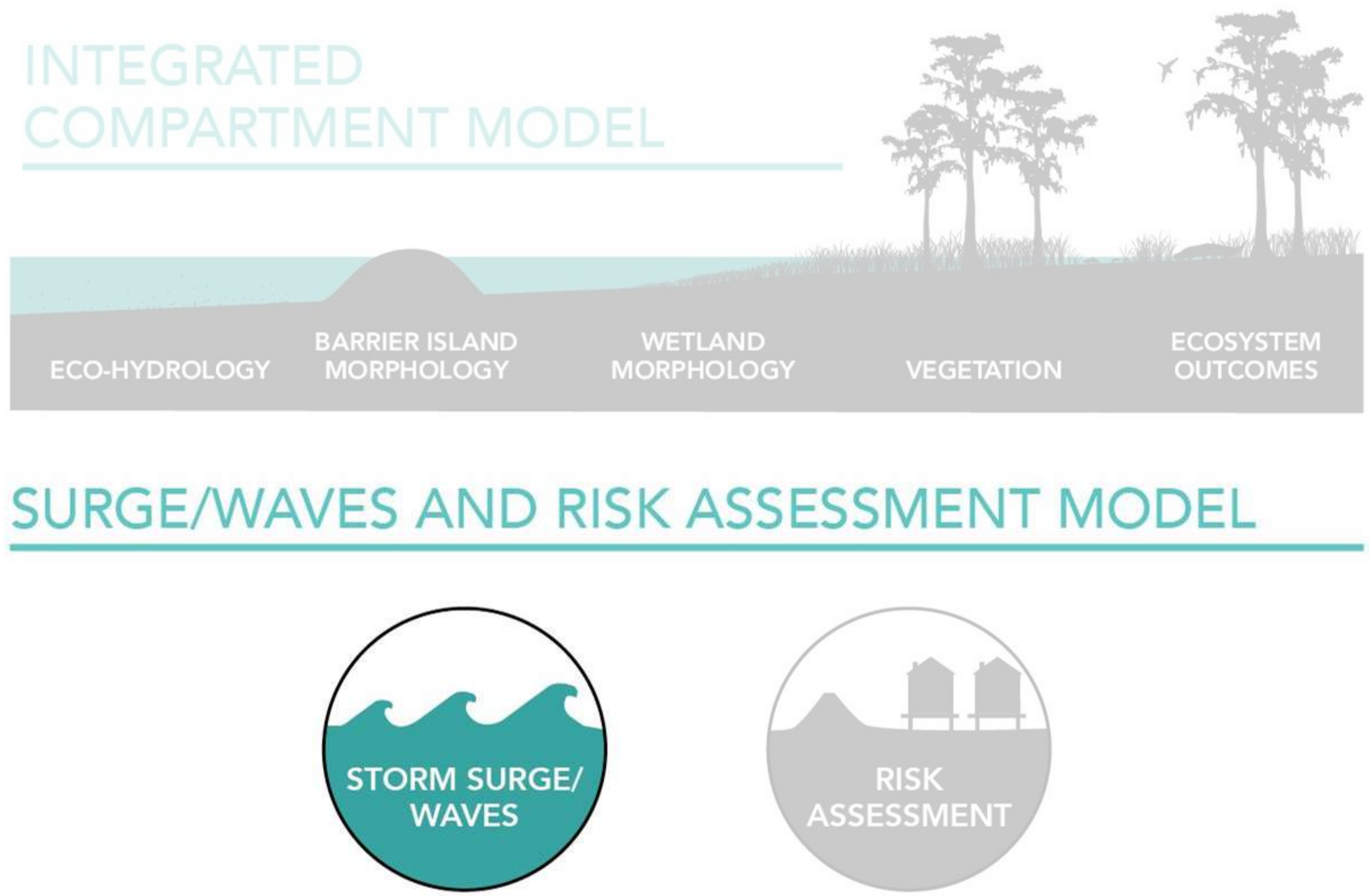

QUESTIONS


5 MINUTE
BREAK



# STORM SURGE AND WAVES MODELING

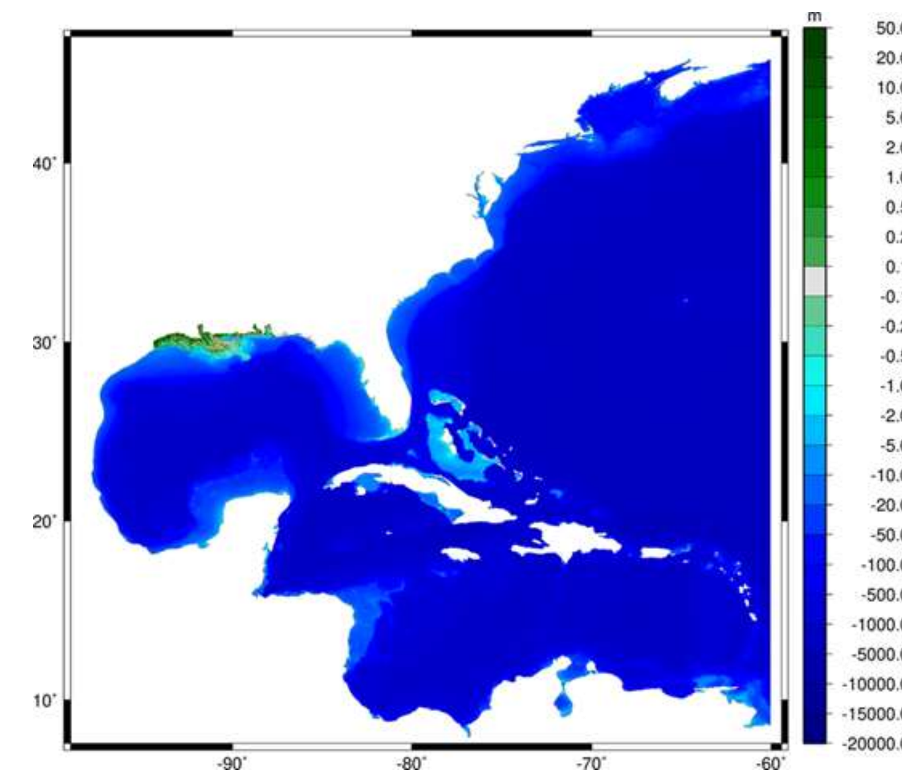
# PREDICTIVE MODELS – STORM SURGE AND WAVES MODELS

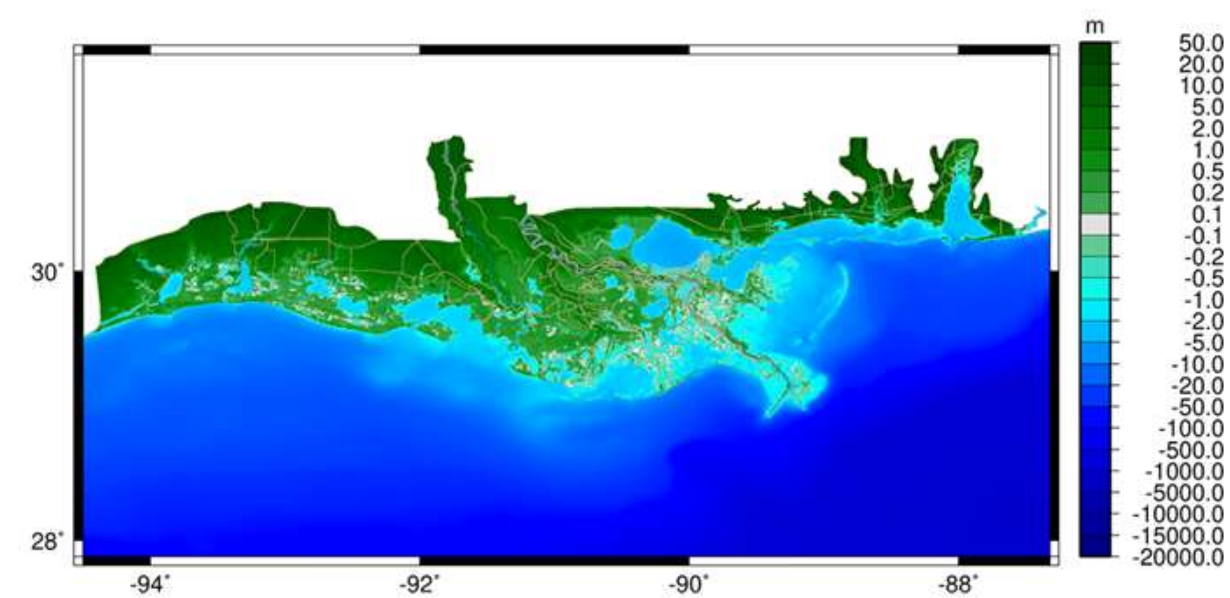


# NUMERICAL MODEL BACKGROUND

## STORM SURGE AND WAVES MODELING

- Storm surge and waves modeled using ADCIRC+SWAN
  - Physics based models
  - Luettich and Westerink (1994)
  - Represent movement of water and wave propagation due to:
    - Astronomical tides
    - Riverine inflows
    - Wind/pressure
  - Highly parallelized code
    - Fortran + MPI
    - Scales to > 10,000 processors
  - Developed with funding from NSF, DHS, USACE, NOAA, and state governments



# NUMERICAL MODEL IMPLEMENTATION - GOVERNING EQUATIONS

## STORM SURGE AND WAVES MODELING

$$\frac{\partial^2 \zeta}{\partial t^2} + \tau_0 \frac{\partial \zeta}{\partial t} + S_p \frac{\partial \tilde{J}_\lambda}{\partial \lambda} + \frac{\partial \tilde{J}_\phi}{\partial \varphi} - S_p U H \frac{\partial \tau_0}{\partial \lambda} - V H \frac{\partial \tau_0}{\partial \varphi} = 0$$

**Generalized Wave Continuity Equation (GWCE)**

- Solved Implicitly (JCG)
- Weight primitive and wave forms of continuity equation using $\tau_0$
- Discretize at *t-1*, *t*, and *t+1*

**2D Momentum Equations**

- Solved Explicitly
- Depth Integrated

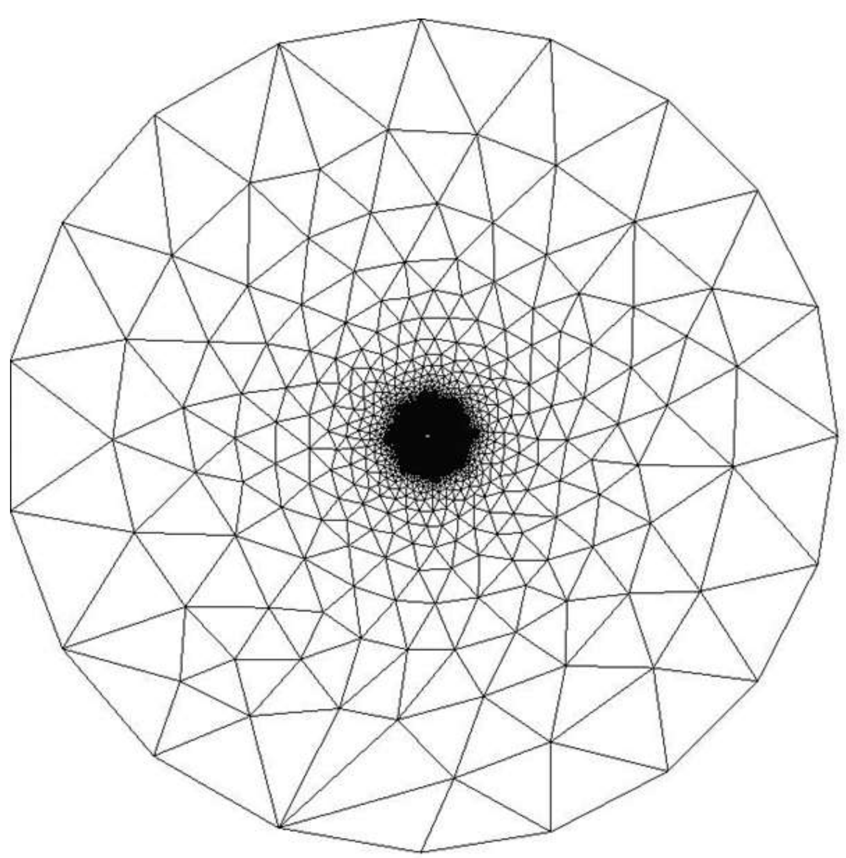
$$\frac{\partial U}{\partial t} + S_p U \frac{\partial U}{\partial \lambda} + V \frac{\partial U}{\partial \varphi} - fV = -g S_p \frac{\partial}{\partial \lambda}\left[\zeta + \frac{P_s}{g\rho_0} - \alpha\eta\right] + \frac{\tau_{s\lambda,winds} + \tau_{s\lambda,waves} - \tau_{b\lambda}}{\rho_0 H} + \frac{M_\lambda - D_\lambda}{H}$$

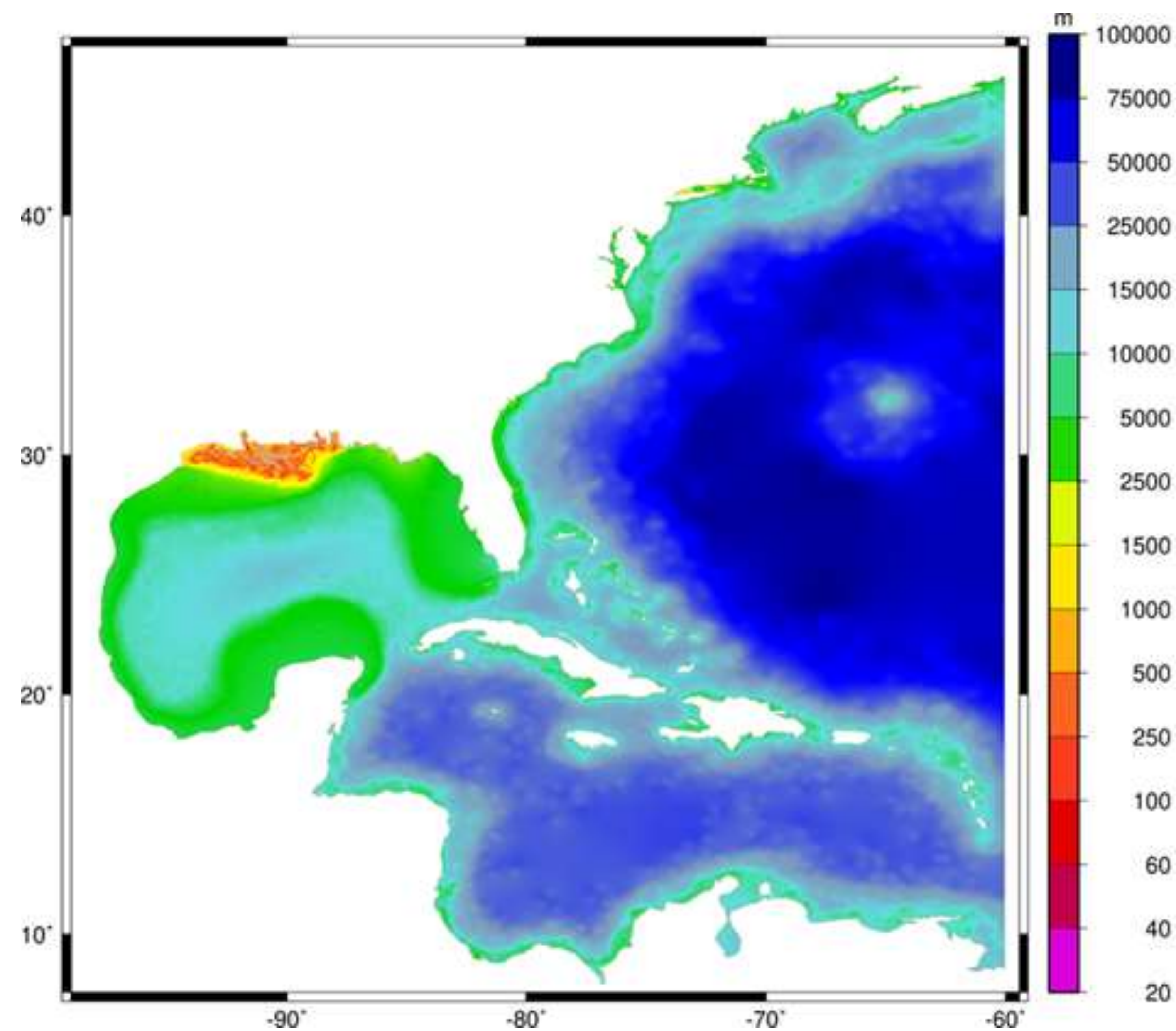
$$\frac{\partial V}{\partial t} + S_p U \frac{\partial V}{\partial \lambda} + V \frac{\partial V}{\partial \varphi} - fU = -g \frac{\partial}{\partial \varphi}\left[\zeta + \frac{P_s}{g\rho_0} - \alpha\eta\right] + \frac{\tau_{s\varphi,winds} + \tau_{s\varphi,waves} - \tau_{b\lambda}}{\rho_0 H} + \frac{M_\varphi - D_\varphi}{H}$$

# MODEL RESOLUTION

## STORM SURGE AND WAVES MODELING

- Models use unstructured triangular mesh
  - Concentrates computational effort in areas of interest

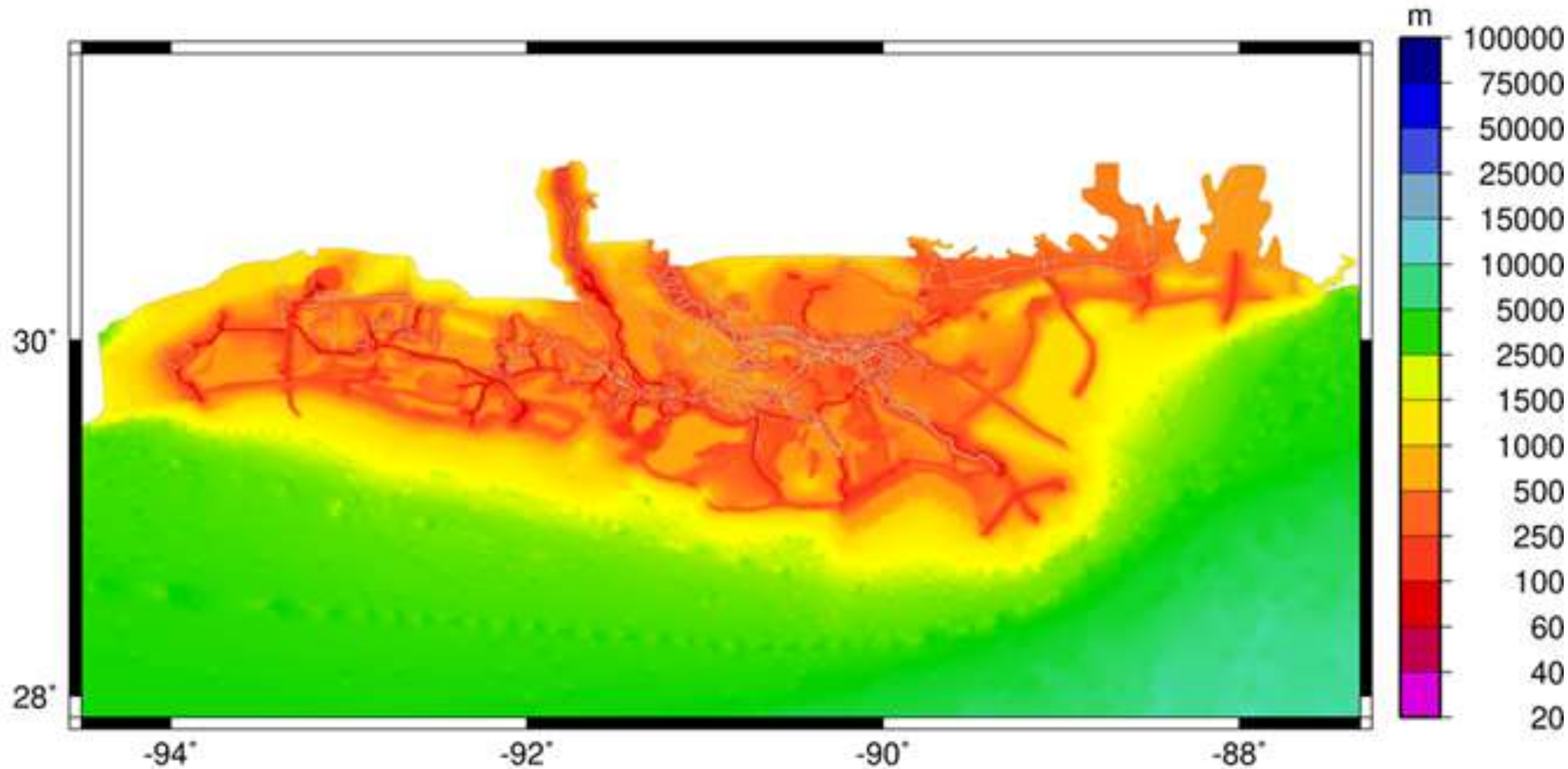




# MESH RESOLUTION

## STORM SURGE AND WAVES MODELING

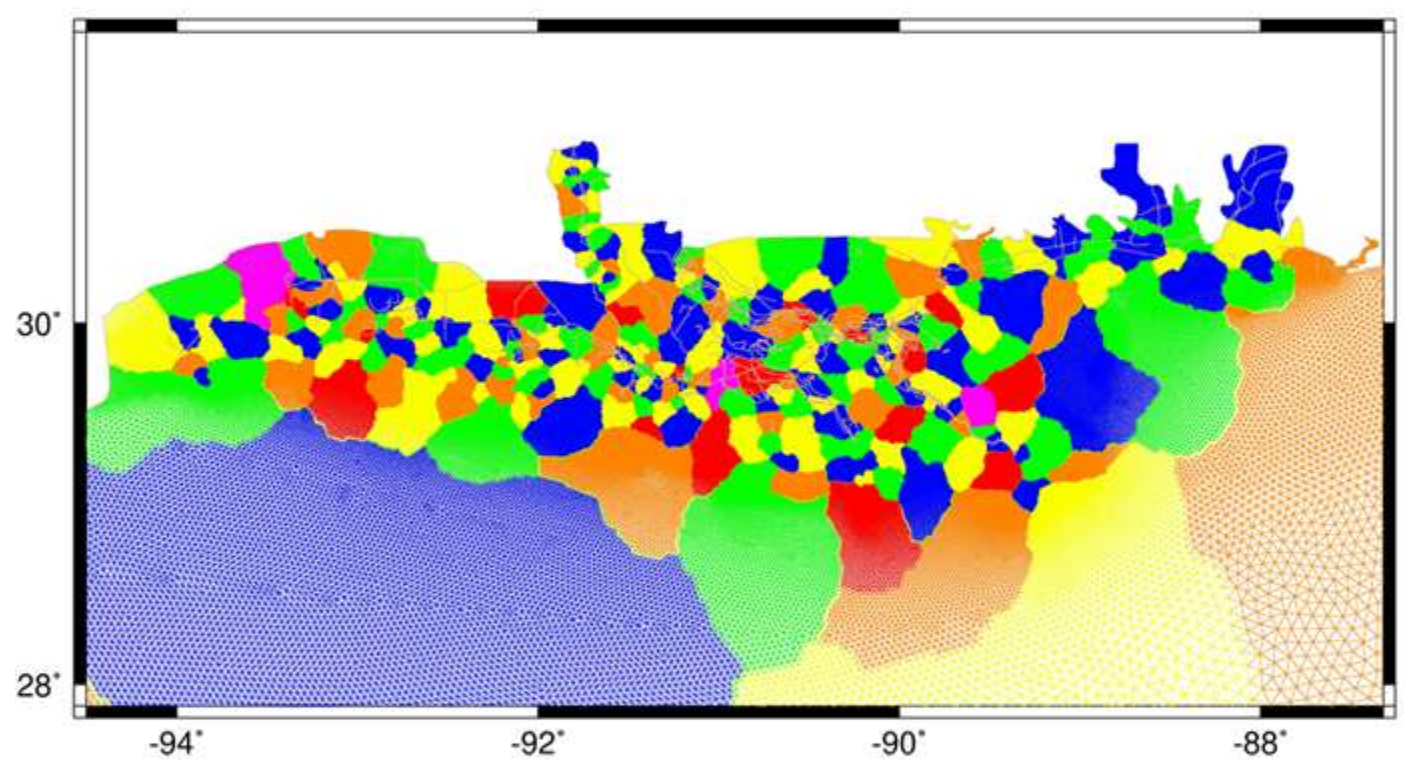
- Mesh resolution varies between 80km in the Atlantic Ocean and 30m in inland channels

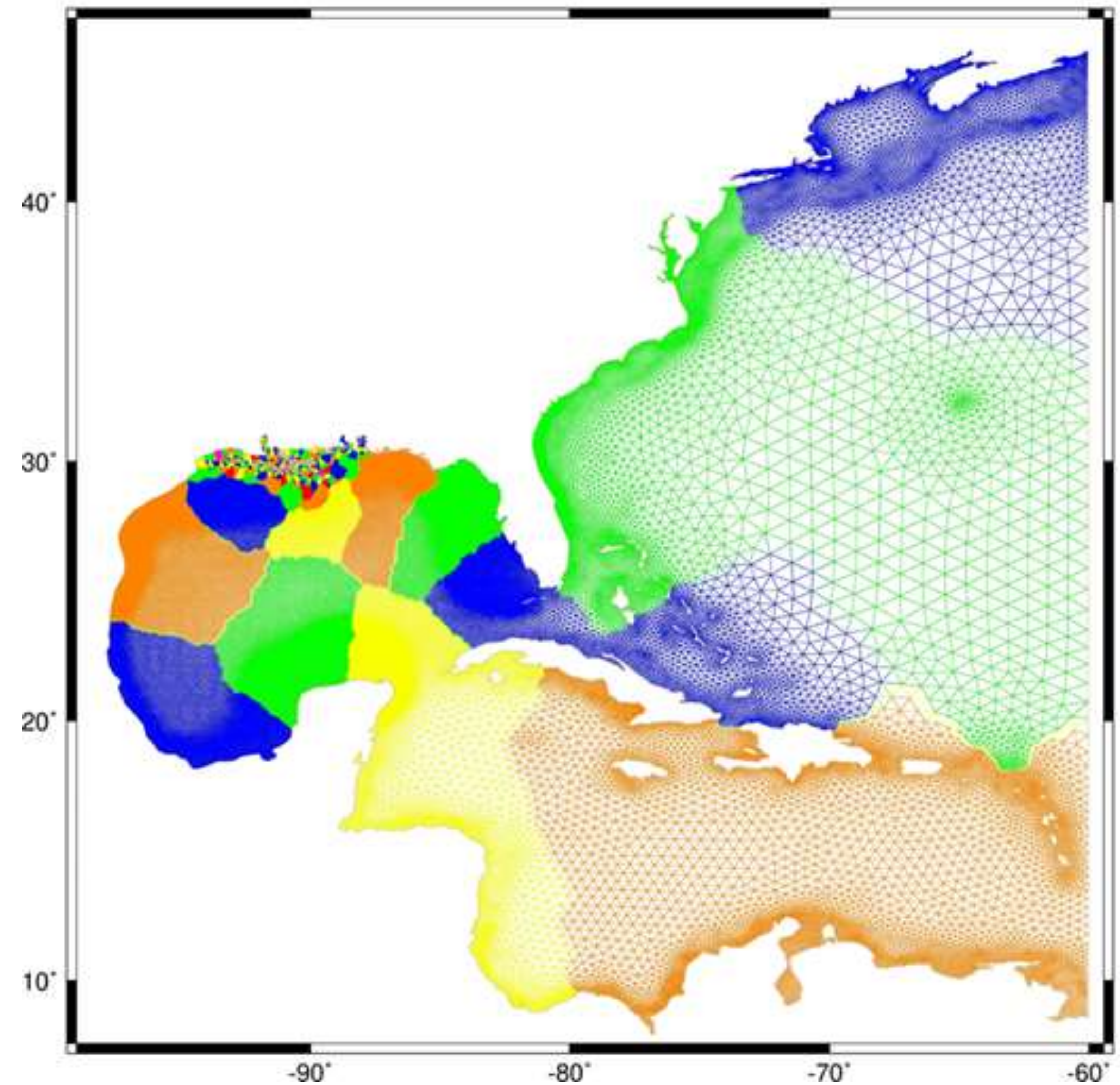


# MODEL DOMAIN DECOMPOSITION

## STORM SURGE AND WAVES MODELING

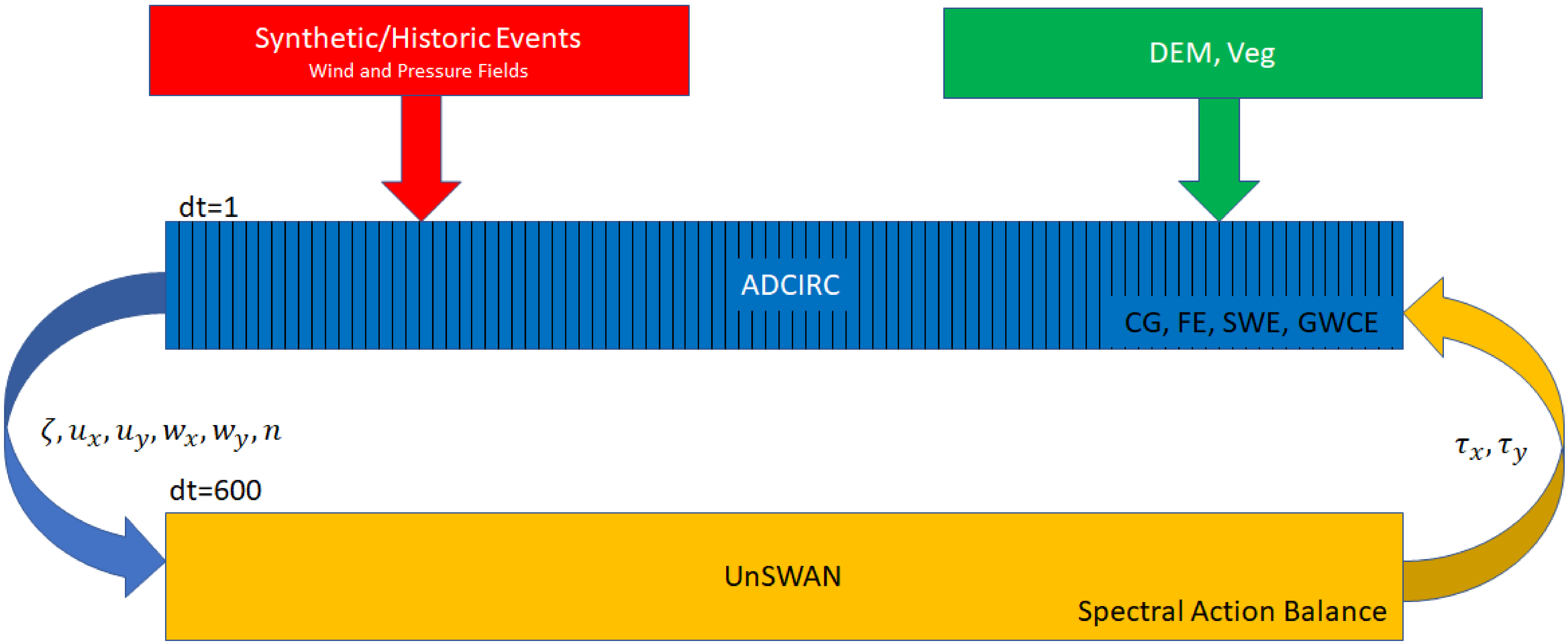
- Model is decomposed to balance load between processors
  - Most processors focused in Southern Louisiana



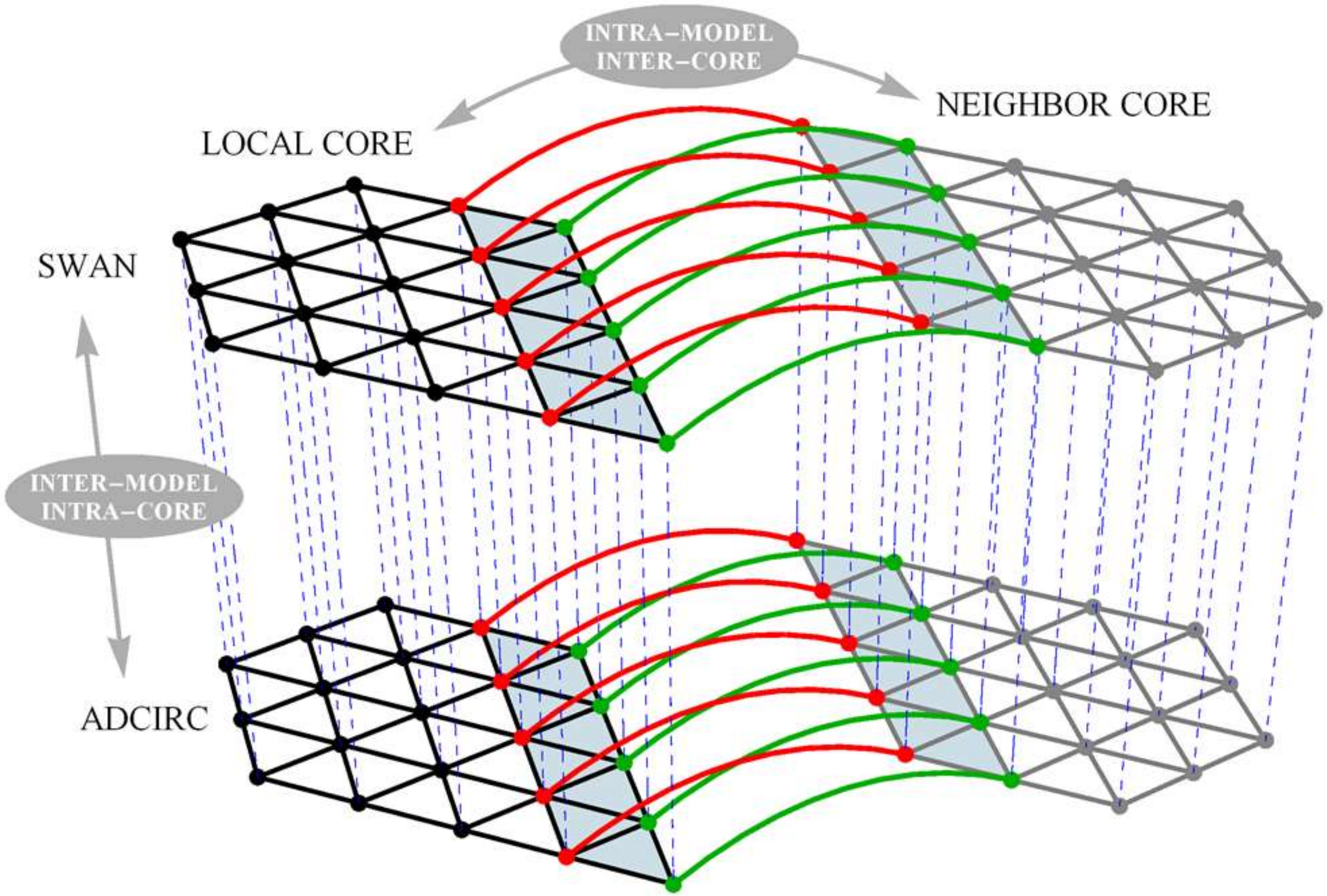
# MODEL COUPLING

## STORM SURGE AND WAVES MODELING



# MODEL COUPLING

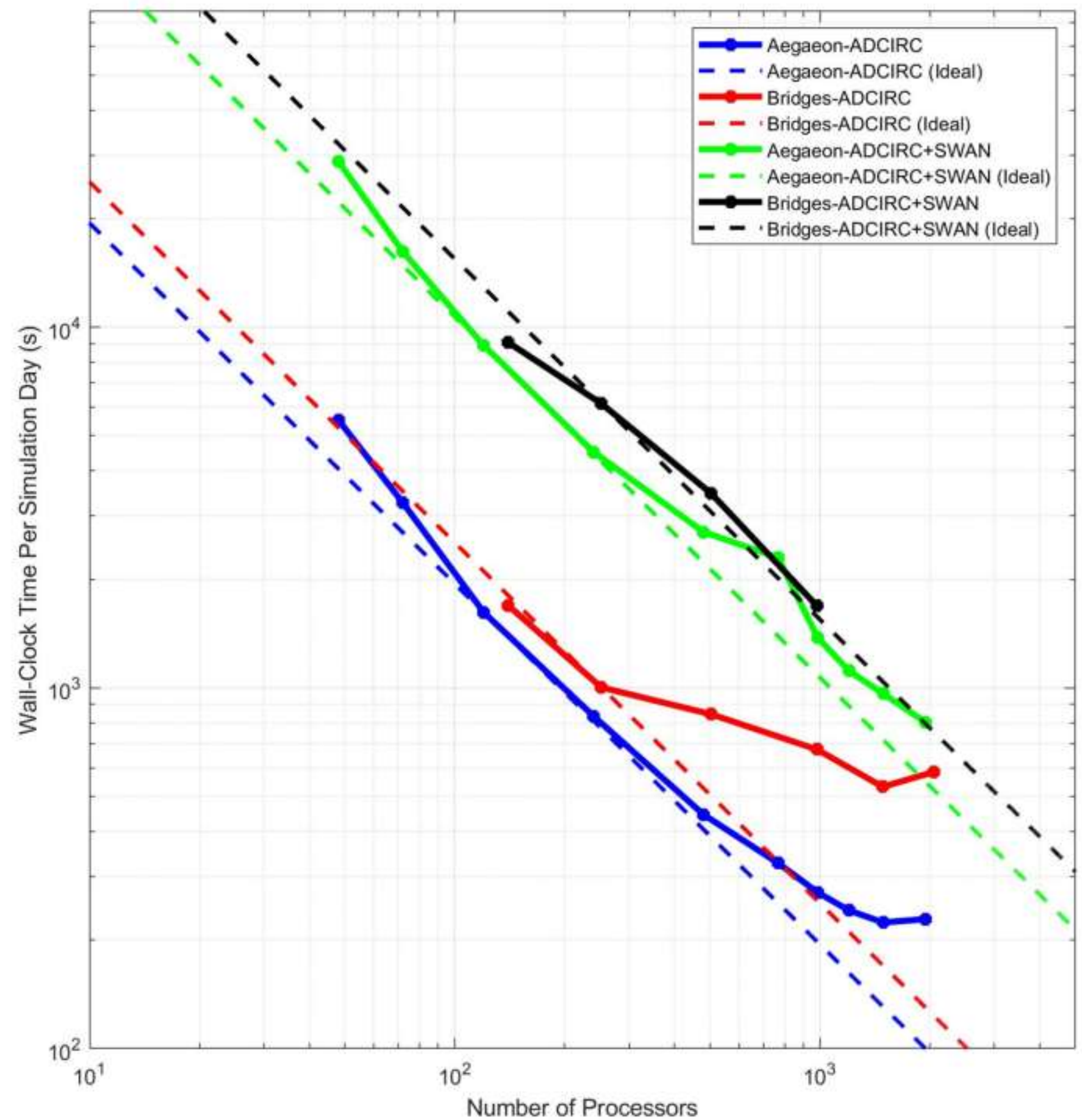
## STORM SURGE AND WAVES MODELING



# MODEL SCALING PERFORMANCE

## STORM SURGE AND WAVES MODELING

- Model scaling tested to 2000 processors on two systems
  - Aegaeon @ Notre Dame
  - Bridges @ Pittsburgh Supercomputing Center
- Model contains ~1.5M nodes
- Model performs best using approximately 256 processors
- Global communication is limiting factor



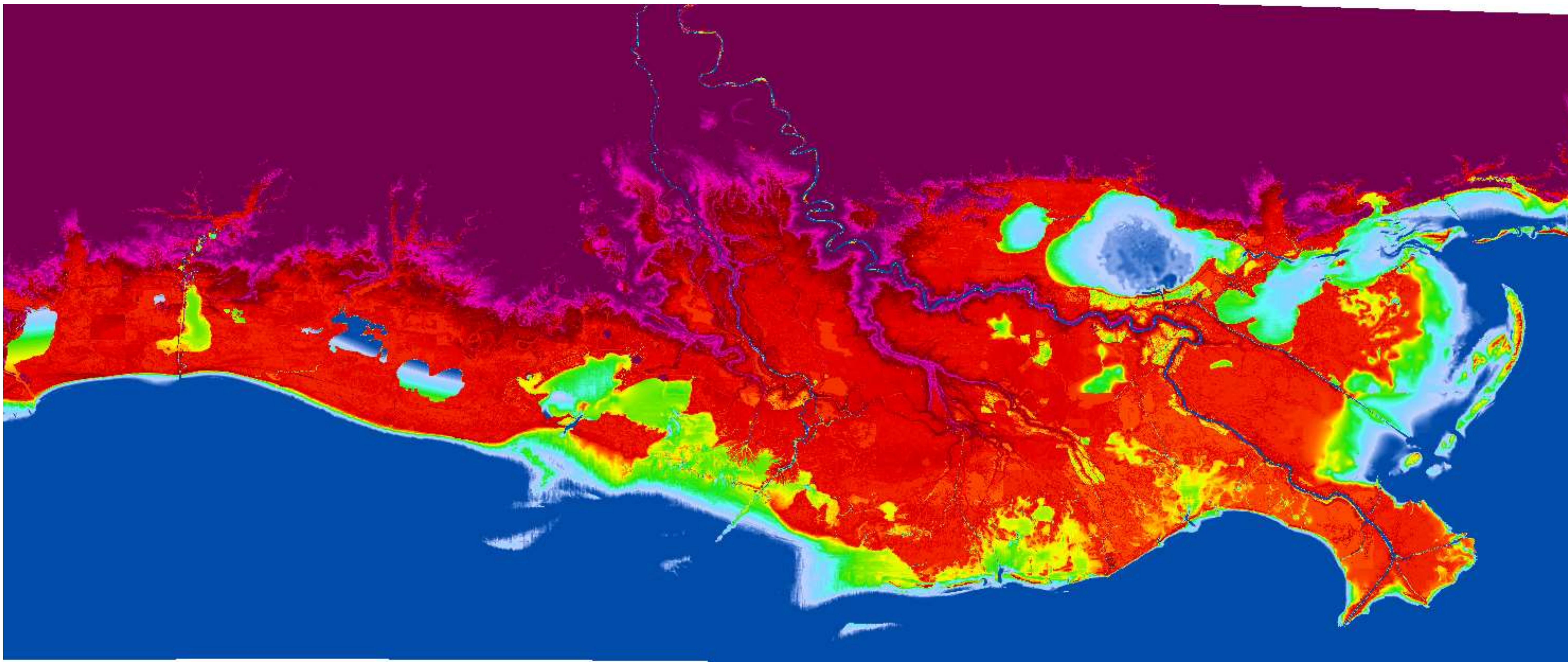
# MODEL INPUT DATA

## STORM SURGE AND WAVES MODELING

- Topography and bathymetry
- Land use classifications
- Levee elevations
- Offshore water levels
    - Changes due to sea level rise
- Riverine inflows
    - Constant for all present and future conditions

# INPUT DATA – TOPOGRAPHY

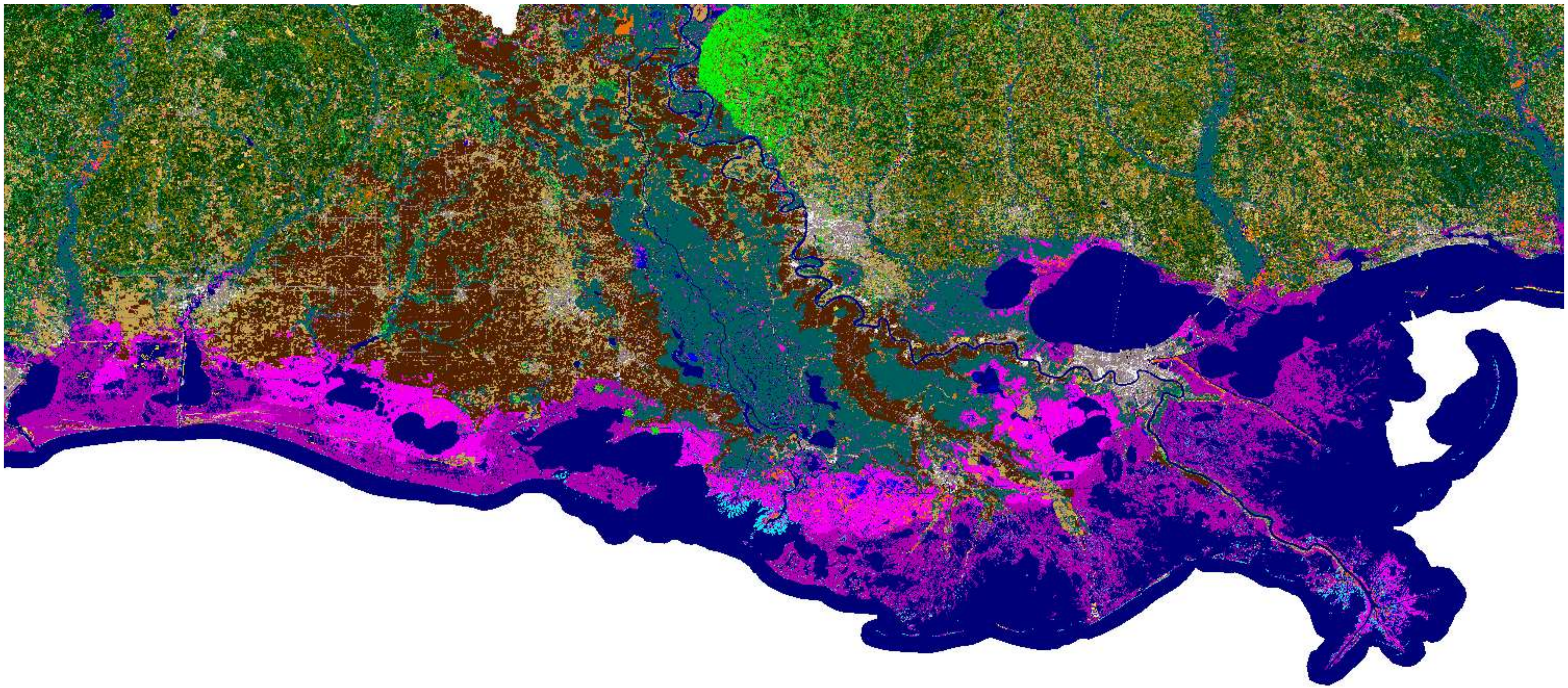
## STORM SURGE AND WAVES MODELING



Digital Elevation Model

# INPUT DATA – LAND USE

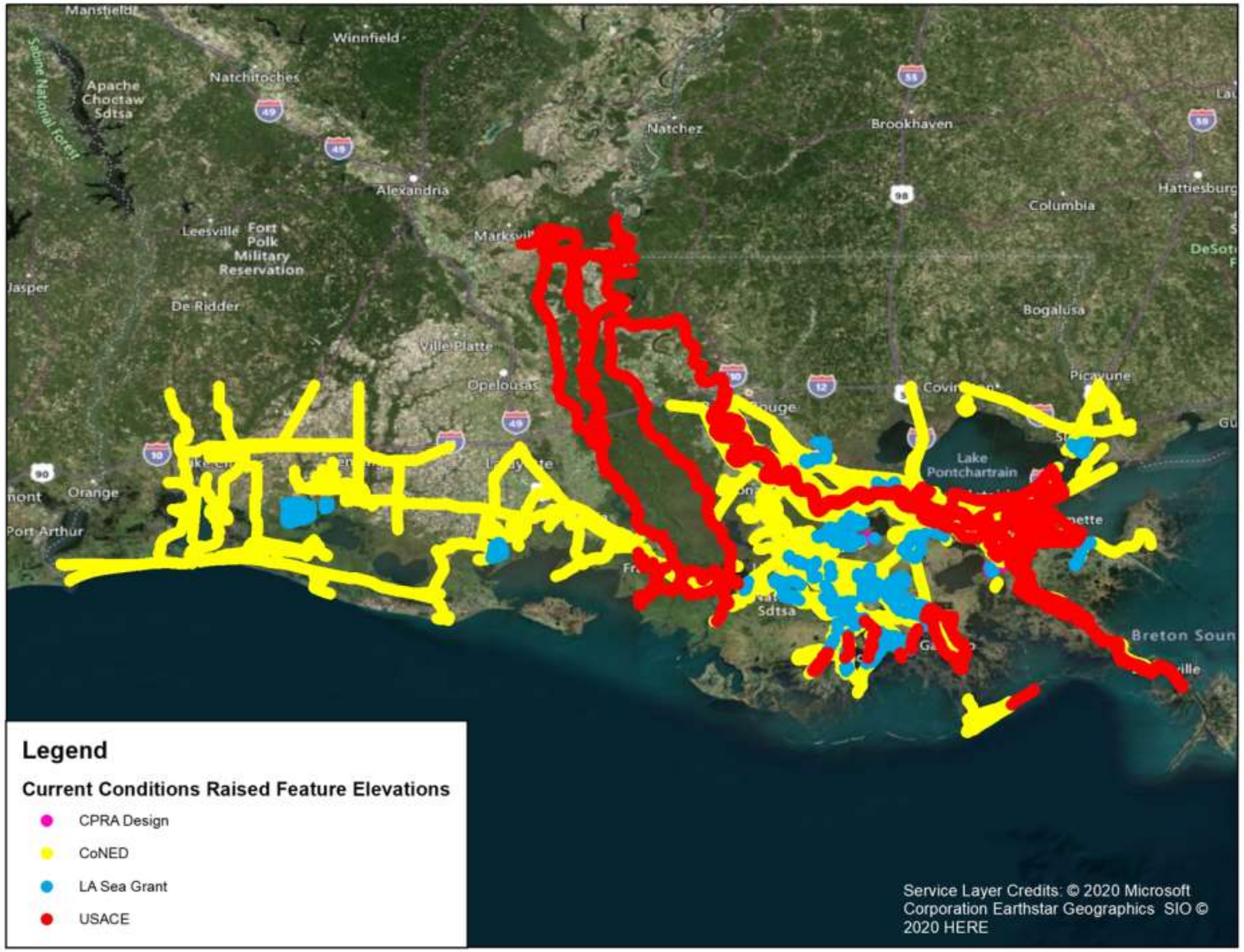
## STORM SURGE AND WAVES MODELING



Land Use Classifications

# RAISED FEATURES AND LEVEES

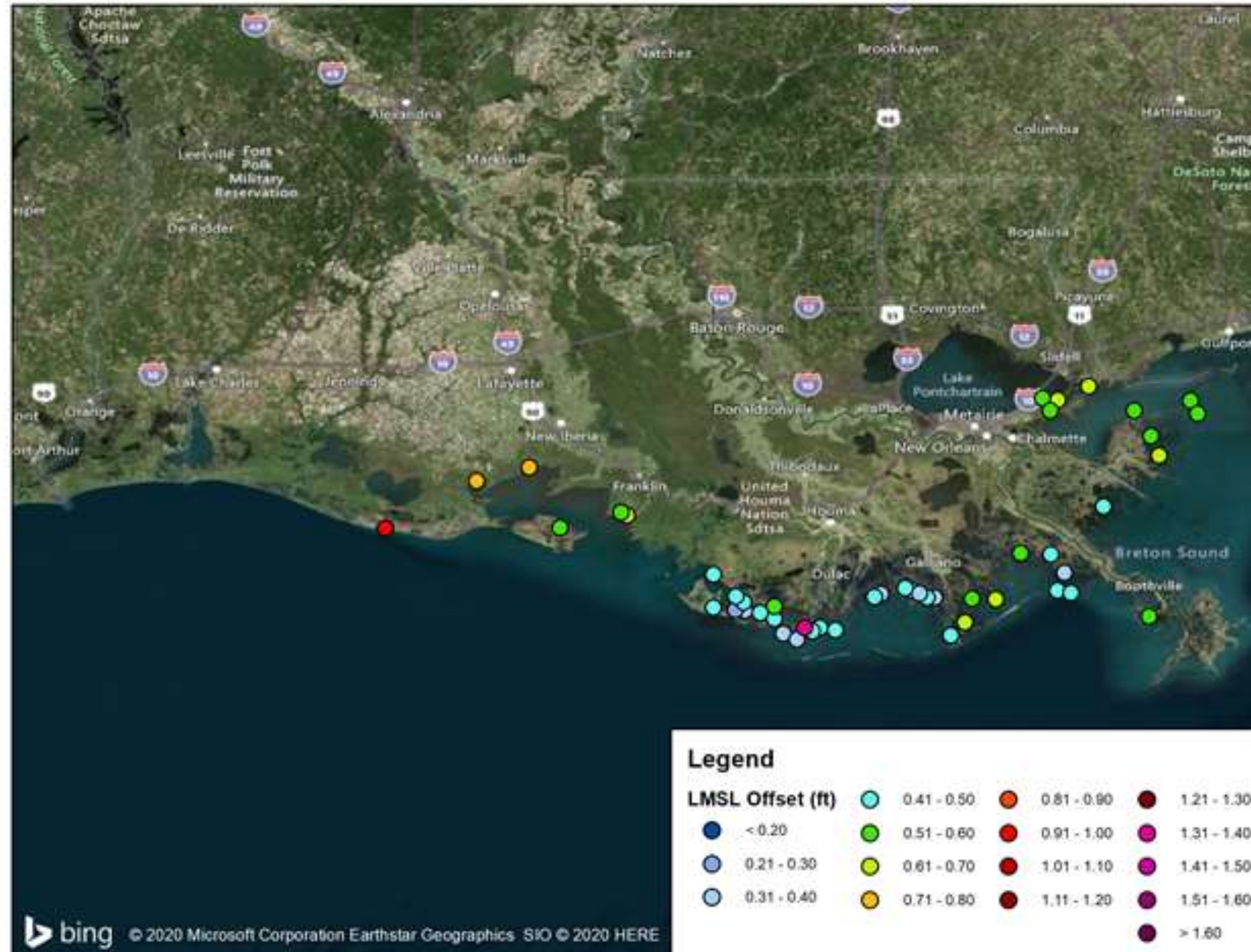
## STORM SURGE AND WAVES MODELING



# OFFSHORE WATER LEVELS

## STORM SURGE AND WAVES MODELING

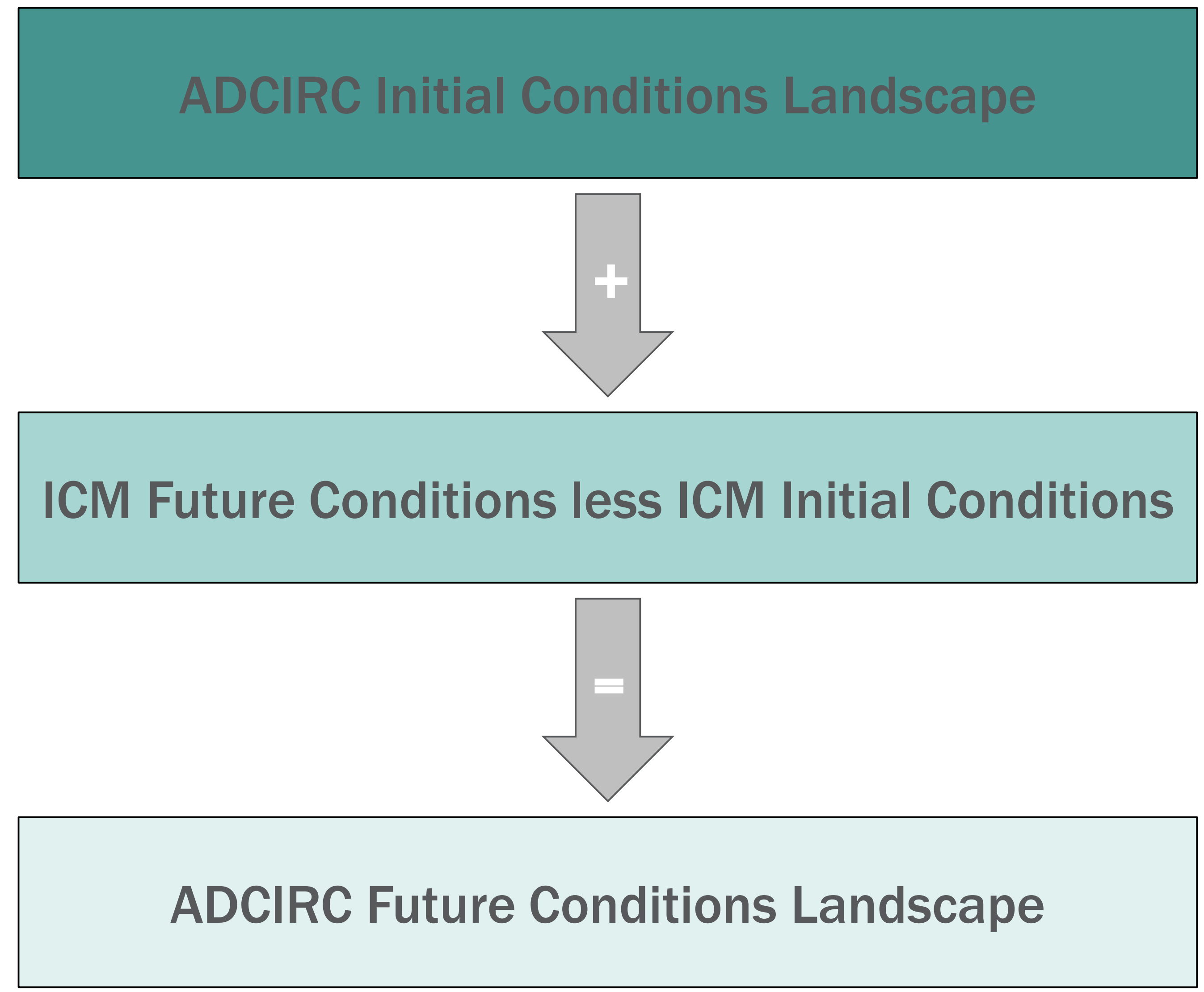
- Model in NAVD88 2009.55
  - Offshore water levels adjust to mean sea level for hurricane season
  - CRMS data used to generate Local Mean Sea Level (LMSL) offset
  - Open water stations used
  - 1.2ft initial water level offset from NAVD88
- Sea level rise is applied as an additional offset from this value



# FUTURE LANDSCAPE SCENARIOS

## STORM SURGE AND WAVES MODELING

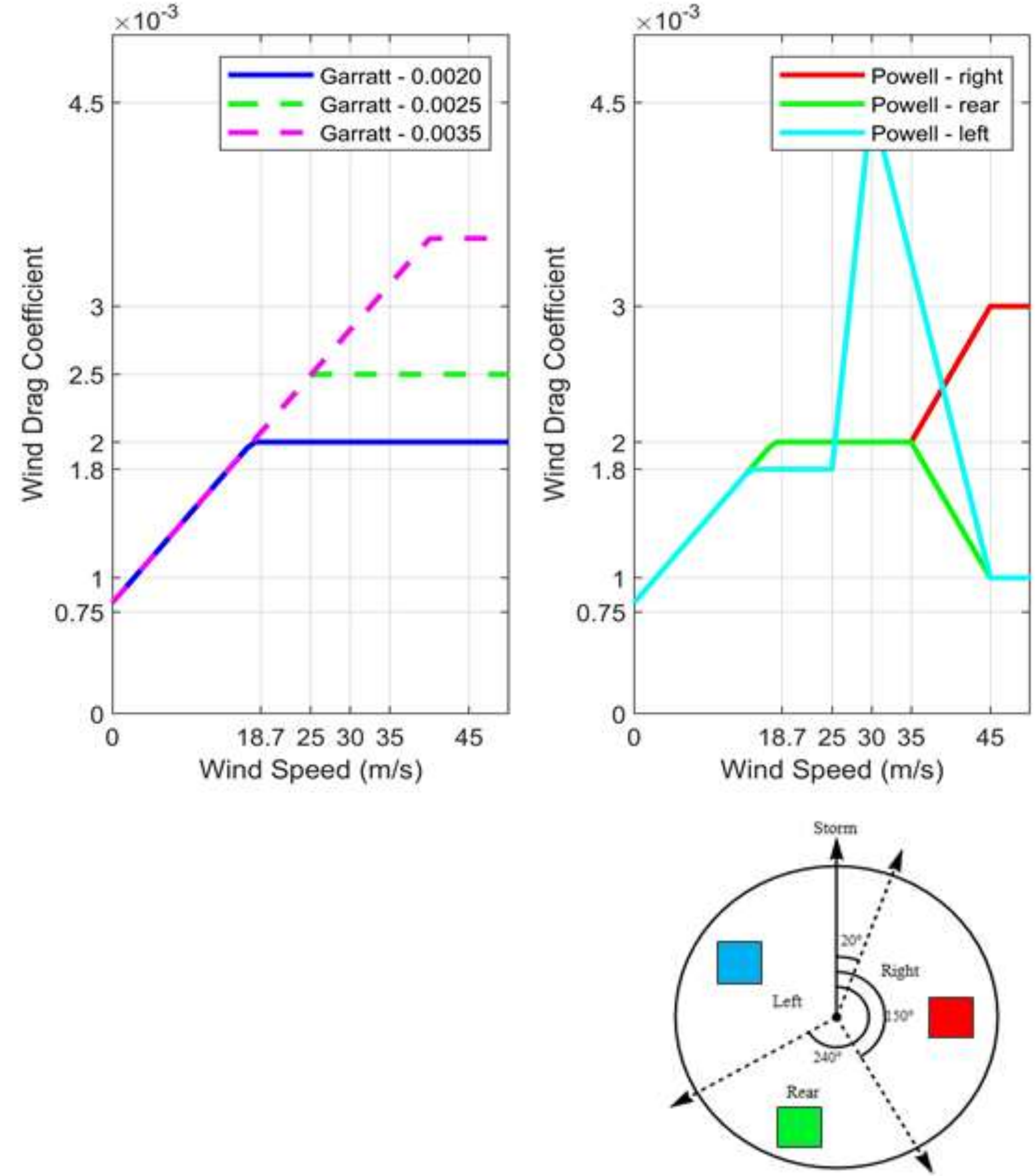
- ICM model output used to generate updated ADCIRC landscape
  - ICM provides updated land elevation and land use
    - Includes subsidence
  - Change in ICM attributes applied to ADCIRC mesh
  - Sea level updated



# MODEL VALIDATION

## STORM SURGE AND WAVES MODELING

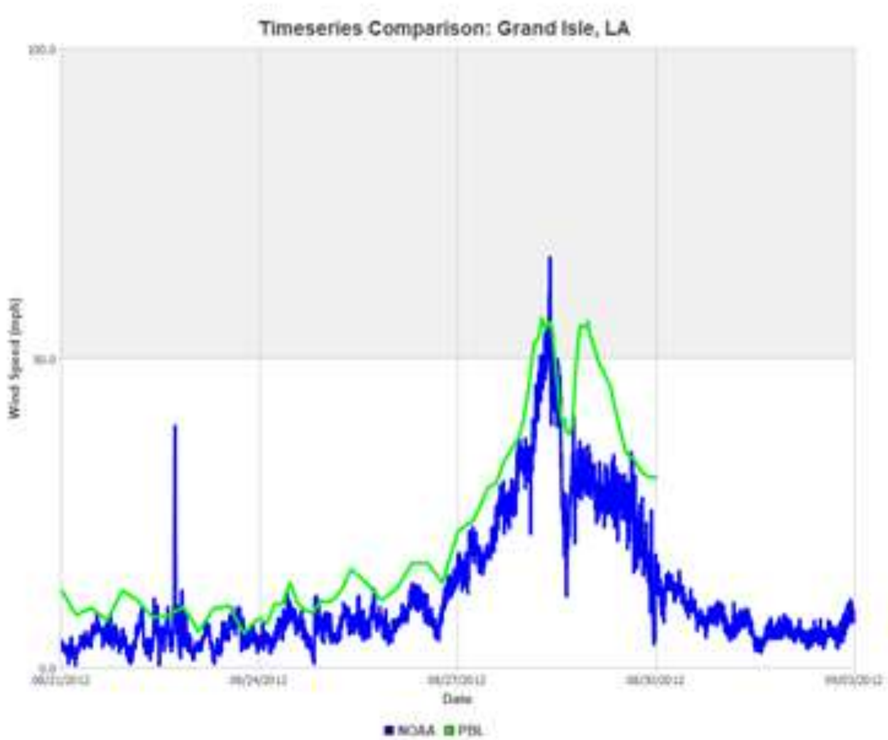
- 5 storm validation suite used
  - Katrina, Rita, Gustav, Ike, Isaac
  - Nate, Harvey, Camille used for additional evaluation
- Evaluation of 18 wind drag and bottom friction formulations used
  - Coordinated evaluation with USACE ERDC, UNC and LSU
  - Create consistency in ADCIRC setup across studies and real-time forecasting

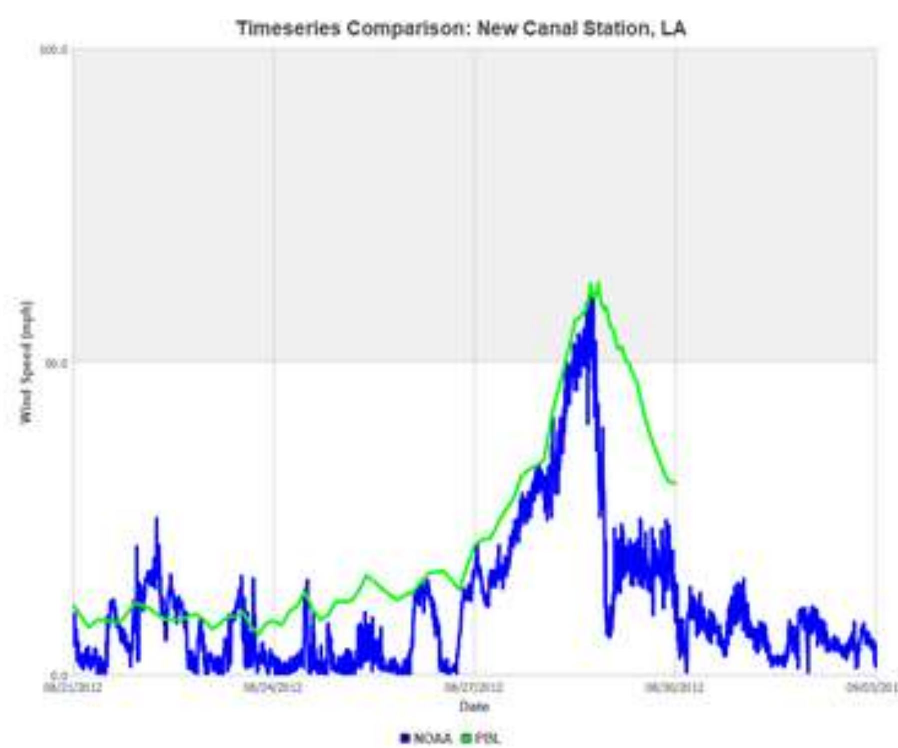


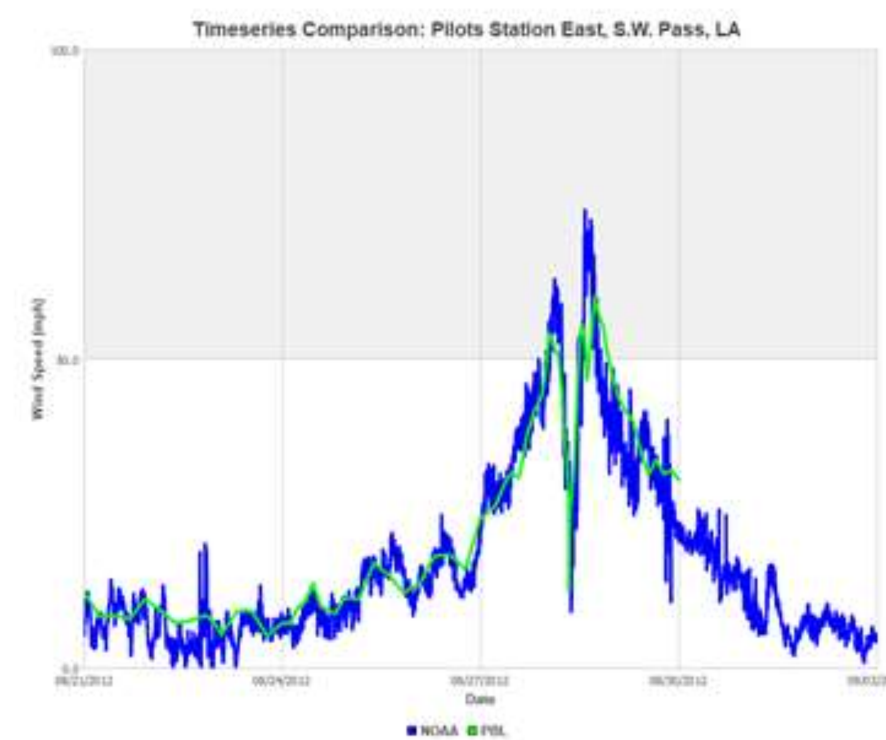
# HURRICANE ISAAC WIND FORCING

## STORM SURGE AND WAVES MODELING

- Examine data assimilated winds to understand limitations of model performance
  - Hurricane Isaac winds show the potential to overestimate in some locations



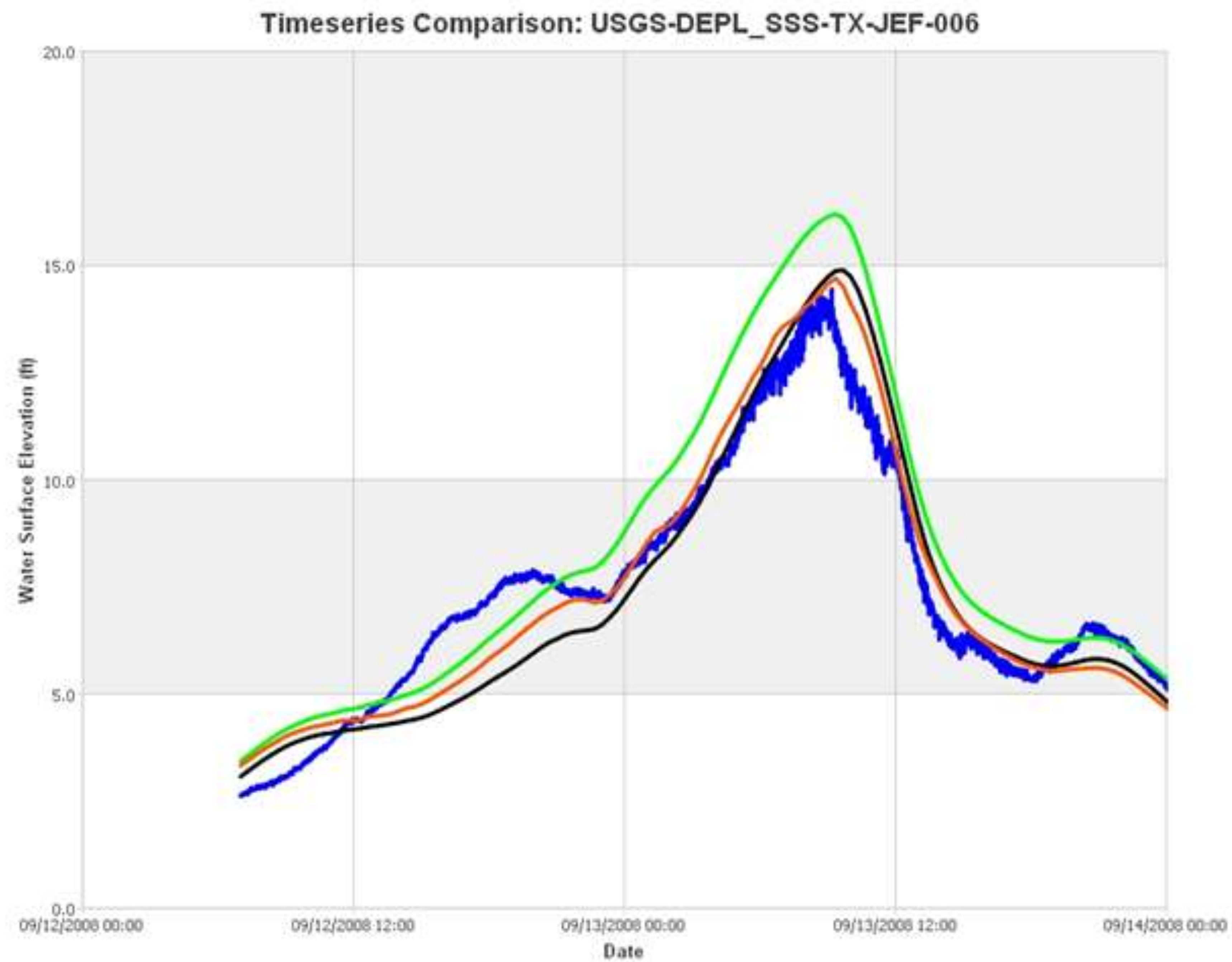



# MODEL VALIDATION - HURRICANE IKE FORERUNNER

## STORM SURGE AND WAVES MODELING

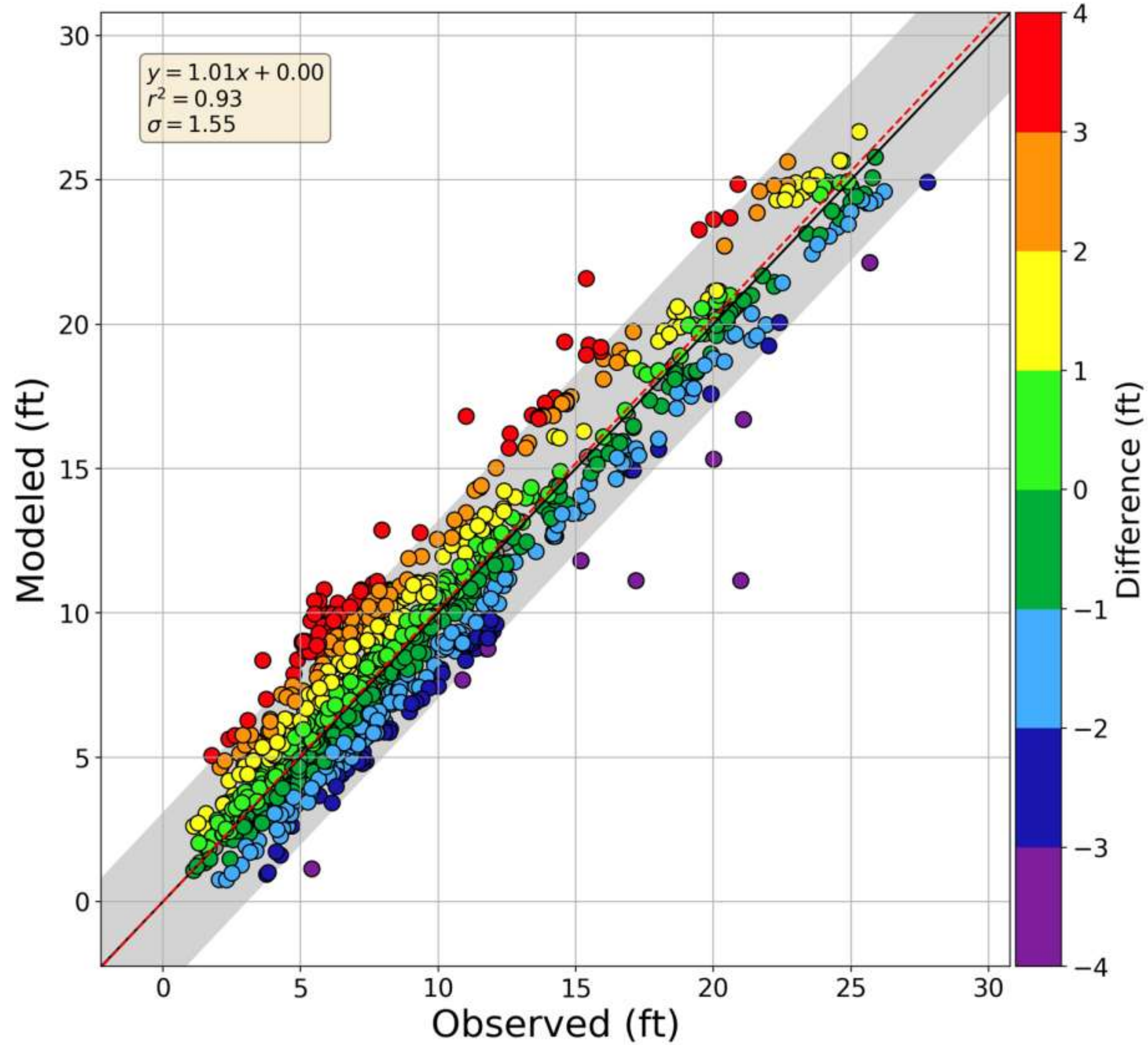
- Hurricane Ike generated a shelf wave due to shore parallel winds
  - Wave arrived in Texas about 12 hours ahead of surge
- Bottom friction and wind drag parameterizations impact shelf waves significantly
  - Blue - USGS Observation
  - Green - Low friction
  - Black - Moderate friction
  - Orange - Low friction, sector-based wind drag



# MODEL VALIDATION

## STORM SURGE AND WAVES MODELING

- Model validation for Katrina, Rita, Gustav, Ike, and Isaac high water marks
- Additional examination of time series hydrographs and waves from observed stations coastwide
- Selected method uses Garratt with bottom friction limit



# SYNTHETIC STORM SUITE

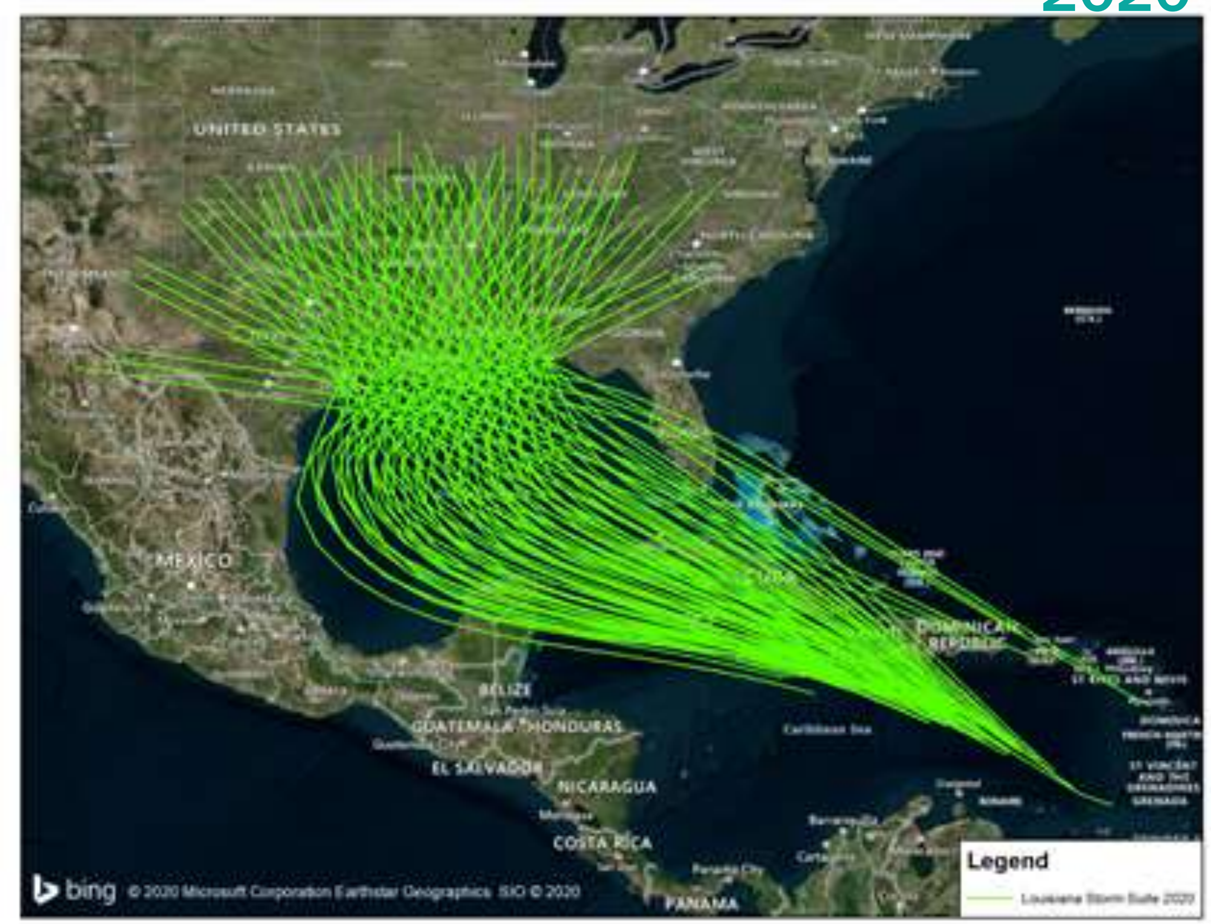
## STORM SURGE AND WAVES MODELING

- Original storm suite developed for FEMA study in 2008
- Updated suite has been generated by USACE

| Parameter | 2008 | 2020 |
|---|---|---|
| Number of Storms | 446 | 645 |
| Intensity (mb) | 975-900 | 1005-865 |
| Forward Speed (kt) | 6.0-17.0 | 4.3-27.0 |
| Radius (nmi) | 6.0-36.0 | 4.3-76.3 |

2008


2020

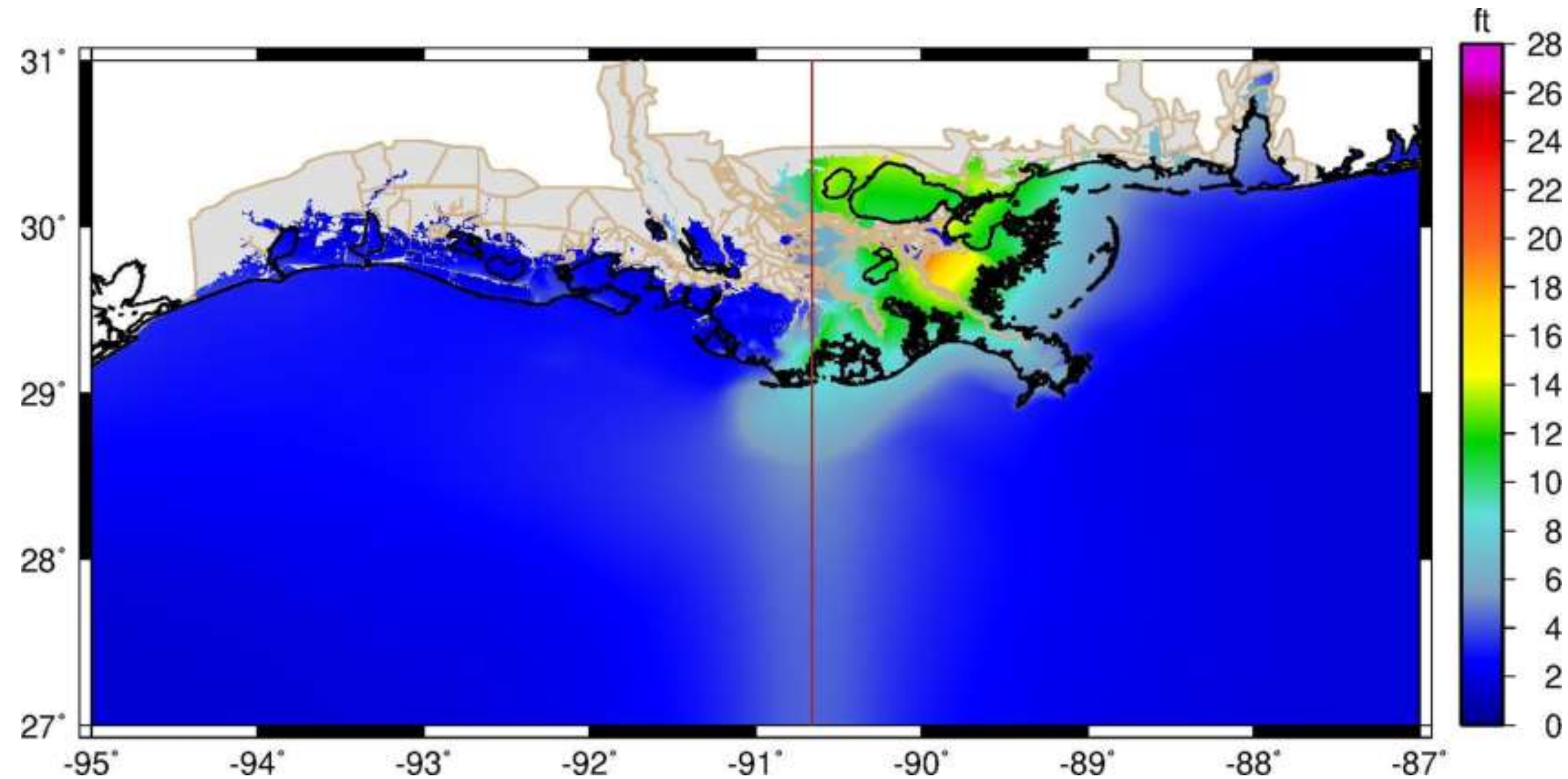


# MODEL OUTPUTS

## STORM SURGE AND WAVES MODELING

- Model outputs consist of
  - Peak Water Levels
  - Peak Wave Height
  - Peak Wave Period
  - Timeseries

| Parameter | Value |
|---|---|
| Minimum Central Pressure | 905mb |
| Radius to Max Winds | 25.9nm |
| Forward Speed | 5.9 kts |
| Storm Duration | 204 hours |



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## STORM SURGE AND WAVES MODELING

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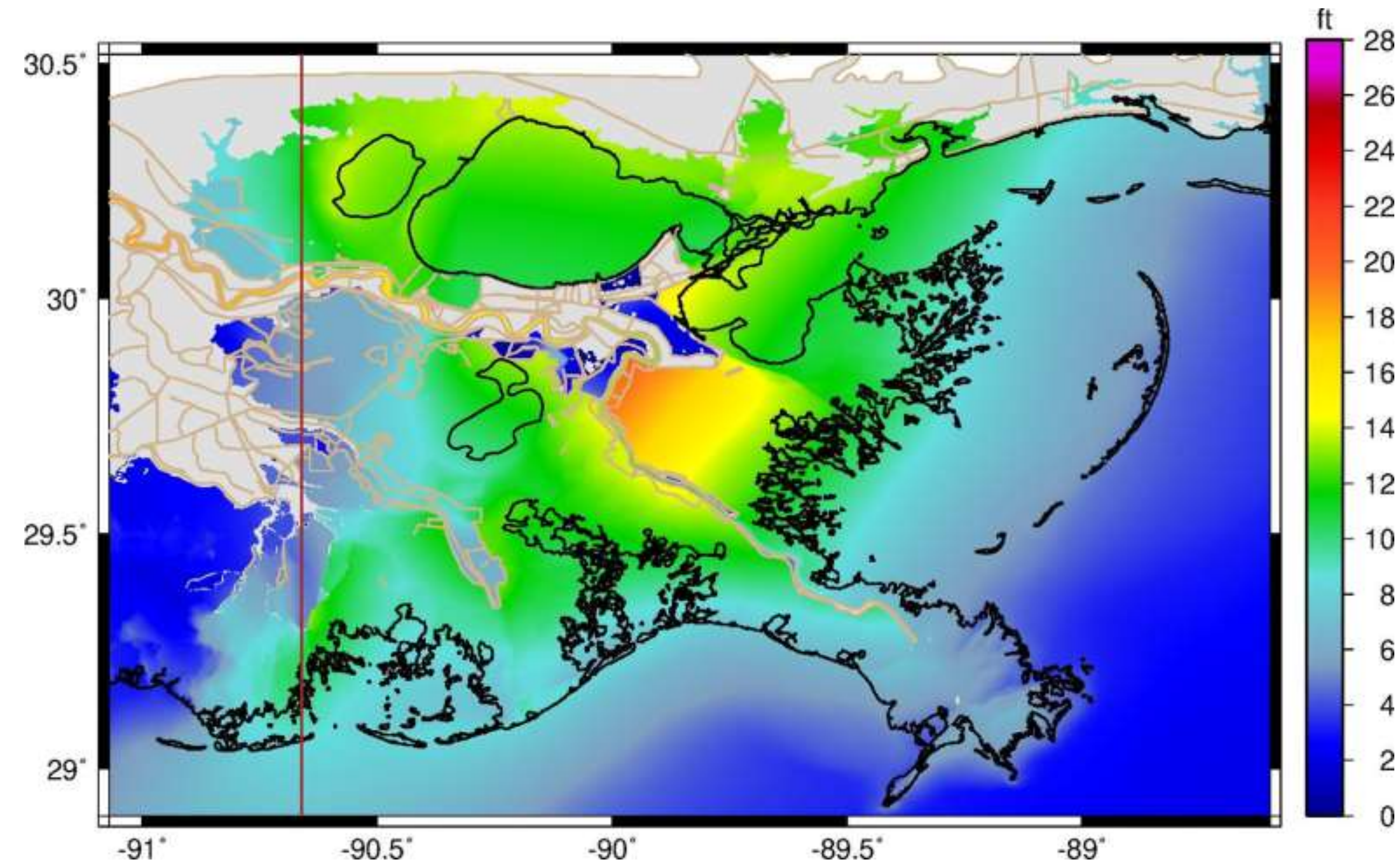


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# MODEL OUTPUTS

## STORM SURGE AND WAVES MODELING

- Model outputs consist of
  - Peak Water Levels
  - **Peak Wave Height**
  - Peak Wave Period
  - Timeseries

| Parameter | Value |
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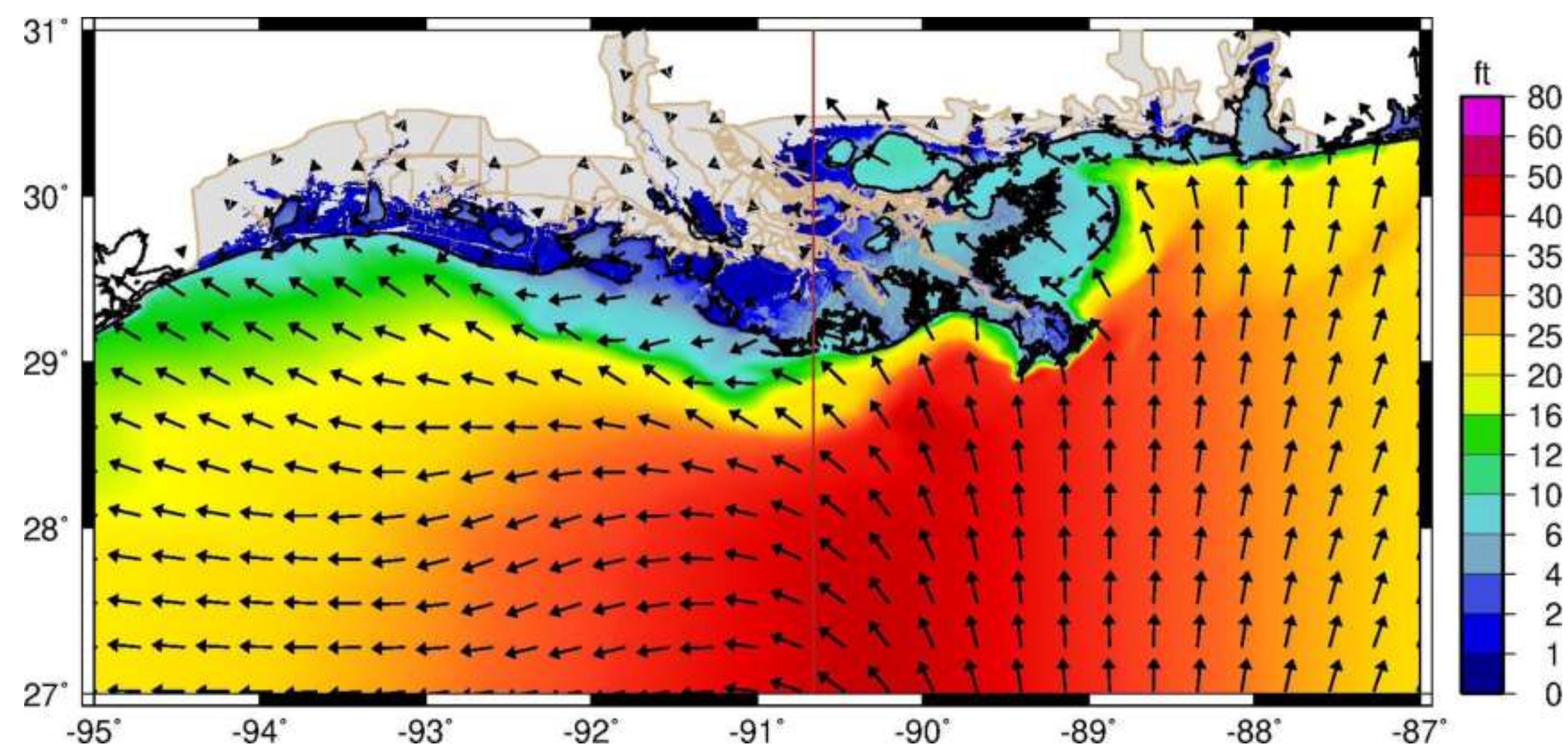

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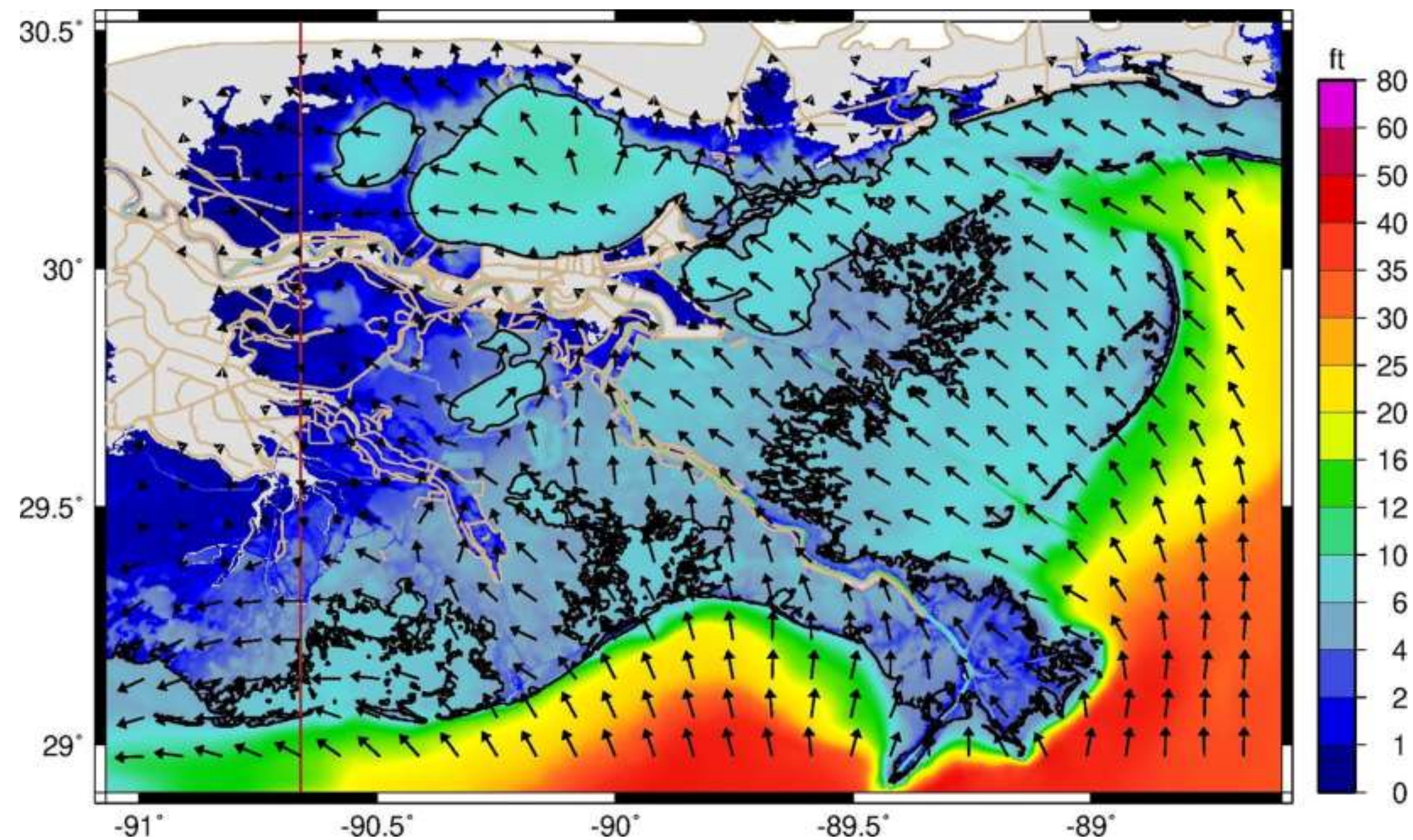
## STORM SURGE AND WAVES MODELING

- Model outputs consist of
  - Peak Water Levels
  - **Peak Wave Height**
  - Peak Wave Period
  - Timeseries

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# MODEL OUTPUTS

## STORM SURGE AND WAVES MODELING

- Model outputs consist of
  - Peak Water Levels
  - Peak Wave Height
  - Peak Wave Period
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| Parameter | Value |
| --- | --- |
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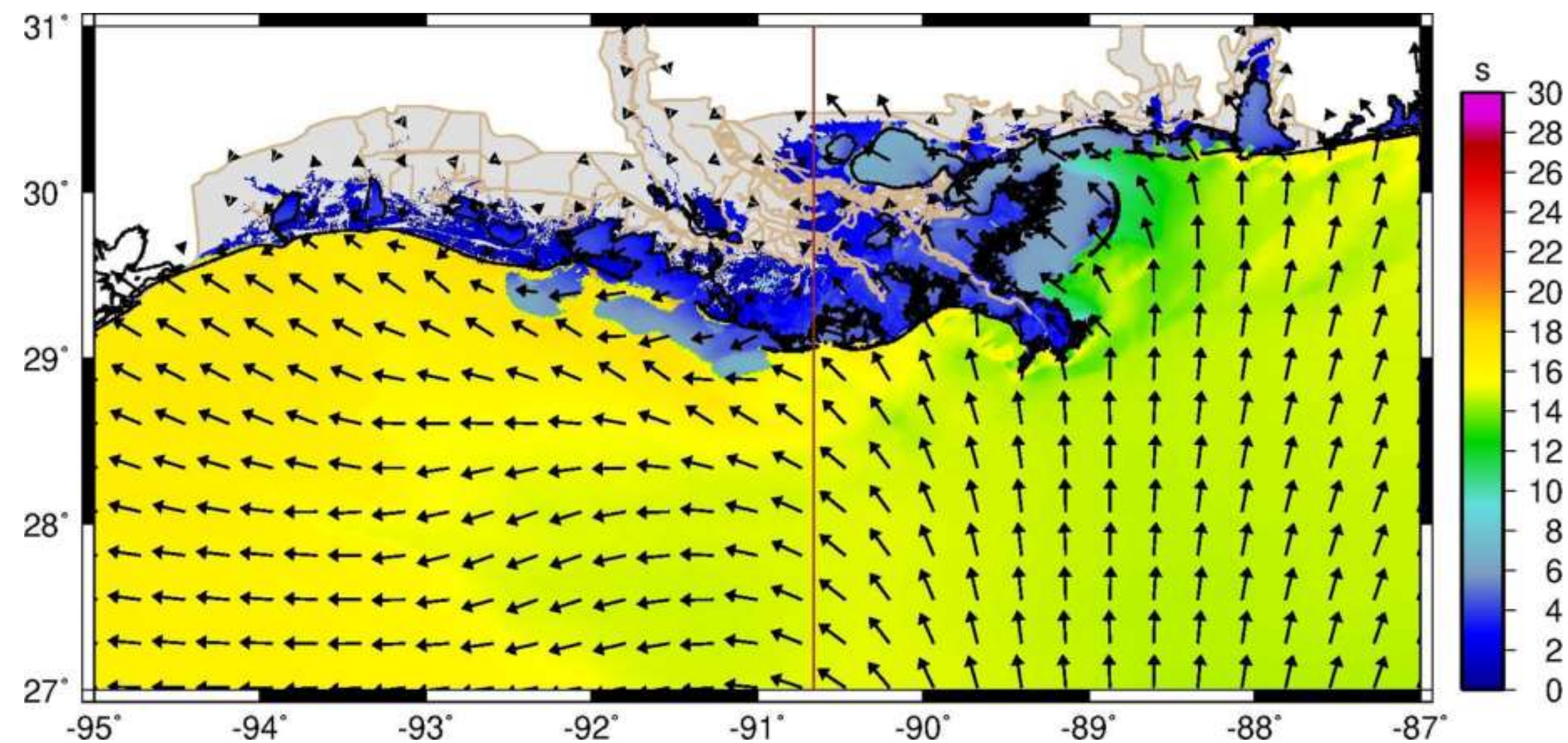
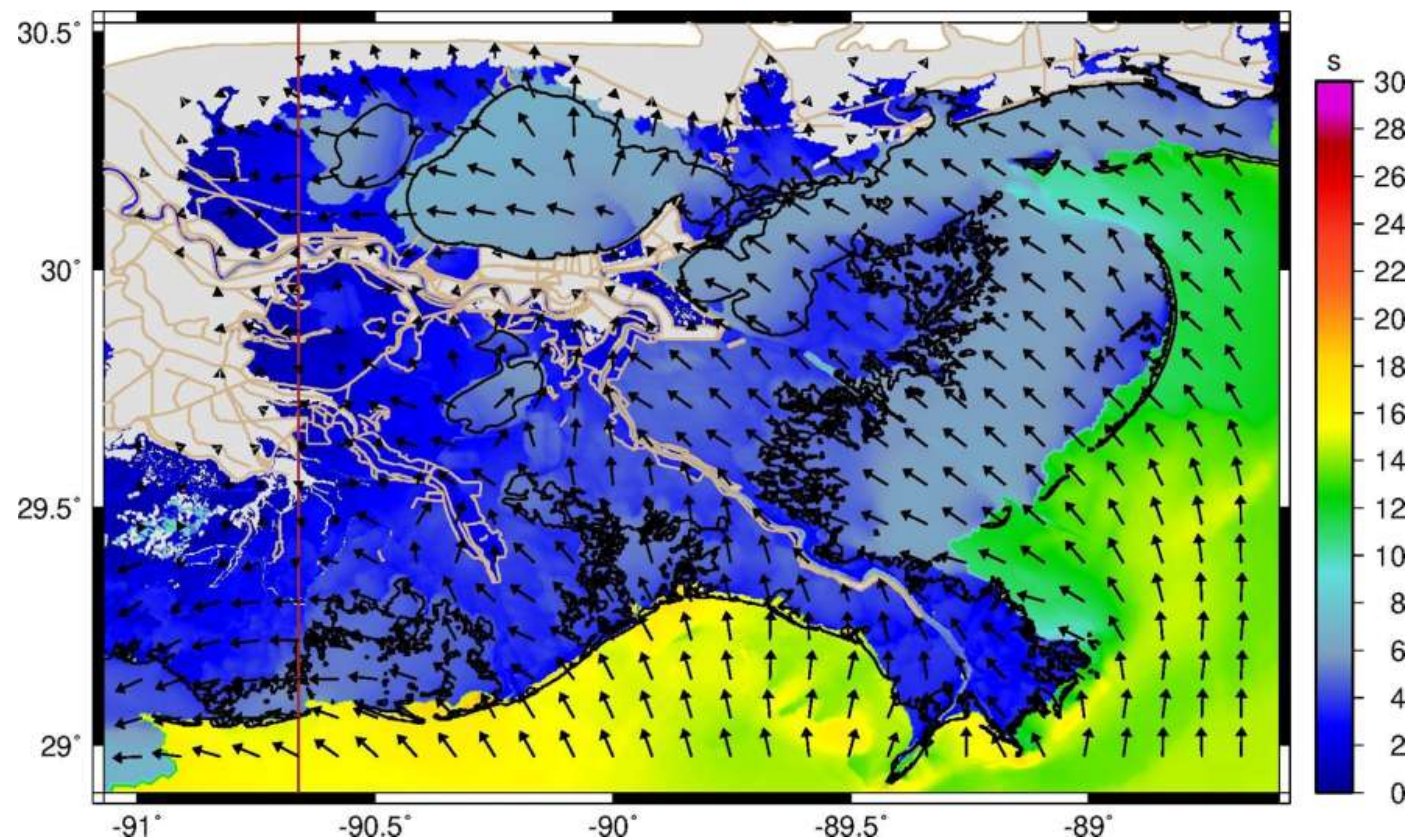


# MODEL OUTPUTS

## STORM SURGE AND WAVES MODELING

- Model outputs consist of
  - Peak Water Levels
  - Peak Wave Height
  - Peak Wave Period
  - Timeseries

| Parameter | Value |
|---|---|
| Minimum Central Pressure | 905mb |
| Radius to Max Winds | 25.9nm |
| Forward Speed | 5.9 kts |
| Storm Duration | 204 hours |



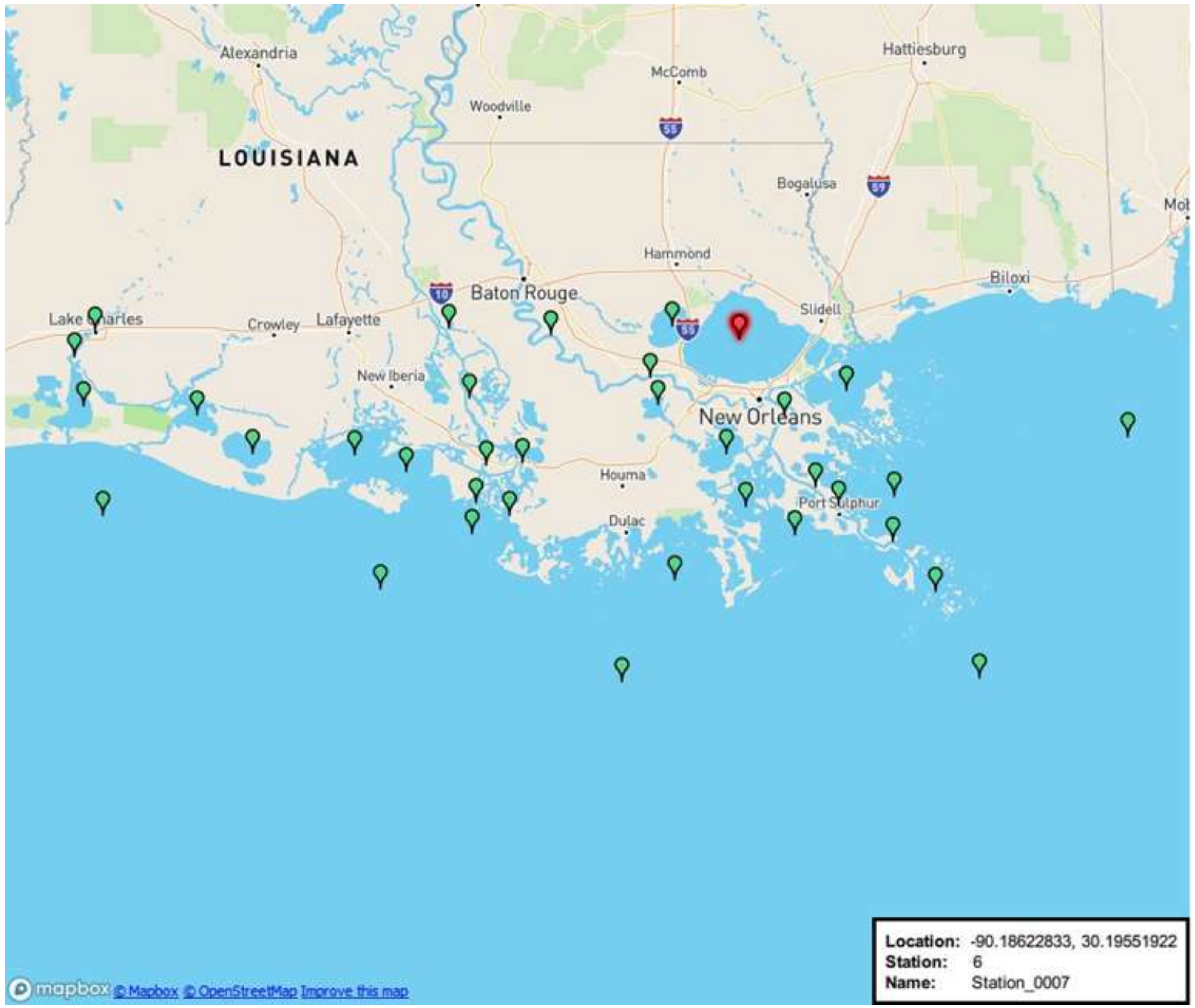
# MODEL OUTPUTS

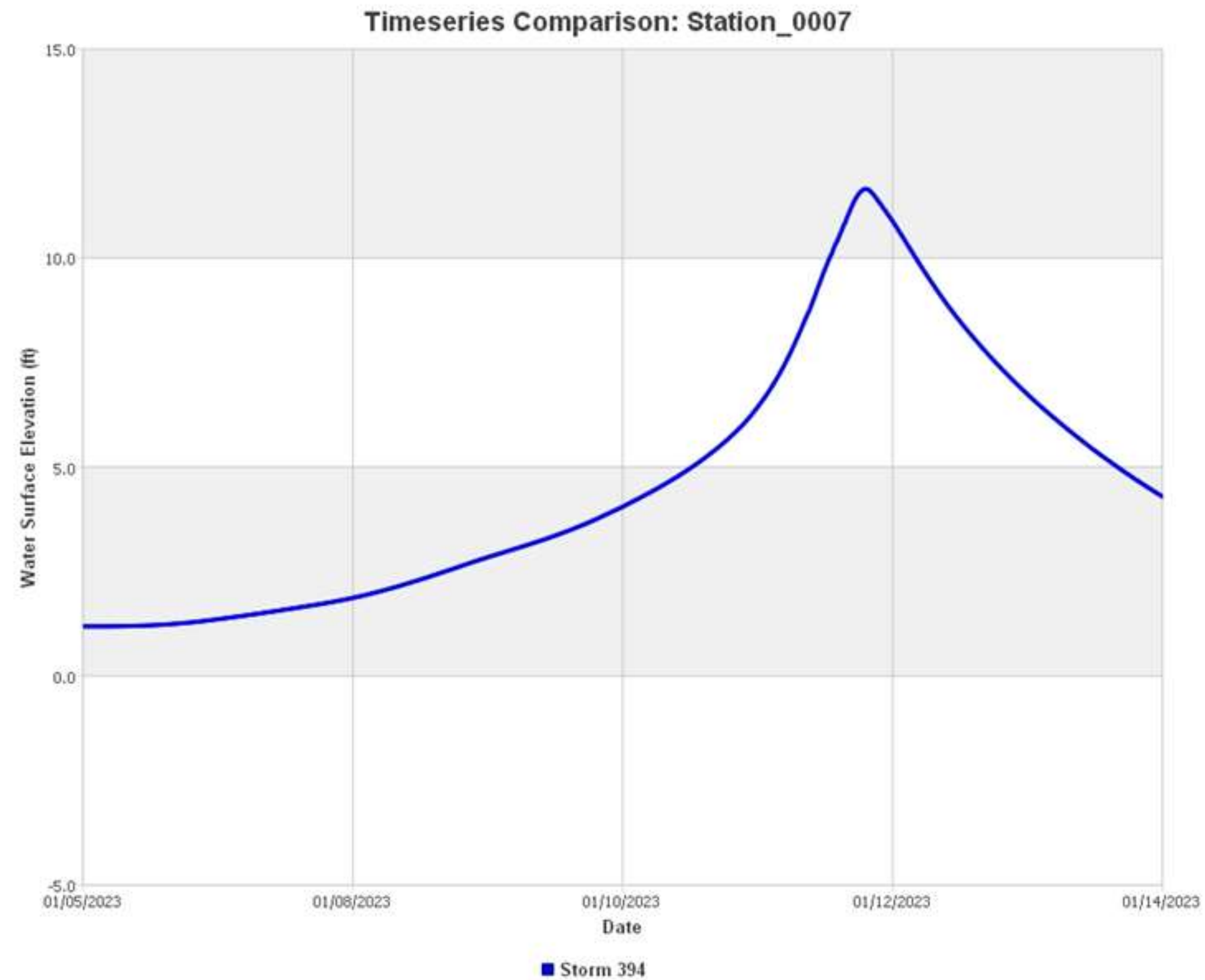
## STORM SURGE AND WAVES MODELING

- Model outputs consist of
  - Peak Water Levels
  - Peak Wave Height
  - Peak Wave Period
  - Timeseries
    - 20 minute global outputs

# MODEL OUTPUTS

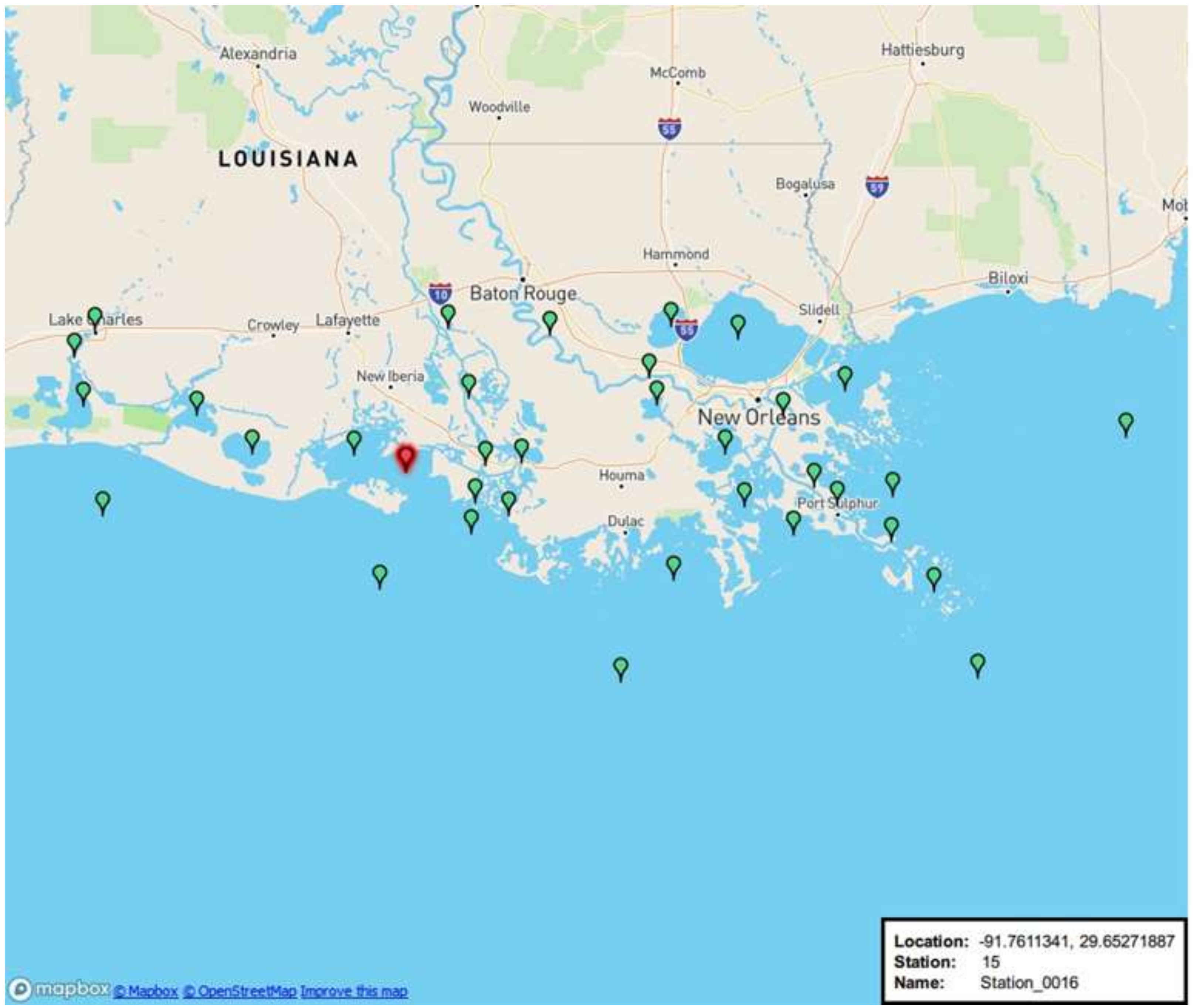
## STORM SURGE AND WAVES MODELING

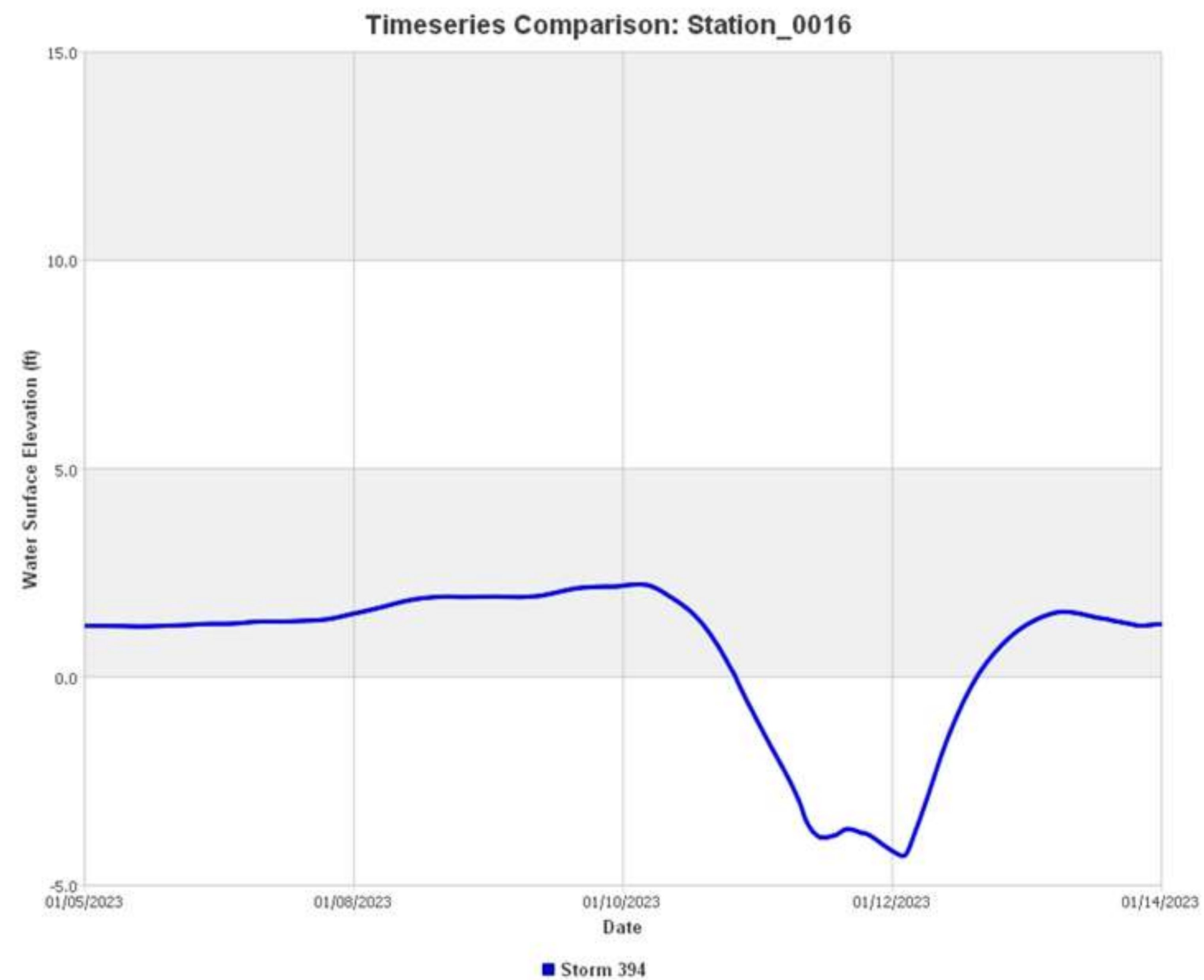


# MODEL OUTPUTS

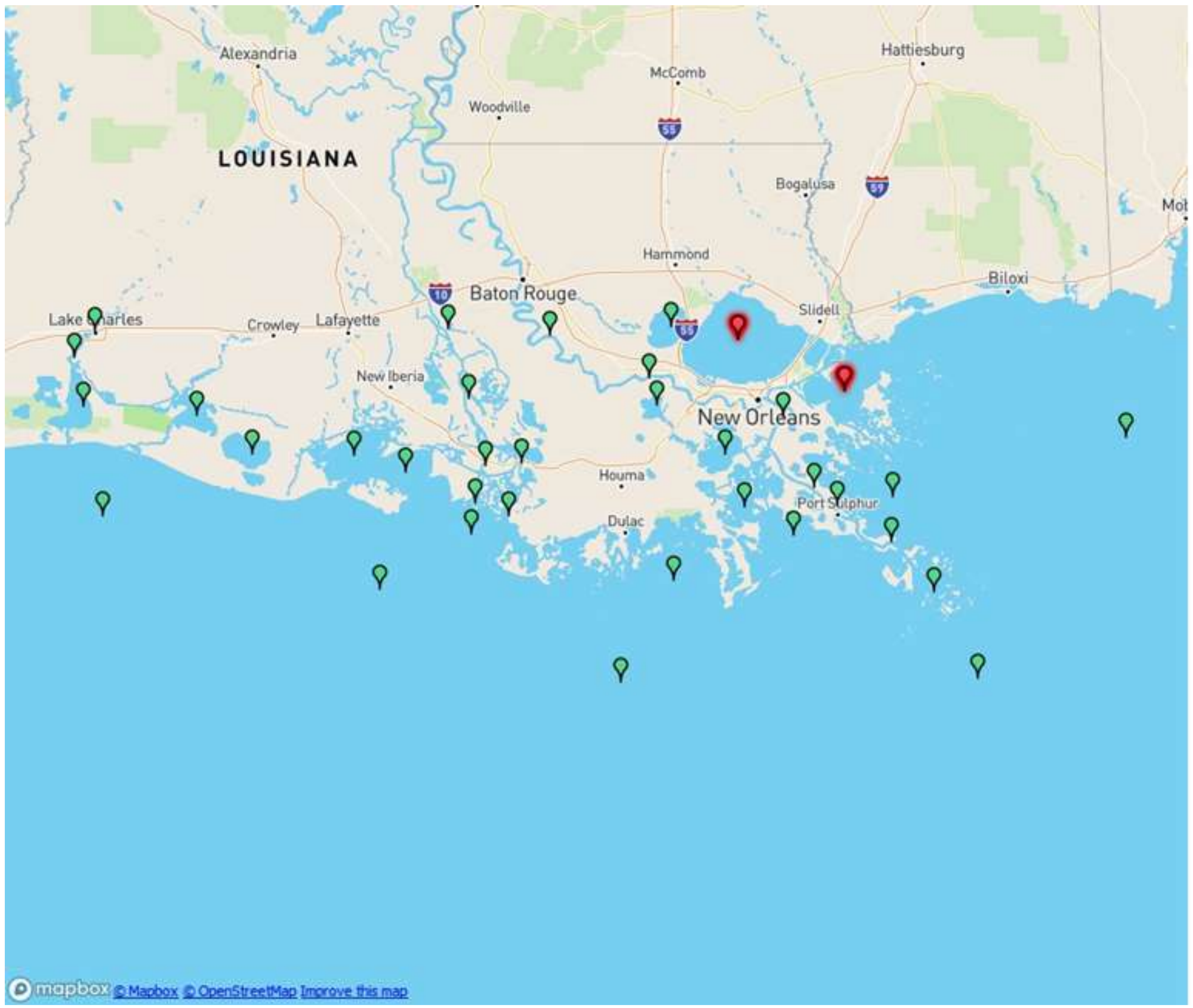
## STORM SURGE AND WAVES MODELING

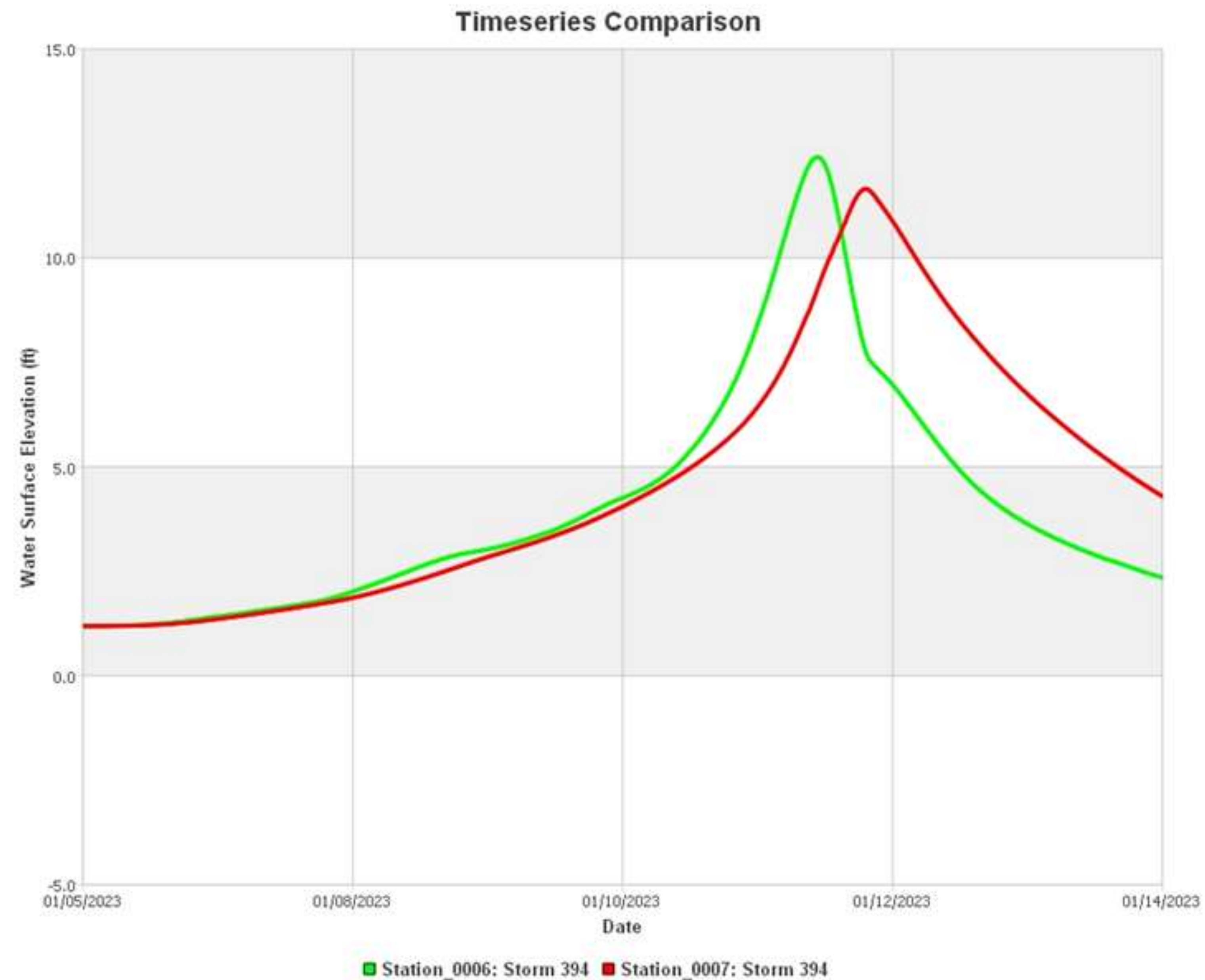


# MODEL OUTPUTS

## STORM SURGE AND WAVES MODELING

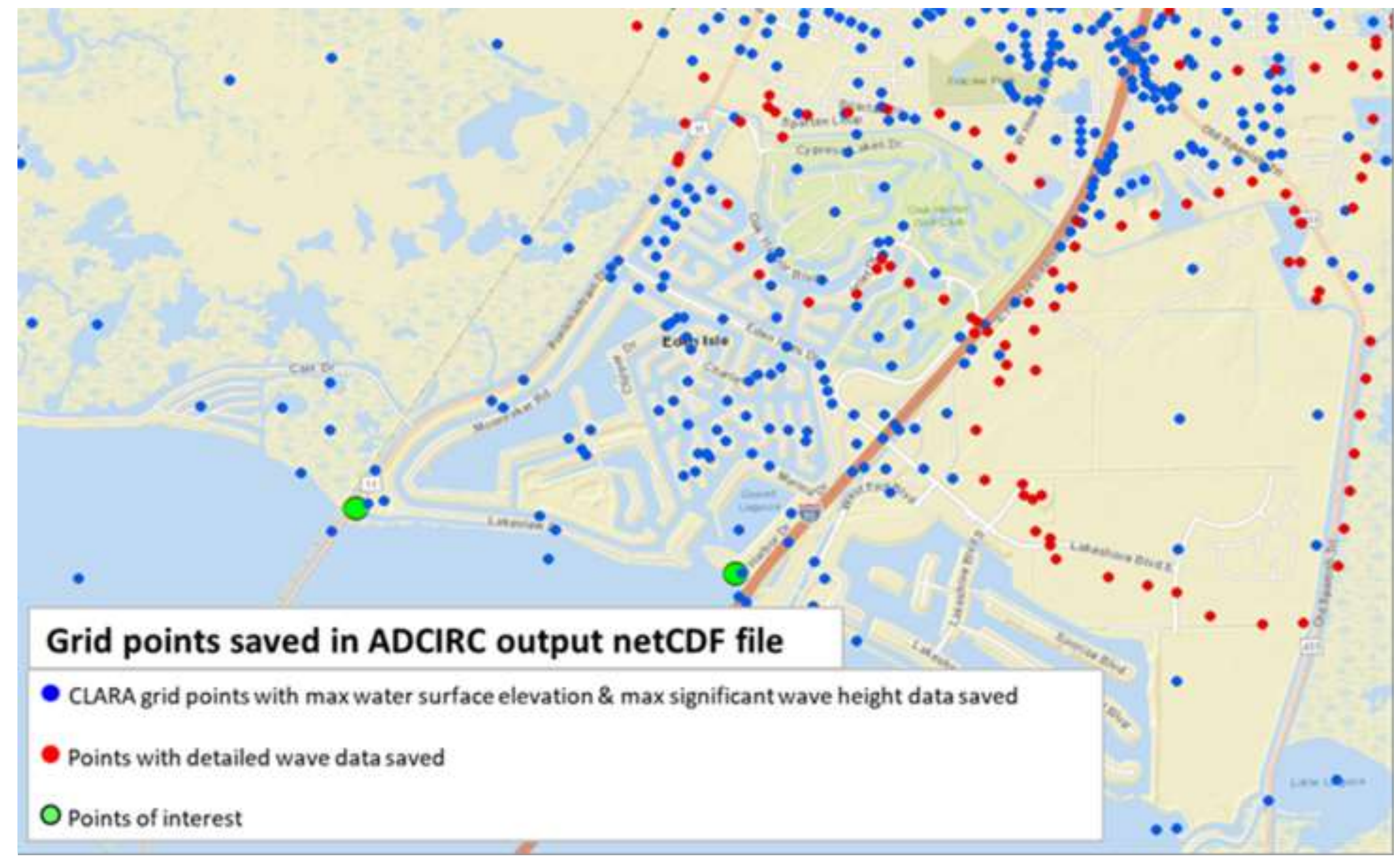


# OUTPUTS TO RISK ASSESSMENT

## STORM SURGE AND WAVES MODELING

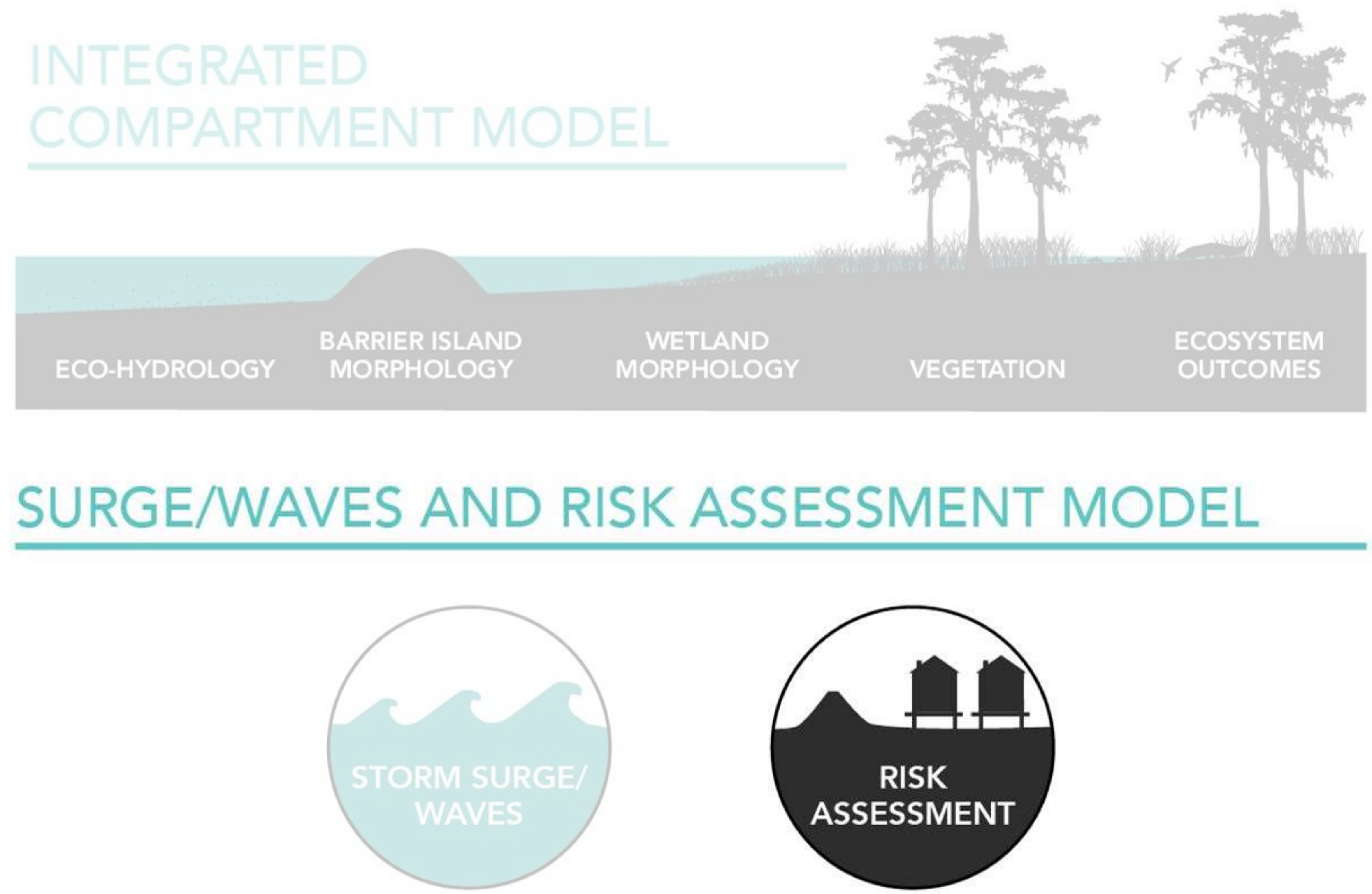
- ADCIRC water surface and wave height data saved at each CLARA grid point
- Additional timeseries data saved adjacent to levees to compute overtopping



# QUESTIONS

# RISK ASSESSMENT

# PREDICTIVE MODELS – RISK ASSESSMENT



# COASTAL LOUISIANA RISK ASSESSMENT MODEL (CLARA)

## RISK ASSESSMENT

**CLARA Model**

**Source Code:**

R (flooding), Analytica (damage)

**Original Developers:**

David Johnson

Jordan Fischbach

Chuck Stelzner

Benjamin Bryant

Matthew Hoover

Jordan Ostwald

David Ortiz

**Additional Developers (2017):**

Ricardo Sanchez

Kenneth Kuhn

James Syme

Edmundo Molina-Perez

**Additional Developers (2023):**

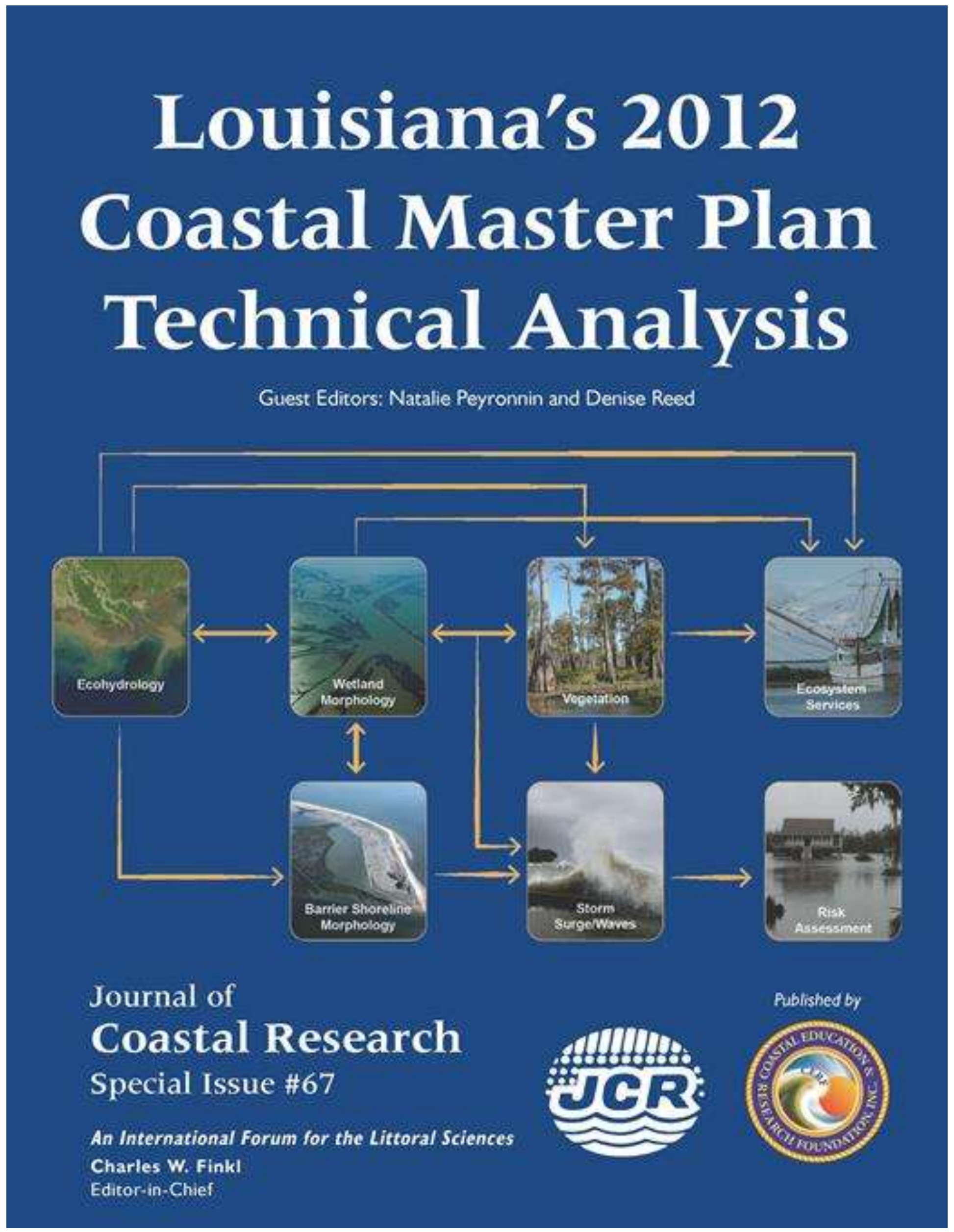
Nathan Geldner

Michael Wilson

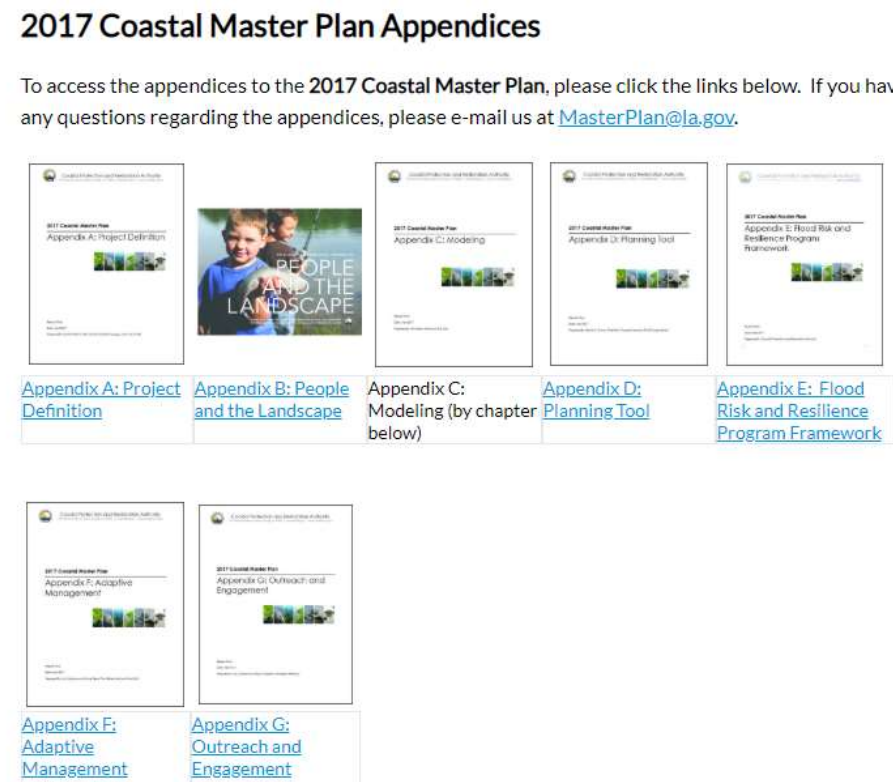
Mikaela Meyer

# TECHNICAL REPORTS & PEER-REVIEWED LITERATURE

## RISK ASSESSMENT




Models for 2012 Master Plan were peer-reviewed and published in a dedicated issue of JCR.




Updates to models for 2017 Master Plan were documented primarily through technical appendices to the plan.


Shisler & Johnson, (2020). *Water*. https://doi.org/10.3390/w12051420

Fischbach et al., (2019). *Env. Research Communications*. https://doi.org/10.1088/2515-7620/ab4b25

Meyer & Johnson, (2019). *J. Marine Sci. & Engineering*. https://doi.org/10.3390/jmse7050145

Johnson, (2019). *Risk Analysis*. https://doi.org/10.1111/risa.13213

Johnson, (2019). *Risk Analysis*. http://doi.org/10.1111/risa.13268

Fischbach et al., (2017). *RAND Technical Report*. https://rand.org/pubs/research_reports/RR1988.html

Groves et al., (2016). *RAND Technical Report*. https://rand.org/pubs/research_reports/RR1449.html

Fischbach et al., (2016). *J. Marine Sci. & Engineering*. https://doi.org/10.3390/jmse4010010

Fischbach et al., (2012). *RAND Technical Report*. https://rand.org/pubs/technical_reports/TR1259.html


Peer-reviewed articles and reports based on CLARA tools and analyses.

# COASTAL LOUISIANA RISK ASSESSMENT MODEL (CLARA)



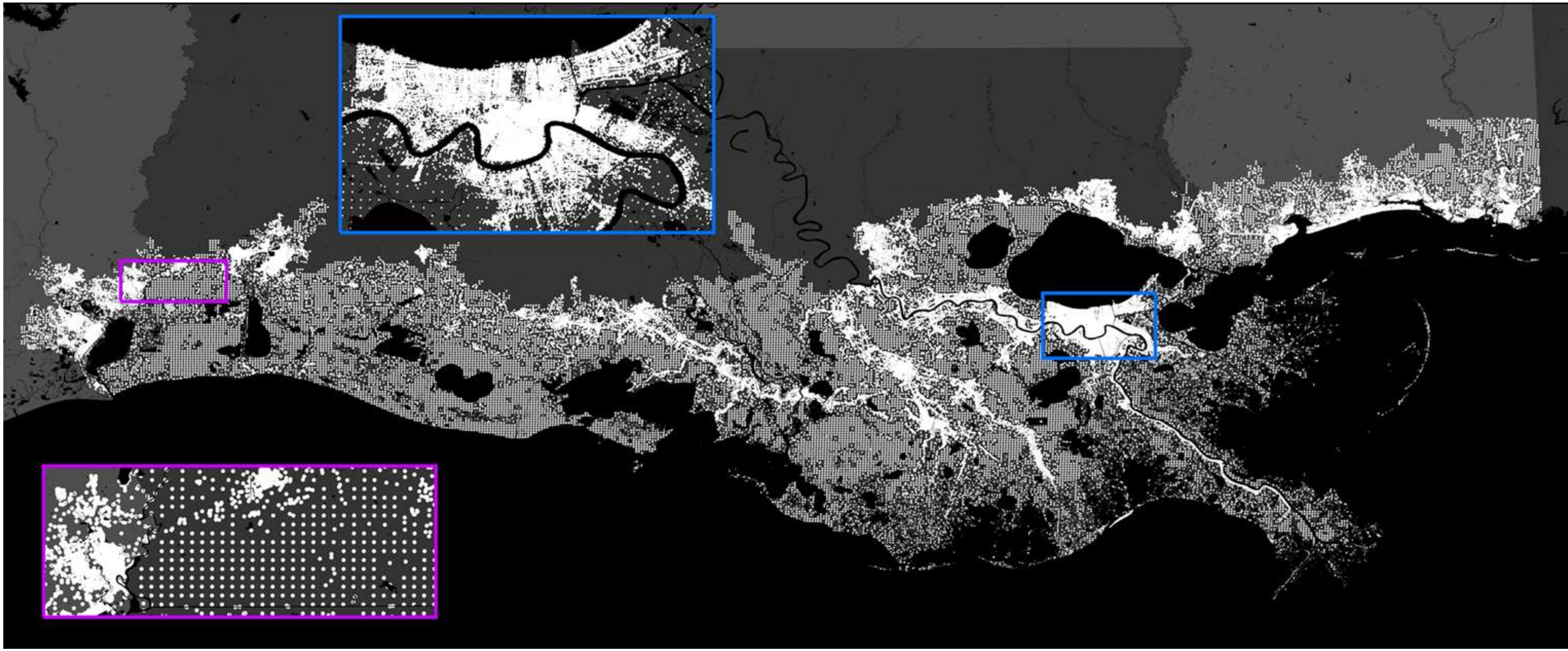
- Draws on post-Katrina flood modeling efforts in Louisiana
  - Louisiana Coastal Protection and Restoration (LACPR)
  - Interagency Performance Evaluation Team (IPET)
  - FEMA Hazards-US Multi-Hazard Model (Hazus-MH)

- Designed in separate modules for iterative improvement
  - Incorporate new methods as they are developed
  - Update database of assets at risk with new data sources

- Flexibly estimates damage reduction over a range of conditions
  - Computationally efficient
  - Designed to run across many future years and scenarios
  - Calculates flood damage impacts from structural, non-structural, and restoration projects

# SPATIAL DOMAIN AND RESOLUTION

## RISK ASSESSMENT



- 2023 model includes approximately 129,000 grid points (105,000 in Louisiana)
- 2023 model implements structure-level risk estimates at approximately 750,000 structures in the model domain

# FACTORS AFFECTING ESTIMATED FLOOD DEPTHS



- No levee protection
  - Storm surge
  - Wave heights


- Unenclosed surge barrier
  - Storm surge overtopping
  - Storm surge "run-around"


- Enclosed protection system
  - Surge overtopping
  - Wave overtopping
  - Rainfall
  - Protection system breach(es)
  - Pumping

# THREE-PART RISK FRAMEWORK

## RISK ASSESSMENT

1. **Hazard**: the probability that a given storm of interest will occur

2. **Vulnerability**: the probability distribution of flood depths resulting from a given storm event

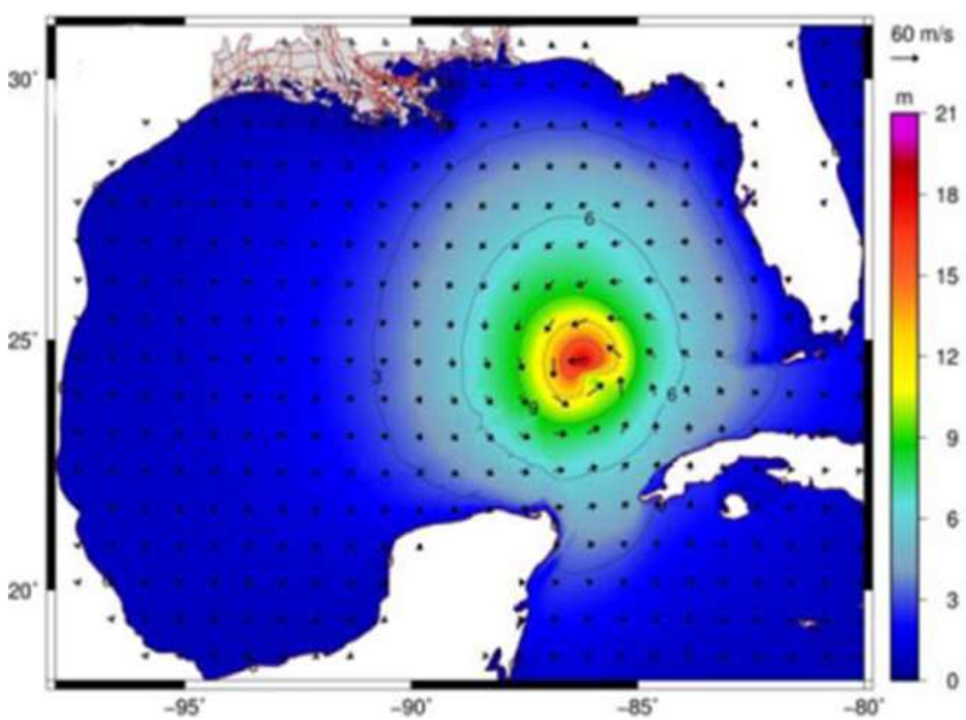
3. **Consequences**: the direct economic damage caused by a given level of flooding

# COASTAL LOUISIANA RISK ASSESSMENT MODEL (CLARA)

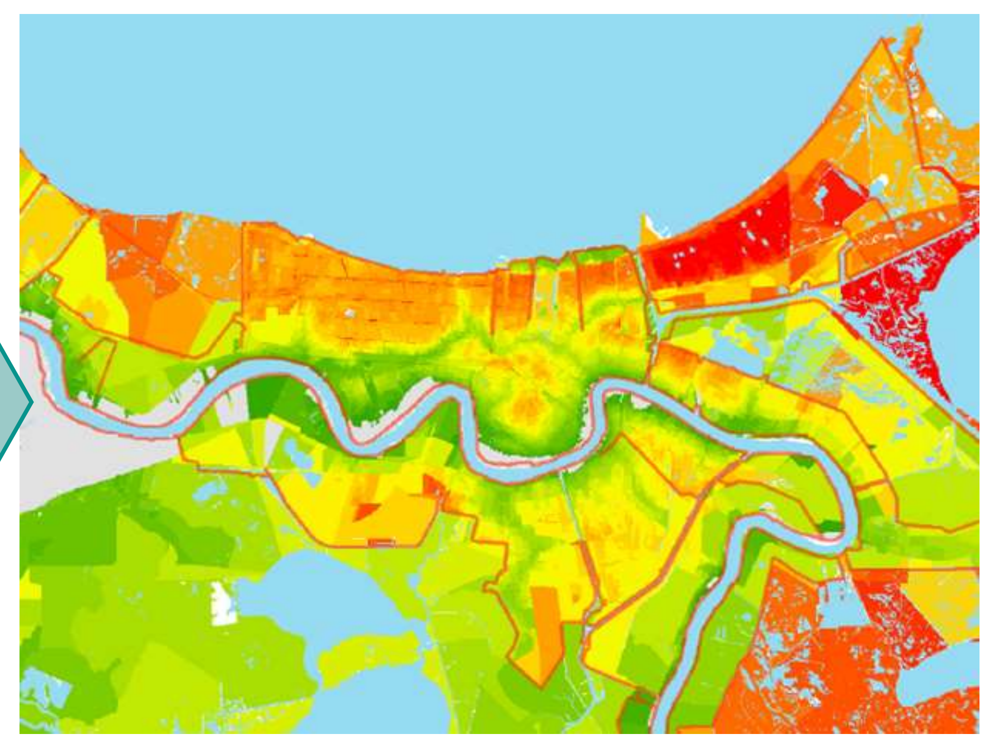
## RISK ASSESSMENT

- CLARA consists of three modules:

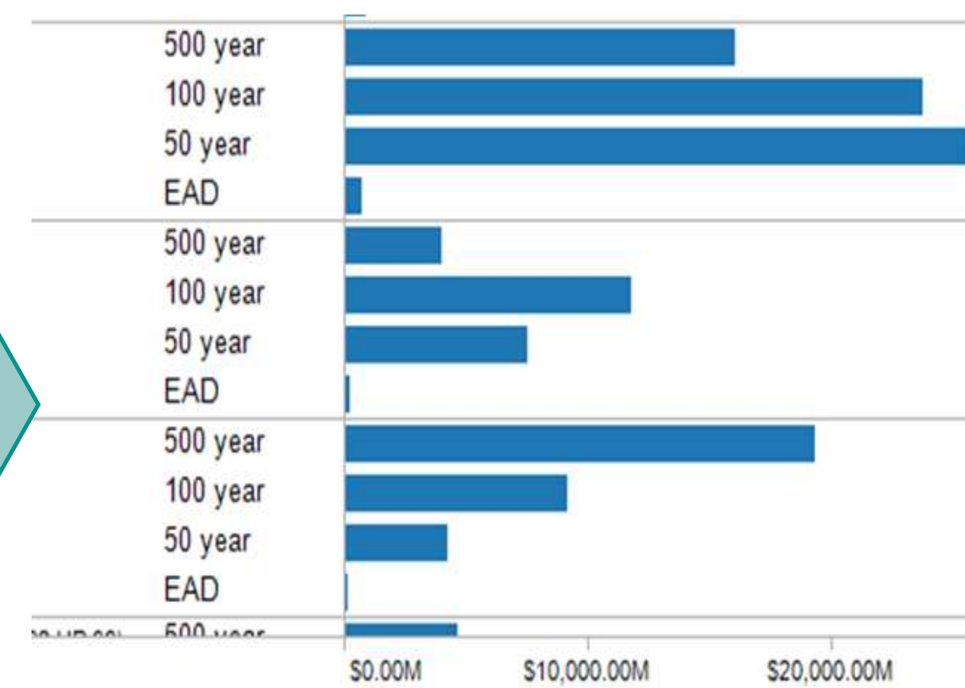
### 1. Statistical Pre-Processing Module



### 2. Flood Depth Module



### 3. Economic Damage Module



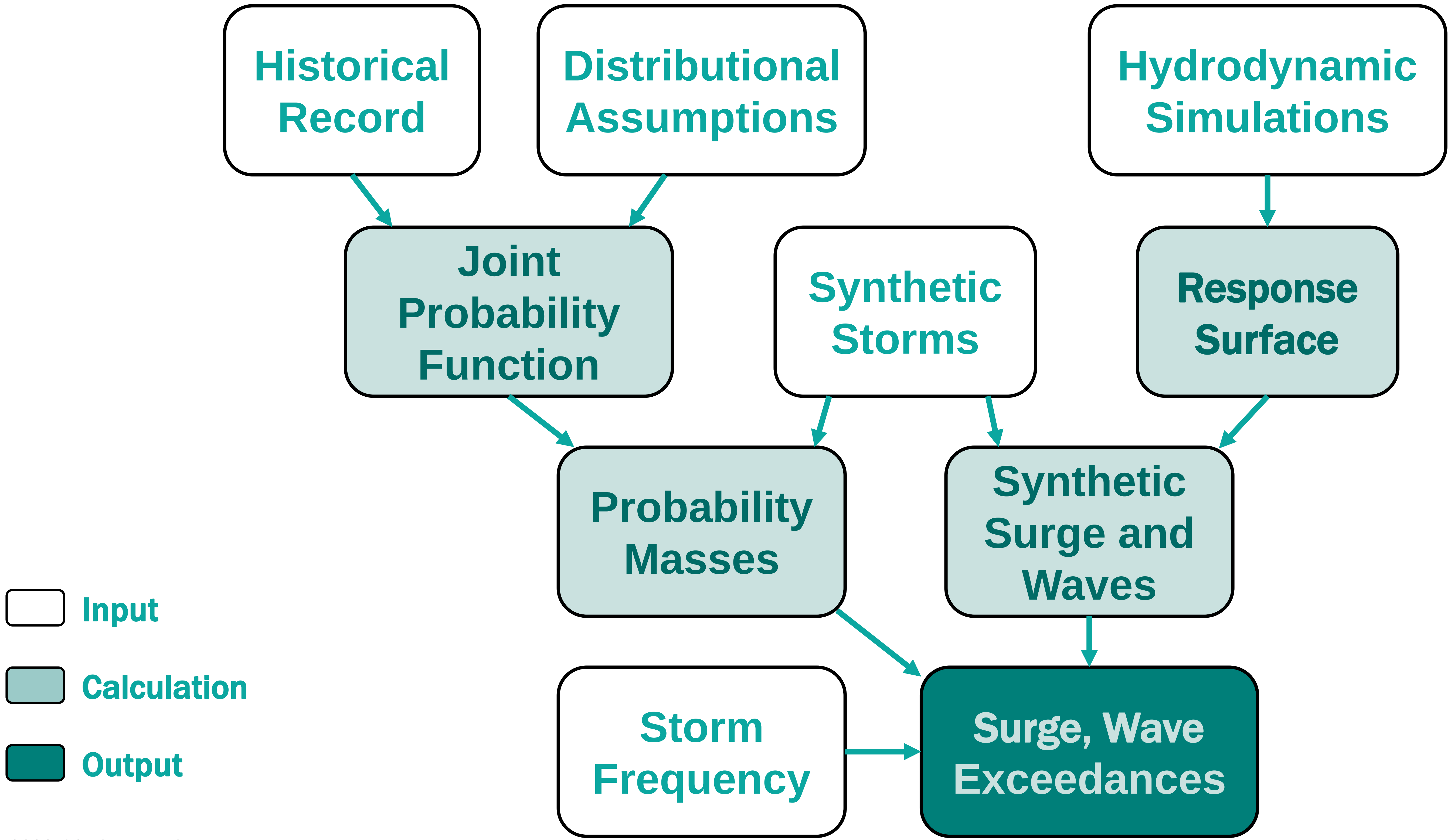
# JOINT PROBABILITY METHOD WITH OPTIMAL SAMPLING (JPM-OS)



- Joint probability model
  - Assesses the relative likelihood of a set of storms
  - Fit using the historical record of observed storms
- Response surface model
  - Predicts surge and wave response as a function of storm parameters
  - Fit using high-resolution hydrodynamic modeling

# JOINT PROBABILITY METHOD WITH OPTIMAL SAMPLING (JPM-OS)

## RISK ASSESSMENT



# JOINT PROBABILITY MODEL

## RISK ASSESSMENT

- Storms are characterized by five parameters:
  - $c_p$ - central pressure deficit
  - $R_{max}$ - radius of maximum wind speeds
  - $v_f$ - forward velocity
  - $x$ - longitudinal location at landfall
  - $\theta_l$ - angle of incidence at landfall
- Parameters from observed historic storms are used to estimate the relative likelihood of occurrence of a storm with any characteristics

# JOINT PROBABILITY MODEL

## RISK ASSESSMENT

- Occurrence of parameters in historic storms is fit to assumed distributions:

$$p(c_p, R_p, v_f, \theta_l, x) = \Lambda_1 \cdot \Lambda_2 \cdot \Lambda_3 \cdot \Lambda_4 \cdot \Lambda_5$$

$$\Lambda_1 = p(c_p \mid x) = \frac{\partial F[a_0(x), a_1(x)]}{\partial c_p} = \frac{\partial}{\partial x}\left\{\exp\left\{-\exp-\left[\frac{c_p - a_0(x)}{a_1(x)}\right]\right\}\right\}$$

$$\Lambda_2 = p(R_p \mid c_p) = \frac{1}{\sigma(\Delta P)\sqrt{2\pi}} e^{-\frac{(\bar{R}_p(\Delta P) - R_p)^2}{2\sigma^2(\Delta P)}}$$

$$\Lambda_3 = p(v_f \mid \theta_l) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\bar{v}_f(\theta_l) - v_f)^2}{2\sigma^2}}$$

$$\Lambda_4 = p(\theta_l \mid x) = \frac{1}{\sigma(x)\sqrt{2\pi}} e^{-\frac{(\bar{\theta}_l(x) - \theta_l)^2}{2\sigma^2(x)}}$$

$$\Lambda_5 = \Phi(x)$$

- Distribution coefficients are fit using maximum likelihood on a small sample of past Gulf storms

# JOINT PROBABILITY MODEL

## RISK ASSESSMENT

- Use joint probability distribution to assess relative likelihood of simulated “synthetic storms”:
  - Plausible values of $c_p$, $R_{max}$, $v_f$, $x$, and $\theta_l$
  - Select set of synthetic storms
  - Partition parameter space so a synthetic storm lies in the center of each cell
  - Integrate the joint probability function over the boundaries of each cell to determine a probability mass associated with each storm

# JOINT PROBABILITY METHOD WITH OPTIMAL SAMPLING (JPM-OS)



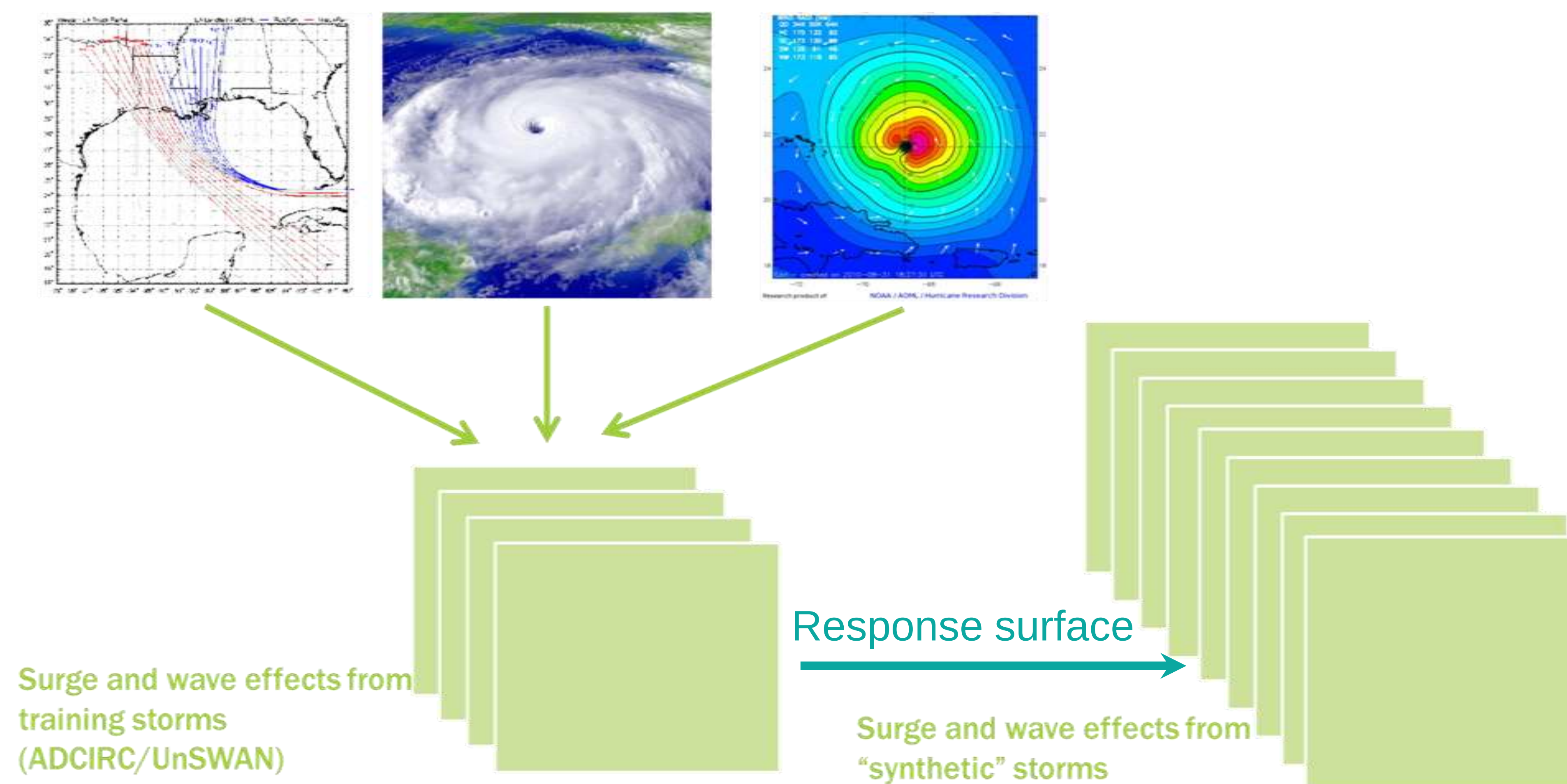
- Joint probability model
  - Assesses the relative likelihood of a set of storms
  - Fit using the historical record of observed storms

- Response surface model
  - Predicts surge and wave response as a function of storm parameters
  - Fit using high-resolution hydrodynamic modeling

# PREDICTING SURGE AND WAVE RESPONSE

## RISK ASSESSMENT

- Response surface model predicts surge and wave response as a function of storm parameters
- Storms are parameterized by a set of landfall characteristics
  - Central pressure
  - Radius of max winds
  - Longitudinal location
  - Heading
  - Forward velocity
- Also utilizes distance from landfall and azimuthal angle between storm landfall and points of interest



# PREDICTING SURGE AND WAVE RESPONSE

## RISK ASSESSMENT

- A set of training storms is run through ADCIRC+SWAN

- Surge elevations and wave heights are predicted for a larger set of storms, using locally-weighted regression
  - Each point is fit separately, but also using data from nearby points

- Response surface model varies depending on how many storms produce surge
  - Full model specification

$$\boldsymbol{s_i, w_i = \beta_0 + \beta_1 c_p + \beta_2 r_{max} + \beta_3 v_f + \beta_4 d_{il}{}^3 + \beta_5 d_{il}{}^2 + \beta_6 d_{il} + \beta_7 \theta_{il} + \beta_8 \sin\varphi_{il} + \beta_9 x + \varepsilon_i}$$

# ESTIMATING ANNUAL EXCEEDANCE PROBABILITIES

## RISK ASSESSMENT

- Surge elevations and wave heights for each synthetic storm are converted to flood depths, then combined with the storms' probability masses to estimate flood depth annual exceedance probabilities (AEP)

$$F_S(d) = P(D \leq d) = \sum_{i \in S} \sum_{D \in D_i, D \leq d} P(S_i) \cdot P(D|S_i)$$

- $F_S(d)$ is the cumulative distribution function (CDF) conditional upon a storm occurring, but we want an annual probability

# ESTIMATING ANNUAL EXCEEDANCE PROBABILITIES



- The arrival of storms is treated as a Poisson process with mean inter-arrival rate $\alpha$
  - The probability of observing *i* storms in a given year is

$$P(i) = e^{-\alpha}\frac{\alpha^{i}}{i!}$$

- Thus, the CDF on an annual basis becomes

$$F_A(d) = \sum_{i=0}^{\infty} F_S(d)^i \cdot P(i) = e^{-\alpha}\sum_{i=0}^{\infty}\frac{F_S(d)^i \cdot \alpha^i}{i!}$$

- The *n*-year flood depth, $d_n$, is the value satisfying

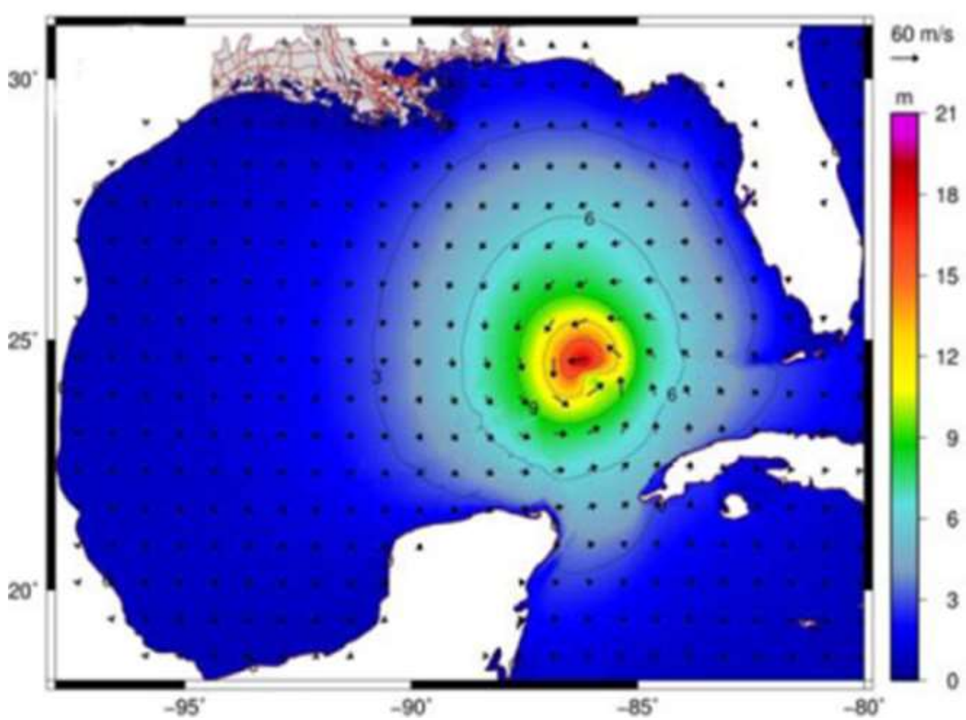
$$F_A(d_n) = 1 - 1/n$$

# COASTAL LOUISIANA RISK ASSESSMENT MODEL (CLARA)

RISK ASSESSMENT

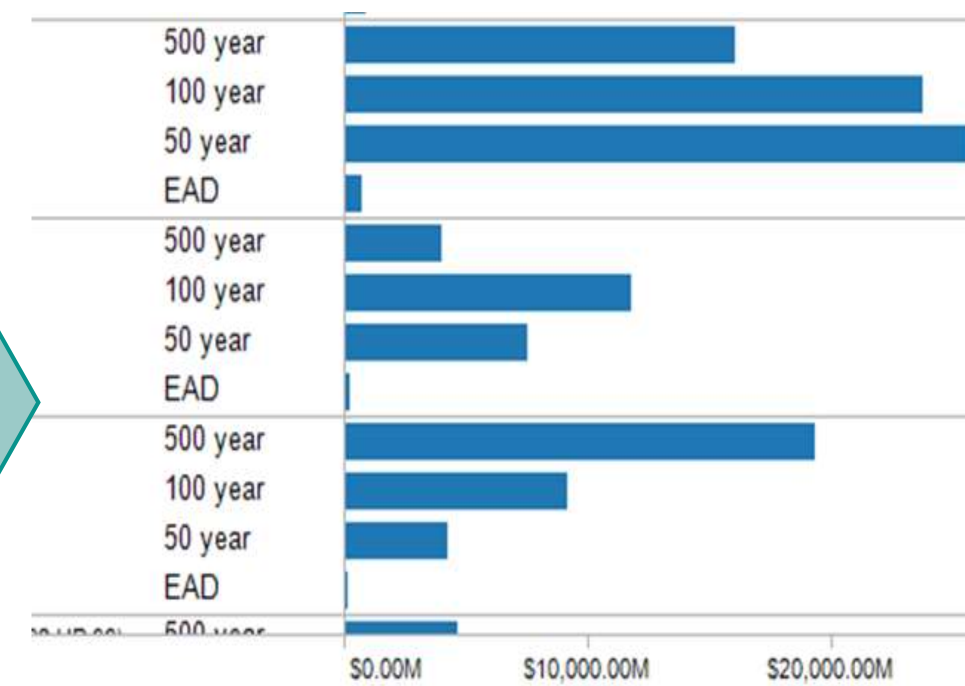
- Additional steps are needed to model interactions with ring levee systems

## 1. Statistical Pre-Processing Module




## 2. Flood Depth Module

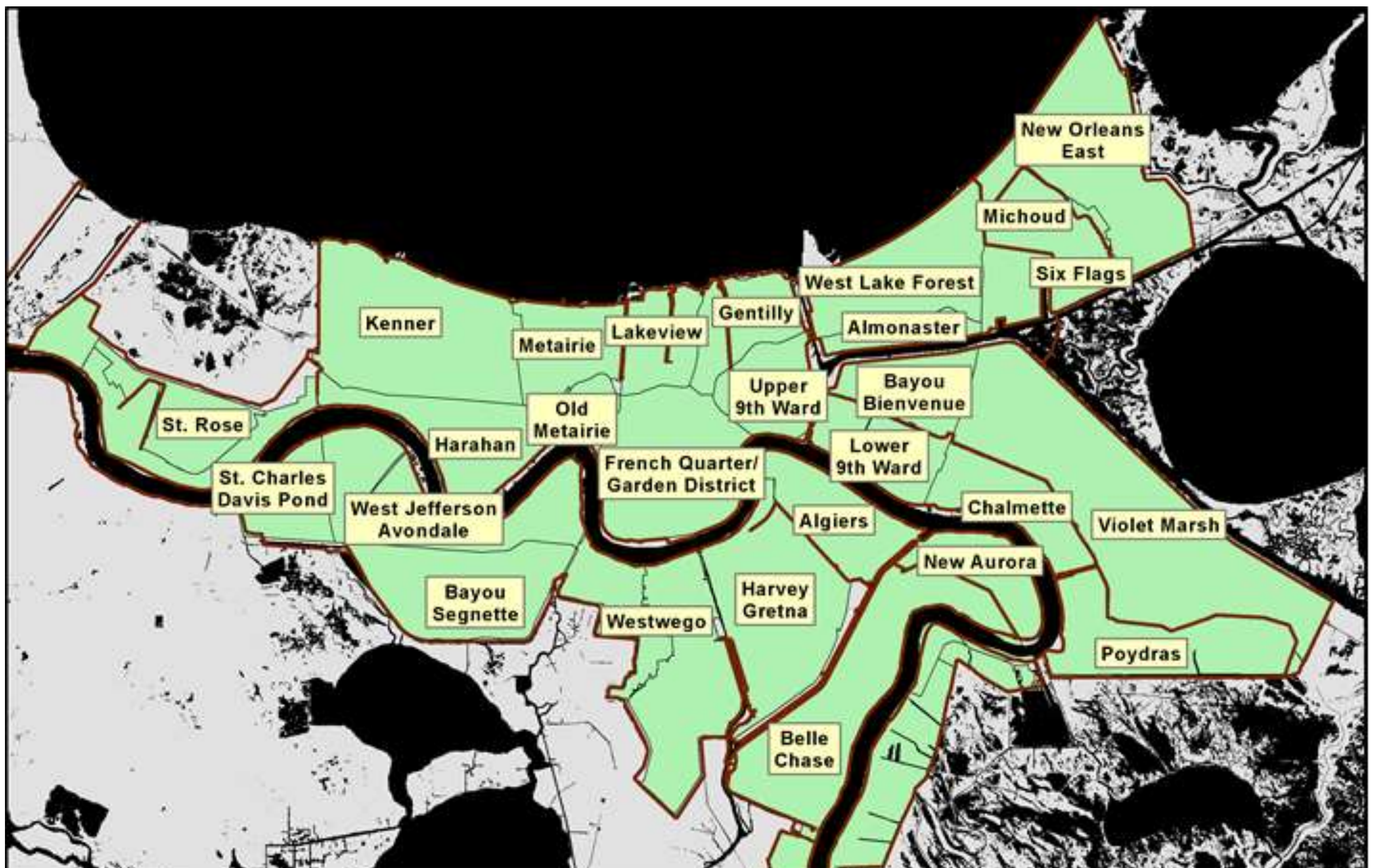
## 3. Economic Damage Module



# FLOOD DEPTH MODULE

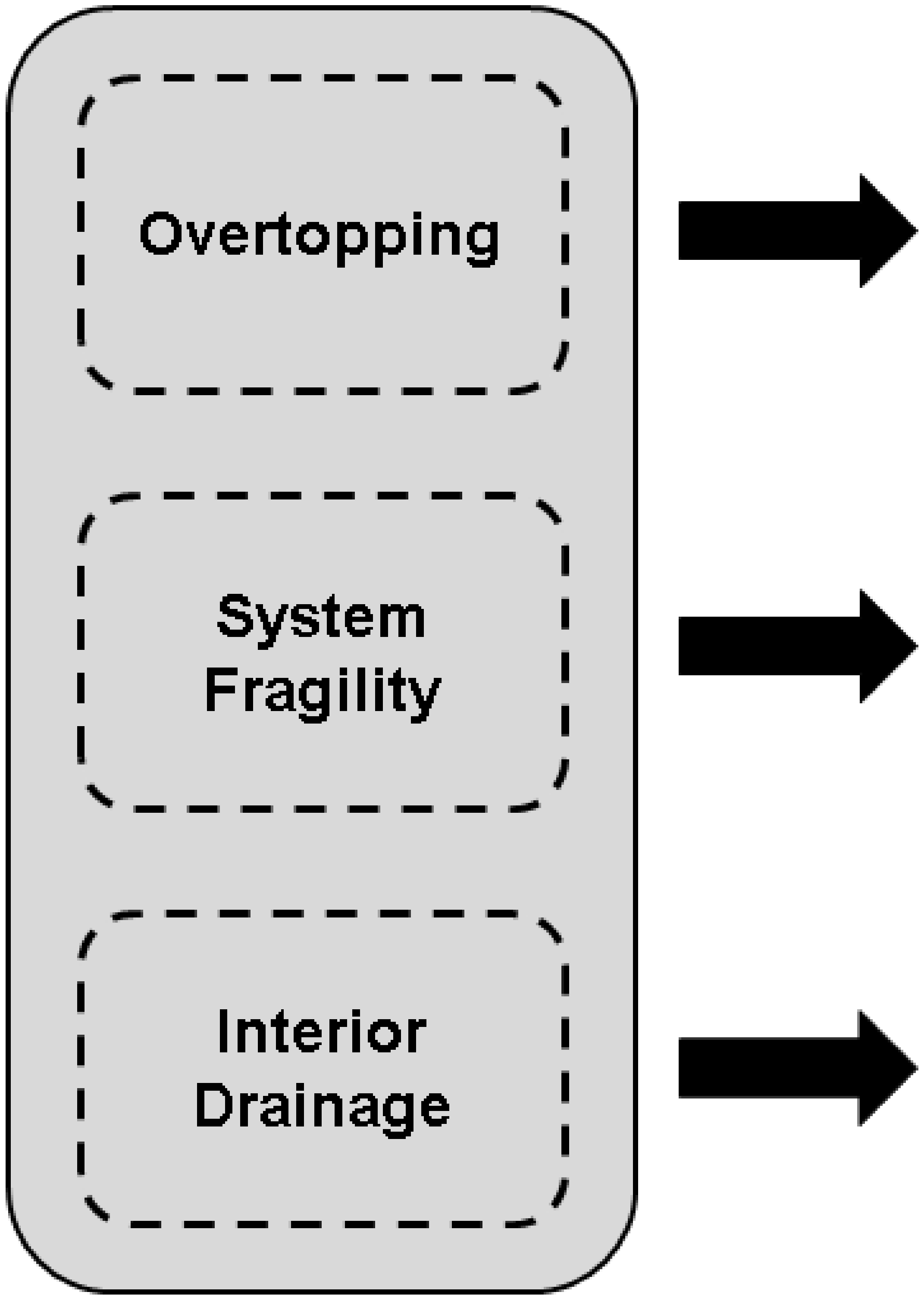
## RISK ASSESSMENT

- The interiors of enclosed protection systems are poldered using LACPR boundaries



# FLOOD DEPTH MODULE

## RISK ASSESSMENT




The flood depth module consists of three components

- Estimates the volume of water entering a protected area by overtopping the protection structure
- Estimates the volume of water entering in the case of a breach

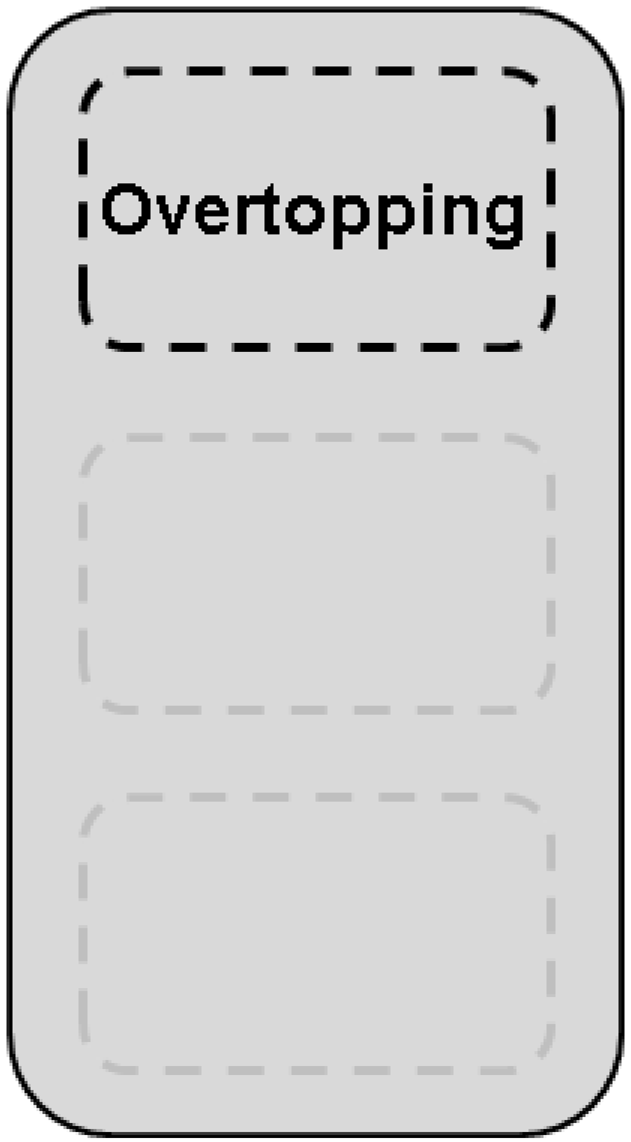
- Estimates the probability of various modes of failure
- Prescribes the consequences of system failures

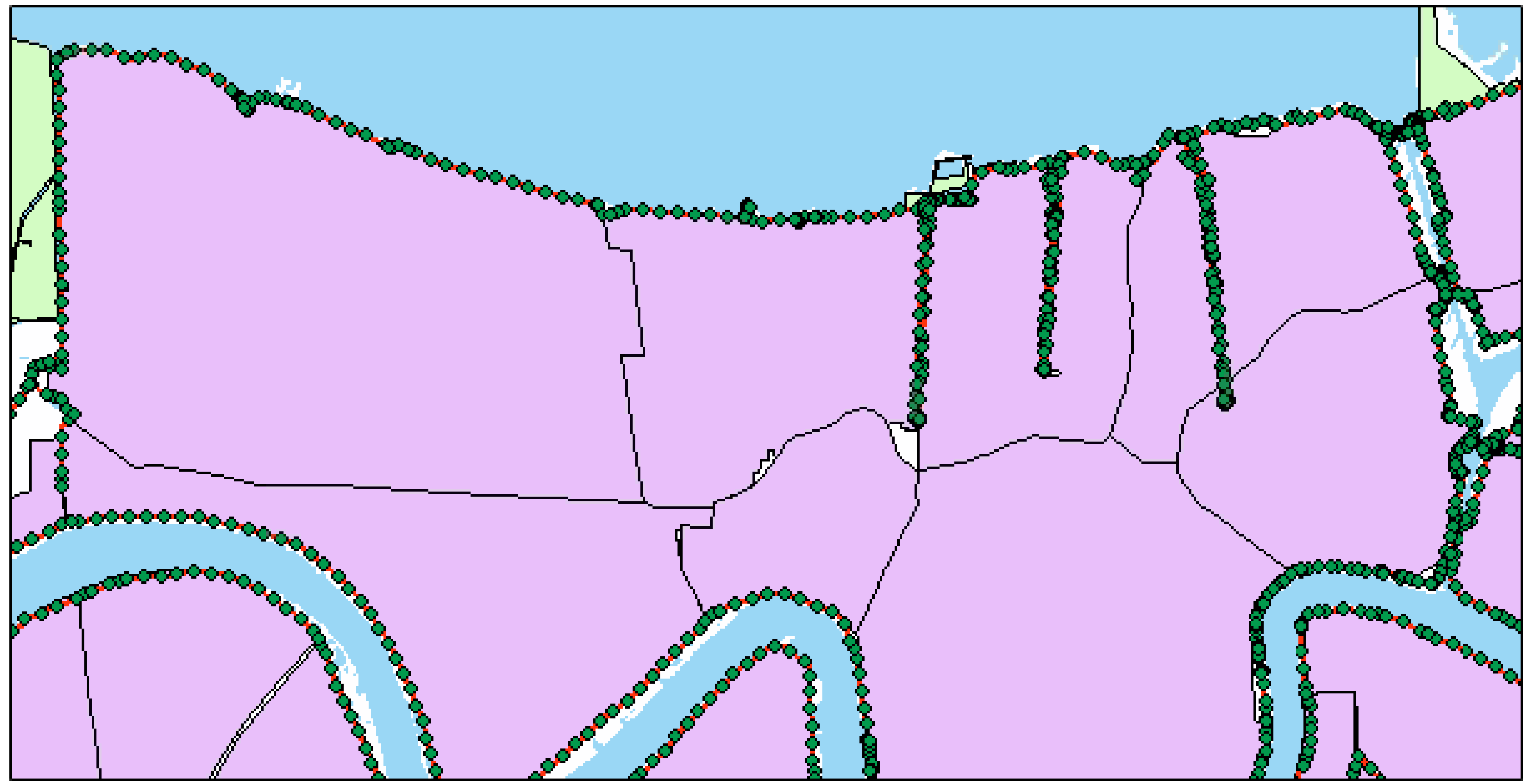
- Distributes flood water, from the linear boundary of the system, throughout the interior area
- Also accounts for rainfall and pumping systems

# FLOOD DEPTH MODULE

## RISK ASSESSMENT

Storm data is sampled and predicted at thousands of points on system boundaries



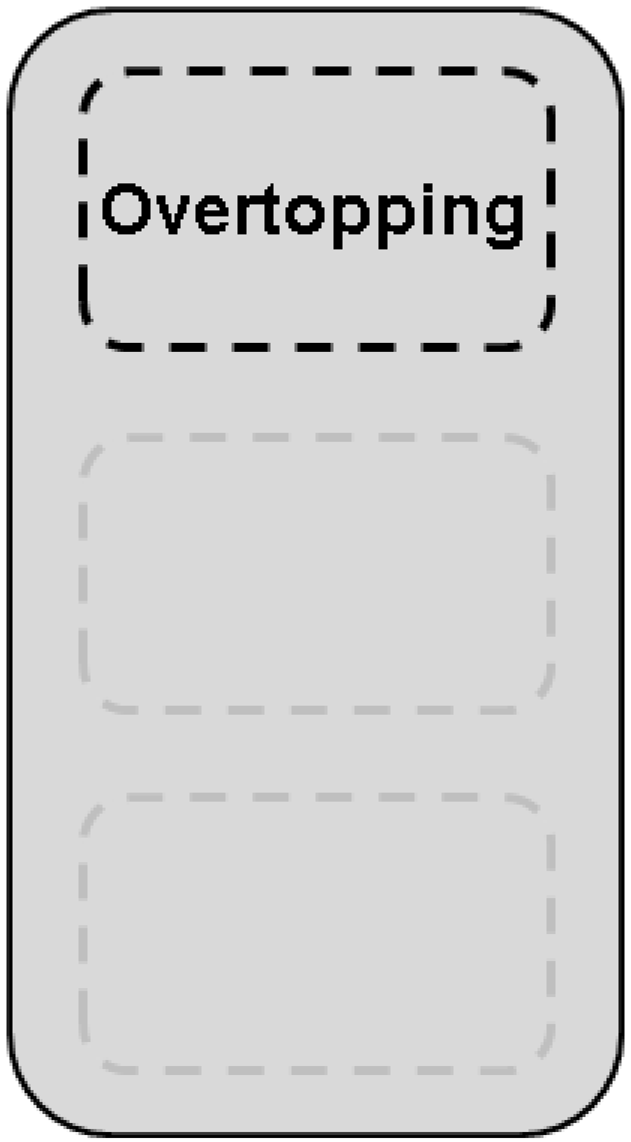



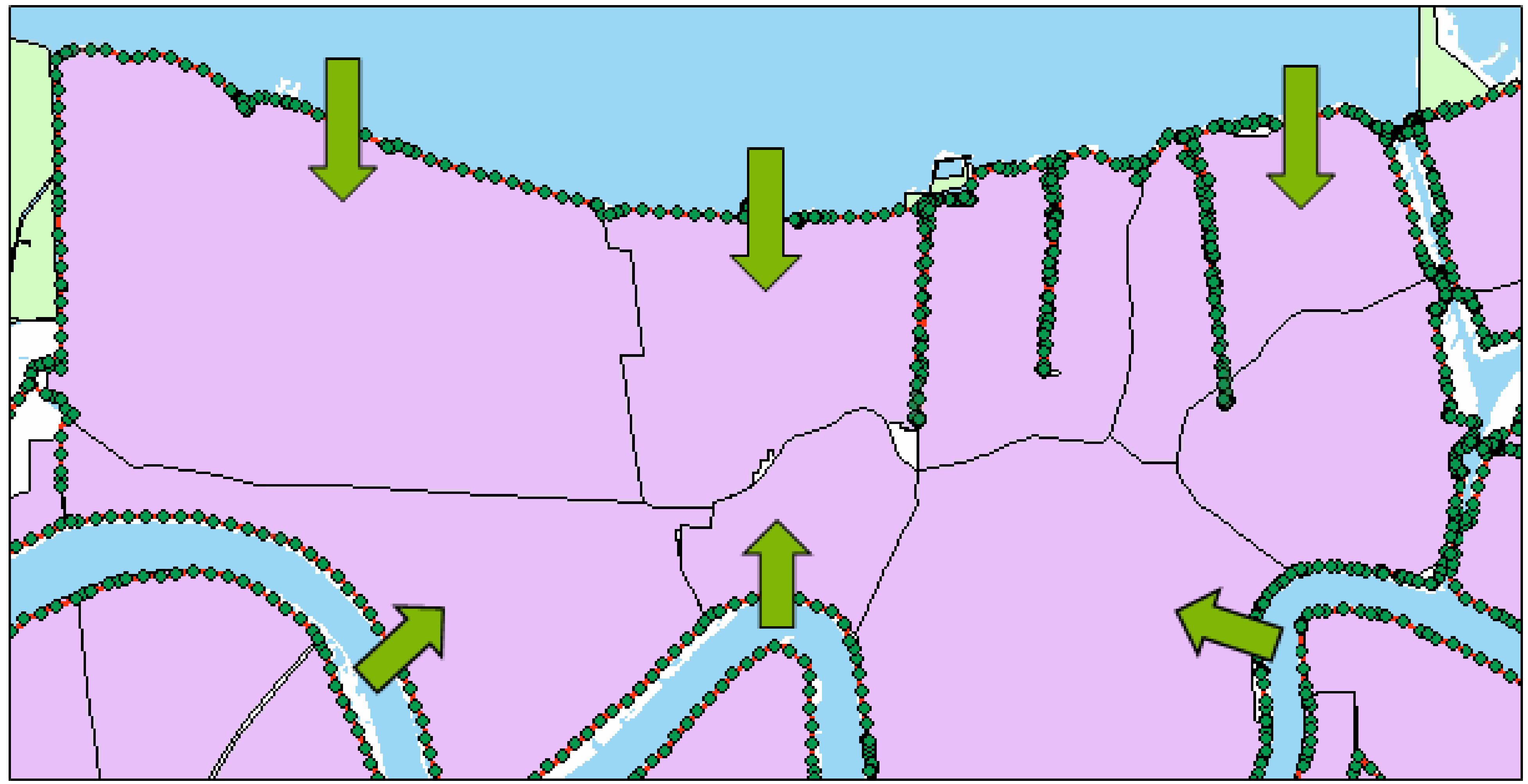
- Surge elevations, wave heights and wave periods are predicted for each synthetic storm at points 200 m in front of system centerlines
  - Surge projected at 20-minute intervals over a 3-day period (2 days runup, 1 day recess)

# FLOOD DEPTH MODULE

## RISK ASSESSMENT

Storm data is sampled and predicted at thousands of points on system boundaries



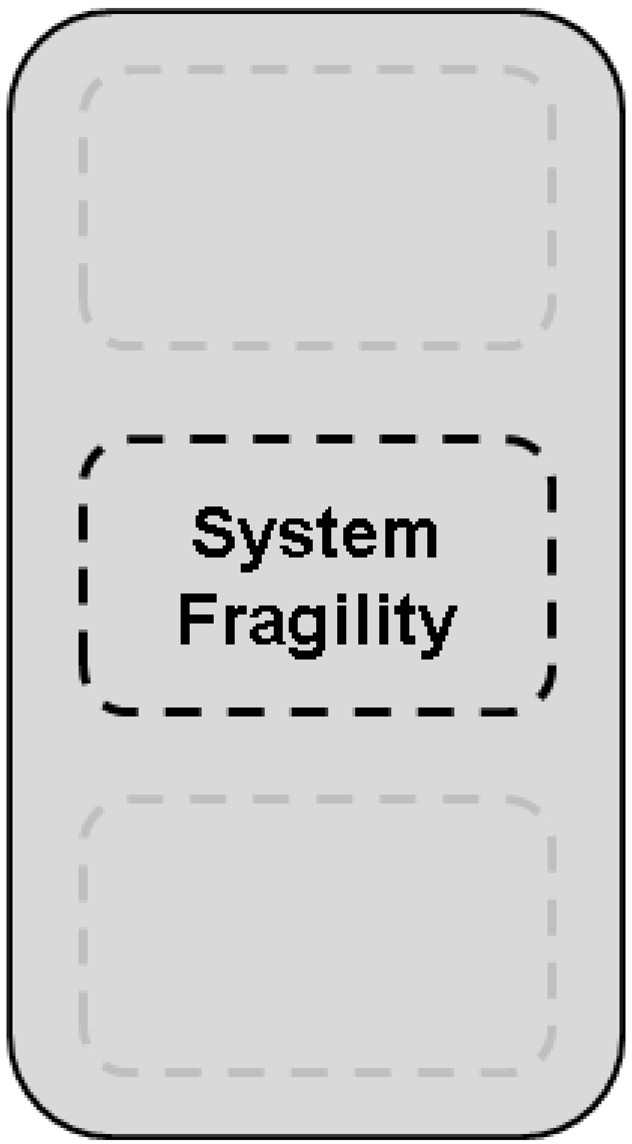



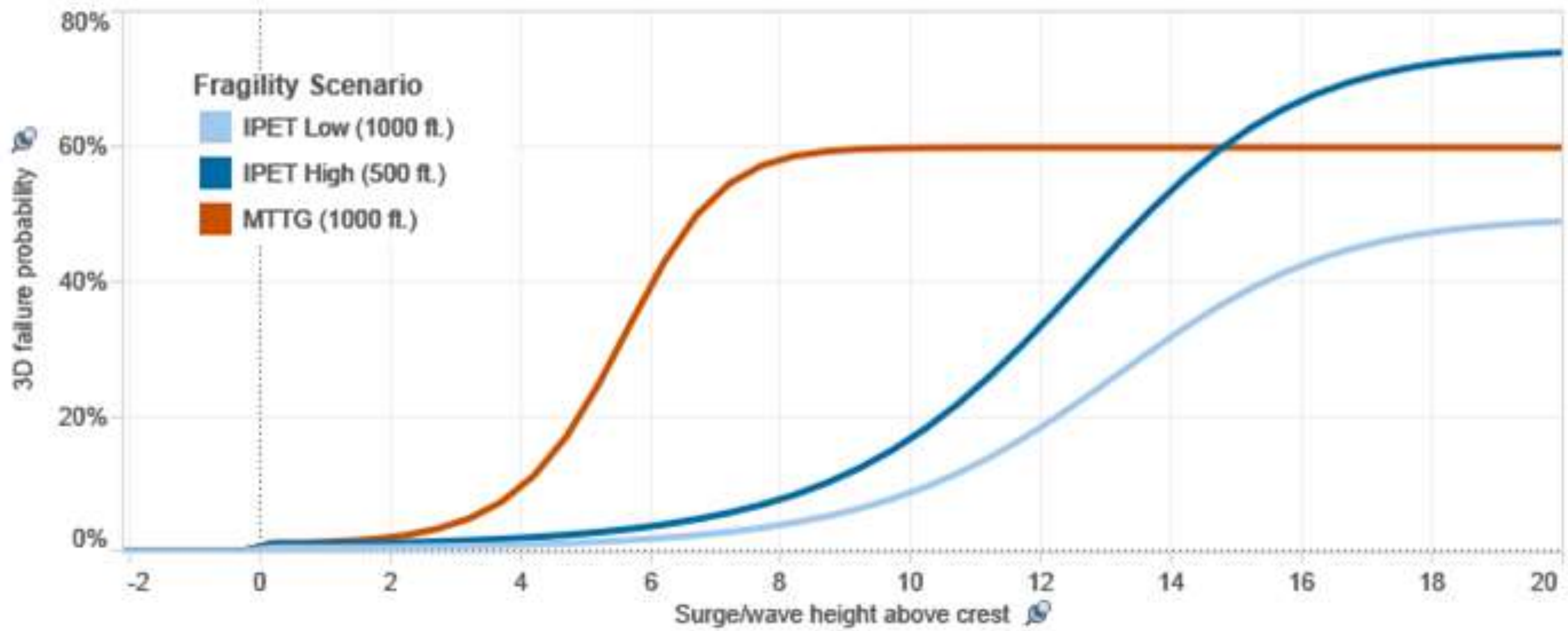
- Overtopping rates/volumes calculated as a function of
  - Surge elevation, significant wave height, period
  - Crest height of protection features
  - Geometry of protection features (berm width, slope, levee vs. floodwall, etc.)

# FLOOD DEPTH MODULE

## RISK ASSESSMENT

### Failure probabilities are calculated over time as a function of overtopping rates



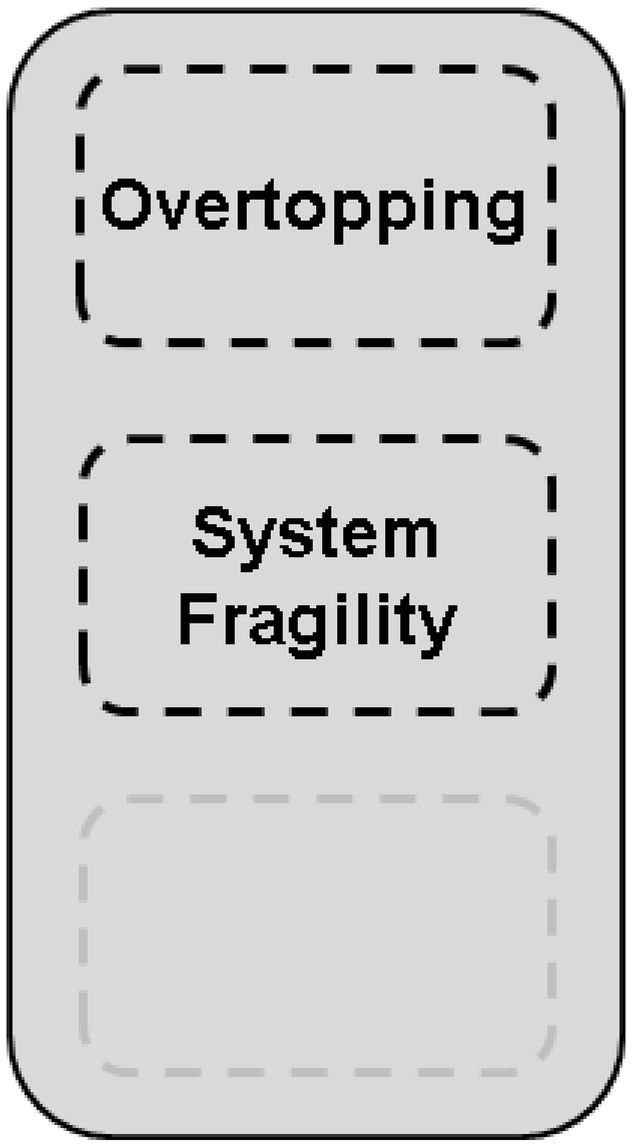




- Breaches are associated with three failure modes
  - Overtopping and backside scour
  - Slope stability
  - Seepage
- Scenario-dependent probabilities derived from recent USACE studies

# FLOOD DEPTH MODULE

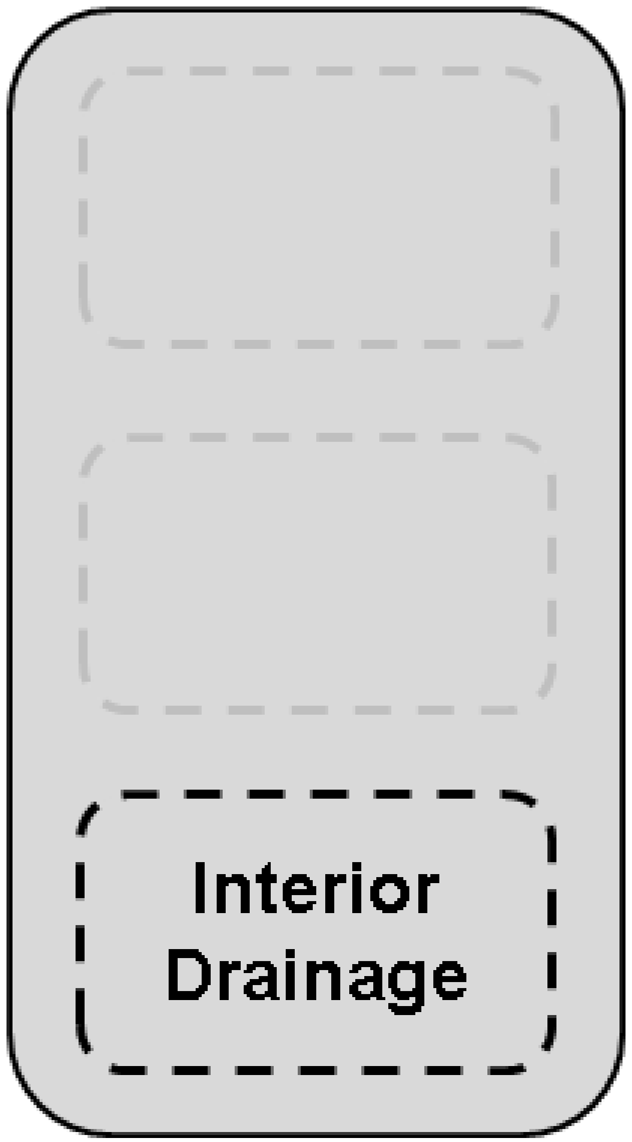


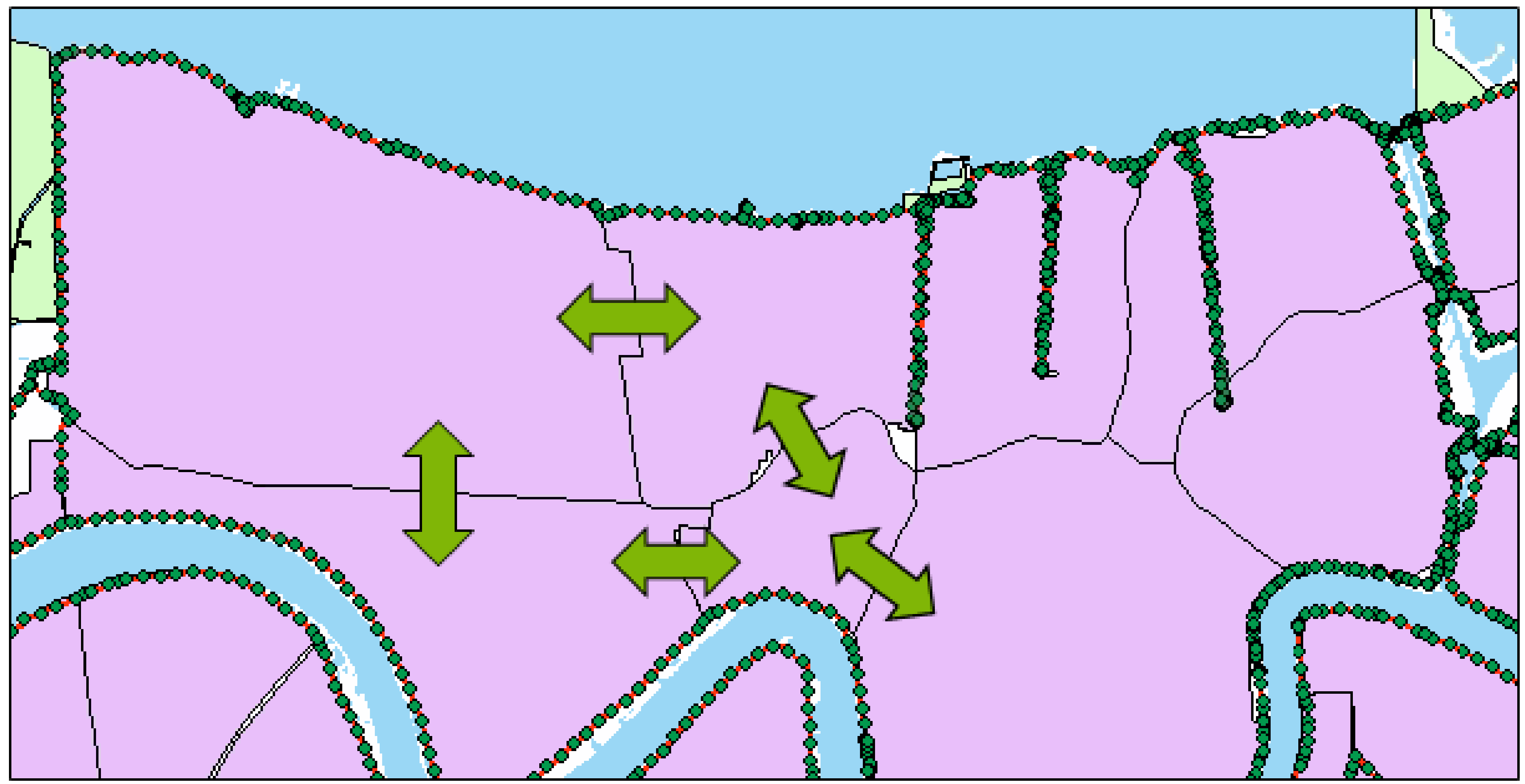
## Total net volume of water entering each polder




1. Volume of water entering over each reach point is calculated using the surge hydrograph and wave heights
   a. Breaches can happen at any time during runup
   b. Breaches are assumed full-depth and -length
2. Breach volumes are added to other overtopping volumes
3. Rainfall in each polder is added
4. Pumping volumes are netted out

## Flood waters are distributed using stage-storage curves and interflow elevations



- Interior drainage iteratively pours water between adjacent polders until equilibrium still-water elevation (SWE) reached
  - Flood elevations of adjacent polders are equal, *or*
  - Both flood elevations are at or below the interflow elevation separating the two polders

# FLOOD DEPTH MODULE

## RISK ASSESSMENT

- Monte Carlo simulation of multiple versions of each synthetic storm
  - Uncertainty in surge hydrograph
  - Variability in overtopping rates
  - System breaches

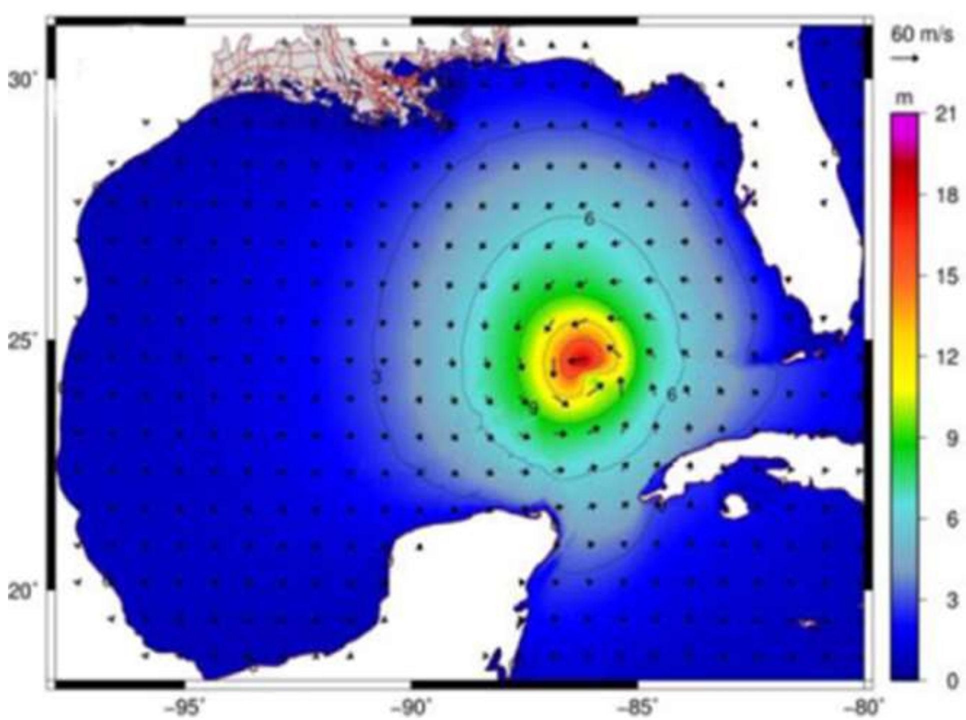
- Frequency distribution of interior SWE used to calculate AEP of flood depths

# COASTAL LOUISIANA RISK ASSESSMENT MODEL (CLARA)

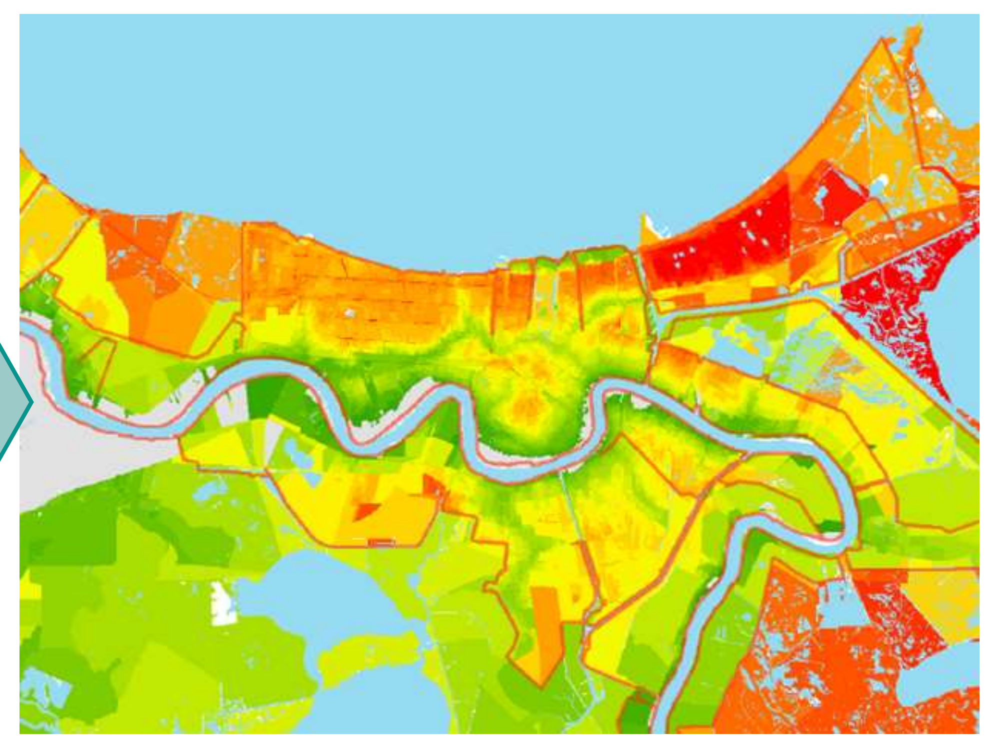
## RISK ASSESSMENT

- The economic module calculates the direct economic damage caused by flooding

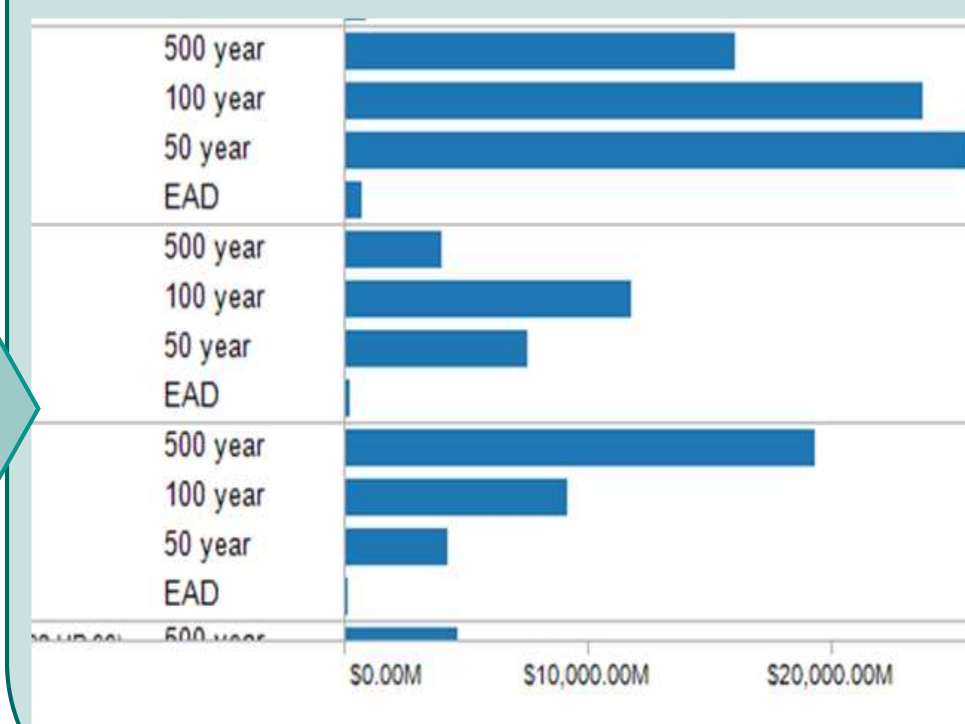
### 1. Statistical Pre-Processing Module




### 2. Flood Depth Module

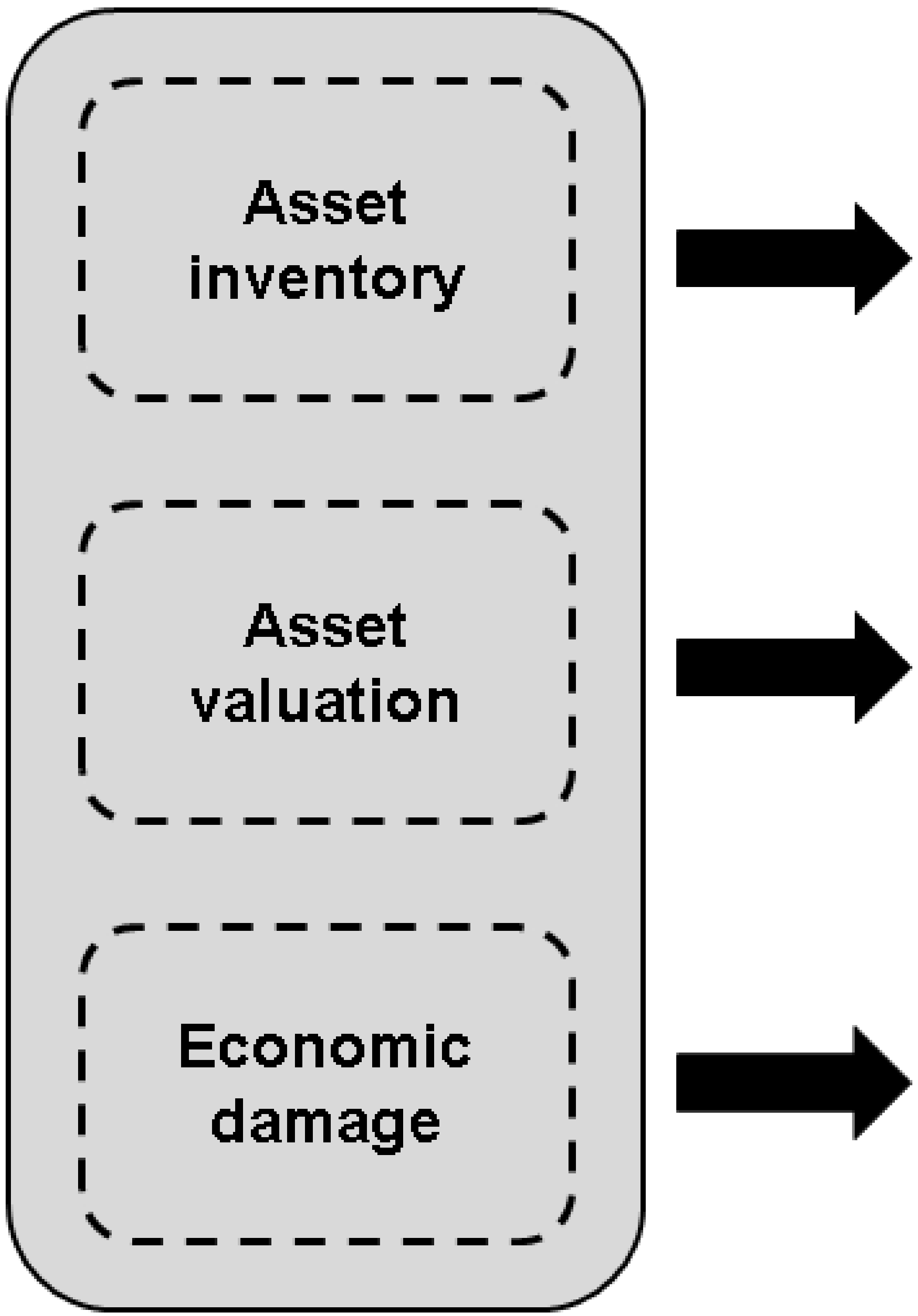


### 3. Economic Damage Module



# ECONOMIC DAMAGE MODULE

## RISK ASSESSMENT




The economic module consists of three components

- Baseline inventory of approximately 750K structures, plus vehicles, crops, and roads
- Projects changes to exposed assets over time in proportion to projected population change

- Based on real or estimated asset features
- Calculates value or replacement/repair value, as appropriate

- Calculates structural damage as a function of flood depths in each scenario
- Estimates repair/reconstruction time and associated losses from various levels of flooding
- Summarizes flood risk using expected annual damage, as a snapshot and over time

# ECONOMIC DAMAGE MODULE

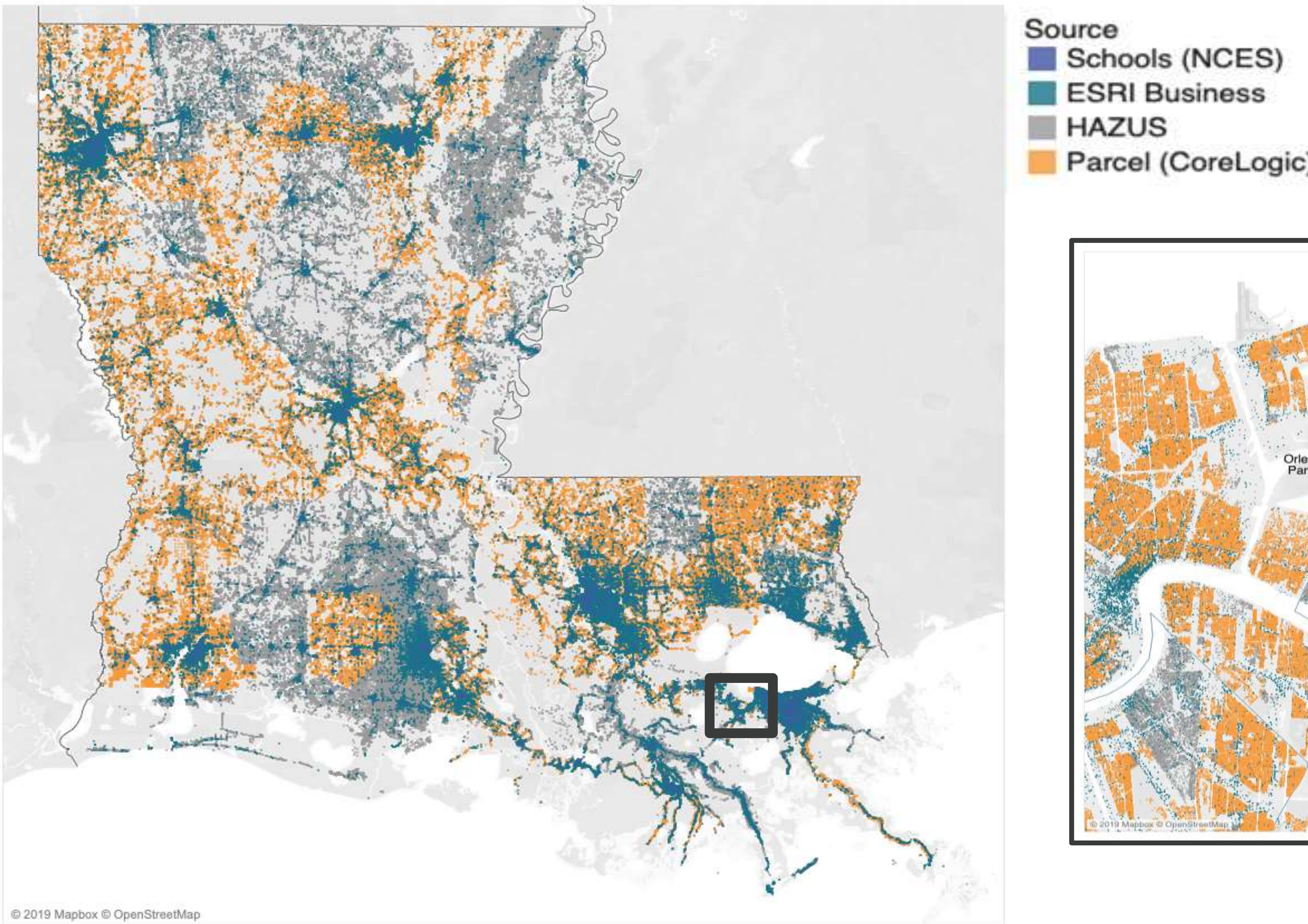


- Changes from the 2017 Coastal Master Plan
  - There has been a substantial increase in the quality, quantity, and accessibility of detailed, parcel-level land use and structure inventory data

- Datasets obtained
  - National Structure Inventory (NSI v2): first state-level pilot of federal dataset (Source: USACE)
  - Homeland Infrastructure Foundational-Level Data (HIFLD): secure and licensed access to CoreLogic and other datasets (Source: DHS)
  - ATTOM Data Solutions: a proprietary, cleaned commercial dataset

# EXAMPLE OF NSI COVERAGE BY DATA SOURCE

RISK ASSESSMENT




# COMPARISON OF STRUCTURE ATTRIBUTES BY DATA SOURCE

## RISK ASSESSMENT

| | NSI (CoreLogic, ESRI Business, etc.)* | HIFLD (CoreLogic, Dun & Bradstreet) | ATTOM |
|---|---|---|---|
| Building Area | X | | X |
| Market Value | | | X |
| Content Value | X | | |
| Vehicle Value | X | | |
| Recent Sale Data | | X | X |
| Year Built (>1992) | X | X | X |
| Building Stories | X | Only Cameron | |
| Residential Units | X | Only St. Mary, St. James, St. Charles, Plaquemines | |
| Construction Material | X | | |
| Foundation Type and Height | X | Only Cameron | |

* Some fields rely partially or entirely on unverified estimates rather than observations

# IMAGE ANALYSIS FOR FEATURE EXTRACTION



- We apply machine learning and automated image analysis to identify structural attributes using Google Street View imagery

- Includes characteristics relevant to flood risk:
  - Foundation heights and types (e.g., pier, concrete slab)
  - Area of building footprints
  - Number of stories
  - Building type classifications (e.g., residential, commercial)

# IMAGE ANALYSIS FOR FEATURE EXTRACTION

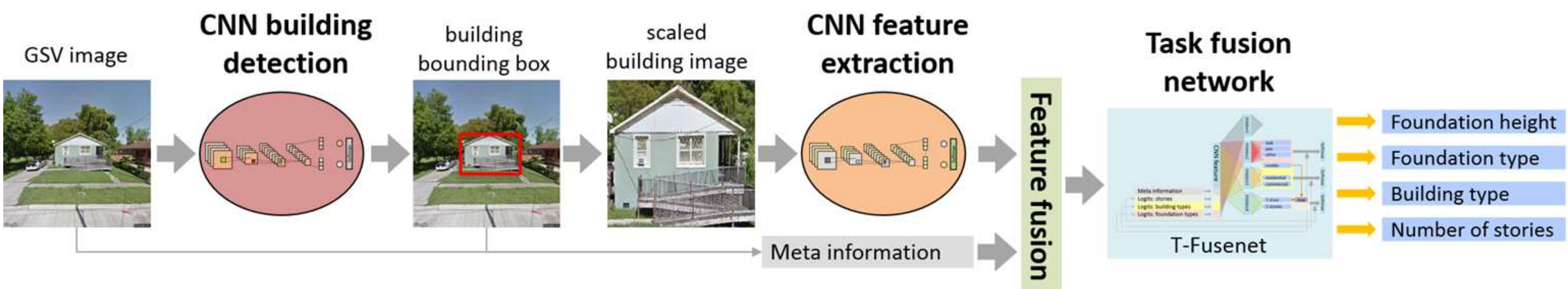
## RISK ASSESSMENT

- We used a ground truth data set of approximately 75,000 buildings across multiple parishes to obtain over 42,000 images of buildings from Google Street View (GSV)

# IMAGE ANALYSIS FOR FEATURE EXTRACTION



- Multiple convolutional neural networks (CNN) are used to detect buildings from images and then extract their features




Resulting coastwide data set has estimates based on a good GSV image for 75% of structures (587K of 781K)

# ECONOMIC DAMAGE MODULE



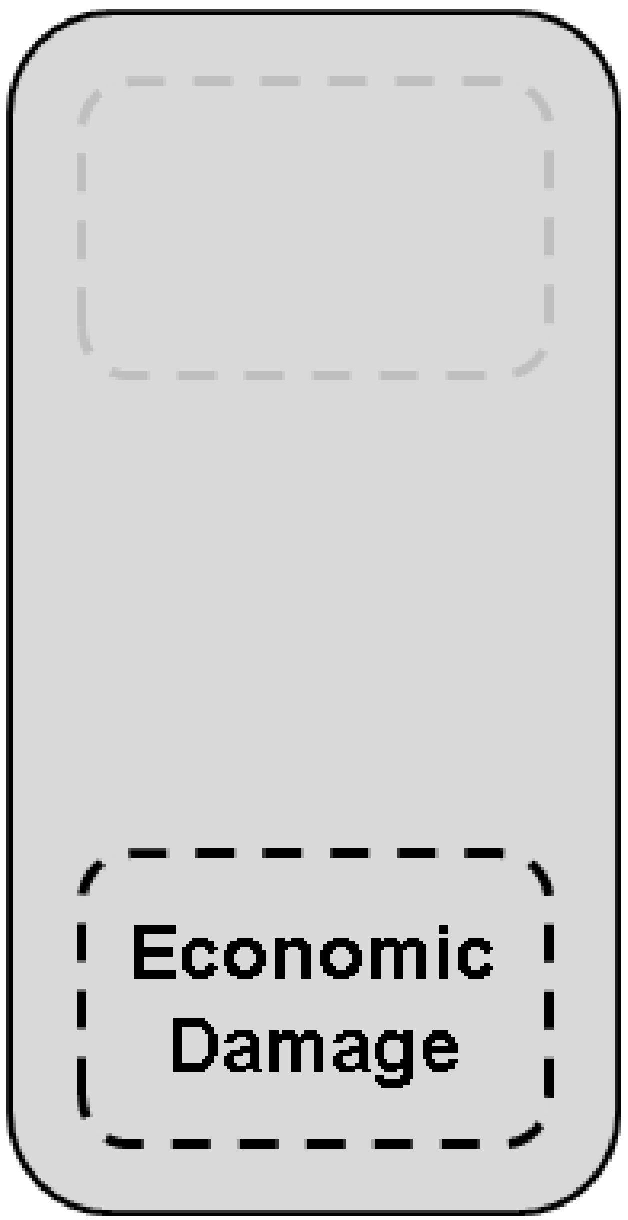
Valuation estimates depend on data availability

- ATTOM reports depreciated value in some areas
  - Convert to replacement cost based on effective age
- In other areas, replacement cost estimated as a function of value and attributes
  - Train on aggregate Hazus-MH methods

Because of uncertainty in individual structure characteristics and value, it is only appropriate to report damage and risk estimates at an aggregated scale

# ECONOMIC DAMAGE MODULE

**RISK ASSESSMENT**

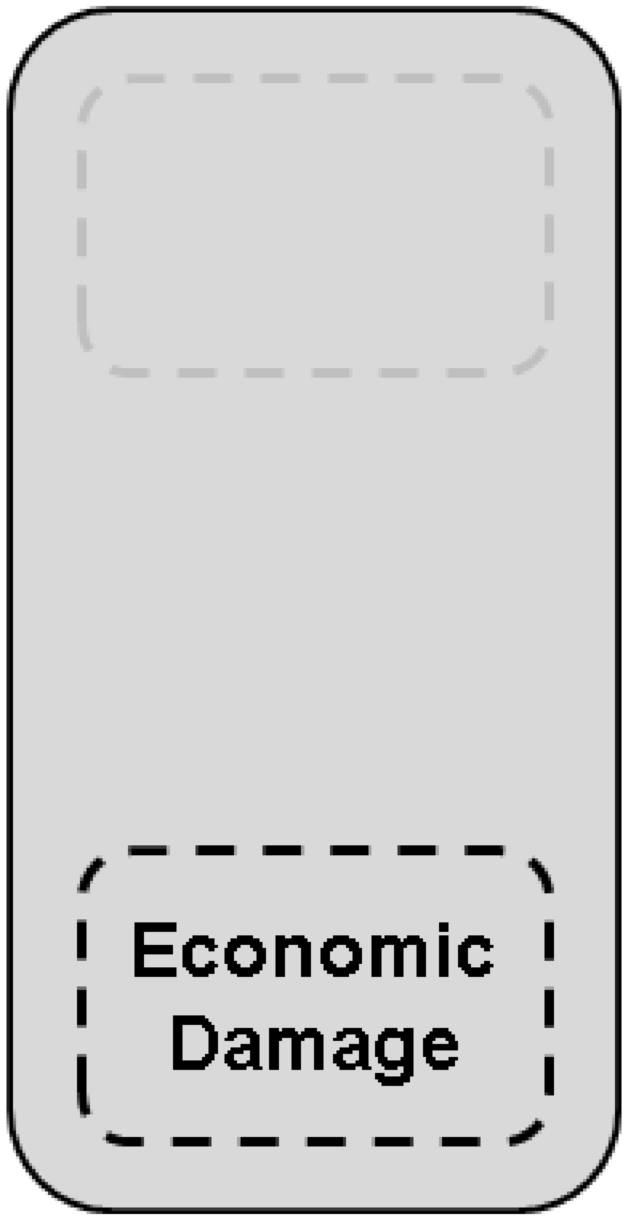



Damage is generally modeled as a proportion of replacement cost

- Depth-damage curves define the relation between flood depth and resulting damage
  - Depths are measured relative to first-floor elevations
- Structures incurring damage greater than 50% of replacement cost assumed to be demolished and reconstructed
- Duration of the repair/reconstruction period is also an increasing function of flood depth
- Damage from non-inundation factors excluded (e.g., wind, floating debris, surge velocity)

# ECONOMIC DAMAGE MODULE






Damage is reported at an aggregate level

- Damage exceedances are primarily based on the damage associated with the corresponding flood depth exceedance
  - For 2023, incorporates uncertainty about structure attributes and future growth

- Expected annual damage (i.e., average annual loss) is a summary metric representing the expected value of damage experienced in a given year
  - Also will be reported as present value of damage over a planning horizon, as EAD changes from 2020 to 2070

# REPRESENTATION OF MASTER PLAN PROJECTS

## RISK ASSESSMENT

- Structural risk reduction
  - Levee/floodwall crest heights changed or added to landscape
    - Hydrodynamic impacts in ADCIRC+SWAN models
    - New polders incorporated into overtopping and fragility simulation
- Nonstructural risk reduction
  - Elevation-in-place raises foundation heights
  - Floodproofing eliminates damage from up to three feet of inundation
  - Voluntary acquisition removes assets from economic inventory
- Restoration
  - Changes to topographic/bathymetric elevations impact surge propagation in ADCIRC+SWAN models


QUESTIONS

# NEXT STEPS


2017 Coastal Master Plan Candidate Projects
Brad
CPRA
Restoring
Louisiana's
Coast
MASTER

# NEXT STEPS

- Survey with options for additional Webinars, for example:
  - Modeling 101
  - ICM subroutines
  - Future Conditions/Scenarios
  - Calibration/Validation
  - Uncertainty
  - Asset Valuation
  - Nonstructural Project Definition
  - Modeling Projects
  - Storm Selection

- More information on predictive models available at links throughout this presentation, as well as at http://coastal.la.gov/our-plan/

- Contact us with questions and feedback at: masterplan@la.gov


QUESTIONS
MasterPlan@la.gov