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Long-term Morphologic Modeling at Coastal Inlets

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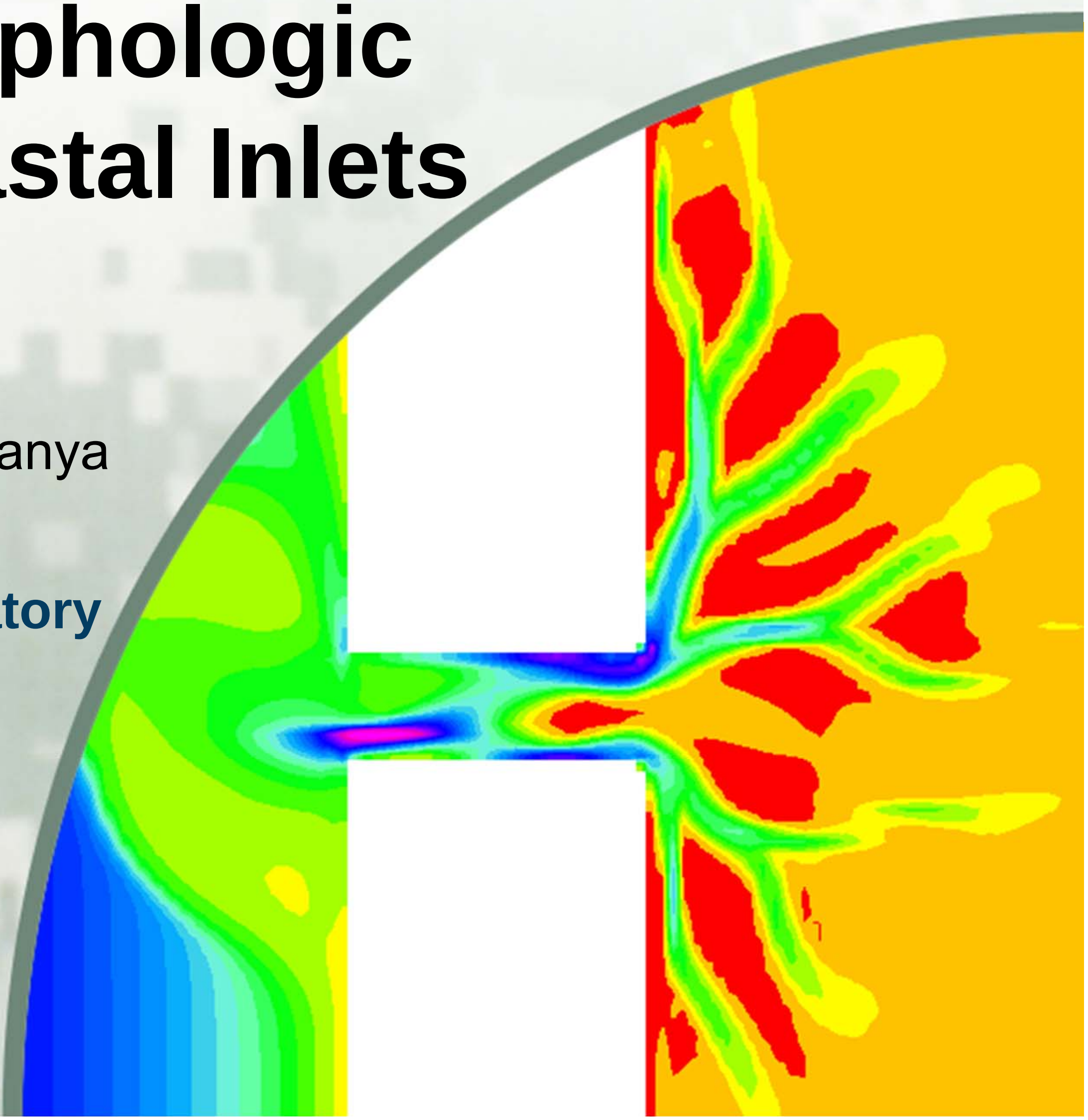

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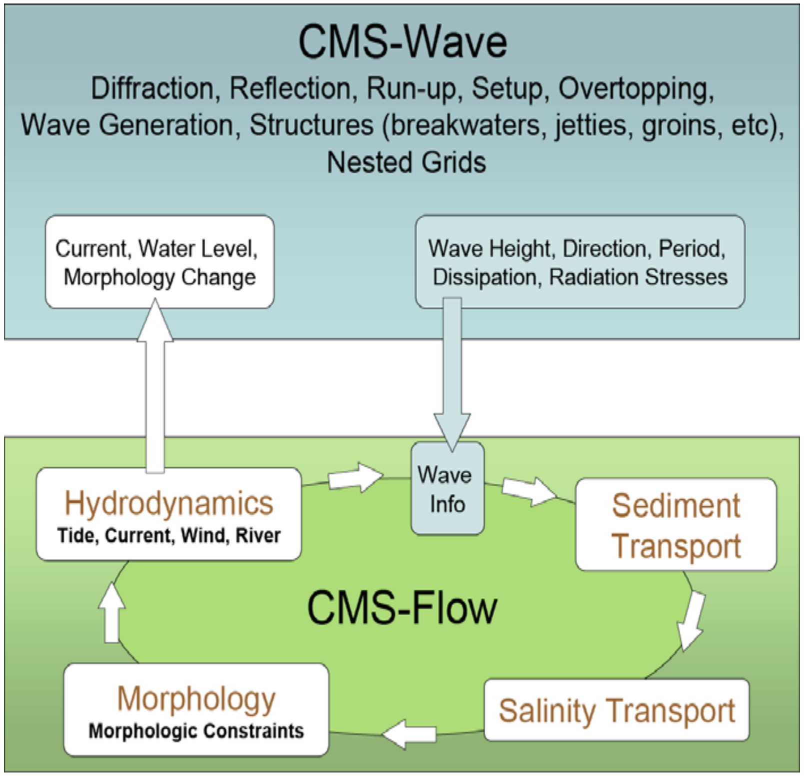
Introduction

- Motivation:
  - Prediction of morphodynamic processes at coastal inlets is challenging but crucial for coastal sediment management, navigation, channel maintenance, and breach erosion protection
- Issue:
  - Difficult to conduct meaningful long-term validation of morphodynamic models using real data
- Approach:
  - Simulate idealized inlets representing 9 US inlets and compare inlet evolution, characteristics, and features with the actual inlets empirical formulas (soft validation)

Introduction:
Coastal Modeling System

- Hydrodynamics:
  - 2DH shallow-water equations
  - Fully implicit, finite-volume method
  - Non-uniform or Telescoping Cartesian grids
- Sediment Transport
  - Inline
  - Total-load non-equilibrium sediment transport
  - Erosion/deposition calculated using an adaptation approach
  - Several options for transport capacity formula
- Waves
  - Spectral wave-action balance equation
  - Implicit finite-difference method



CMS-Wave

Diffraction, Reflection, Run-up, Setup, Overtopping,
Wave Generation, Structures (breakwaters, jetties, groins, etc),
Nested Grids

Current, Water Level,
Morphology Change

Wave Height, Direction, Period,
Dissipation, Radiation Stresses

CMS-Flow

Hydrodynamics
Tide, Current, Wind, River

Wave
Info

Sediment
Transport

Salinity Transport

Morphology
Morphologic Constraints

SMS

Empirical Relations

- Cross-sectional area
  - ▶ O'brien (1931, 1969), Kraus (1998), Jarrrett (1976), van der Kreeke (1992), Powell et al. (2006), etc.

$$A = CP^n$$

$A \rightarrow$ Cross-sectional area $[m^2]$

$P \rightarrow$ Tidal prism $[m^3]$

$C \rightarrow 8.83\times10^{-6} - 1.88\times10^{-3}\ [m^{-1}]$

$n \rightarrow 0.81 - 1.10\ [-]$

- Ebb tidal shoal volume
  - ▶ Walton and Adams (1976)

$$V_{ebb} = aP^b$$

$a \rightarrow 5.3\times10^{-3} - 8.4\times10^{-3}$

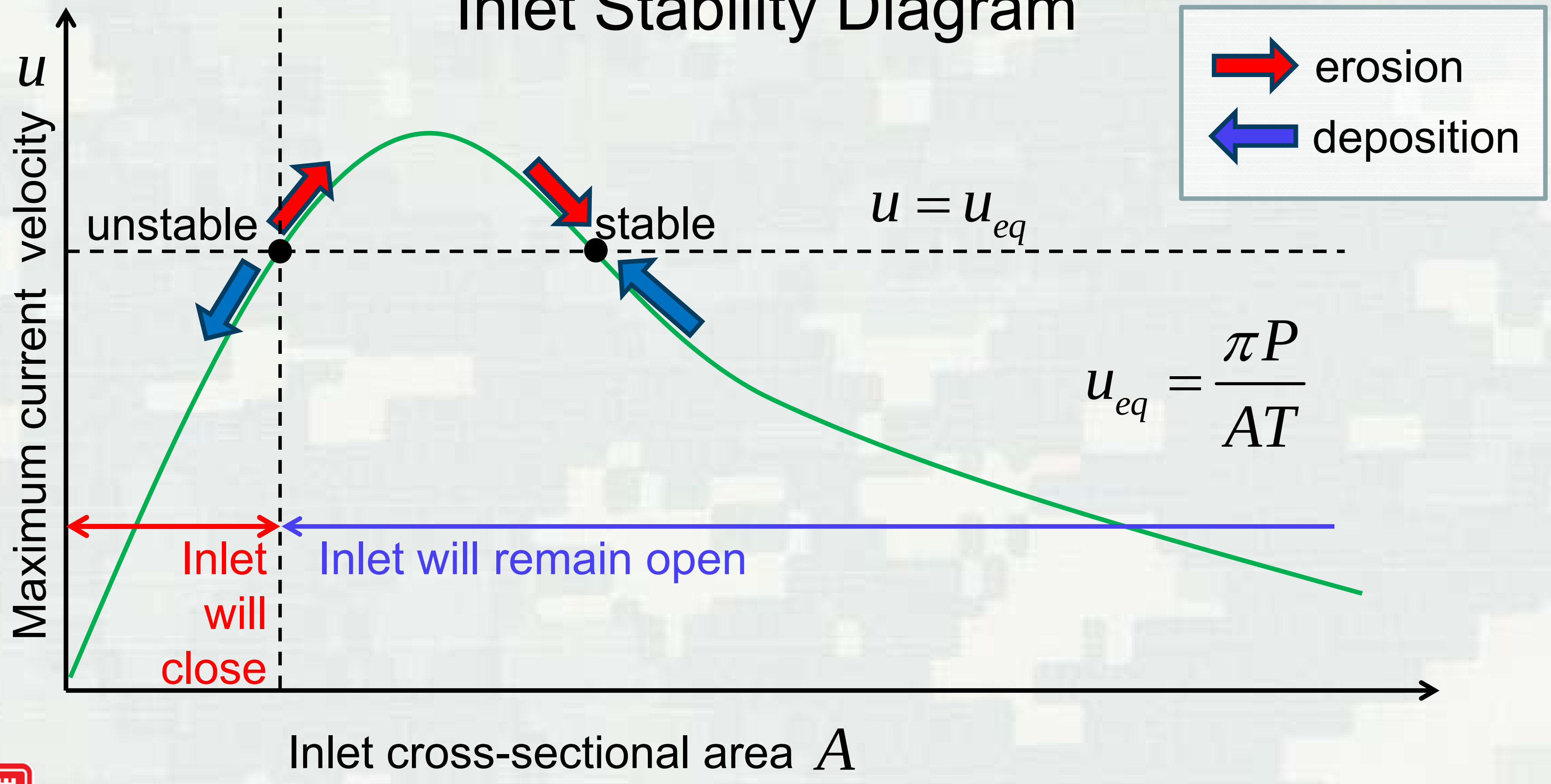
$b \rightarrow 1.23$

  - ▶ Hicks and Hume (1996)

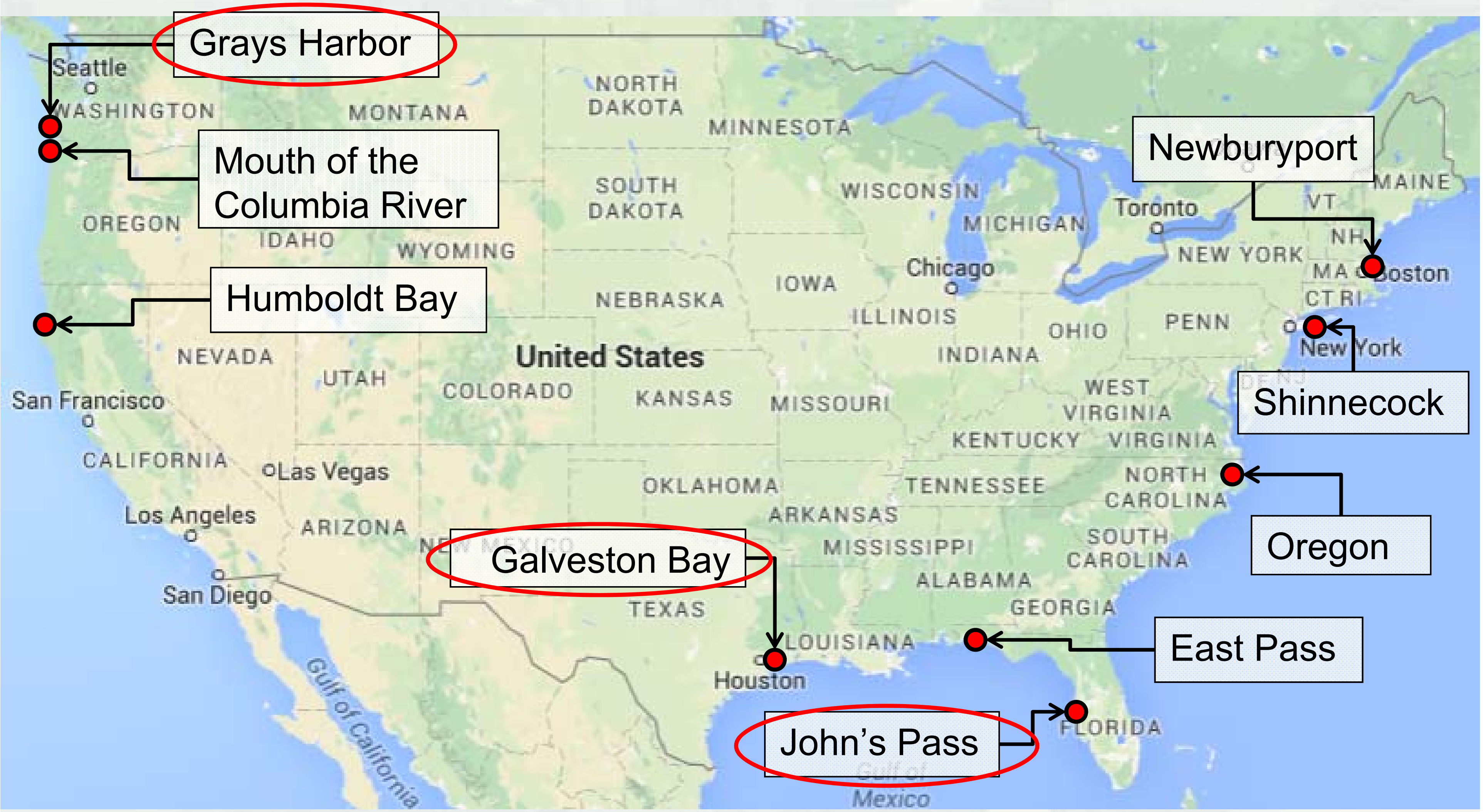
$$V_{ebb} = 1.37\times10^{-3} P^{1.32} (\sin\theta)^{1.33}$$

Inlet Stability Analysis

Escoffier's (1940)
Inlet Stability Diagram



Methods: Base Inlets



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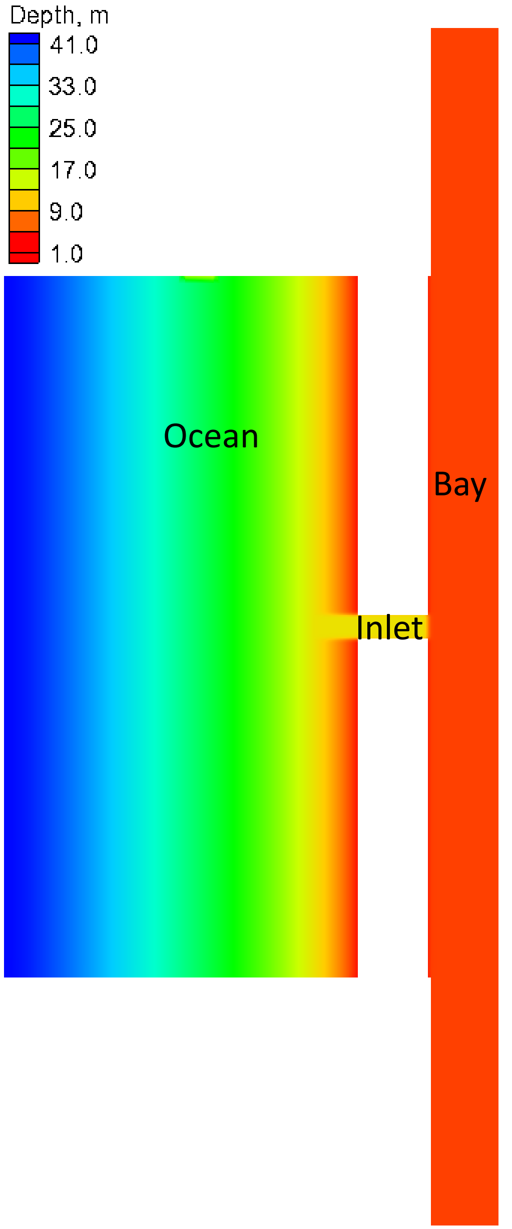
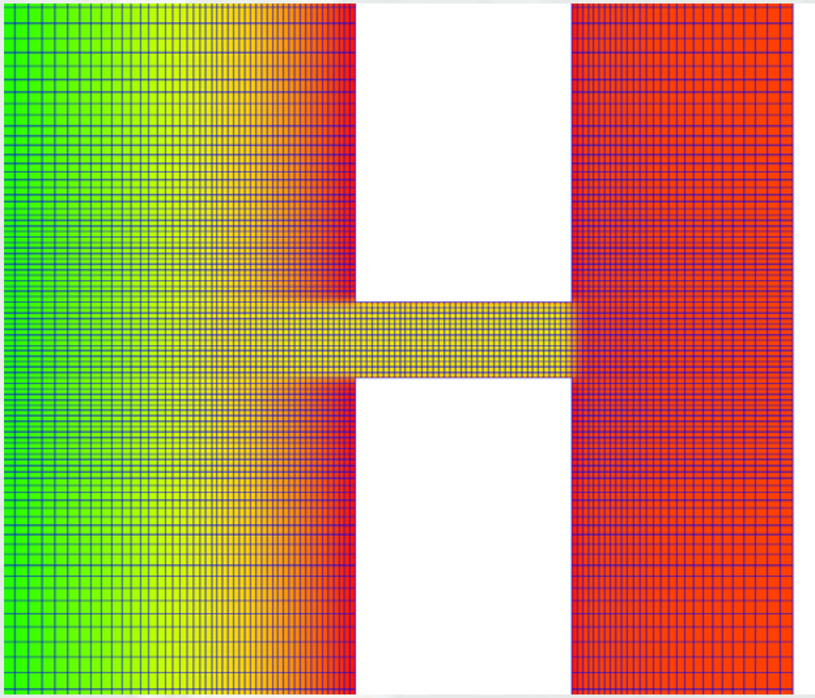
Methods: Idealized Inlets

- Initial Morphology
  - Equilibrium offshore profile based on measured bathymetry or median grain size
  - Flat rectangular bay with dimensions based on actual inlet. Bay width and length adjusted to match actual bay area
  - Flat rectangular inlet with width and area matching actual inlet
- Water levels
  - Tidal constituents
- Waves
  - Representative year based on mean sediment transport rate estimated from the CERC formula and nearby buoy data



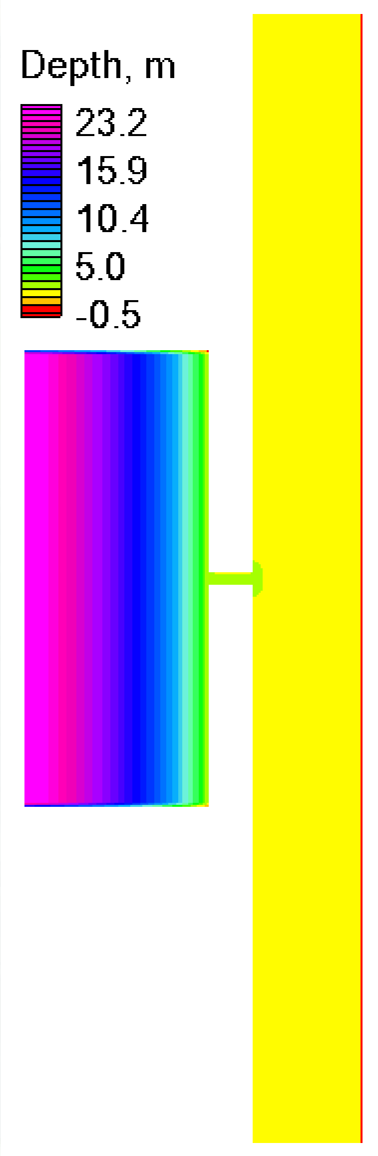
Methods: Model Setup

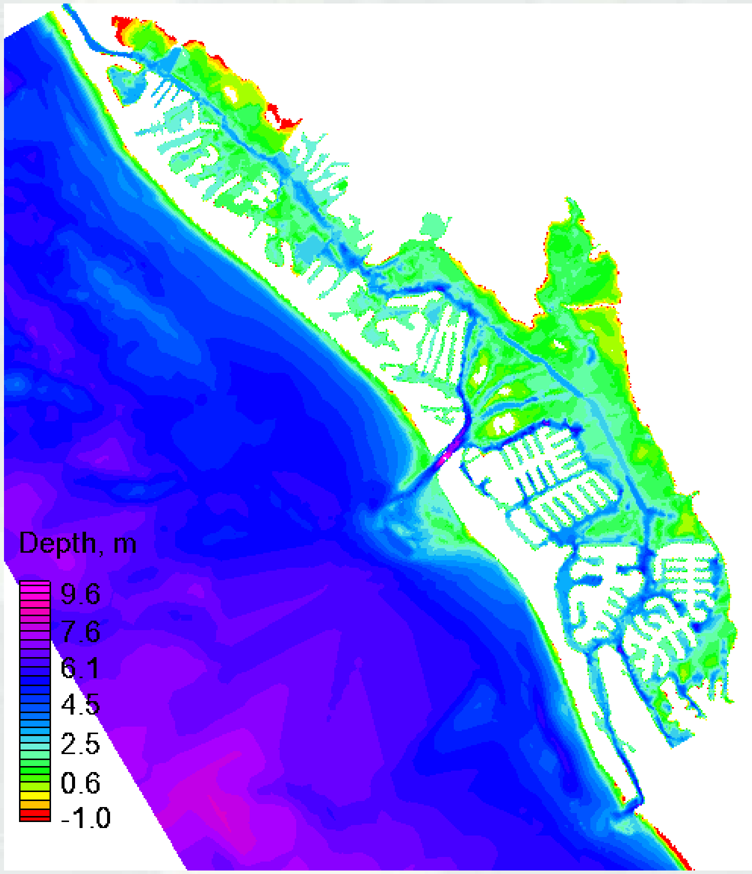
- Flow
  - Manning's n = 0.025 $s/m^{1/3}$
  - Coriolis
- Sediment transport
  - Single representative grain size
  - Morphologic acceleration factor = 10
- Time stepping
  - Flow and sediment: 15 min
    - Second-order scheme
  - Waves: 1 hr
- Grids
  - Same for flow, sediment, and waves
  - Resolution
    - At least 10 cells across inlet



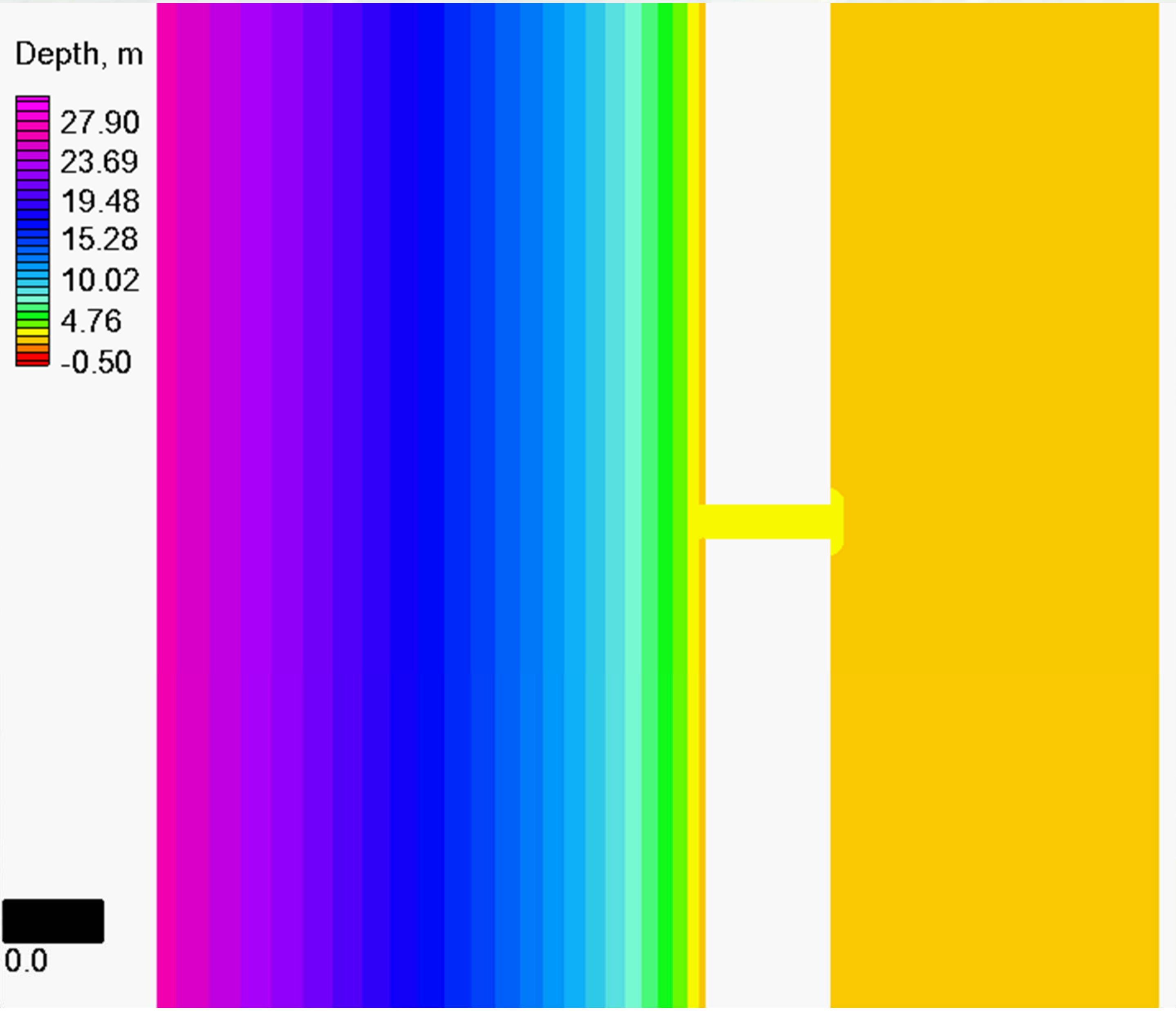
John’s Pass, FL

- Waves
  - ► H_{mo} = 0.73 m
  - ► T_p = 4 s
- Tidal range
  - ► 0.43 m
- Bay Dimensions
  - ► Area = 4.5e7 m^2
  - ► Length = 27 km
  - ► Width = 19 km
- Inlet
  - ► Area = 845 m^2
  - ► Width = 300 m



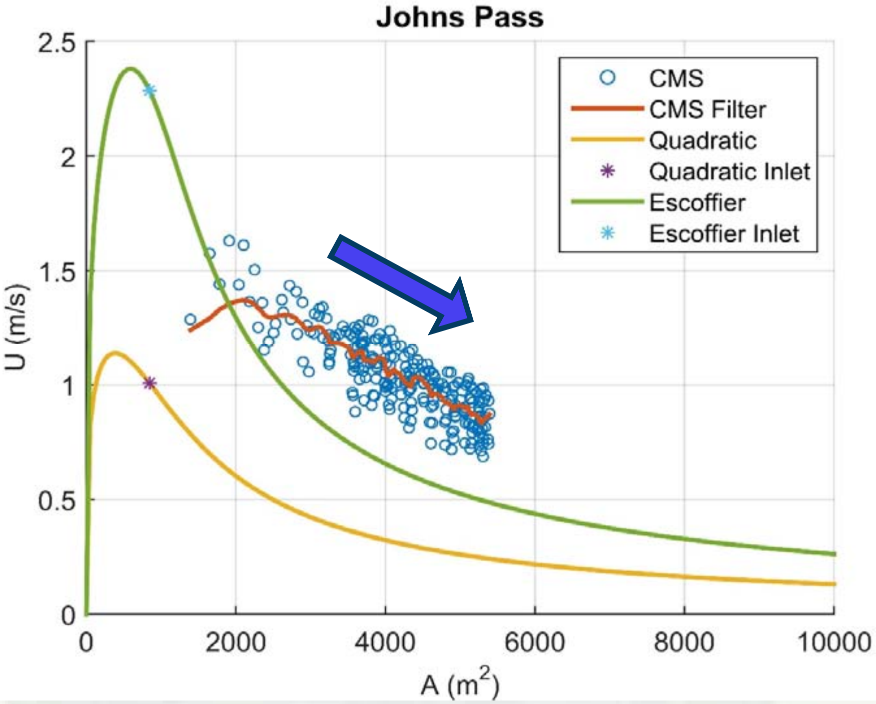


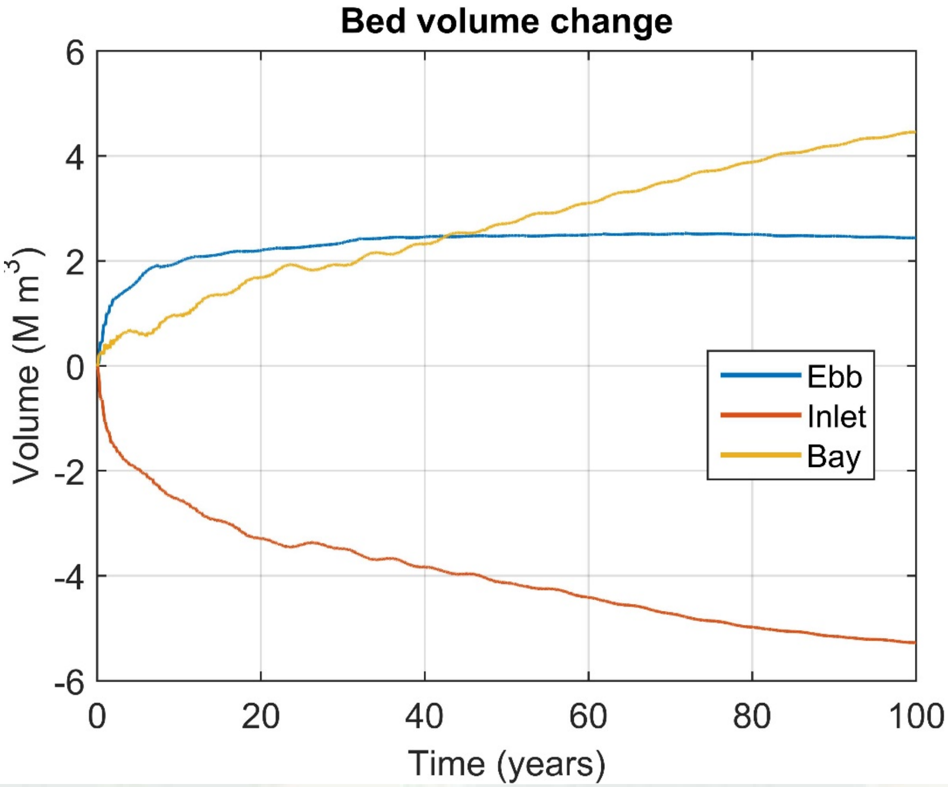
Johns Pass, FL



Results: Johns Pass, FL

Flood dominant



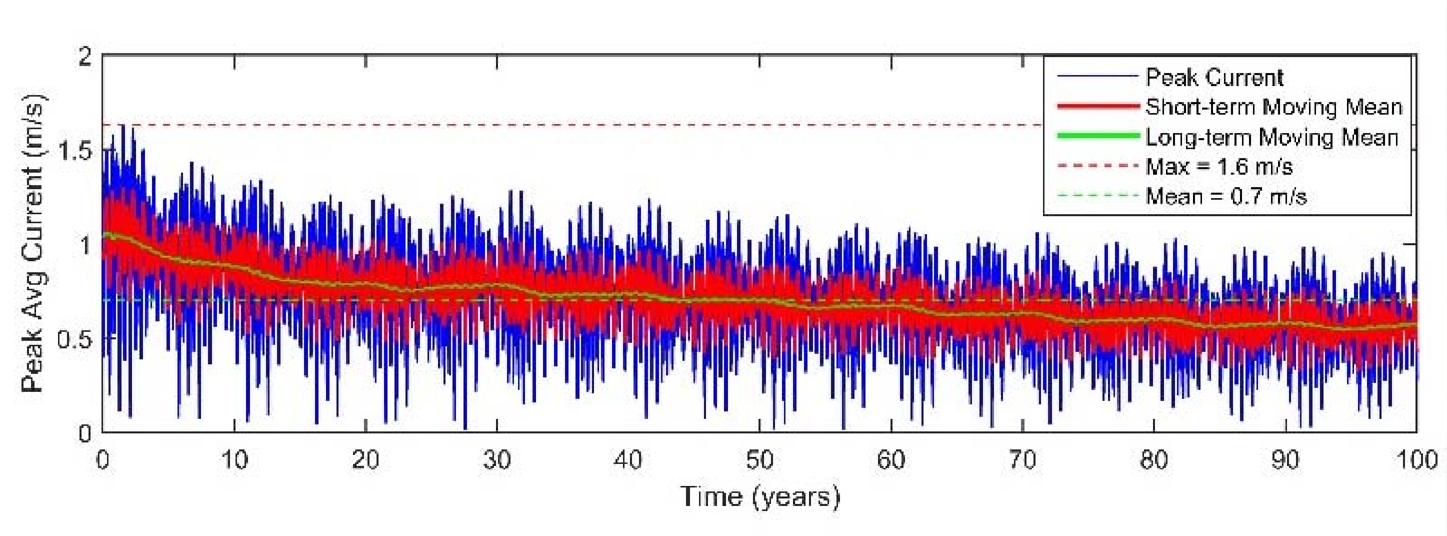


- Actual ebb shoal volume
  - 2.1 to 2.3 M m^3

Results: Johns Pass, FL

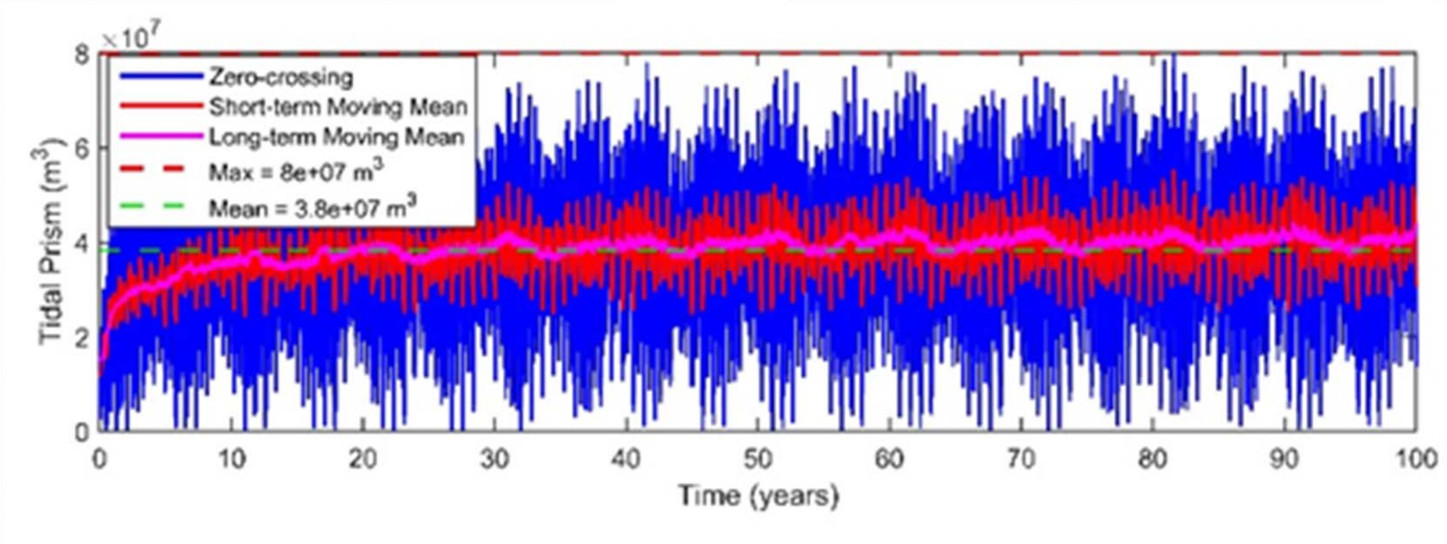
Actual peak current velocity

~1.2 m/s



Tidal Prism:

2.1 x10^{7} m^{3}



Results: Johns Pass, FL

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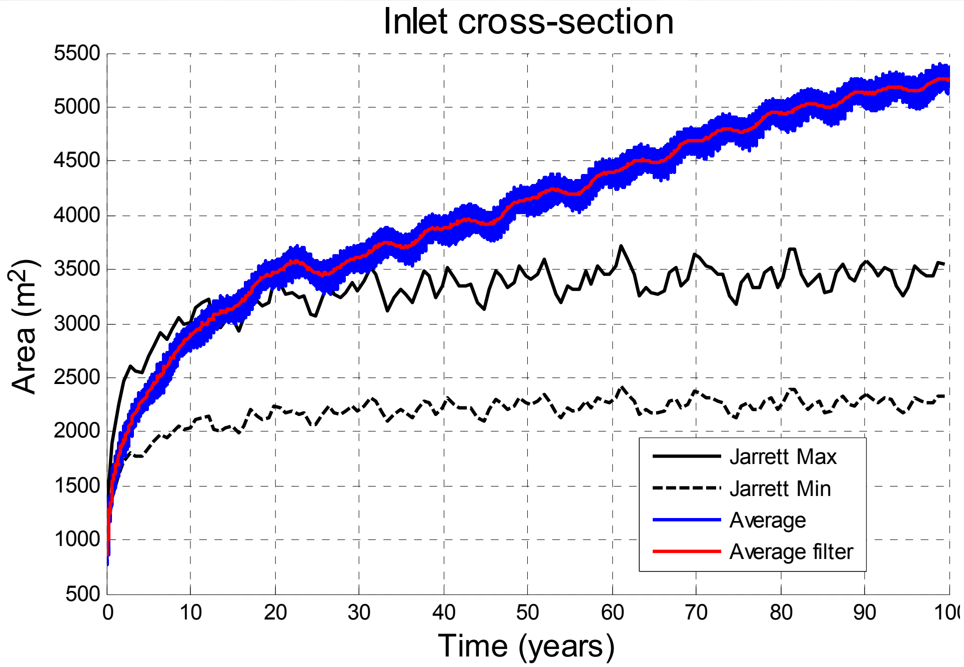
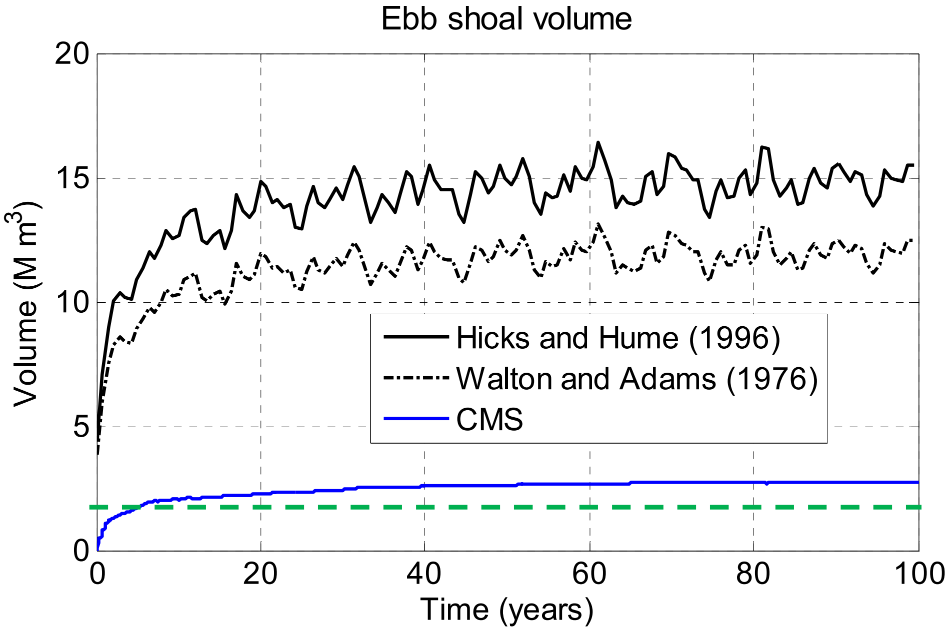


- Inlet does not reach equilibrium
- Ebb shoal does reach equilibrium but is underestimated



Results: Grays Harbor

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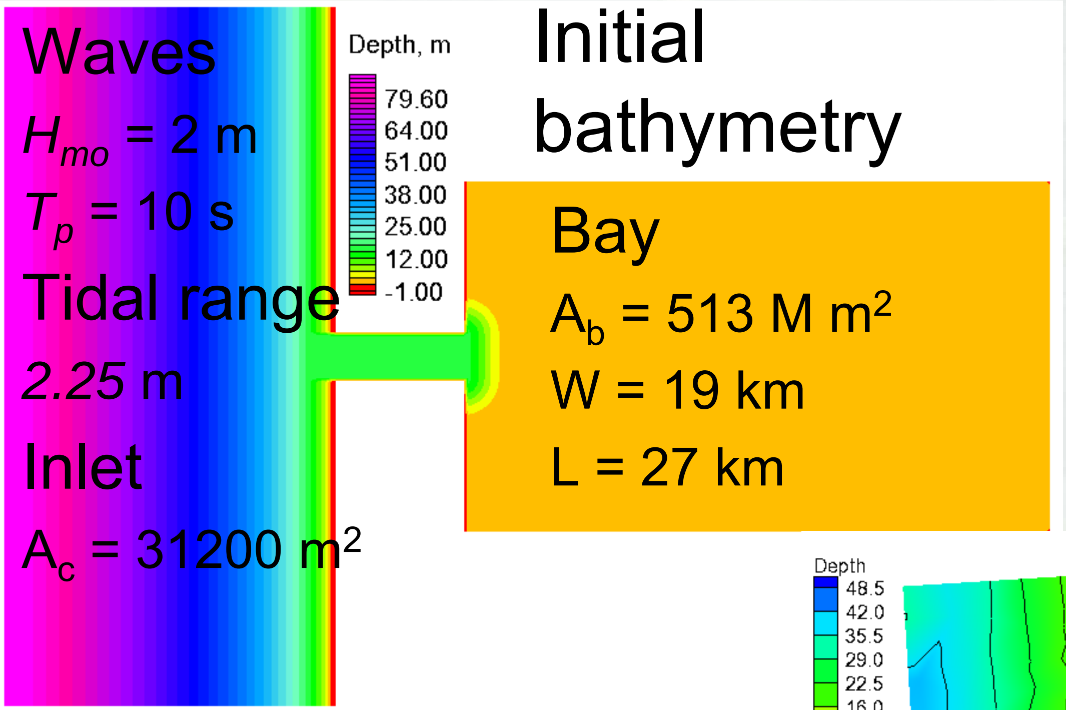


Initial bathymetry

Waves

H_{mo} = 2 m

T_p = 10 s

Tidal range

2.25 m

Inlet

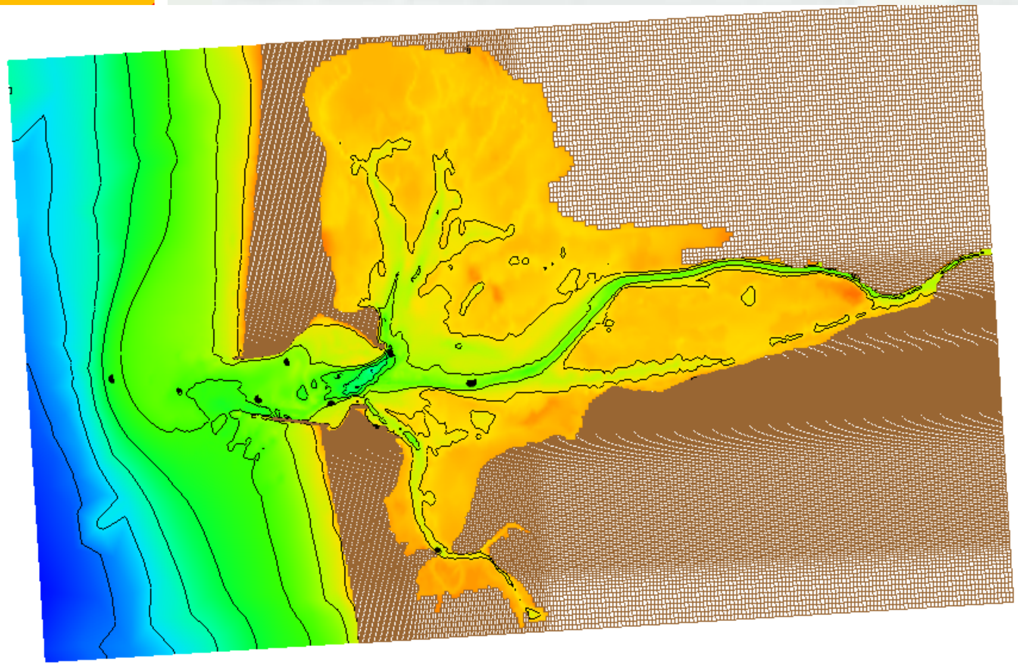
$A_c = 31200\ m^2$

Bay

$A_b = 513\ M\ m^2$

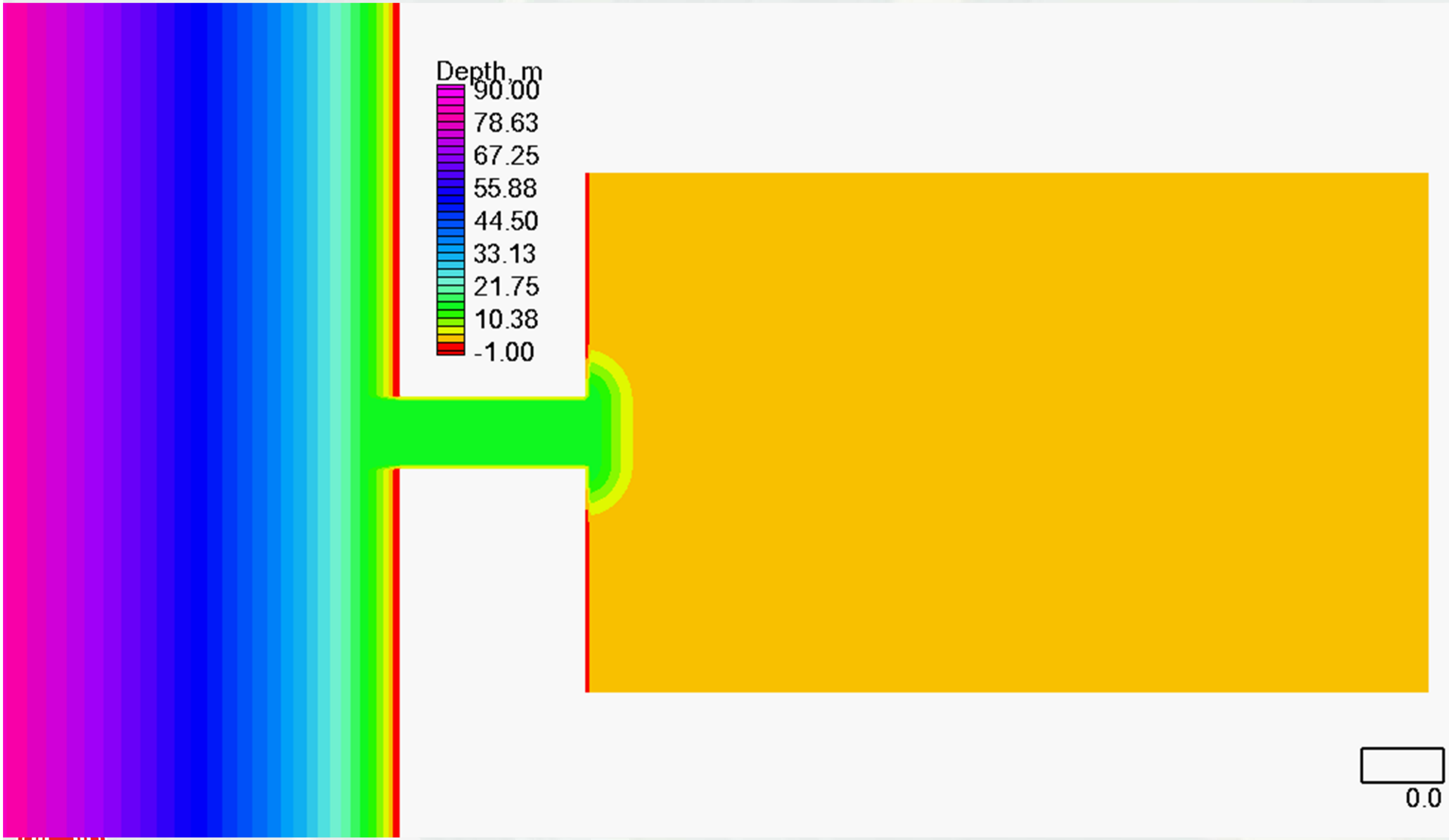
W = 19 km

L = 27 km



Actual bathymetry

Results: Grays Harbor, WA



Grays Harbor, WA

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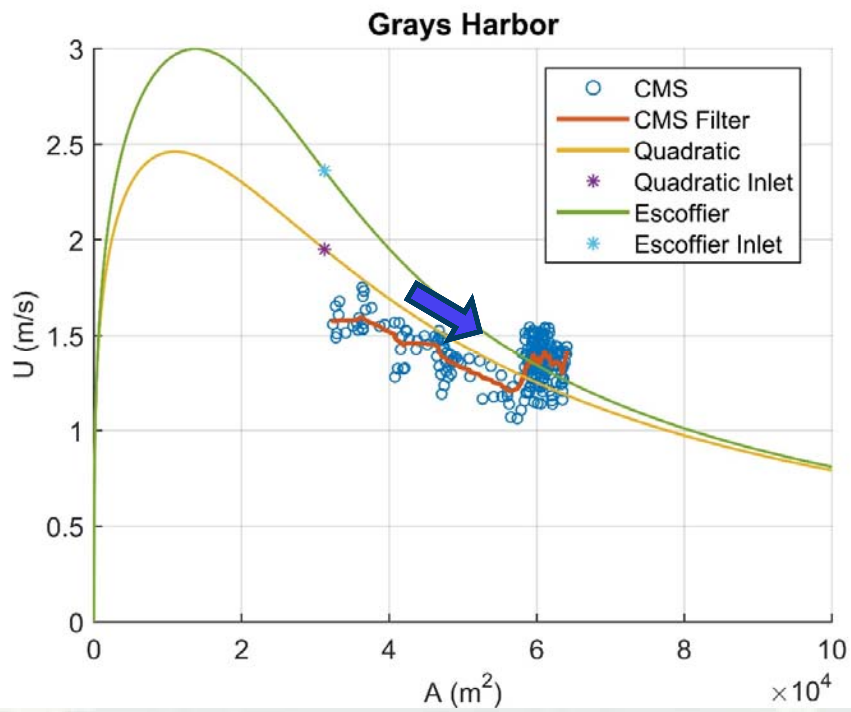
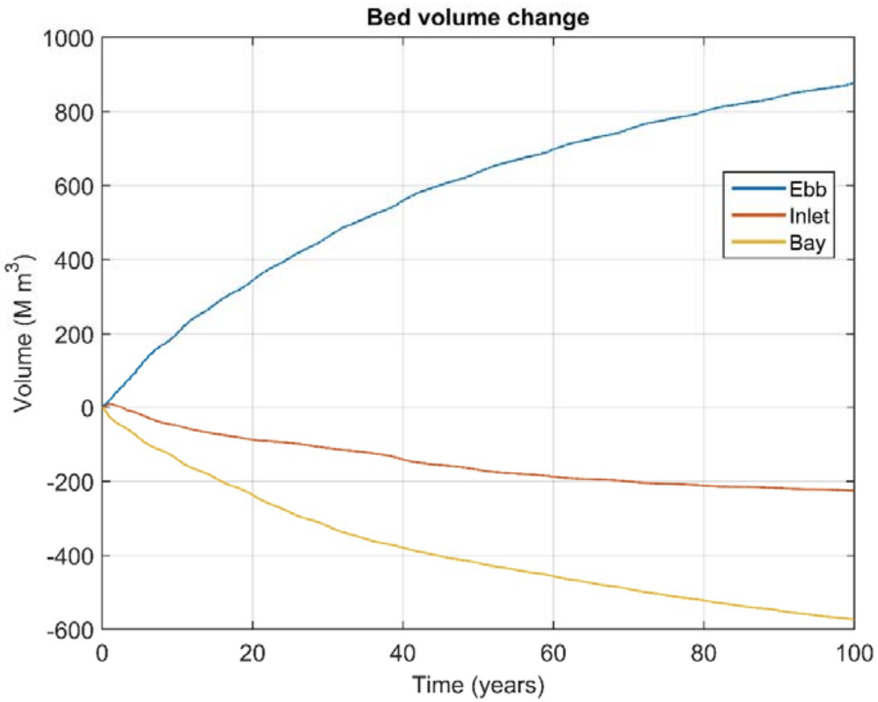


Equilibrium cross-sectional area of idealized inlet larger than initial condition



Inlet still evolving after 100 years

Results: Grays Harbor, WA

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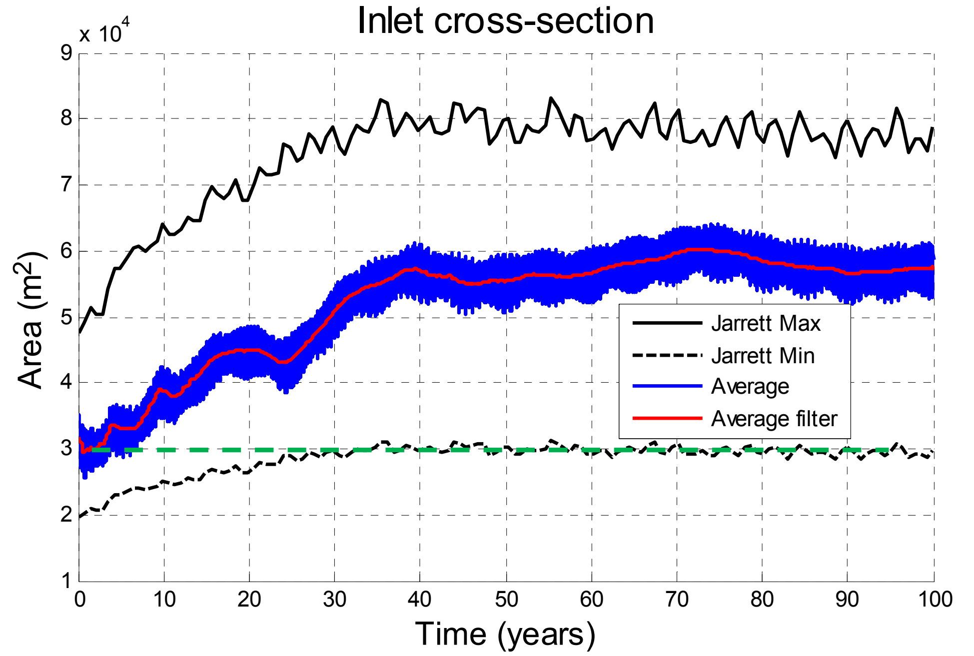
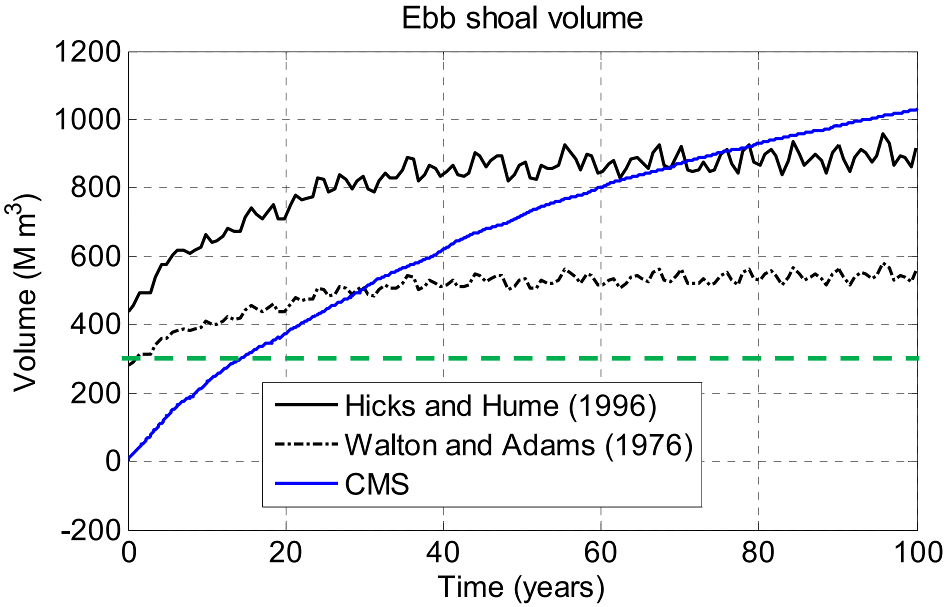


- Actual ebb shoal volume
  - ▶ 240 to 250 M m^3



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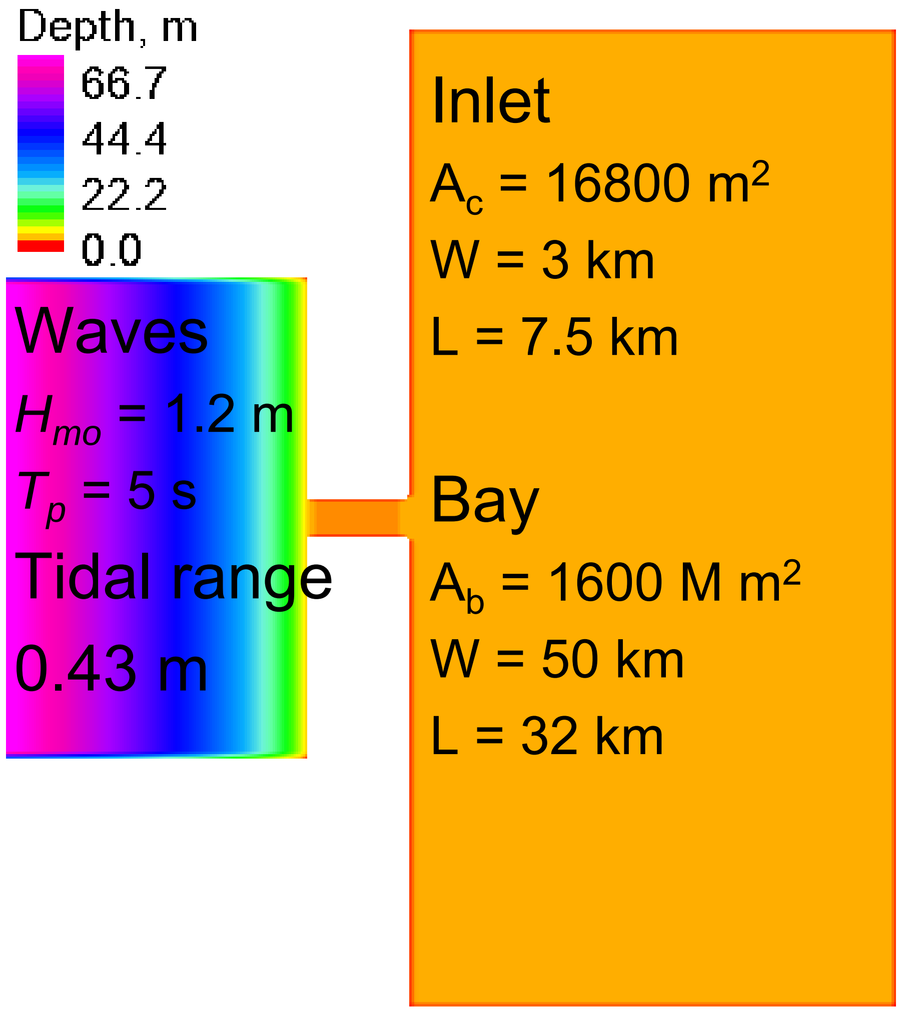
Initial bathymetry



Waves

H_{mo} = 1.2 m

T_p = 5 s

Tidal range

0.43 m

Inlet

A_c = 16800 m^2

W = 3 km

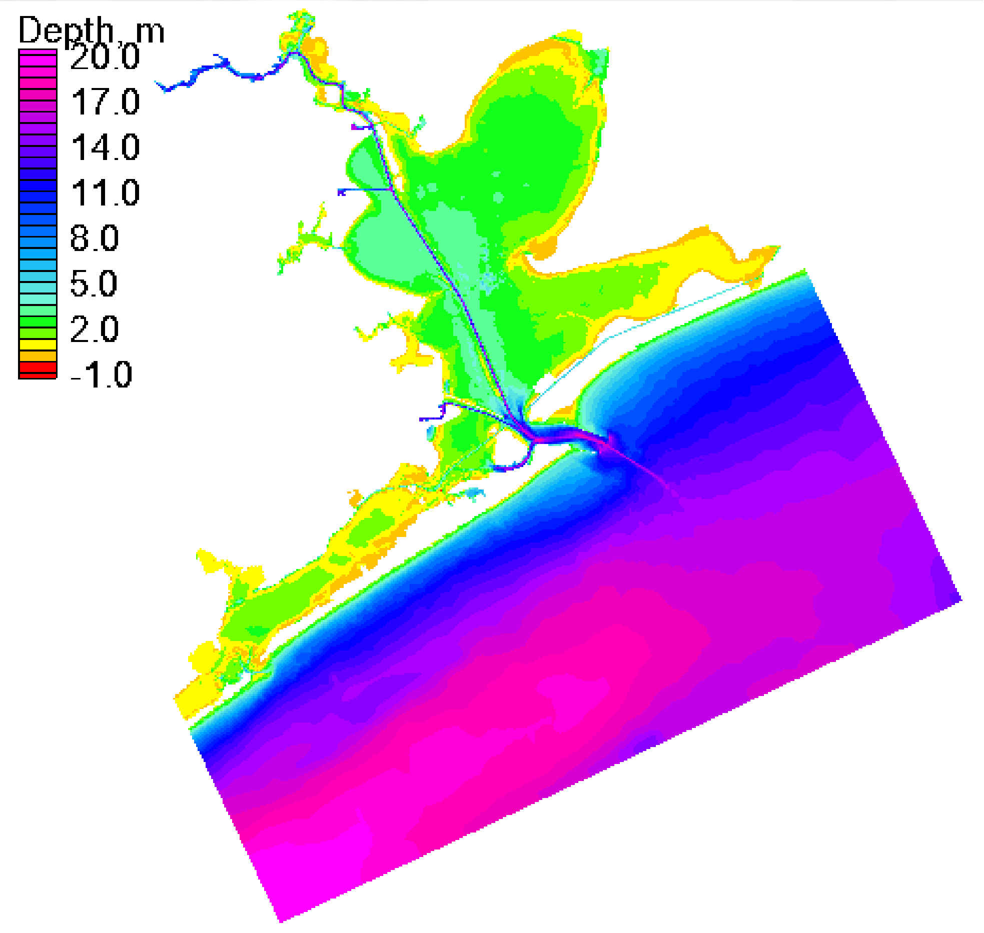
L = 7.5 km

Bay

A_b = 1600 M m^2

W = 50 km

L = 32 km



Results: Galveston, TX

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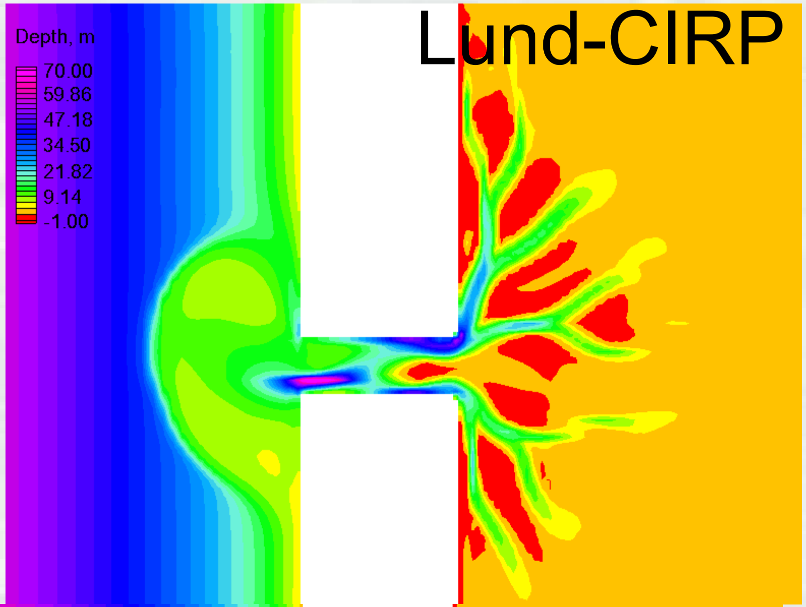
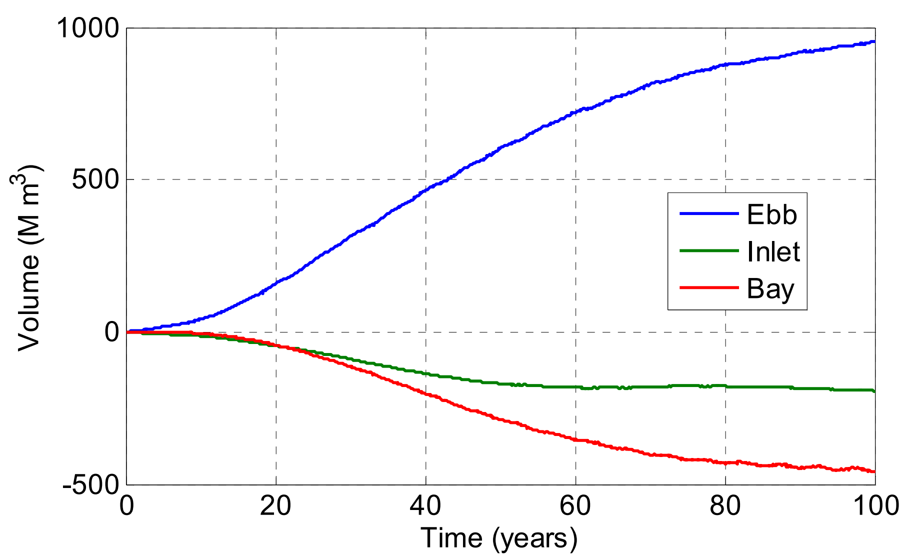
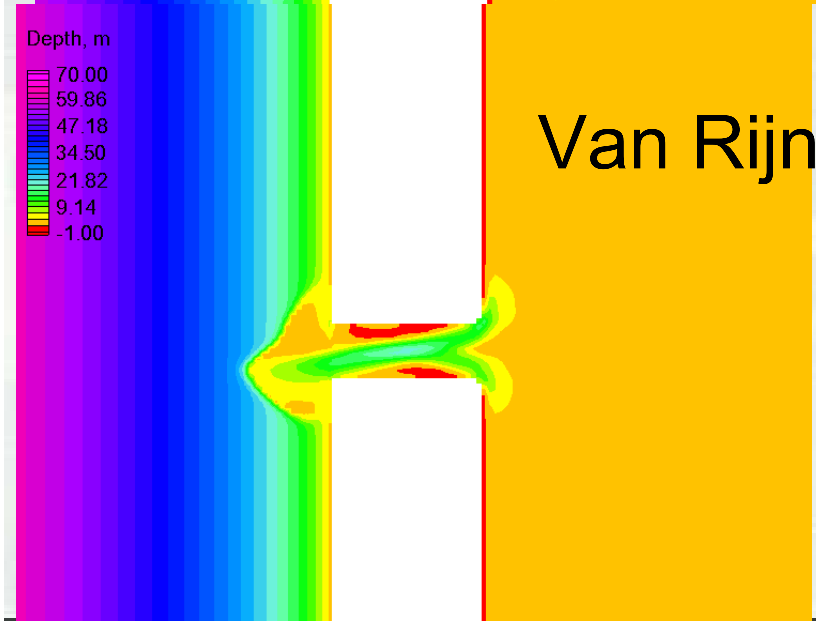
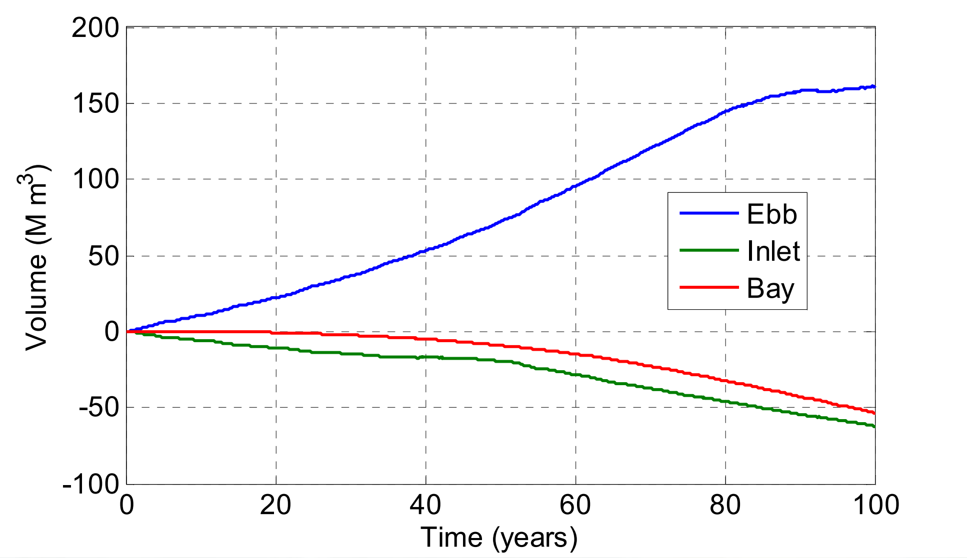


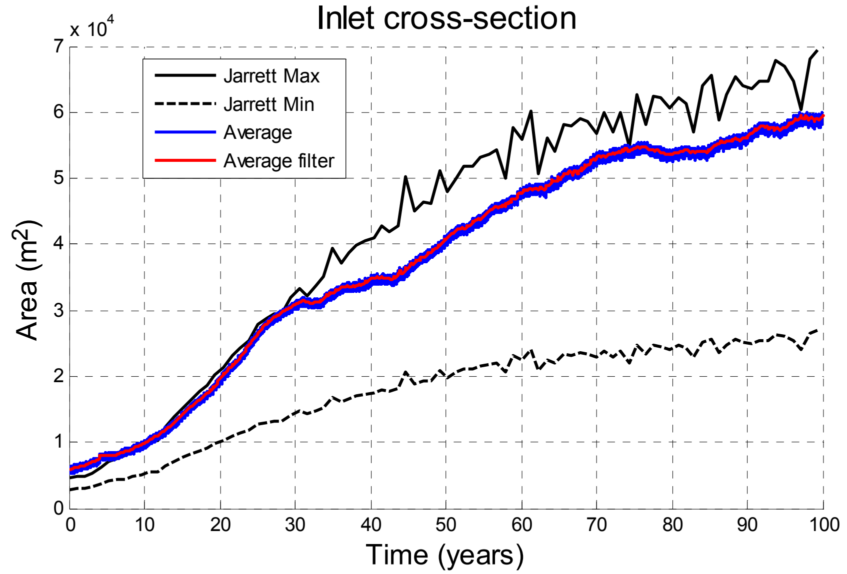


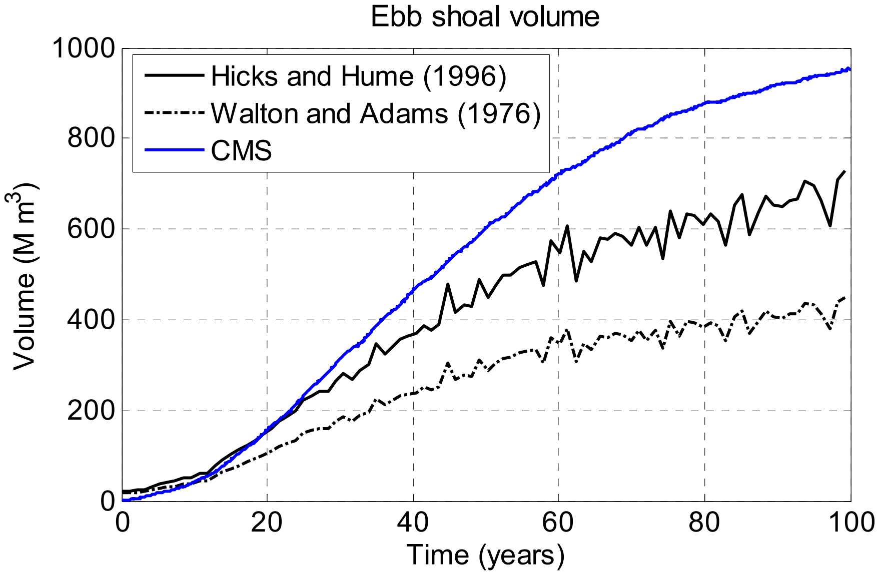




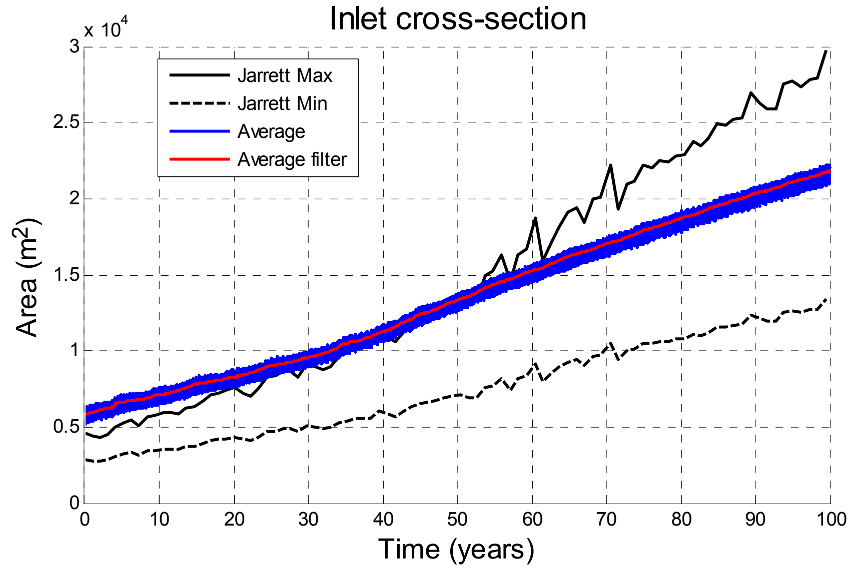
Results: Galveston, TX

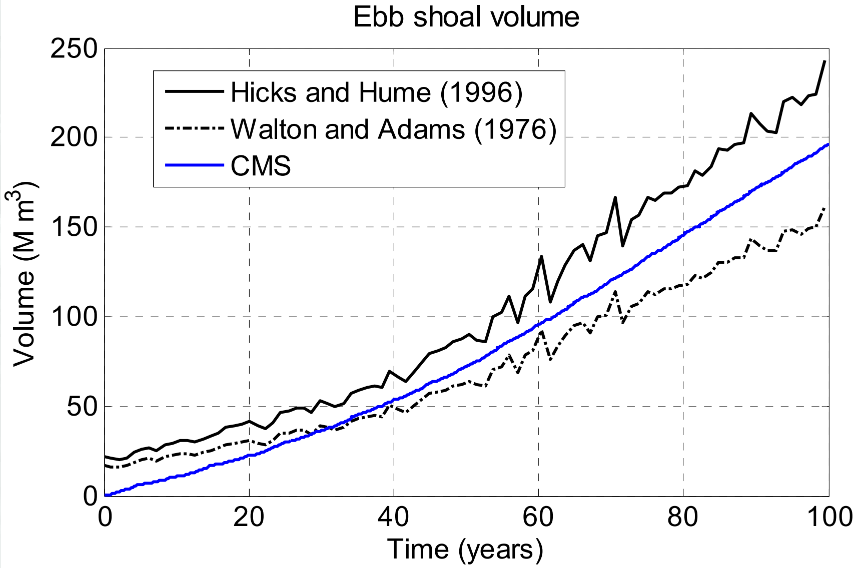
Lund-CIRP





Van Rijn





Discussion and Conclusions

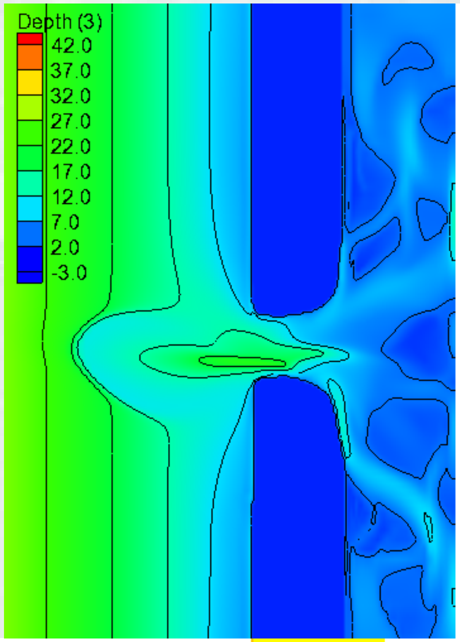
- Rate of bed change within the first 10-20 years is rapid and then slows
- None of the simulated inlets reached a full dynamic equilibrium after 100 years suggesting that either:
    1. The adaptation time of the simulated inlets is longer than 100 years
    2. The inlets may never reach equilibrium due to missing or incorrect processes necessary for a stable equilibrium
- Significantly different results were obtained for different sediment transport capacity formula

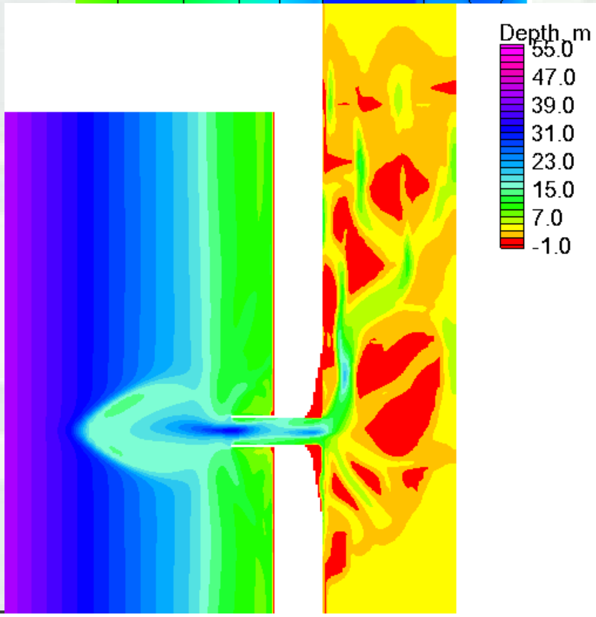
Discussion and Conclusions

- Model computational times were reasonable
  - 100 years in about 7-10 days on a PC
- Model stability was very reasonable
- Cross-sectional areas were generally over-predicted
- Ebb and flood shoal morphologies and evolution were reasonable
- Comparison to the Escoffier curves were reasonable

Future Work

- Multiple grain sizes
  - Reduce channel erosion
  - Help reach dynamic equilibrium faster
- Dynamic roughness
  - Function of the bed gradation and bedforms
- Bank erosion feature
- Influence of jetties, asymmetric bays, and dredging
- Inlet infilling and closure?





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Thank you

Questions?