Overview of the Coastal Modeling System

Mitch Brown

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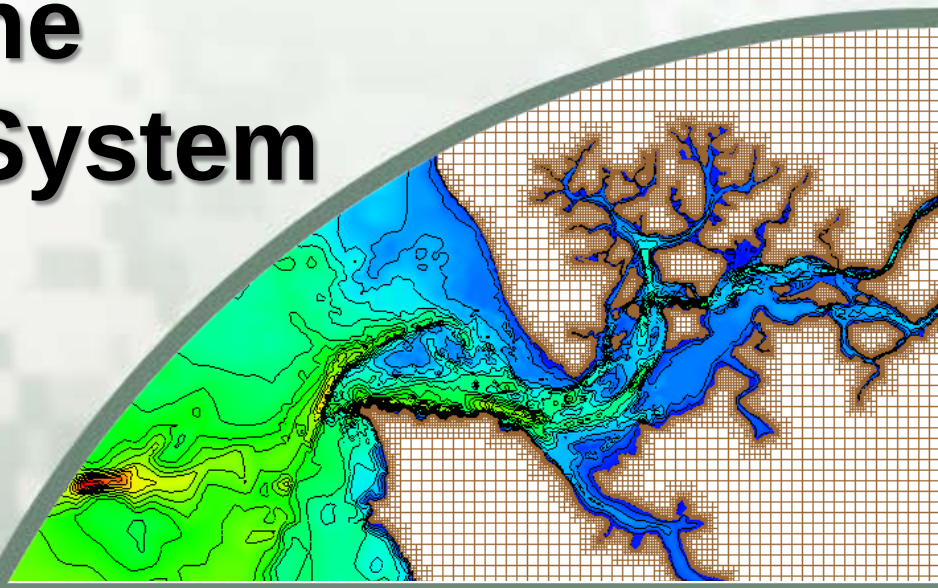
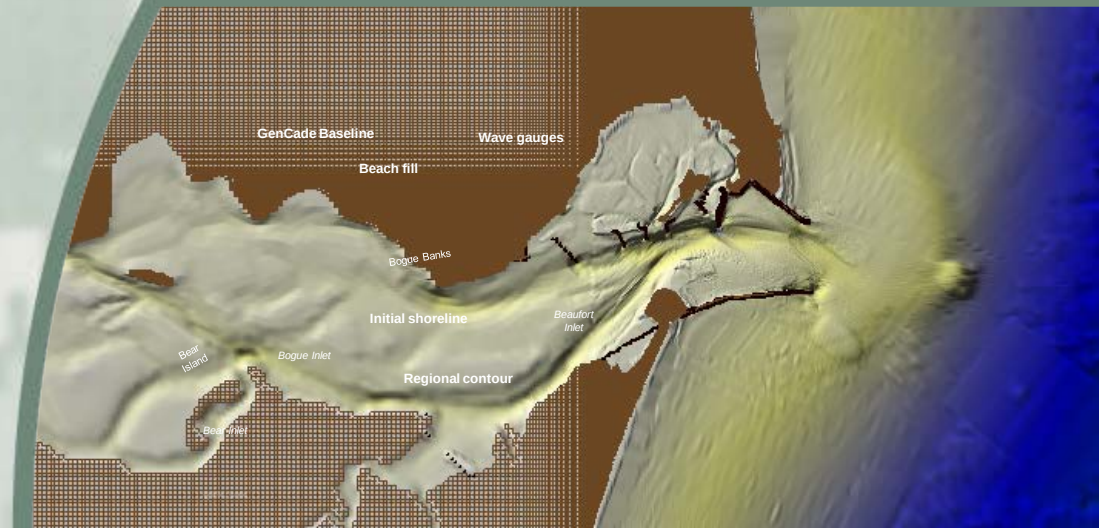
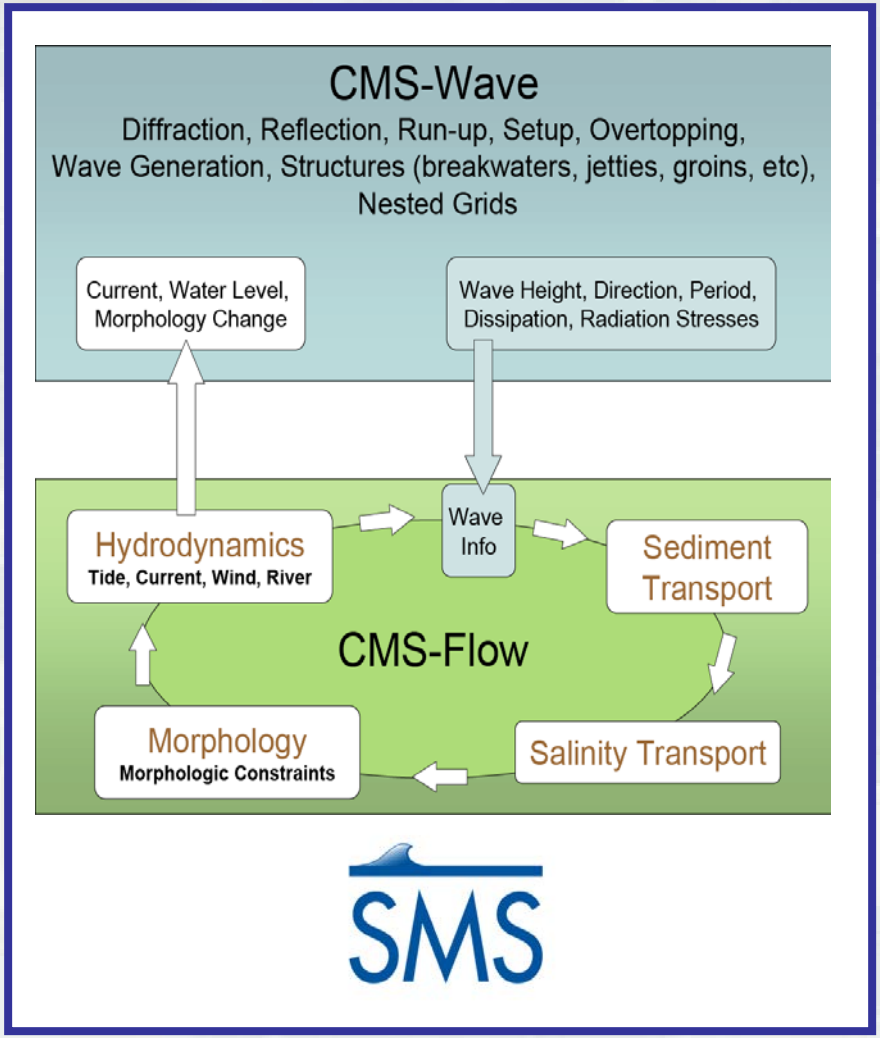




Outline

- Overview
- Mathematical Formulations
- Numerical Methods
- Verifications and Validation
- Example Applications
- Future work
- Summary

Coastal Modeling System



What is the CMS?

- Integrated wave, current, and morphology change model in the Surface-water Modeling System (SMS).

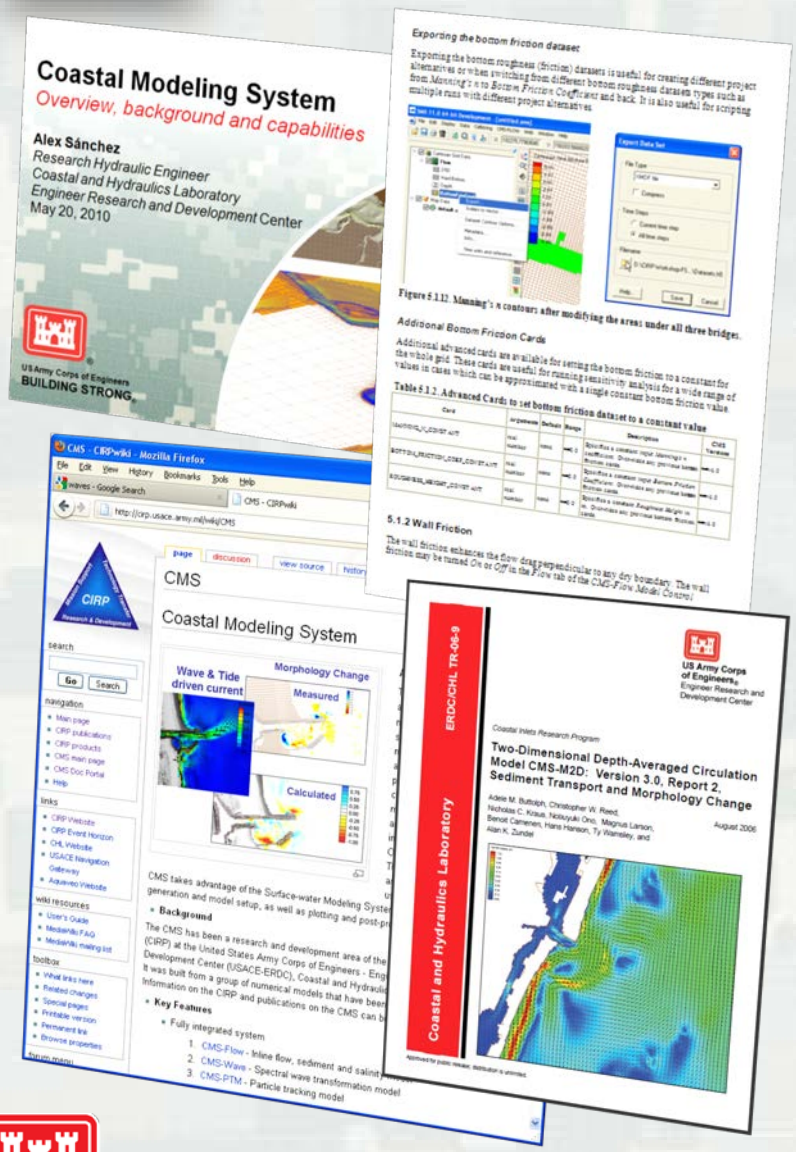
Why CMS?

- Operational at 10 Districts and many consulting companies
- Validated with real applications
- Robust and user-friendly
- Practice-oriented:
  1 year simulation ~ 1-3 days on PC

Types of Applications

- **Channels:** Deepening, widening, lengthening, realigning
- **Jetties:** Lengthening, raising, rehabbing
- **O&M:** Placement areas – berms, wetlands
- **Processes:** *Navigability* – waves and currents; *Environmental* – circulation, and sediment transport

Coastal Modeling System



Availability

- Comes with SMS installation package
- CIRP website (under Products)
- CMS is Free and interface is relatively inexpensive
- POC's:
  - ▷ Alejandro.Sanchez@usace.army.mil
  - ▷ Lihwa.Lin@usace.army.mil
  - ▷ Mitchell.E.Brown@usace.army.mil

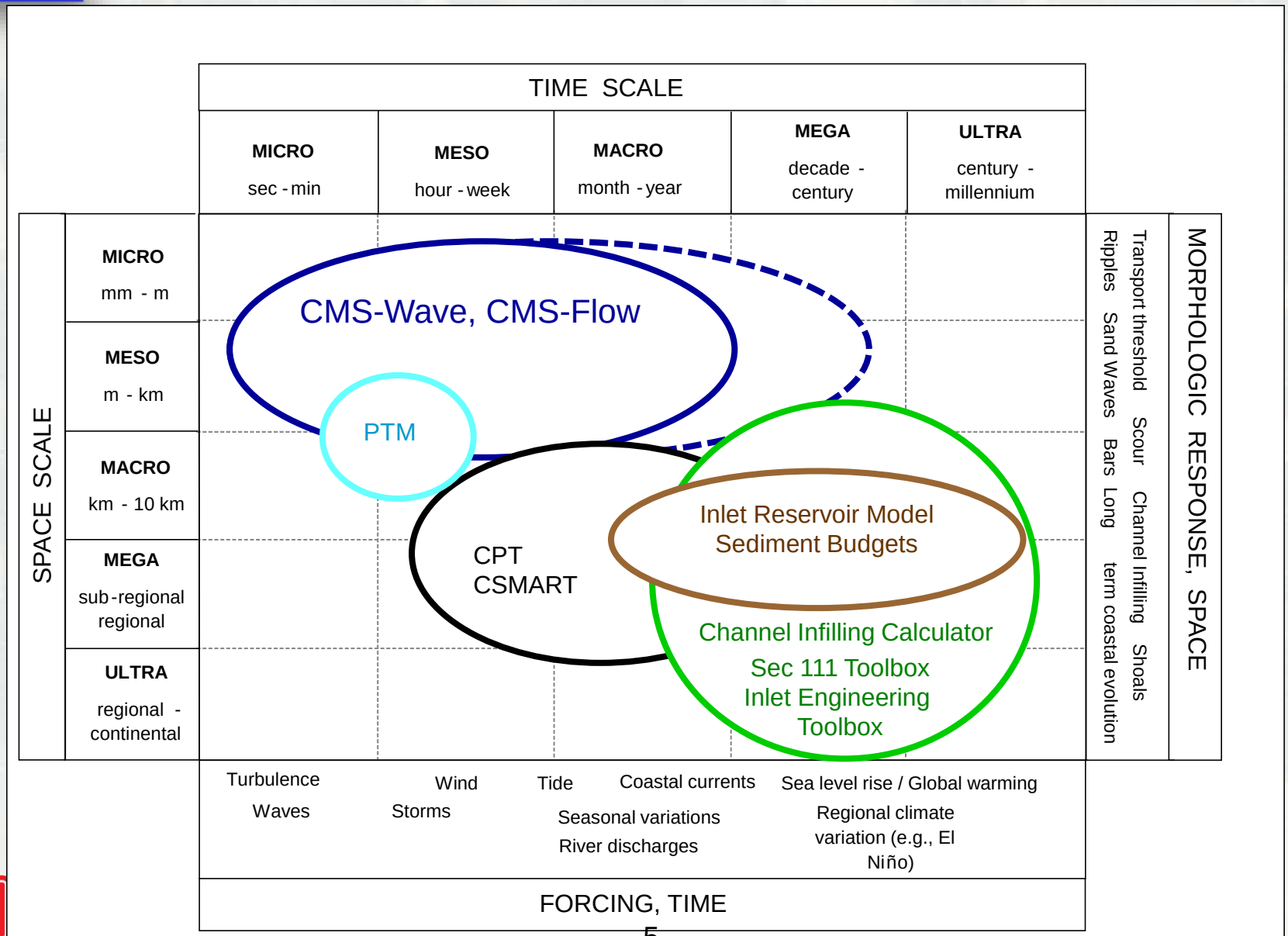
Documentation

- Several TR's, CHETN's and journal papers
  - ▷ http://cirp.usace.army.mil/pubs/
- CIRP Wiki
  - ▷ http://cirp.usace.army.mil/wiki/CMS
- New Technical Report will be available this fall

Training and Support

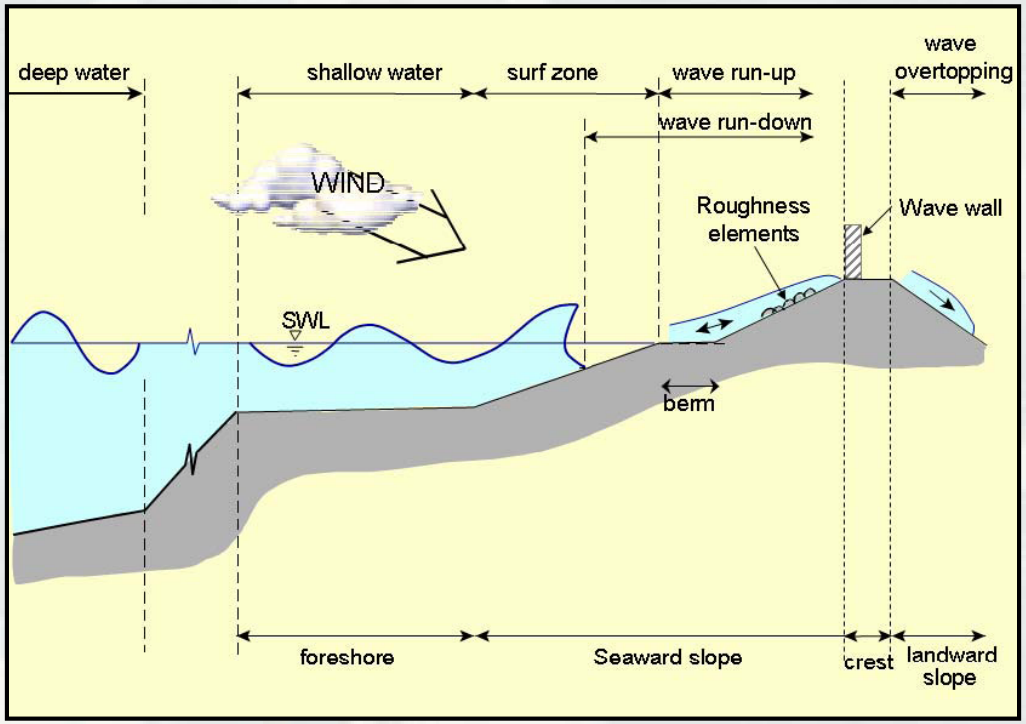
- Annual workshops (13 years)
  - ▷ http://cirp.usace.army.mil/workshops/
- CMS instructional webinars on CIRP website
  - ▷ http://cirp.usace.army.mil/webinars/

Scales of Coverage



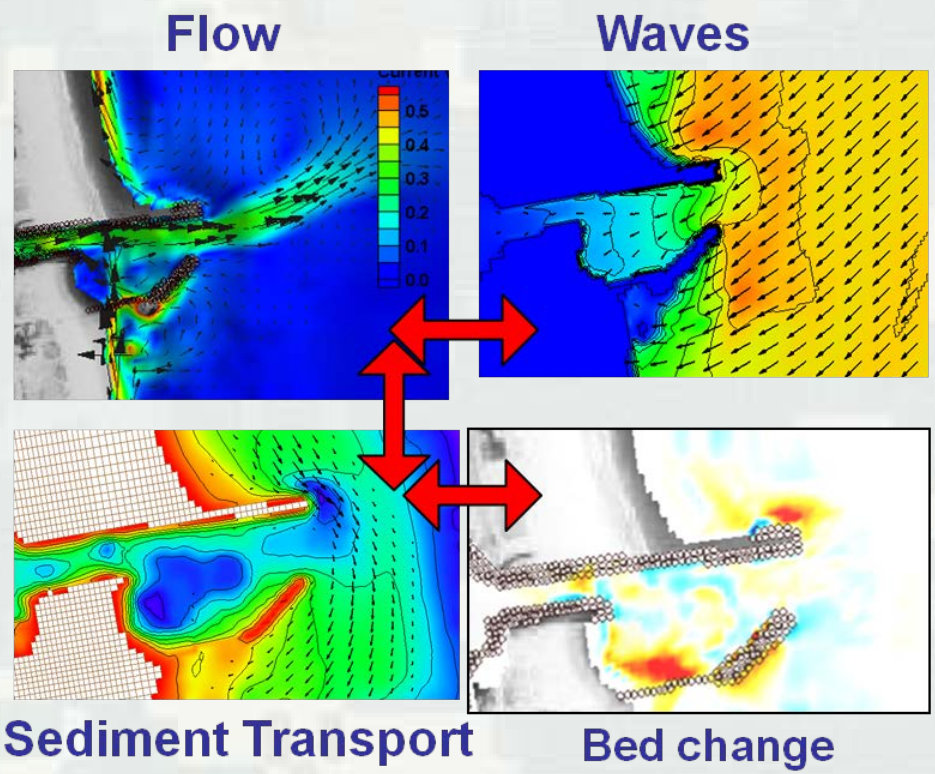
CMS-Wave: Key Features

- Shoaling, refraction, diffraction, reflection
- Bottom friction
- White capping
- Wave breaking (4 options)
- Wind generation
- Wave-current, and wave-wave interactions
- Transmission, runup and overtopping
- Muddy bottom
- Automatic grid rotation
- Non-uniform Cartesian grid with nesting capability
- “Fast Mode”



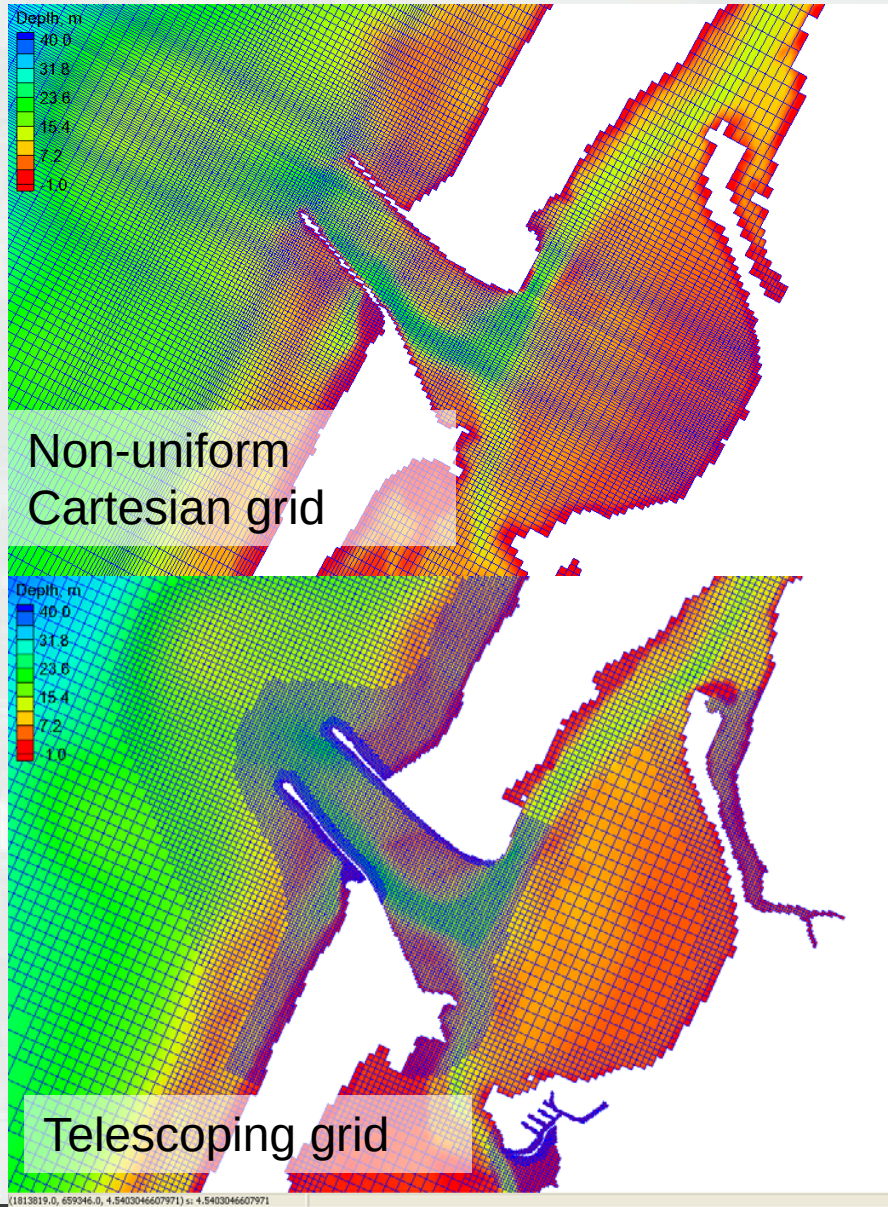
CMS-Flow: Key Features

- Finite Volume Method
  - Conserves mass
  - Stable
- Inline CMS-Wave model
  - Wave-current interactions
- Inline sediment transport and morphology change
  - Non-equilibrium total load
  - Multiple-sized transport
  - Bed sorting and layering
- Nesting capability
- Forcing
  - Tide, river, wind, atm. pres., waves, etc.
- Integrated Particle Tracking Model (CMS-PTM)



CMS-Flow: Key Features

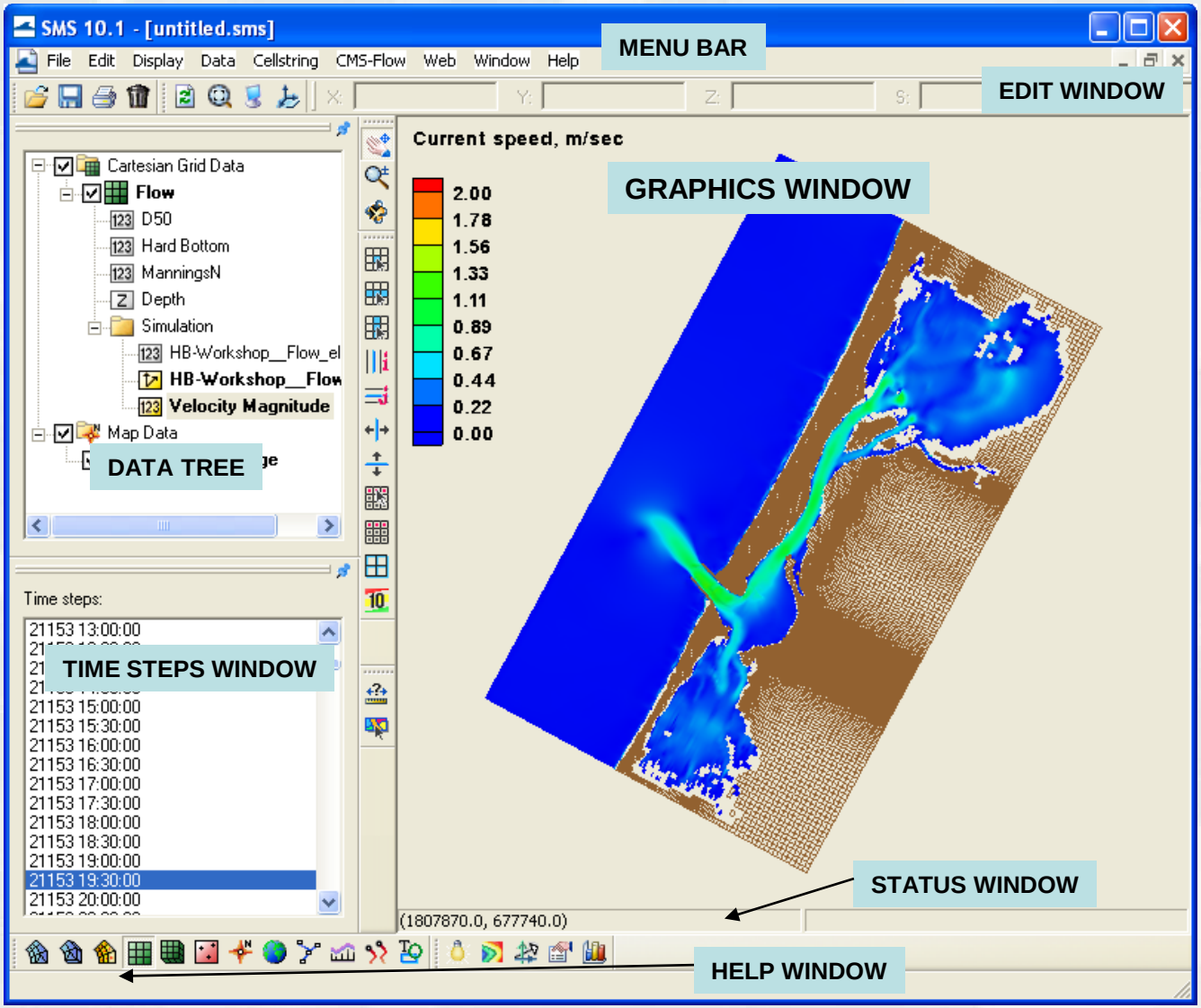
- Grid options
  - Non-uniform Cartesian grid: Easy to setup
  - Telescoping grid: Efficient, easy, flexible
- Solver options
  - Implicit: Tidal flow, long-term morphology change: ~10 min time step
  - Explicit: Flooding, breaching, super-critical flow: ~ 1 sec time step
- Parallel processing using OpenMP



SMS Interface

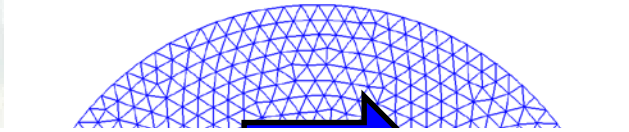
The Project Explorer (Data Tree) is a dockable window that appears by default on the left side of the SMS screen.

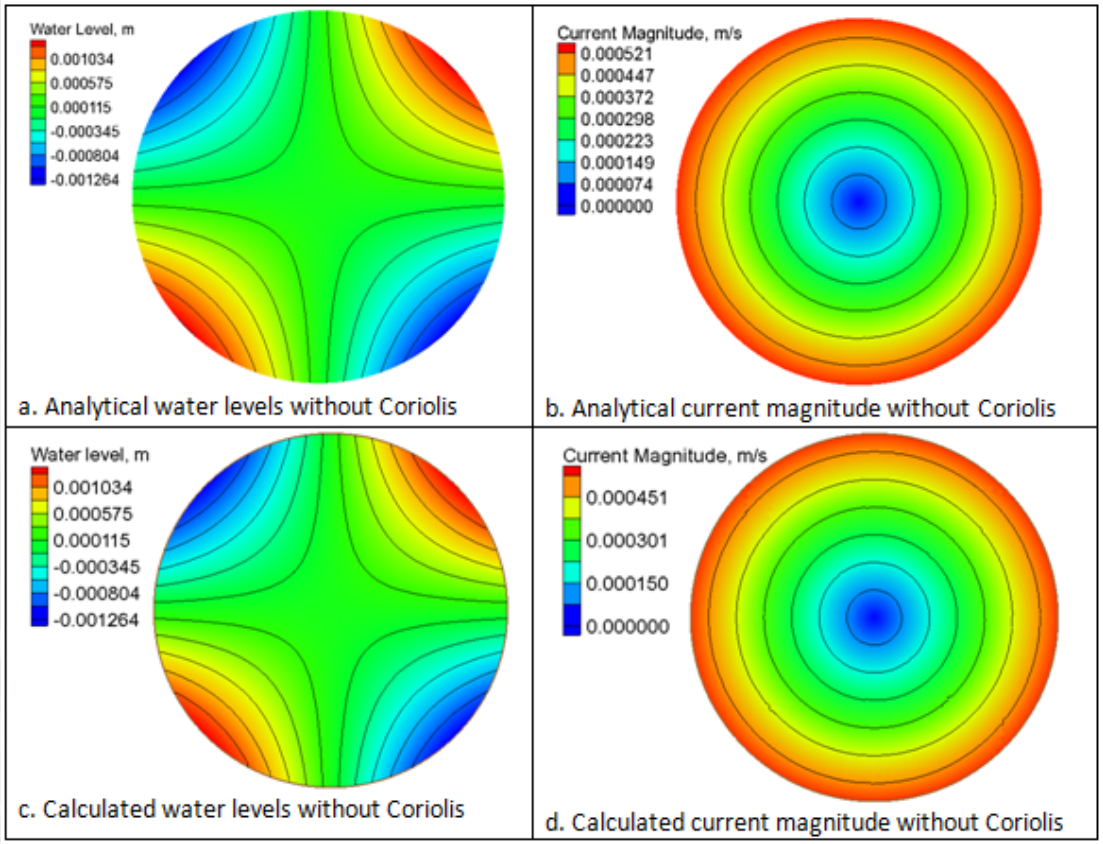
This window displays a hierarchical tree structure representing all data currently being managed in an SMS simulation.

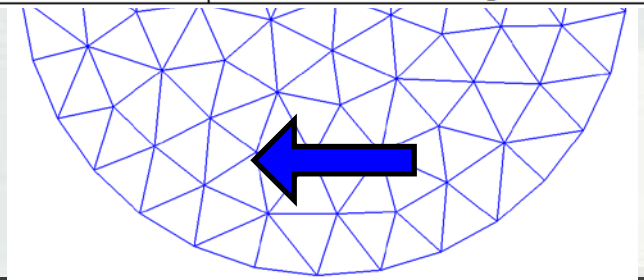


Validation/Verification

Wind Driven Flow in a Circular Basin

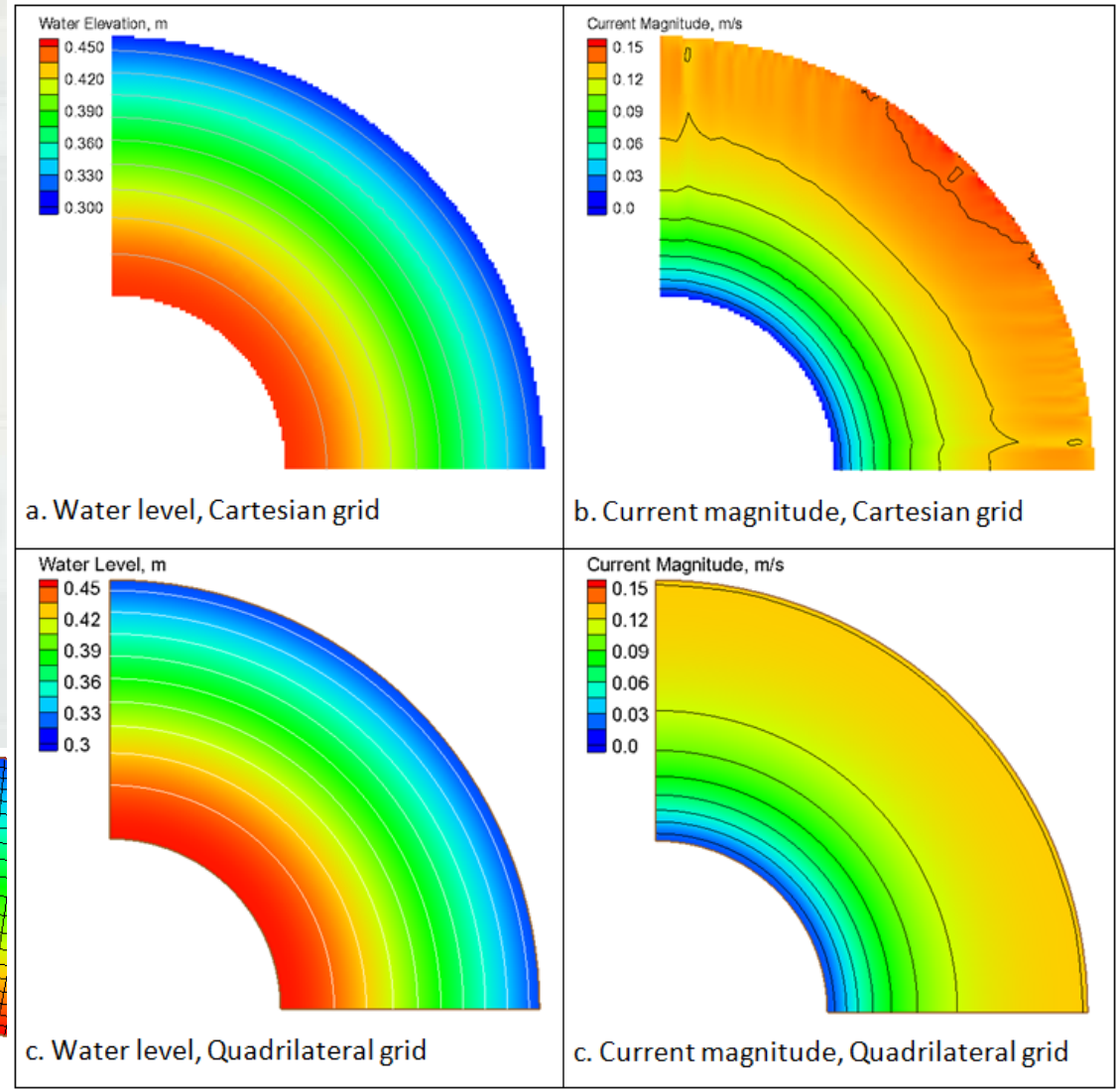


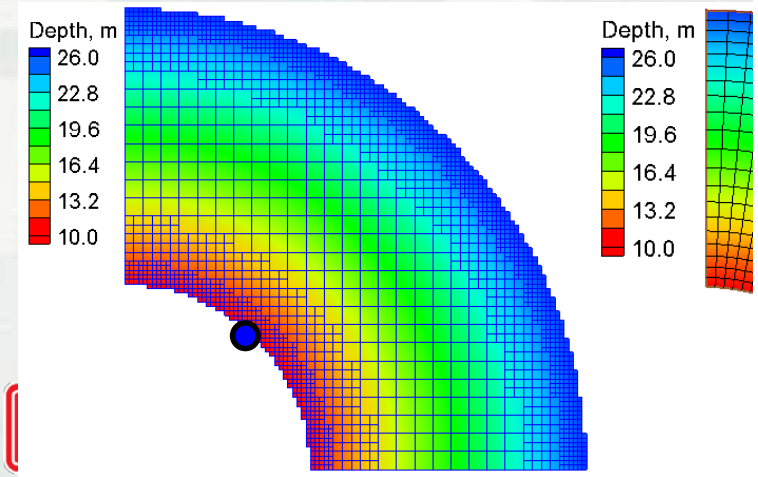


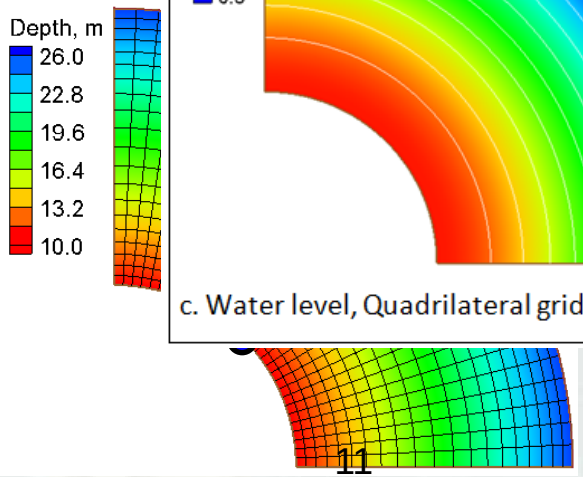


Quarter Annulus

- M2 Tide: 0.305 m
- No bottom friction
- No wall friction
- No Coriolis
- Time Step: 15 min
- Duration 5 days

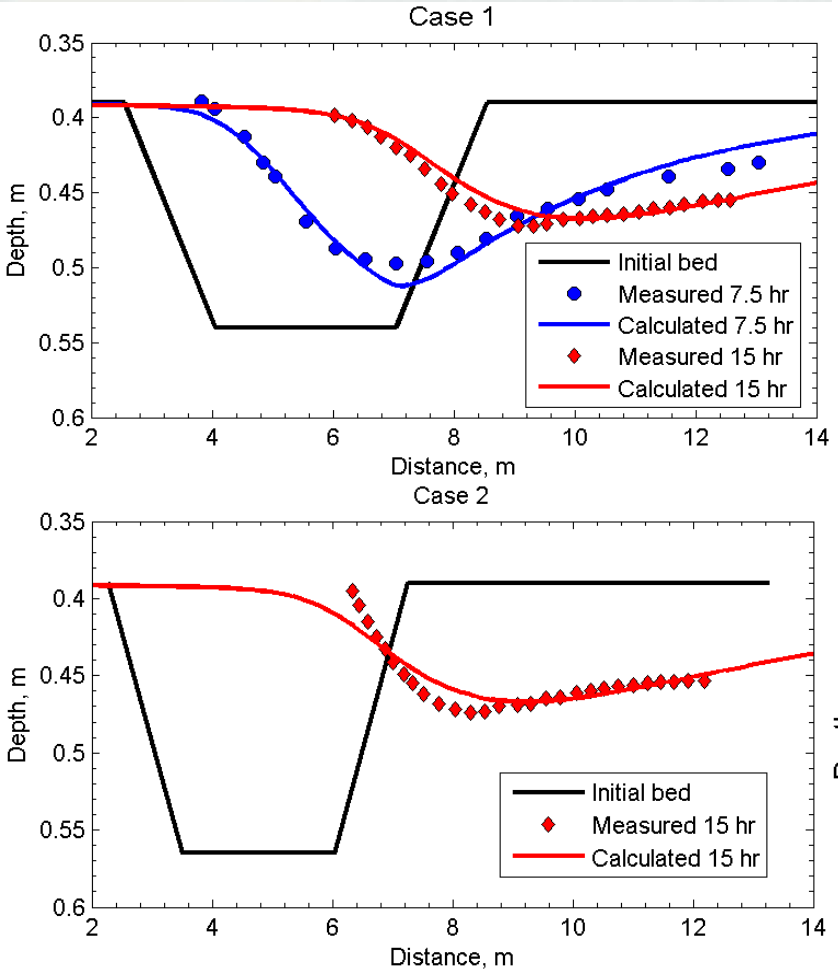


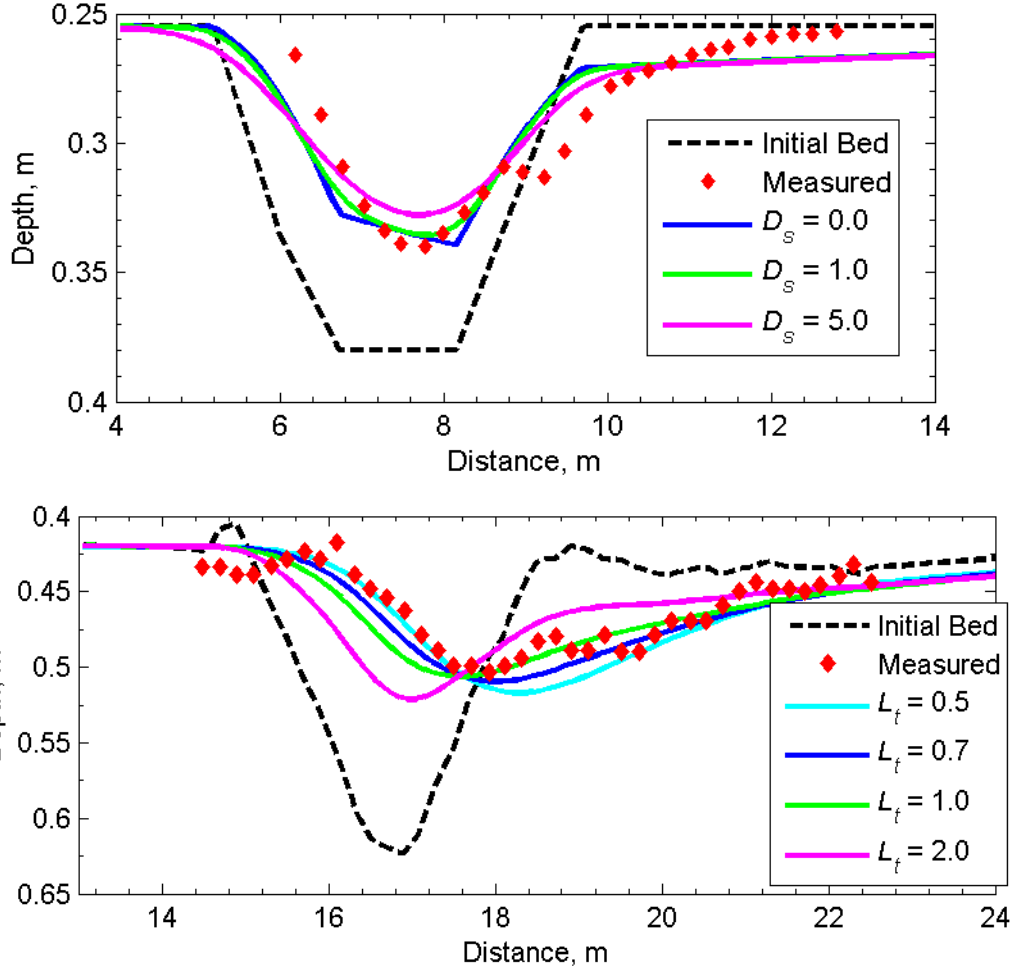




Channel Infilling

Van Rijn (1986)



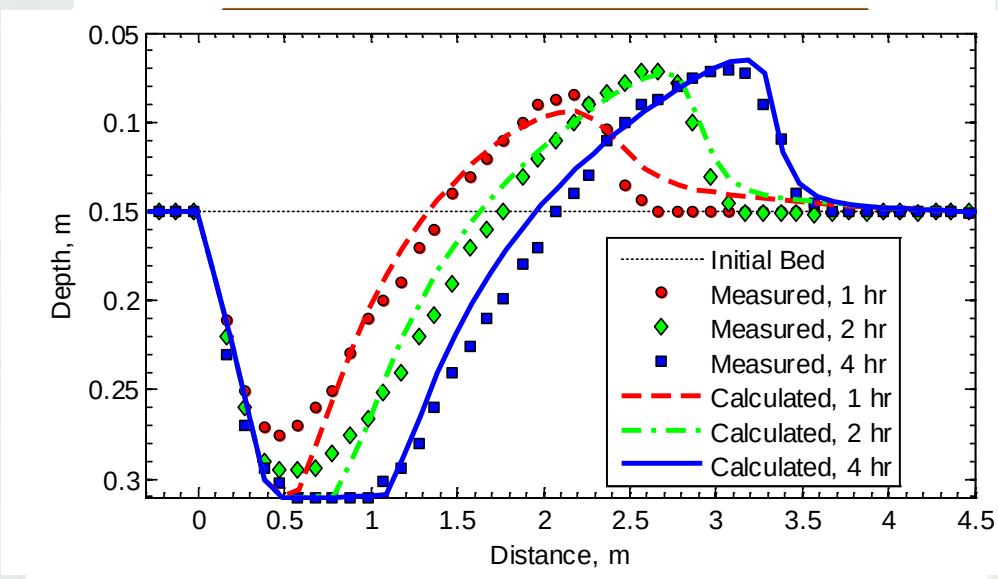


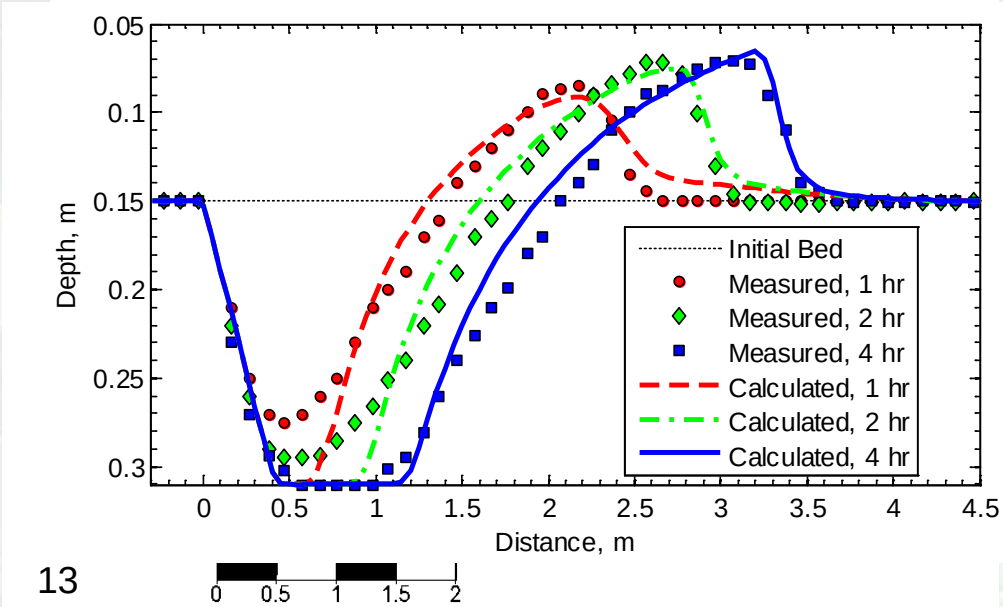
DHL (1980)

Van Rijn and Havinga (1995)

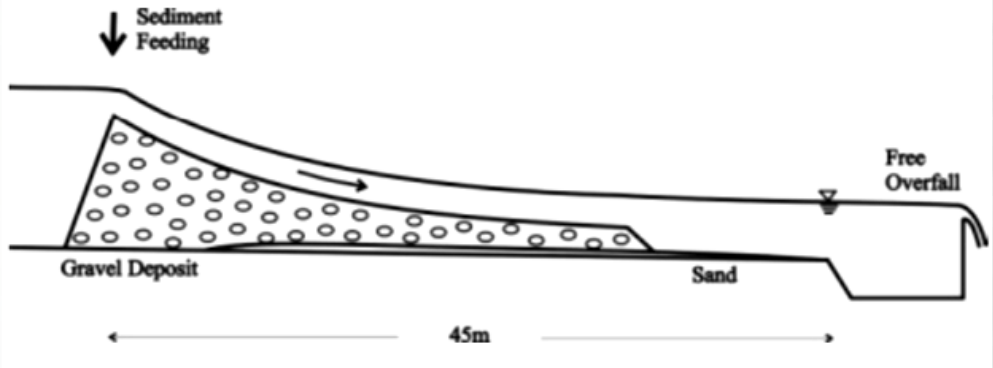
Clear Water Inflow over a Hard Bottom

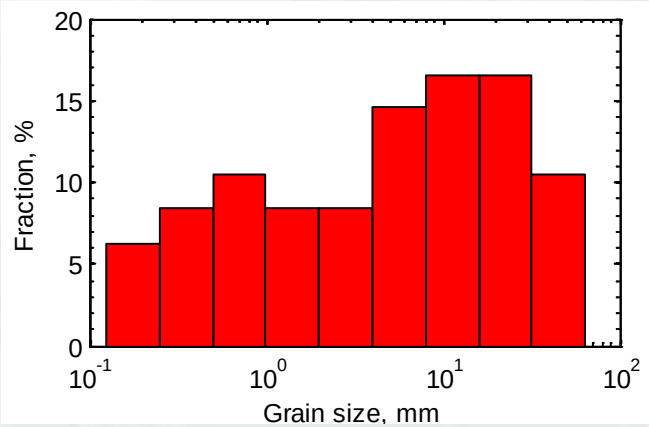
- Initial depth: 0.15 m
- D50: 0.6 mm
- Hard bottom: 0.31 m
- Inflow velocity: 0.6 m/s
- Time step: 30 sec
- Simulation duration: 4.25 hrs
- Manning's coefficient: 0.03 s/m^3
- Transport formula: Soulsby-van Rijn

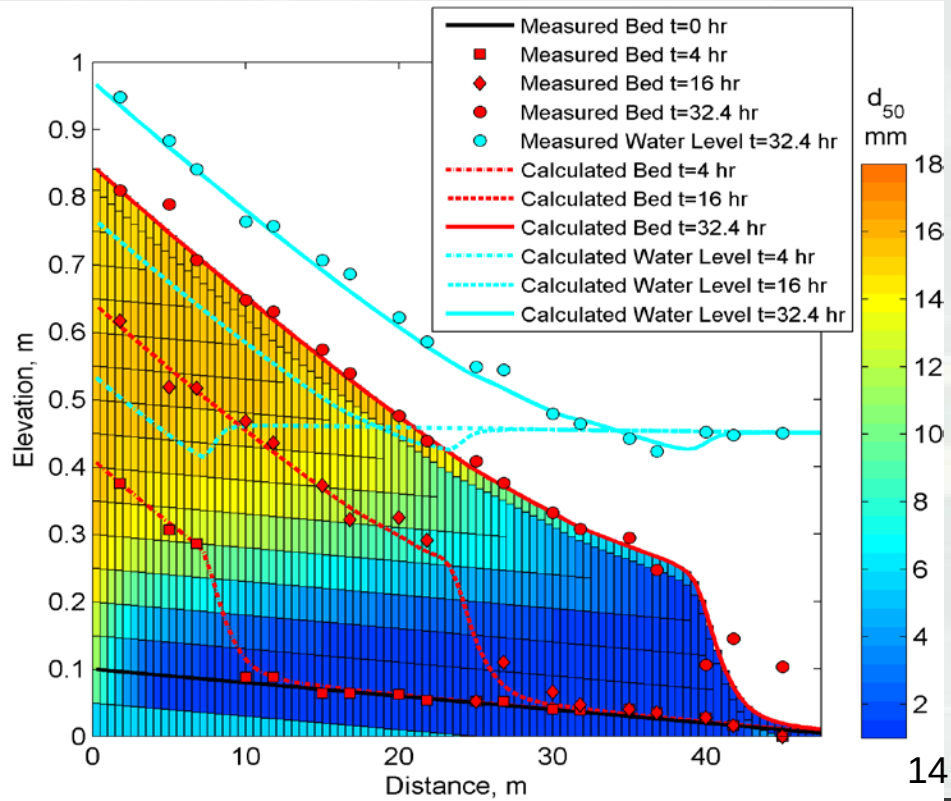


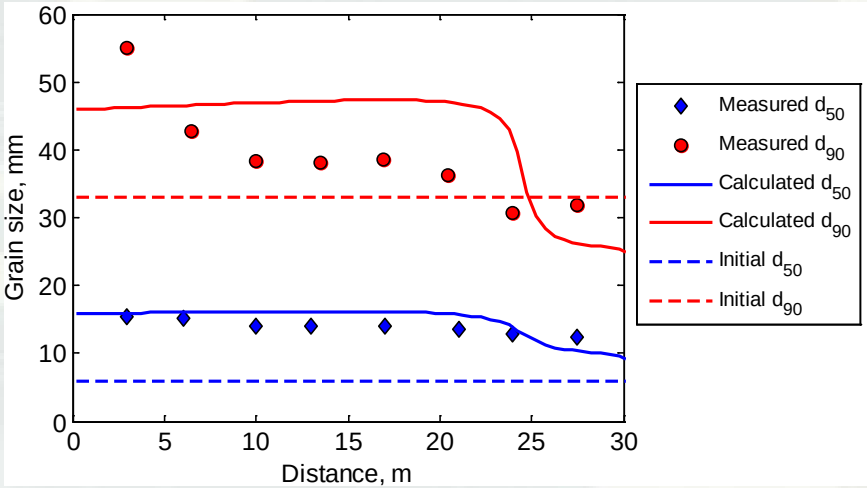


Bed Aggradation (Multiple-sized sediments)

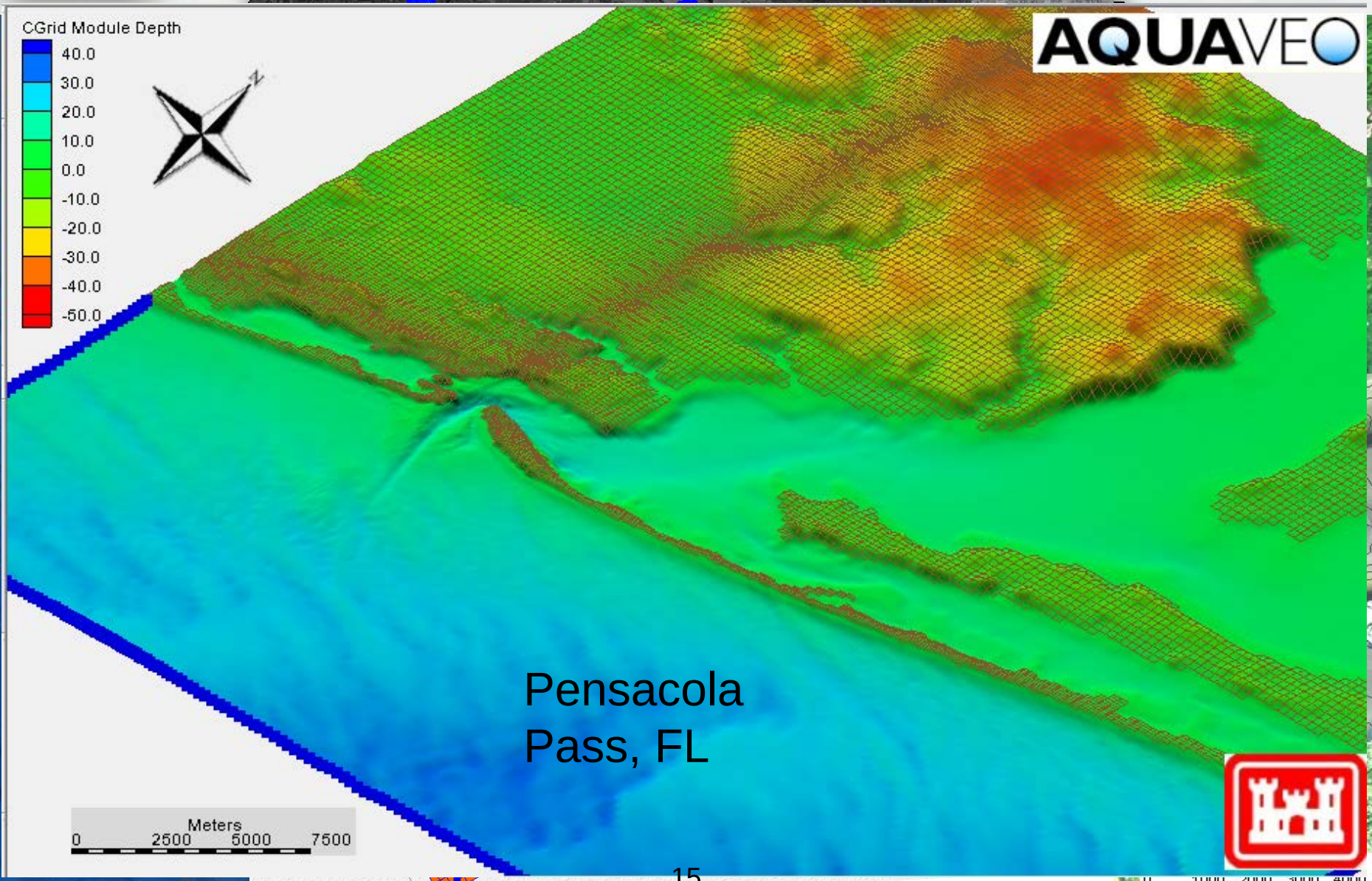






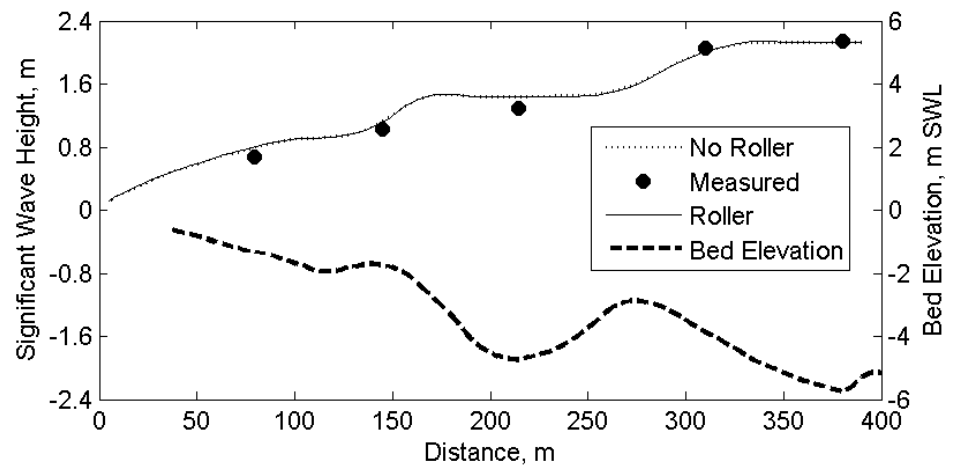


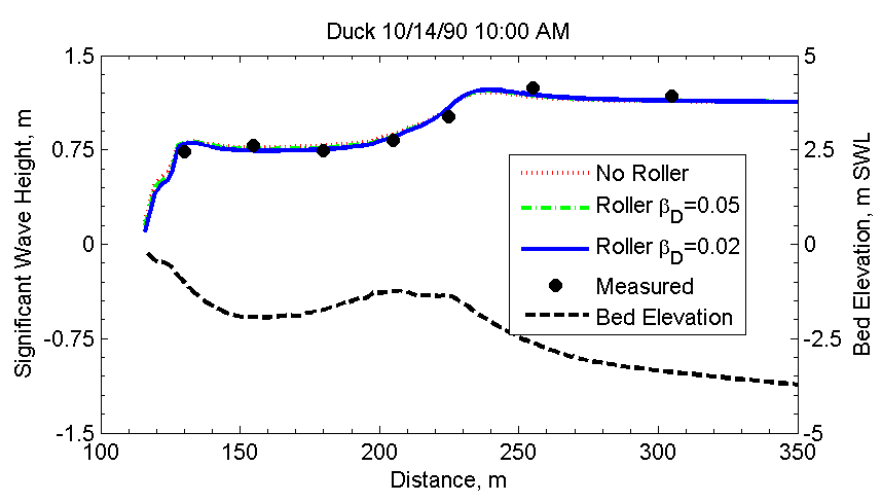
Field Applications

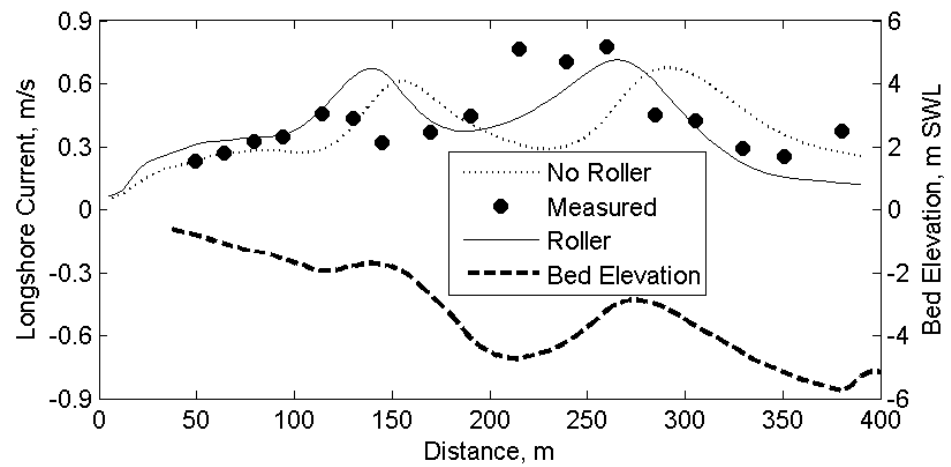


Pensacola Pass, FL

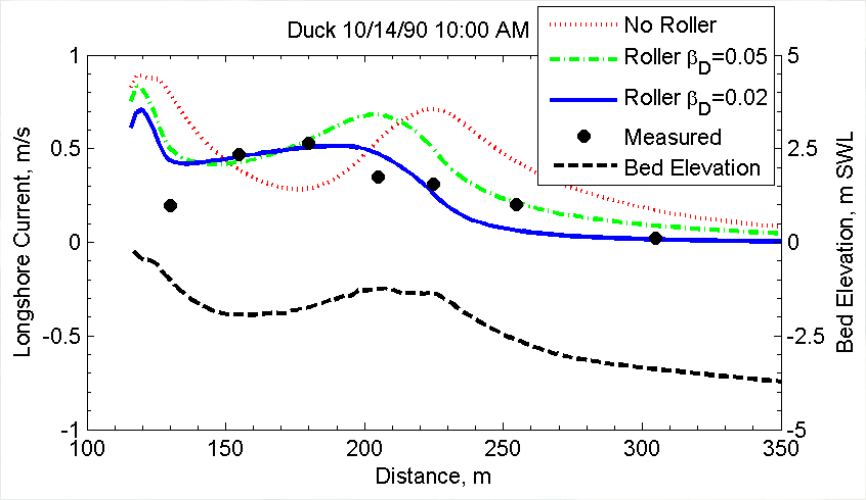
Nearshore Currents and Wave Heights







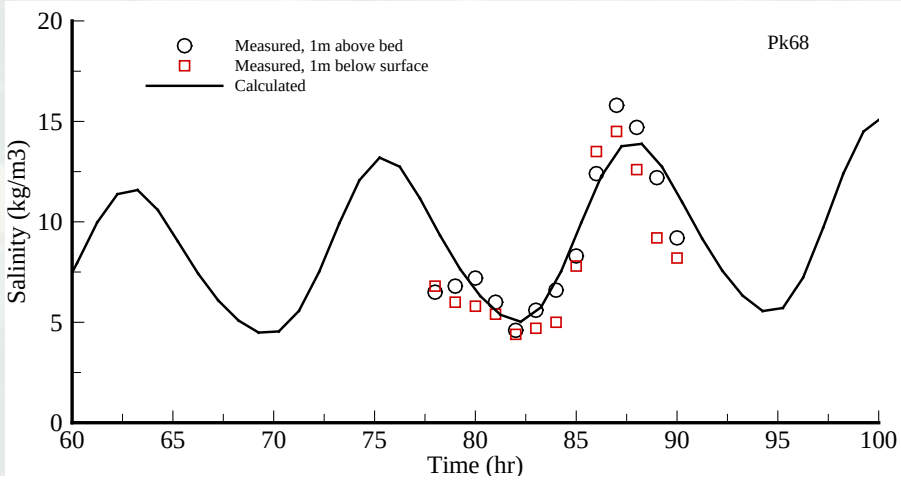
HORF test case

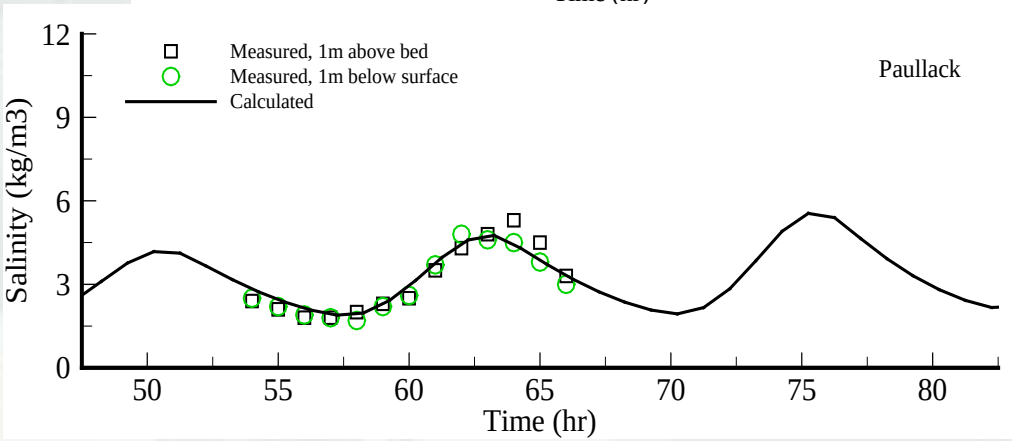


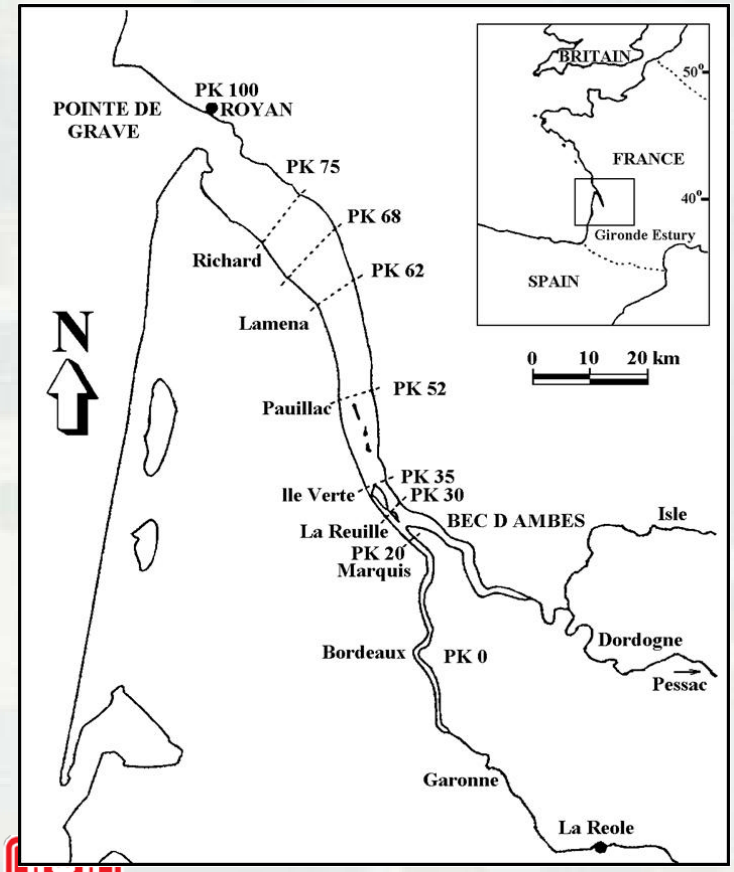
Duck90 test case

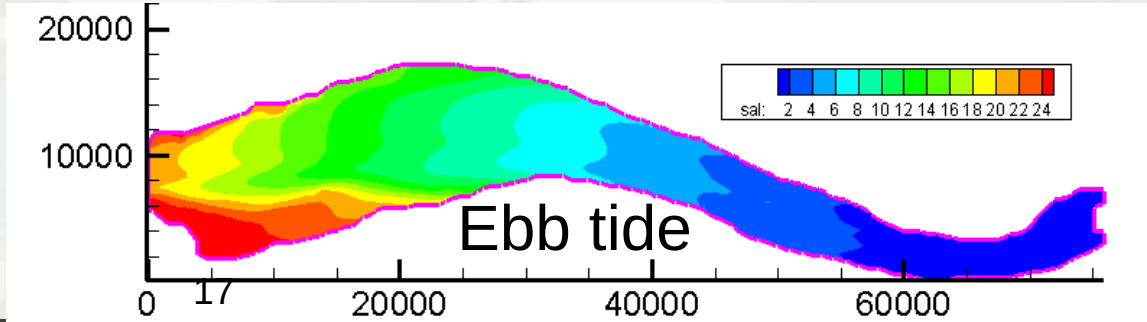
Salinity Validation

- Gironde Estuary, FR









Kawaihae Harbor, HI

- **Objective**

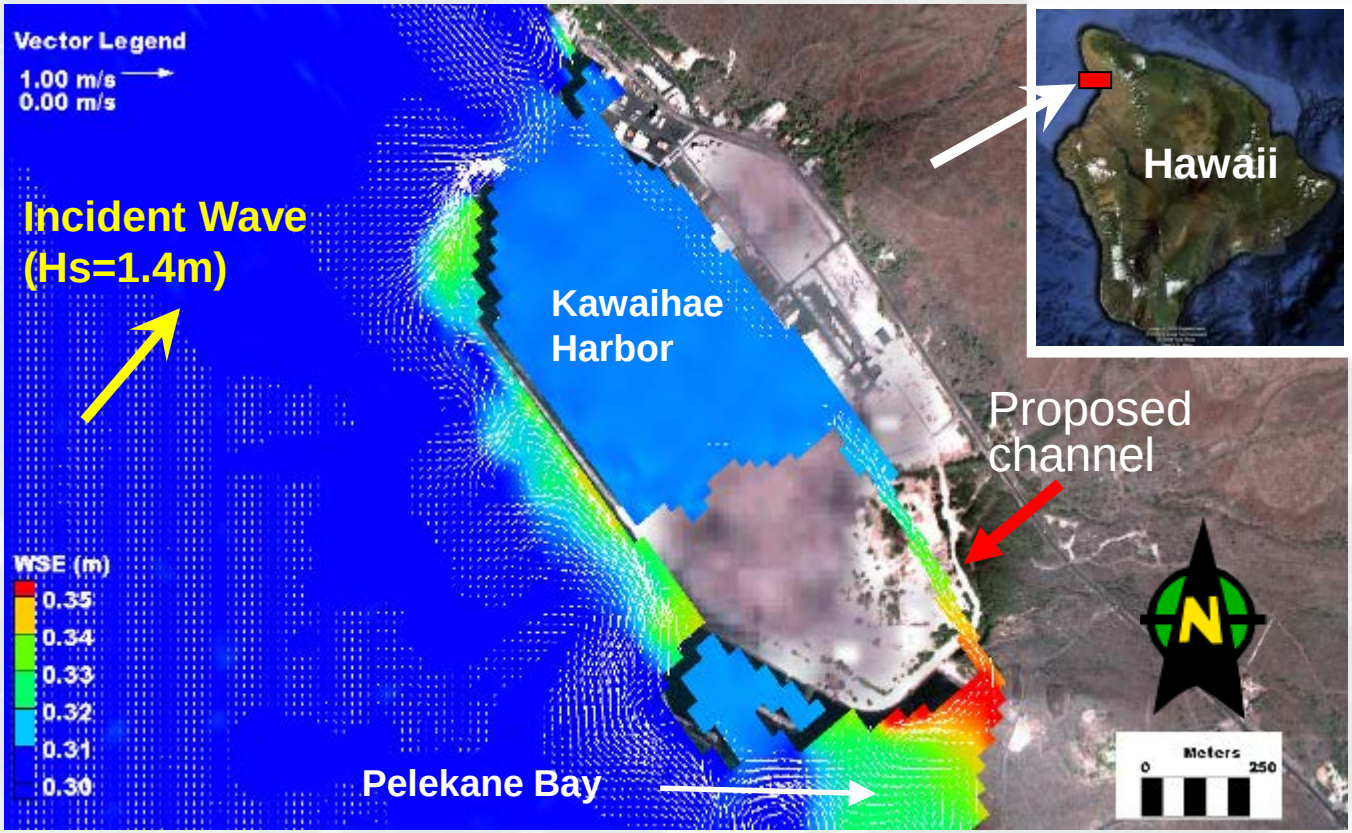
Determine benefit of ***proposed circulation channel*** to improve water quality in the bay

- **Result**

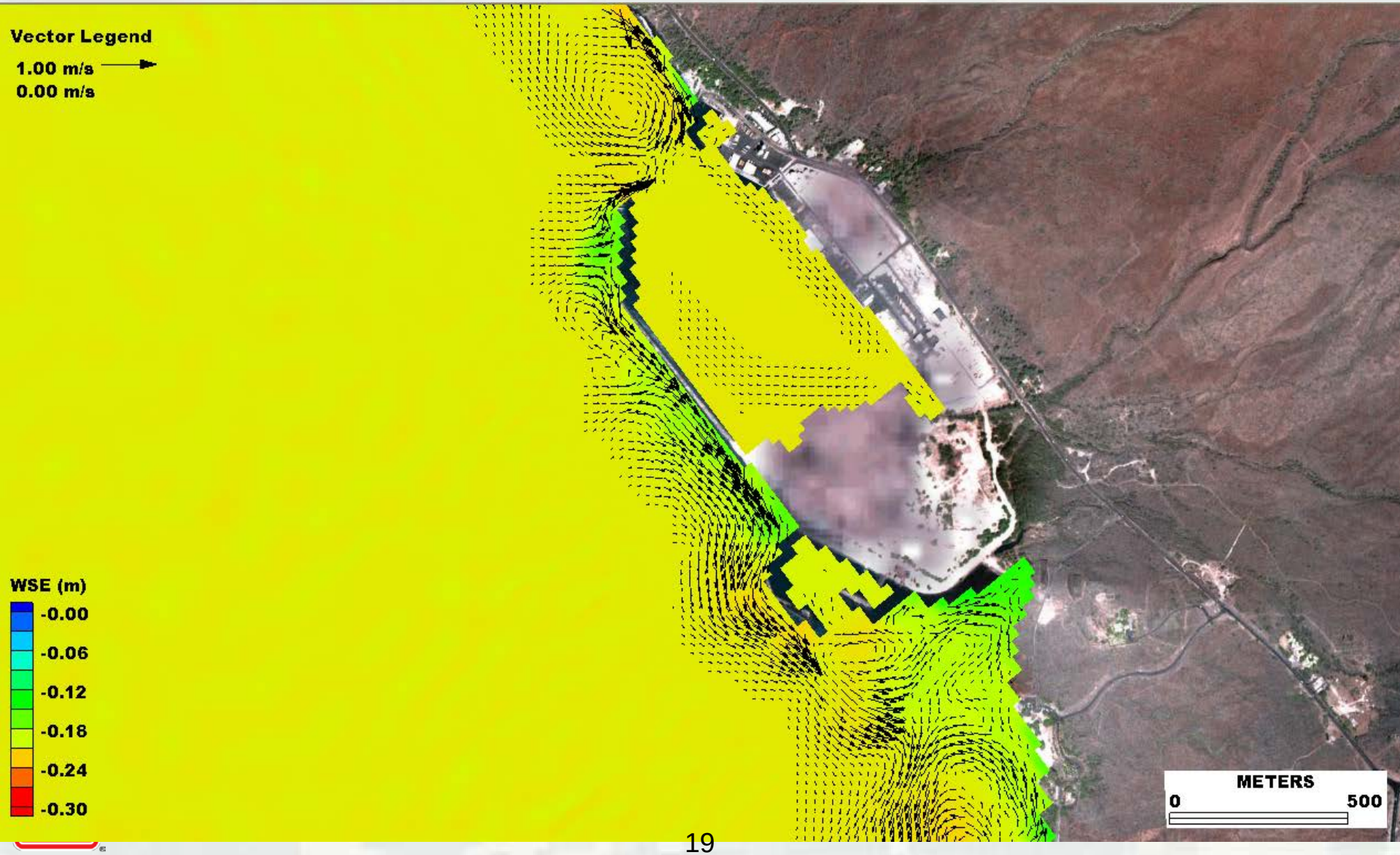
Water flow through channel due to wave setup in Pelekane Bay

- **Analyze Alternatives**

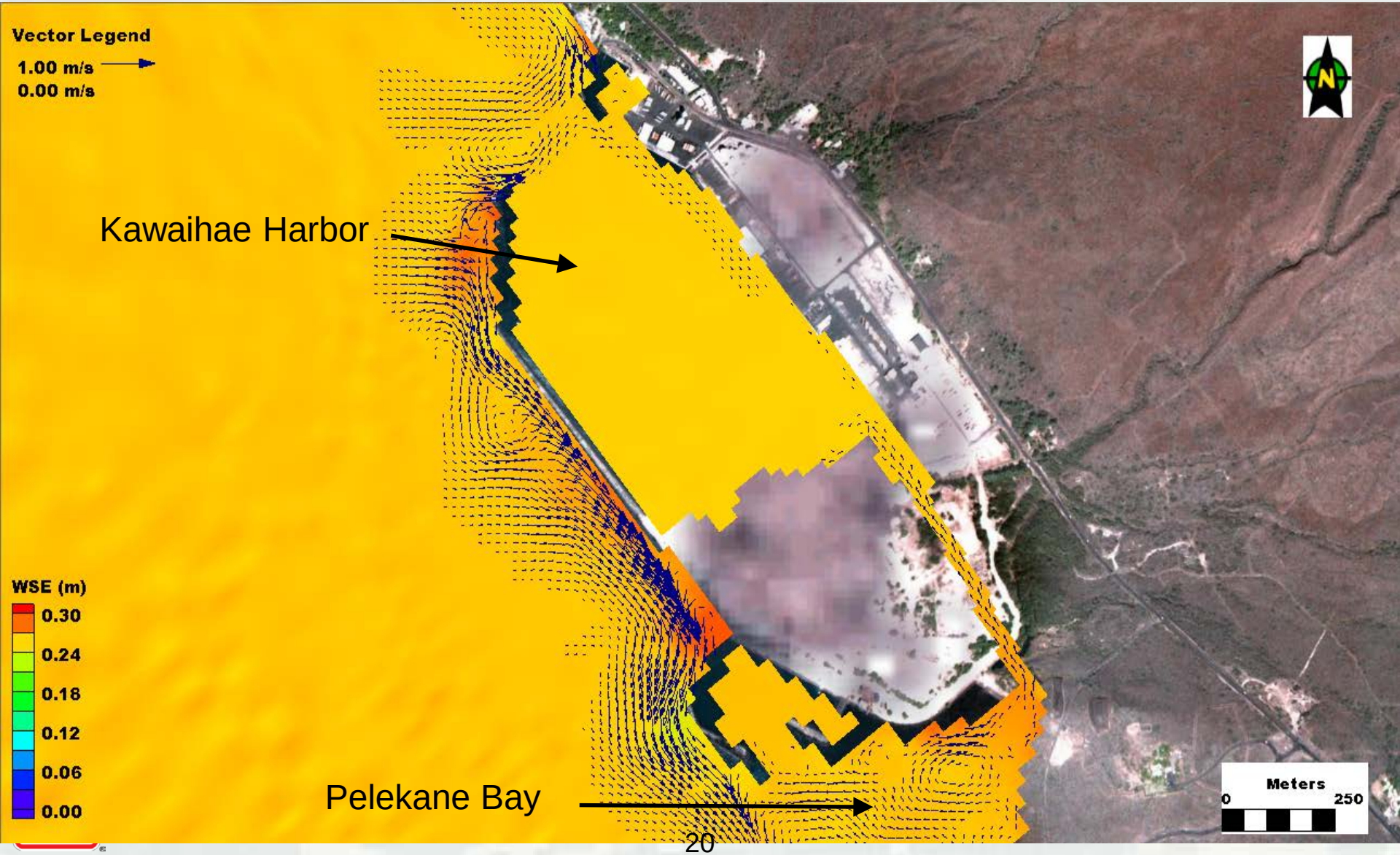
Several channel design alternatives investigated interactively with POH



Kawaihae Harbor, HI: Current Condition



Kawaihae Harbor, HI: With Proposed Channel



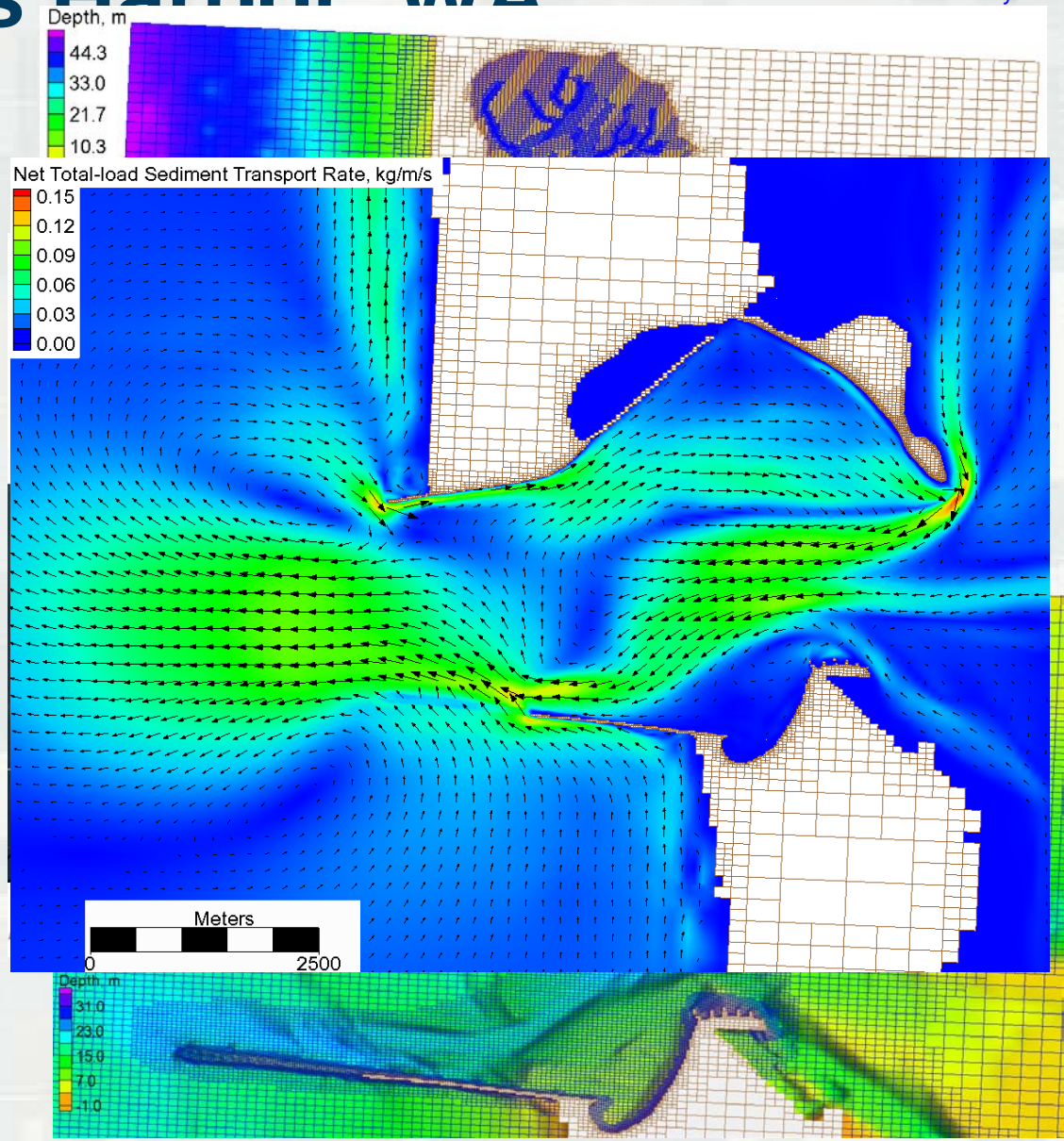
Grays Harbor, WA

Objective

- Determine if growing spit will affect adjacent nav. channel

Result

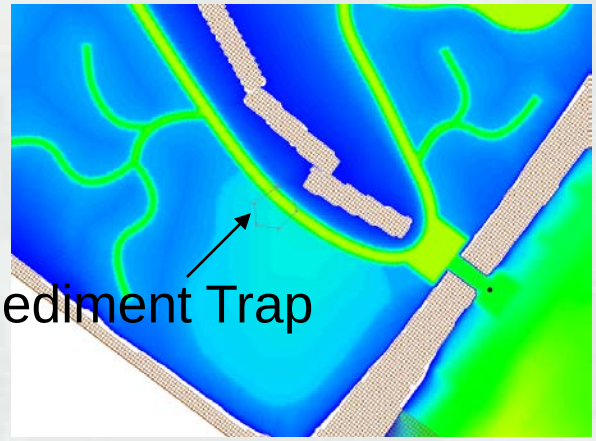
- Cause and prediction of spit growth determined
- Spit does and not expected to significantly impact nav. Channel in next 3 years

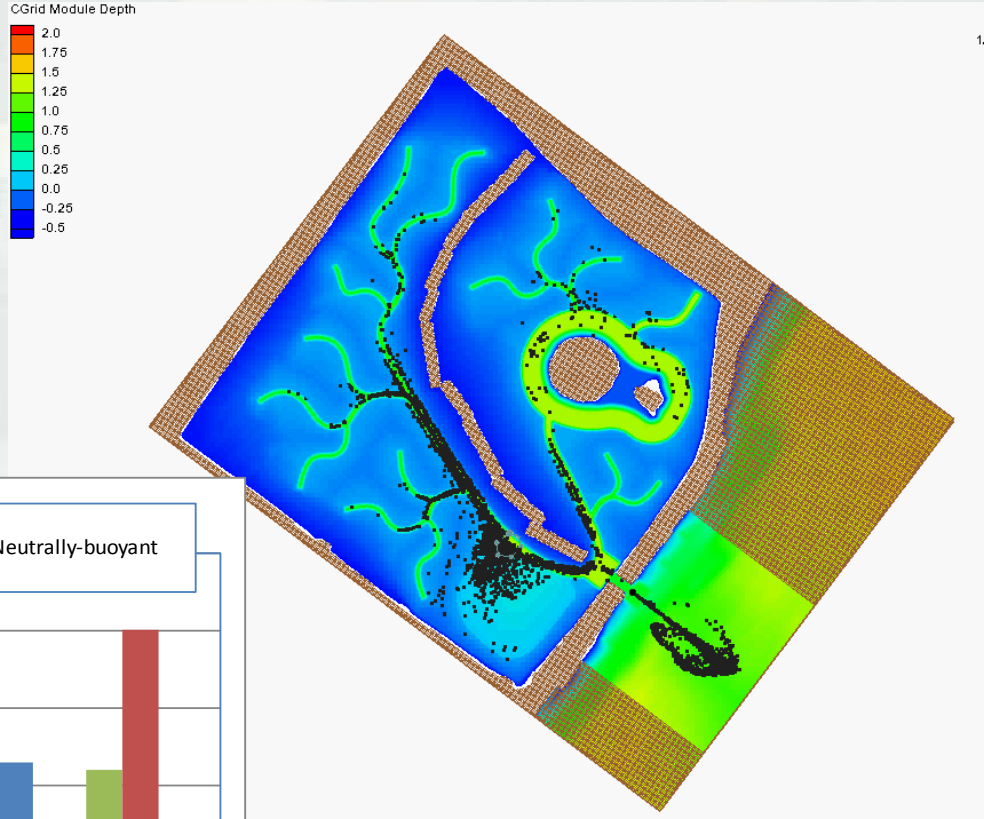


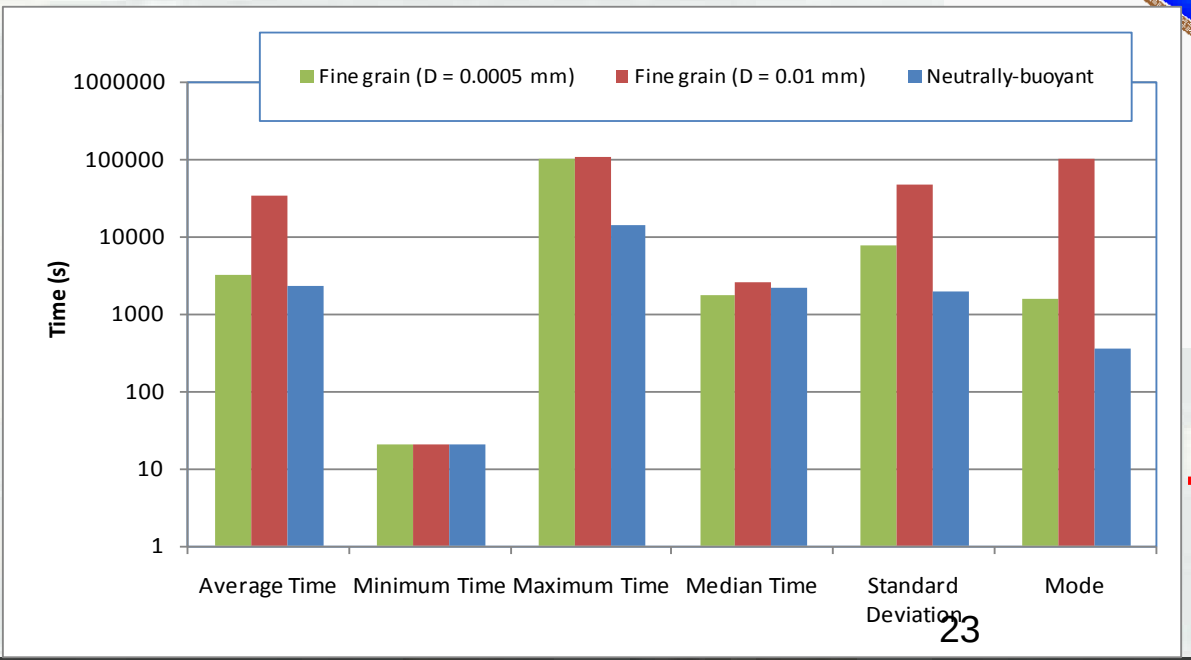
Particle Tracking Model (PTM)

- Lagrangian approach to simulating the transport, dispersion, entrainment and settlement of particles and dissolved constituents under both currents and waves
- Fully integrated with CMS-Flow and implemented in the SMS
- Improved visualization for communication of transport to sponsors
- Large variety and flexibility in specifying sources and sinks
- Calculated spatial maps of sediment mobility, bedform, sediment pathways, etc.

CMS-PTM Application: Poplar Island, MA



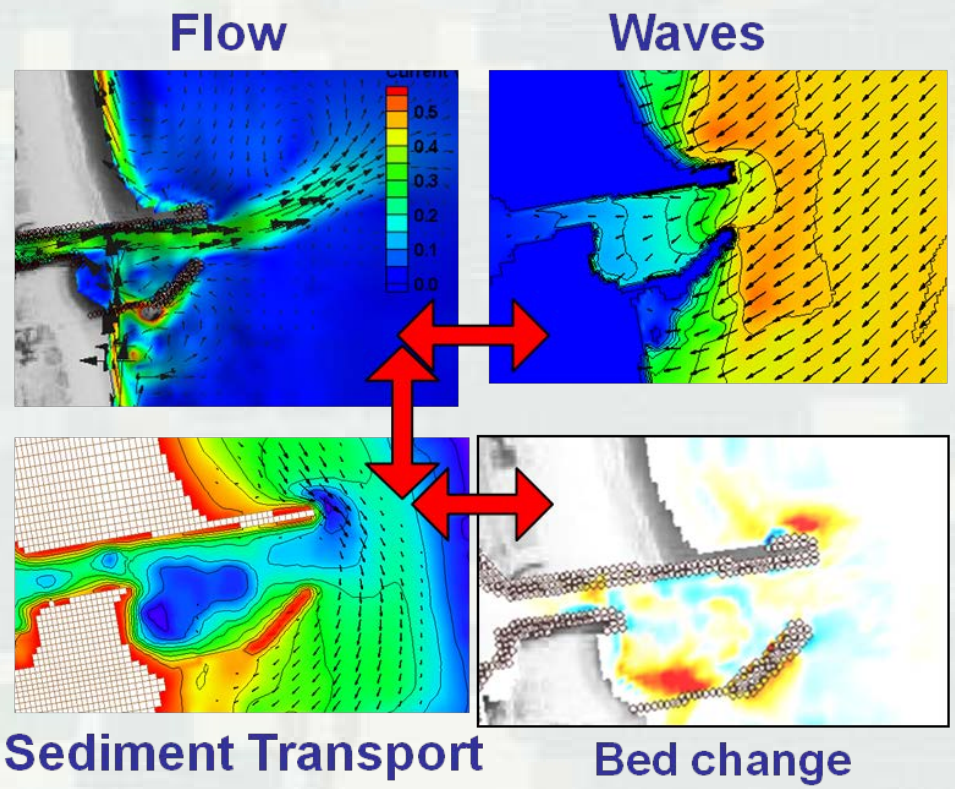




Residence Times

Summary

- Depth-integrated and wave-averaged
  - Hydrodynamic and
  - Sediment transport and morphology change models
- Coupled to
  - Spectral wave model
  - Roller model
- Model extensively verified and tested with analytical, laboratory, and field test cases
- Field applications demonstrate the model capability for engineering projects



Thank You
Questions?

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Coastal Inlets Research Program
http://www.cirp.usace.army.mil/

Coastal and Hydraulics Laboratory
http://chl.erdc.usace.army.mil/

Engineer Research and Development Center
http://www.erdc.usace.army.mil/

1D Scalar Transport

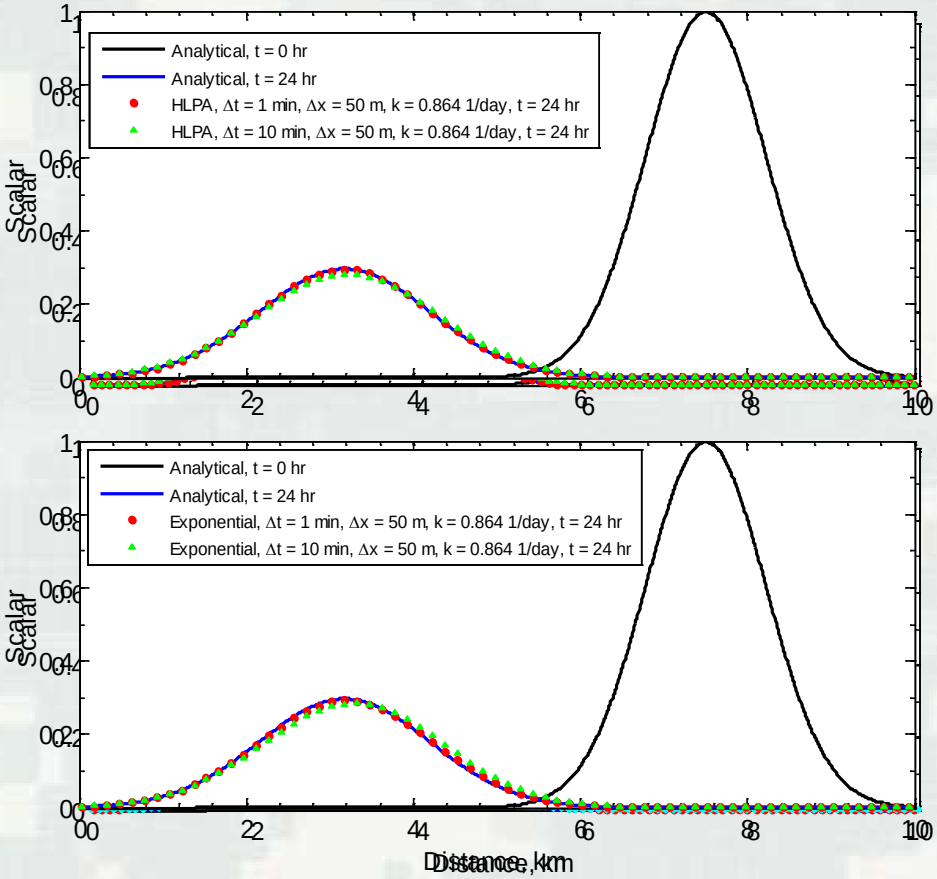
- Governing equation

$$\frac{\partial(h\phi)}{\partial t}+\frac{\partial(hU\phi)}{\partial x}=\frac{\partial}{\partial x}\left(\Gamma h\frac{\partial\phi}{\partial x}\right)-kh\phi$$

- Solution

$$\phi(x,t)=\frac{M}{2\sqrt{\pi(\Gamma t+C)}}\exp\left[-\frac{(x-x_0-Ut)^2}{4(\Gamma t+C)}-kt\right]$$

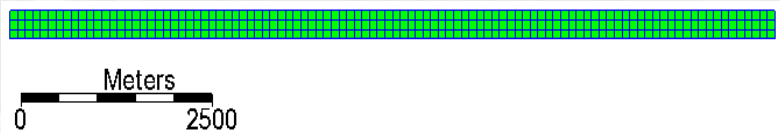
- Model Setup
  - Duration: 24 hrs
  - Ramp: 0.0 hrs
  - Time step: 1,10 min

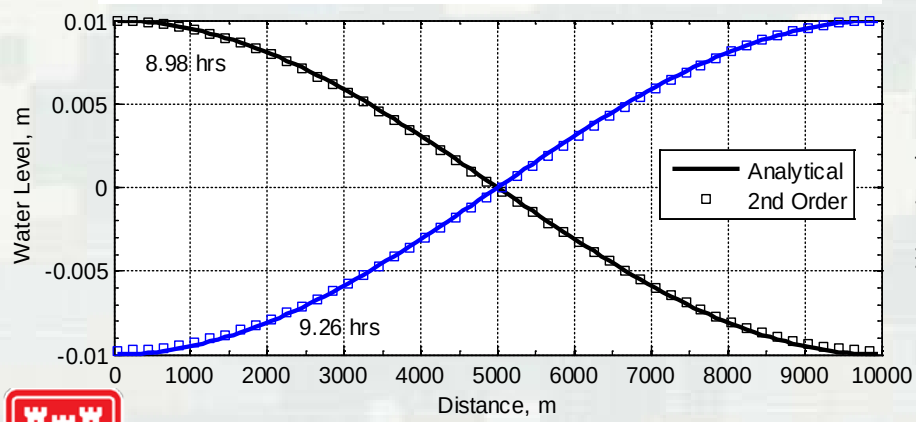


Advection, diffusion, and sink

Tidal Propagation in a Rectangular Basin

- No bottom or wall friction
- No advection
- No diffusion
- No Coriolis
- Duration 10 days
- Grid:





- Governing Equations

$$\frac{\partial \eta}{\partial t} + h\frac{\partial U}{\partial x} = 0 \qquad \frac{\partial U}{\partial t} = -g\frac{\partial \eta}{\partial x} \qquad \boxed{\frac{\partial^2 \eta}{\partial t^2} = gh\frac{\partial^2 \eta}{\partial x^2}}$$

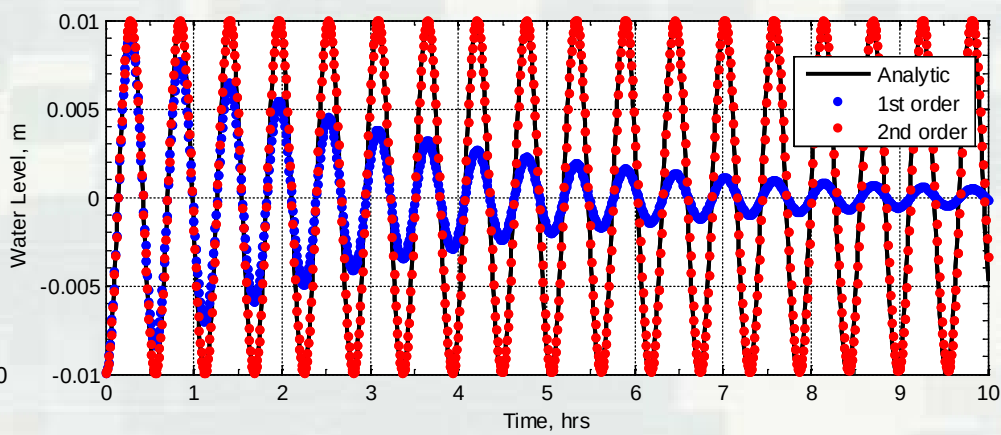
- Solution

$$\eta(x,t) = A\cos(kx)\exp(i\omega t)$$

- Temporal Scheme

$$\frac{\partial \phi}{\partial t} = \frac{(1+0.5\hat{\theta})\phi^{n+1} - (1+\hat{\theta})\phi^{n} + 0.5\hat{\theta}\phi^{n-1}}{\Delta t}$$

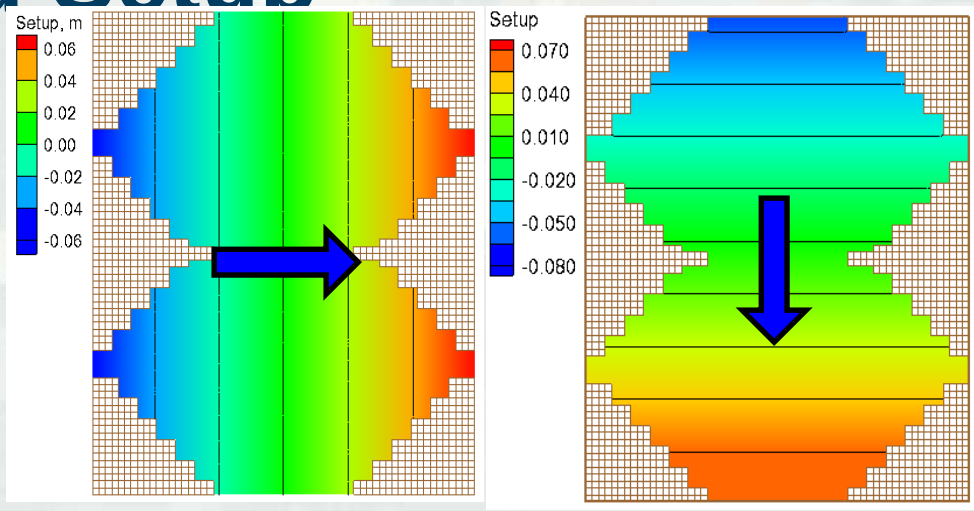
$$\hat{\theta} = \begin{cases} 0 \rightarrow \text{First Order} \\ 1 \rightarrow \text{Second Order} \end{cases}$$



Wind Setup

- Governing equation

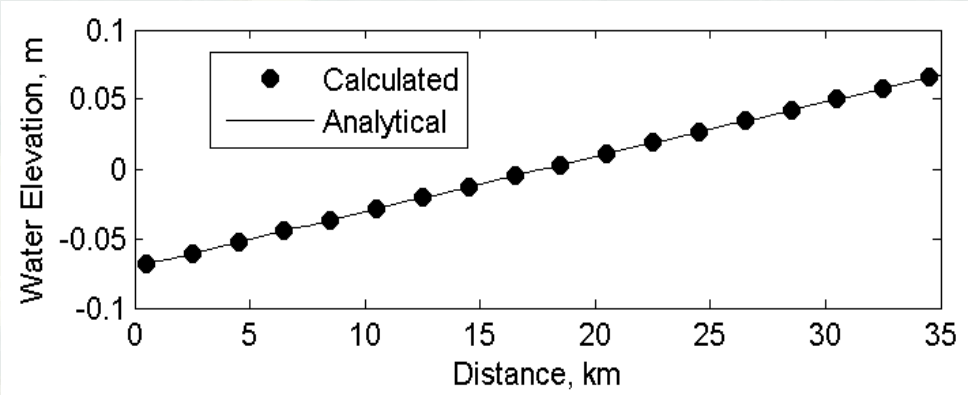
$$\rho g h \frac{\partial \eta}{\partial y} = \rho_a C_D |W| W$$



- Solution

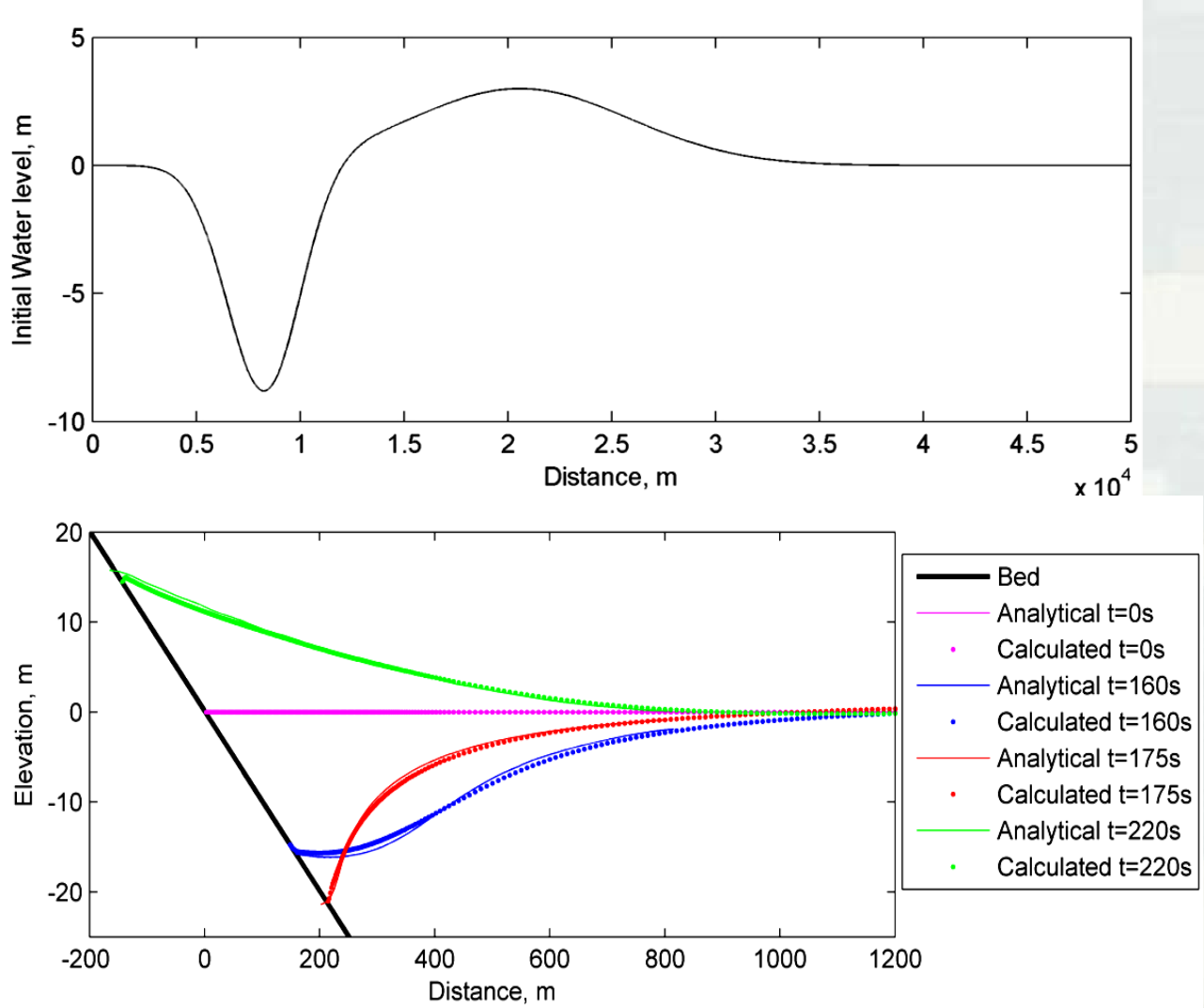
$$\eta = \sqrt{\frac{2\rho_a C_D |W| W}{\rho g}(y + C) + \zeta^2} - \zeta$$

- Model setup
  - Time step: 10 min
  - Duration: 48 hrs
  - Ramp: 3 hrs
  - Wind speed: 10 m/s



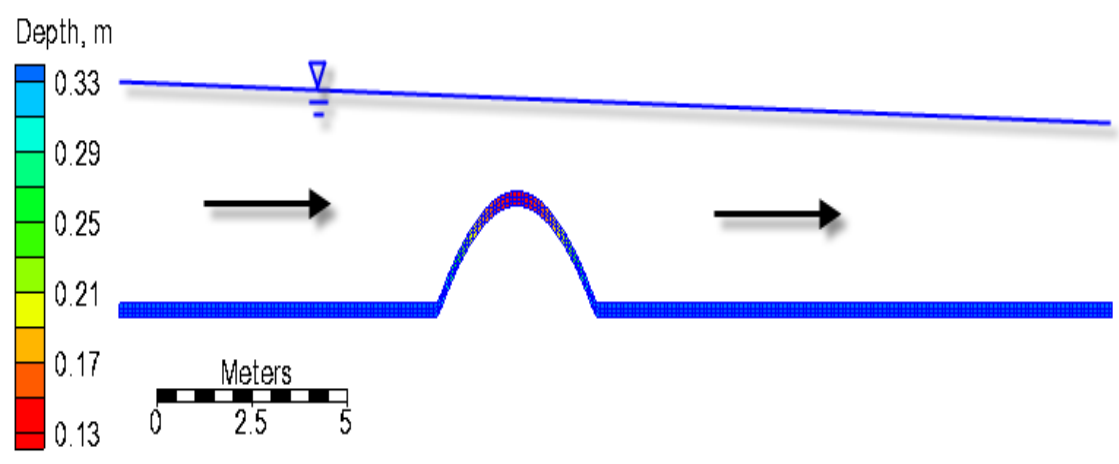
Long-wave Runup over a Planar Frictionless Slope

Parameter	Value
Time step	0.1 s
Simulation duration	360 s
Ramp duration	0.0 s
Wetting/drying depth	0.01 m
Wall friction	Off
Mixing terms	Off
Bottom friction	Off

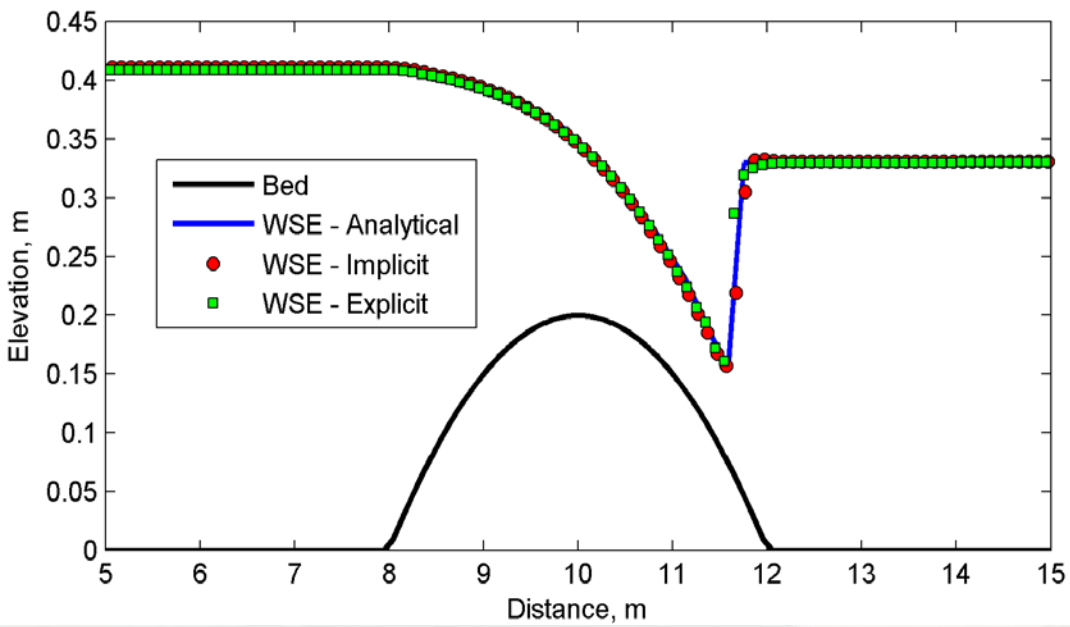


Transcritical Flow over a Bump

Parameter	Value
Flow discharge	0.18 m^3/s
Downstream water depth	0.33 m
Bottom Friction	None

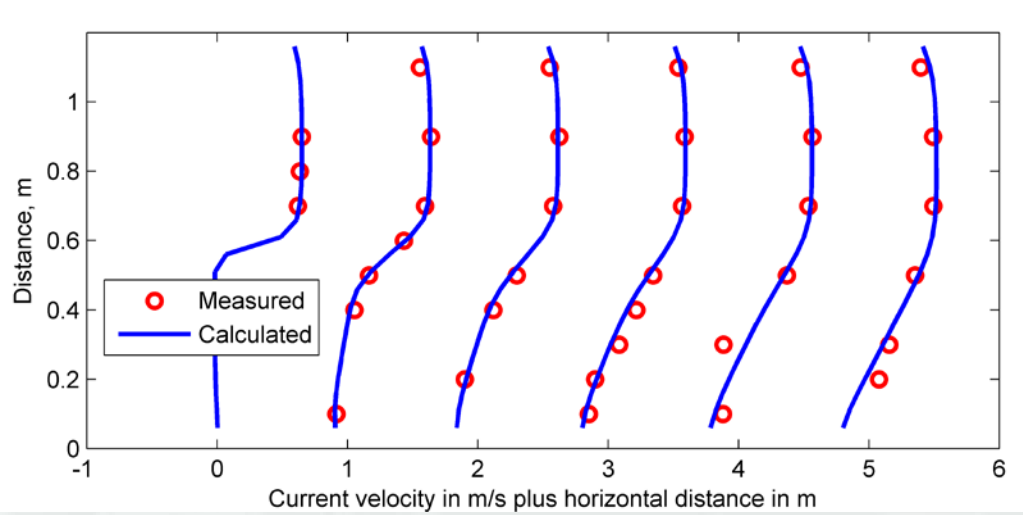


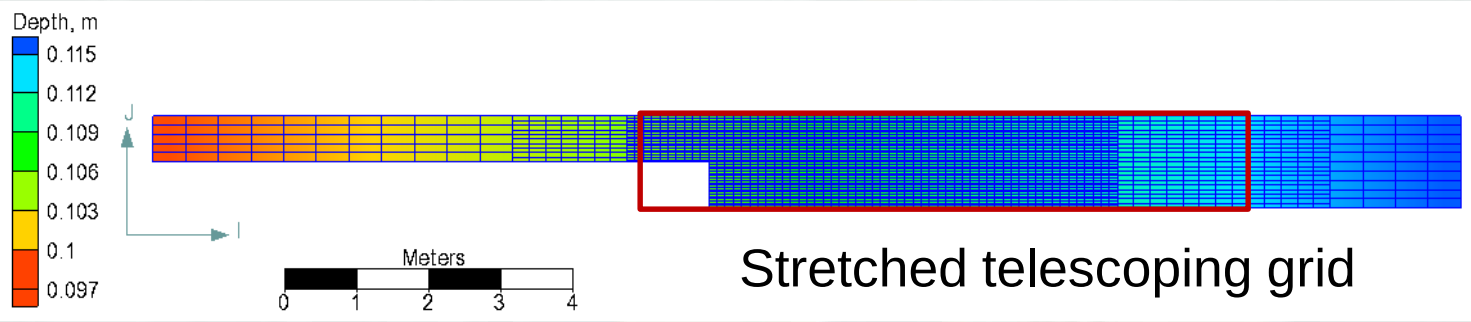
Parameter	Value
Time step	0.0781-20 s
Simulation duration	3 hr
Ramp duration	2.75 hr
Wall friction	0ff
Manning's coefficient	0.0 $s/m^{1/3}$



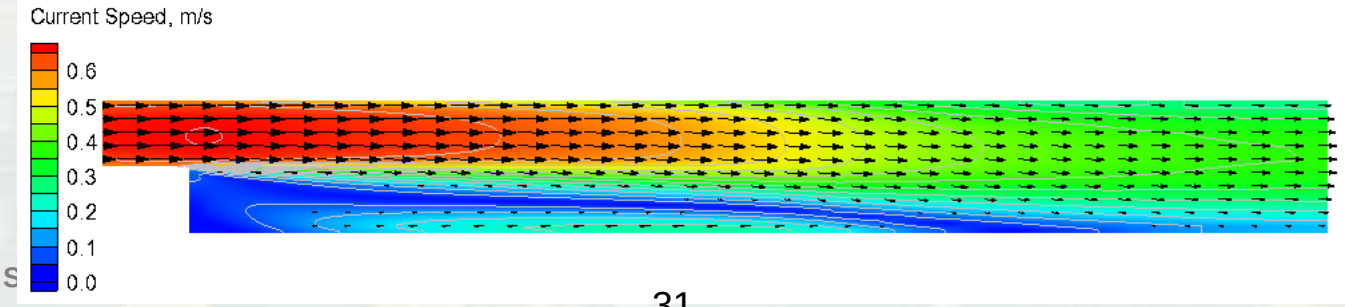
Rectangular Flume with a Sudden Expansion

- Time step: 30 sec
- Simulation duration: 1 hr
- Ramp duration: 30 min
- Manning's coefficient: 0.0
- Turbulence model: Mixing-length





Stretched telescoping grid



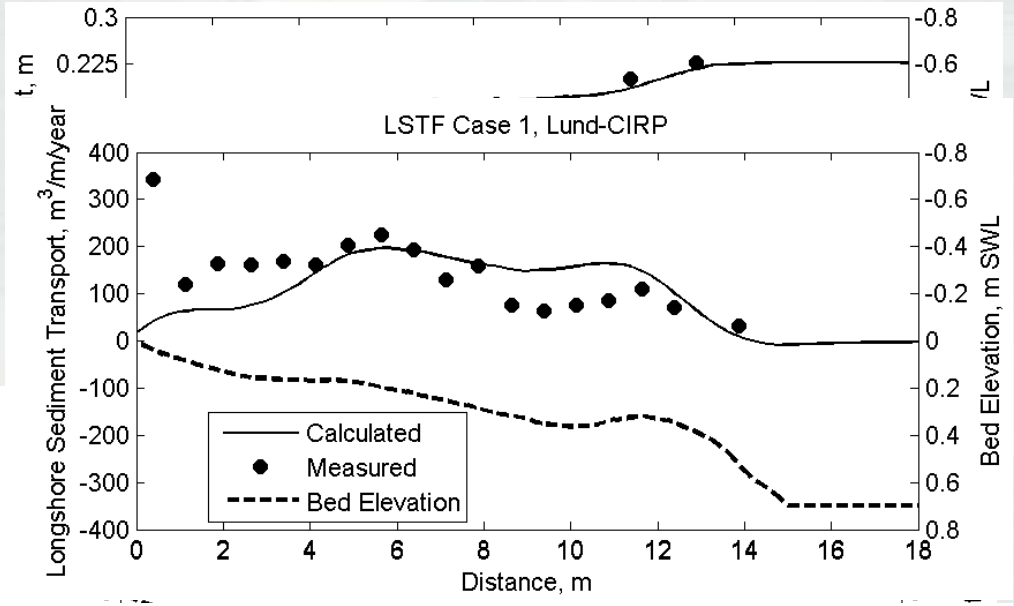
Large-Sediment Transport Facility

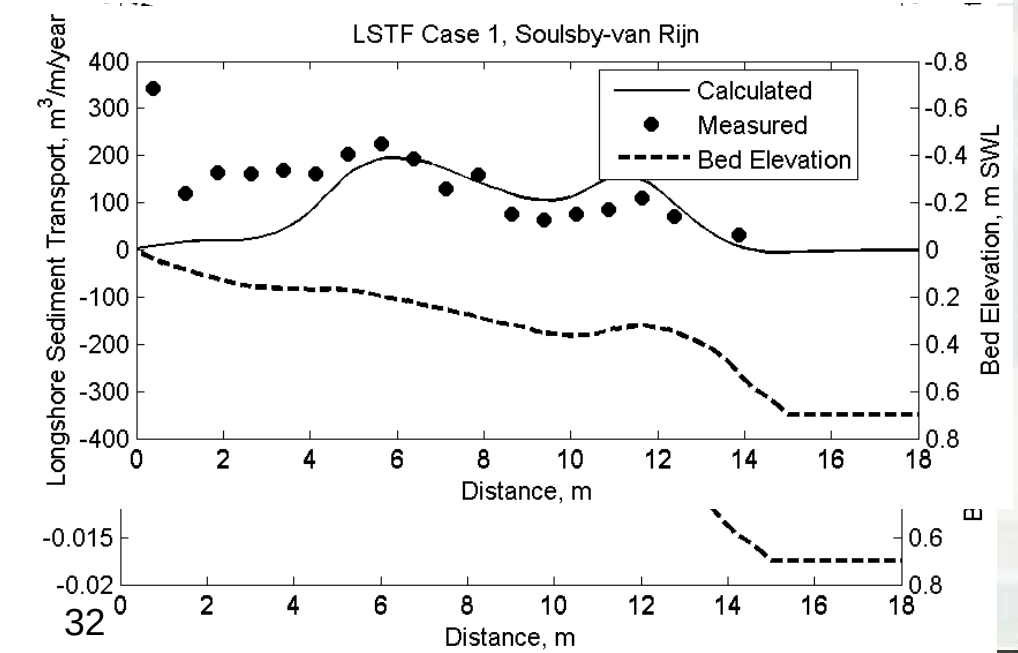
Flow and Sediment

- Time step: 1 min
- Simulation duration: 3 hr
- Ramp duration: 2.5 hr
- Grain size: 0.15 mm

Wave and Roller

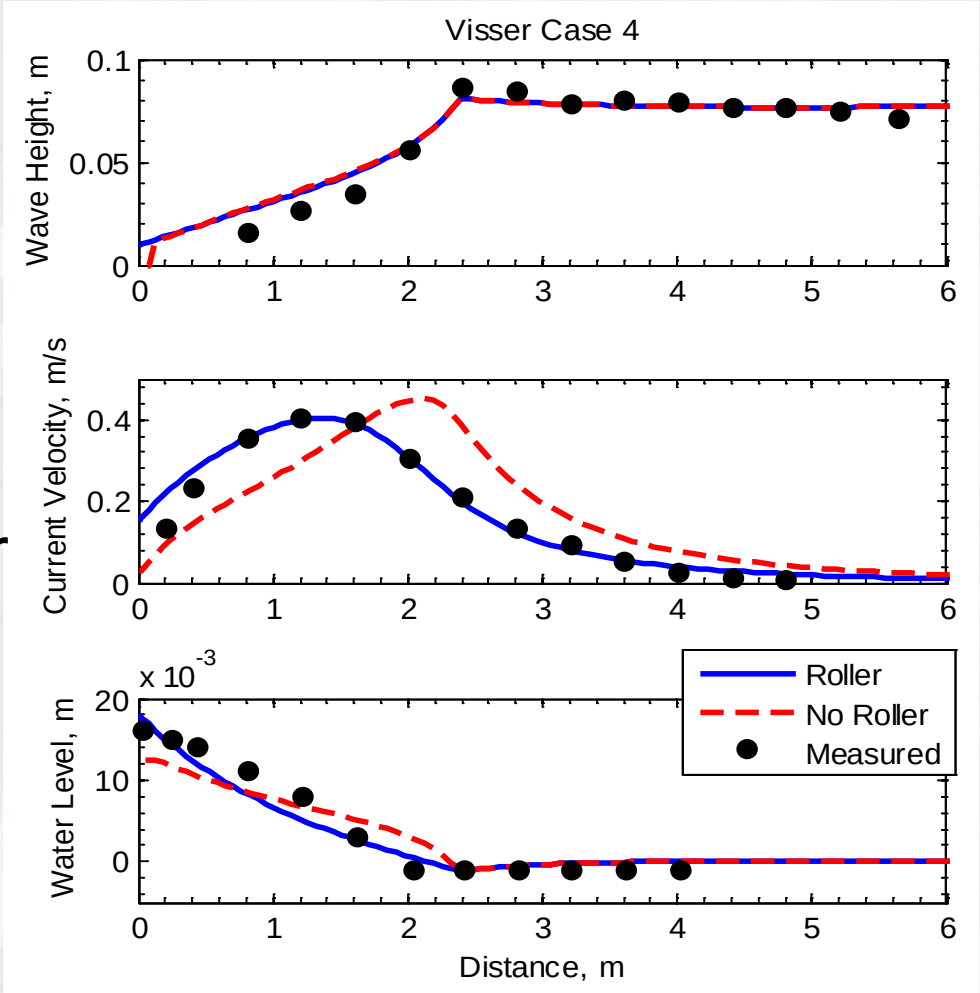
- Steering interval: 0.25 hr
- Wave breaking: Battjes an Janssen (1978)
- Roller dissipation: 0.05
- Roller efficiency: 0.5





Planar Sloping Beach with Oblique Incident Regular Waves

- Wave height: 0.078 m
- Wave period: 1.02 s
- Incident angle: 15.4º
- Time step: 1 min
- Simulation duration: 3 hr
- Ramp duration: 2 hr
- Steering interval: 20 min



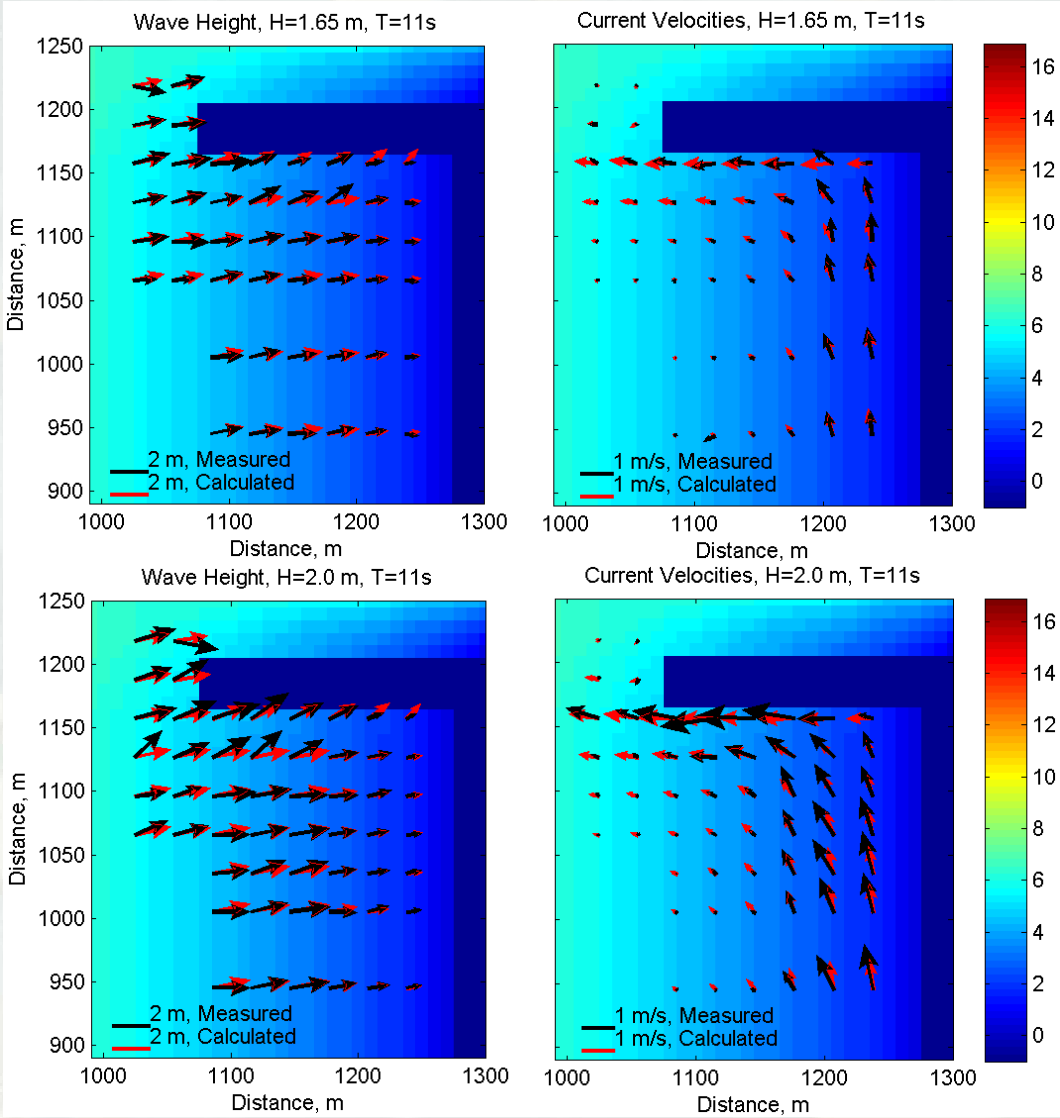
Laboratory Study of an Idealized Inlet

Flow

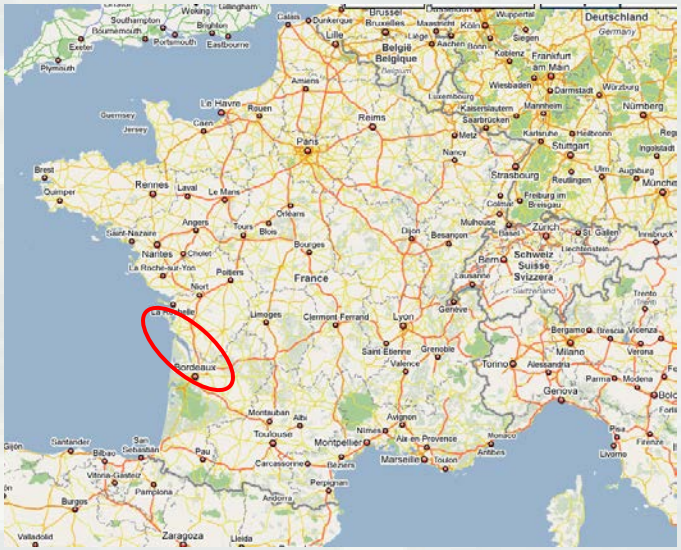
- Time step: 6 min
- Duration: 4 hrs
- Ramp: 3 hrs
- Manning's: 0.025 s/m$^{1/3}$

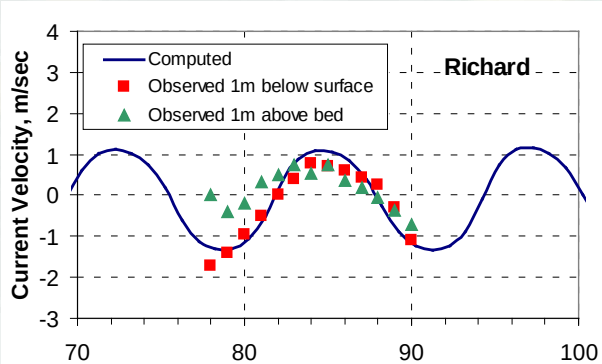
Wave

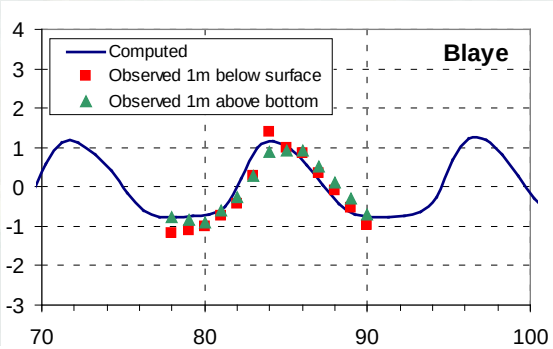
- Steering interval: 1 hr
- Roller efficiency: 1.0
- Roller dissipation: 0.05

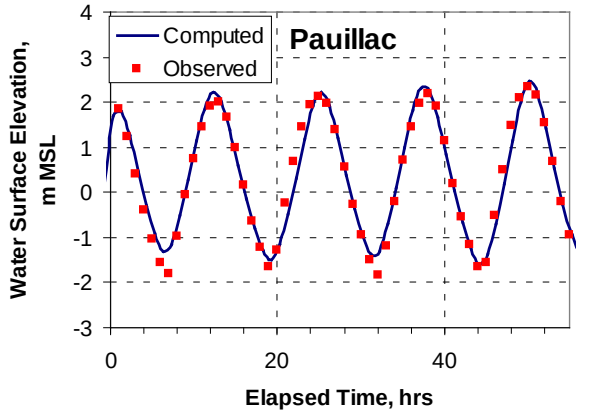


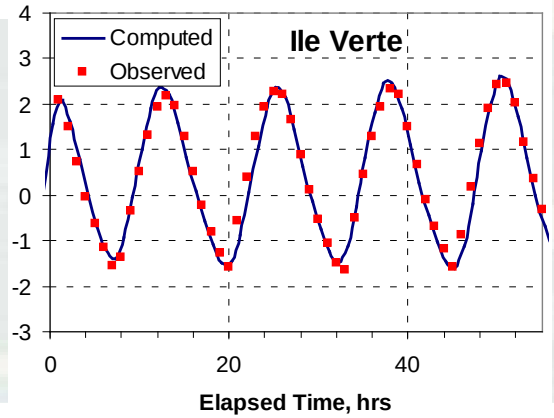
Gironde Estuary, FR

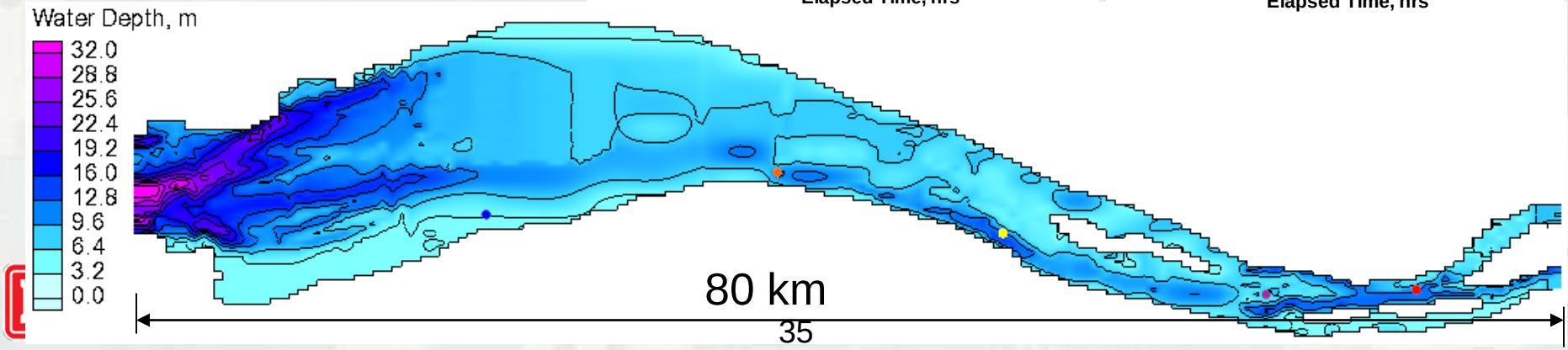












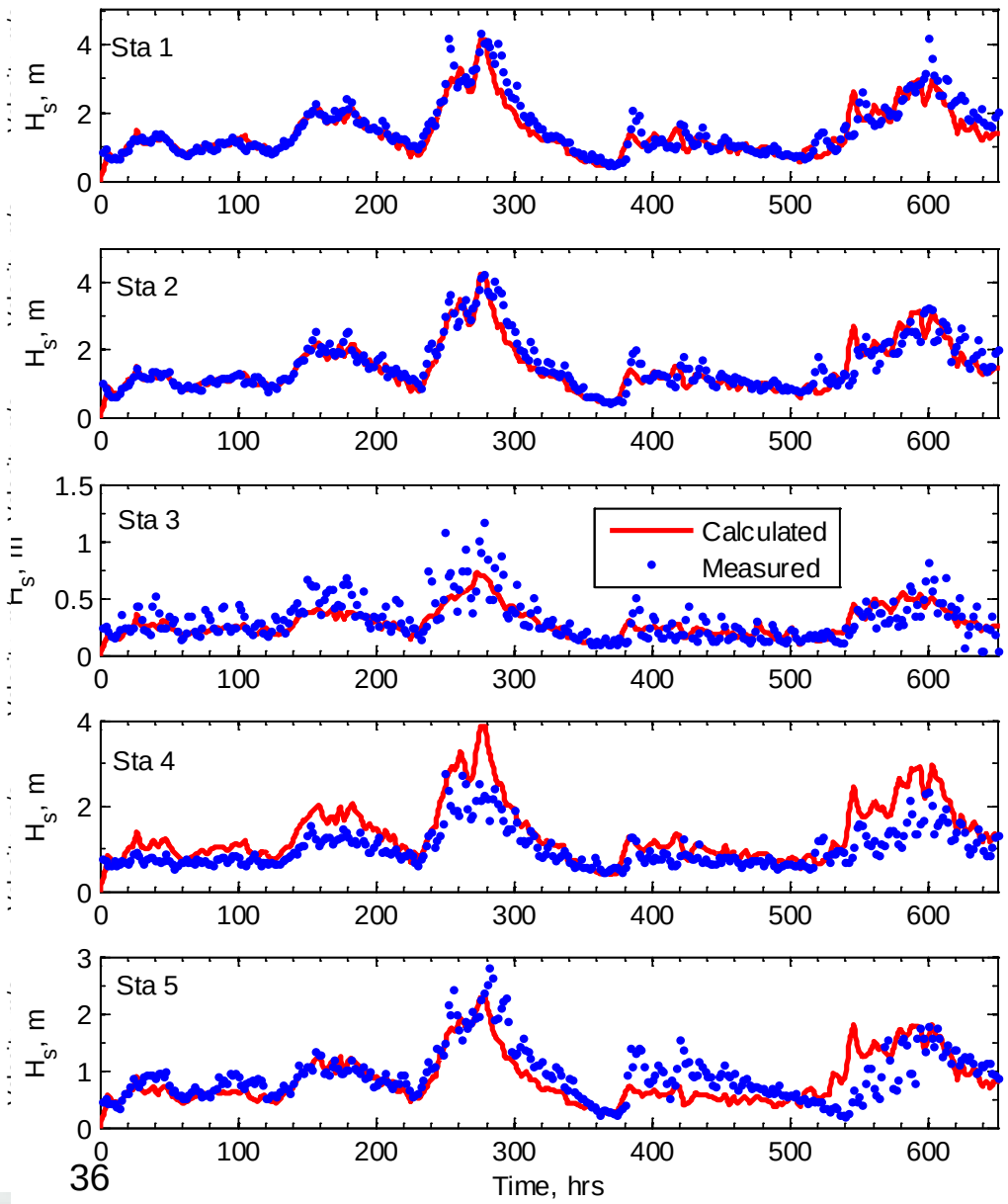
Grays Harbor, WA: 1999 Field Study

Flow Model

- Water levels from Sta 0
- Nonuniform Cartesian grid
  - ~67k cells
- Time steps:
  - Implicit: 15 min
  - Explicit: 0.5 sec
- Duration 27 days
- Manning's: 0.018 s/m$^{1/3}$

Wave Model

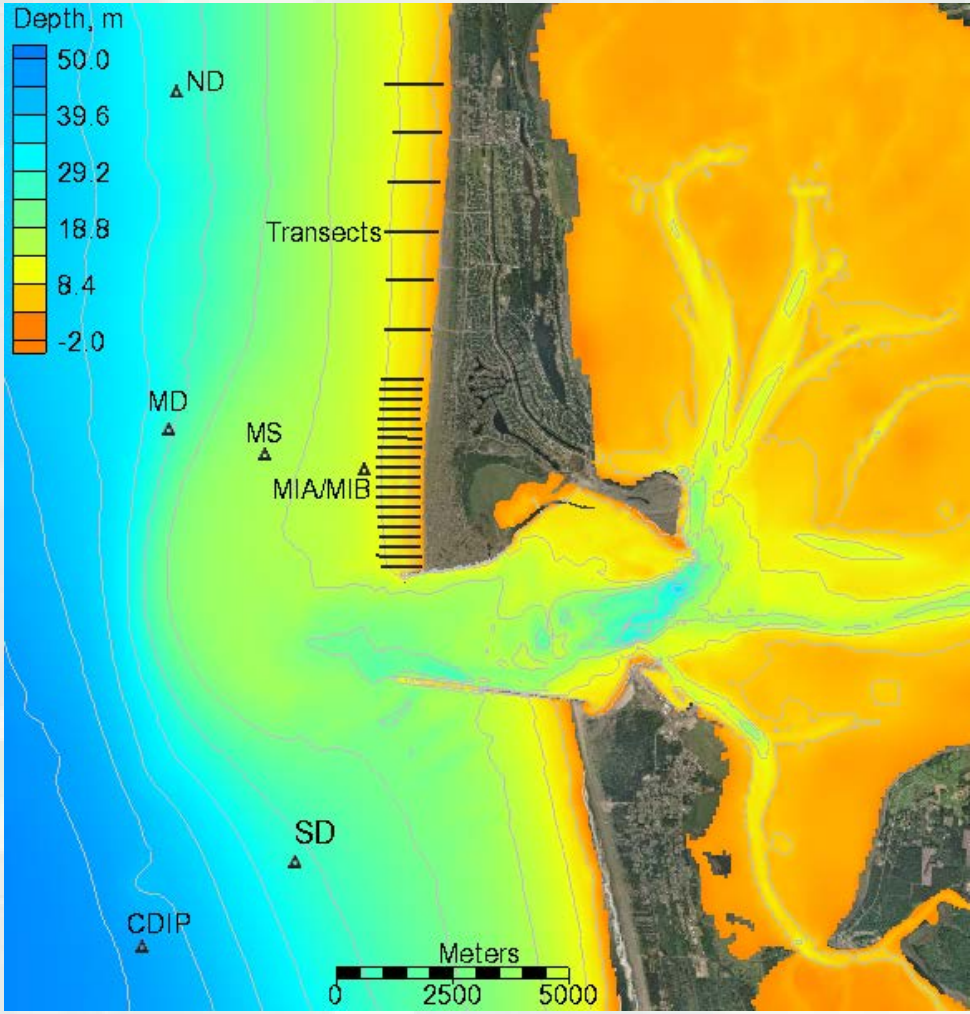
- Steering interval: 3 hr
- Waves from Buoy
- Same grid as flow model



BUILDING STRONG®

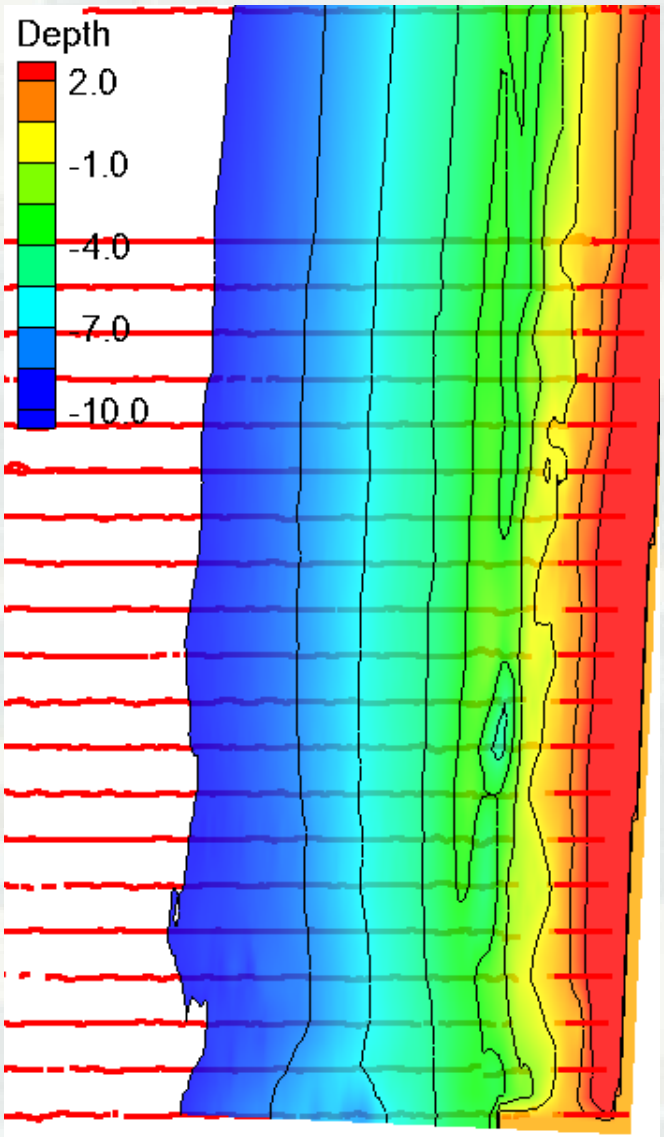
Grays Harbor, WA 2001 Field Study

- 6 Tripods deployed from May 5 to July 2001
- Weekly topo and monthly bathy surveys along 50-200 m spaced transects
- Grab sediment samples taken at tripod locations



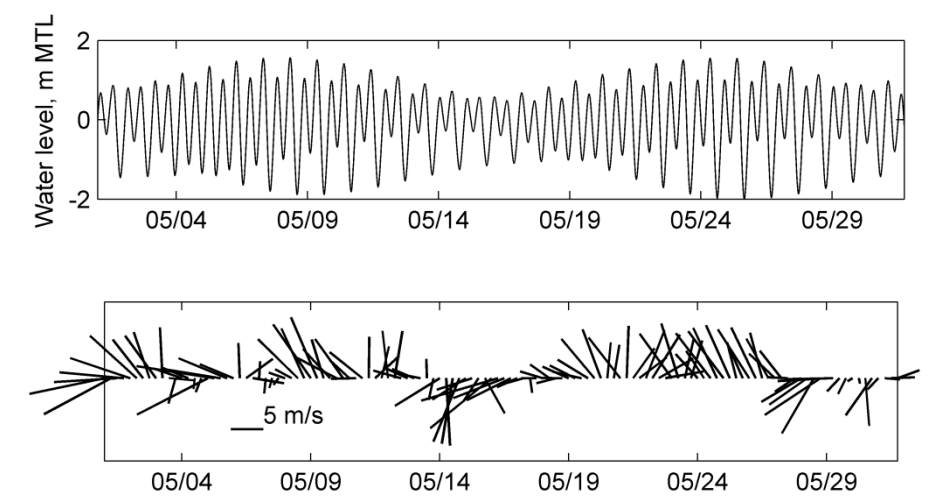
Field Conditions

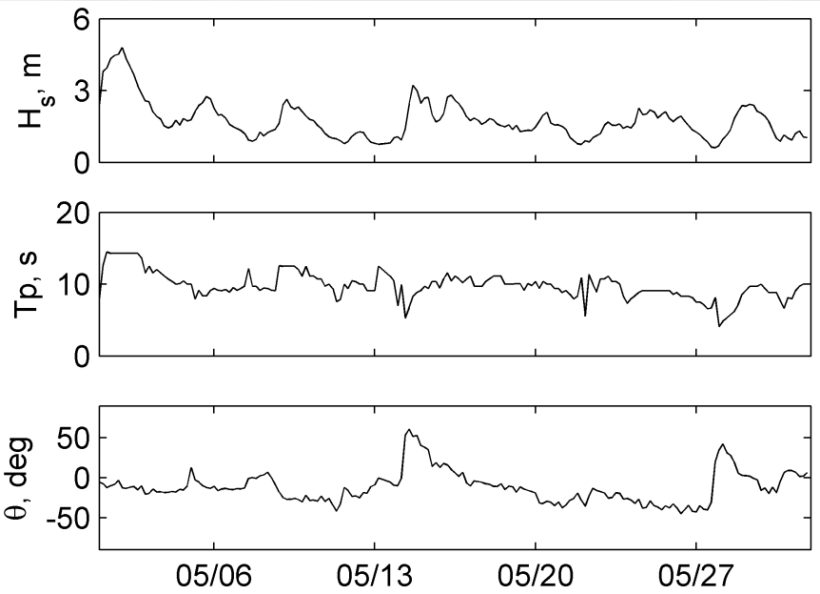
- Morphology transitioning from dissipative to intermediate planforms (Wright and Short 1984)
  - Onshore migration of a crecentric bar
  - Mini rips and mega cusps
  - Meandering longshore current
- Influence by inlet
  - Wave refraction over ebb shoal
  - Strong ebb/flood currents



Model Setup

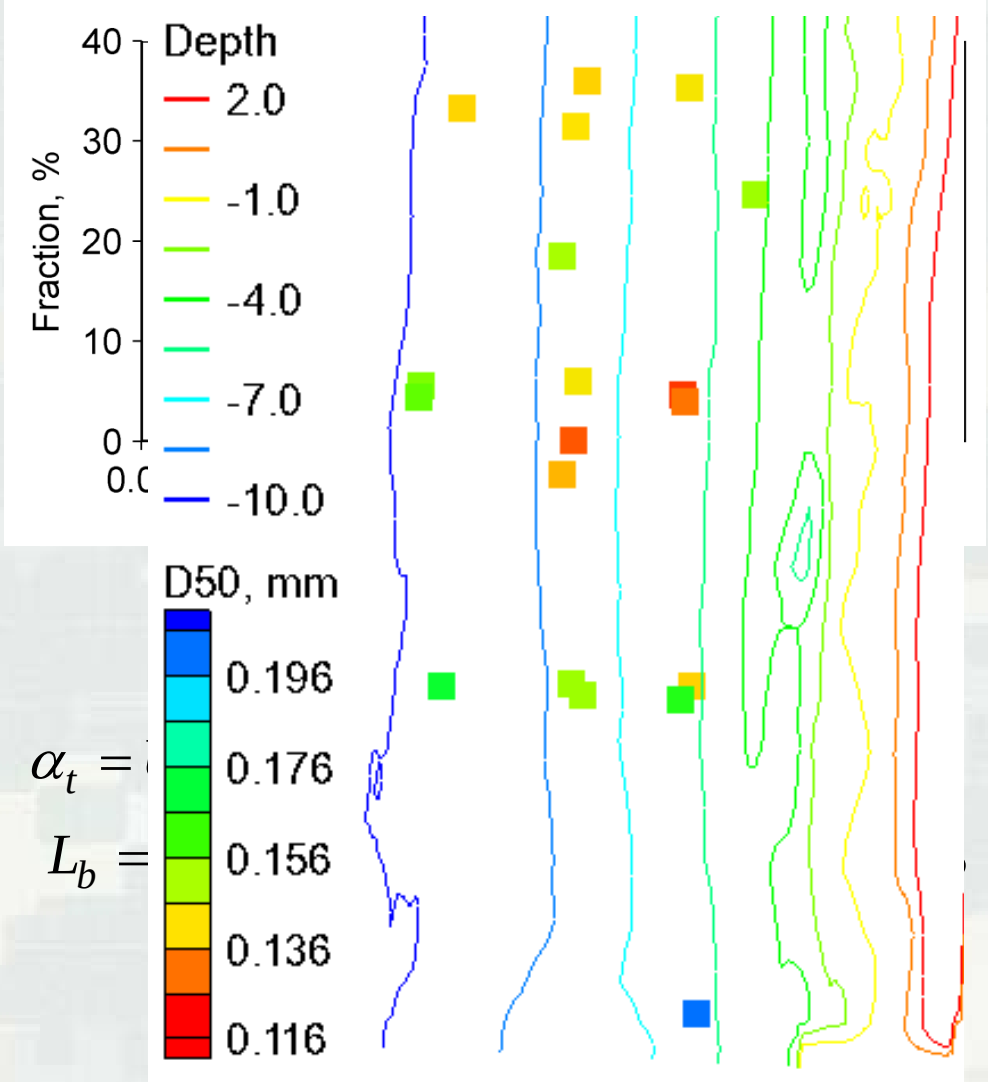
- Forcing
  - Tide from Westport Harbor (corrected phase)
  - Winds from NCDC Blended Sea Winds
  - Waves from CDIP buoy (42 m depth)
  - River flows from USGS
- Hydro and sediment transport
  - 10 min time step
  - Ramp of 5 days
- Waves
  - 2 hr steering interval
- 30 day simulation (~10 hrs PC)





Sediment Transport Setup

- Grain size distributions?
  - Expect coarser on bar and beach face and finer in trough
  - No before and after
- Spatially constant initial grain size distribution
- Lund-CIRP transport formula
- Bed porosity = 0.3
- Adaptation coefficient
- 10 bed layers
- Initial thickness of second layer and below = 0.5 m

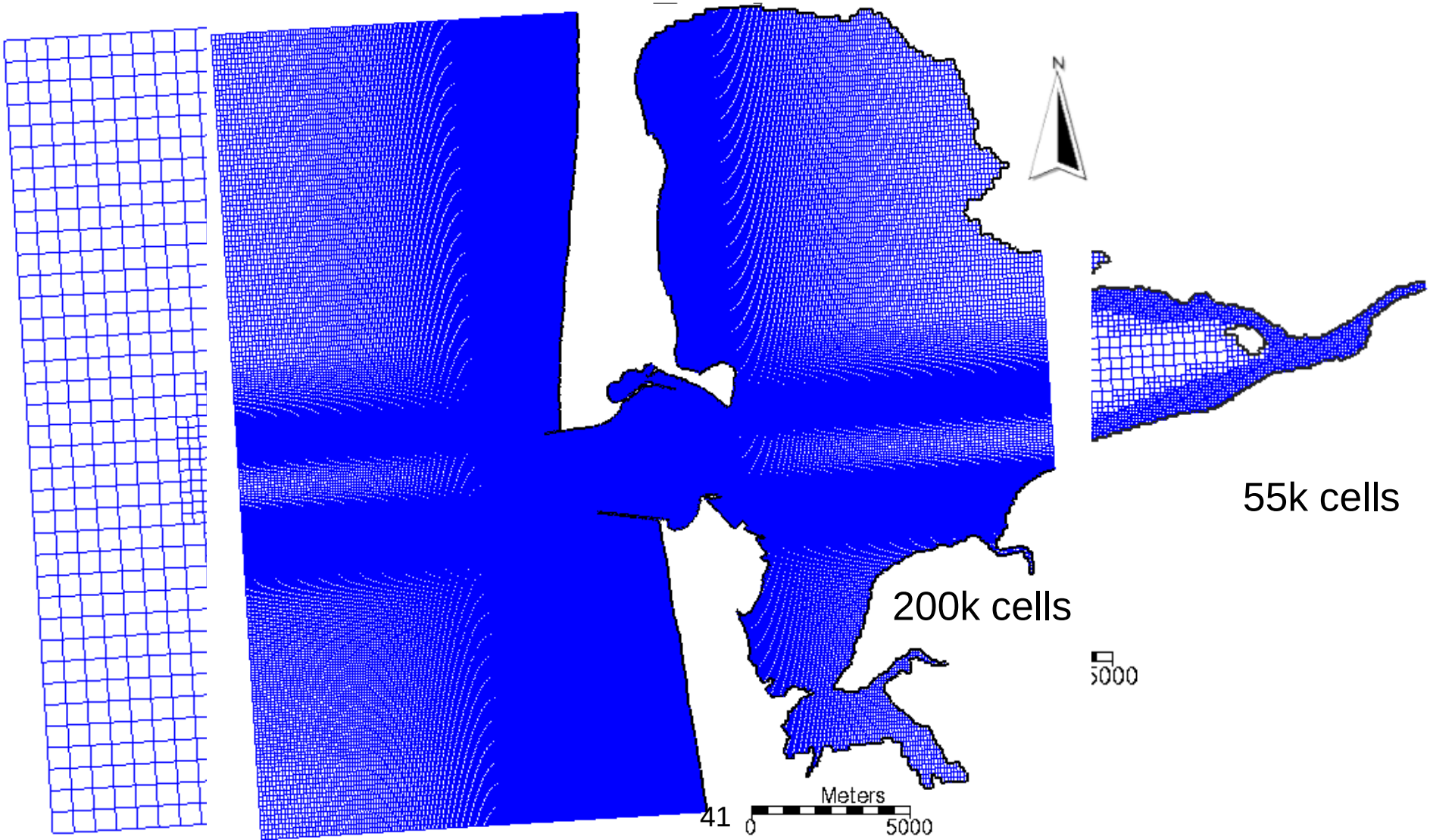


$\alpha_t =$

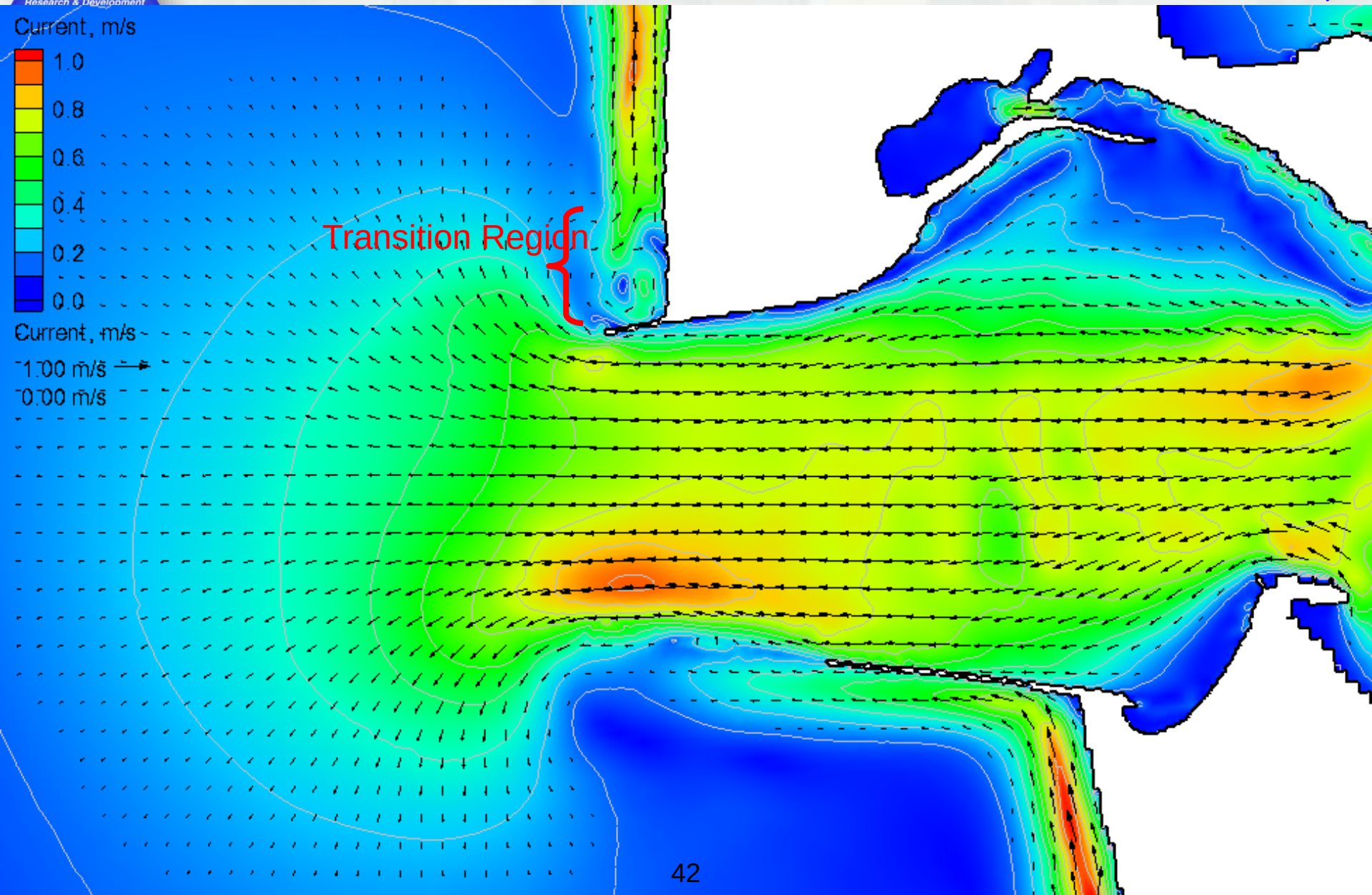
$L_b =$

Computational Grids

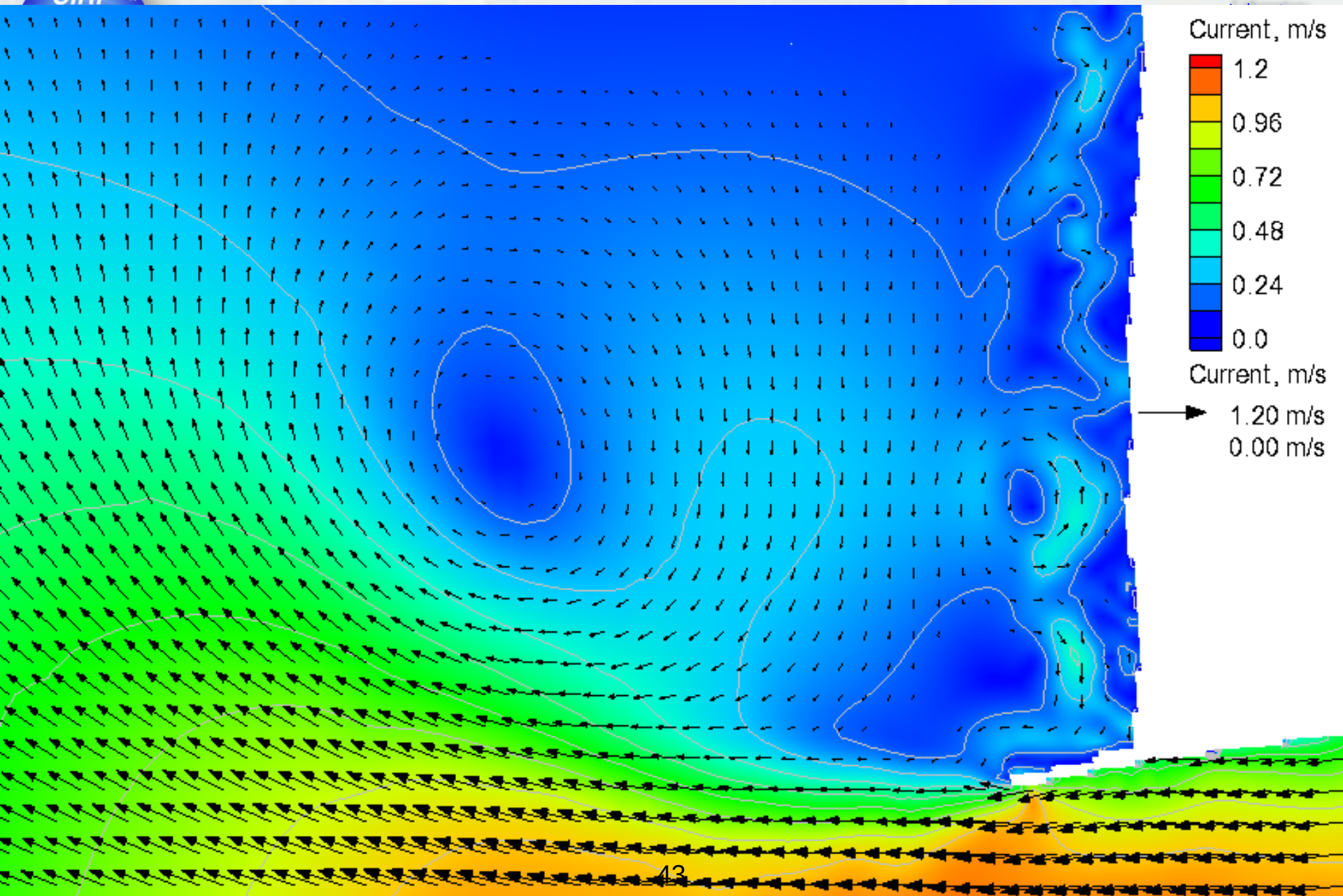
CMS-Wave grid



Current velocities (May 14, 2001)

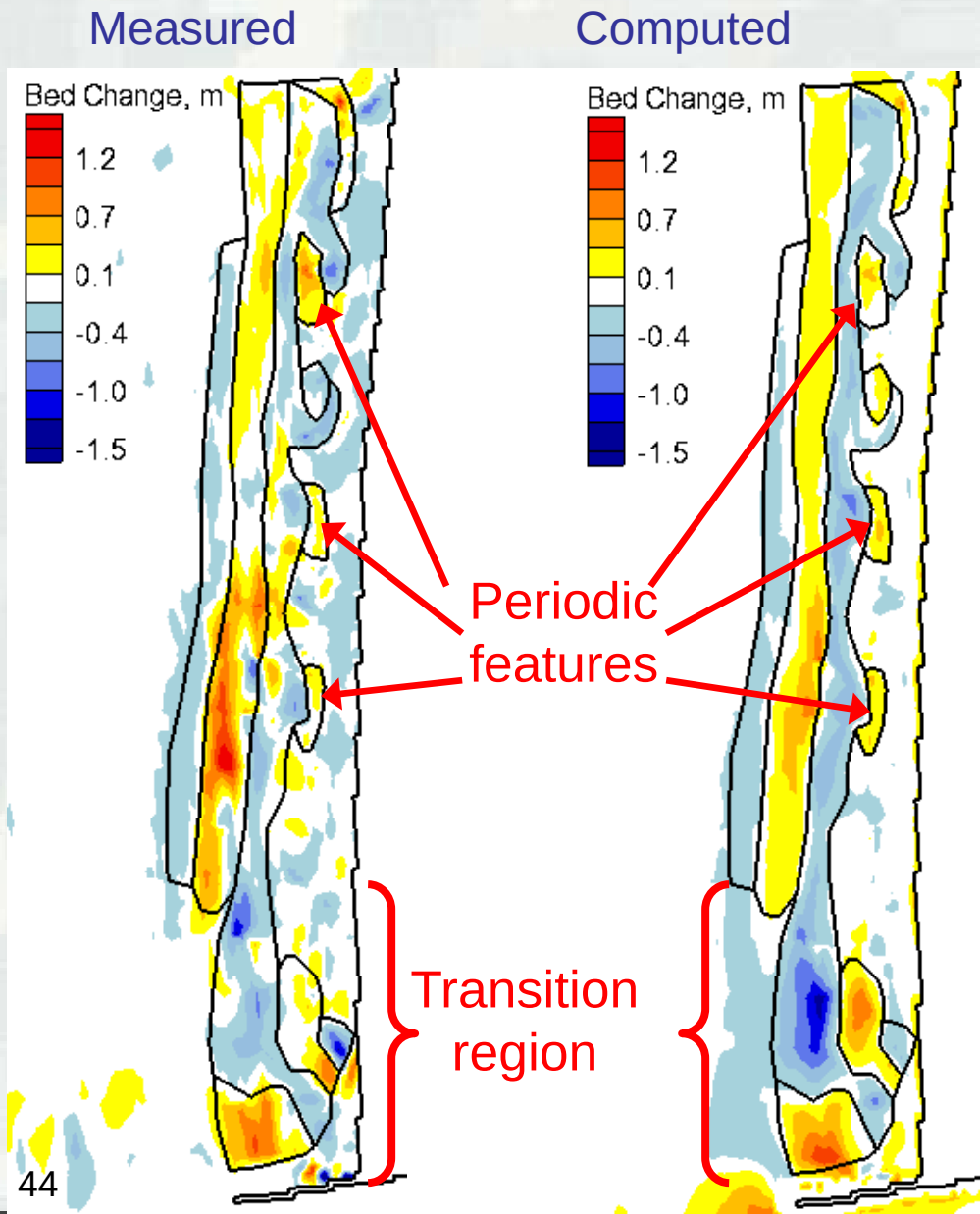


Current velocities (May 6, 2011)

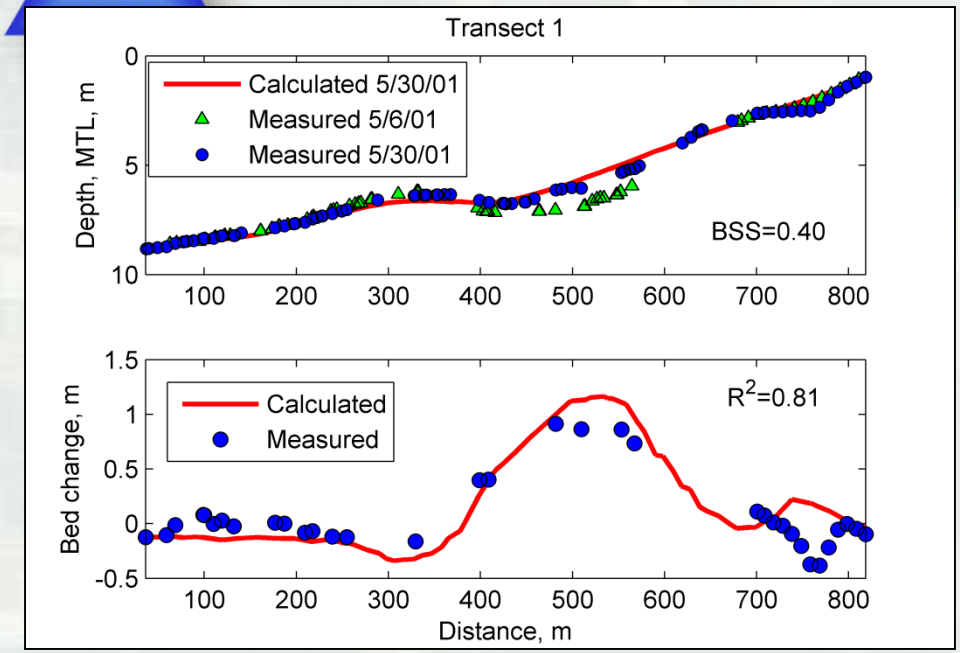


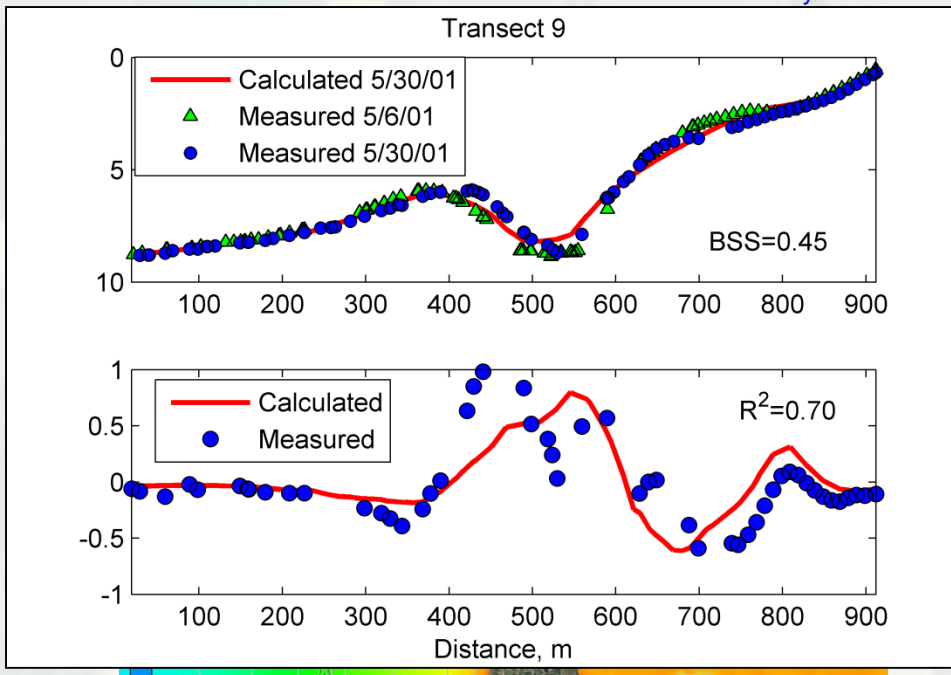
Results - Bed Change

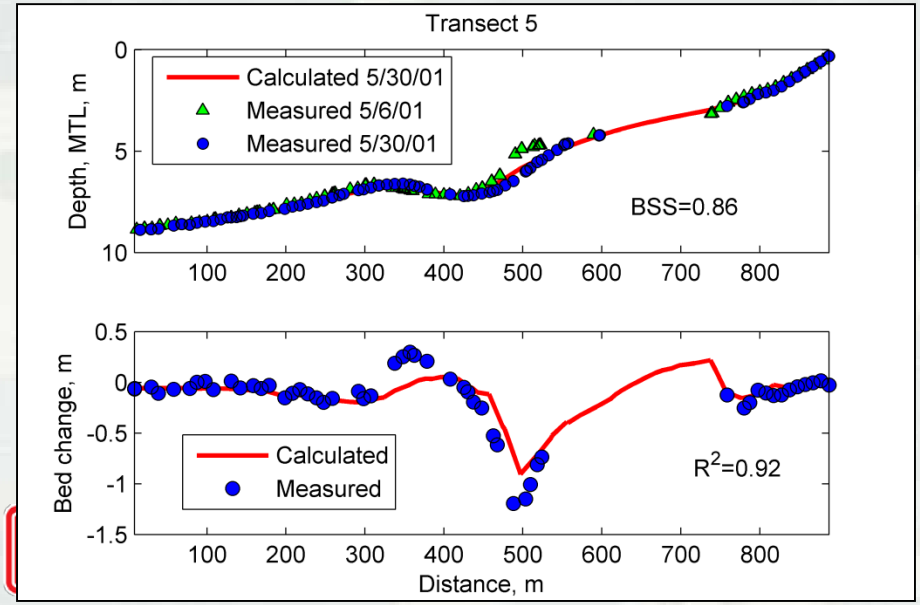
- Areas of calculated deposition and erosion are highlighted with black polygons
- Similar erosional and depositional trends
  - Erosion of outer bar
  - Deposition at inner bar face
  - Erosion of inner trough face
- Measured bed change shows more variability

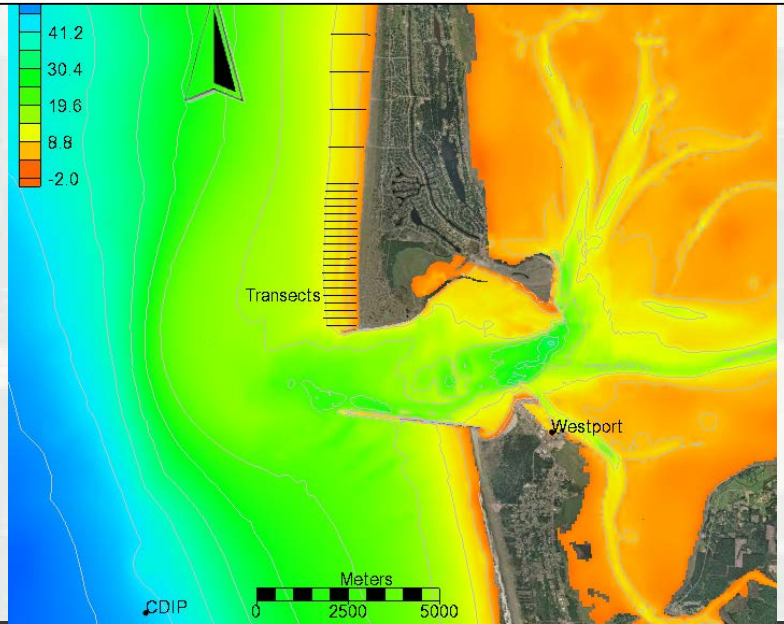


Transects

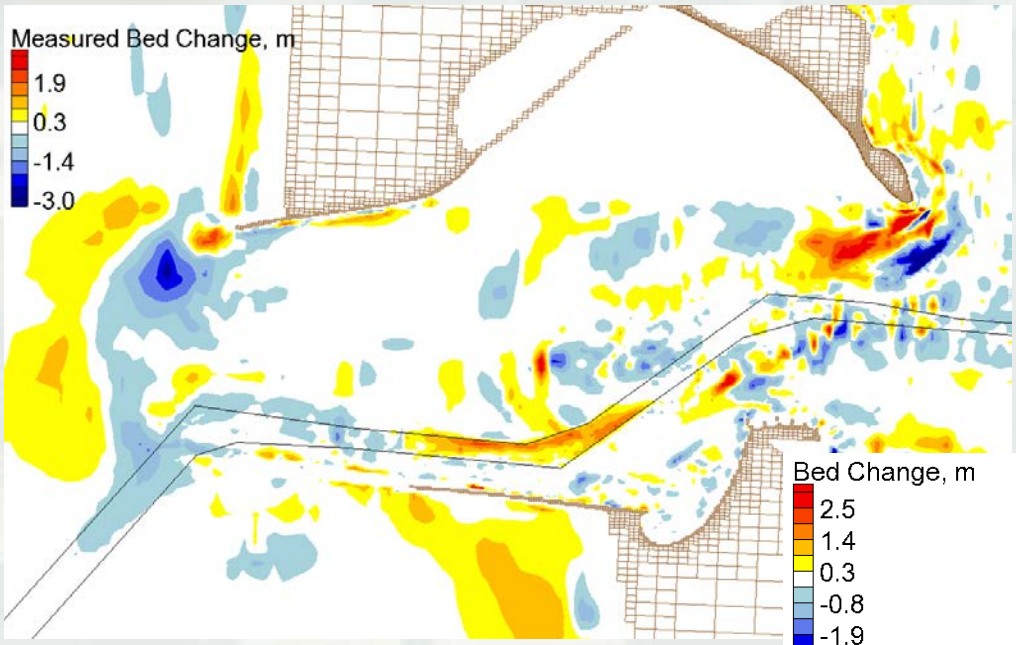

Transect 1
Calculated 5/30/01
Measured 5/6/01
Measured 5/30/01
BSS=0.40
Depth, MTL, m
Calculated
Measured
R^2=0.81
Bed change, m
Distance, m

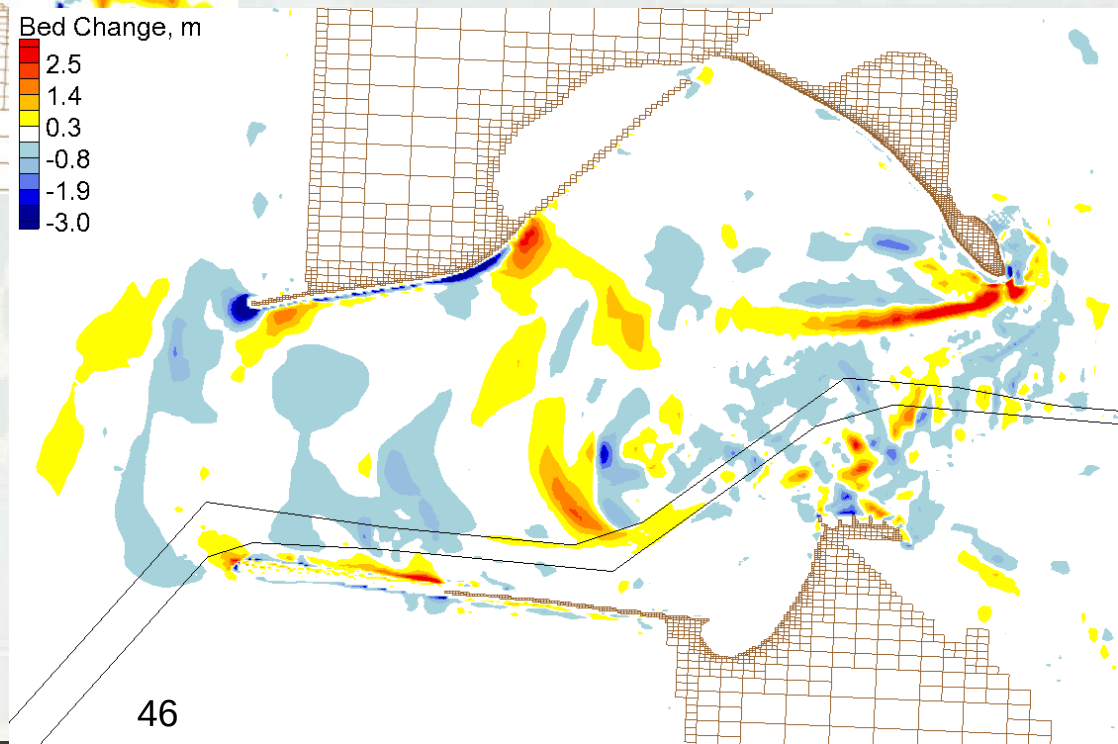

Transect 9
Calculated 5/30/01
Measured 5/6/01
Measured 5/30/01
BSS=0.45
Calculated
Measured
R^2=0.70
Distance, m


Transect 5
Calculated 5/30/01
Measured 5/6/01
Measured 5/30/01
BSS=0.86
Depth, MTL, m
Calculated
Measured
R^2=0.92
Bed change, m
Distance, m


41.2
30.4
19.6
8.8
-2.0
Transects
Westport
CDIP
Meters
0
2500
5000

“9-month” Bed Change



Measured

Calculated