Verification and Validation of HEC-RAS

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Definitions

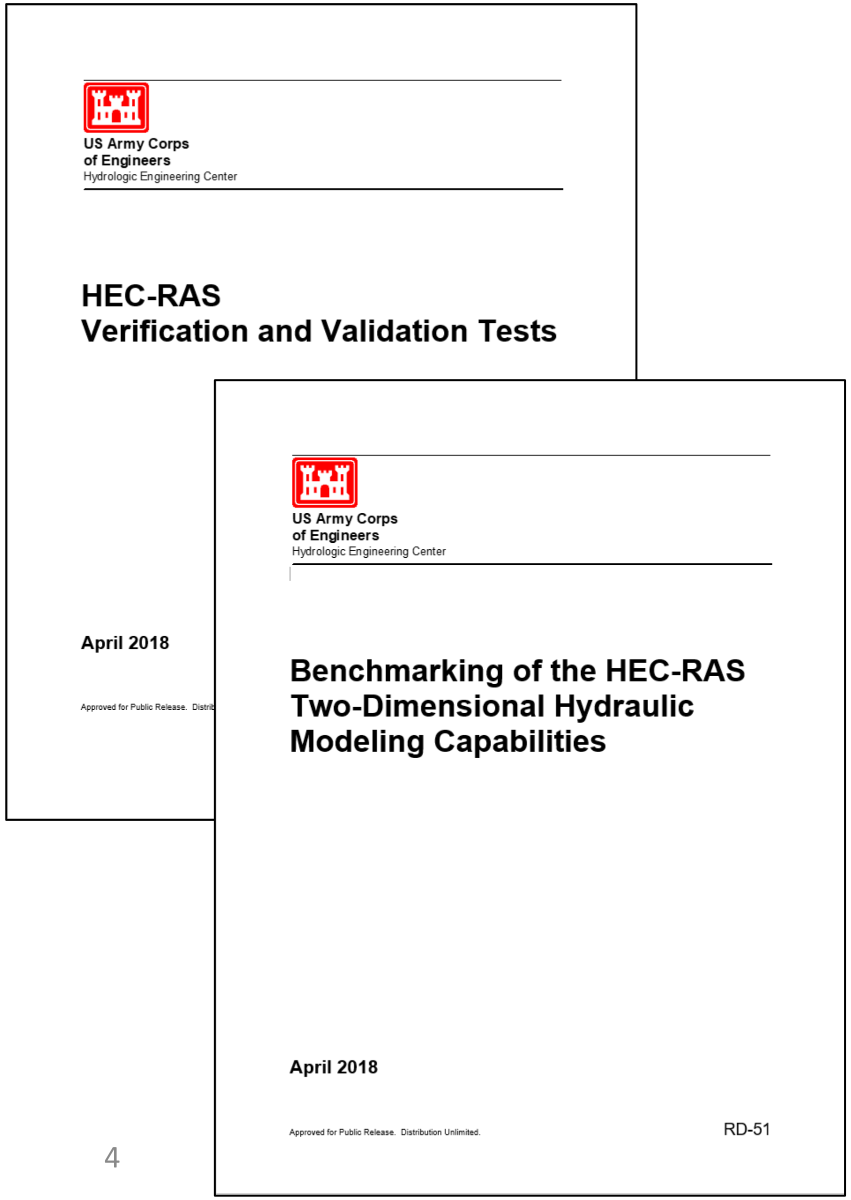
- Independent Procedures or Processes:

1. Verification:
   - Are the equations being solved correctly?
   - Does the software do what it was designed to do?
2. Validation:
   - Do the equations represent the physical system?
   - Does the software meet the needs of the user?

HEC-RAS Verification & Validation

- Categories:
  - 1D Steady Flow
  - 1D/2D Unsteady Flow
  - 1D/2D Non-Newtonian Flow
  - 1D/2D Sediment Transport
- Test Case Types:
  - Analytical and Textbook data sets
  - Laboratory experiments
  - Field

Research Documents 51 and 52


US Army Corps
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HEC-RAS
Verification and Validation Tests

April 2018

Approved for Public Release. Distrib

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Benchmarking of the HEC-RAS
Two-Dimensional Hydraulic
Modeling Capabilities

April 2018

Approved for Public Release. Distribution Unlimited.

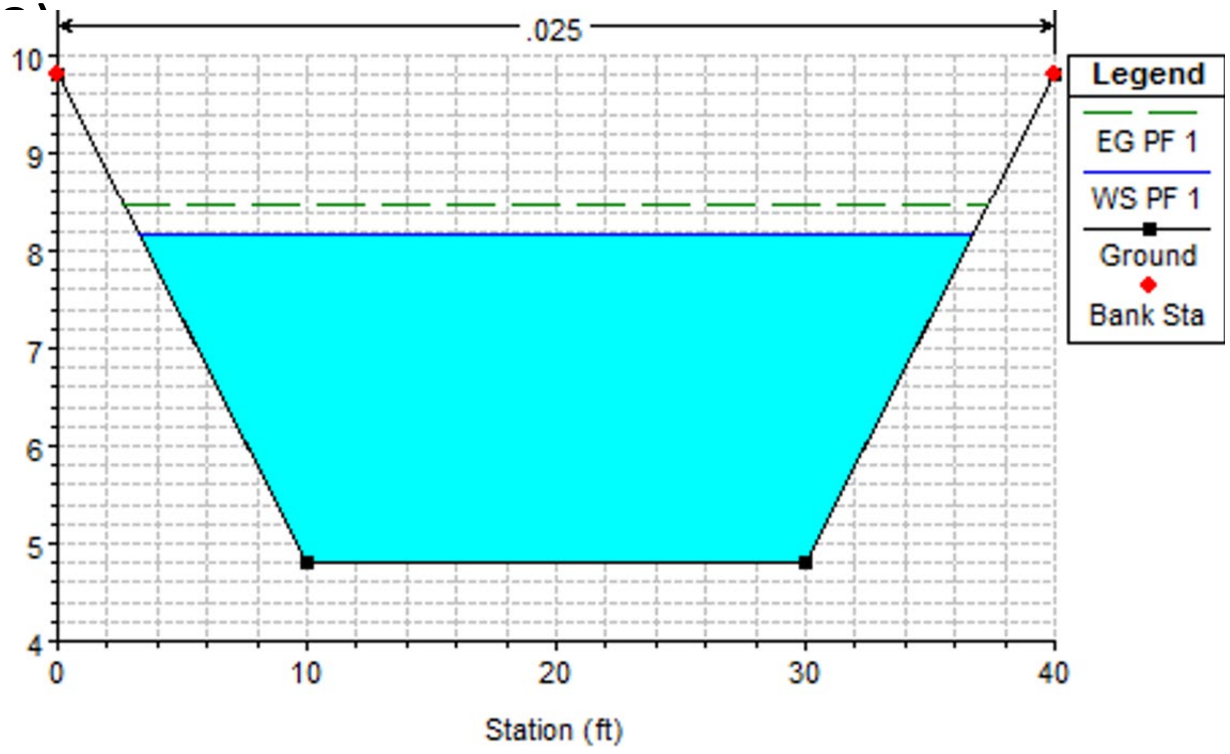
RD-51

- RD-51
  - 2D Benchmark tests developed by UK's Joint DEFRA (Department of Environmental Flood and Rural Affairs) Environment Agency
  - No analytical solutions or observed data!
- RD-52
  - 1D and 2D Verification and Validation tests
- Available from
  - https://www.hec.usace.army.mil/software/hec-ras/documentation.aspx

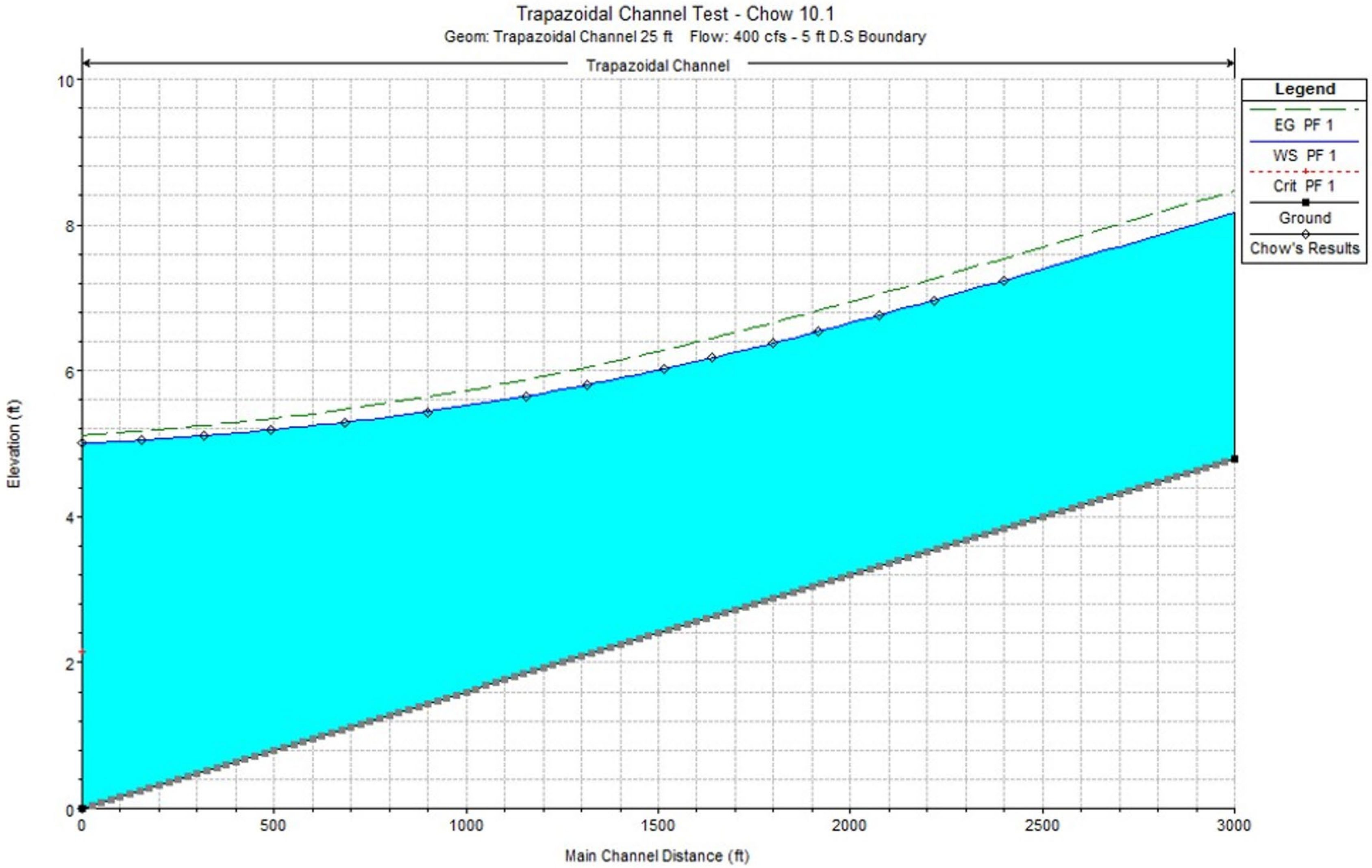
Verification: 1D Backwater in Trapezoidal Channel

- Analytical Solution from Chow (19
- Problem Description

Parameter	Value
Bottom width, b (ft)	20
Side slopes (H:V)	2:1
Bed slope	0.0016
Manning's n	0.025
Flow rate (cfs)	400
Downstream Stage (ft)	5.0

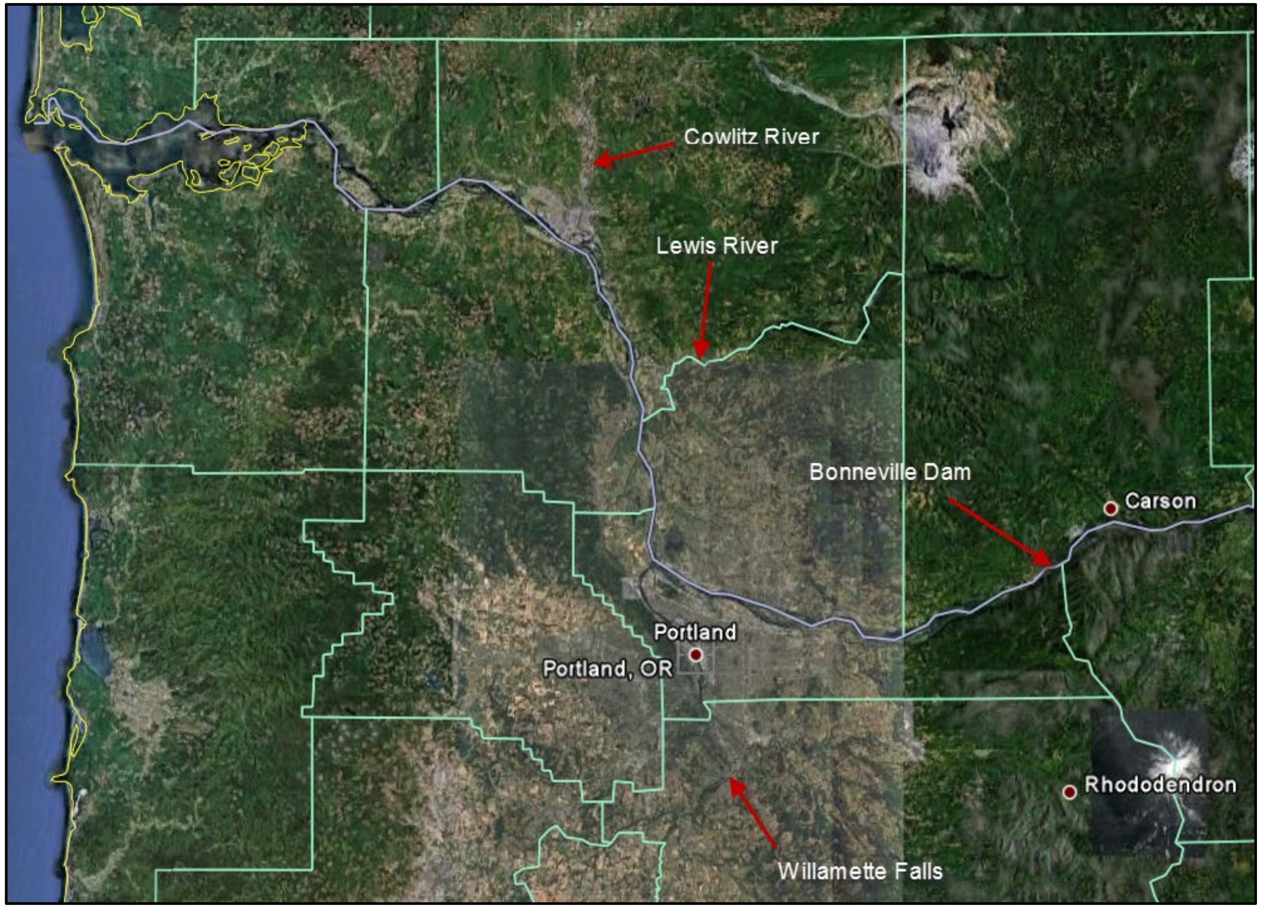


Results: 1D Backwater



Validation: Lower Columbia River

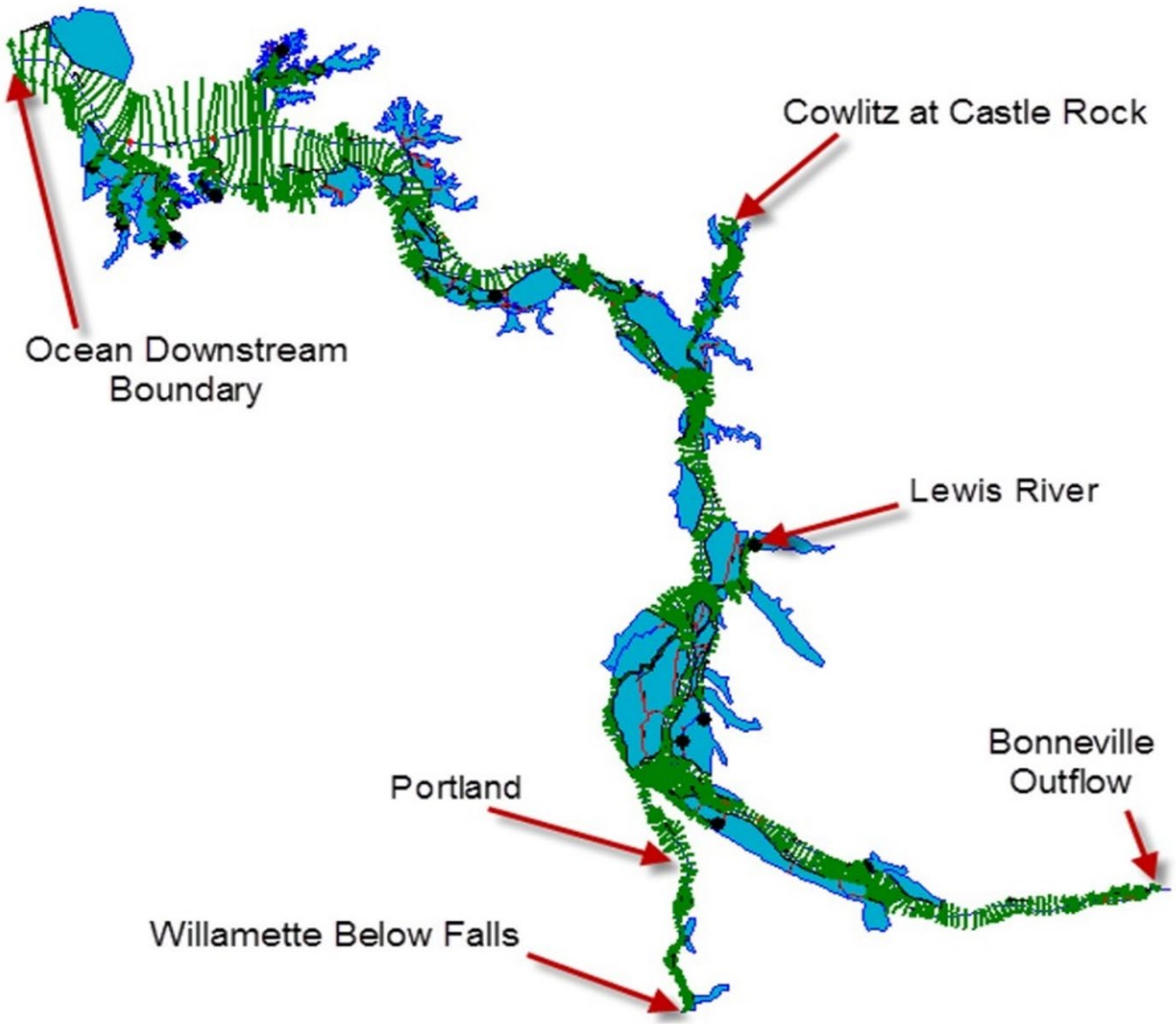
- Evaluation of flood risks in the Columbia River and tributaries by reservoir operations
- Purpose was to predict 0.2% annual exceedance (500-year) event



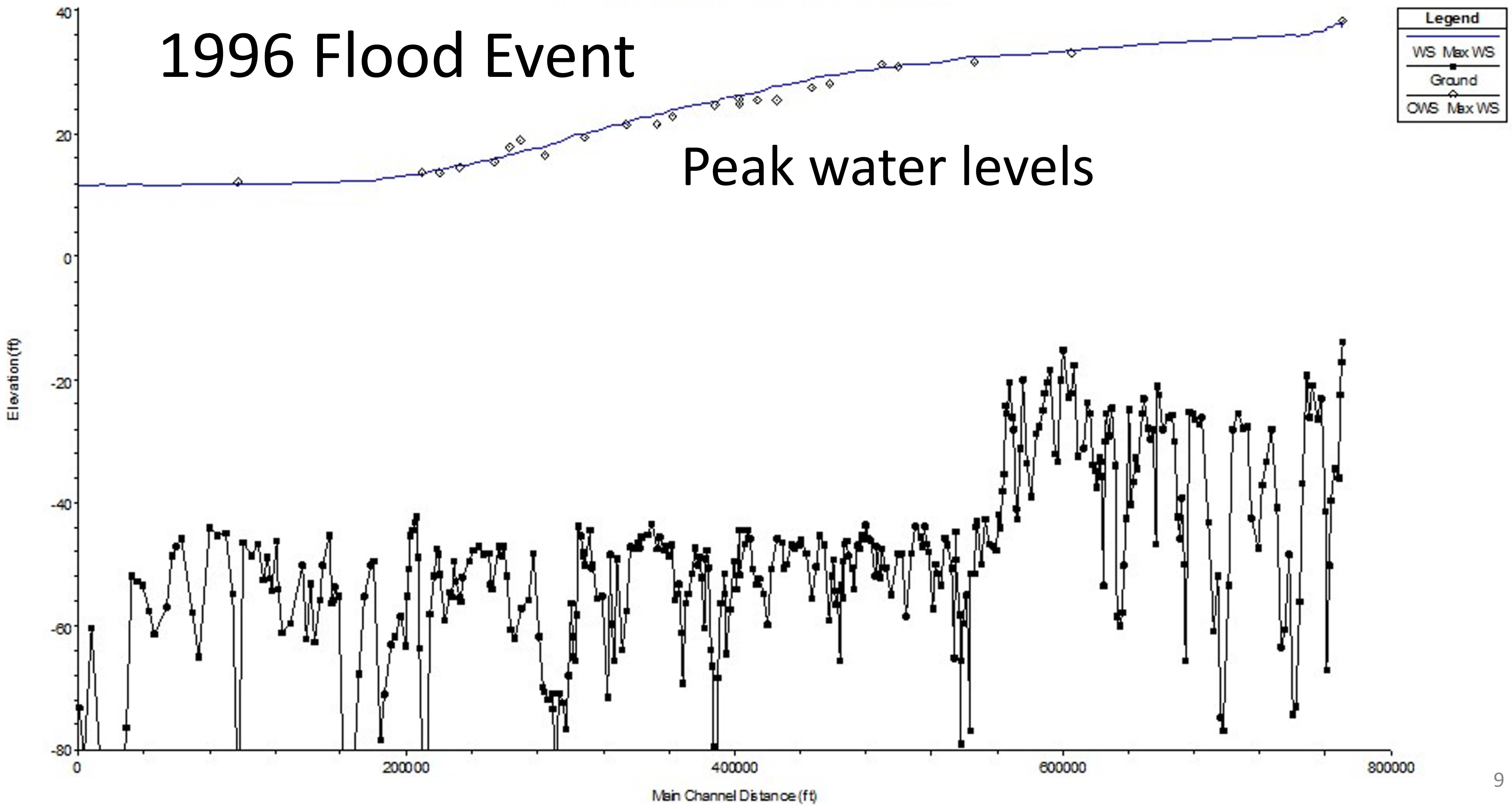
Model Setup and Calibration

- Tidal stage BC
- 208 lateral structures
- 106 storage areas
- Calibrated to 3 flood events

River Name	Main Channel Manning's n	Overbank Manning's n
Columbia River	0.028 - 0.035	0.05 - 0.10
Willamette River	0.03 - 0.039	0.05 - 0.15
Cowlitz River	0.025 - 0.031	0.05 - 0.10
Lewis River	0.032	0.05 - 0.10
All Other Channels	0.03	0.05 - 0.15

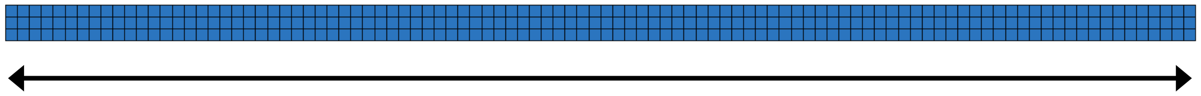


Results: Lower Columbia River



Verification: Sloshing in a Rectangular Basin

- Purpose
  - Temporal schemes
  - Time step convergence
  - Numerical dissipation
- Setup
  - Resolution: 100 m
  - Flat bed
  - Depth: 10 m



$L = 10 \text{ km}$

- Classical Wave Equation

$$\frac{\partial^2 \eta}{\partial t^2} = c^2 \frac{\partial^2 \eta}{\partial x^2}$$

$$c = \sqrt{gh}$$

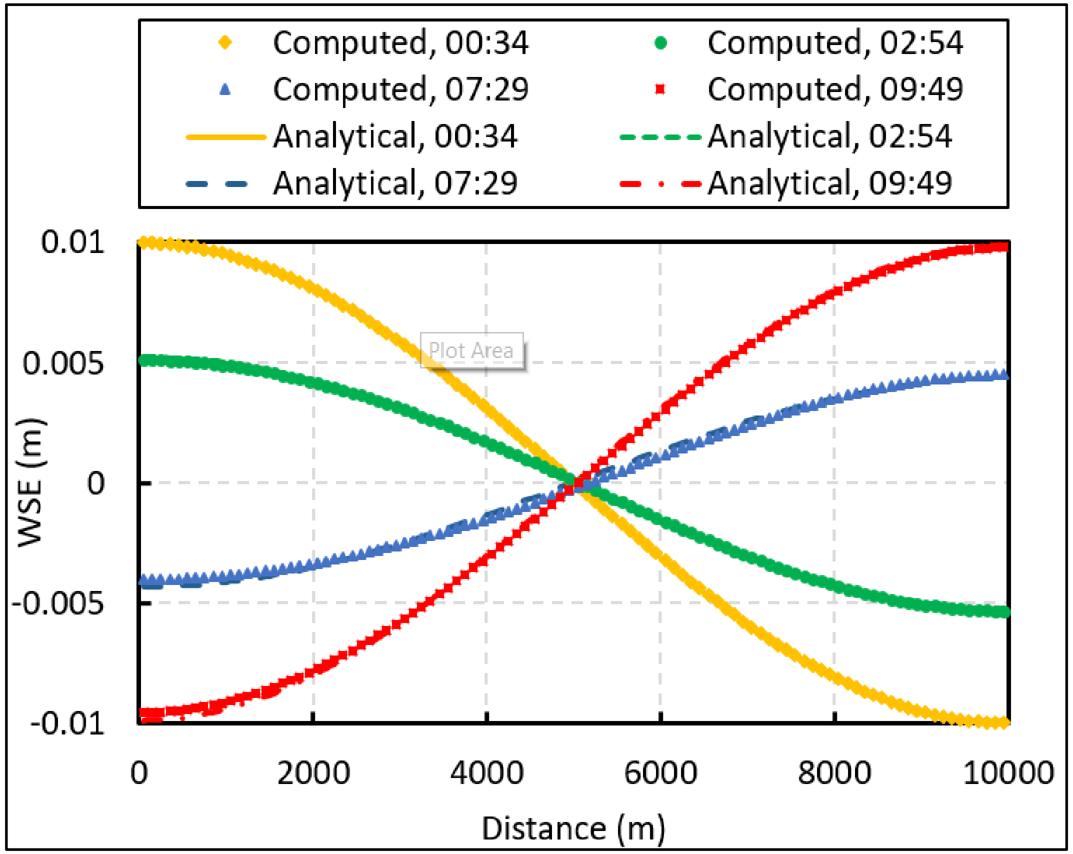
- Solution

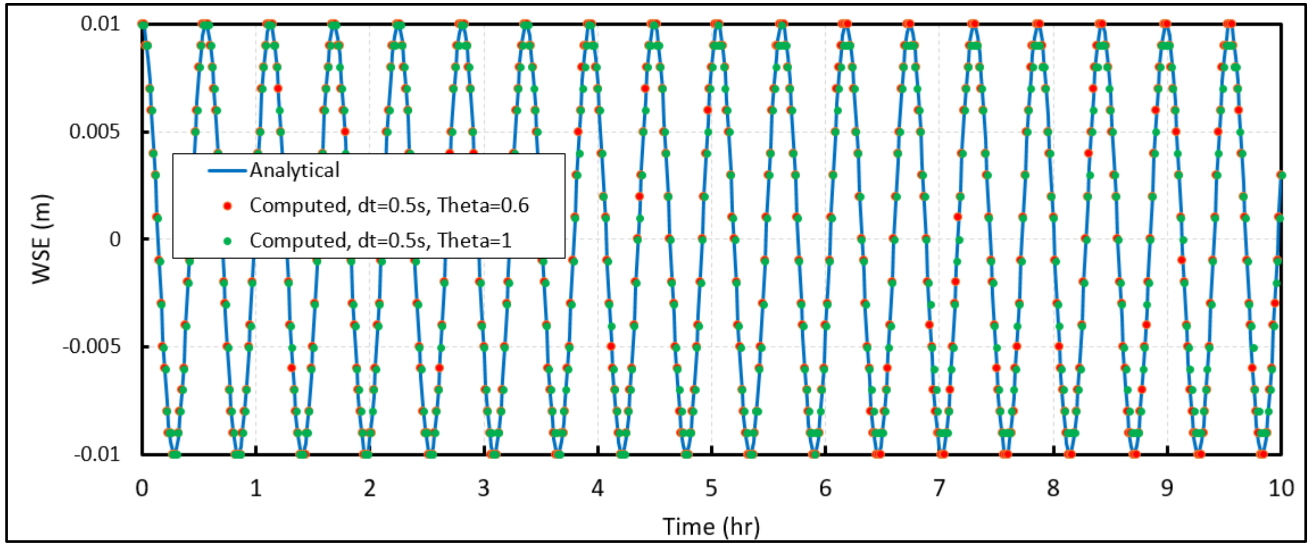
$$\eta = A \cos\left(\frac{m\pi}{L} x\right) \exp\left(i \frac{2\pi}{T} t\right)$$

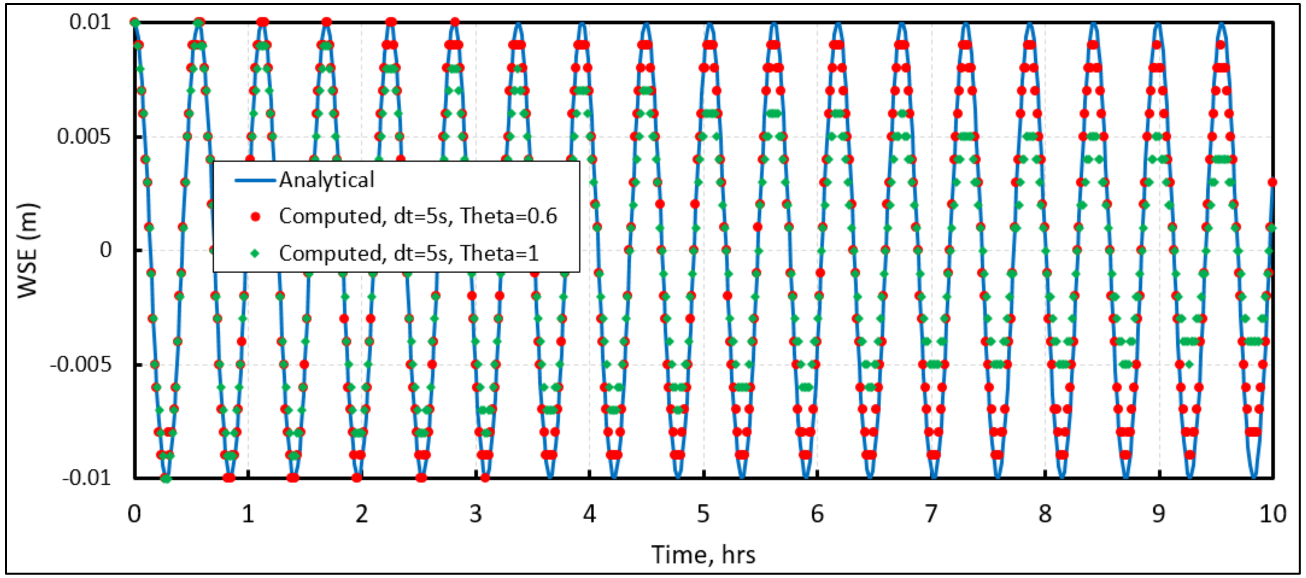
$$m = 1 \qquad T = \frac{2L}{mc}$$

$$A = 1 \text{cm}$$

Sloshing in a Rectangular Basin







Verification: Wind

- Governing Equations

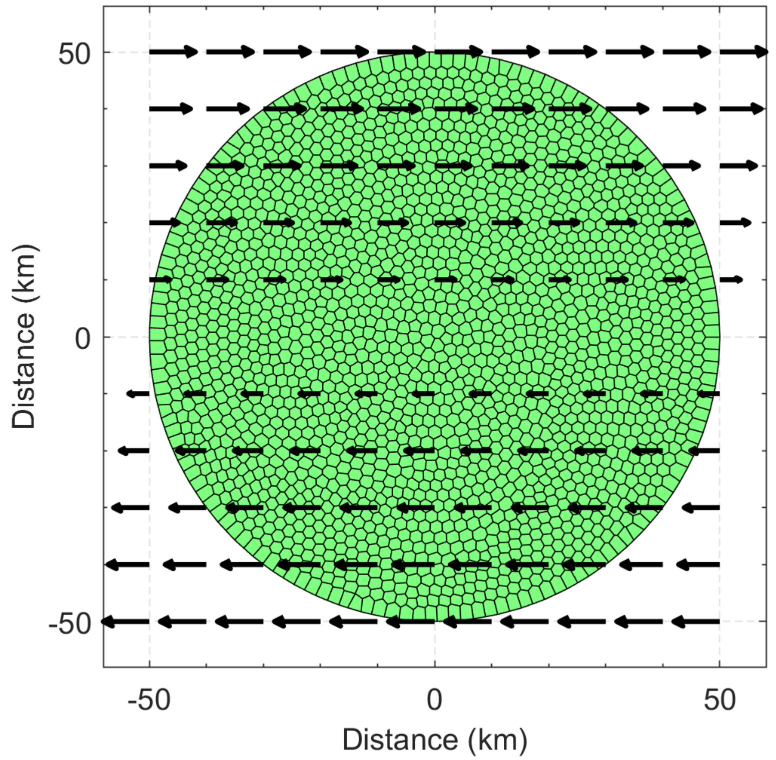
$$\frac{\partial \eta}{\partial t} + \nabla \cdot (h\boldsymbol{V}) = 0$$

$$\frac{\partial \boldsymbol{V}}{\partial t} - f\boldsymbol{k} \times \boldsymbol{V} = -g\nabla \eta - \gamma \boldsymbol{V} + \boldsymbol{F}$$

- Setup
  - Flat circular basin
  - Linear bottom friction
  - Wind in the x-direction only

$$\boldsymbol{F} = \left(\frac{Wy}{R}, 0 \right)^T$$

Mesh and Wind

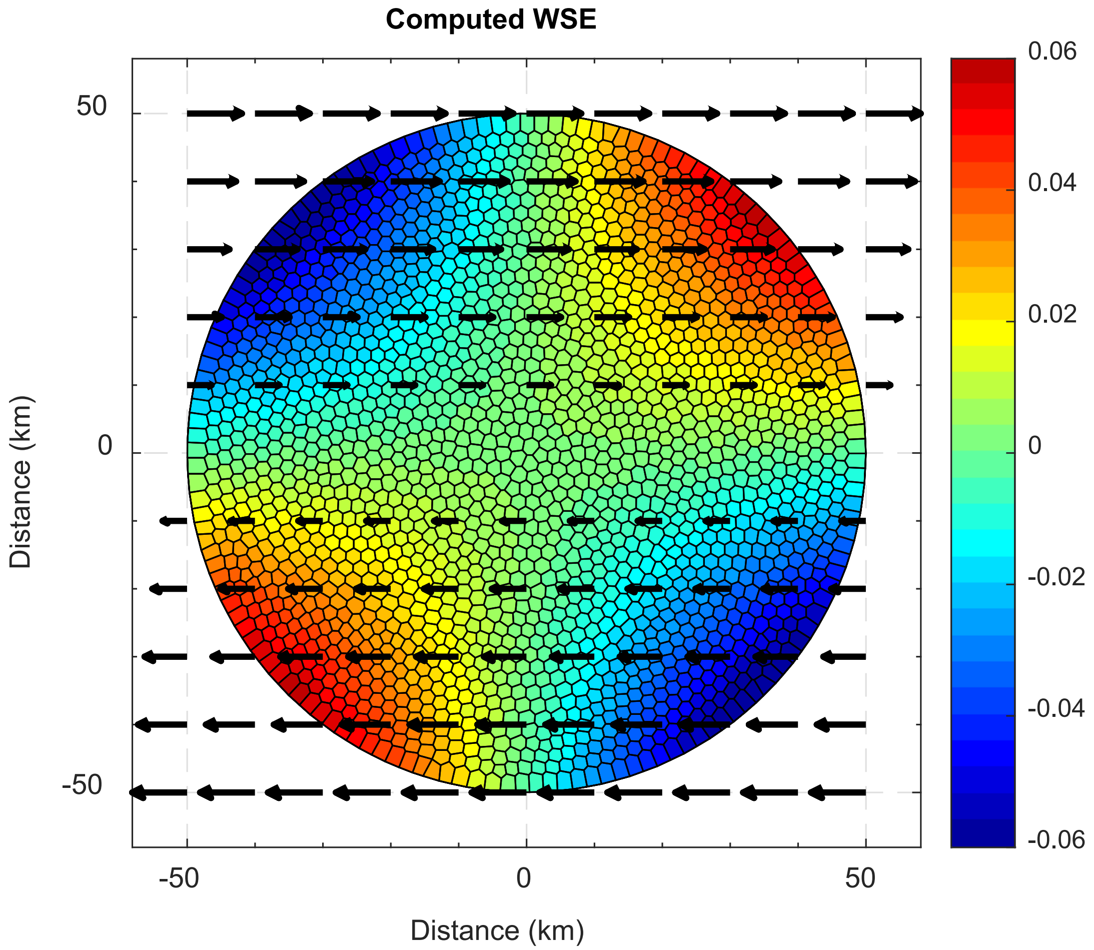


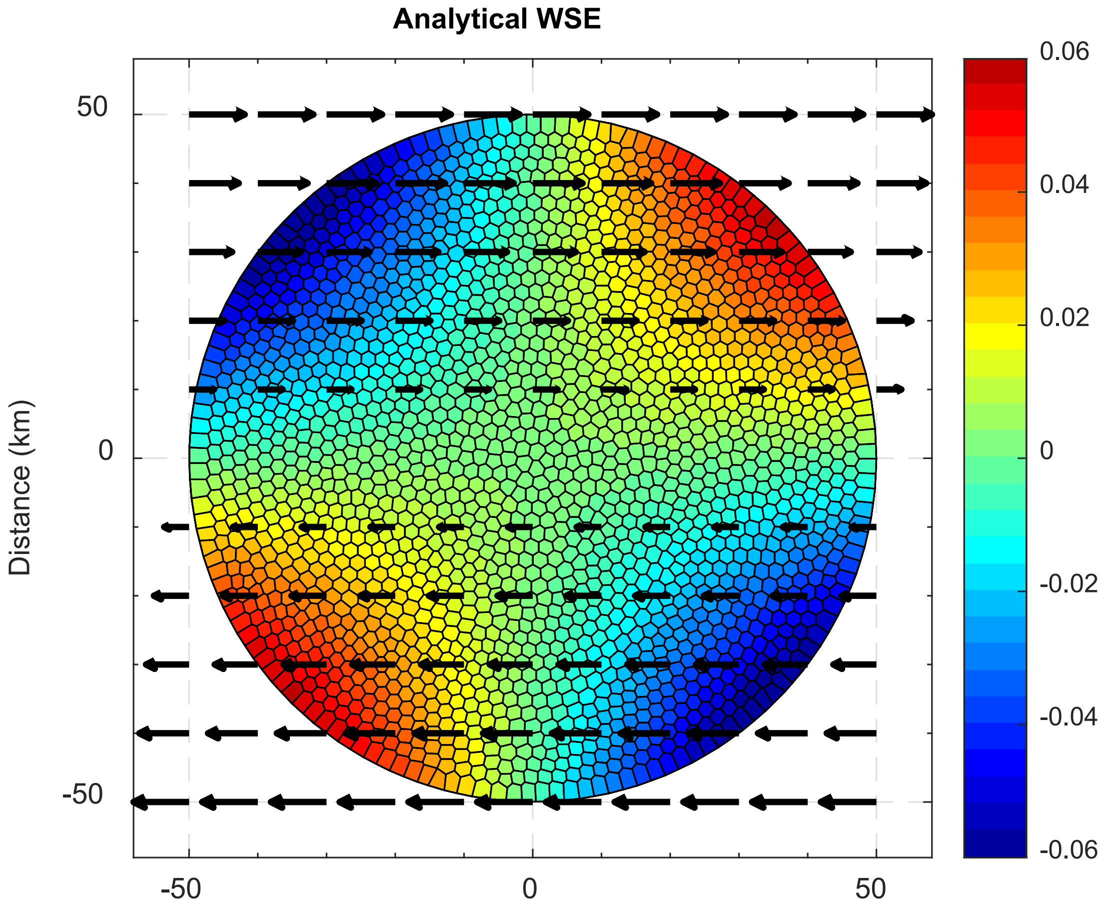
- Solution

$$\eta = \frac{Wf}{RgH\gamma} \left[\frac{R^2}{8} + \frac{r^2}{4} \left(\frac{\gamma}{f} \sin(2\theta) - 1 \right) \right]$$

$$U = \frac{W}{2R\gamma} y \qquad V = -\frac{W}{2R\gamma} x$$

Verification: Wind





Verification: Flood Wave

- Problem Description
  - "Manufactured" solution valid for both DWE and SWE
- Model Setup
  - Grid Resolution: 2 cm
  - Manning's n: 0.009 s/m$^{1/3}$
  - Diffusion-Wave and Shallow Water Equations
  - Time Step: 0.025 s
  - Theta: 0.60
  - Mixing Coefficient: 0.2 (SWE only)
- Classical Wave Equation

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(\beta \frac{\partial h}{\partial x}\right)$$

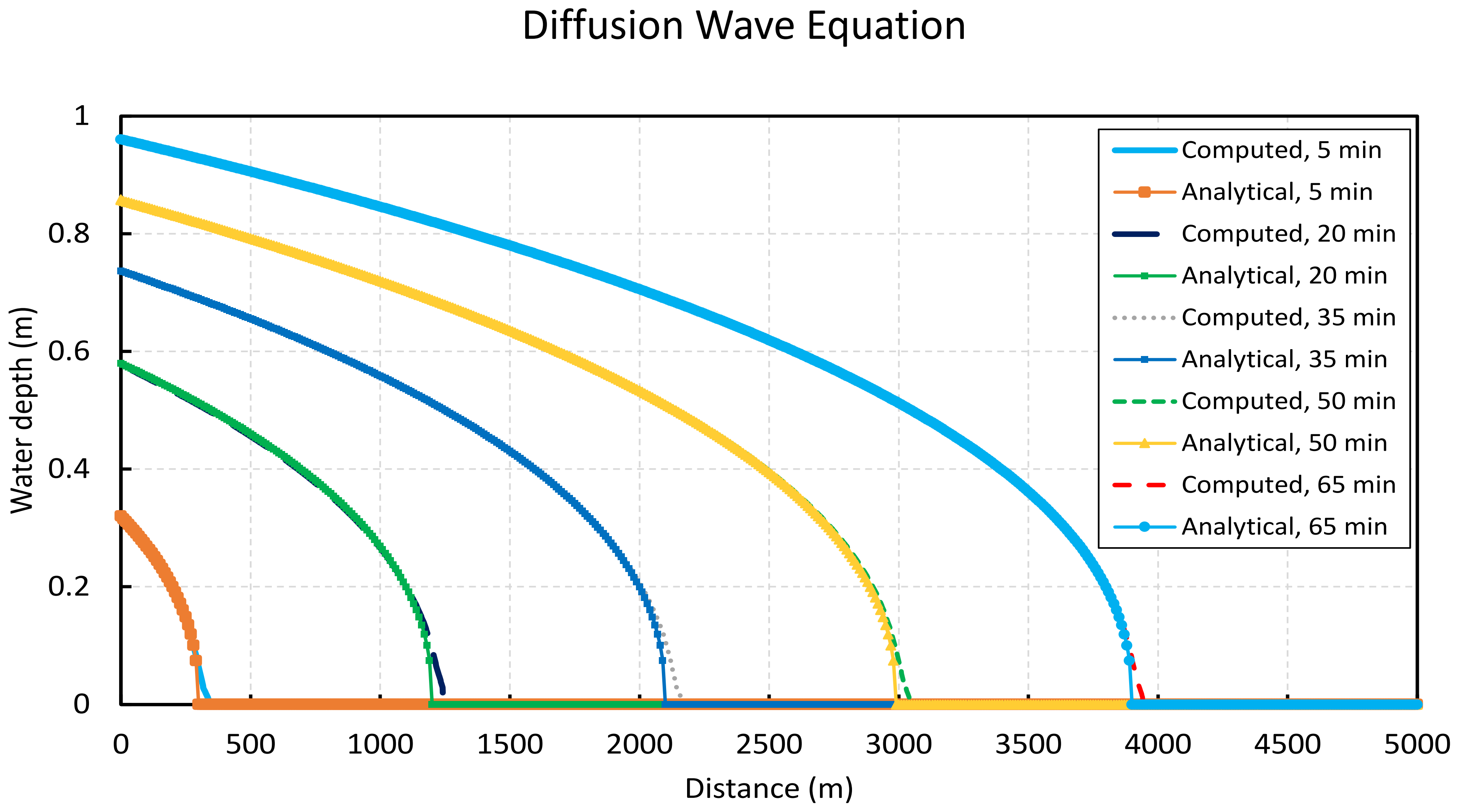
$$\beta = \frac{h^{5/3}}{n\left|\nabla h\right|^{1/2}}$$

- Solution

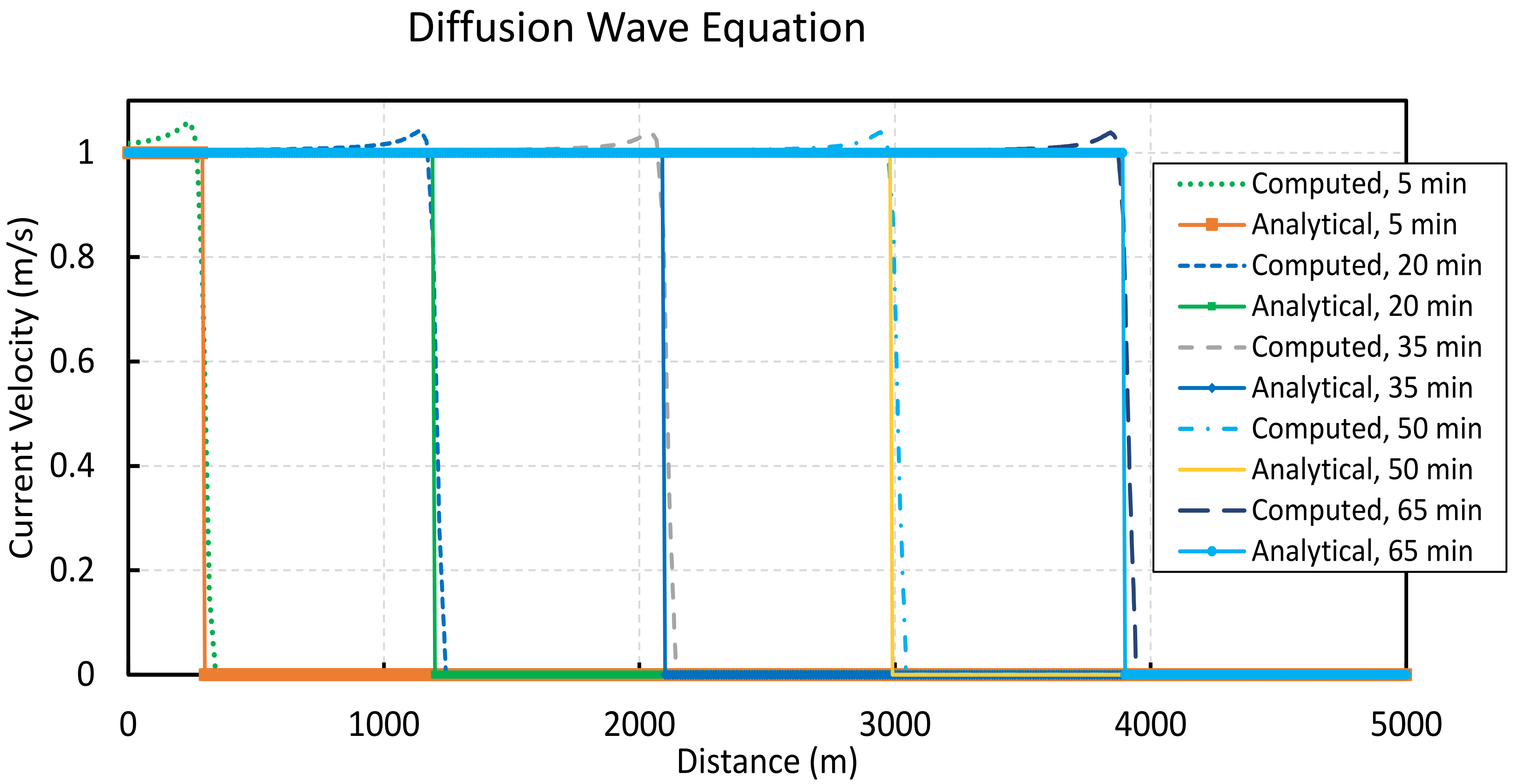
$$h = \left\{\frac{7}{3}\left[C - n^2 U^3 \left(x - Ut\right)\right]\right\}^{3/7}$$

$$C = 1,\ U = 1 \text{ m/s},\ n = 0.01\ s/\text{m}^{1/3}$$

Results


Diffusion Wave Equation
Water depth (m)
Distance (m)
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Computed, 5 min
Analytical, 5 min
Computed, 20 min
Analytical, 20 min
Computed, 35 min
Analytical, 35 min
Computed, 50 min
Analytical, 50 min
Computed, 65 min
Analytical, 65 min

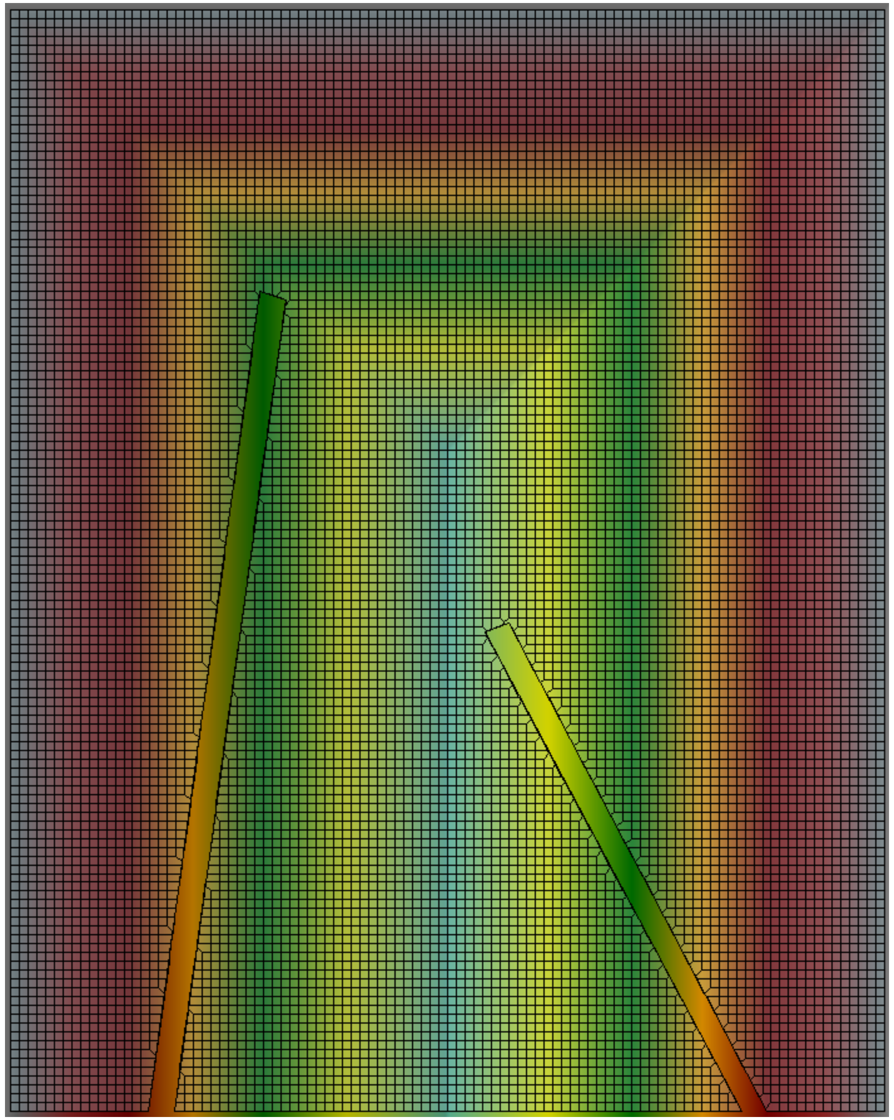
Results



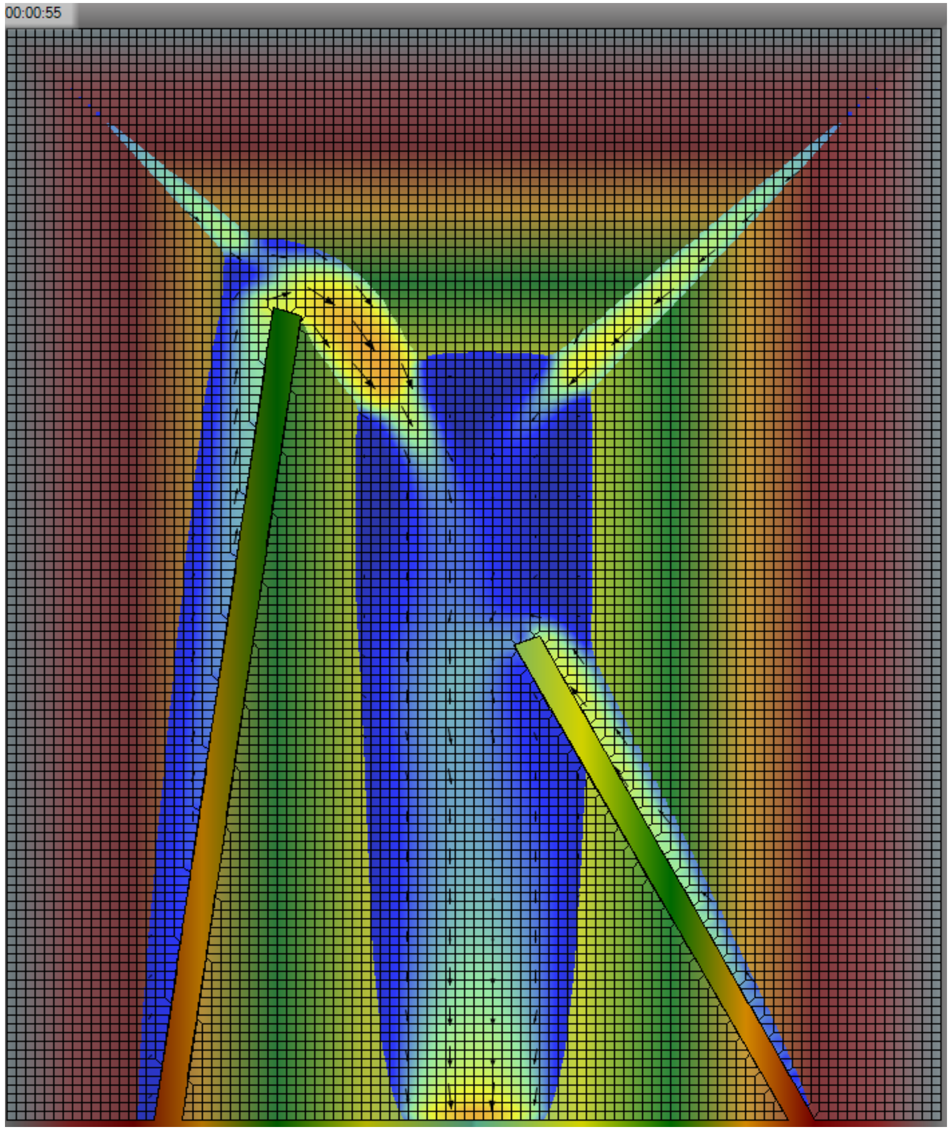
Diffusion Wave Equation
Current Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
0
1000
2000
3000
4000
5000
Distance (m)
Computed, 5 min
Analytical, 5 min
Computed, 20 min
Analytical, 20 min
Computed, 35 min
Analytical, 35 min
Computed, 50 min
Analytical, 50 min
Computed, 65 min
Analytical, 65 min

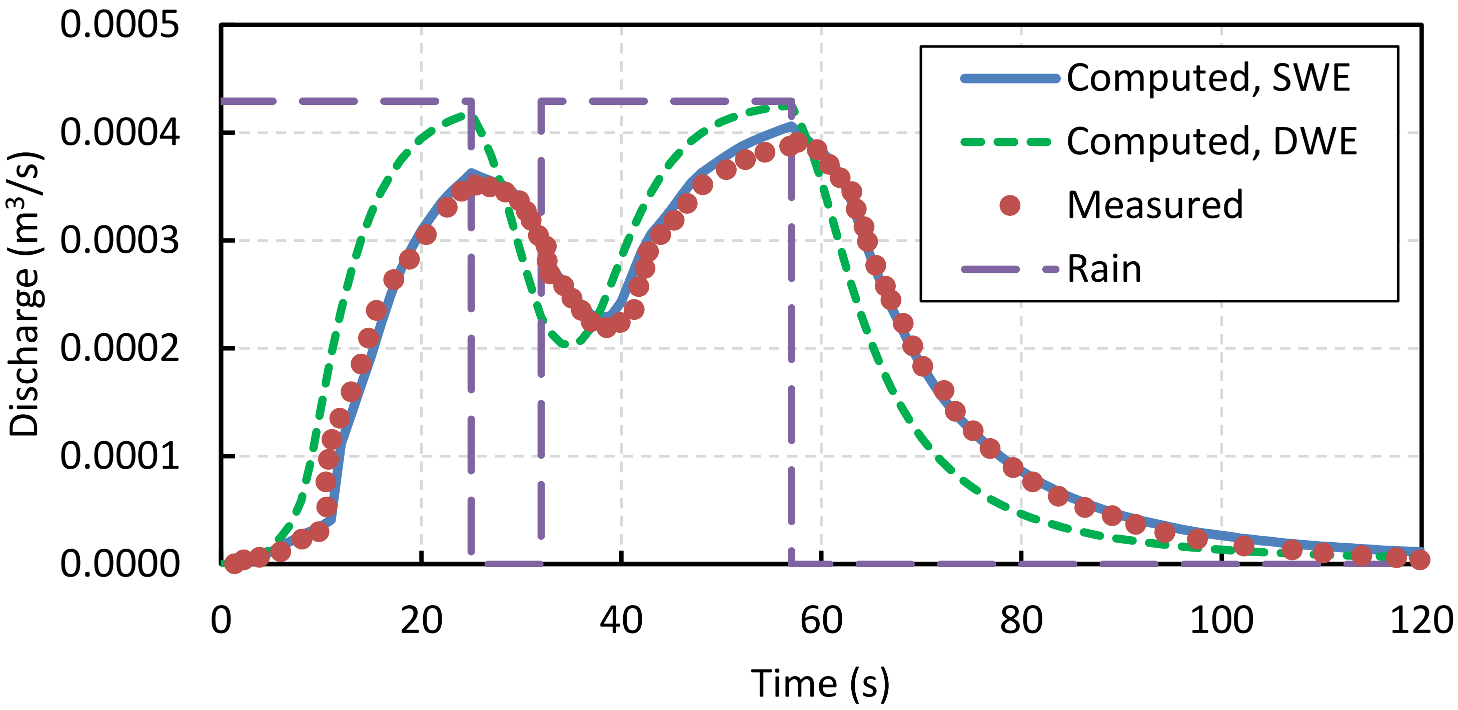
Validation: Surface Runoff

- Experimental Setup
  - Rainfall intensity: 328 mm/hr
  - 3 stainless steel planes with 5% slopes
  - 2 walls to block redirect flow
- Model Setup
  - 2 x 2 cm grid cells
  - Manning's n: 0.009 s/m$^{1/3}$
  - Diffusion-Wave and Shallow Water Equations
  - Time Step: 0.025 s
  - Theta: 0.60
  - Mixing Coefficient: 0.2 (SWE only)

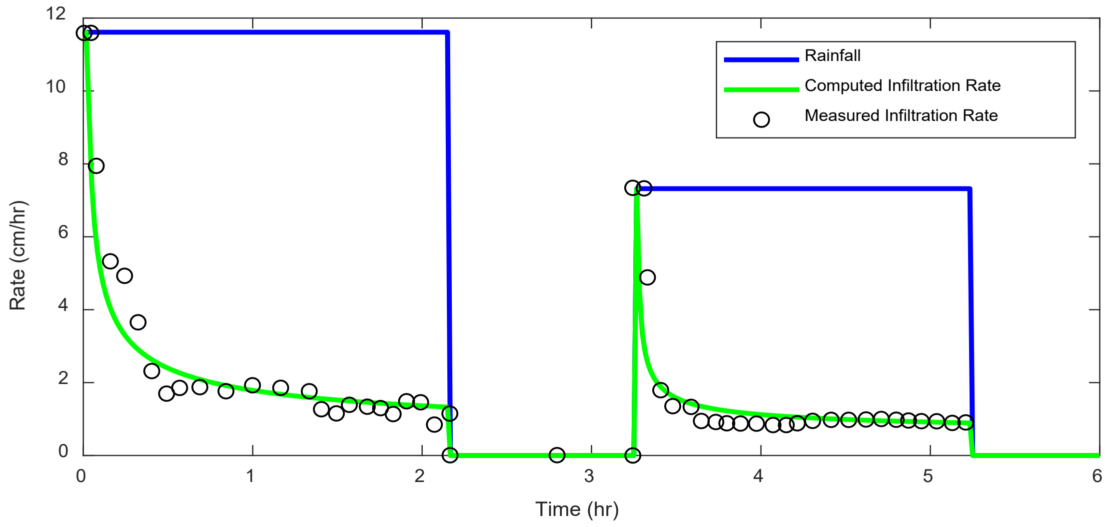


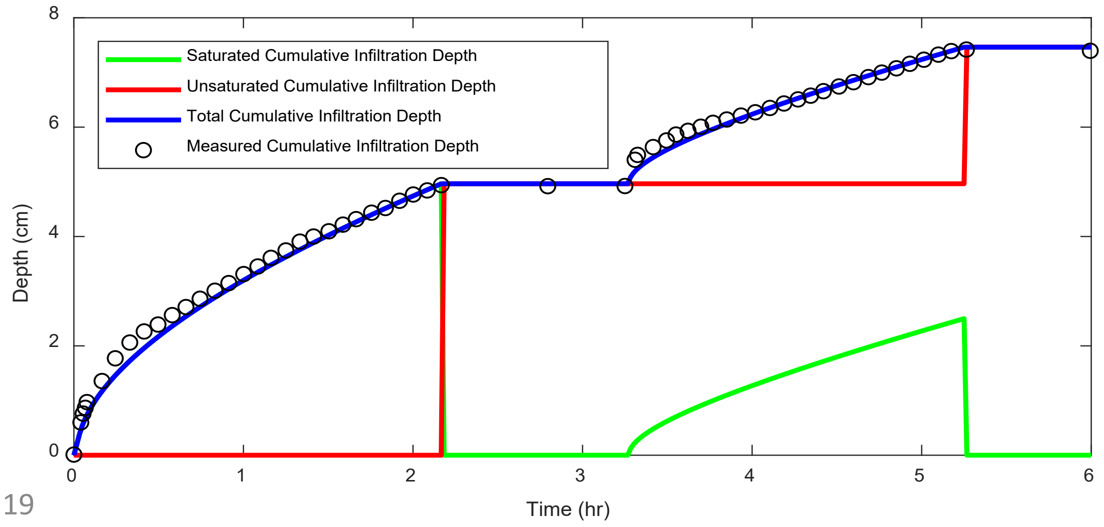
Surface Runoff: Results





Validation: Green and Ampt with Redistribution



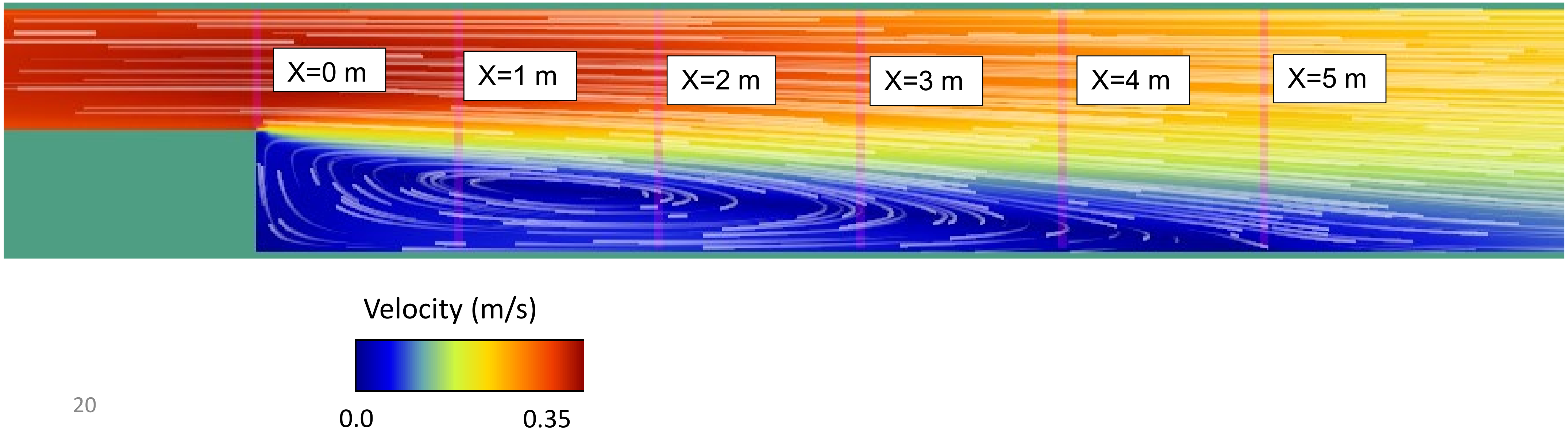


Comparison with Alapaha Sand Tests (Rawls et al. 1976)

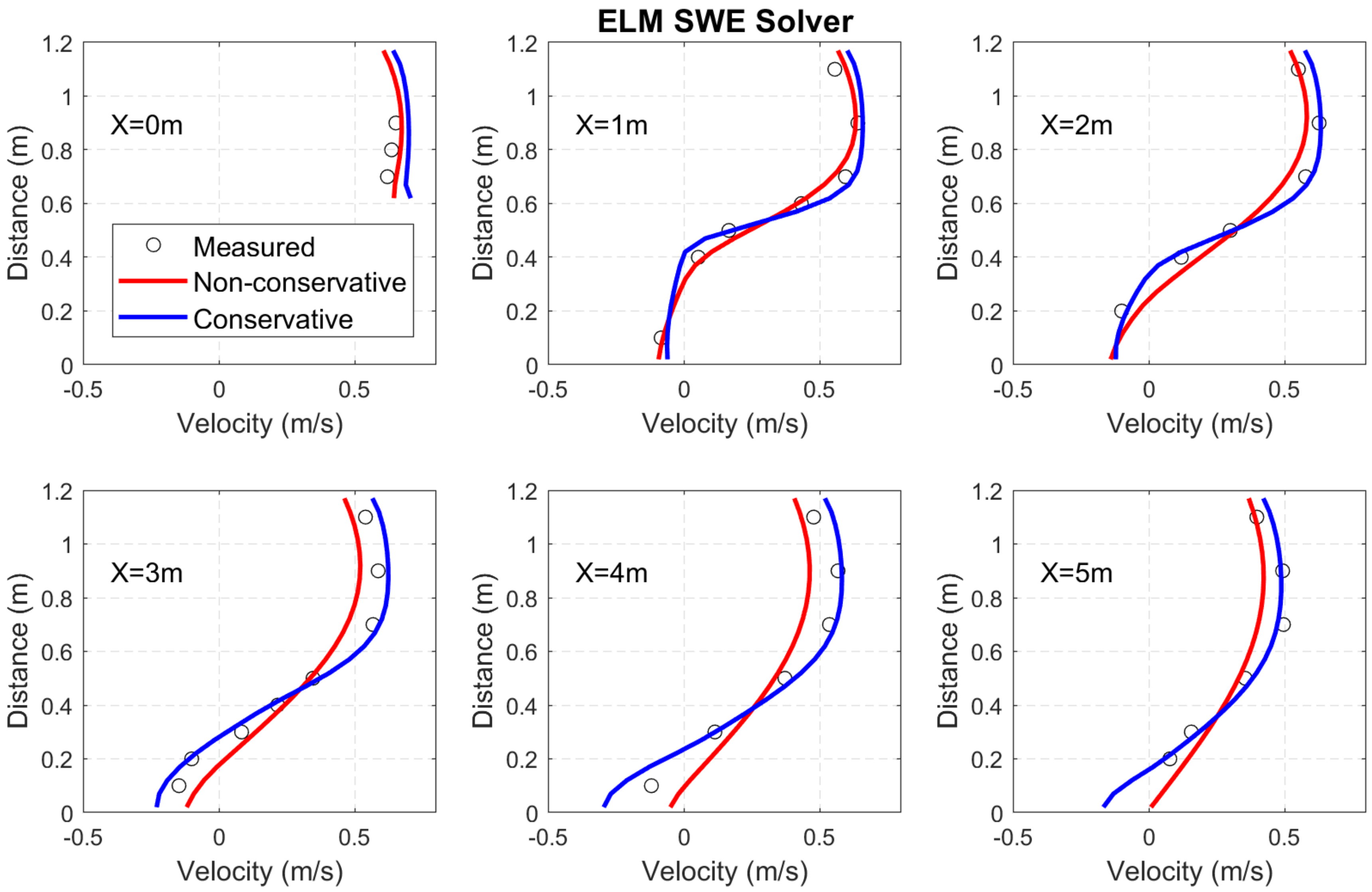
Parameter	**Value**
Saturated hydraulic conductivity (cm/hr)	0.47
Suction at the wetting front (cm)	45
Saturated water content (-)	0.38
Residual water content (-)	0.06
Initial water content (-)	0.19
Pore distribution index	0.45

Sudden Expansion Lab Experiment

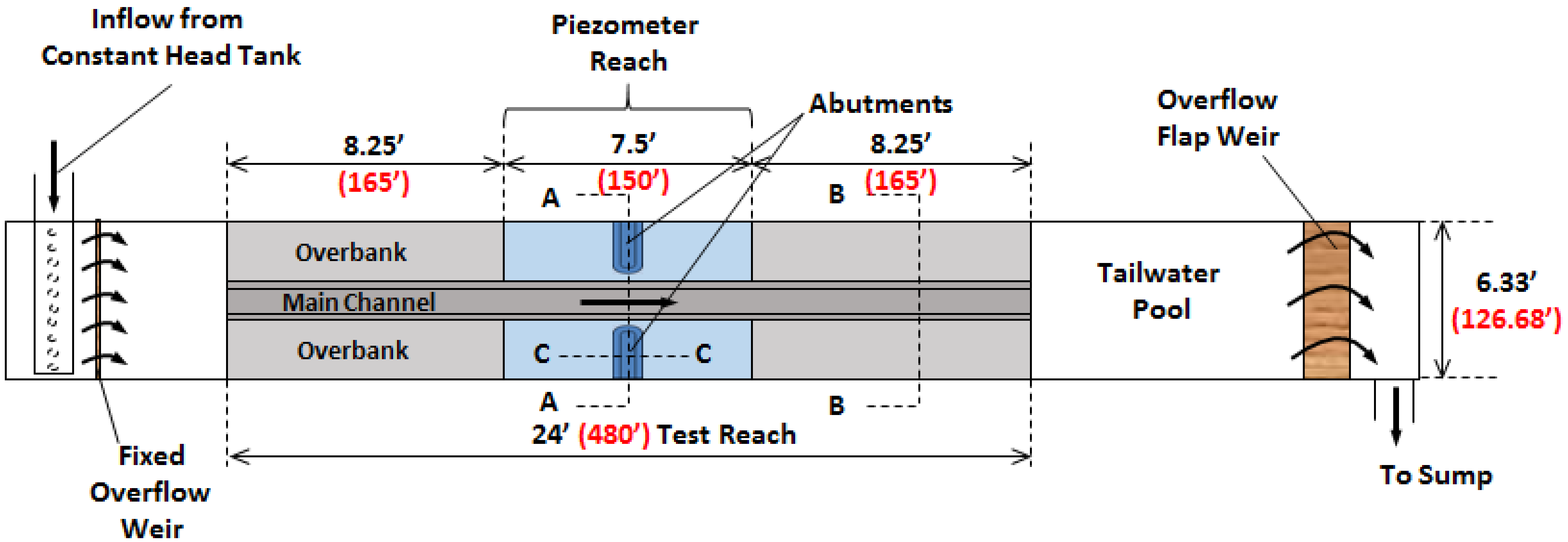
- Inflow: 0.039 m^3/s
- Downstream depth: 11 cm
- Slope: 0.0001
- Grid Resolution: 2.5 cm
- Time step: 0.0333 s
- Manning's n: 0.015 $s/m^{1/3}$



Results: Sudden Expansion



Flow Through a Bridge Opening

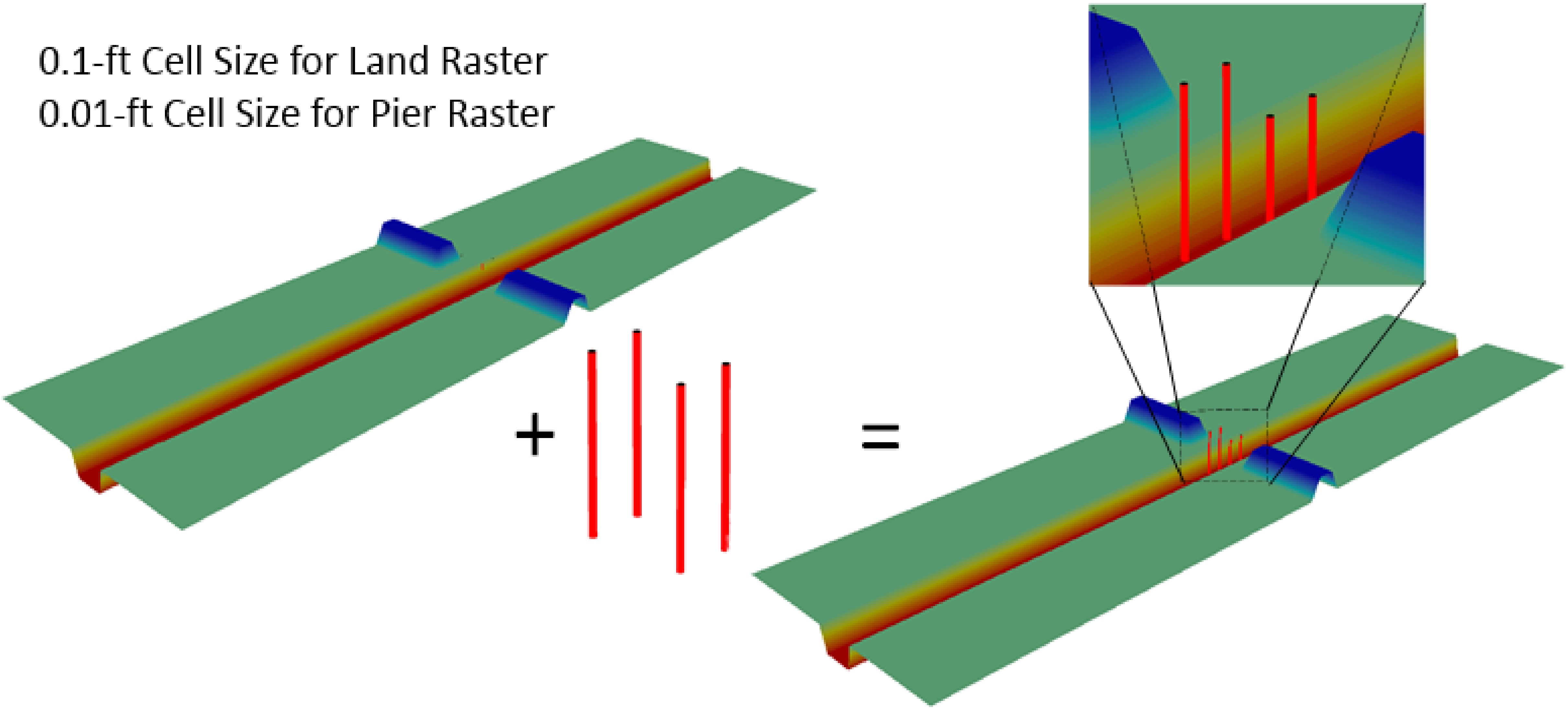


* From research work of Dr. David A. Parr, Professor; Evan Deal, Research Assistant; and Bryan C. Young, Associate Professor, all are in the Civil, Environmental and Architectural Engineering Department at the University of Kansas.

Terrain

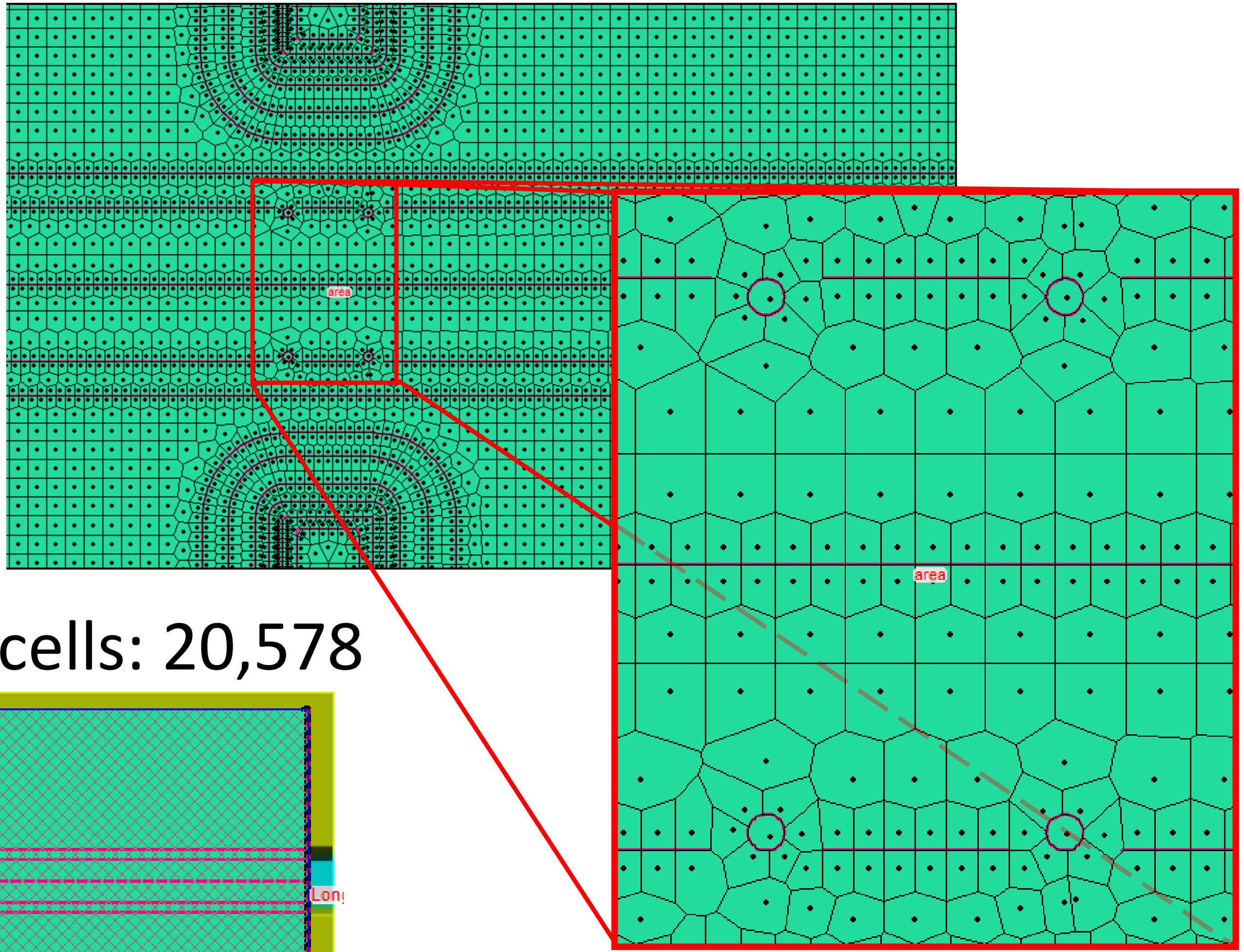
0.1-ft Cell Size for Land Raster

0.01-ft Cell Size for Pier Raster

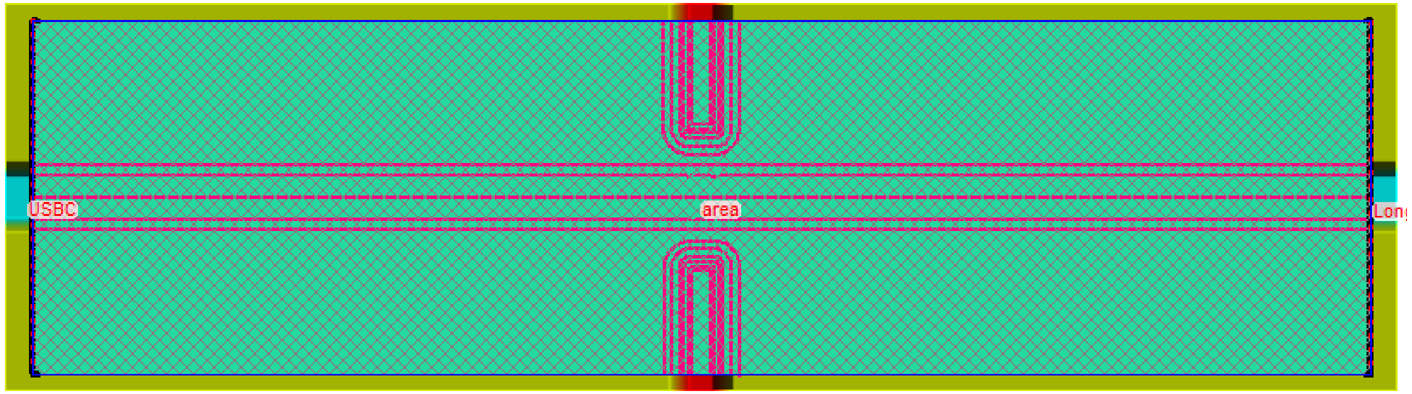


Model Setup

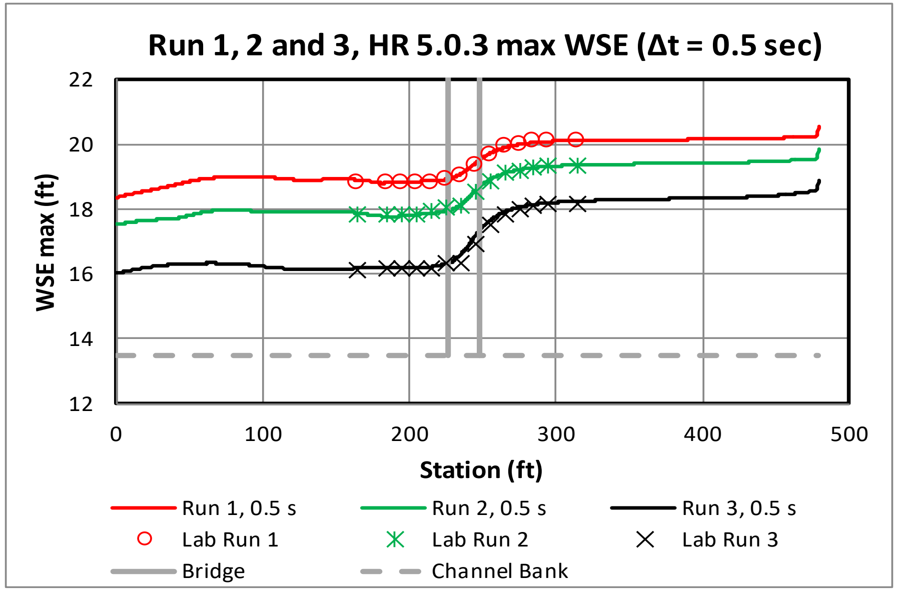
- Flow BC upstream
- Stage BC downstream
- Mesh resolution: 1 to 2 ft
- Manning's n: 0.0141 s/m$^{1/3}$
- Time step: 0.5 s, C ≈ 1
- Shallow water equations



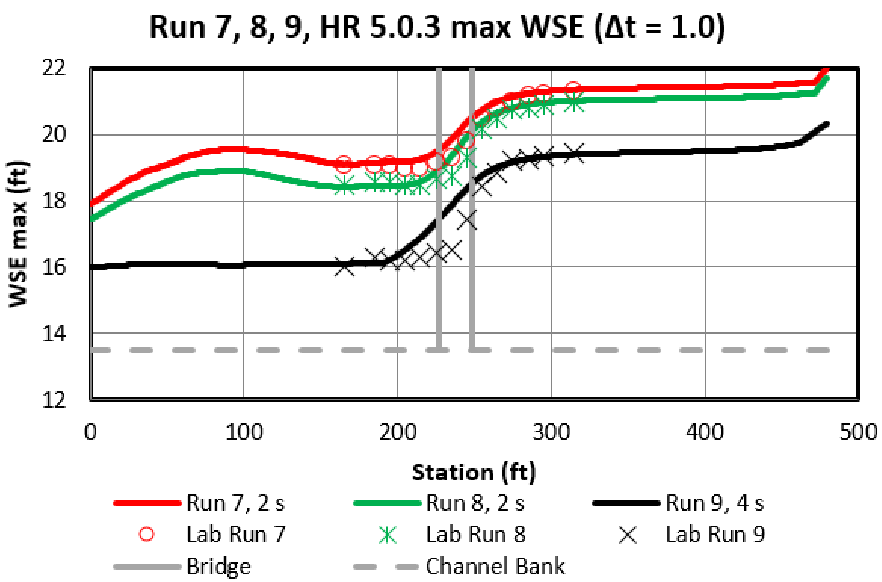
Number of cells: 20,578



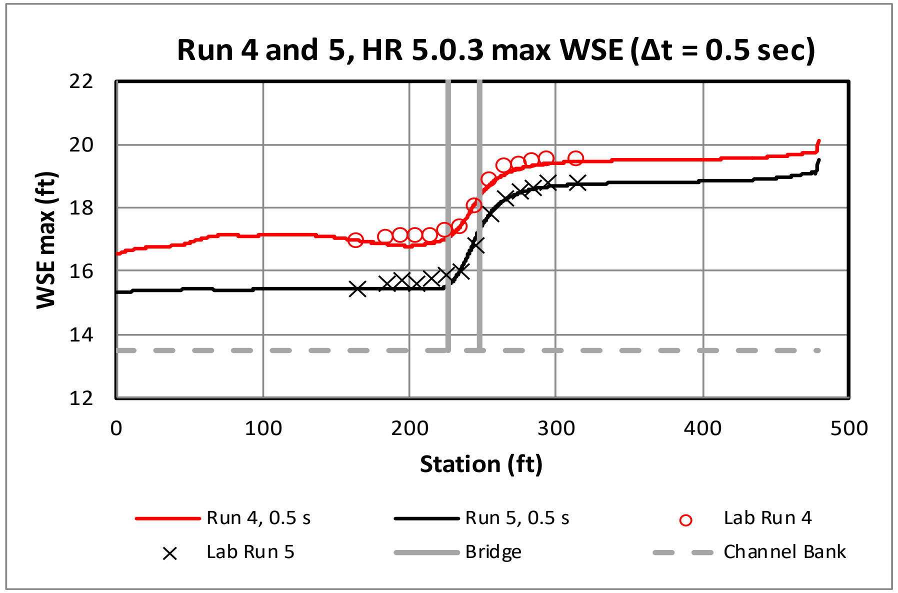
Results



Run 1, 2 and 3, HR 5.0.3 max WSE (Δt = 0.5 sec)
WSE max (ft)
22
20
18
16
14
12
0
100
200
300
400
500
Station (ft)
Run 1, 0.5 s
Run 2, 0.5 s
Run 3, 0.5 s
Lab Run 1
Lab Run 2
Lab Run 3
Bridge
Channel Bank



Run 7, 8, 9, HR 5.0.3 max WSE (Δt = 1.0)
WSE max (ft)
22
20
18
16
14
12
0
100
200
300
400
500
Station (ft)
Run 7, 2 s
Run 8, 2 s
Run 9, 4 s
Lab Run 7
Lab Run 8
Lab Run 9
Bridge
Channel Bank



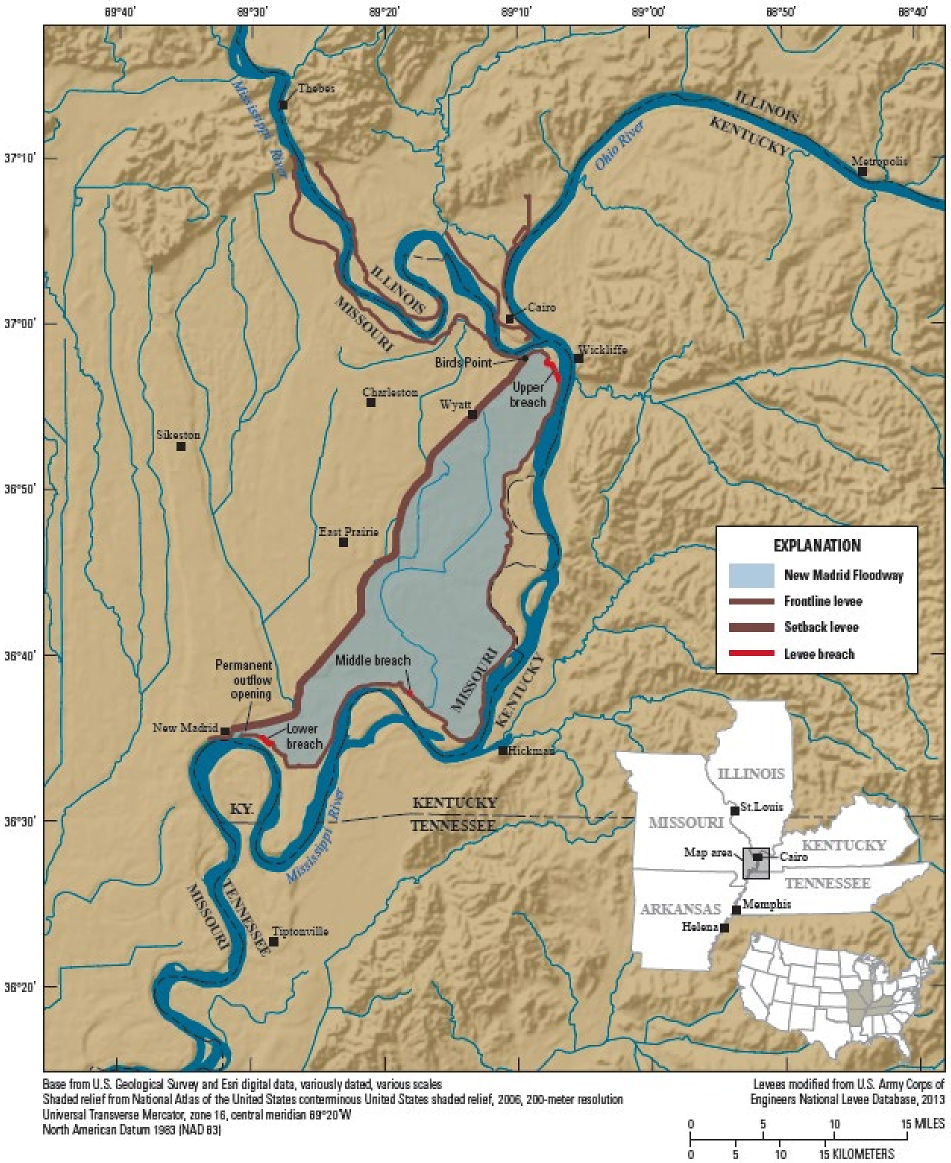
Run 4 and 5, HR 5.0.3 max WSE (Δt = 0.5 sec)
WSE max (ft)
22
20
18
16
14
12
0
100
200
300
400
500
Station (ft)
Run 4, 0.5 s
Run 5, 0.5 s
Lab Run 4
Lab Run 5
Bridge
Channel Bank

New Madrid Floodway and Breaches

During the May 2011 flood in the Mississippi and Ohio rivers, the New Madrid floodway was activated by blowing up the levee in three locations, in order to reduce flooding along the Mississippi and Ohio rivers.

Before the levee was activated, the U.S. Geological Survey (USGS) went out and placed 38 pressure transducers within the floodway, in order to measure the water levels during the event.

The levee system was activated by the US Army Corps of Engineers on May 2, 2011.

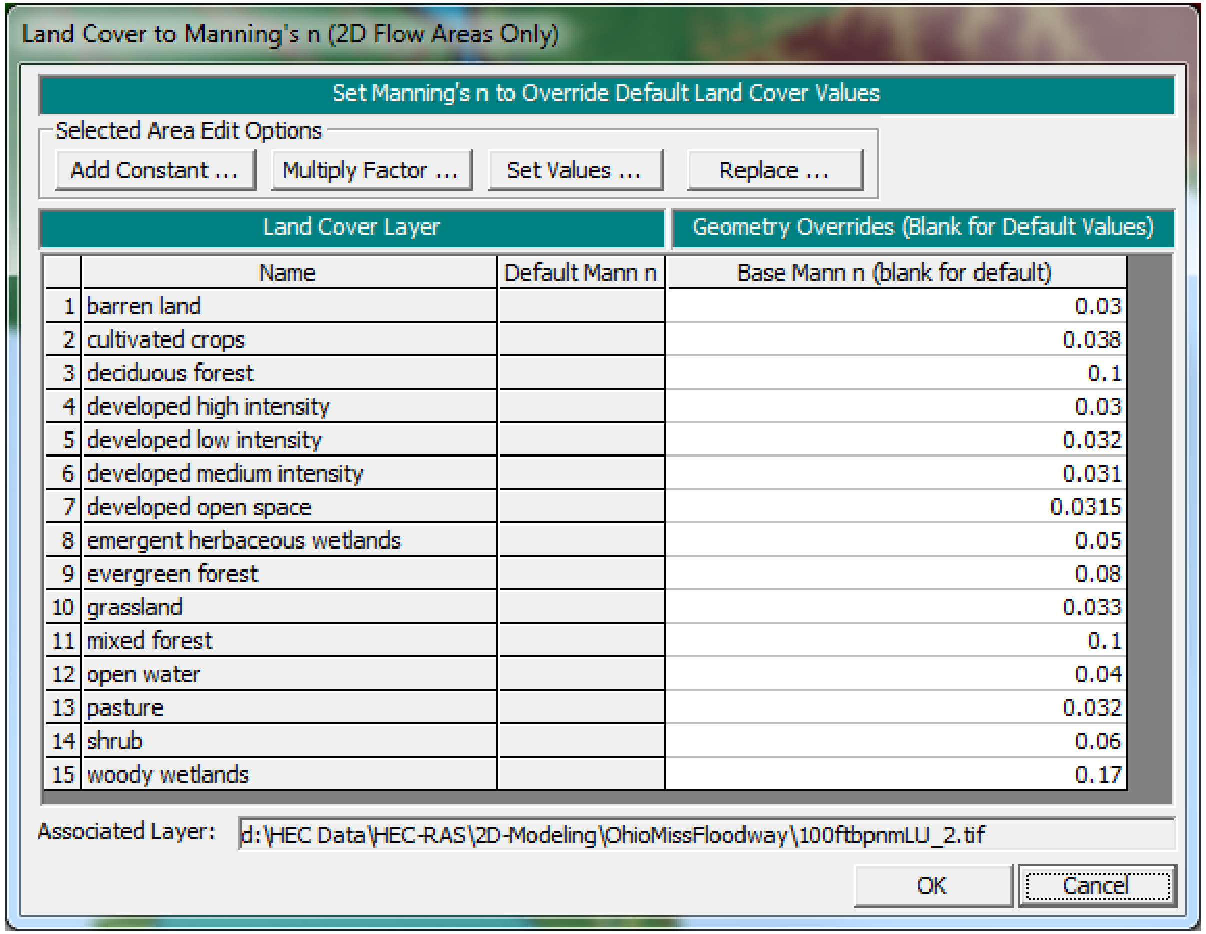


Model Setup

- Flood way is 40 miles long and 10 miles wide
- Grid Resolution: 500 ft

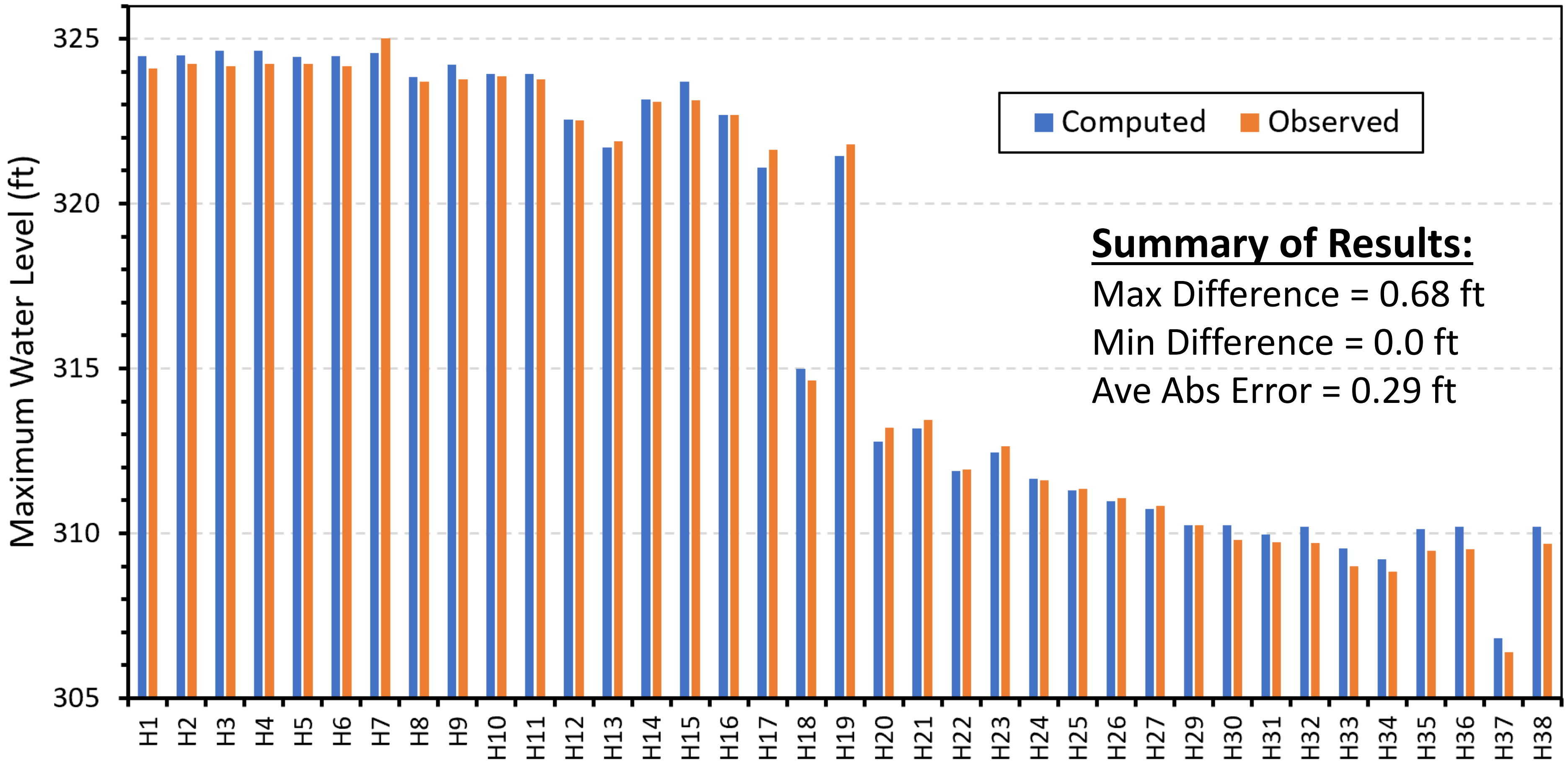
Parameter	Value
Time step	2 minutes
Governing Equations	Shallow Water Equations
Implicit Weighting Factor	1
Manning's roughness 1D rivers	0.021 – 0.033 main channel 0.080 – 0.200 overbank areas
Upper Levee Breach width	9400 ft
Middle Levee Breach width	690 ft
Lower Levee Breach width	4100 ft

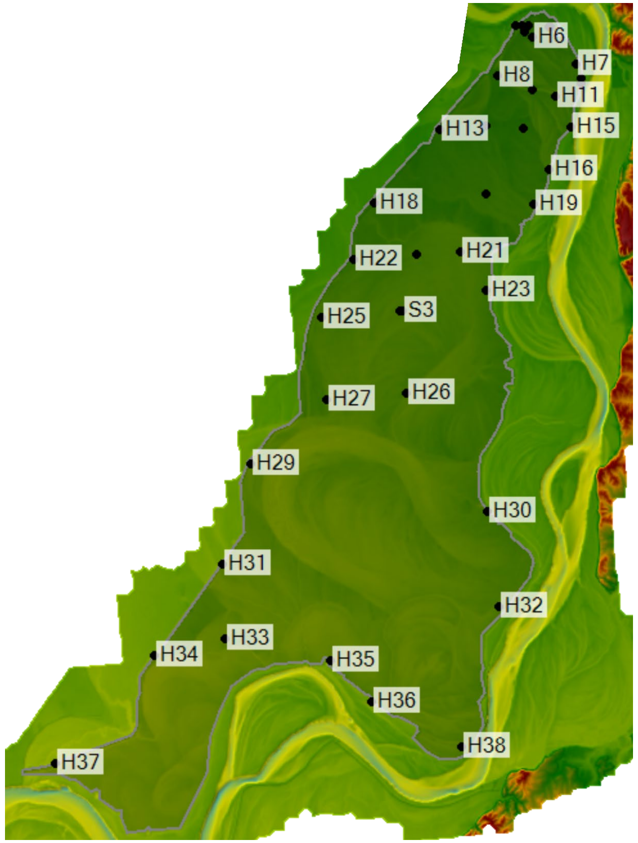
- Manning's n within floodway based on Land Cover



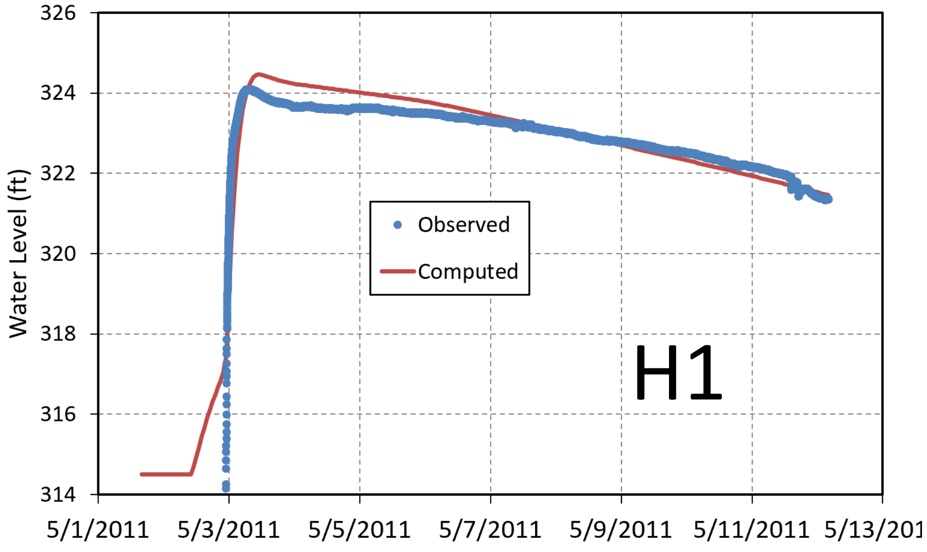
	Name	Default Mann n	Base Mann n (blank for default)
1	barren land		0.03
2	cultivated crops		0.038
3	deciduous forest		0.1
4	developed high intensity		0.03
5	developed low intensity		0.032
6	developed medium intensity		0.031
7	developed open space		0.0315
8	emergent herbaceous wetlands		0.05
9	evergreen forest		0.08
10	grassland		0.033
11	mixed forest		0.1
12	open water		0.04
13	pasture		0.032
14	shrub		0.06
15	woody wetlands		0.17

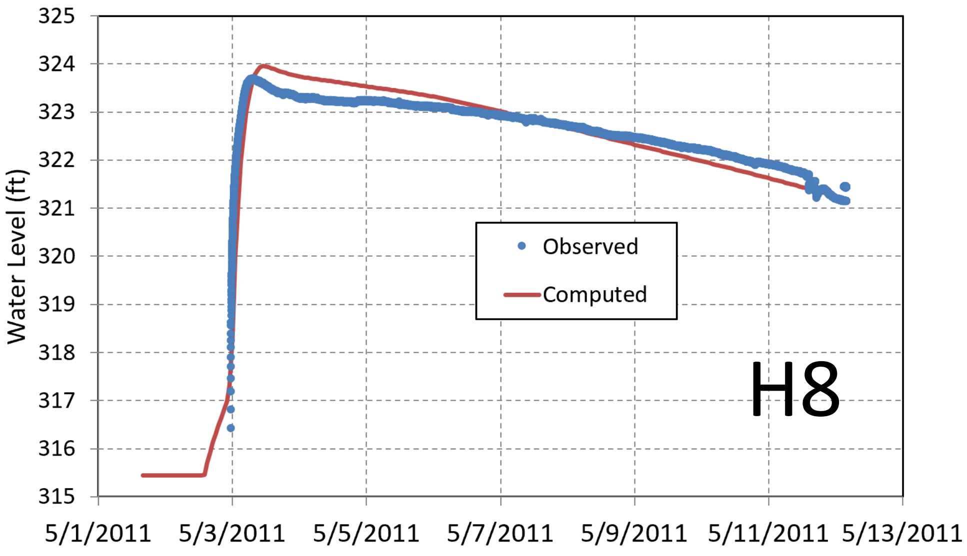
Results for all 38 Locations

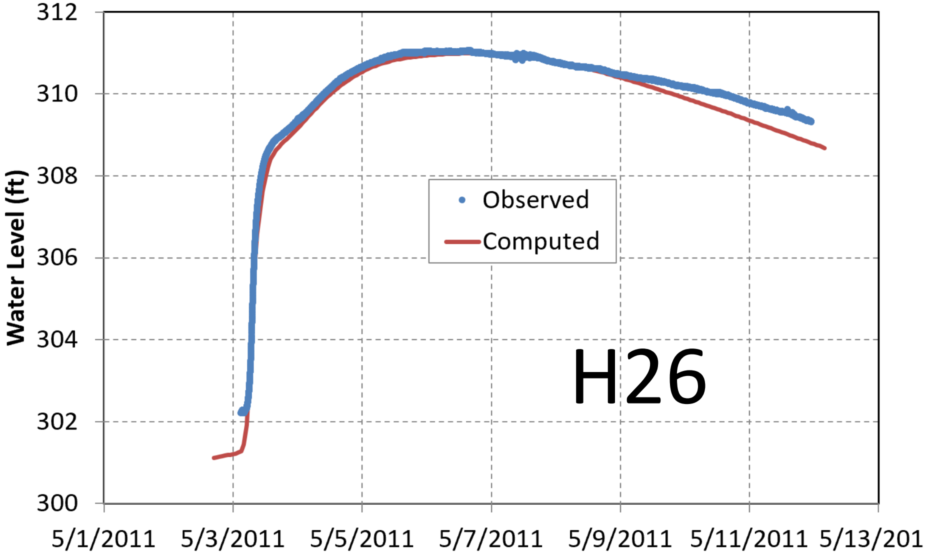


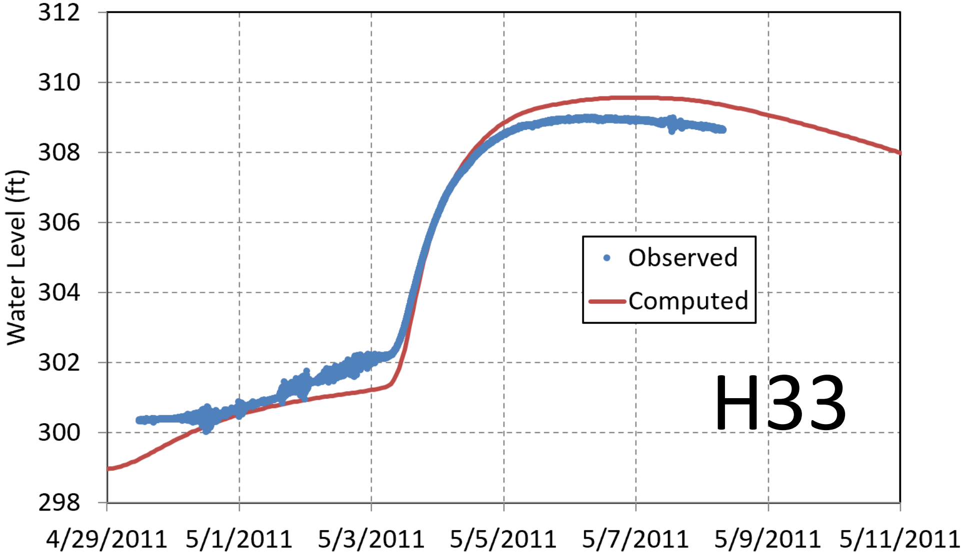


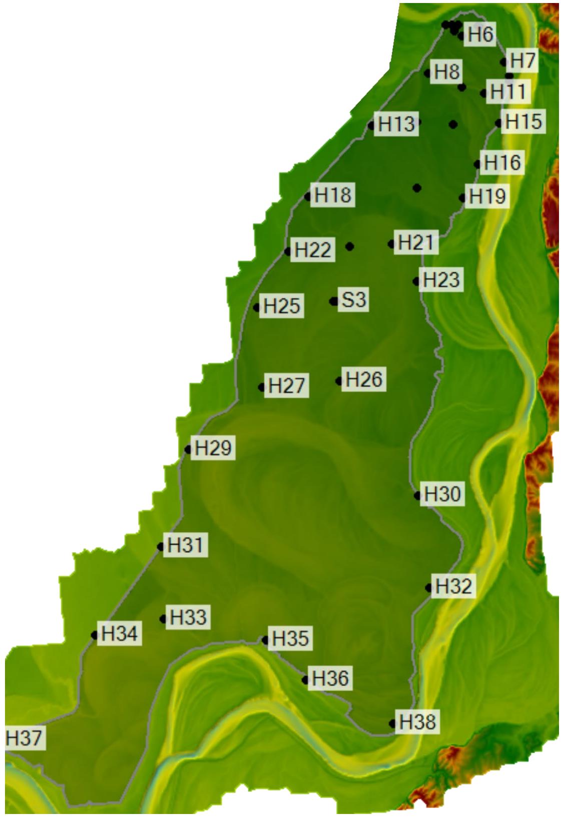
Computed vs Observed Water Levels











Brumadinho Mine Tailings Failure

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Prof Leonardo Moura (University of Brasilia),
Dr. Stanford Gibson (HEC)

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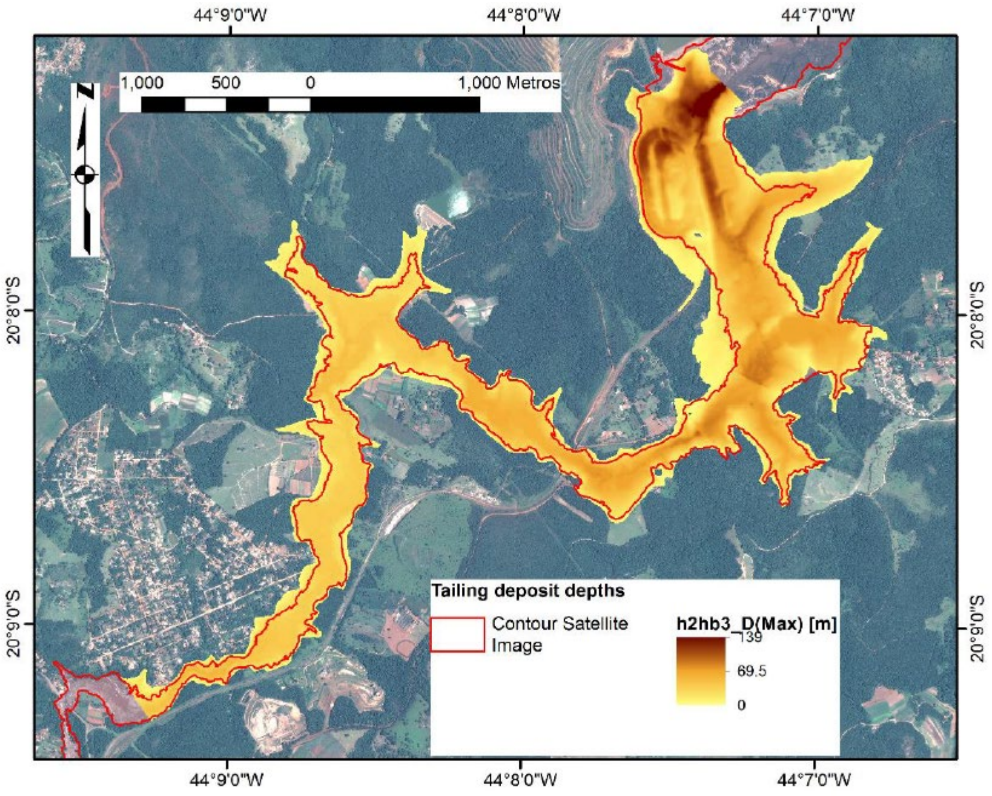

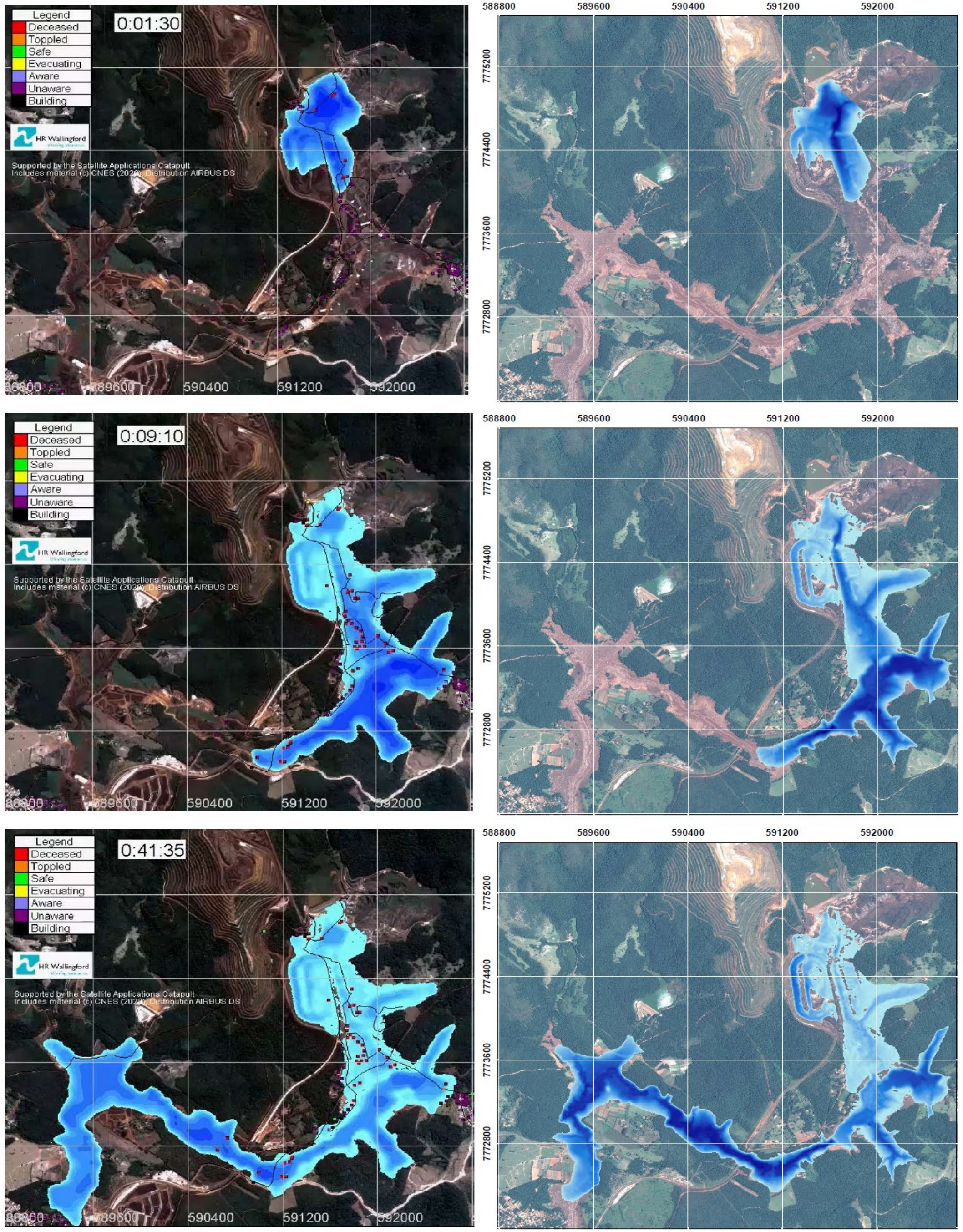

Questions?