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Managing Water in the West

2D River and Watershed Modeling with GSTAR-W v1.0

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Outline

- Background
- Advantages/Capabilities/Features/Limitations
- Formulation and Numerical Methods
- Modeling Steps
- Verification Cases
- Application Cases

GSTAR-W Stands for:

Generalized **S**ediment **T**ransport for

Alluvial **R**ivers and **W**atersheds

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Acquiring GSTAR-W v1.0

- **Website: http://www.usbr.gov/pmts/sediment**
- **Download executable GSTAR-W + User's Manual**
- **Selected papers & project reports**

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General Capability

- Two Dimensional (2D) Depth-Averaged Modeling

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Why GSTAR-W?

- Commercial Codes
  - Too expensive to own
  - Black-box: garbage-in garbage-out
  - Too many inputs & turning parameters
  - Limited sediment and erosion capabilities
- Research Codes
  - Availability issue
  - Hard wired
  - User unfriendly
  - Error prone

GSTAR-W Advantage

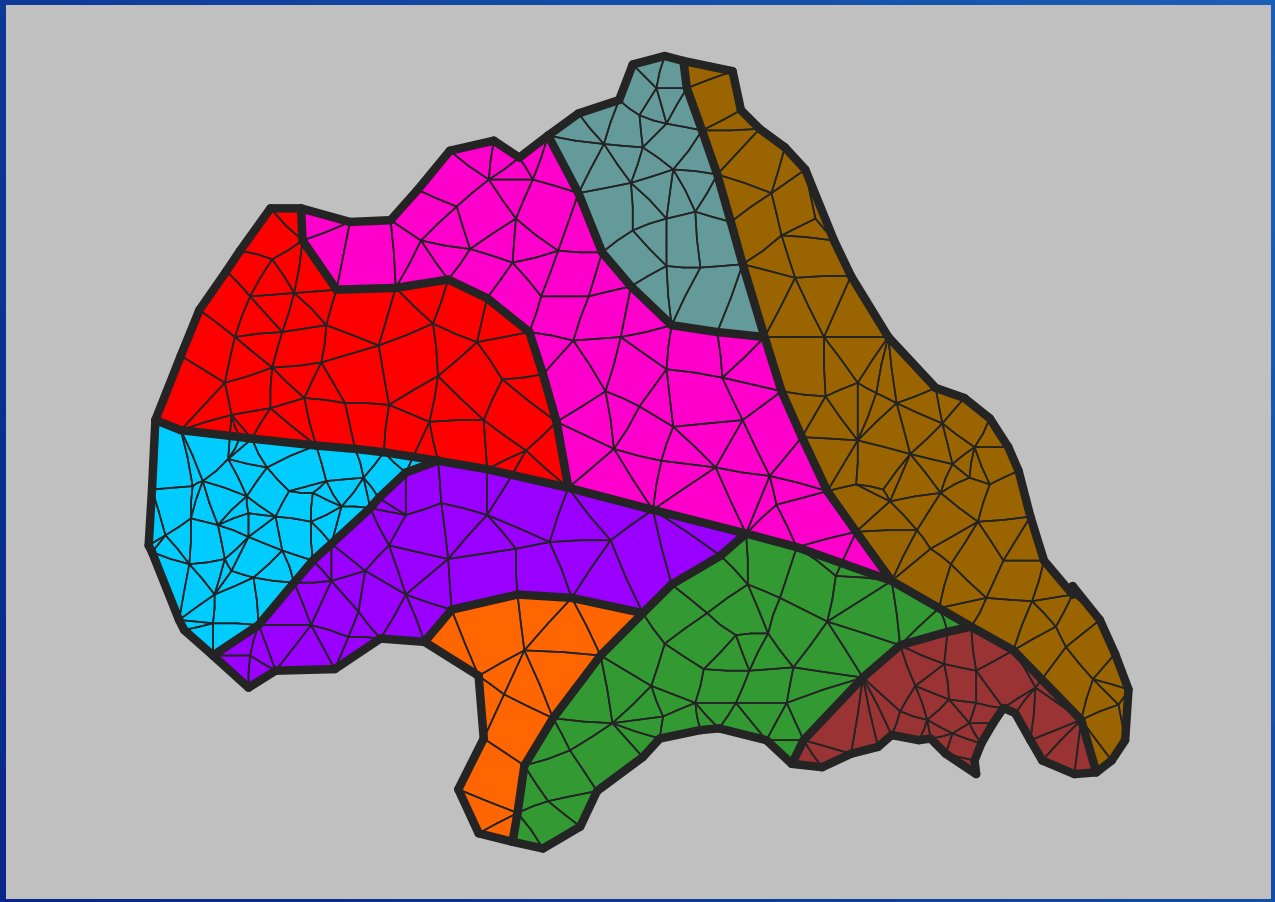
- Easy to Learn
  - A tutorial case + occasional reference to User's Manual
  - An interactive preprocessor to guide input setup
- Easy to Apply
  - Flexible mesh: generous requirements of mesh topology and requirements
  - Dynamic execution control
  - Very few input parameters for tuning
  - Interface with SMS for mesh generation
  - Interface with SMS or GIS for result post-processing
- Easy to Solve
  - Stable and fast numerical algorithm

GSTAR-W Features

- River Application or Watershed Applications
- River Application:
  - Main channels + Side Channels + Floodplain + Structures
  - Diffusive Wave or Dynamic Wave
  - Purely 2D Analysis
- Watershed Application:
  - Distributed Modeling
  - Diffusive Wave Only
  - Purely 2D Analysis; or 2D Watershed + 1D Channel Network

Modeling Concept: Zonal Modeling

- 1D or 2D zone, arbitrary cut or along Natural features (topography, channel line, land use, soil types, etc.)



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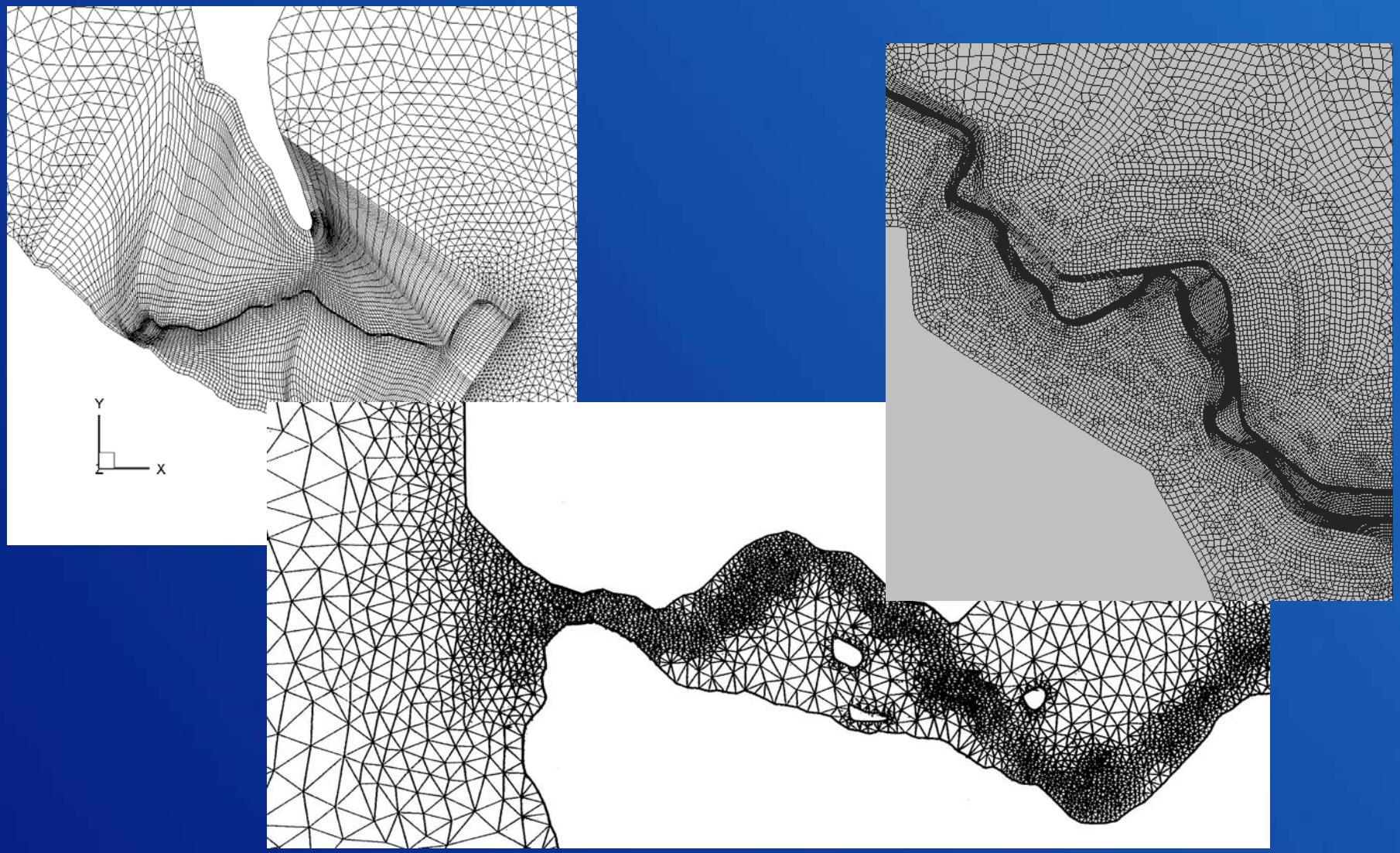
Modeling Feature: Flexible Mesh



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Major Capabilities

- Two Dimensional (2D) Depth-Averaged
- Diffusive wave or dynamic wave equations
- Steady or unsteady flows
- Sub-, Super-, and Trans-Critical Flows
- Implicit solver
- Unstructured or structured 2D meshes
- Output: water surface elevation, water depth, depth averaged velocity, and bed shear stress.

Version 1.0 Limitations

- Flow runoff and flow hydraulics only;
- Erosion and sediment transport will be added in future versions;
- Solution module only: mesh generation relies on SMS; post processing uses SMS, GIS, or TECPLOT;
- Only Pentium-based Personal Computers with Windows 2000/XP or NT operating systems.

Governing Equations

- **Dynamic Wave Equations (St Venant Equations)**

$$\frac{\partial h}{\partial t}+\frac{\partial hU}{\partial x}+\frac{\partial hV}{\partial y}=e$$

$$\frac{\partial hU}{\partial t}+\frac{\partial hUU}{\partial x}+\frac{\partial hVU}{\partial y}=\frac{\partial hT_{xx}}{\partial x}+\frac{\partial hT_{xy}}{\partial y}-gh\frac{\partial z}{\partial x}-\frac{\tau_{bx}}{\rho}$$

$$\frac{\partial hV}{\partial t}+\frac{\partial hUV}{\partial x}+\frac{\partial hVV}{\partial y}=\frac{\partial hT_{xy}}{\partial x}+\frac{\partial hT_{yy}}{\partial y}-gh\frac{\partial z}{\partial y}-\frac{\tau_{by}}{\rho}$$

Governing Equations

- **Diffusive Wave Equations**

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(\frac{h^{\beta}}{n\sqrt{S}}\frac{\partial z}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{h^{\beta}}{n\sqrt{S}}\frac{\partial z}{\partial y}\right) + e$$

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Numerical Method

- Finite Volume Method
- Implicit Time Discretization
- Segregated Solver
- Upwind or central difference scheme for convection
- 2nd-order scheme for diffusion term

Initial Conditions

- Steady Simulation
  - Only water surface elevation Z is critical, the rest, such as velocities, are setup automatically by GSTAR-W
  - Options for initial Z:
    - Constant Z
    - Dry bed
    - Automatic distributed wet cell setup by GSTAR-W
    - From another GSTAR-W solution
- Unsteady Simulation
  - Use a steady-state solution from GSTAR-W

Boundary Condition: Inlet

- Inlet: water flows into the domain
- Multiple inlets may be used
- BC at an inlet: Flow Discharge (steady or hydrograph)
  - Constant-V Setup: uniform velocity across the inlet; or
  - Constant-q Setup: uniform q=Vh across the inlet
- Additional Condition at Inlet if Supercritical:
  - Water Surface Elevation

Boundary Condition: Exit

- Exit: water flows out of the domain
- Multiple exits may be used
- BC at an exit:
  - Water surface elevation if subcritical exit
    - Constant Z
    - Time series
    - Rating curve (Z ~ Q)
  - None if supercritical exit

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GSTAR-W Solution Steps

- Mesh Generation
  - SMS
- Input Preparation
  - GSTAR-W Preprocessor: gswpre10
- Solution
  - GSTAR-W Main Solver: gstarw10
- Post-Processing
  - SMS, GIS, TECPLOT

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A Simple Tutorial Case:

- MacDonald (1995) Test Case 1
- 1D Subcritical Flow (Fr = 0.40 ~ 0.77)
- 1000m by 10m domain
- Q = 15 cms
- Z_exit = 0.7484m

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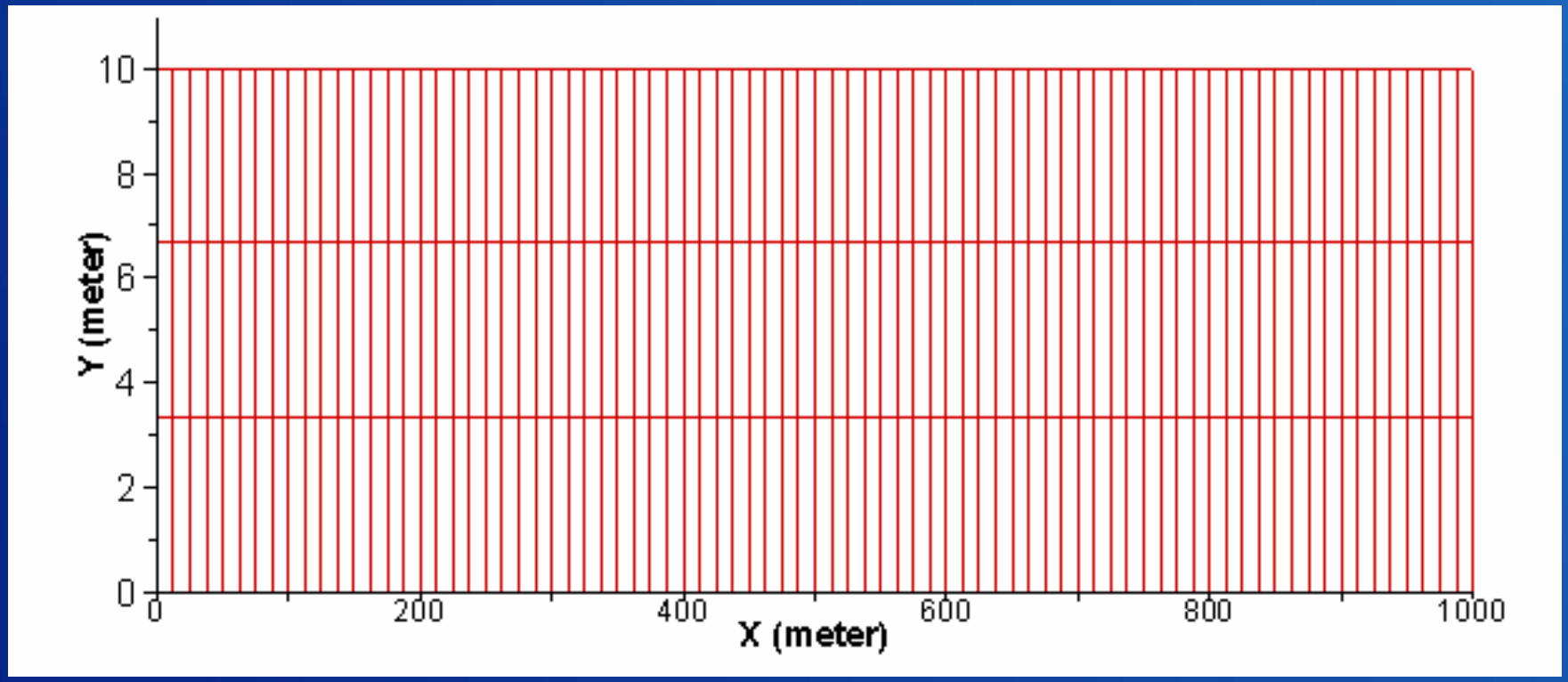
Simulation Steps & Input

- **Step 1: Mesh Generation (81X4 mesh)**



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Step 2: Input Setup using GSWPRE10

gswpre10

File Edit View State Window Help

Graphic1

```
            the rest gives:  Time(s) ~ Variable(SI-Unit)
            Note that only SI unit is assumed for the variable!

==> STEADY-OR-UNSTEADY-SIMULATION
    Enter: 1 --> Steady-State Simulation
           2 --> Unsteady Simulation

==> UNSTEADY-SIMULATION-PARAMETERS:
    Enter: TSTART DT NTSTEP (space separated)
    where:
    TSTART: simulation starting time in second; 0 is used normally
    DT:     time step in second
    NTSTEP: total number of time steps used
    NOTE: dt and ntstep may be changed during code execuation through casename_DIP.dat f

==> MOLECULAR-VISCOSITY-FOR-WATER
    Enter 1 or 2:
          1 --> Constant Value
          2 --> From a formula given the temperature (to be done)

==> CONSTANT-KINEMATIC-VISCOSITY
    Enter kinematic viscosity in m^2/s (about 1.0e-6)

==> TURBULENCE-MODEL-SELECTION
    1= Laminar Flow
    2= Depth-Averaged Parabolic Model Vis=a*Vstar*h
       a=0.7 is used; use casename_DIP.dat is different a is used
    3= Standard k-e model (unavailable currently)
end of file run.save reached. Start on-screen input !

==> TURBULENCE-MODEL-SELECTION
    1= Laminar Flow
    2= Depth-Averaged Parabolic Model Vis=a*Vstar*h
       a=0.7 is used; use casename_DIP.dat is different a is used
    3= Standard k-e model (unavailable currently)
```

Running | Input pending in Graphic1

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Script Input File (SIF) Generated

```
// Flow Solver Selection (2=diffusive 3=dynamic)
3
// List-of-Output-Variables
wse wd u v fr
// Steady-or-Unsteady (1=Steady 2=Unsteady)
1
// Molecular-Kinematic-Viscosity
0.0
// Constant Initial Condition for WSE
6. 0
```

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Script Input File (SIF) Generated (continued)

```
// Mesh File Name and Format
mesh.dat  PLOT3D
// Manning Coefficient
0.03
// Boundary Type Definition
1  inlet-Q  15.0  cms
2  exit
// BC ID
2
// WSE
0.7484
```

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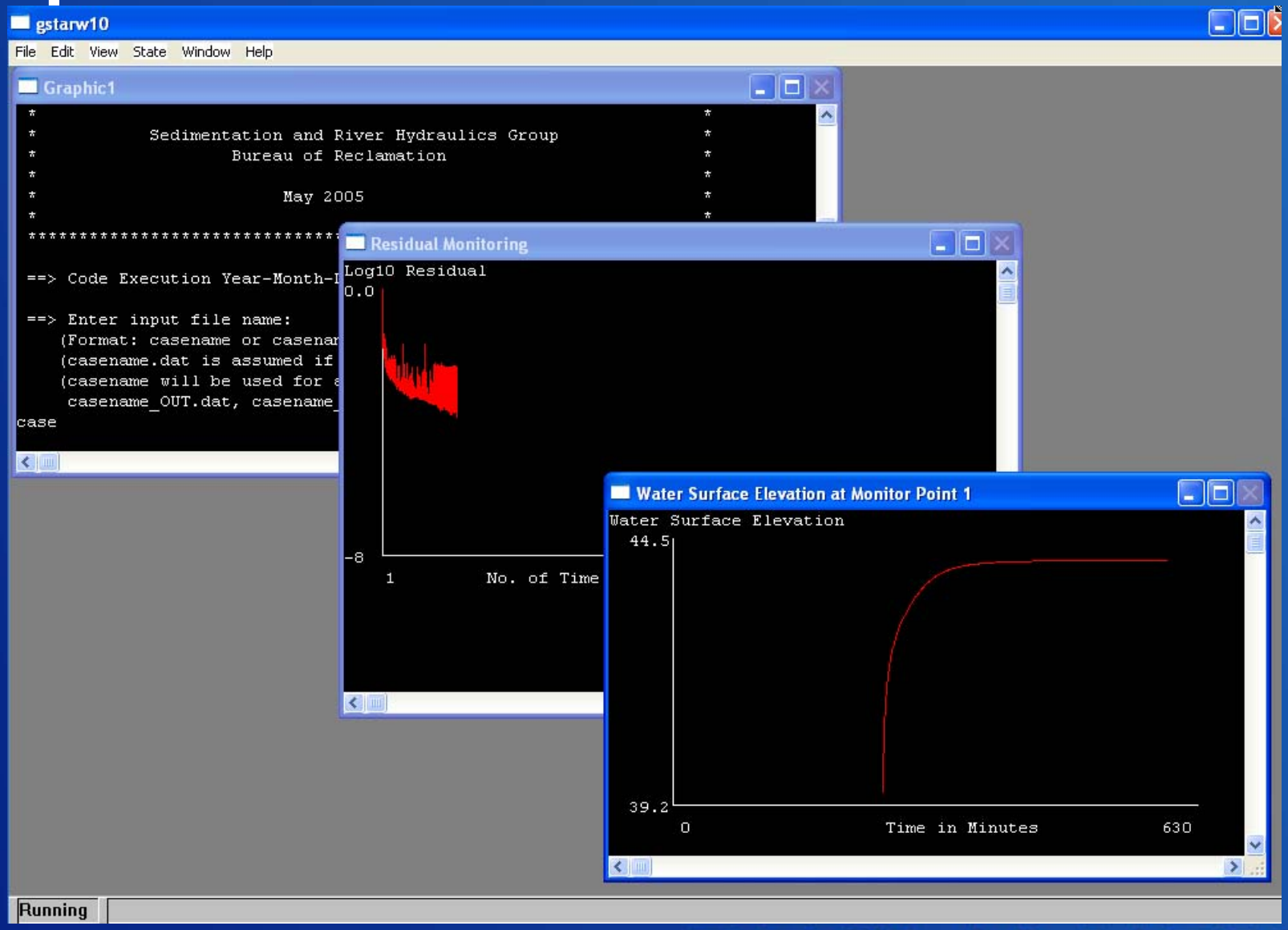
Step 3: Execute GSTARW10



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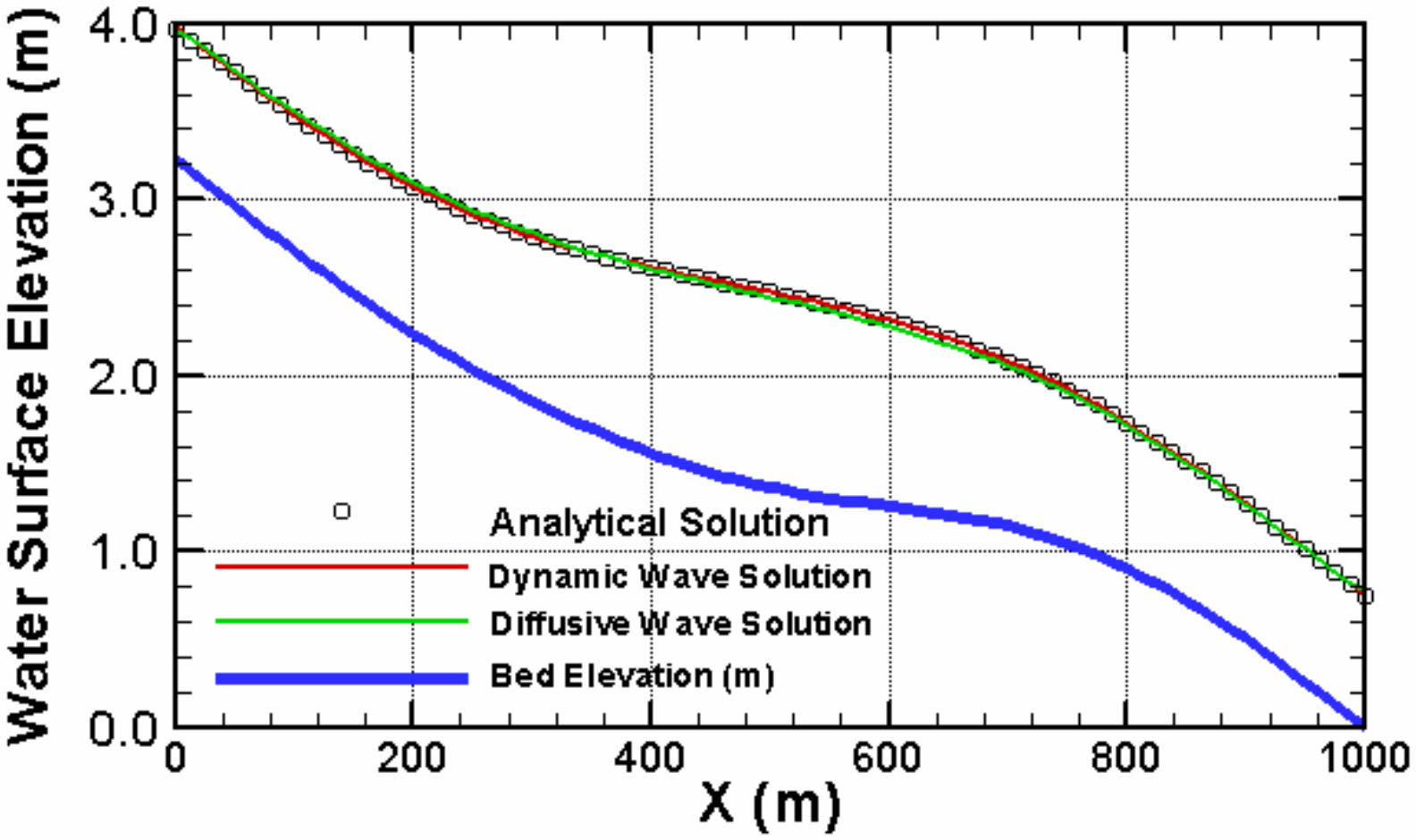
Step 4: Post-process Results



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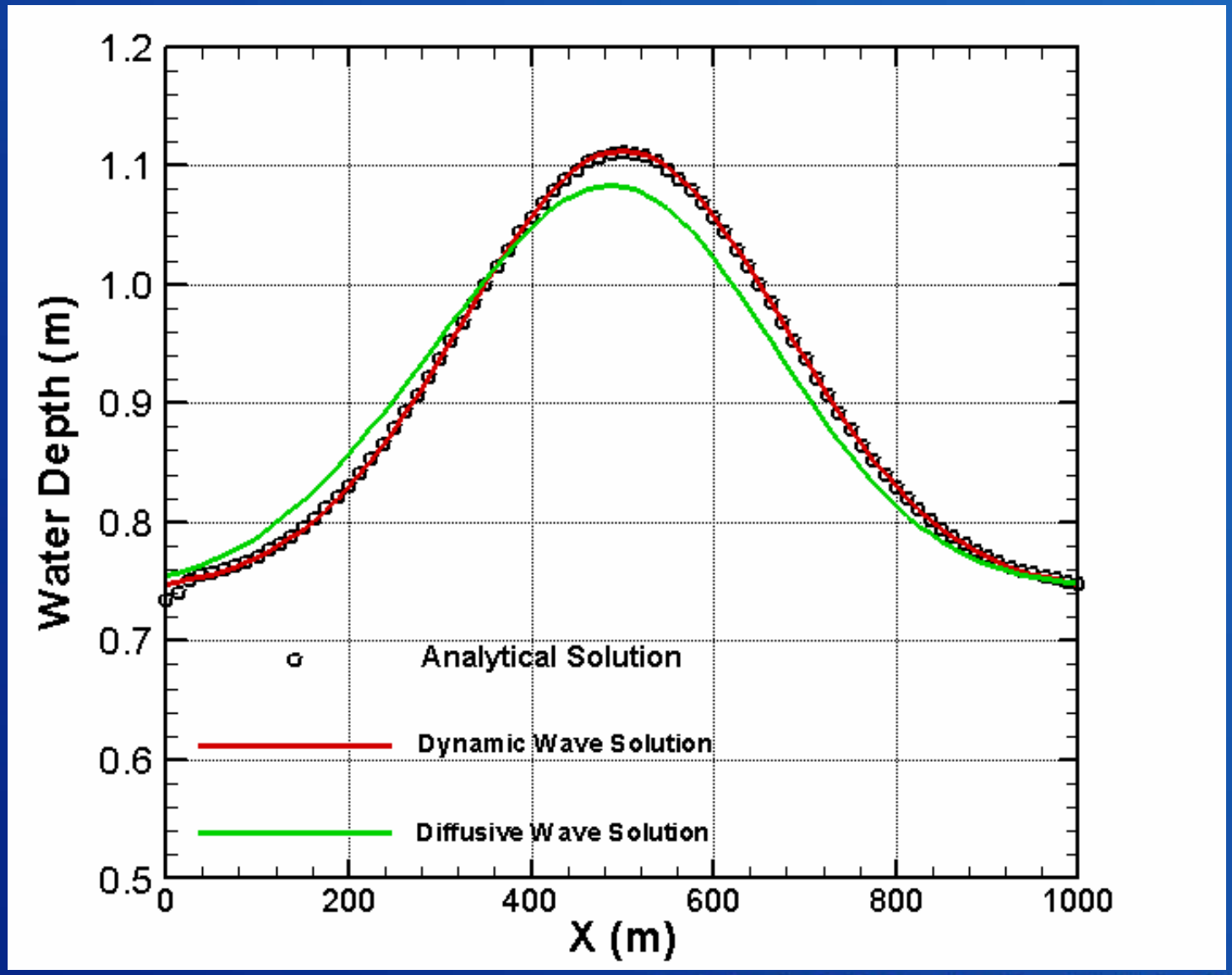
Water Depth Comparison



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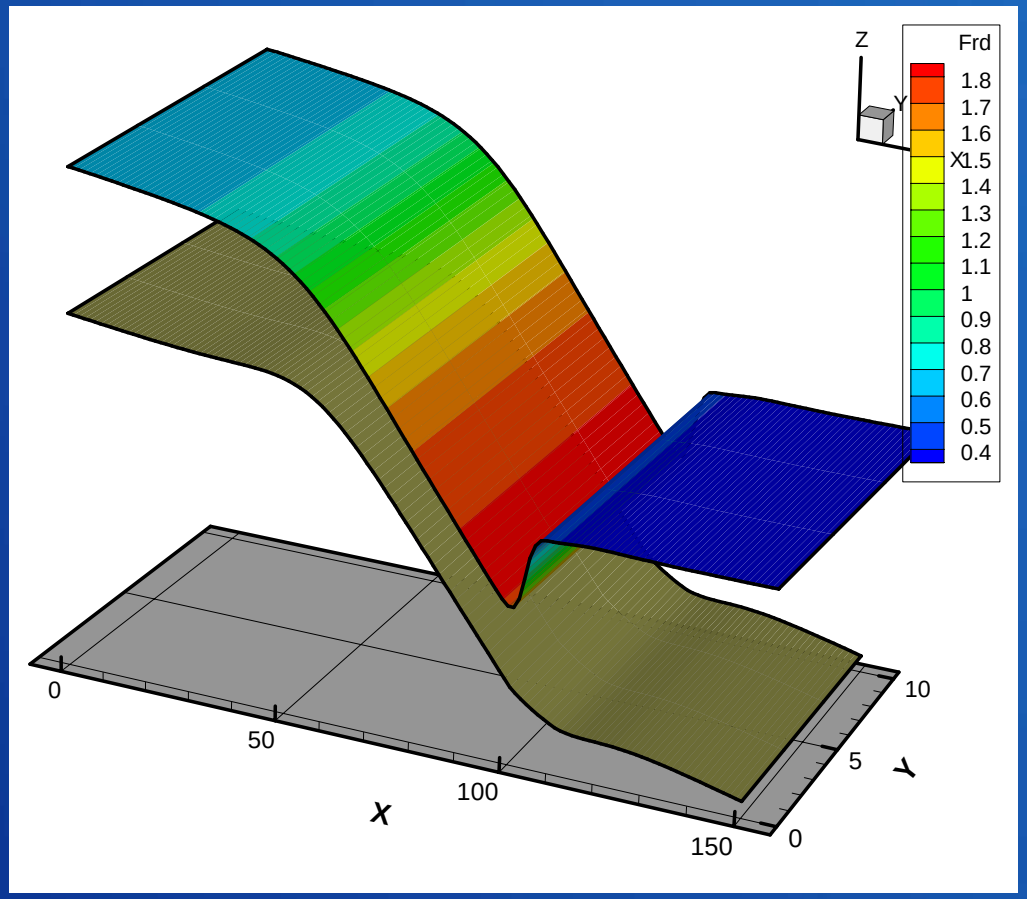
Another Simple Test Case: MacDonald (1995) Test Case 6

- 1D Transcritical Flow with Hydraulic Jump
- 150m by 10m Domain
- 121X4 Mesh
- Inlet: subcritical Q = 20 cms
- Exit: WSE = 1.7m
- Manning's Coefficient = 0.031752



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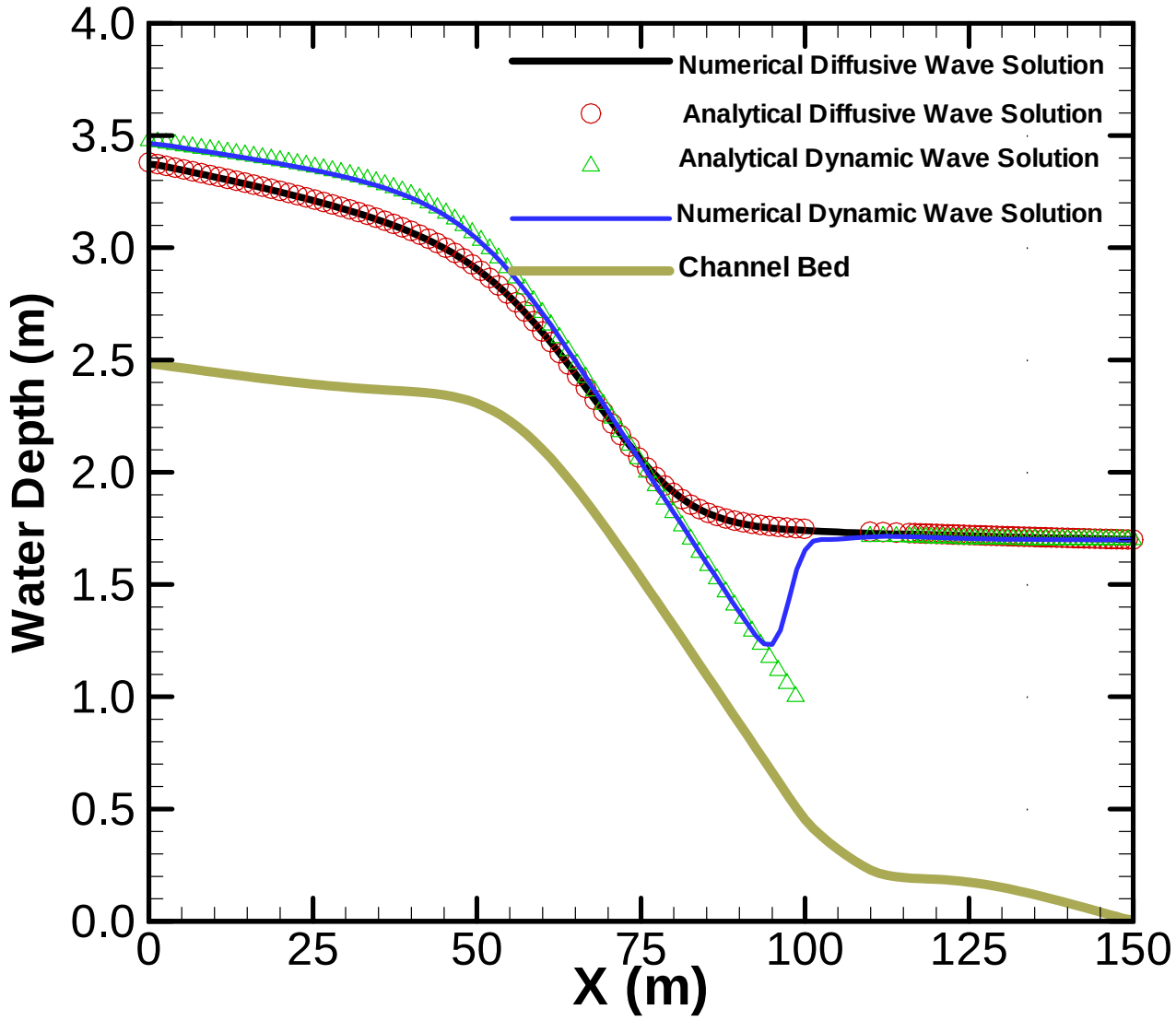
Comparison of Water Surface Elevation



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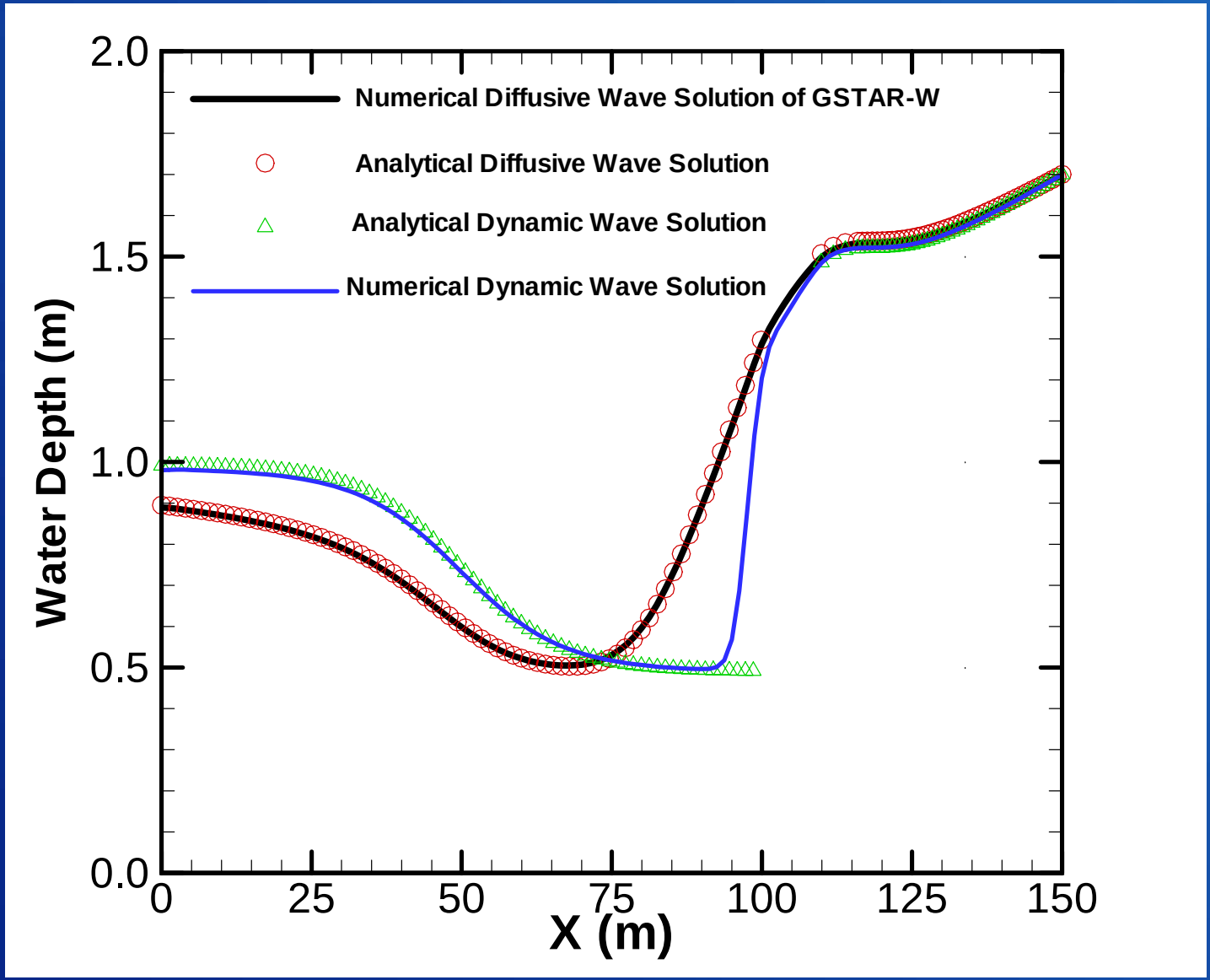
Comparison of Water Depth



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Verification & Validation Cases:
Savage Rapids Dam (SW Oregon)

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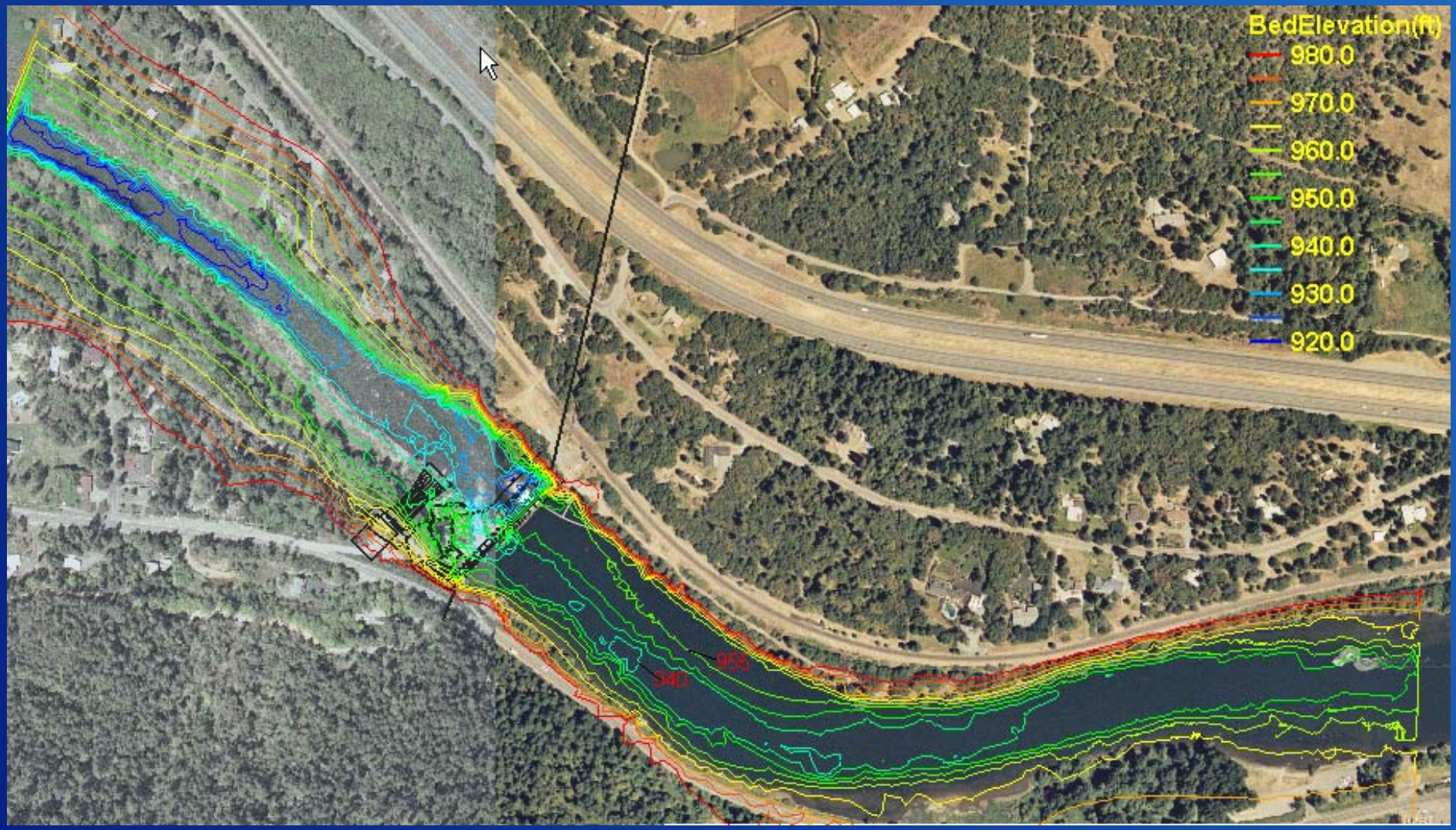
Plainview and Contours



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Mesh: 20,468 Points; Flow: 2,800cfs

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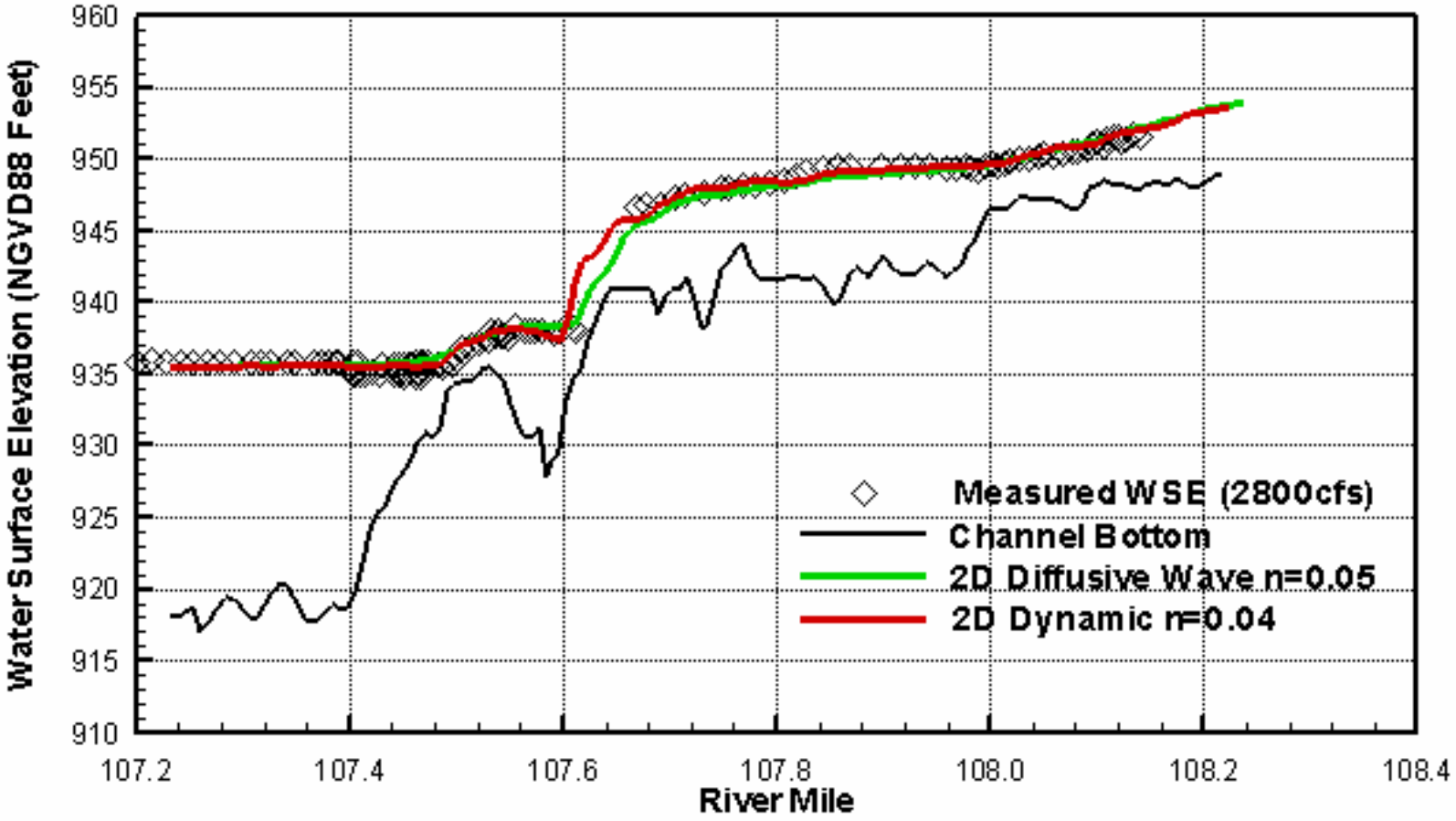
Comparison of Water Surface Elevation (Q=2,800 cfs)



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Measurement Points for Velocity Comparison

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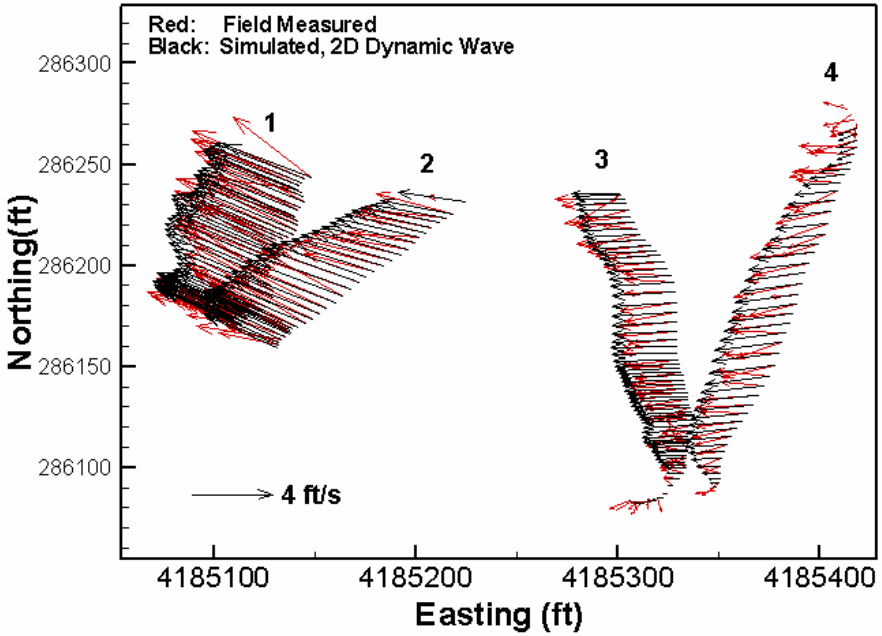
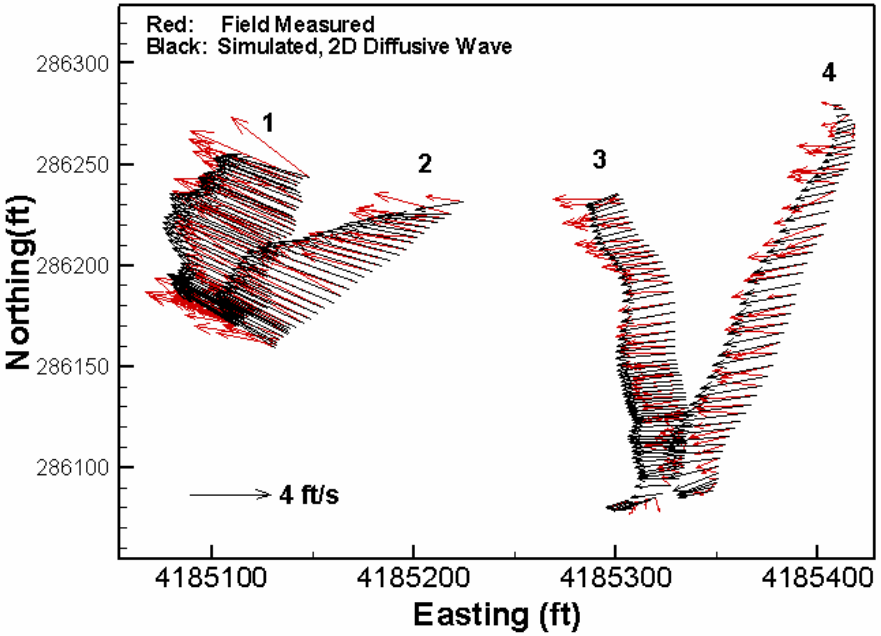
Velocity Comparison at XS 1 to 4

Dynamic Solver



Diffusive Wave Solver



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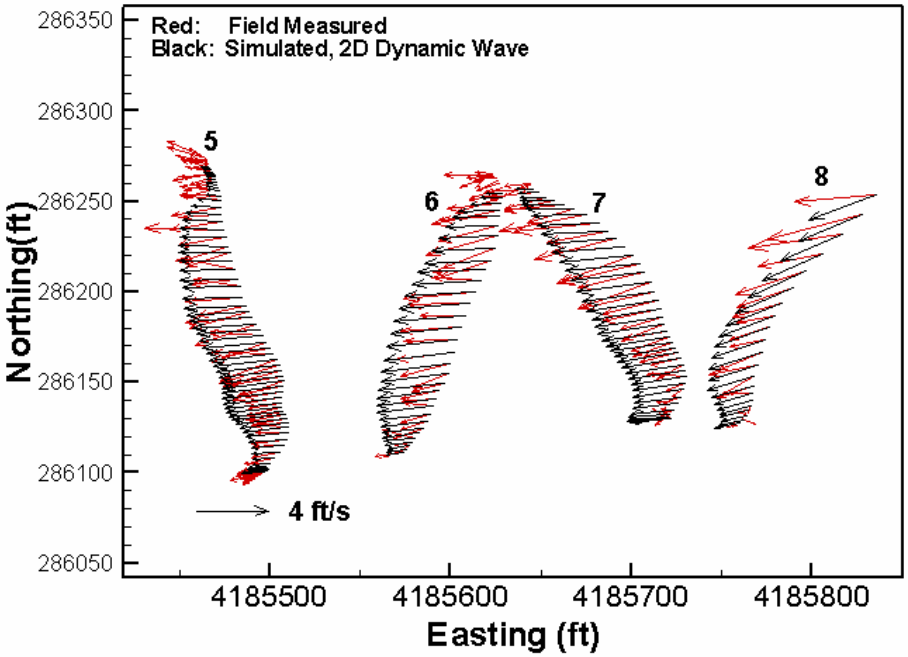
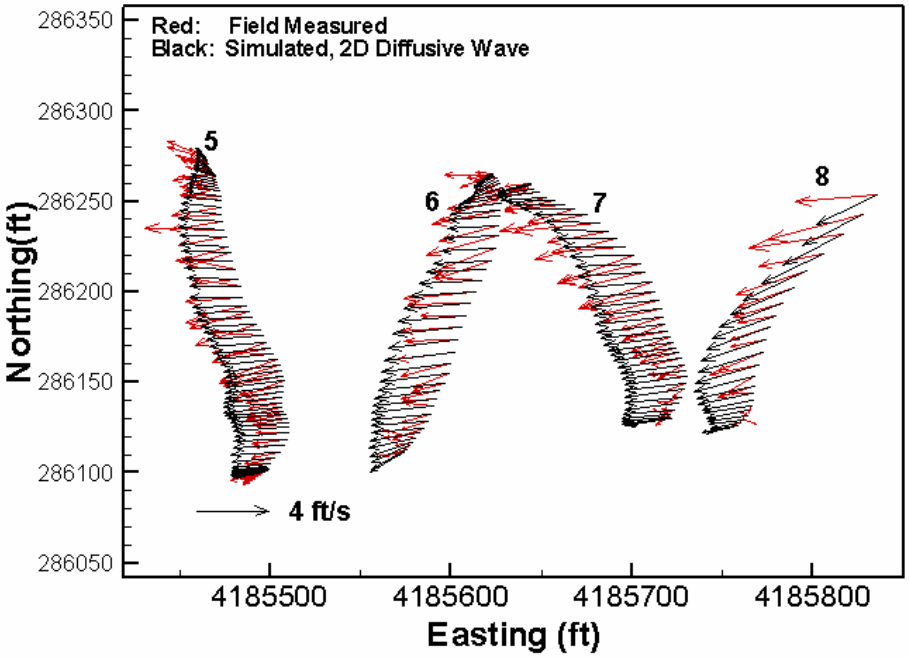
Velocity Comparison at XS 5 to 8

Dynamic Solver



Diffusive Wave Solver



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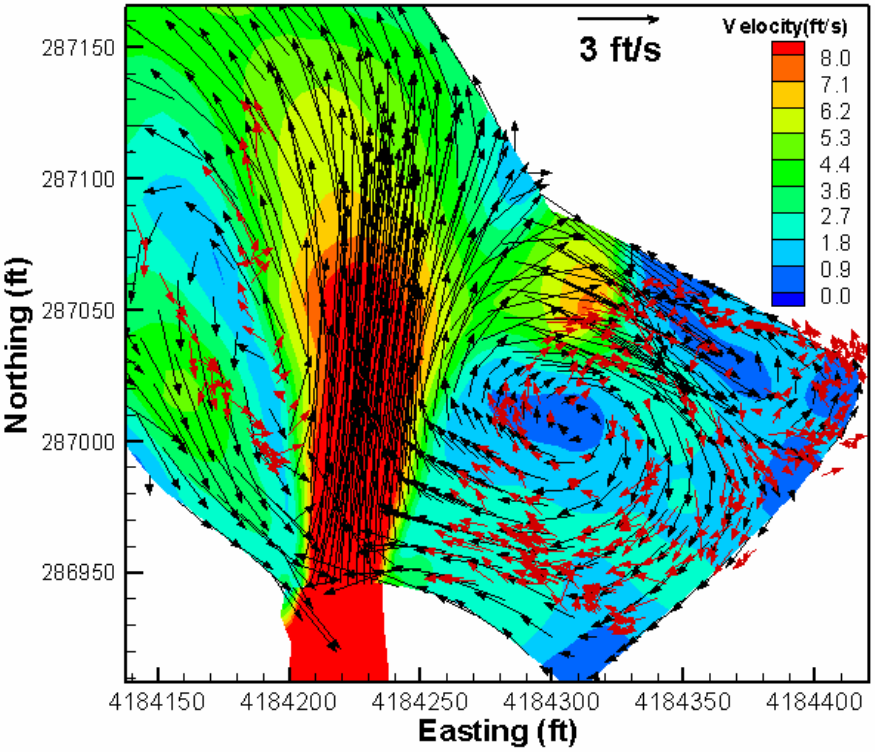
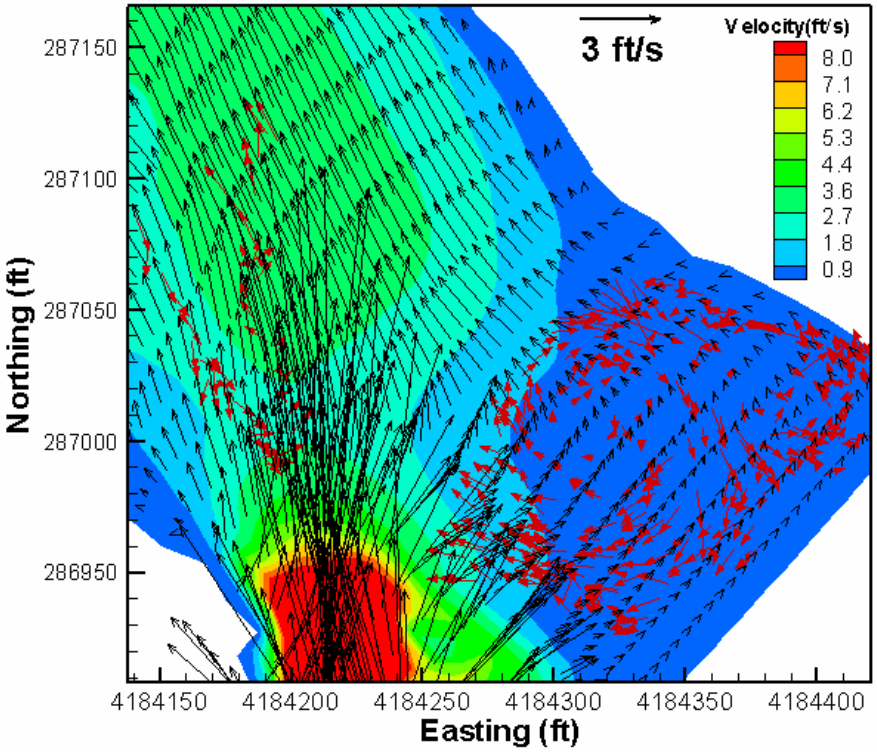
Velocity Comparison downstream of Dam

Dynamic Solver



Diffusive Wave Solver



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Verification & Validation Cases:
Elwha Surface Diversion Project (WA)

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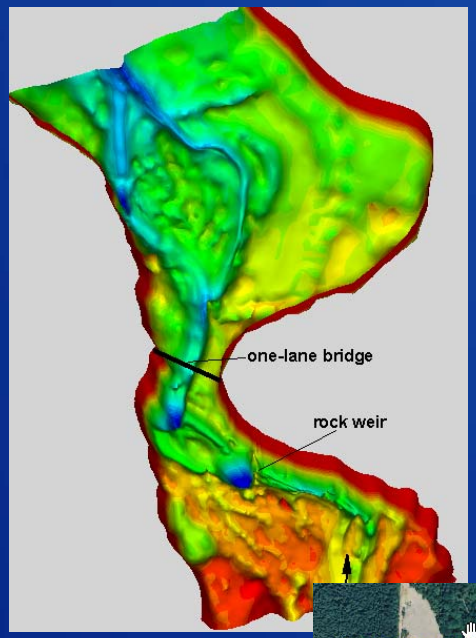
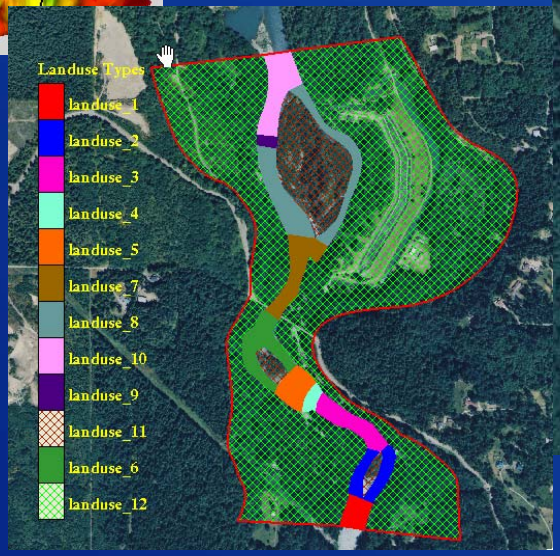
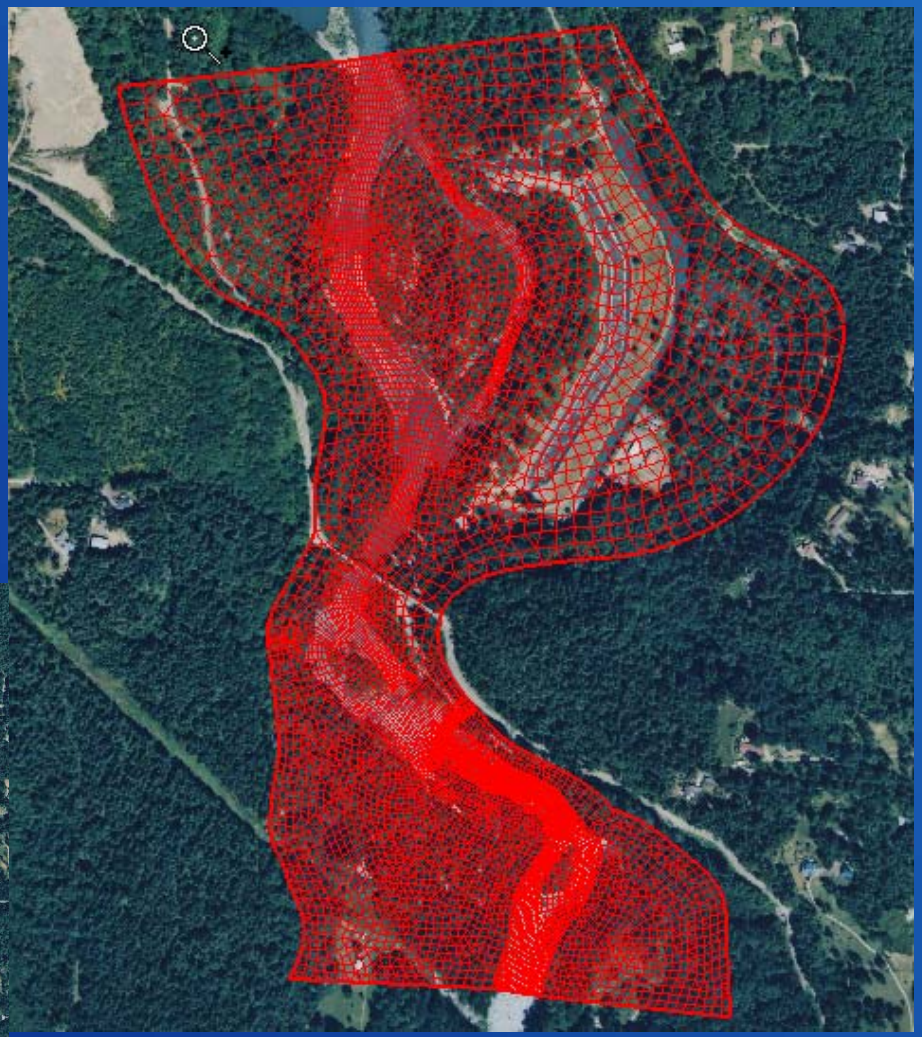
Mesh: ~ 10,000 Points; Low Flow: 1,025 cfs
High Flow: 28,500cfs (2002 Flood)







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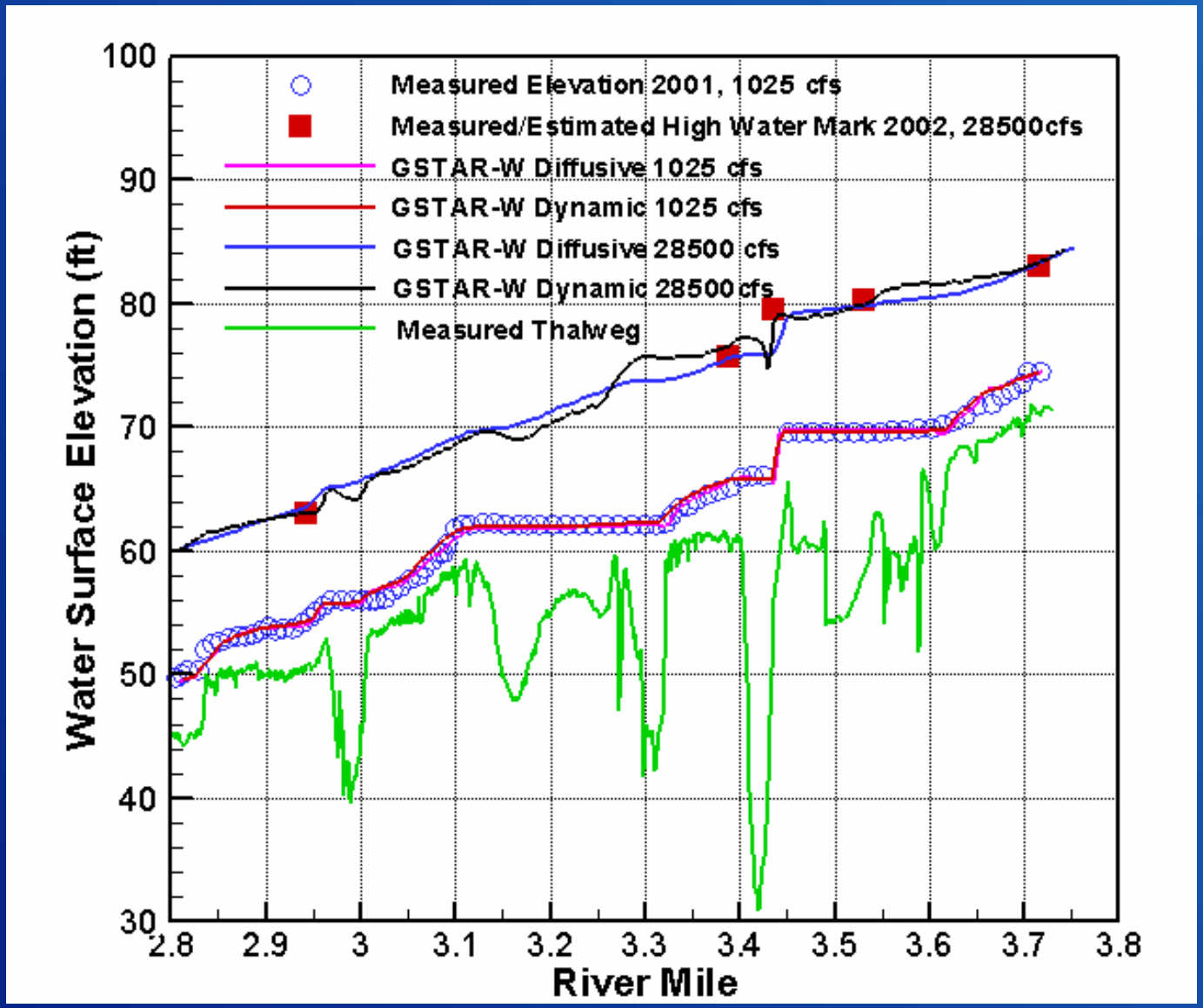
Comparison of Water Surface Elevation



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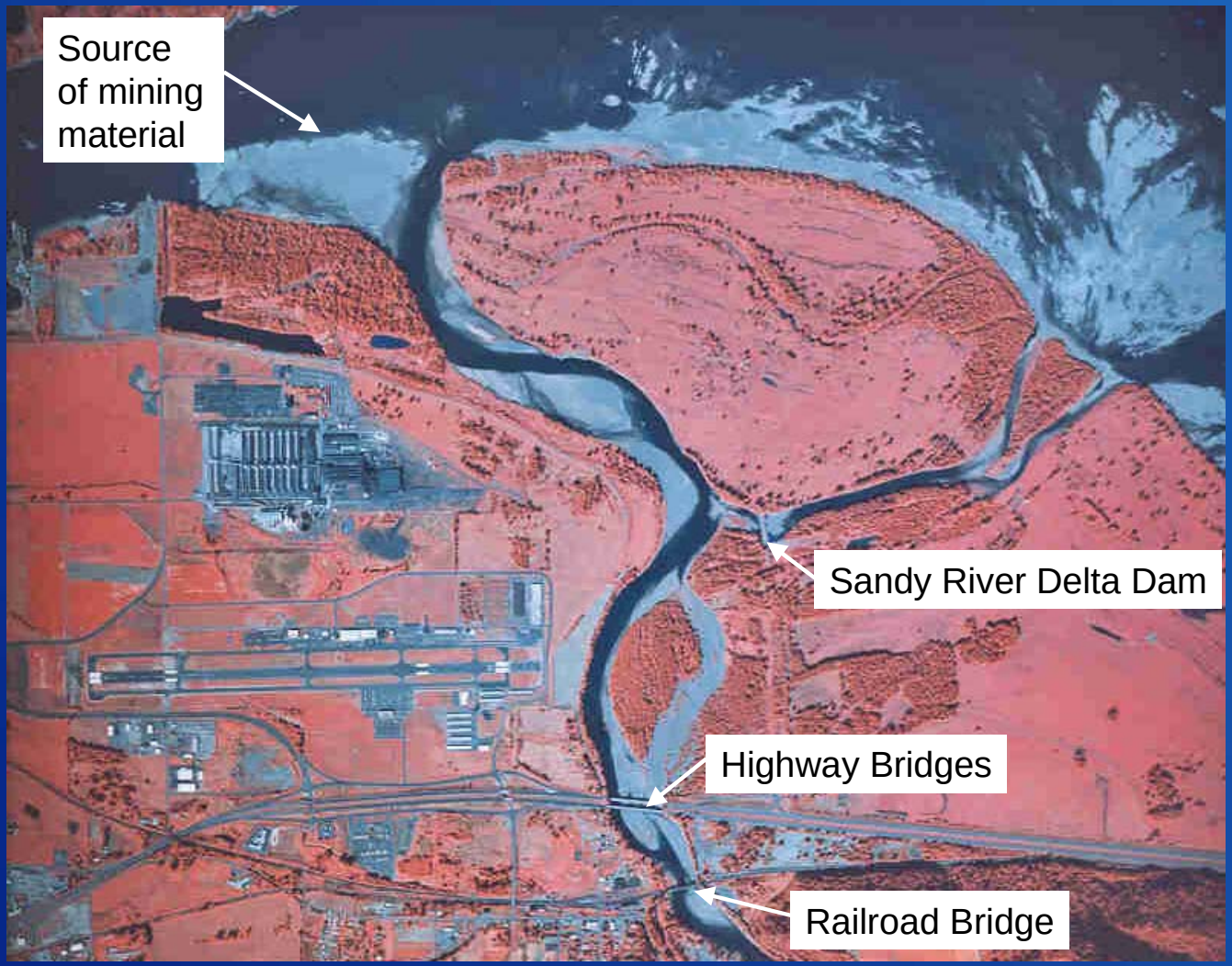
Verification & Validation Cases: Sandy River Delta (Oregon)



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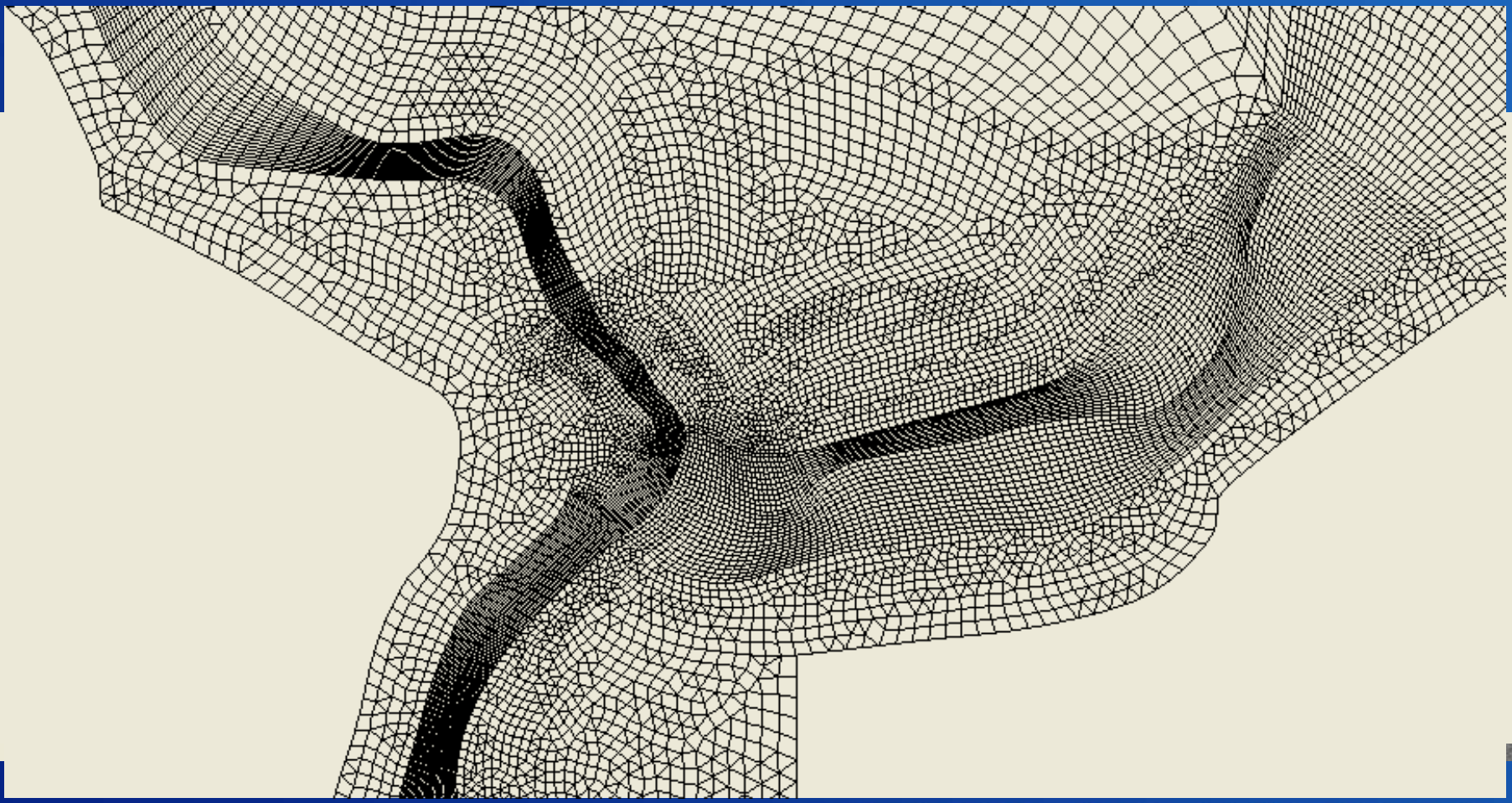
Domain: 9.5 mi of Columbia River
1.2 mi of Sandy River

Mesh: ~ 40,000 points



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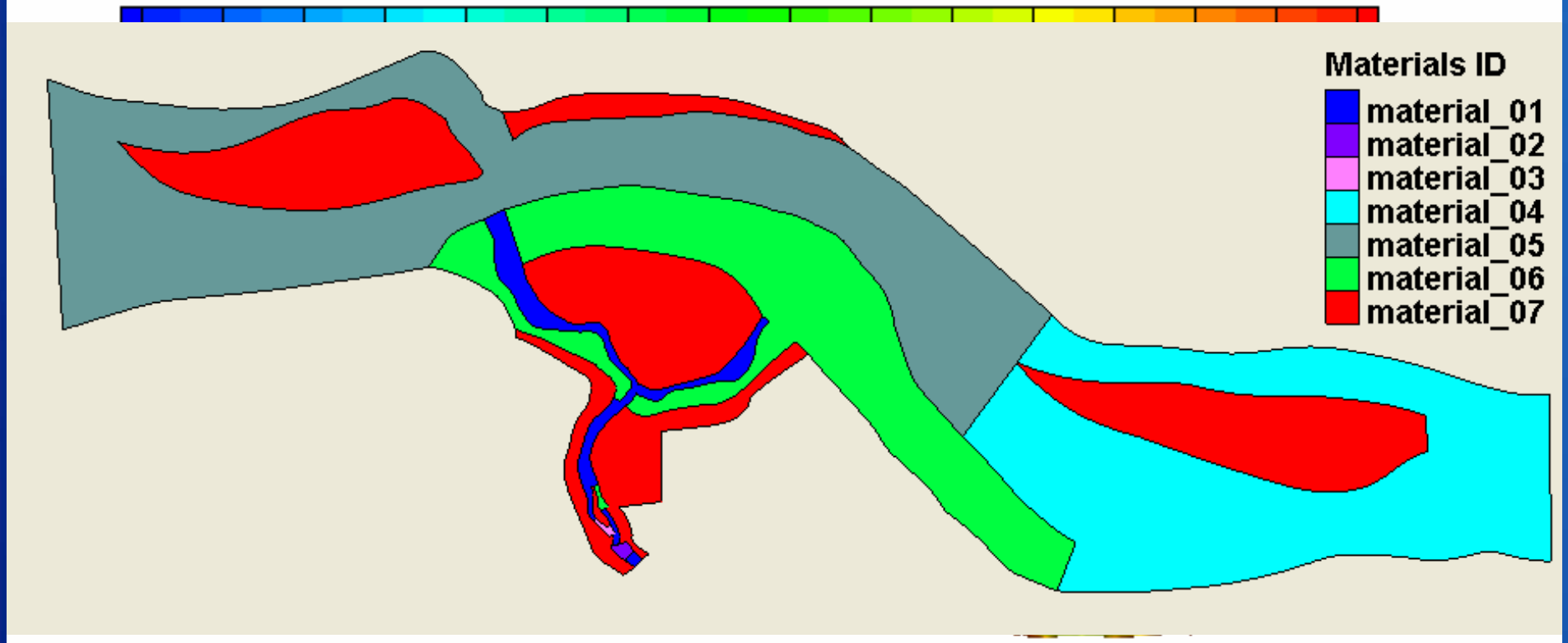
Topography & Landuse Zones



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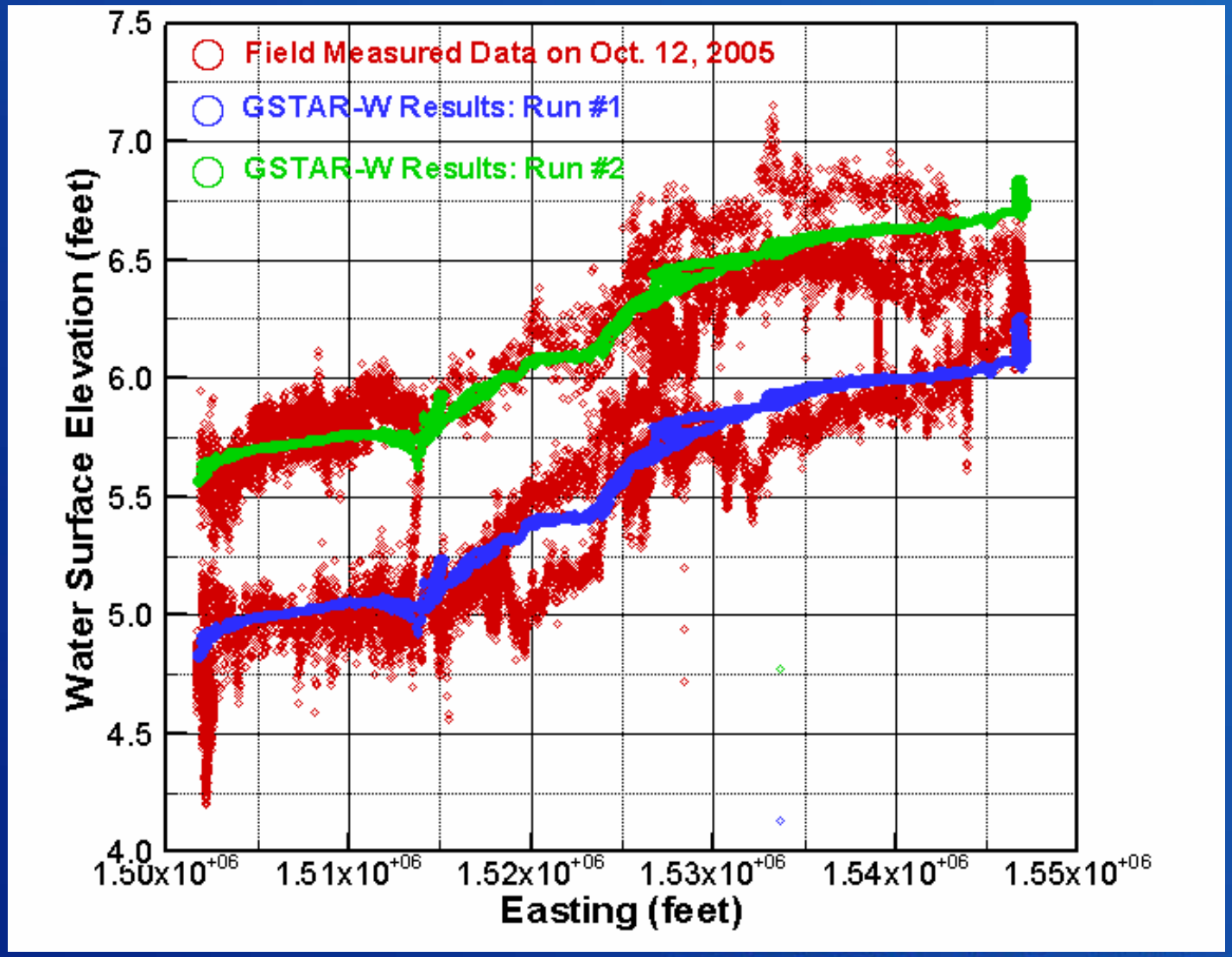
Comparison of Water Surface Elevation
(Q_{Sandy}=377cfs; $Q_{Columbia}$=123,000cfs)



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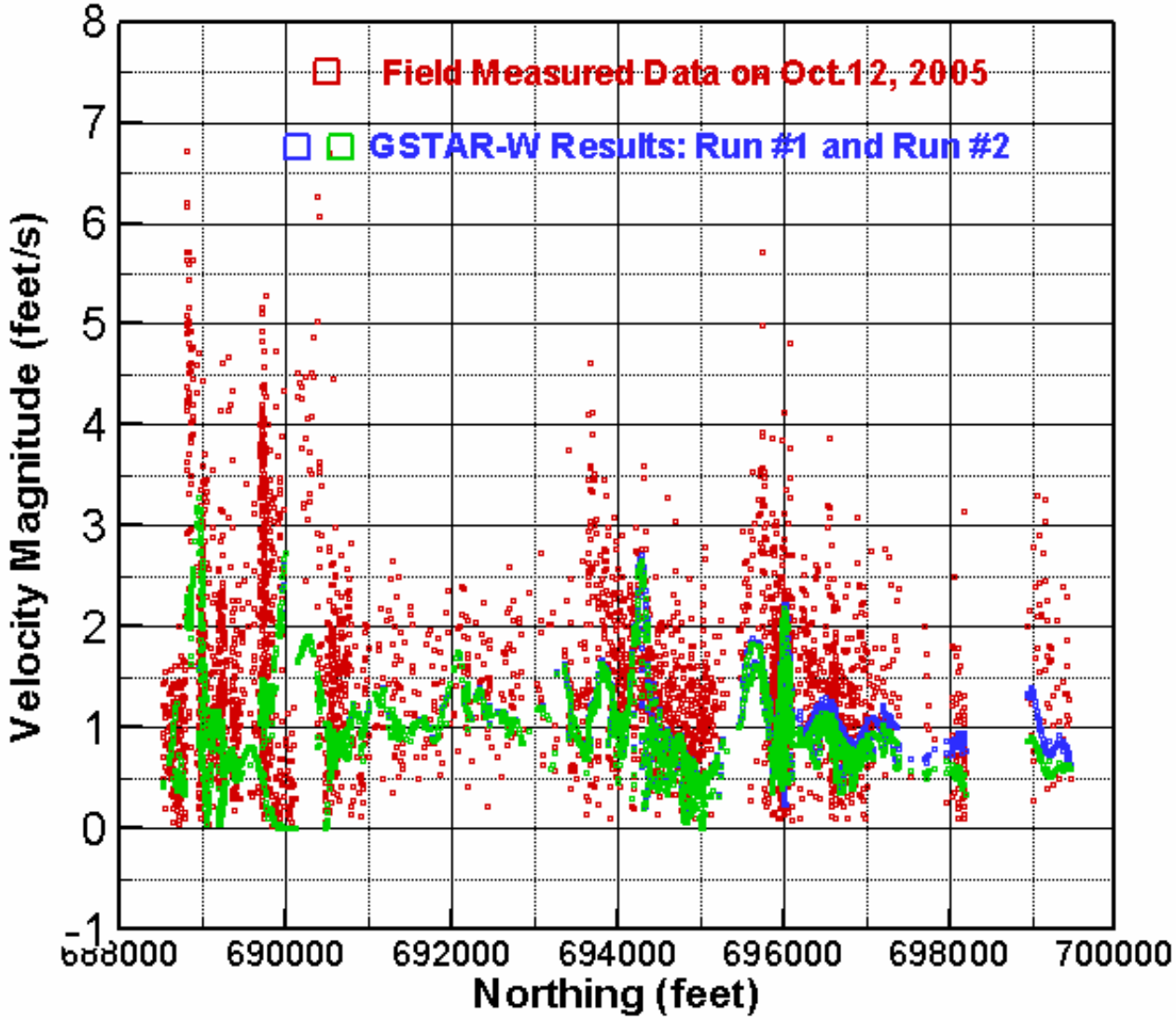
Comparison of Velocity Magnitude



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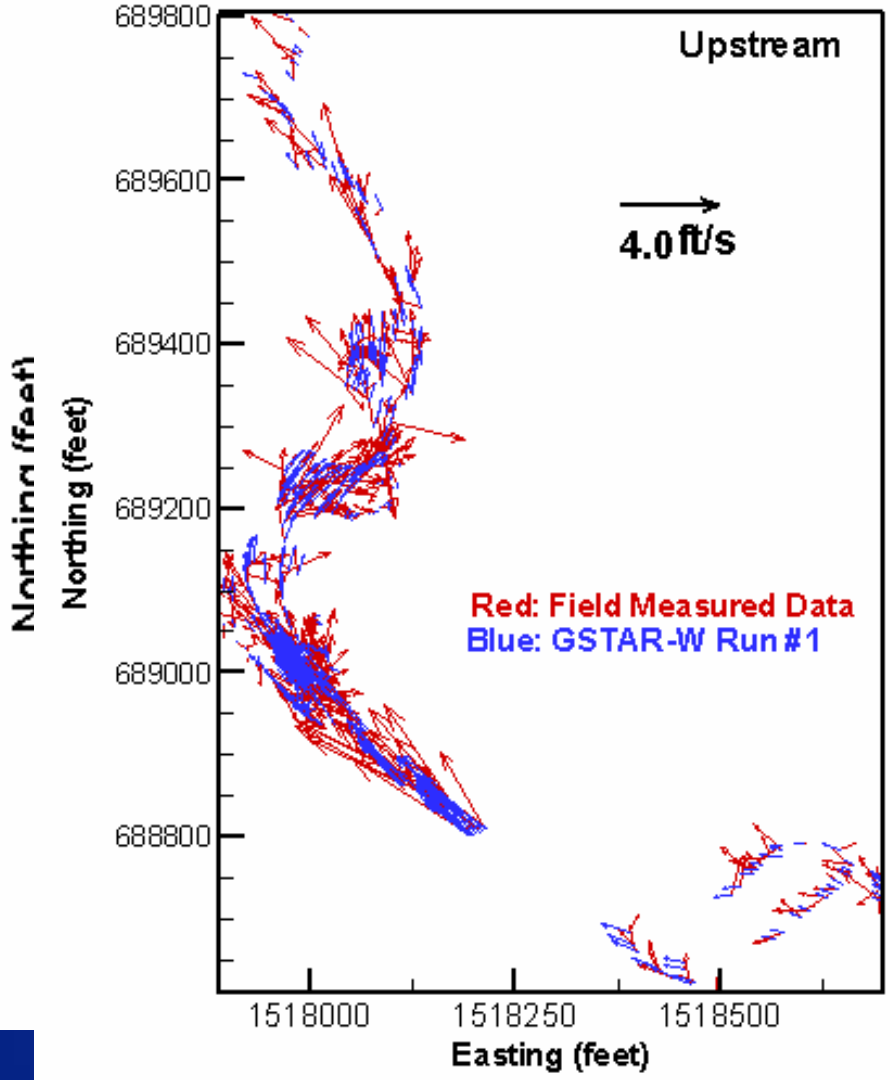
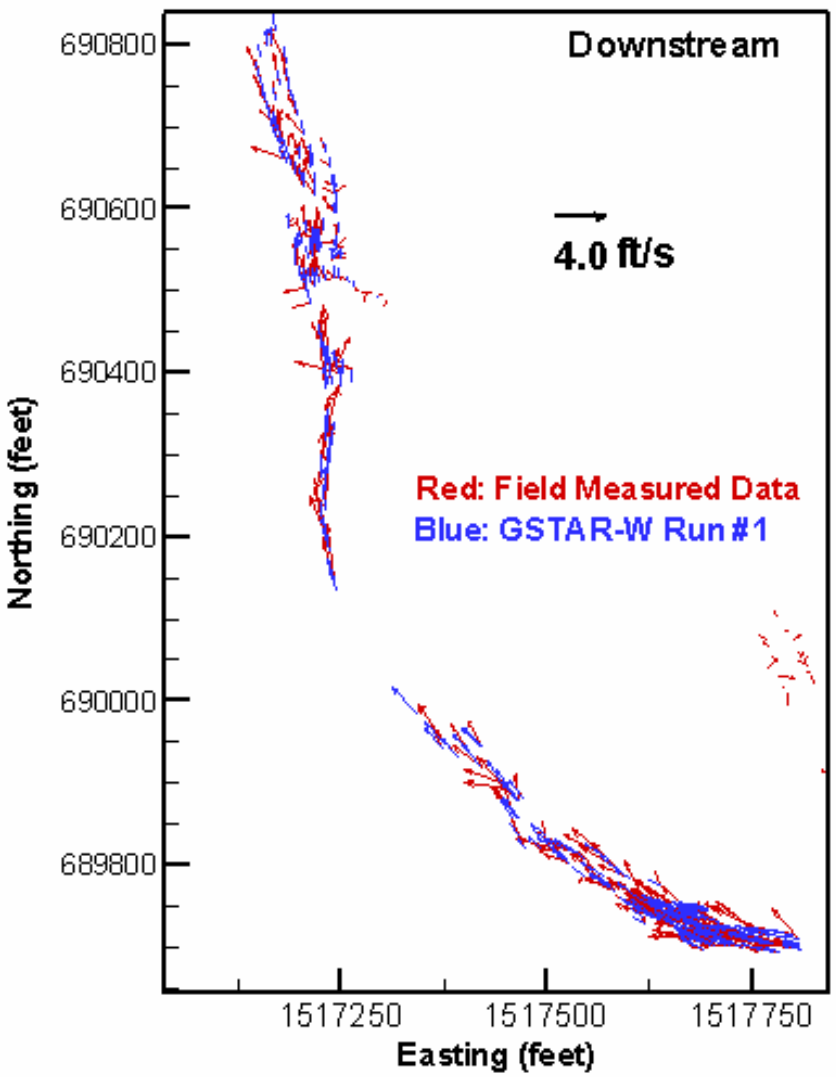
Comparison of Velocity Vector





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Sample Applications

- Savage Rapids Dam Removal Study
- Elwha Surface Diversion Project
- Lower Dungeness Levee Setback Study

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Savage Rapids Dam Removal Study

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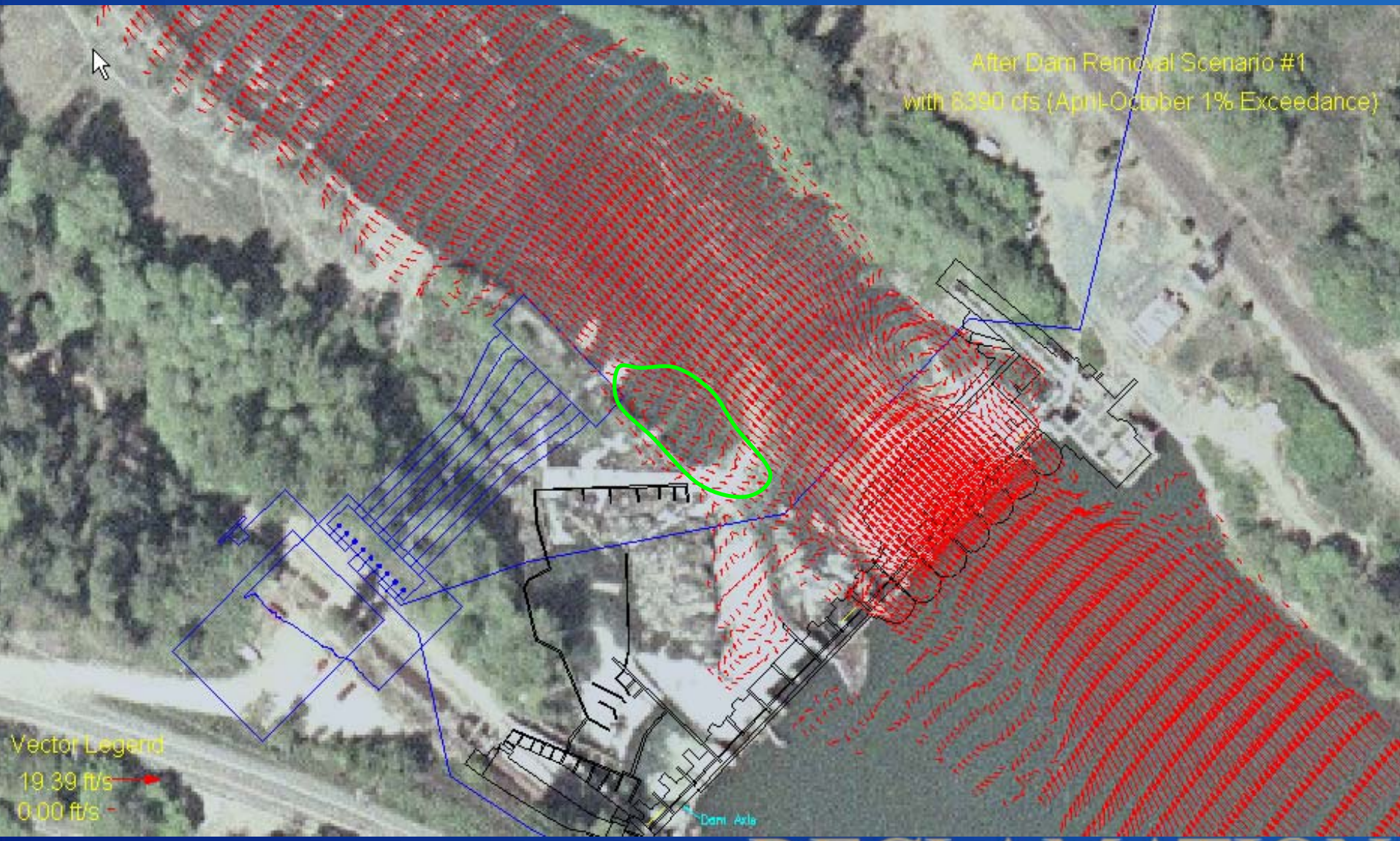
Intake Location Selection



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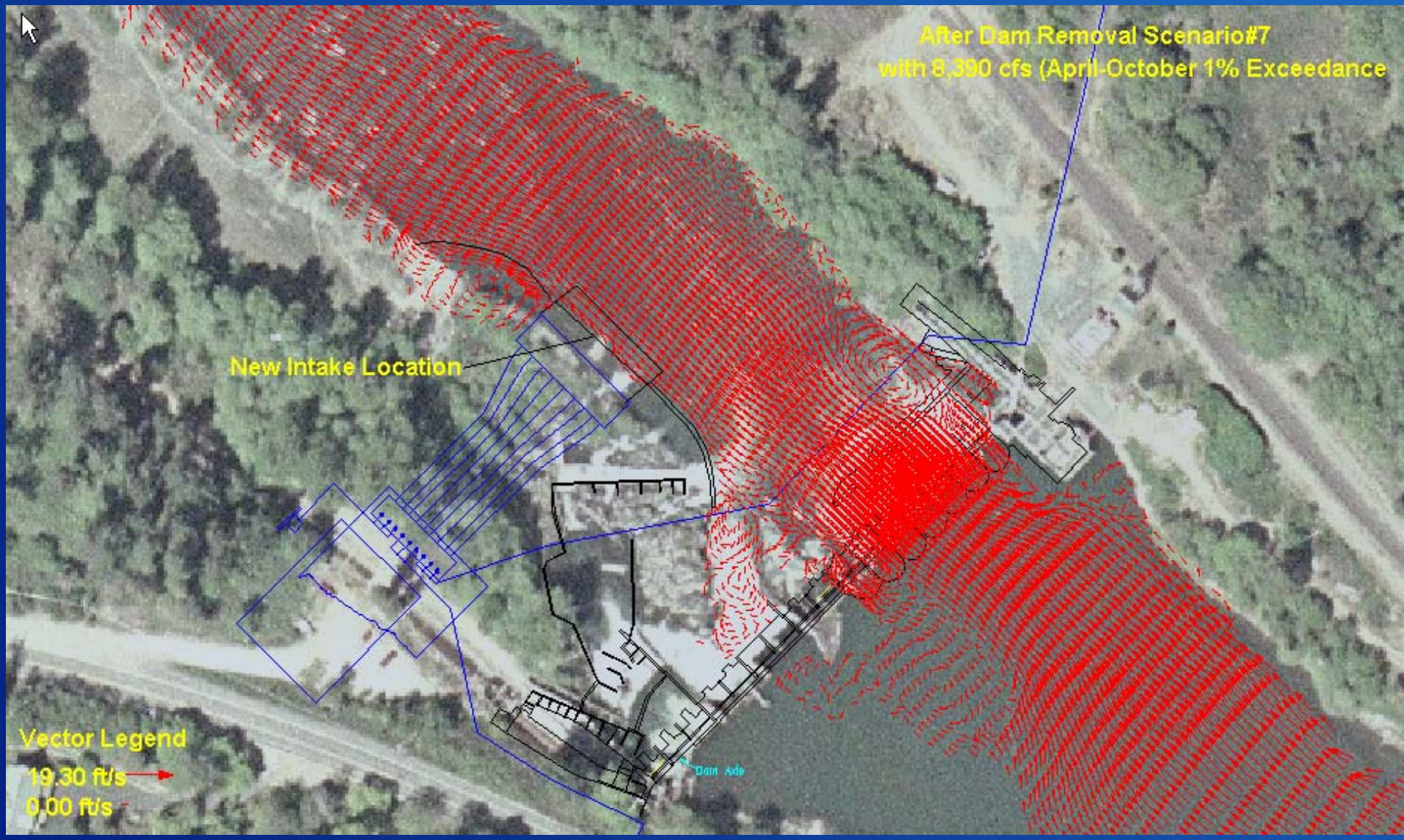
Intake Location Selection



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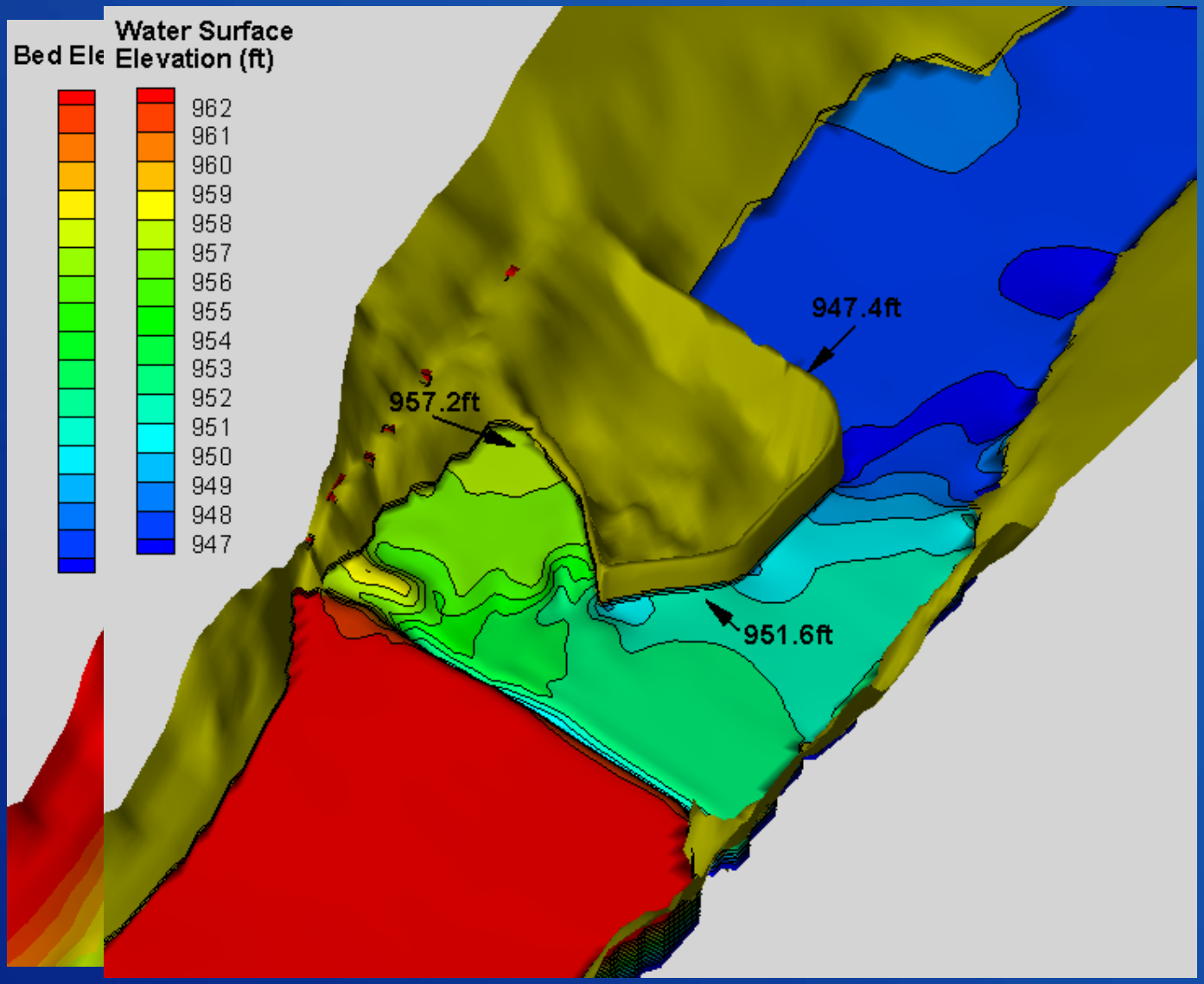
Intake Cofferdam



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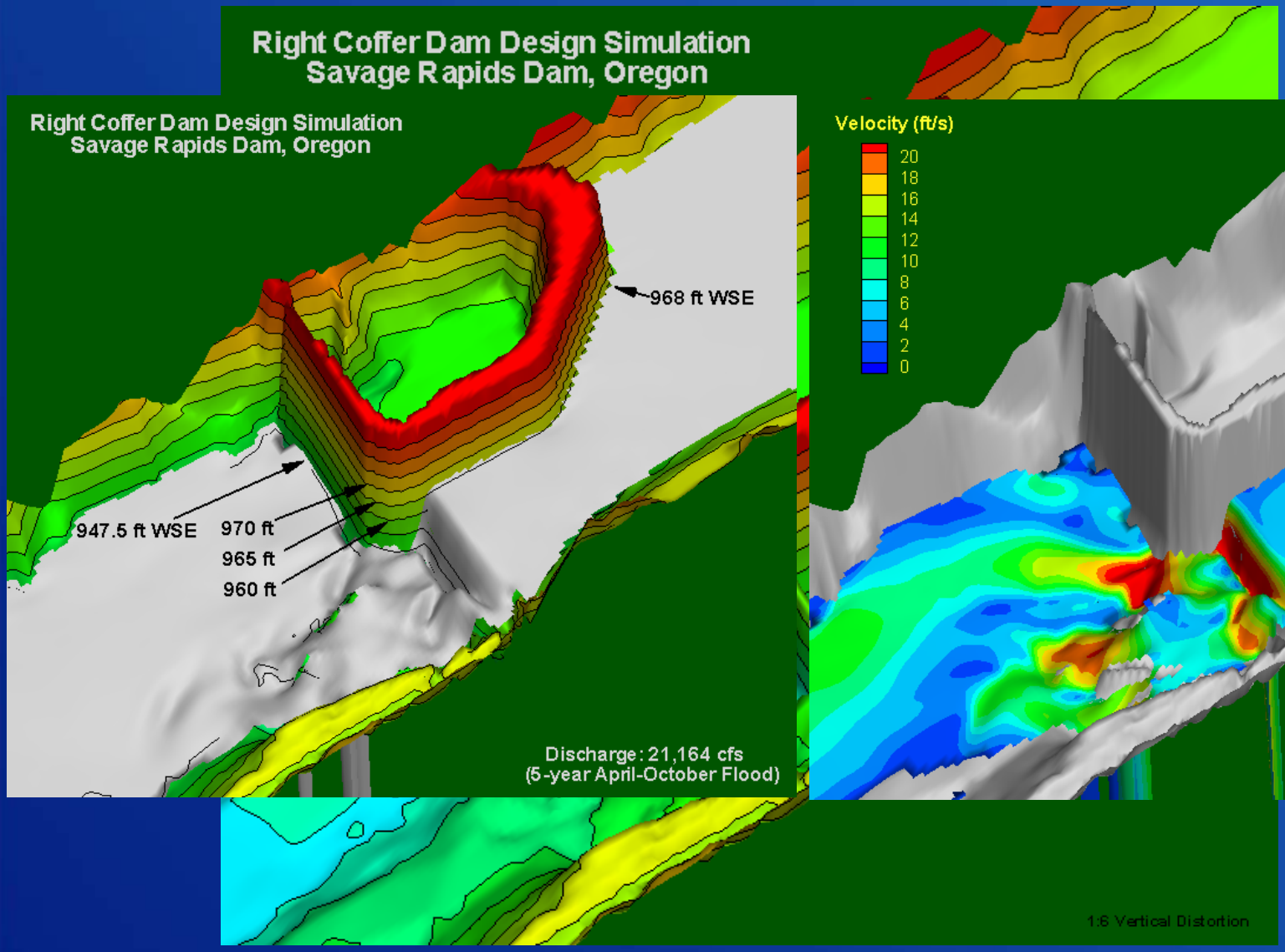
Right Cofferdam Design



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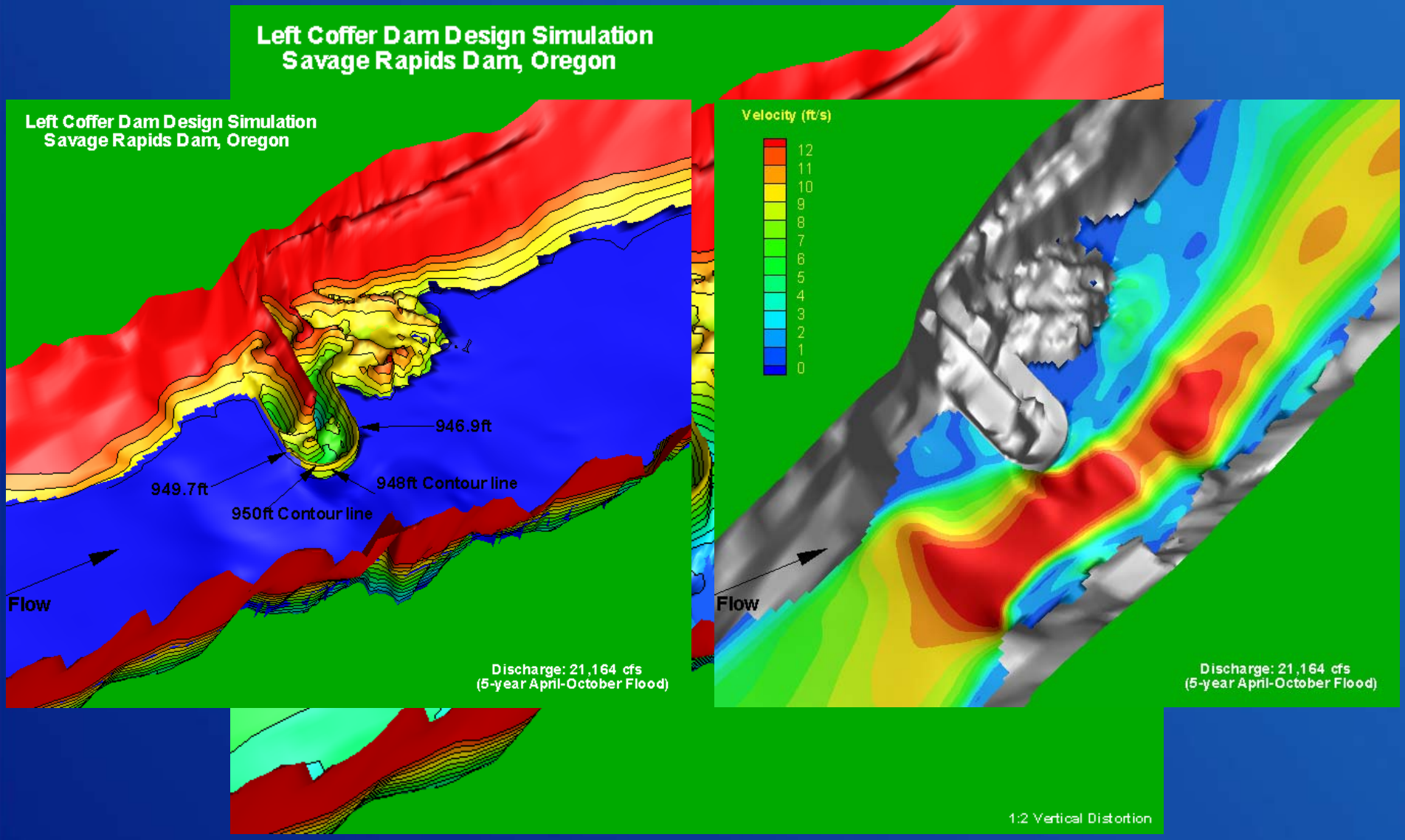
Left Cofferdam Design



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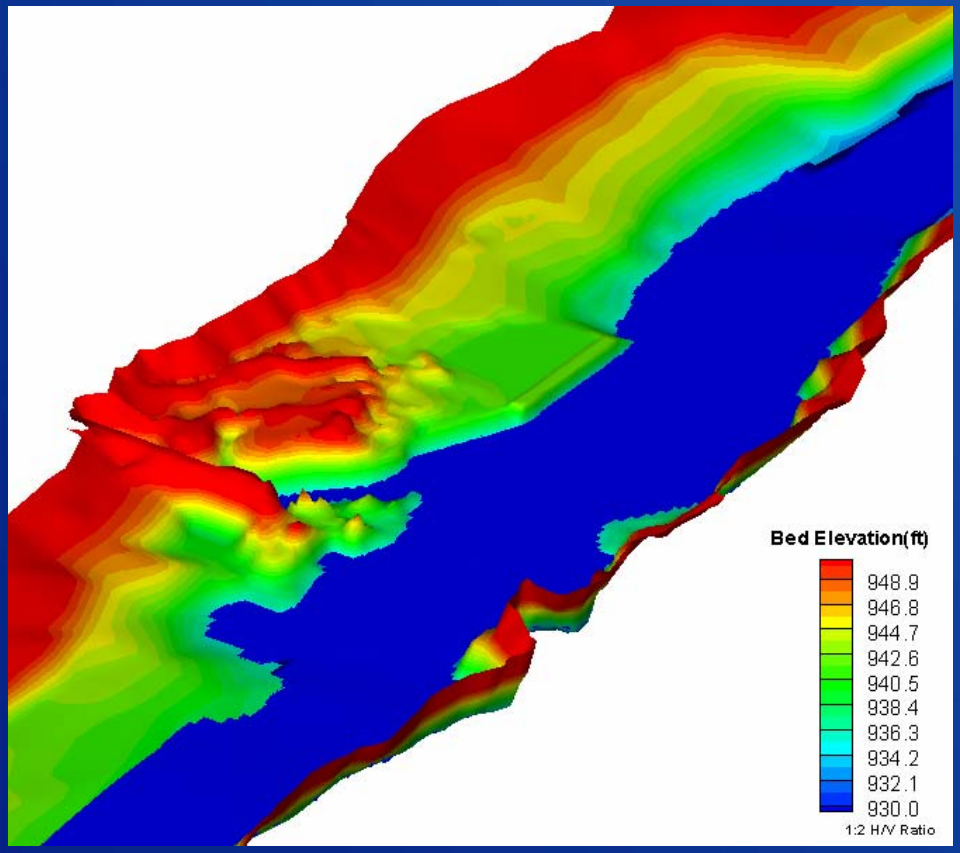
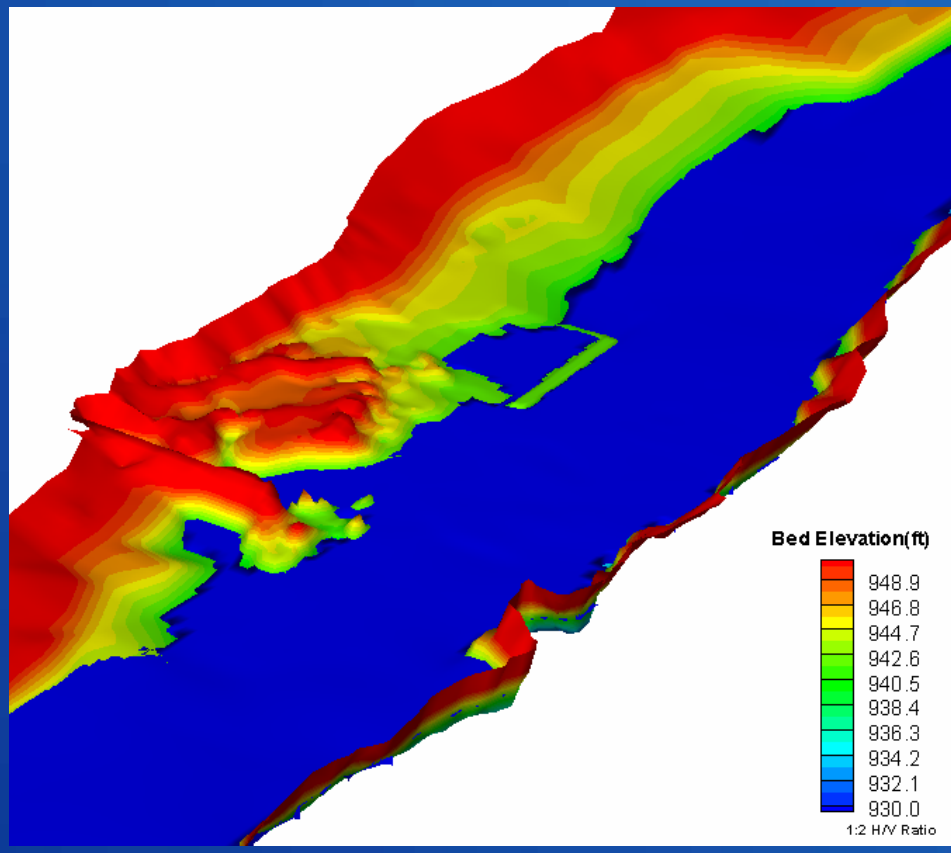
After Dam Removal Inundation

900cfs **8,390cfs**





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Elwha Surface Diversion Project

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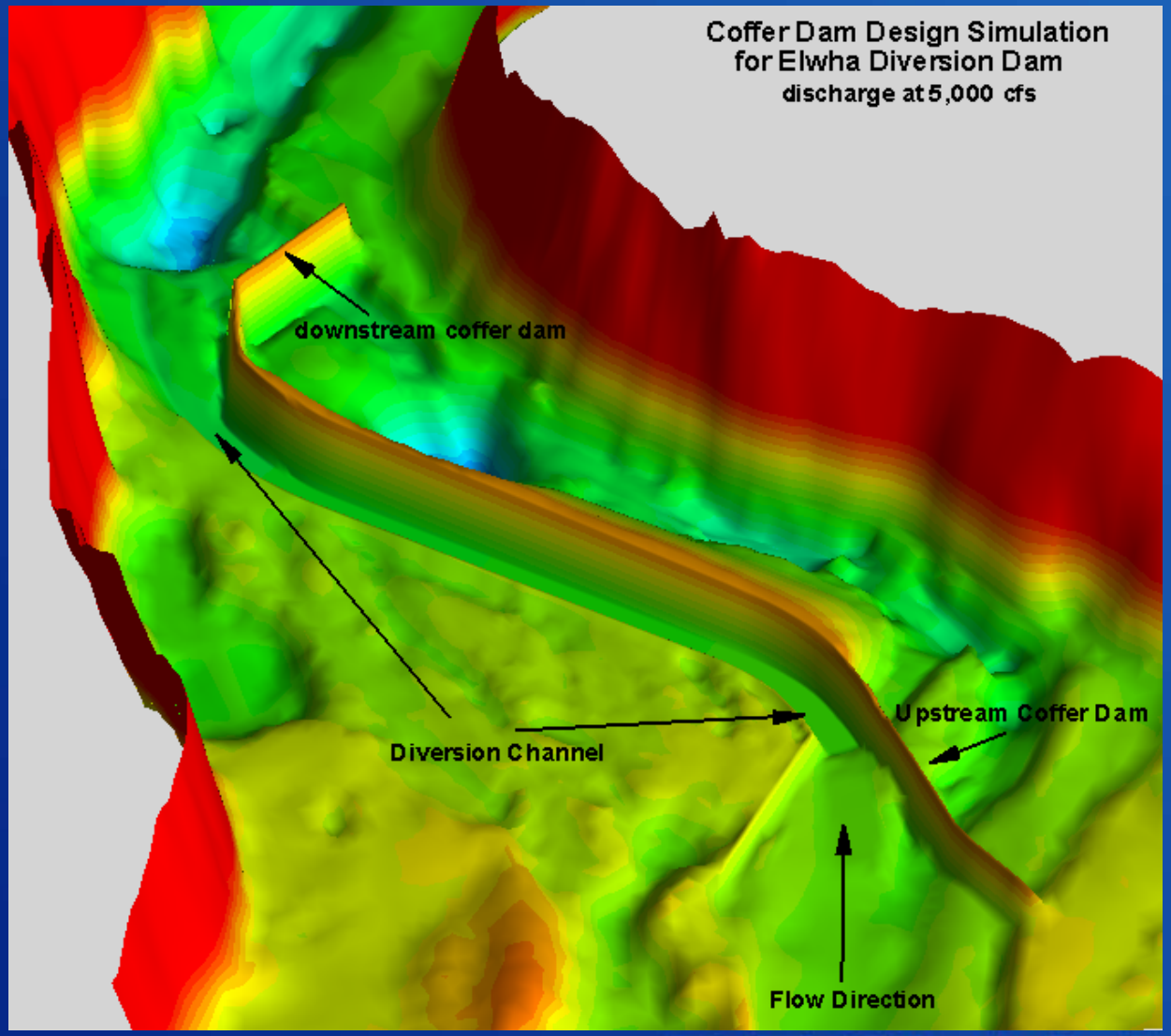
Topography by Mesh



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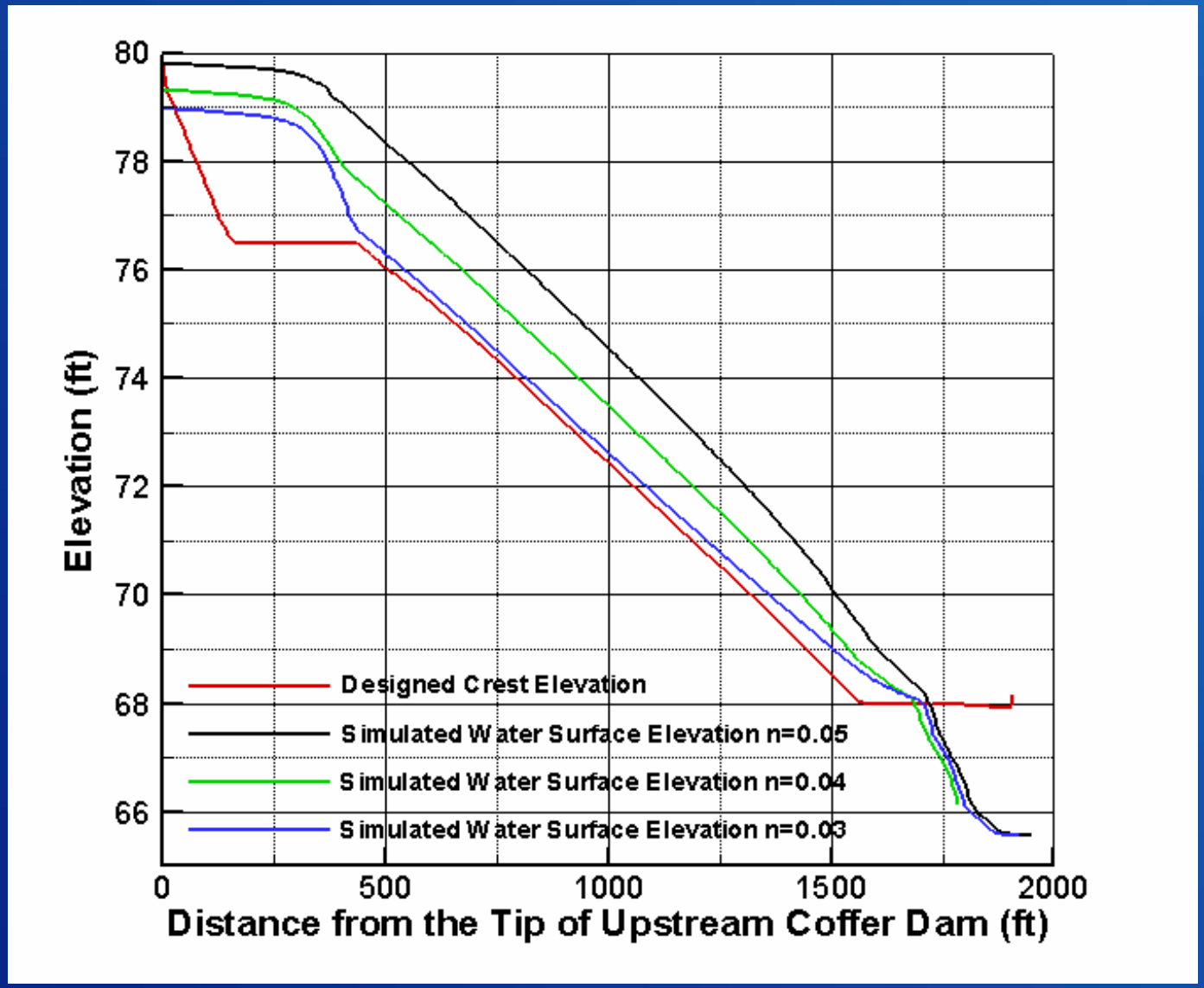
Cofferdam Design & Inundation at Q=5,000cfs



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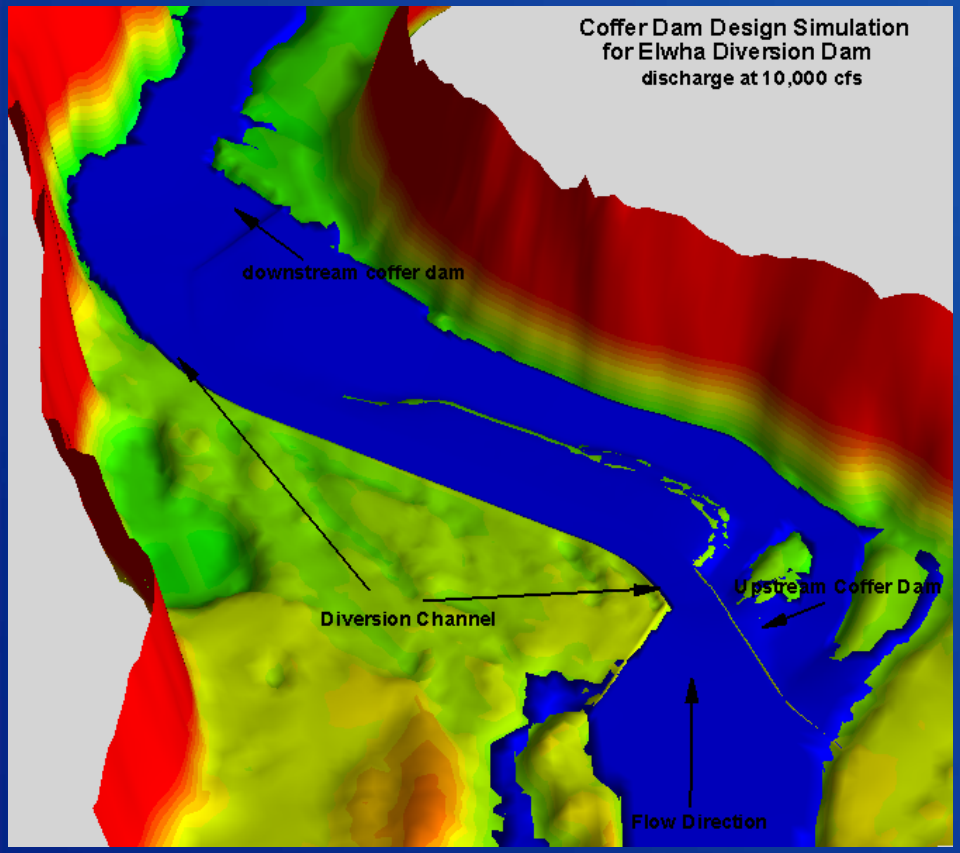
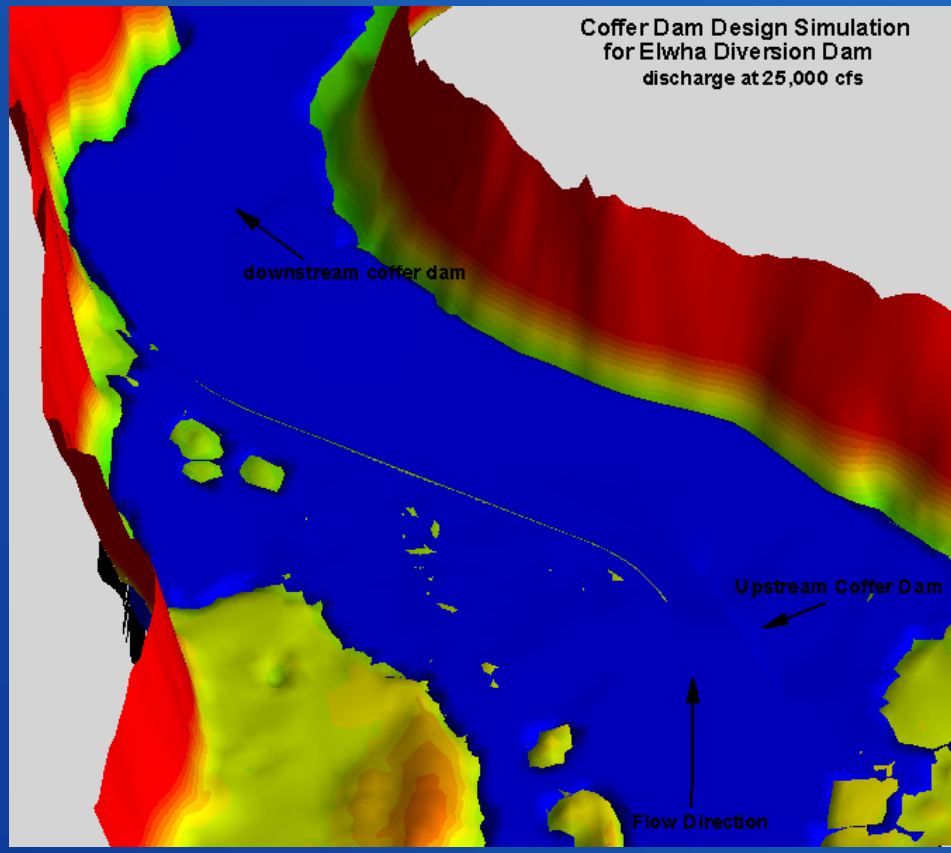
Flood Inundation

10,000cfs



25,000cfs



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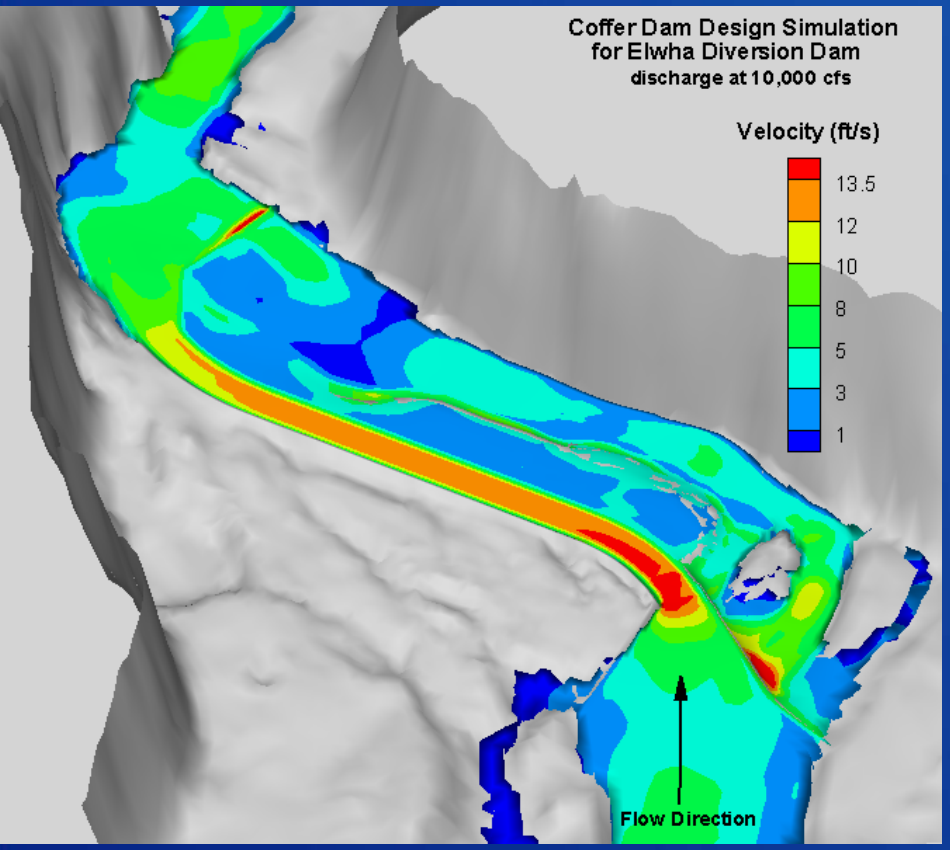
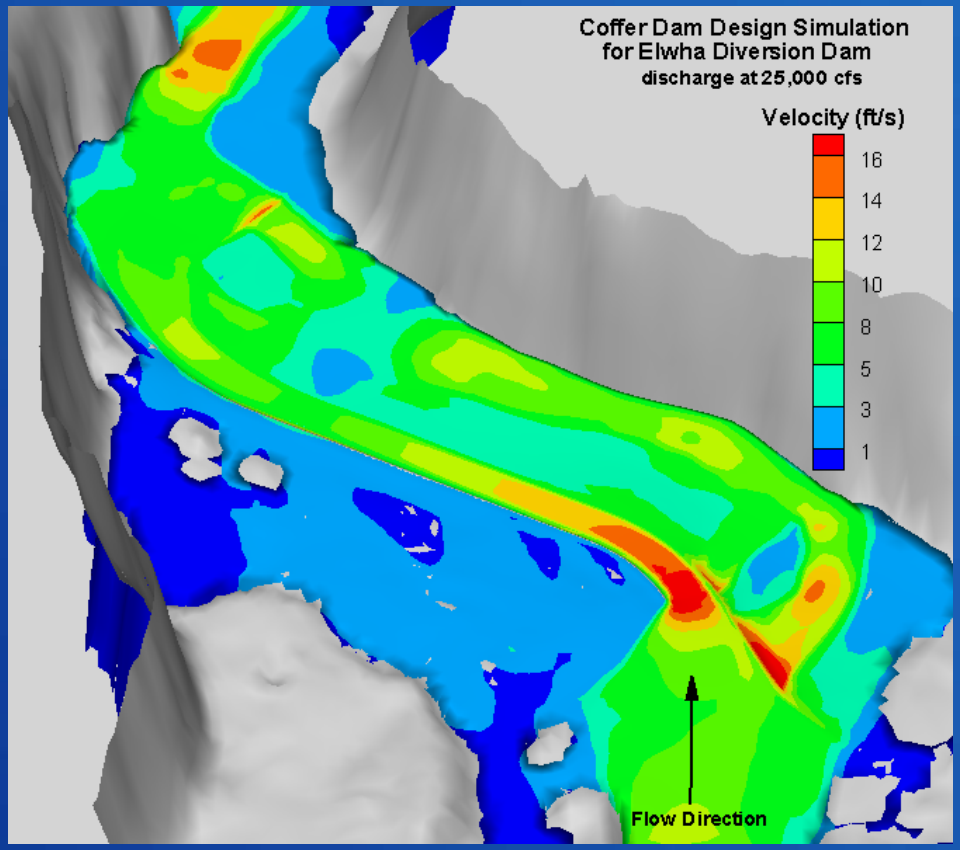
Velocity

10,000cfs



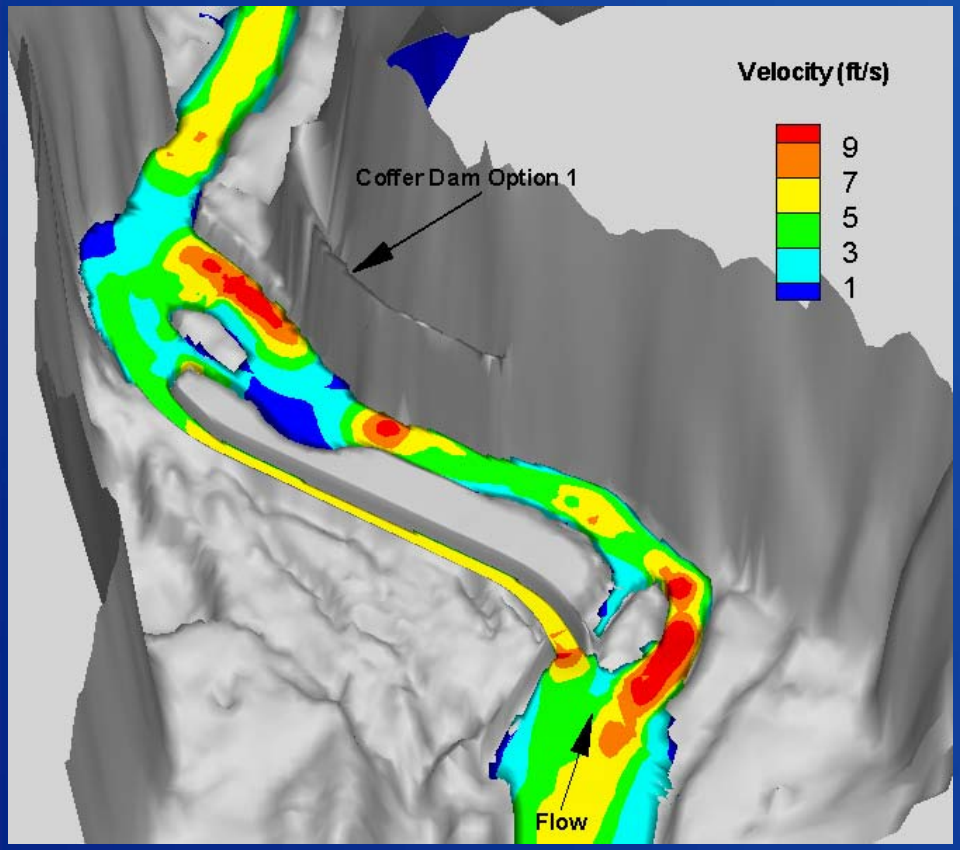
25,000cfs



RECLAMATION

Intake Cofferdam Design

5,000cfs



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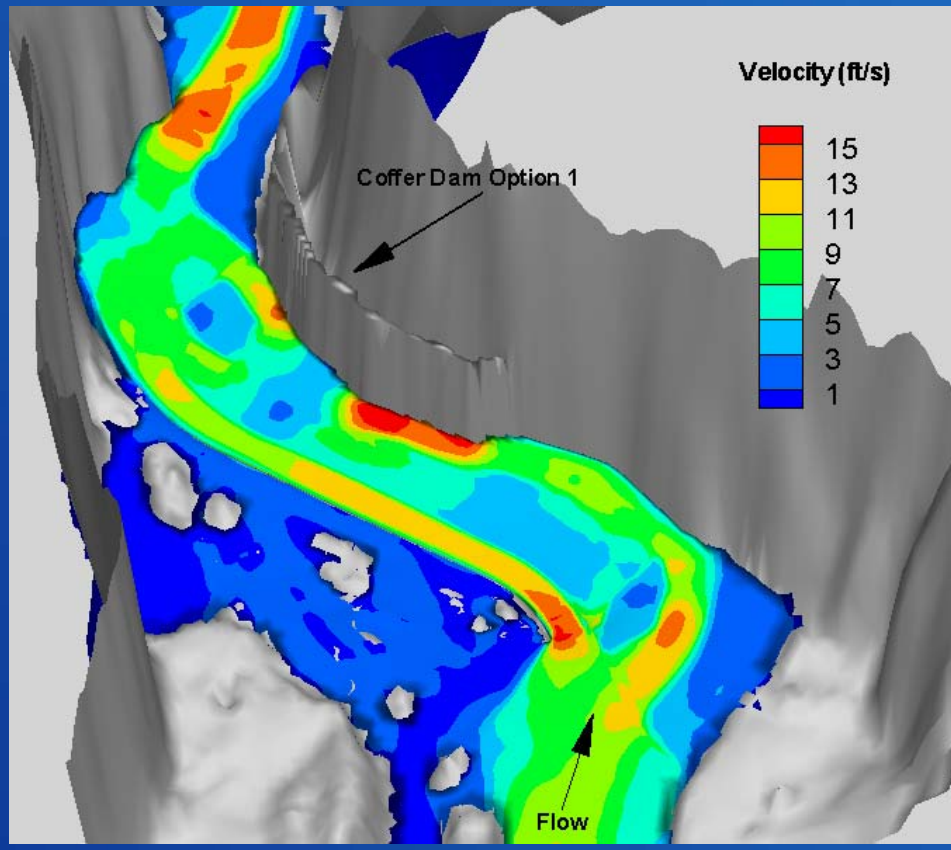
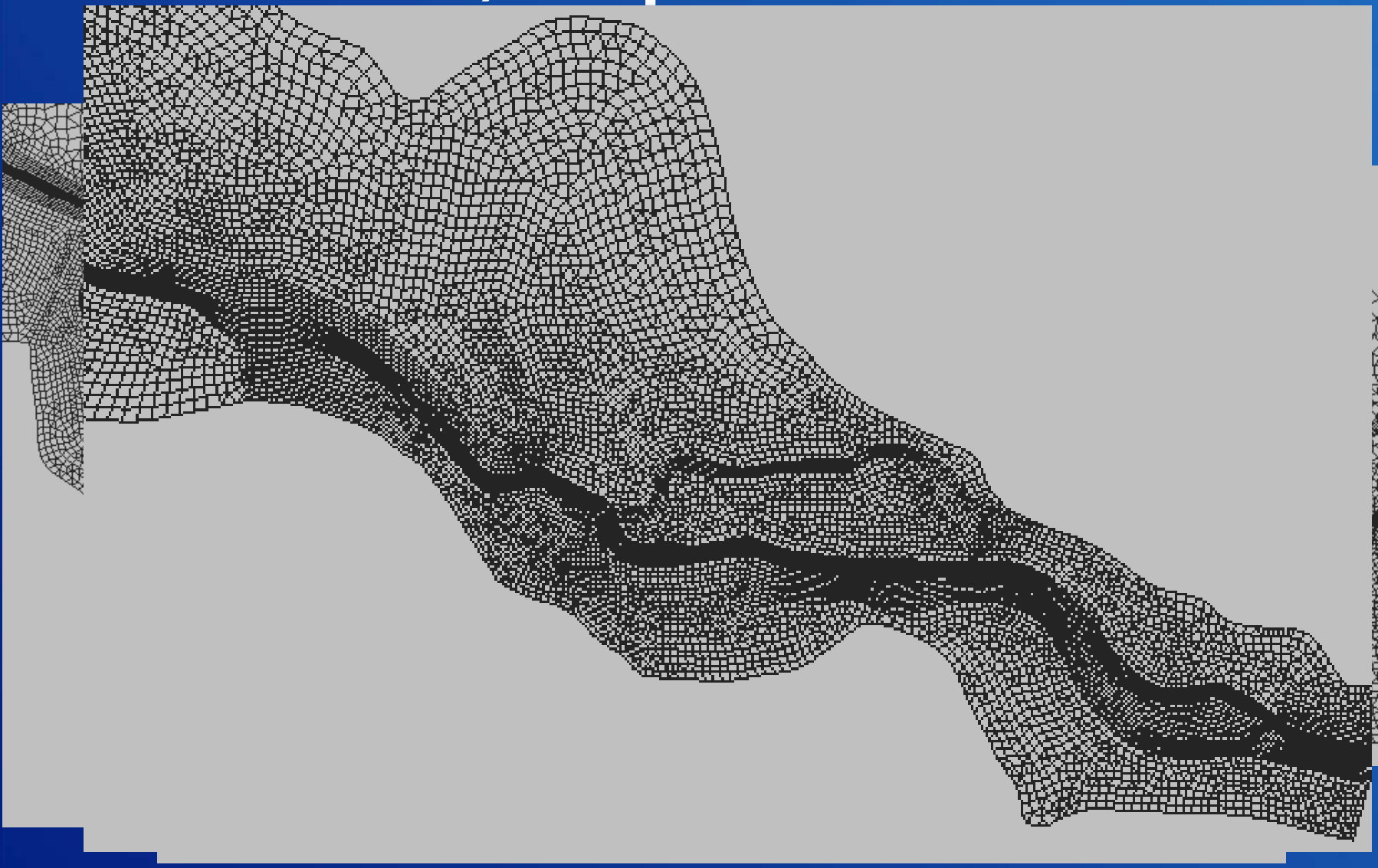


RECLAMATION

Lower Dungeness Levee Setback Study

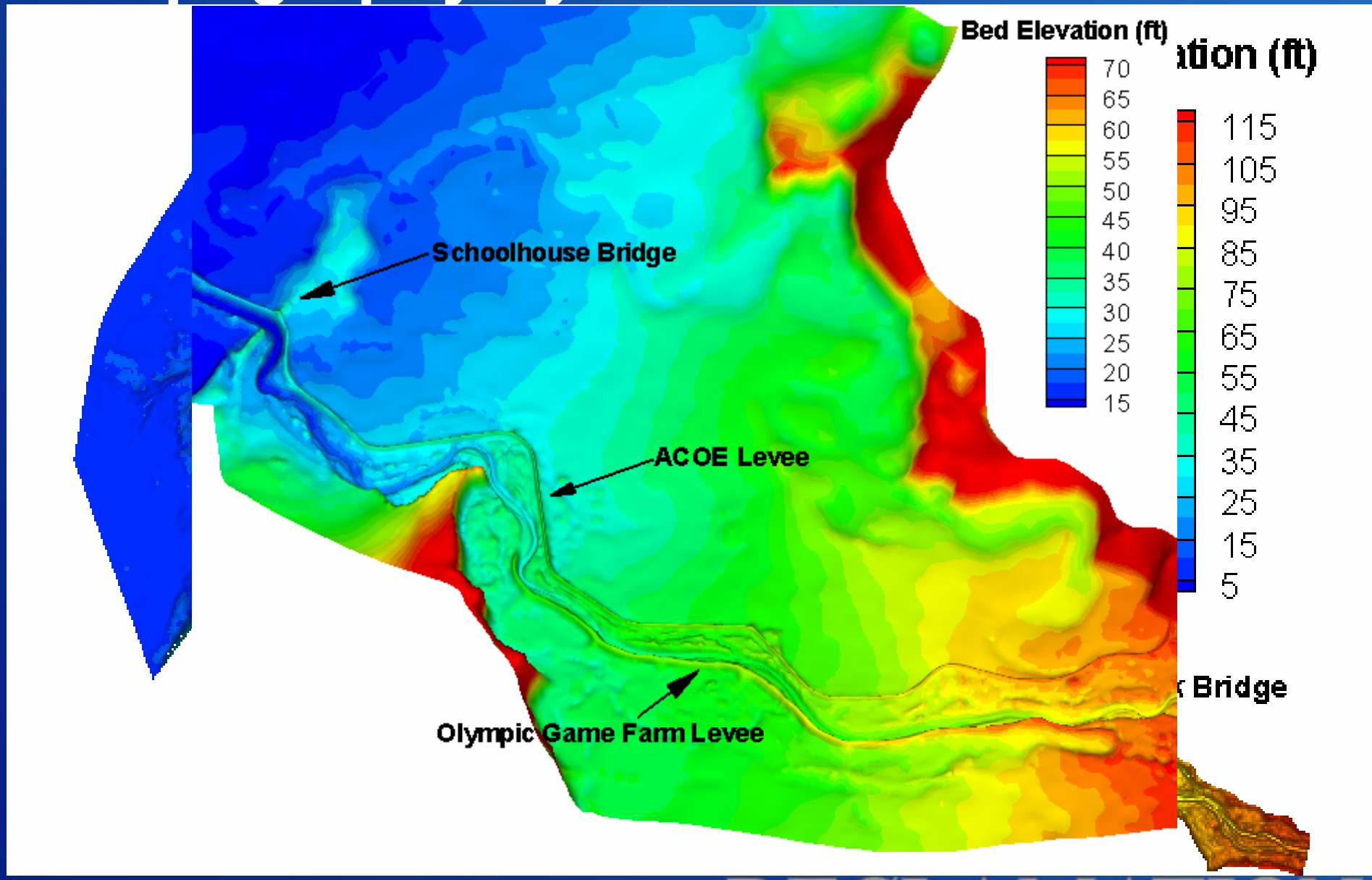
RECLAMATION

Mesh: ~ 50,000 points

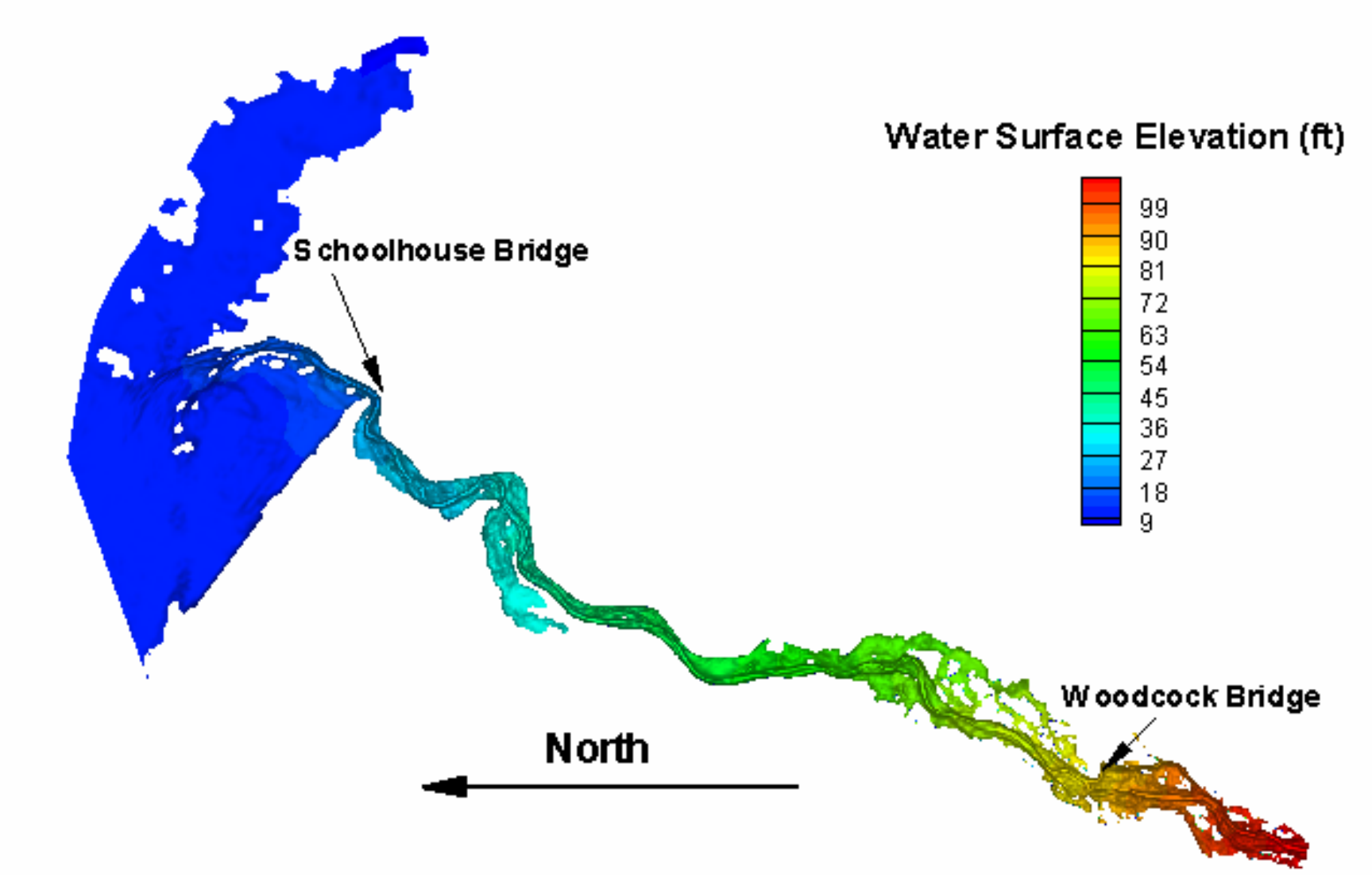


RECLAMATION

Topography by Mesh

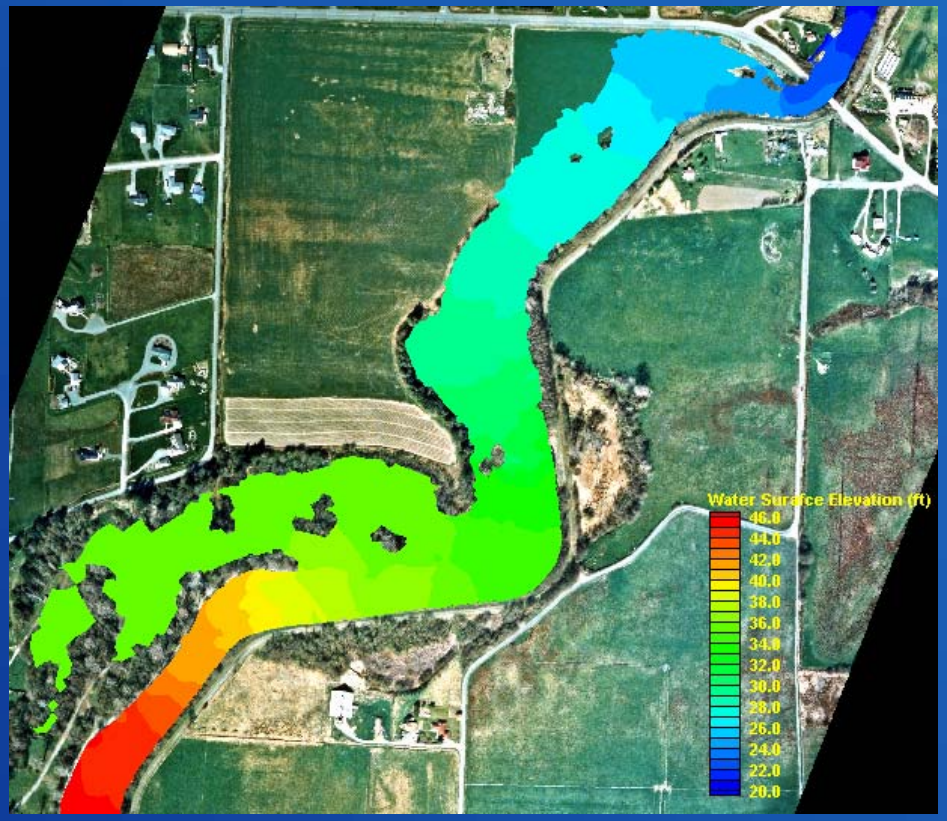


2002 Flood Simulation (6,280cfs)



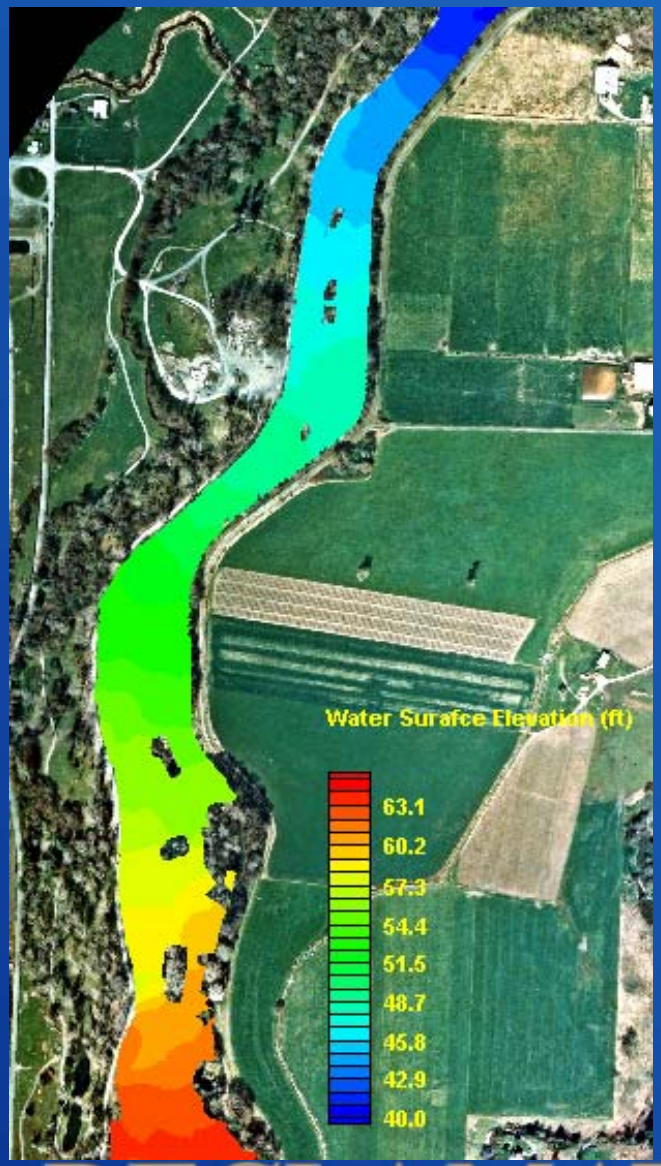
RECLAMATION

Comparison of Inundation



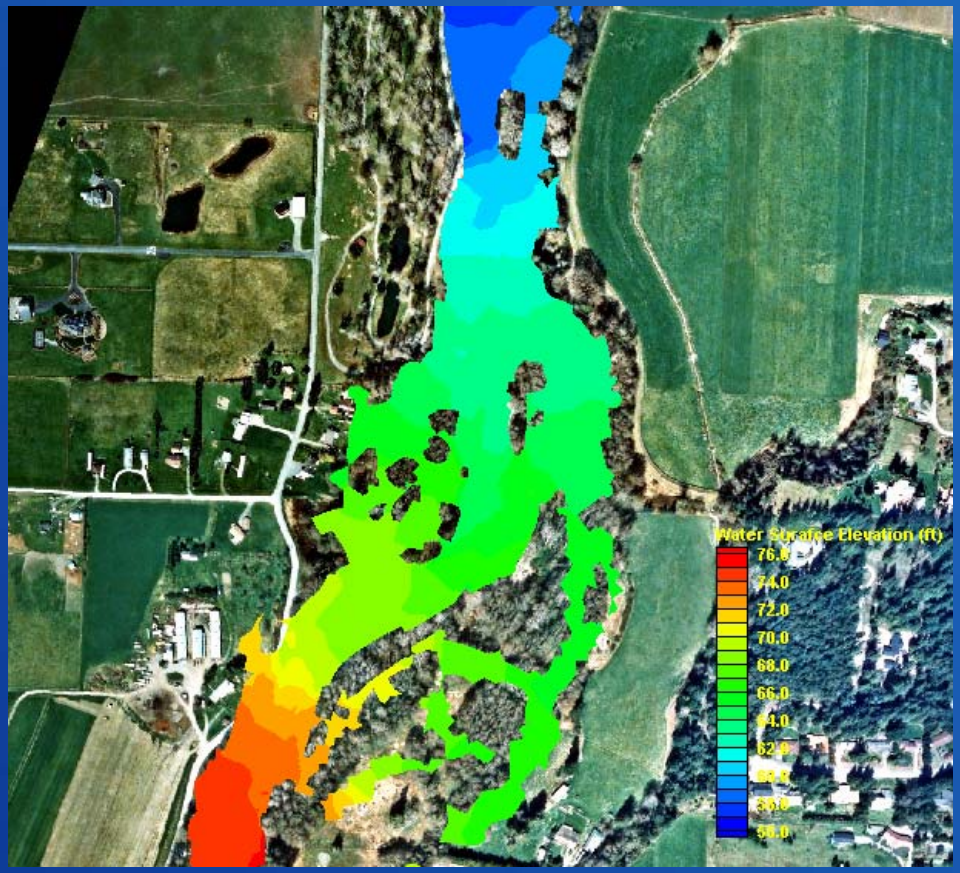
RECLAMATION

Comparison of Inundation



RECLAMATION

Comparison of Inundation



RECLAMATION

THANK YOU
QUESTIONS ?
5 10:37AM