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Managing Water in the West

2D Flow Modeling with SRH-2D

Yong G. Lai, Ph.D., Hydraulic Engineer
Sedimentation and River Hydraulics
Technical Service Center

Part 1: Introduction

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SRH-2D Stands for:

Sedimentation and River Hydraulics – 2D

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Major Capabilities

- Two Dimensional (2D) Depth-Averaged Modeling for Open Channel Flows
- Dynamic Wave Solver
- Steady or Unsteady Flows
- Sub-, Super-, and Trans-Critical Flows
- Unstructured or Structured Arbitrarily-Shaped Meshes

Why SRH-2D?

- Commercial Codes
  - Not convenient for occasional use
    - Expensive to own
    - Too many inputs & turning parameters
  - Not suitable for advanced use
    - Black-box style: garbage-in garbage-out

- Research Codes
  - Availability issue
  - Hard wired
  - User unfriendly
  - Error prone

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SRH-2D Development Philosophy

- Easy to Learn
  - A tutorial case exercise + Occasional references to the User's Manual
  - An interactive preprocessor to guide input setup
- Easy to Apply
  - Flexible mesh: less restrictive on the requirements of mesh
  - Very few input parameters for model tuning
  - Dynamic run-time execution control
  - Interface with SMS or GIS for result post-processing
- Easy to Solve
  - Robust and stable numerical algorithm for field applications

Current Limitations

- **Flow Only:**
  Erosion and sediment transport will be added in future versions.

- **Solver Module Only:**
  Mesh generation: SMS
  Post-Processing: SMS, GIS, or TECPLOT

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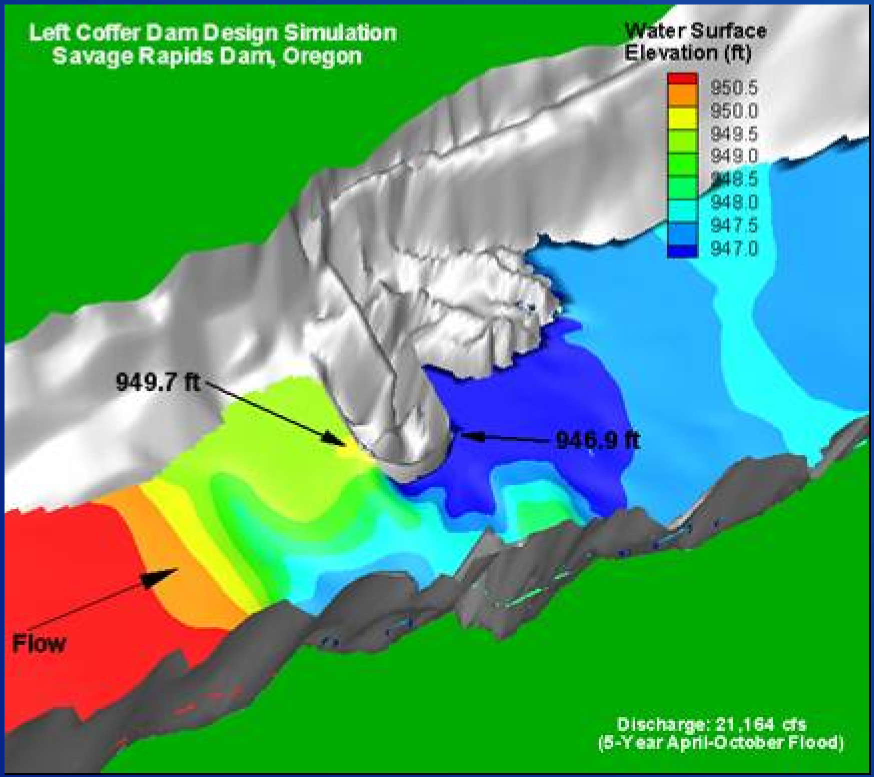
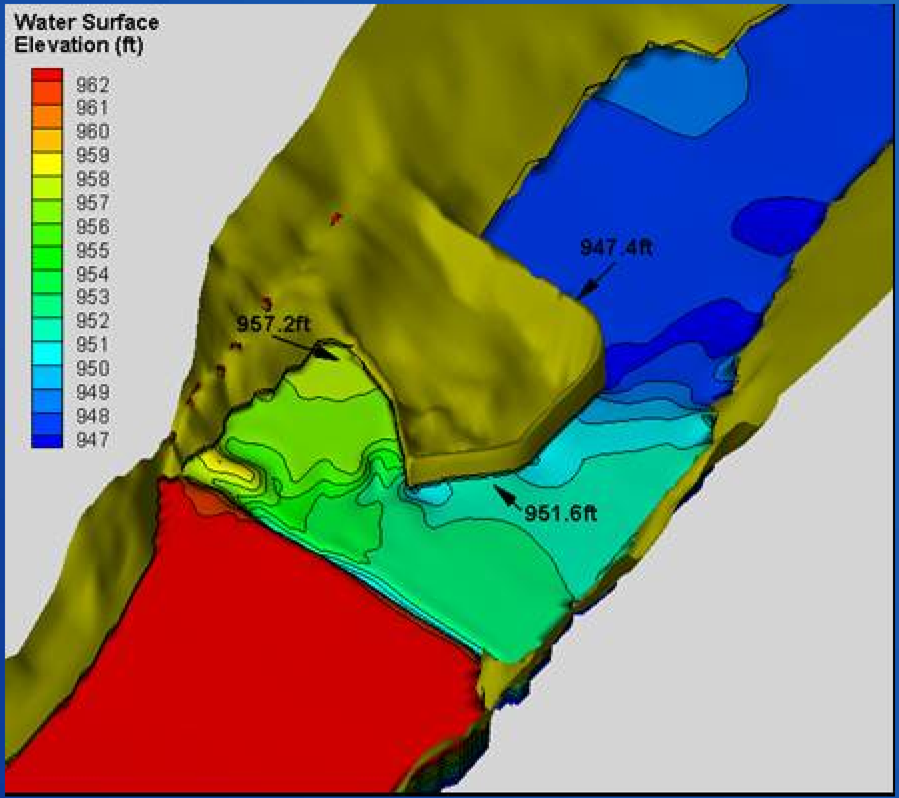
Why 2D Modeling?

- **Flows with in-stream structures such as weirs, diversion dams, release gates, cofferdams, etc.**





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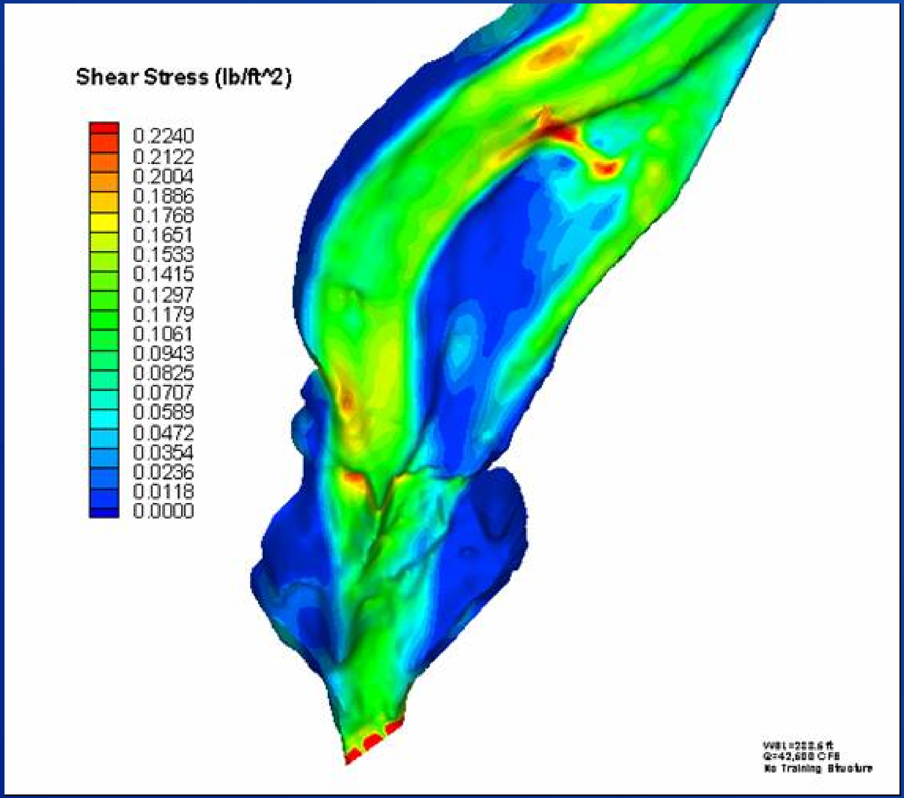
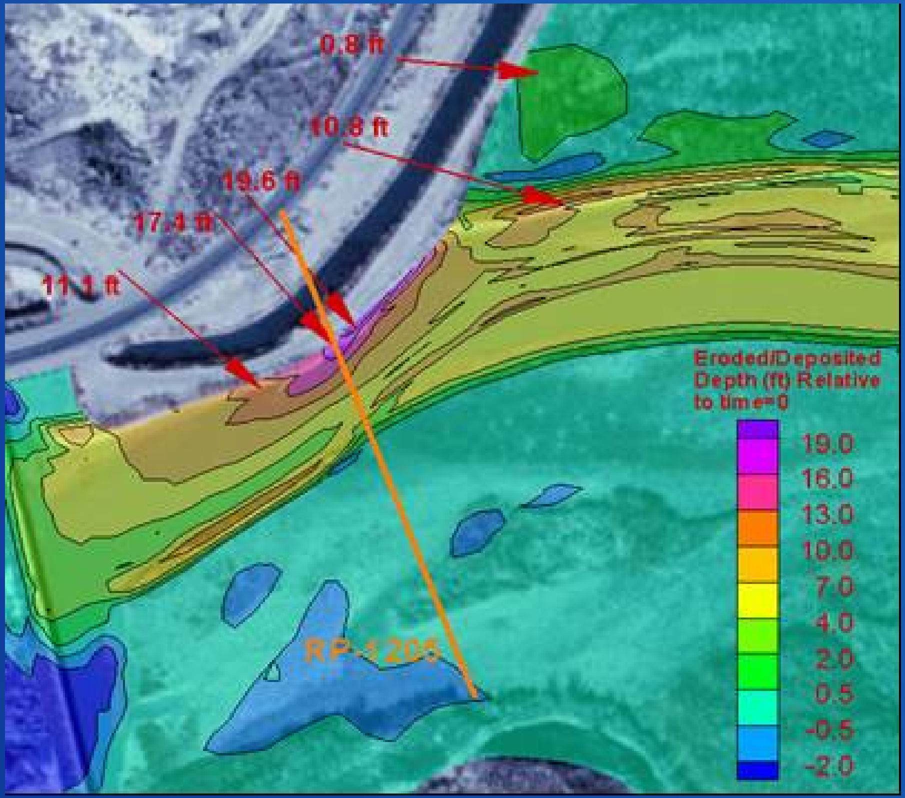
Why 2D Modeling?

- **Flows through meander bends**





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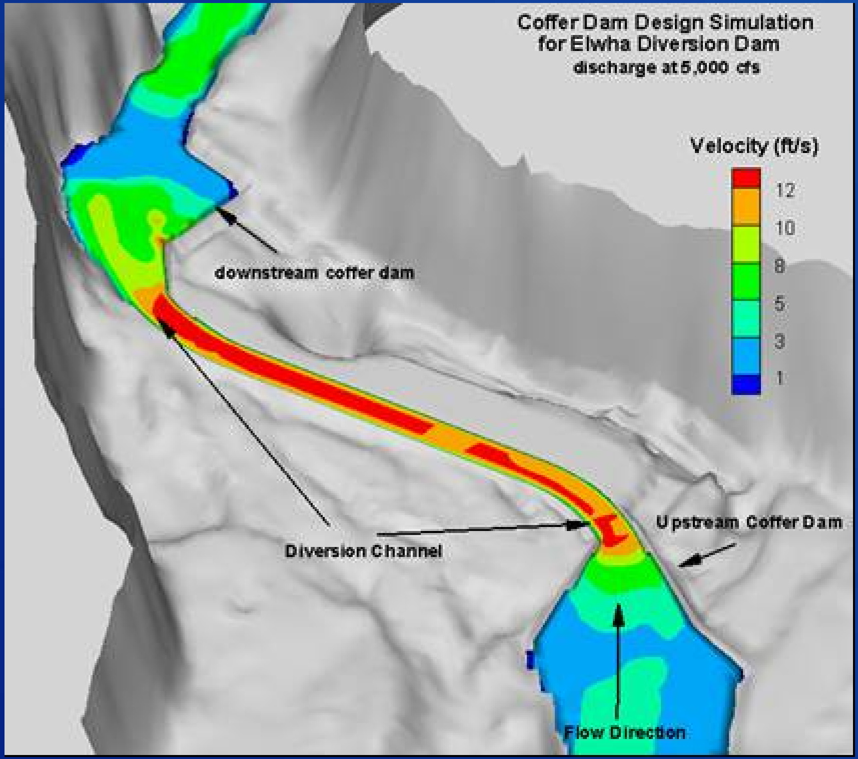
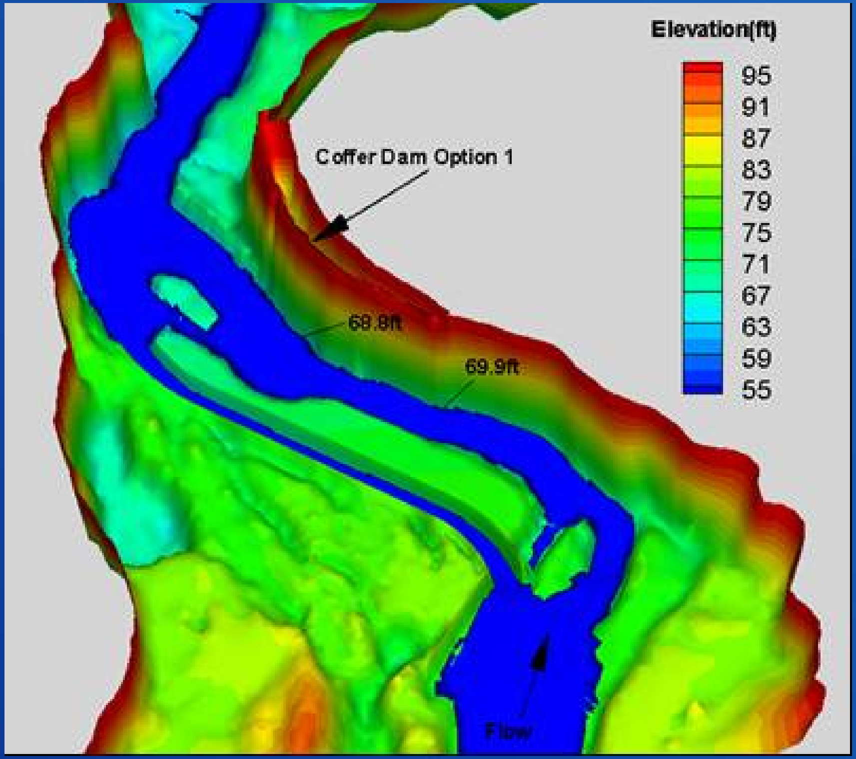
Why 2D Modeling?

- Perched channel system
- Flows with multiple channel systems.





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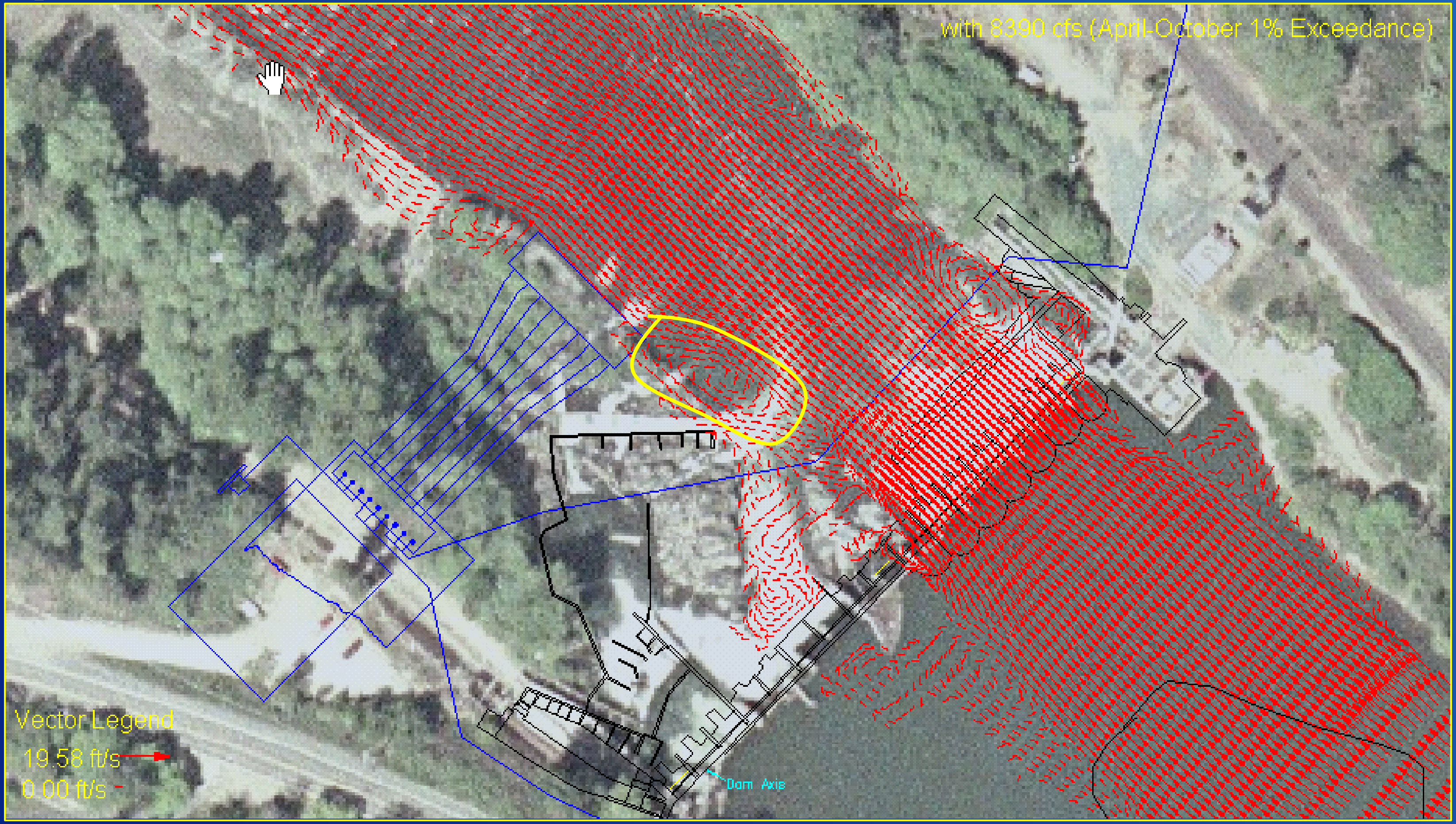
Why 2D Modeling?

- **Interested in local flow velocities, eddy patterns, and flow recirculation**



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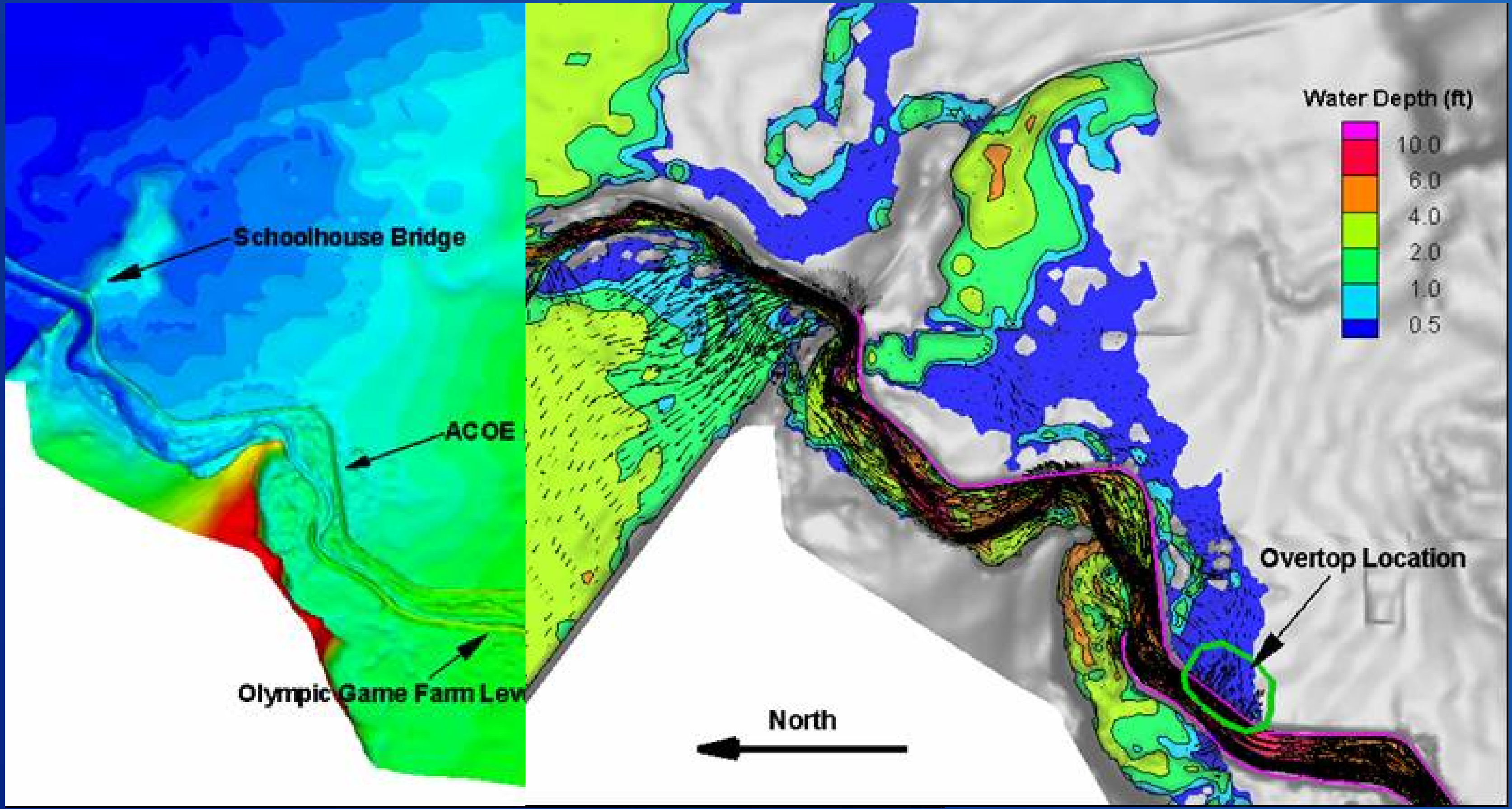
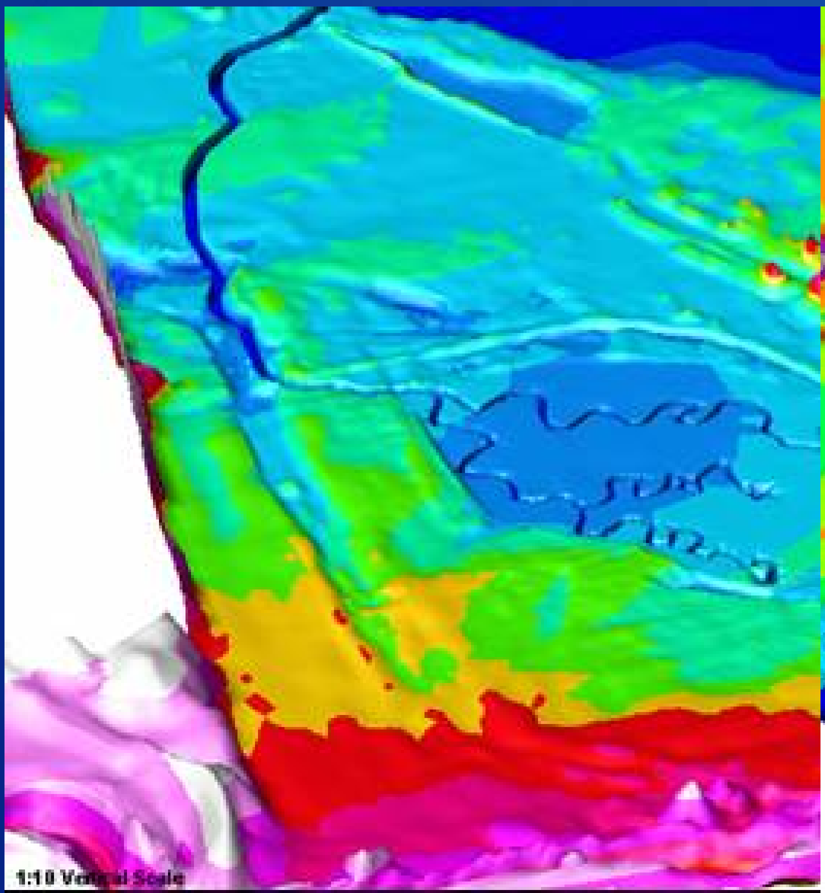
Why 2D Modeling?

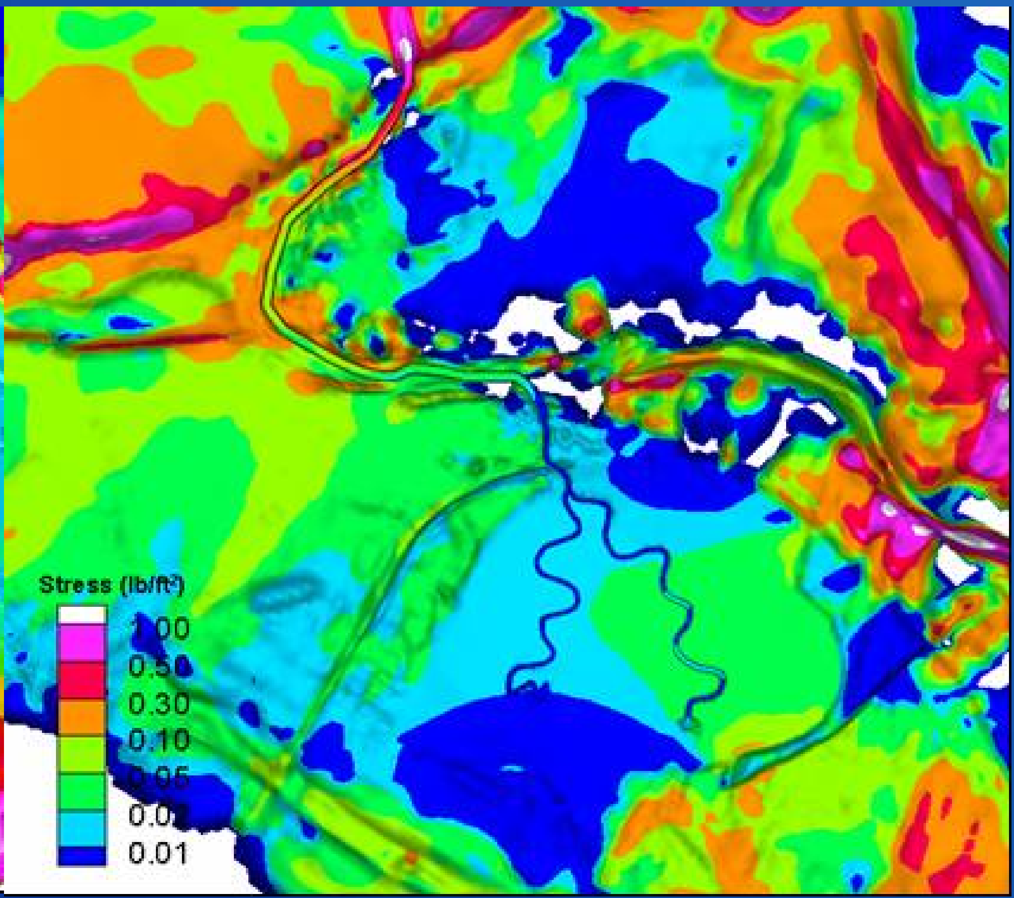
- Interested in lateral variations
- Flow spills over banks and levees



Why 2D Modeling?

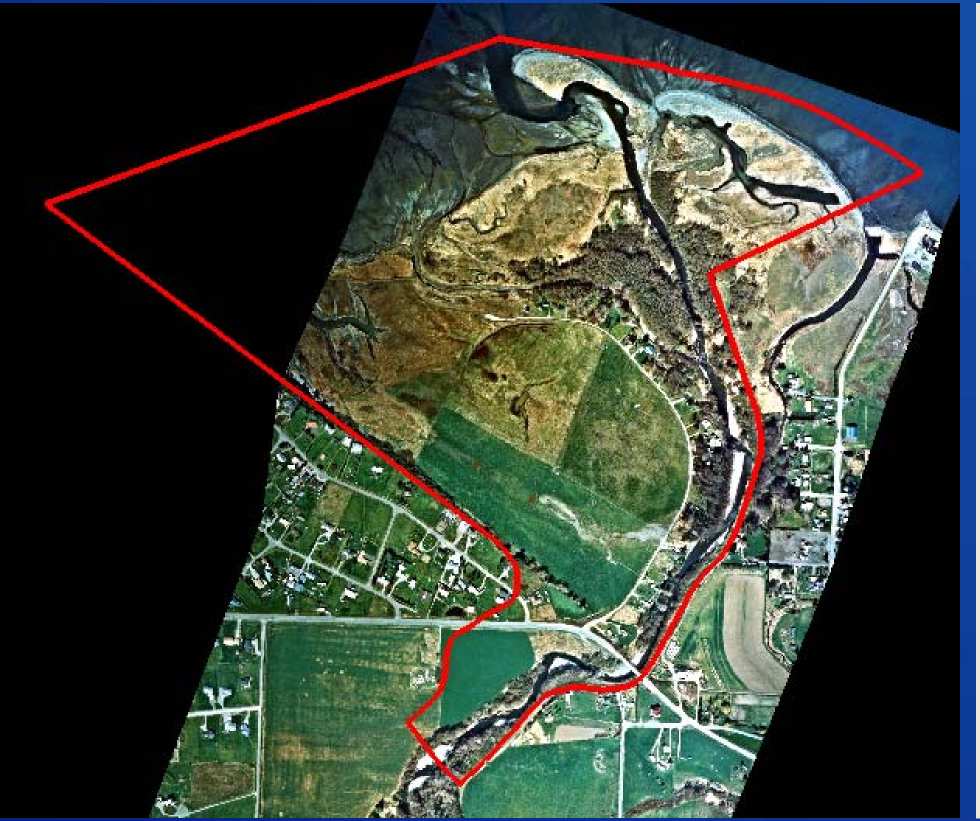
- **Flow over vegetated areas and interaction with main channel flows**





Zonal Modeling

- **Roughness Zone**



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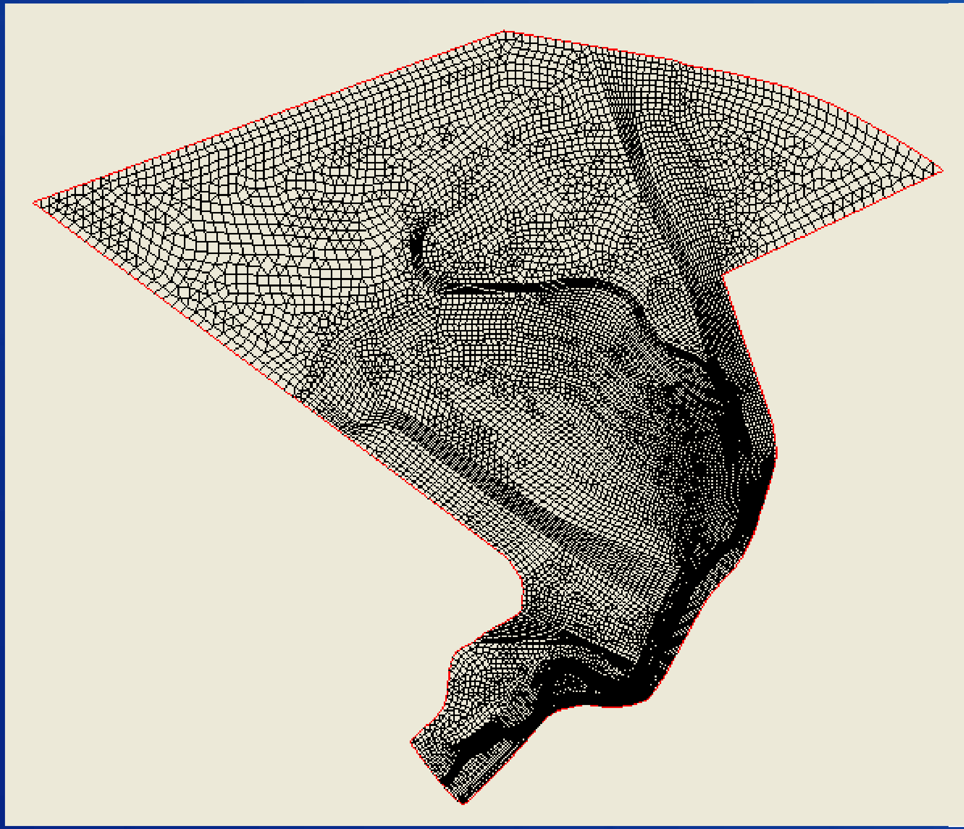
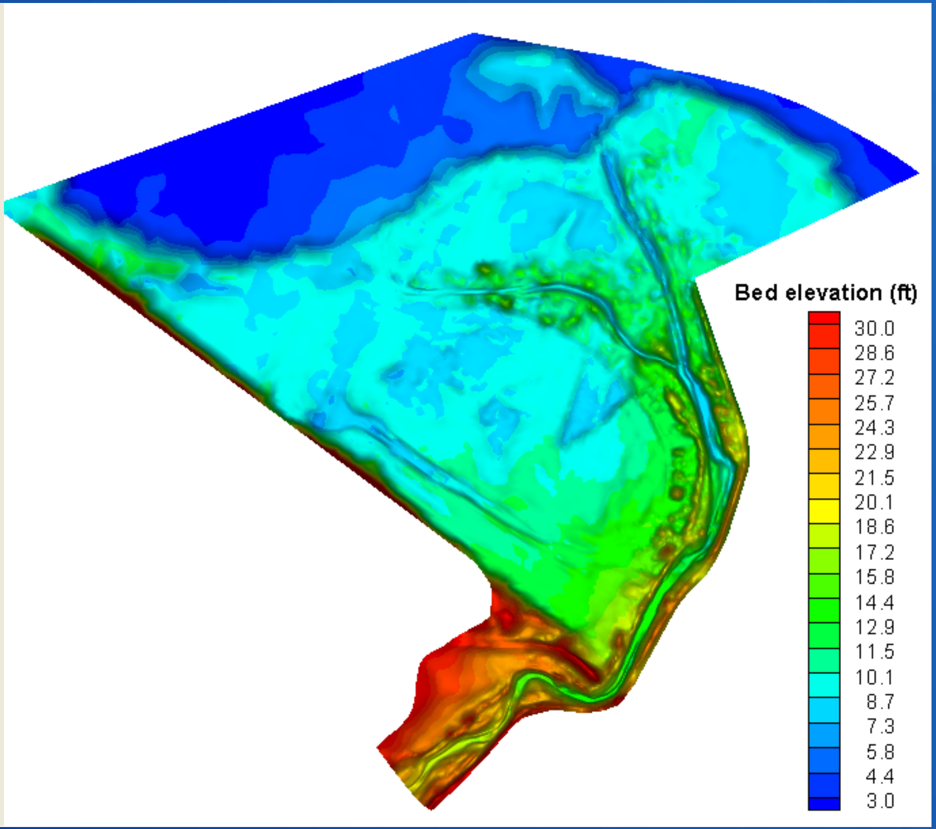
Zonal Modeling





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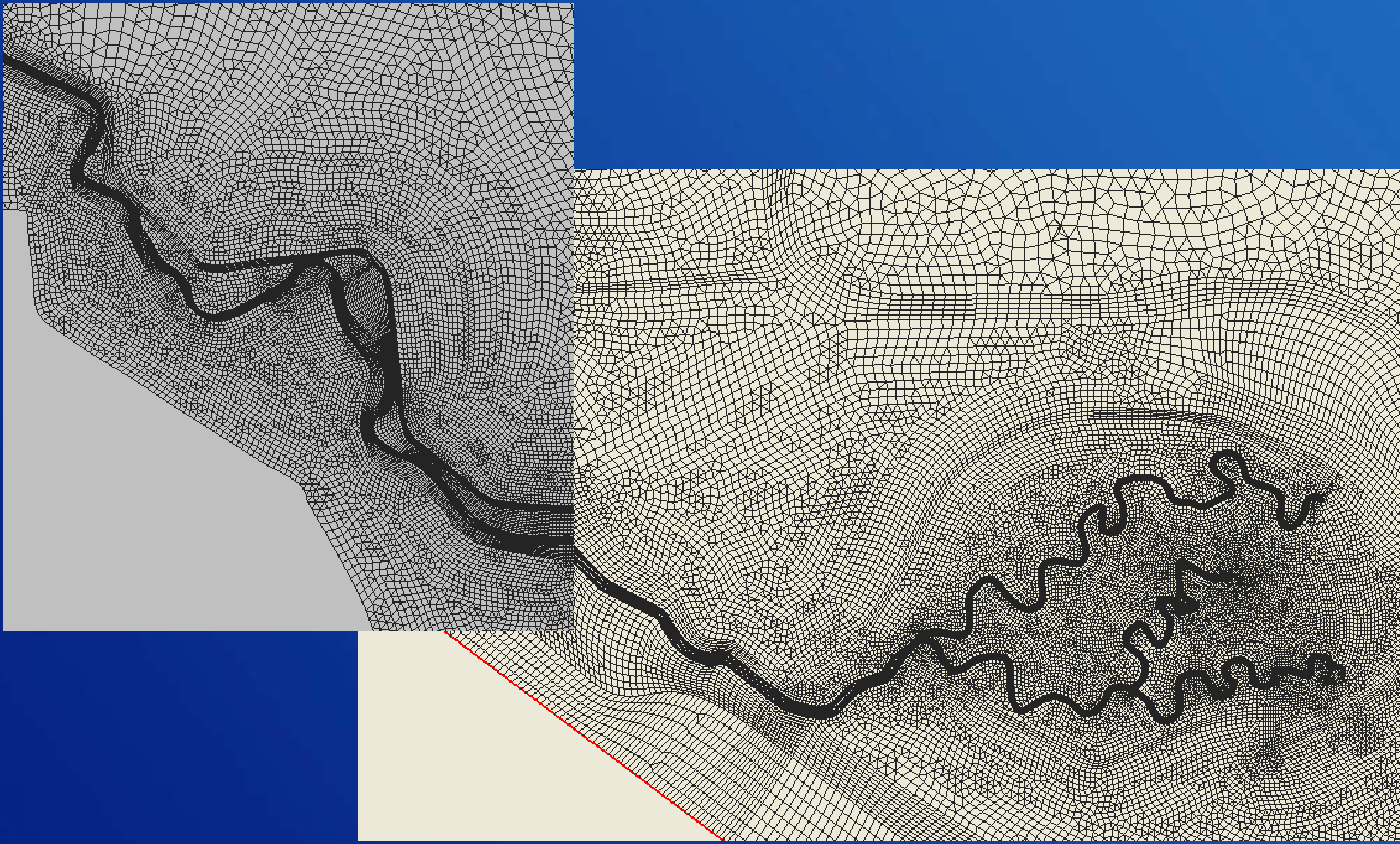
Modeling Feature: Flexible Mesh



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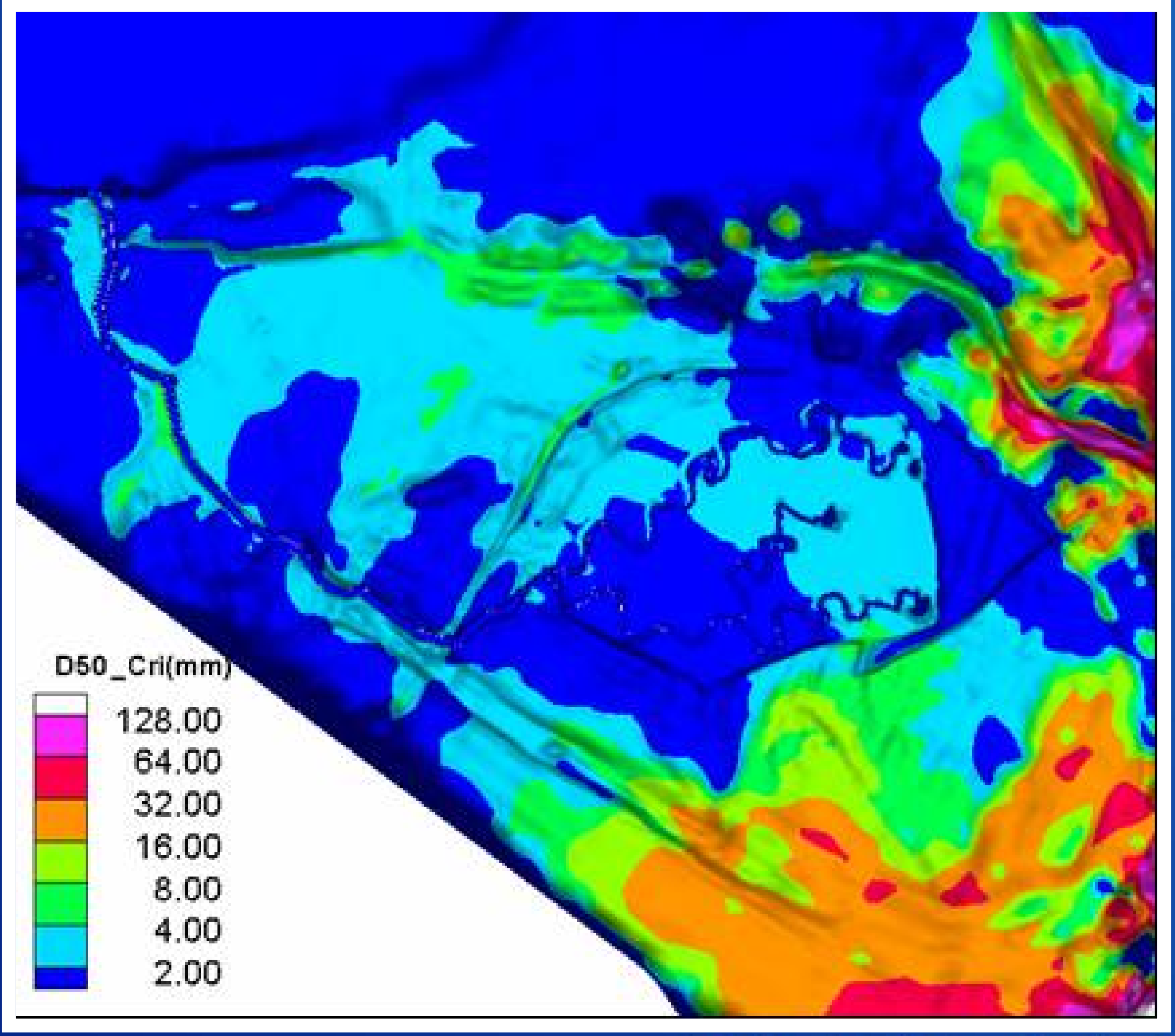
Model Output Variables:

- Inundation Map
- Water Surface Elevation
- Water Depth
- Velocity Vector and Magnitude
- Froude Number
- Bed Shear Stress
- Sediment Transport Capacity
- Critical Sediment Diameter

Output for Geomorphic Assessment:
Critical Diameter



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SRH-2D Structure

What's Needed?

Three Steps → Three Modules

- Mesh Generation
  - SMS (Map Mesh Scatter)
- Numerical Solution
  - SRH-2D program
- Post Processing
  - SMS, TECPLOT, or GIS

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About SRH-2D

SRH-2D consists of two modules

- **Preprocessor**
  - **srhpre**
- **Solver**
  - **srh2d**

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SRH-PRE:

Interactive Q&A session

- Prepare an Input File for SRH-2D:
  - named as case.dat
- Script Output File (SOF):
  - case_SOF.dat
- Script Input File (SIP):
  - case_SIF.dat
- See Chapter 4 of the Manual for all inputs

SRH-2D: Flow Solver Module

- Read Input File
  - case.dat
- Run Time Monitoring
- Output Results for Post Processing
  - case_SMSi.dat

Part 2: Governing Equations and Boundary Conditions

Governing Equations

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

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

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

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

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Manning's Roughness Equations

- **Equation:**

$$\begin{pmatrix} \tau_{bx} \\ \tau_{by} \end{pmatrix} = \rho C_f \begin{pmatrix} U \\ V \end{pmatrix} \sqrt{U^2 + V^2}; \qquad C_f = \frac{gn^2}{h^{1/3}}$$

- **About Manning's Coefficient:**
  - **Does not change with flow**
  - **Spatially distributed depending on bed types.**
  - **Conversion from equivalent roughness height using the Strickler's formula:**

$$n = \frac{k_s^{1/6}}{A}$$

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Turbulence Stress Equations

$$T_{xx} = 2(\upsilon + \upsilon_t)\frac{\partial U}{\partial x} - \frac{2}{3}k$$

$$T_{xy} = (\upsilon + \upsilon_t)(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x})$$

$$T_{yy} = 2(\upsilon + \upsilon_t)\frac{\partial V}{\partial y} - \frac{2}{3}k$$

Turbulence Models

- **Parabolic Equation:**

$$\upsilon_t = C_t U_* h$$

- **Two-Equation *k-e* Model:**

$$\frac{\partial hk}{\partial t} + \frac{\partial hUk}{\partial x} + \frac{\partial hVk}{\partial y} = \frac{\partial}{\partial x}\left(\frac{h\upsilon_t}{\sigma_k}\frac{\partial k}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{h\upsilon_t}{\sigma_k}\frac{\partial k}{\partial y}\right) + P_h + P_{kb} - h\varepsilon$$

$$\frac{\partial h\varepsilon}{\partial t} + \frac{\partial hU\varepsilon}{\partial x} + \frac{\partial hV\varepsilon}{\partial y} = \frac{\partial}{\partial x}\left(\frac{h\upsilon_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{h\upsilon_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial y}\right) + C_{\varepsilon 1}\frac{\varepsilon}{k}P_h + P_{\varepsilon b} - C_{\varepsilon 2} h \frac{\varepsilon^2}{k}$$

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Initial Conditions

- Steady Simulation
  - U, V, WSE are needed in theory
  - Only water surface elevation is critical
  - U and V are setup automatically by SRH-2D
  - Options for initial WSE:
    - Dry bed
    - From another SRH-2D solution
- Unsteady Simulation
  - Use a steady-state solution from SRH-2D

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Boundary Condition: Inlet

- **Inlet:** water is to flow into the domain
  - Portion of the boundary may be dry!
- **Multiple inlets** may be used
- Information needed at an inlet:
  - Flow Discharge (steady or time-series hydrograph)
  - Lateral Velocity Distribution:
    - Constant-v Setup: uniform velocity across the inlet
    - Constant-q Setup: uniform q=vh across the inlet
  - Sub-critical or Super-critical?
- Additional Information at a Supercritical Inlet:
  - Water Surface Elevation

Boundary Condition: Exit

- **Exit:** water is to flow out of the domain
  - Portion of the boundary may be dry!
- Multiple exits may be used
- Information needed at an exit:
  - Sub-critical or Super-critical?
  - Water Surface Elevation if a Sub-critical Exit
    - Constant WSE
    - Time series WSE
    - Normal Depth
  - None if Super-critical Exit

Additional Boundary Conditions

- **Solid Wall: No User Definition is Needed**
  - no water is flowing through
  - represent banks and islands
  - No-slip condition; the boundary exerts a frictional force

- **Symmetry: User Definition is Needed**
  - no water is flowing through
  - the boundary is frictionless, slip condition
  - Derivatives of all main variables are zero except the normal velocity (zero normal velocity)

Part 3: Selected Verification Studies: a presentation

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2D Diversion Flow in a Channel

Shetta and Murthy (1996)

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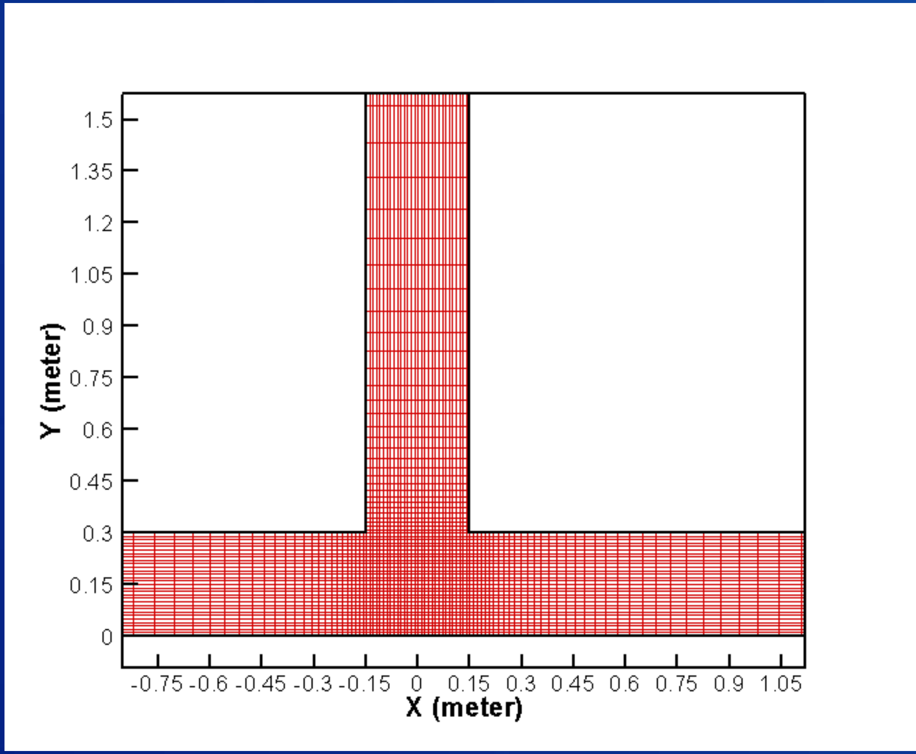
Case Description

- **Solution Domain:**
  - **a main channel: 6.0m in length and 0.3m in width**
  - **a side channel: 3.0m in a length and 0.3m in and width**
- **Mesh:**
  - **main channel: 120-by-30 elements**
  - **side channel: 40-by-30 elements**



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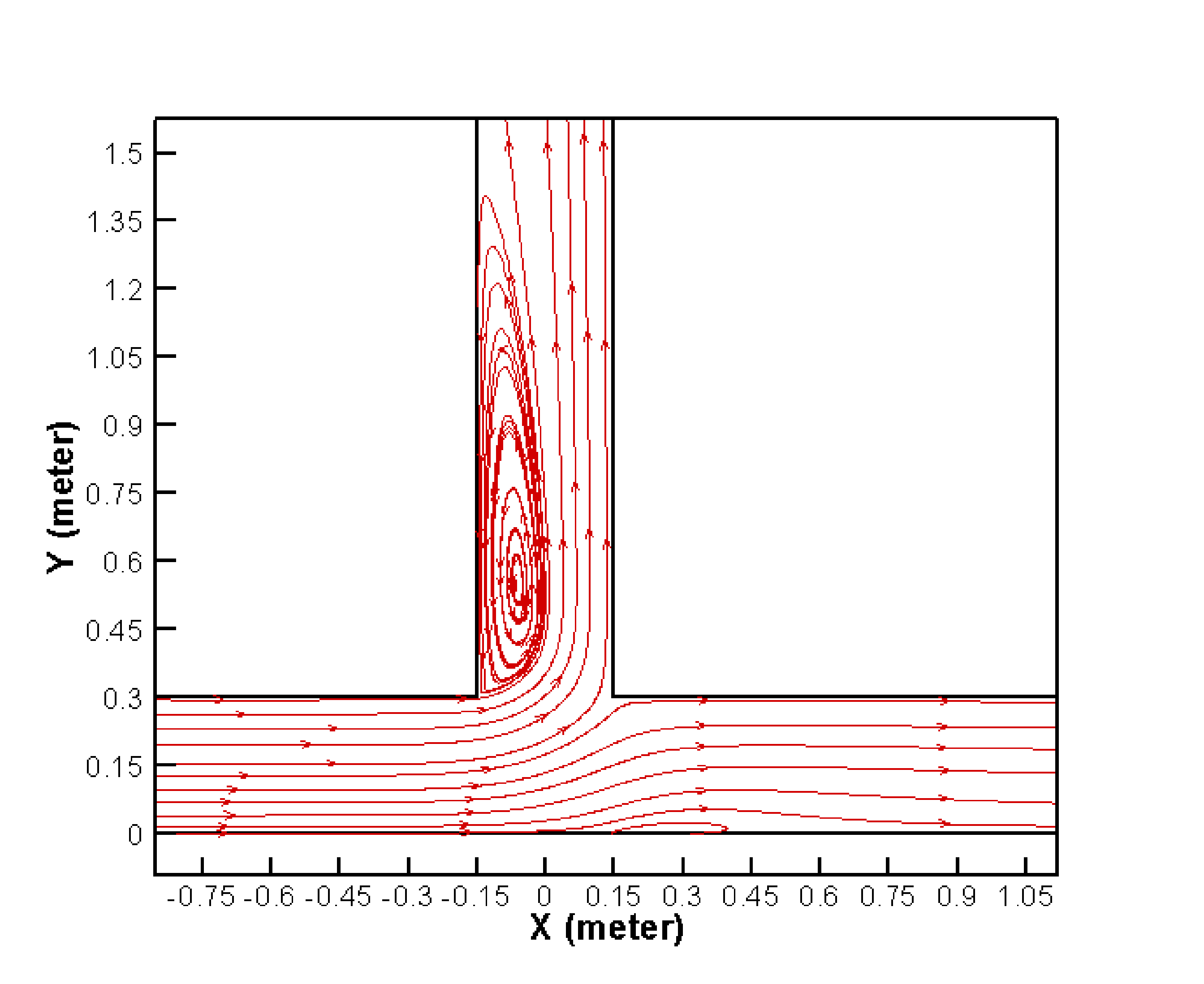
Flow Condition

- Main channel flow discharge: 0.00567 m3/s
- Water surface elevation at main channel exit: 0.0555m
- Water surface elevation at side channel exit: 0.0465m
- The Manning's roughness coefficient: 0.012
- The parabolic or k-e turbulence model

Flow Streamlines



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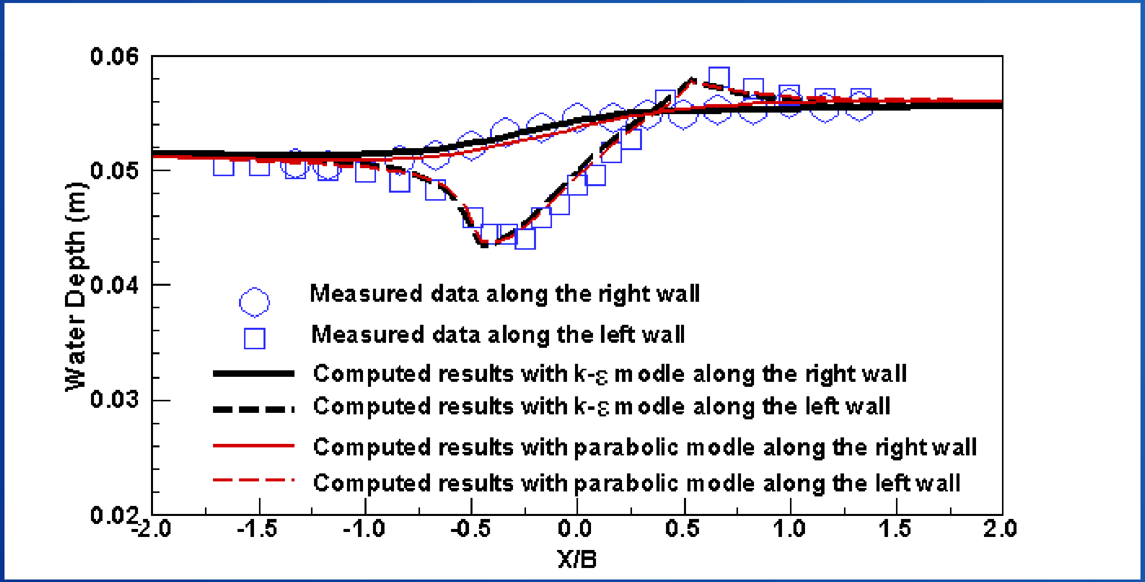
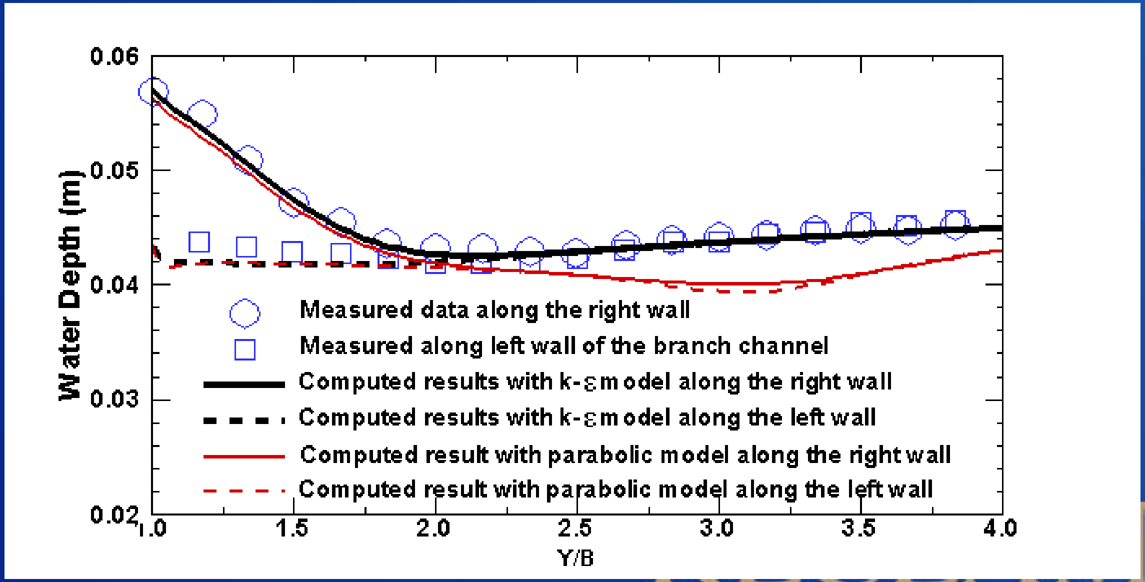
Comparison of WSE

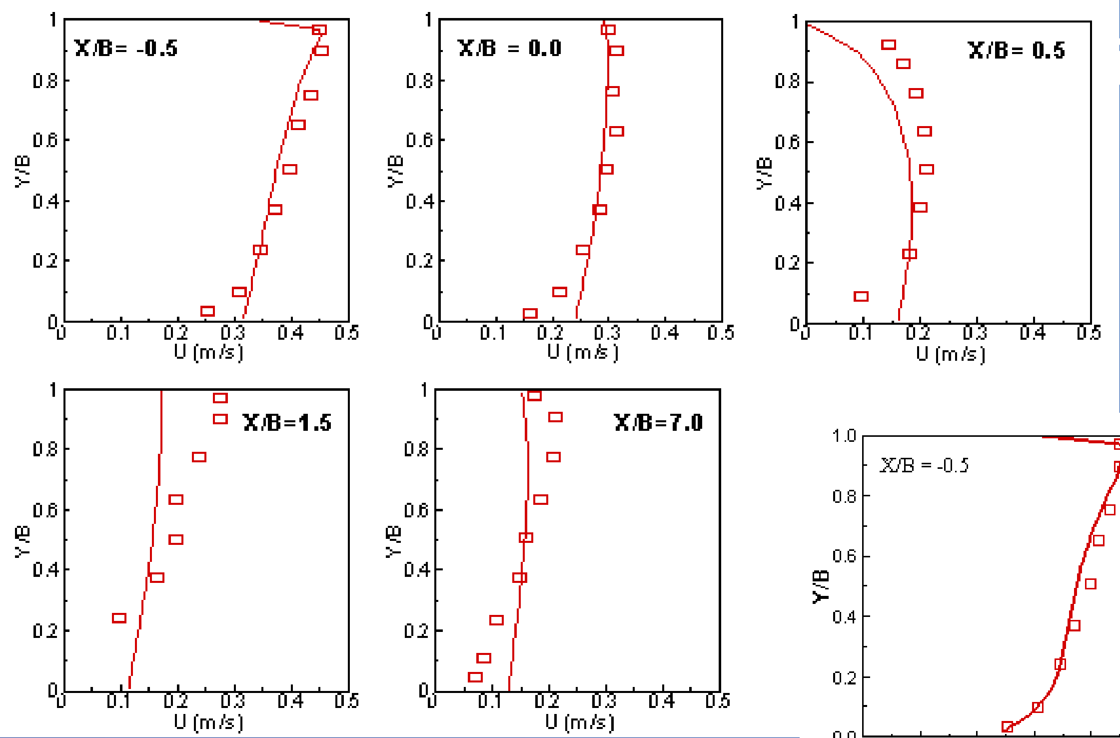
- Along both walls of the main channel

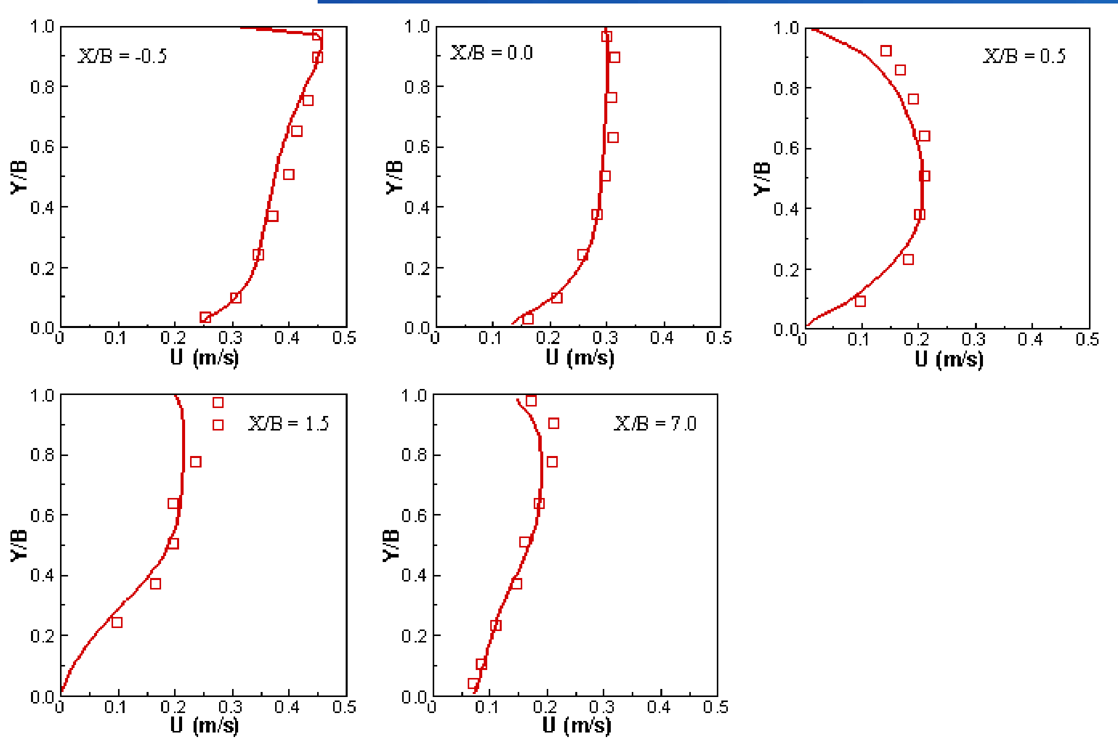


- Along both walls of the side channel

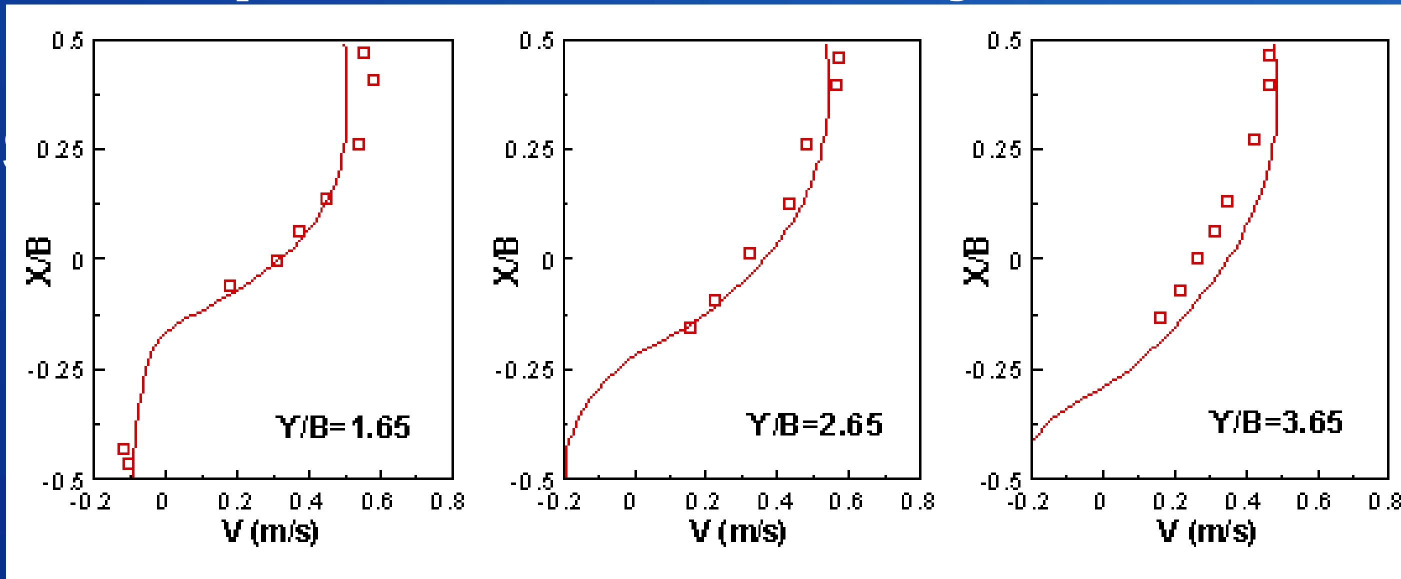


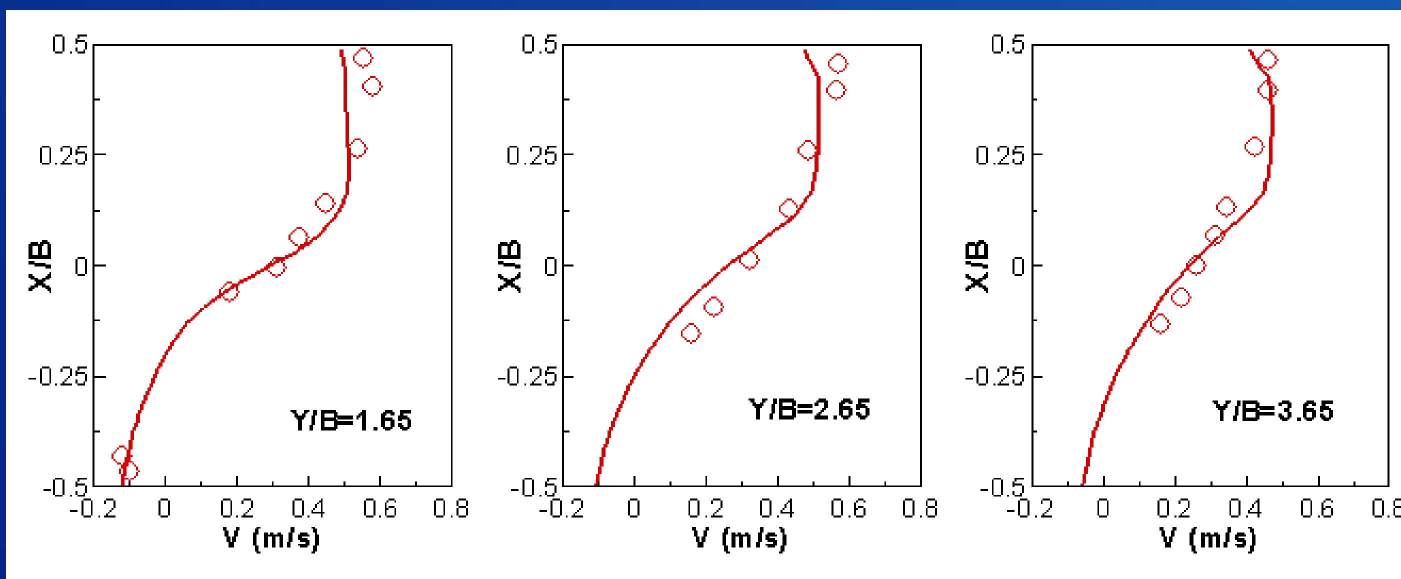
Comparison of Velocity … in Channel





Comparison of Velocity





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

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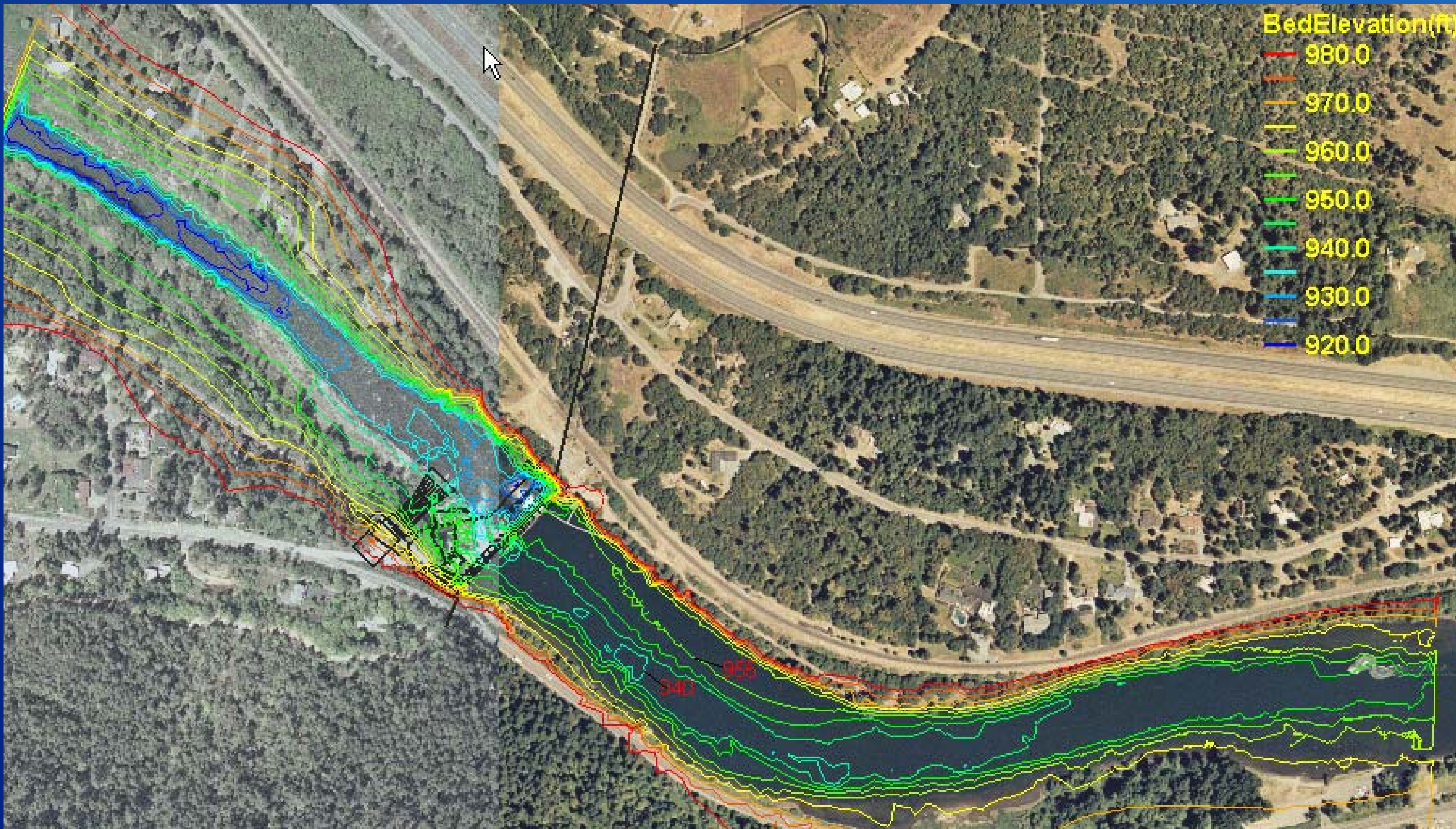
Plainview and Contours



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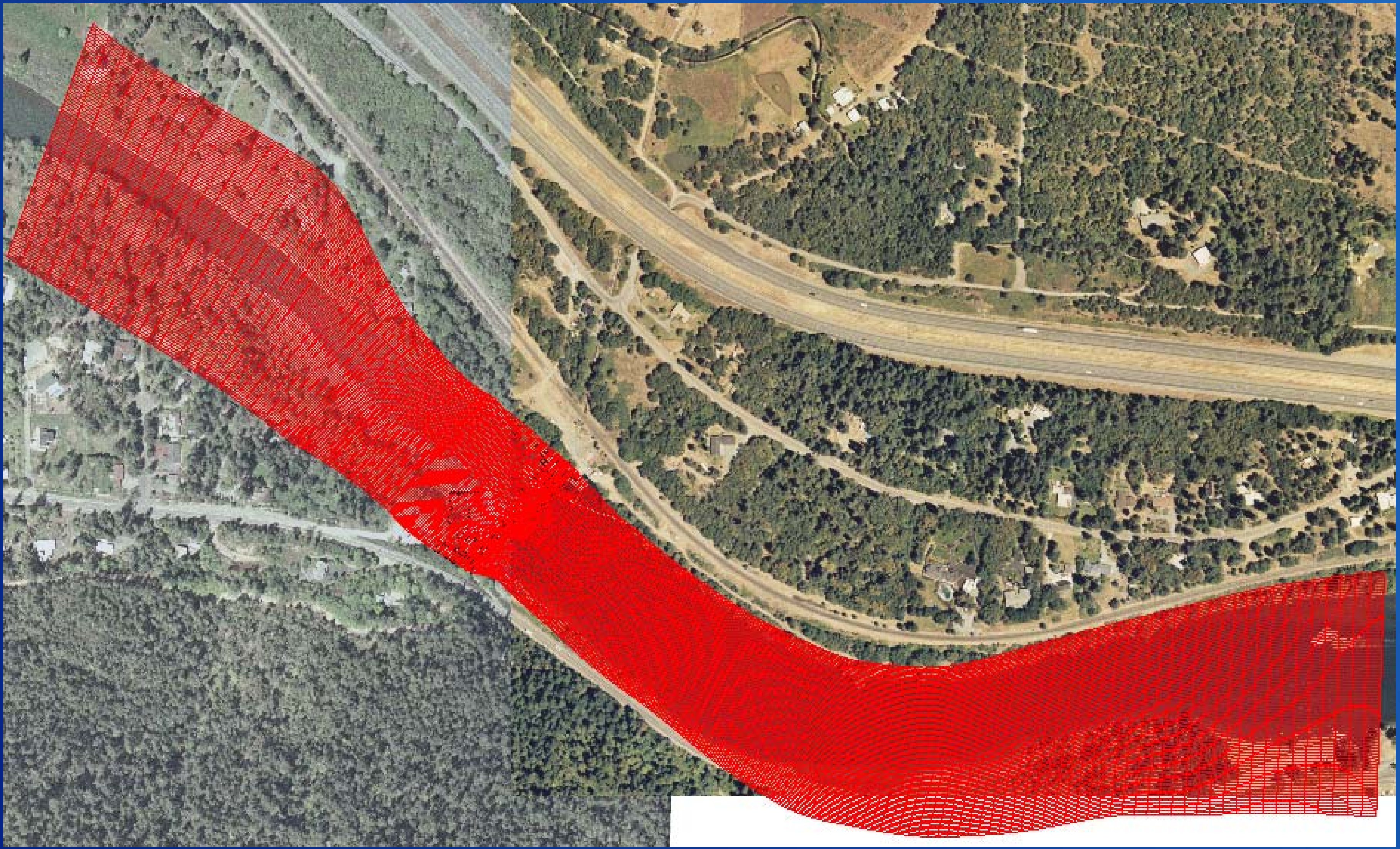
Mesh: 20,468 Points; Flow: 2,800cfs



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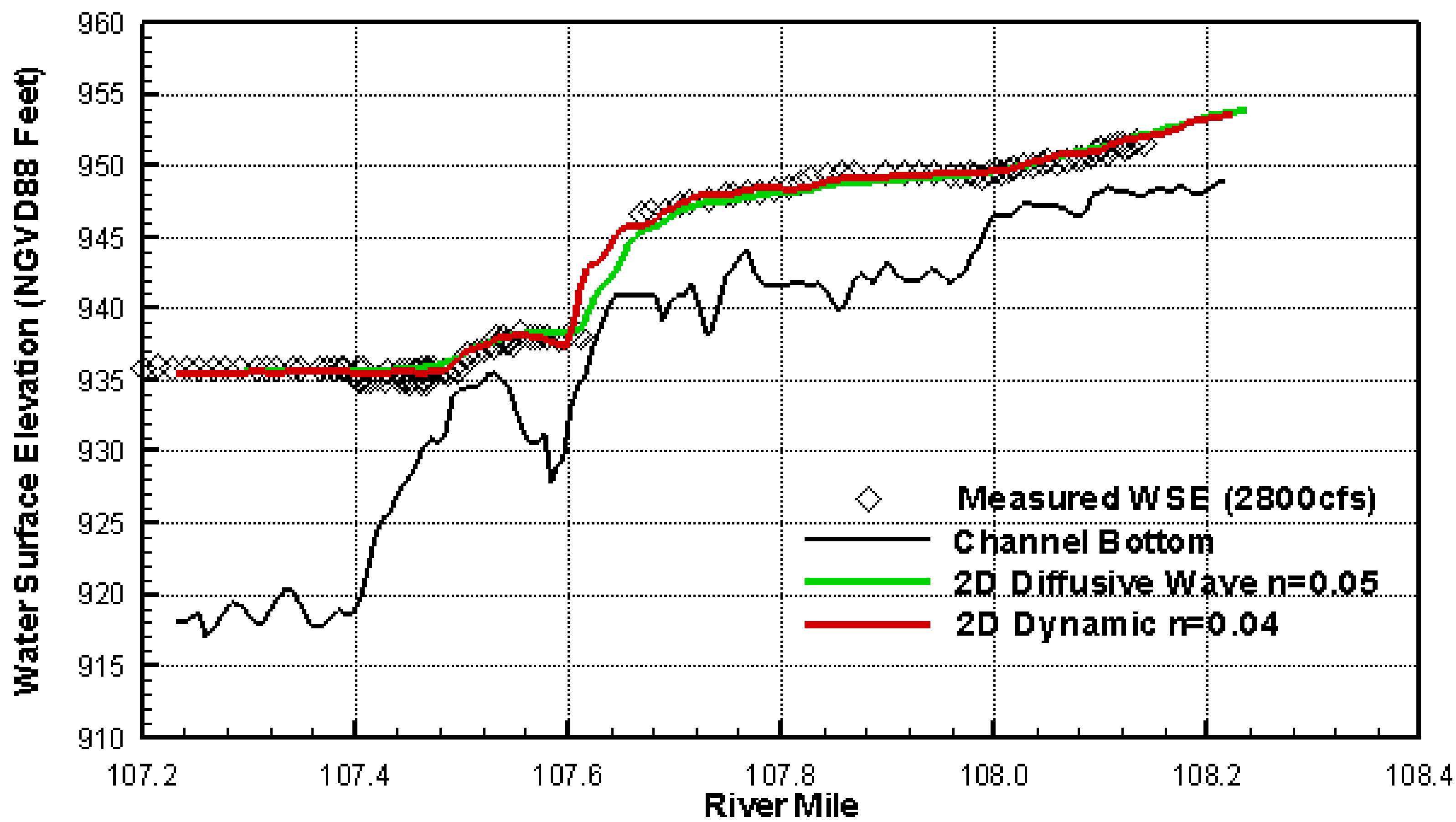
Comparison of Water Surface Elevation (Q=2,800 cfs)



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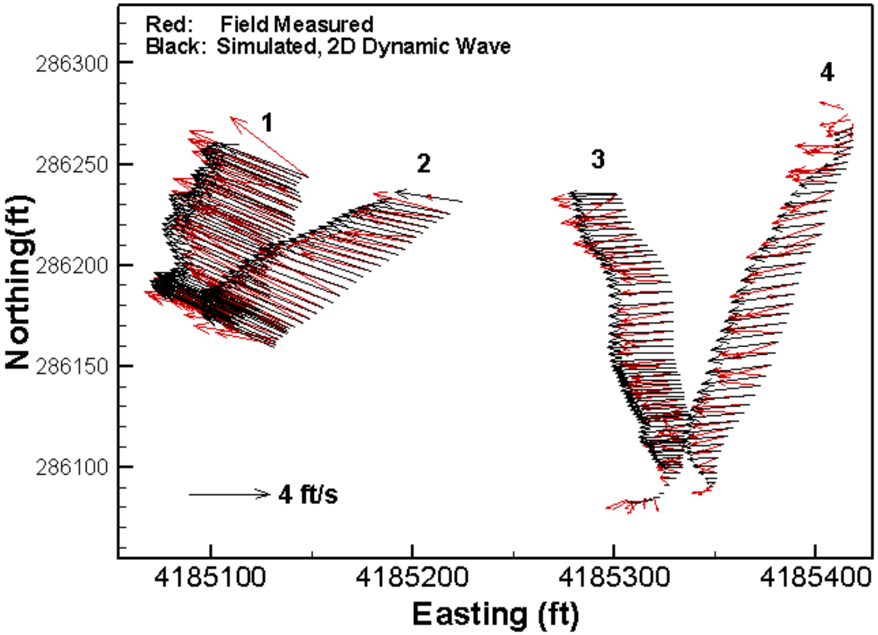
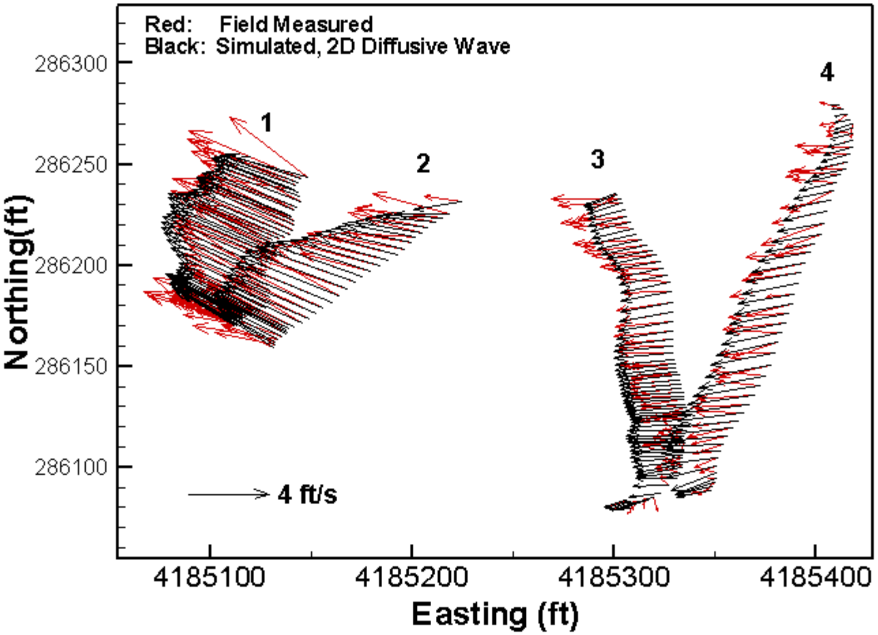
Measurement Points for Velocity Comparison

Velocity Comparison at XS 1 to 4

Dynamic Solver



Diffusive Wave Solver



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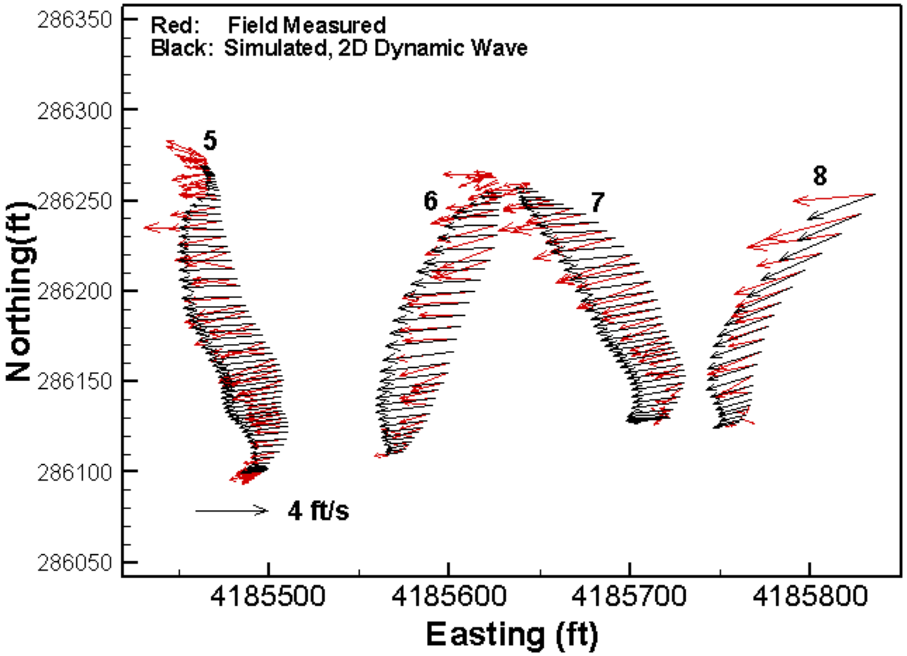
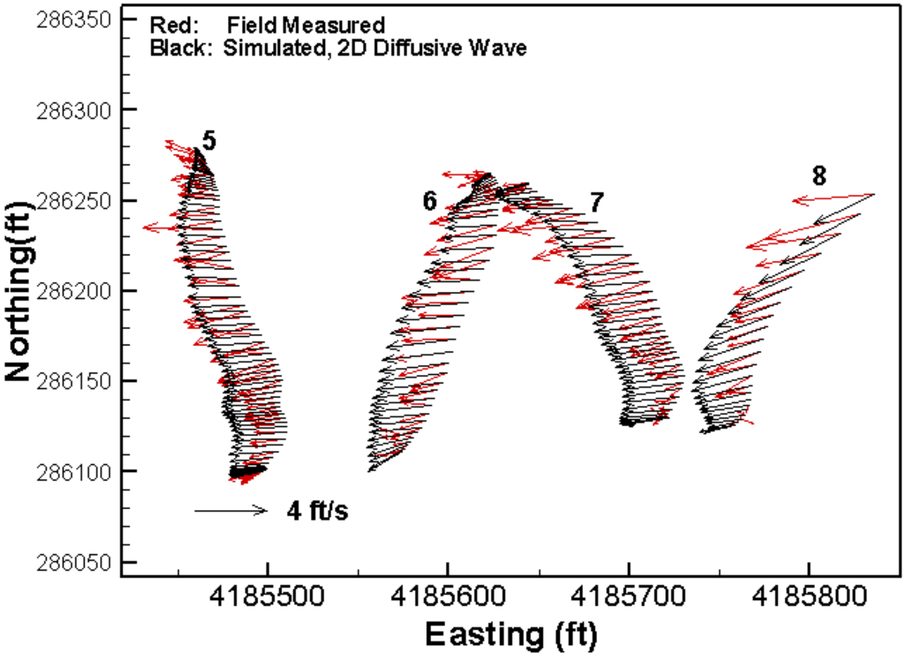
Velocity Comparison at XS 5 to 8

Dynamic Solver



Diffusive Wave Solver



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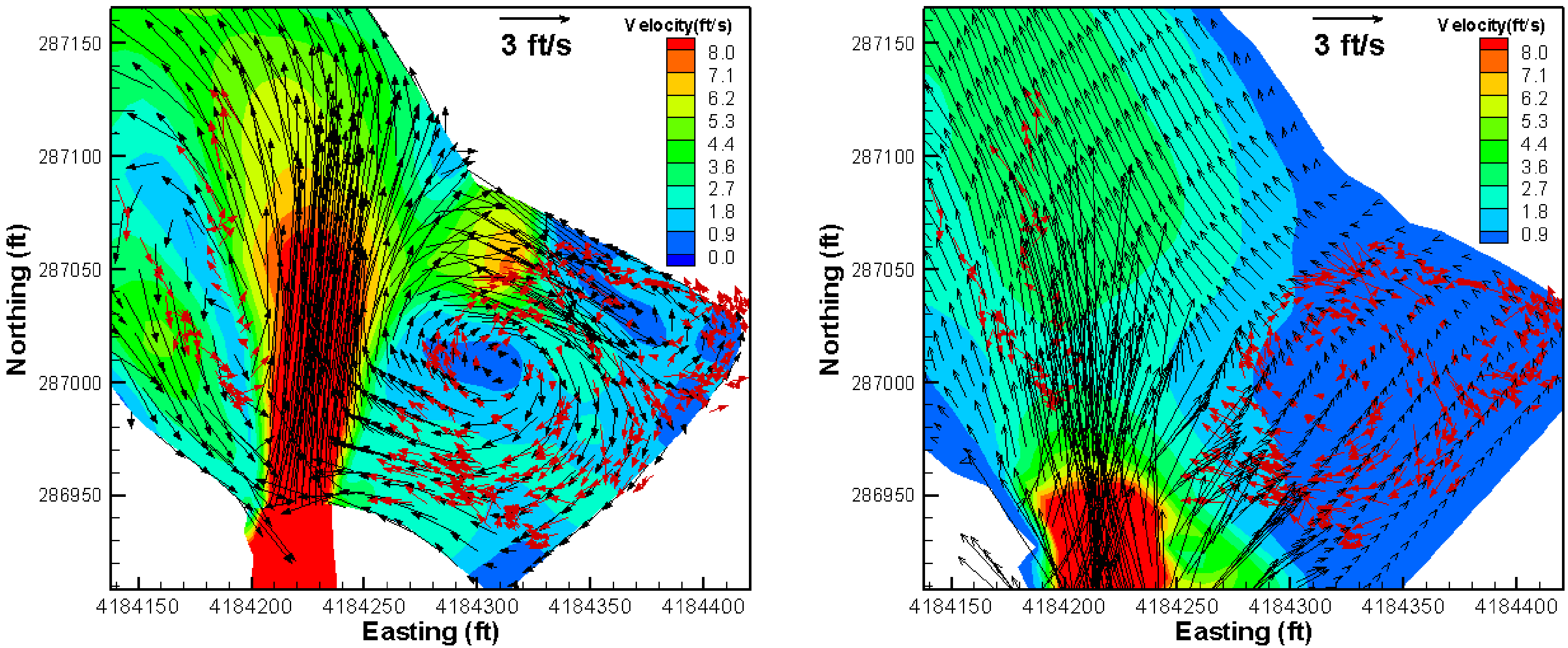
Velocity Comparison downstream of Dam

Dynamic Solver   Diffusive Wave Solver



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

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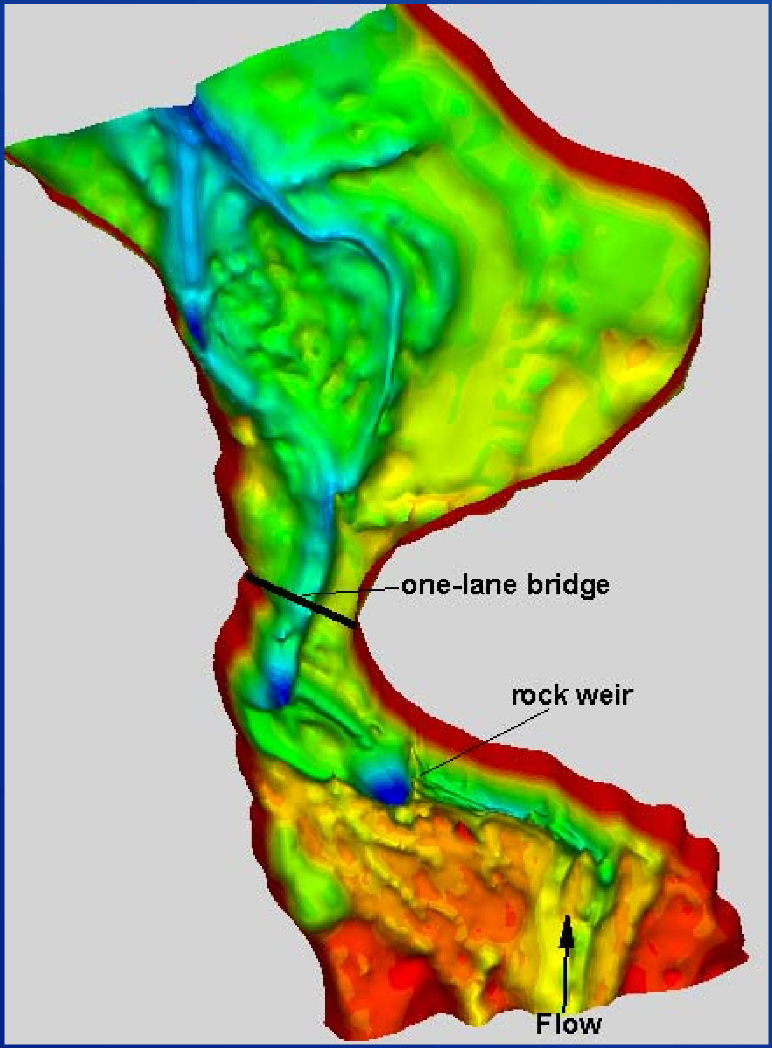
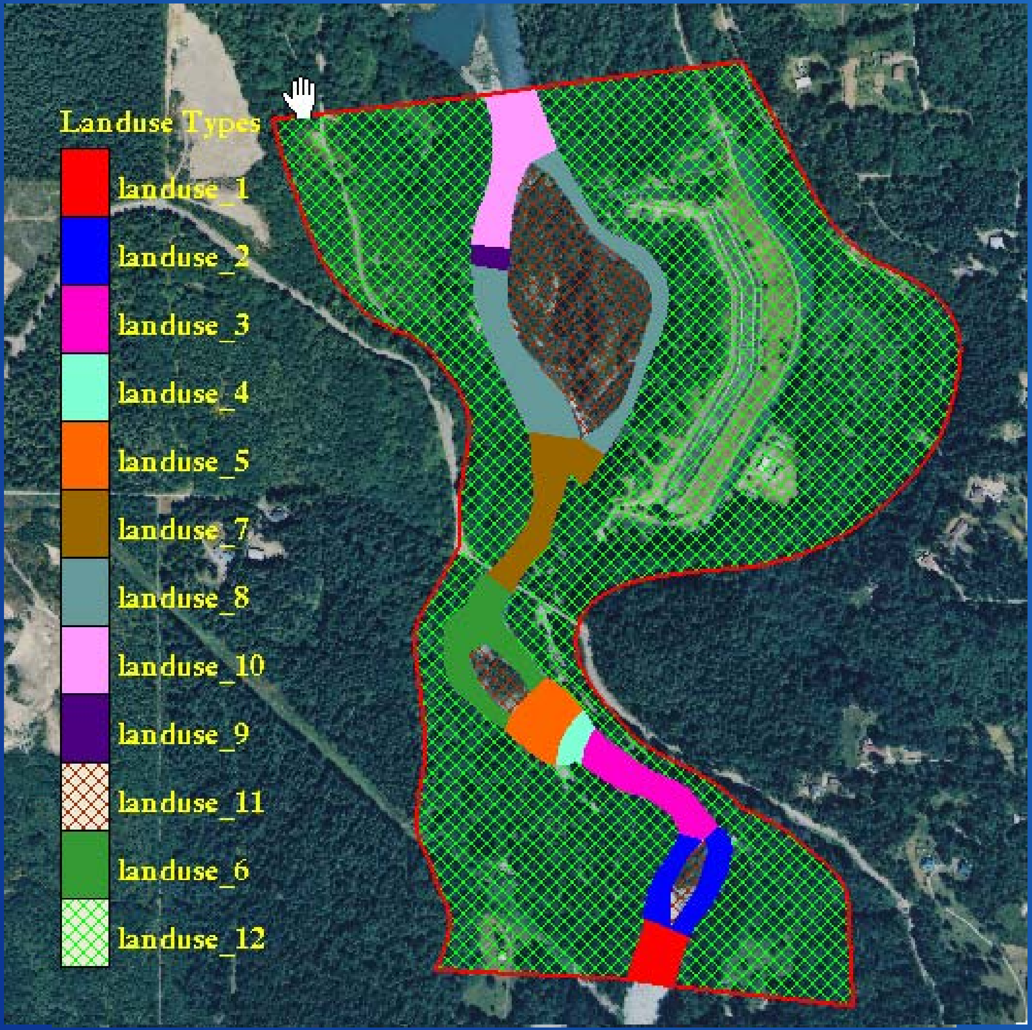
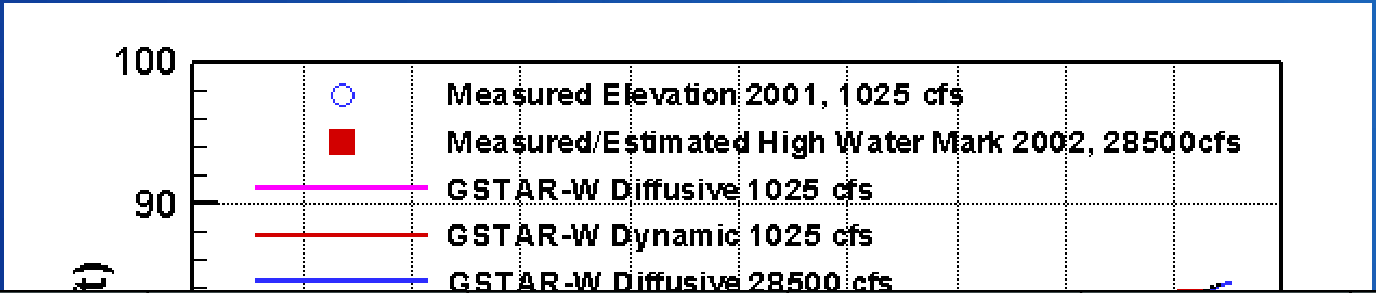
Mesh: ~ 10,000 Points; Low Flow: 1,025 cfs High Flow: 28,500cfs (2002 Flood)





Comparison of Water Surface Elevation



	Collins House East Bank	West Bank upstream Bridge	Rainney Well	Intake at Diversion Dam	High Voltage Area
Surveyed /Estimated(ft)	83.0	80.2	79.4	75.7	63.0
Model Predicted(ft)	84.1	78.9	78.5	75.6	62.8

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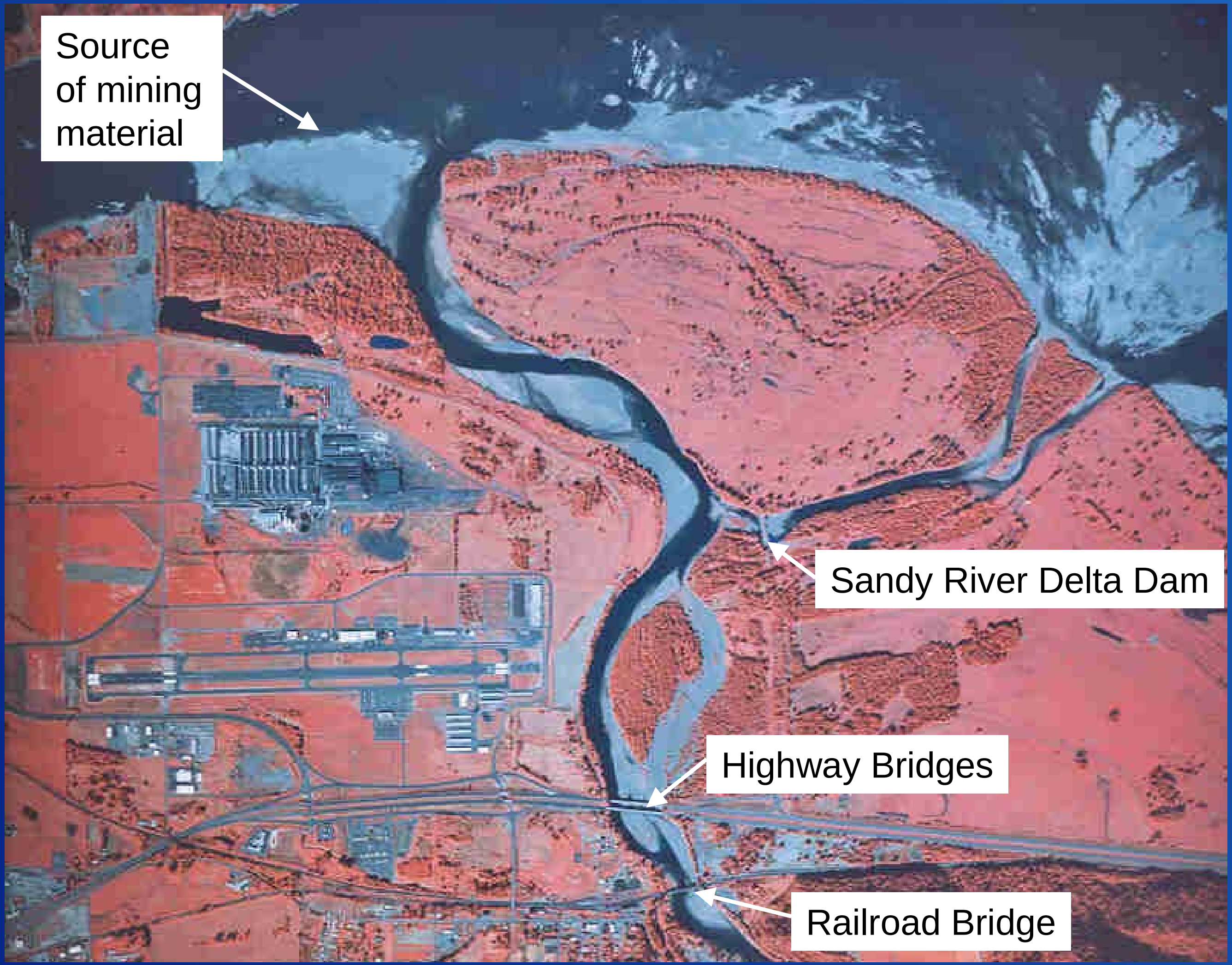
Verification & Validation Cases: Sandy River Delta (Oregon)



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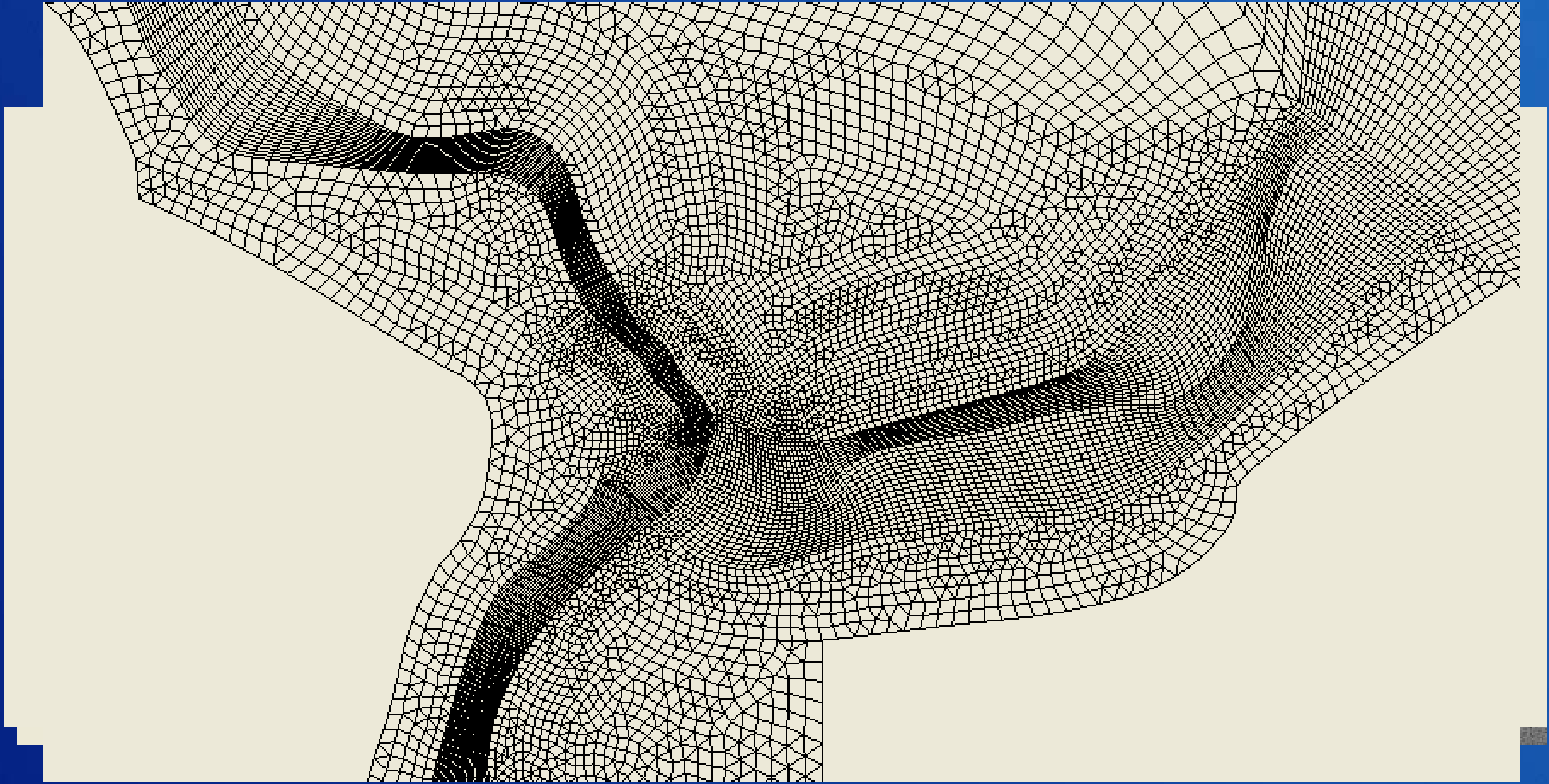
Domain: 9.5 mi of Columbia River
1.2 mi of Sandy River
Mesh: ~ 40,000 points



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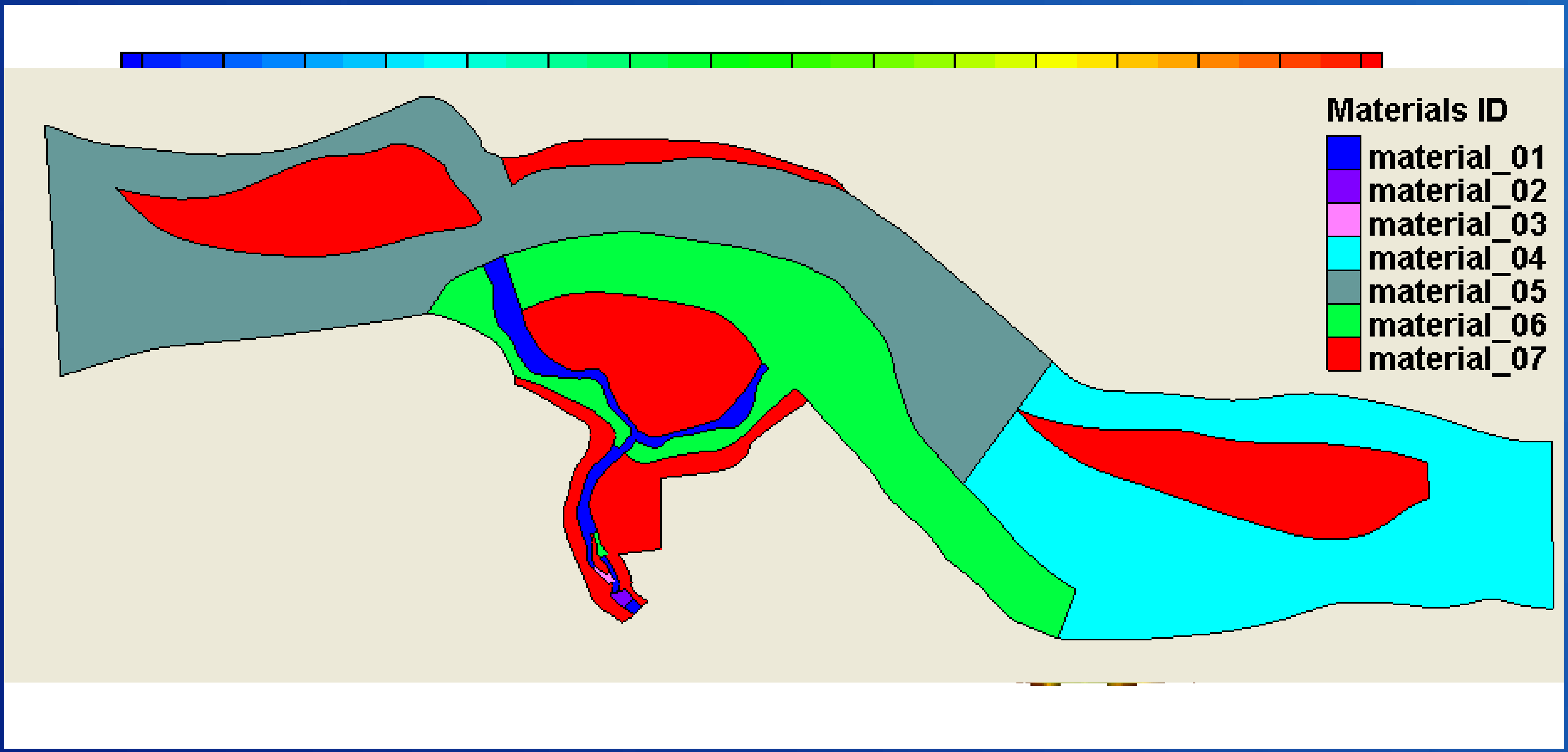
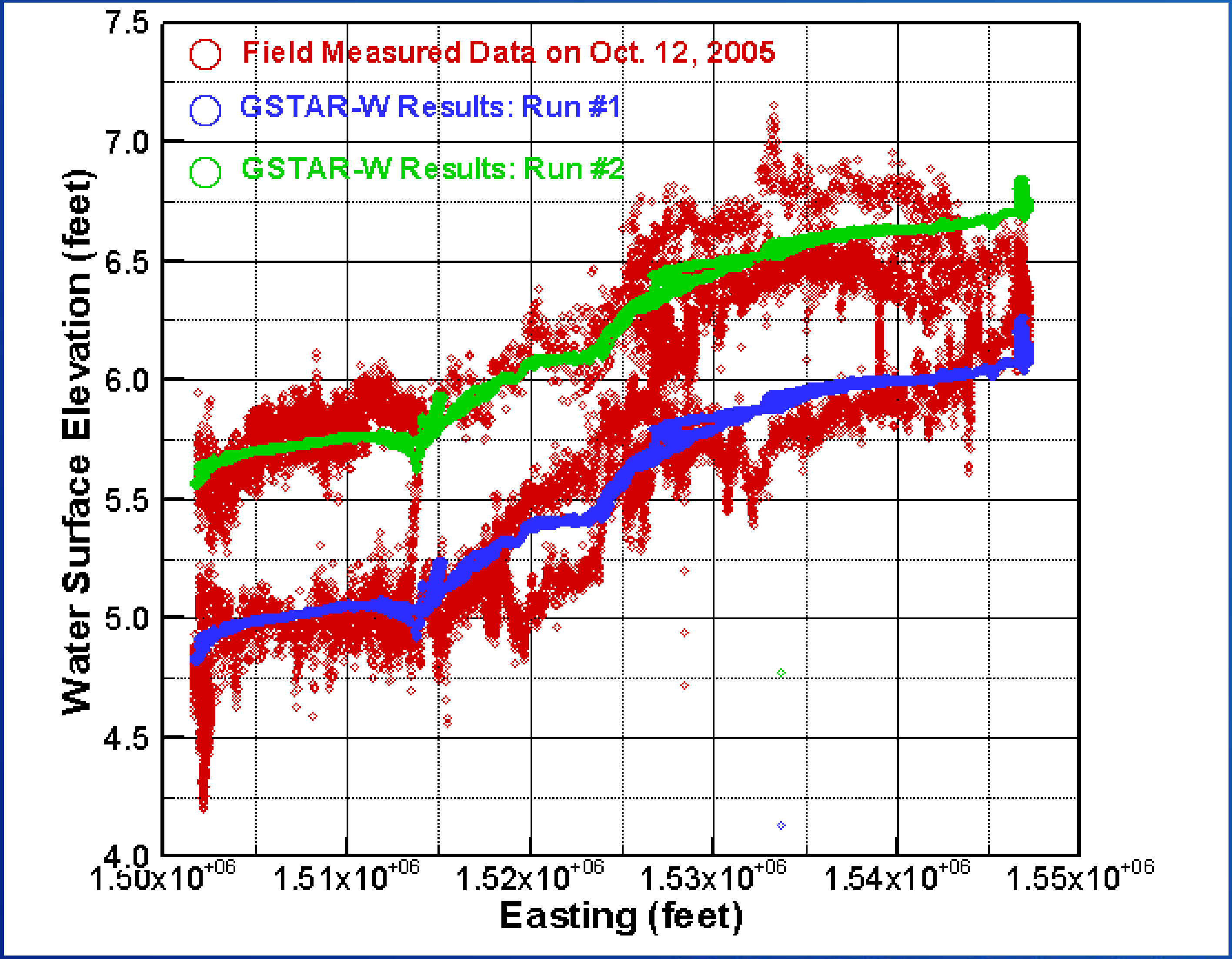
Topography & Landuse Zones



Comparison of Water Surface Elevation
(Q_Sandy=377cfs; Q_Columbia=123,000cfs)



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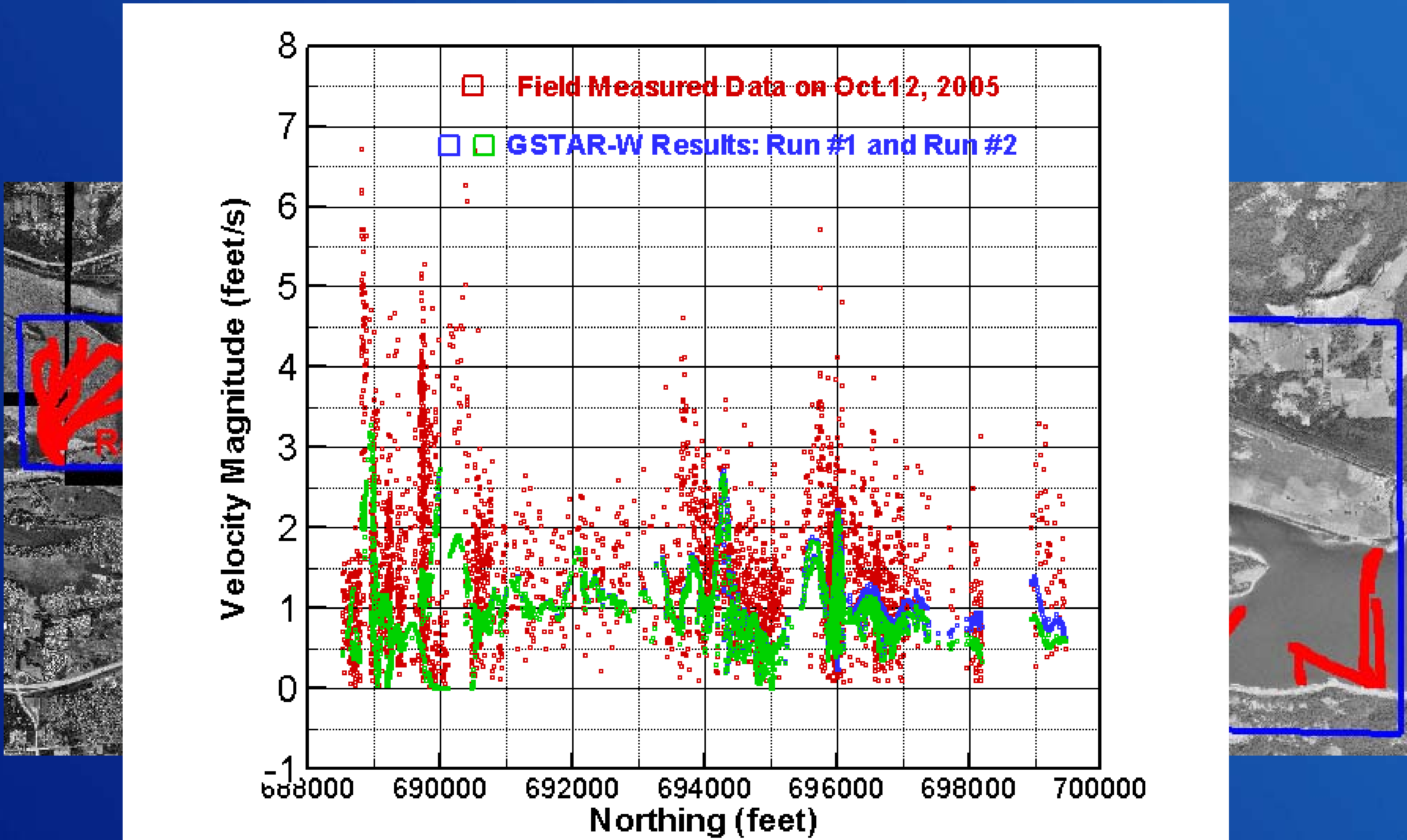
Comparison of Velocity Magnitude



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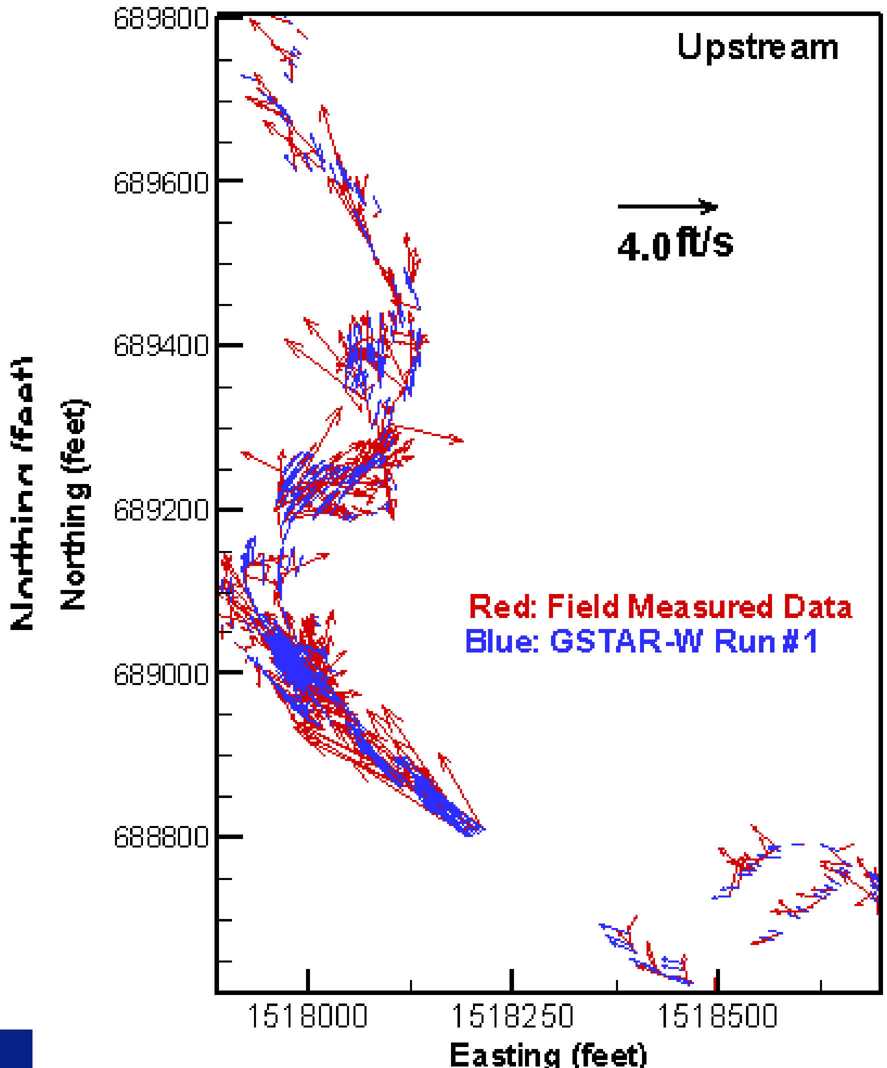
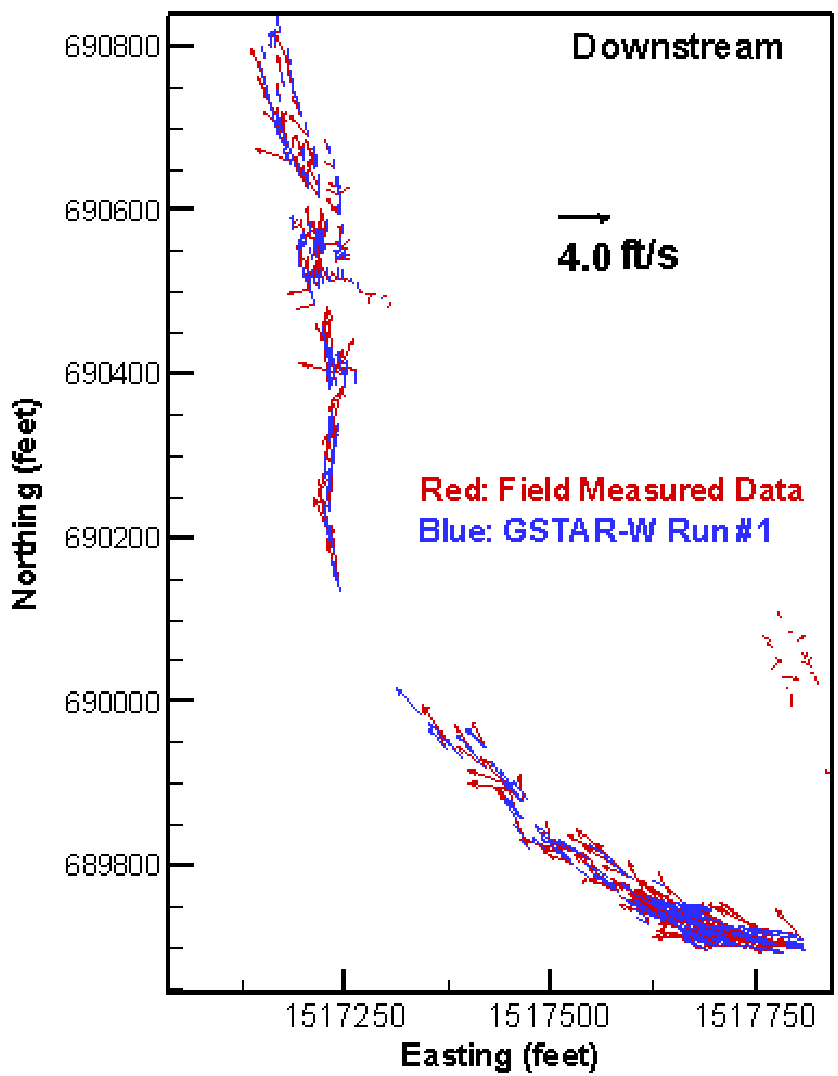
Comparison of Velocity Vector





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Part 4: Sample Practical Applications

Sample Applications

- Dam Removal: Savage Rapids Dam
- Temporary Diversion: Elwha River
- Levee Setback: Lower Dungeness River

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Savage Rapids Dam Removal Study

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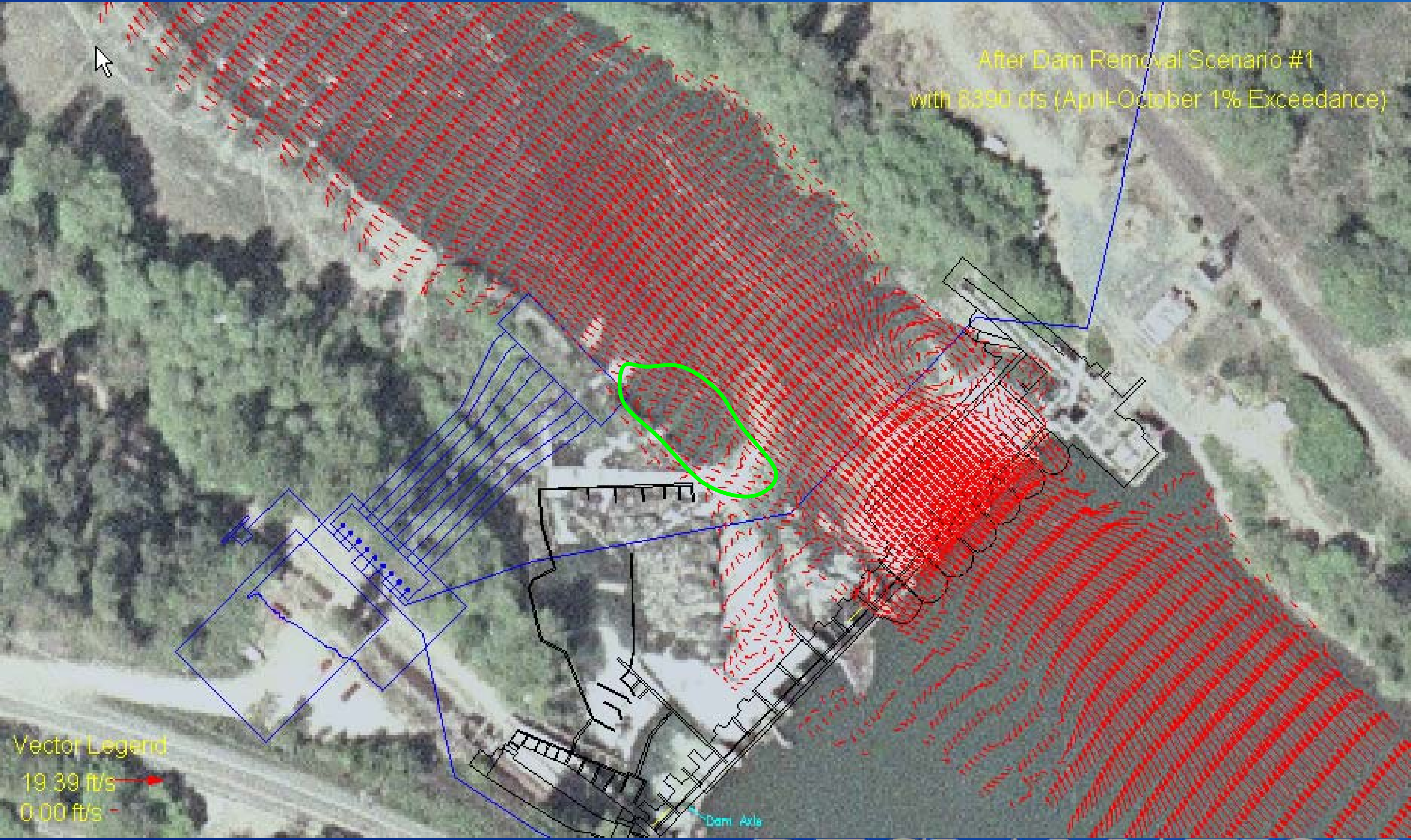
Intake Location Selection



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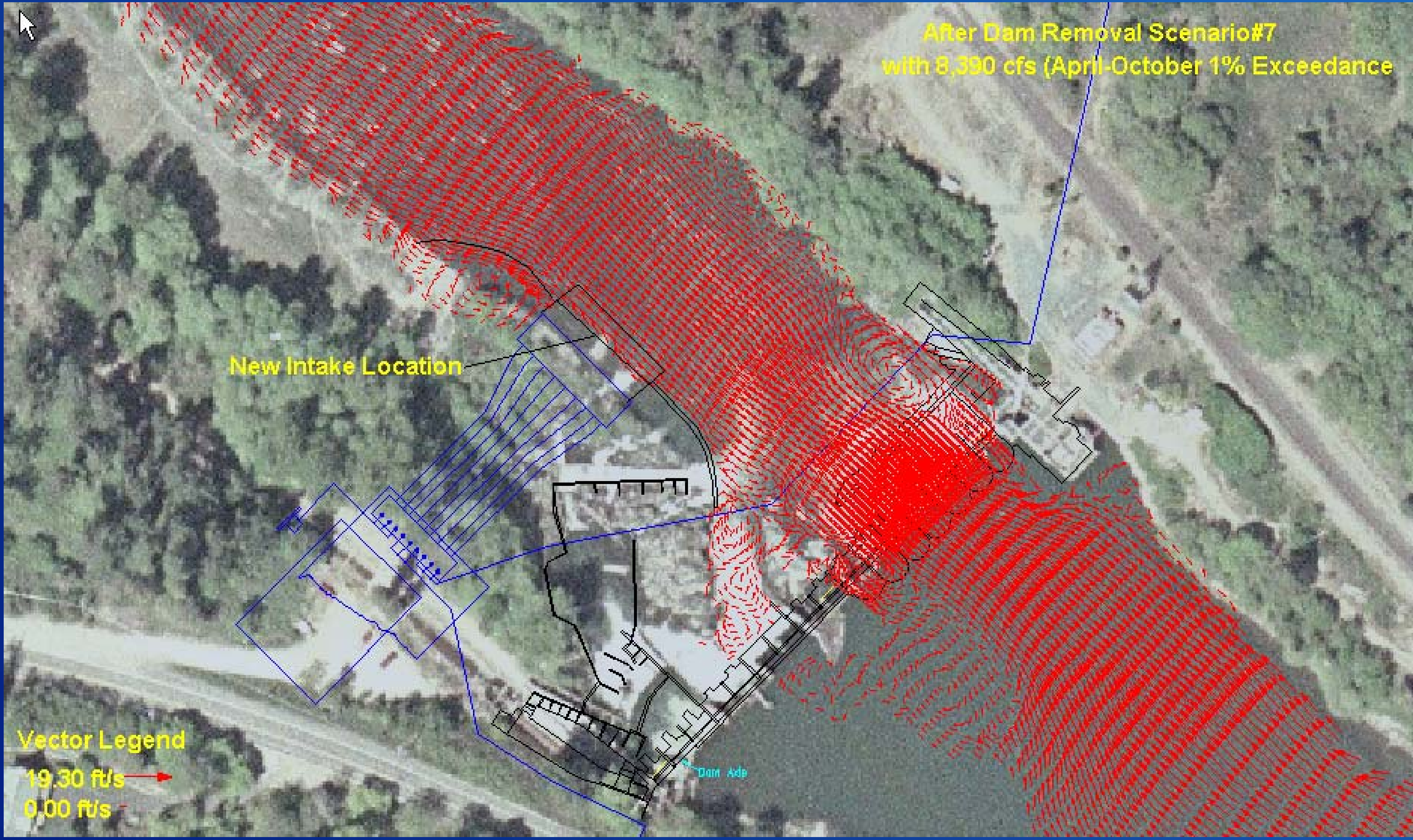
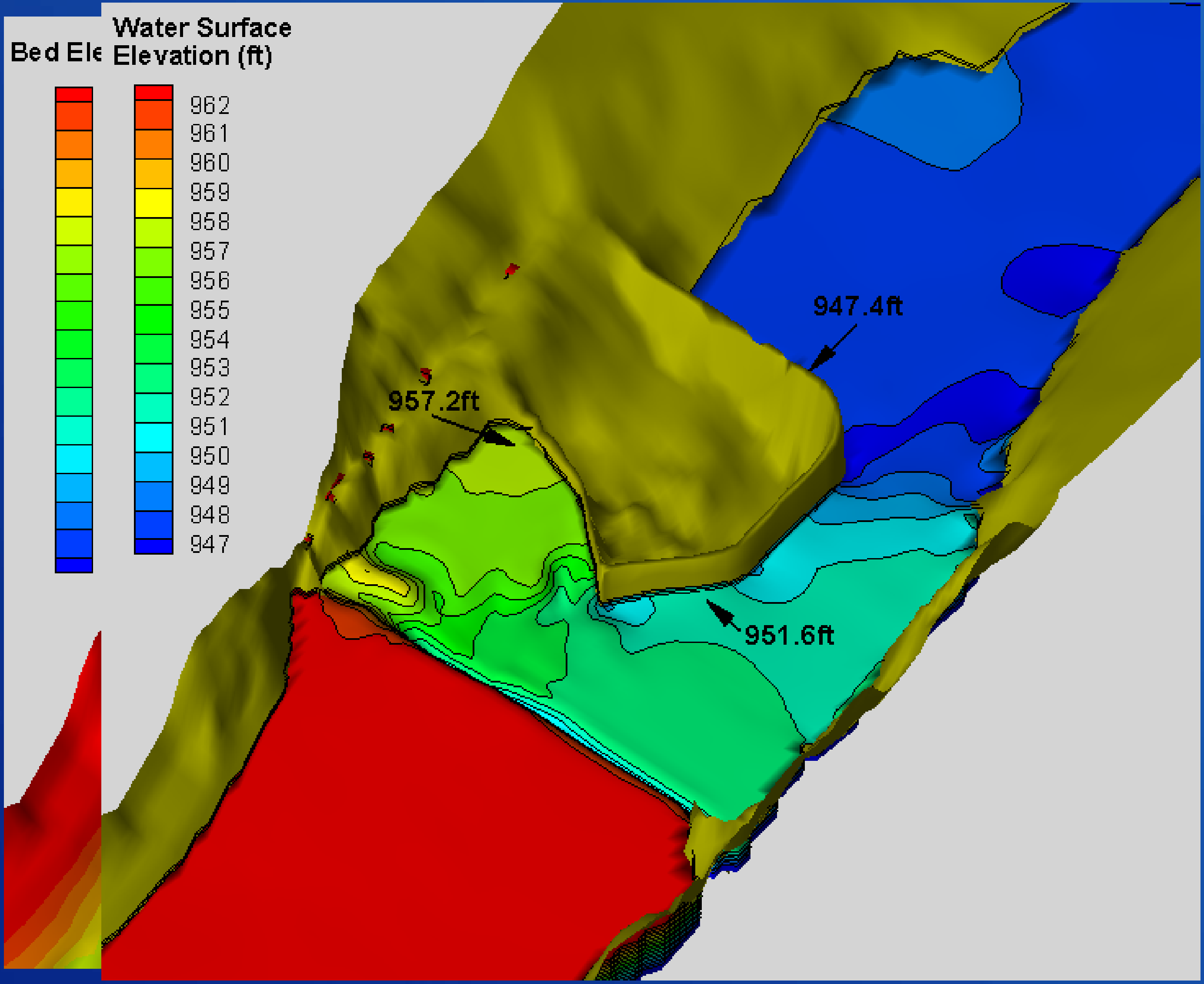
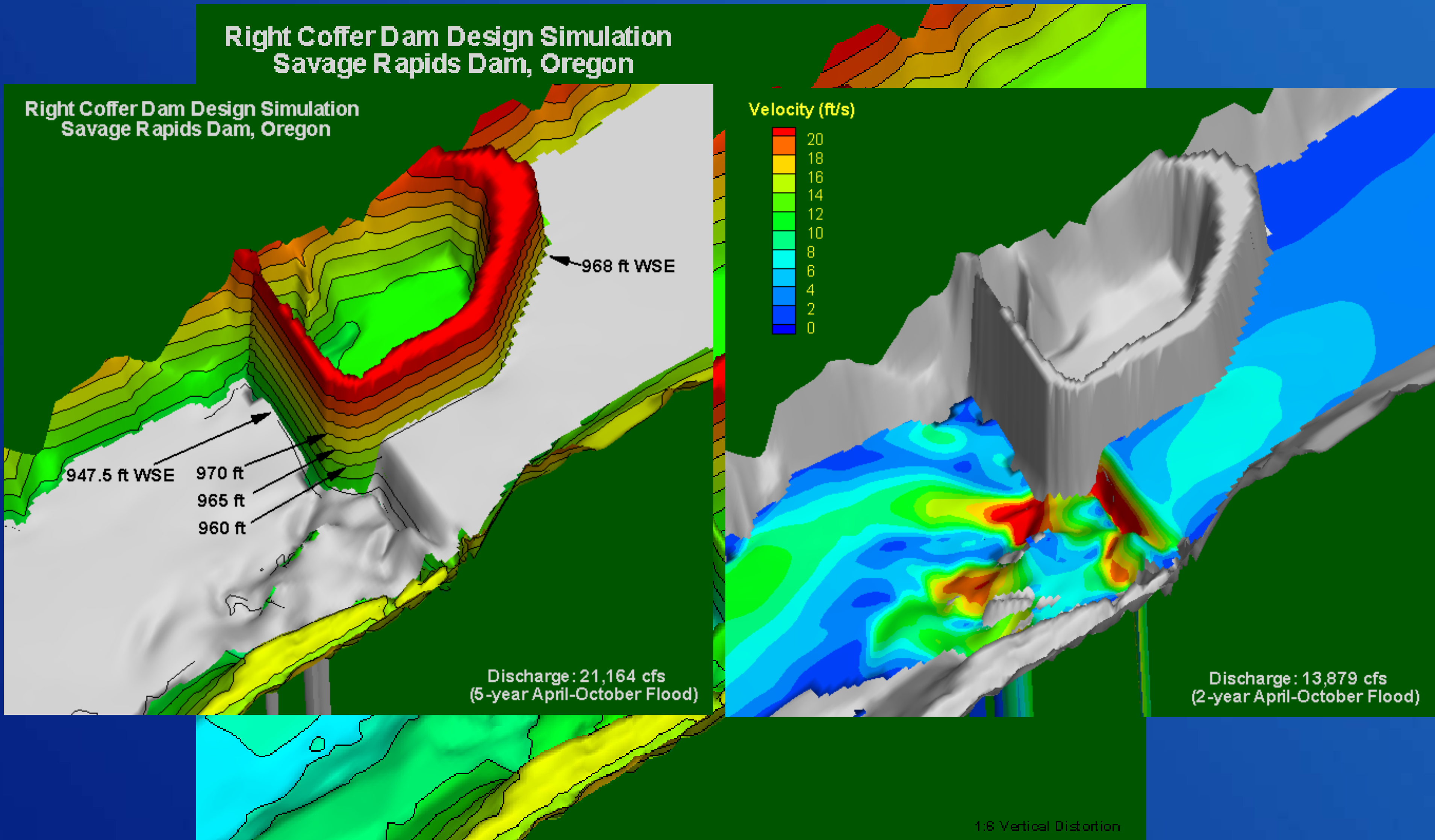
Intake Location Selection



Intake Cofferdam



Right Cofferdam Design



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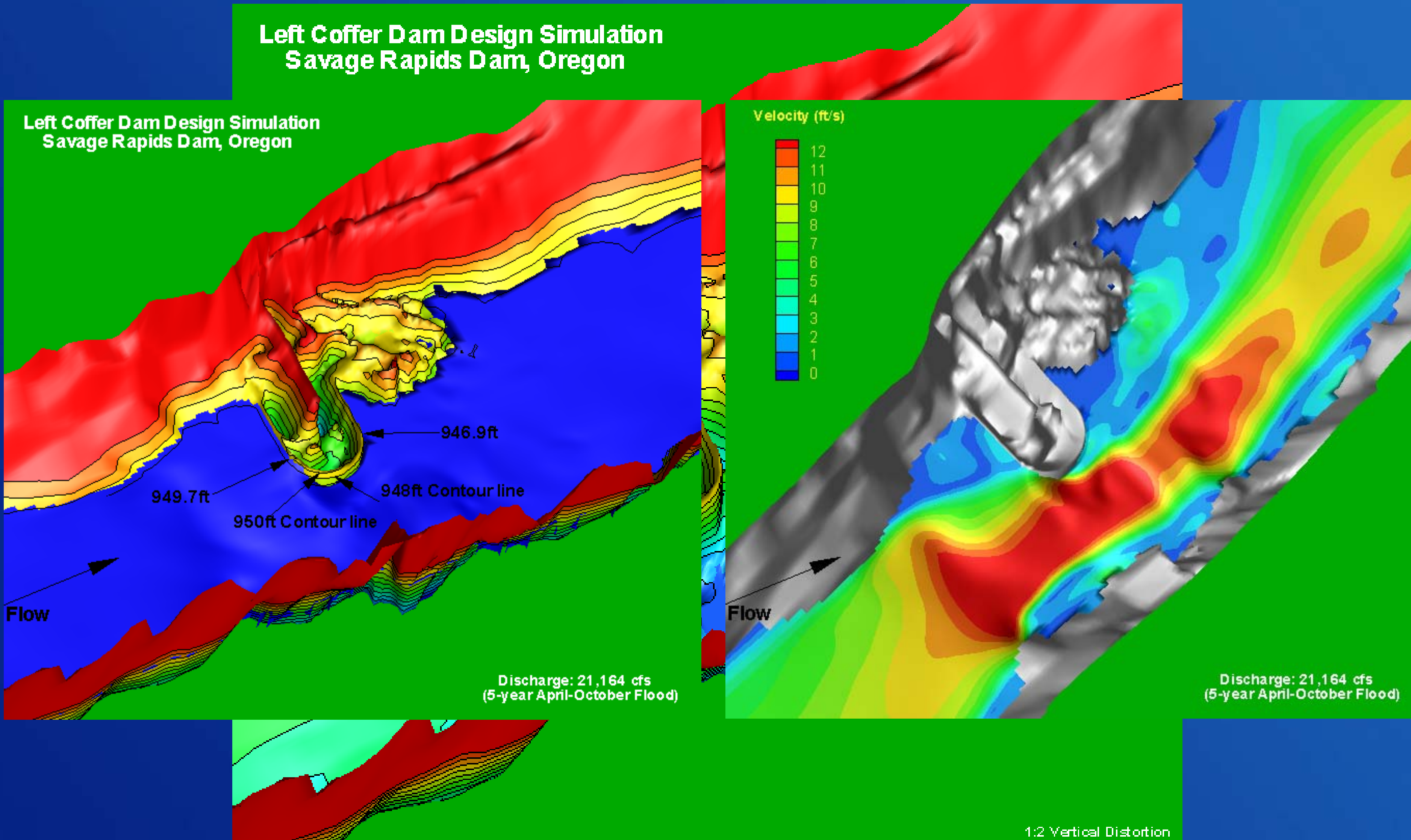
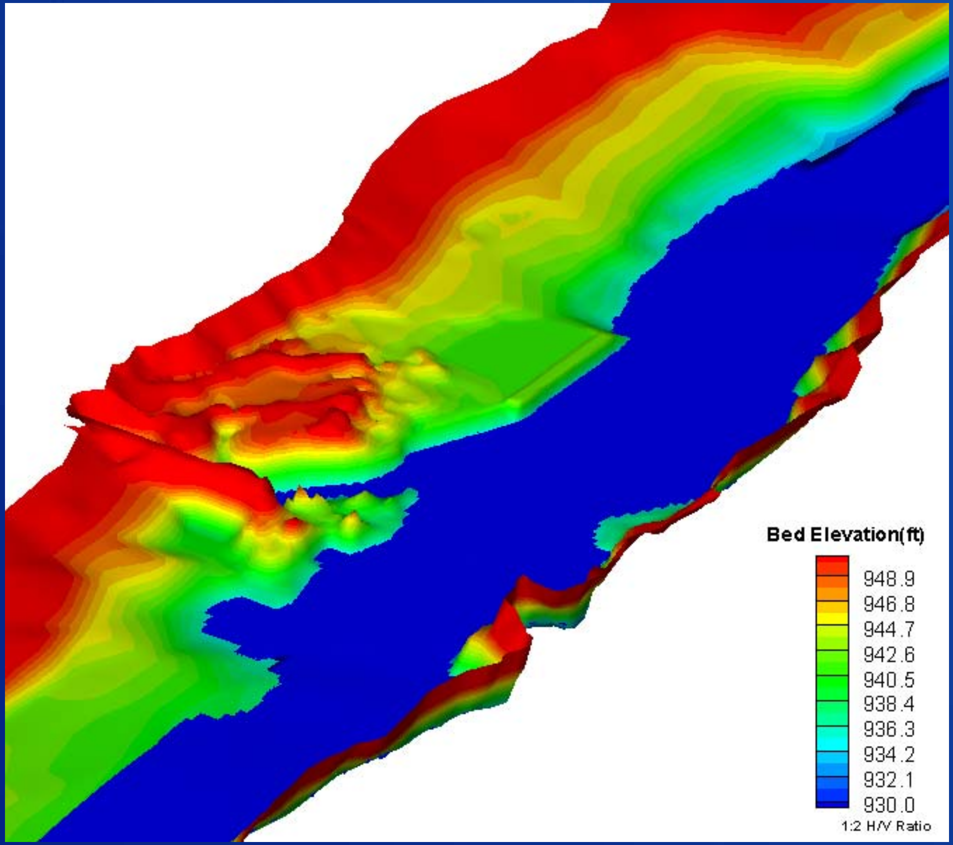
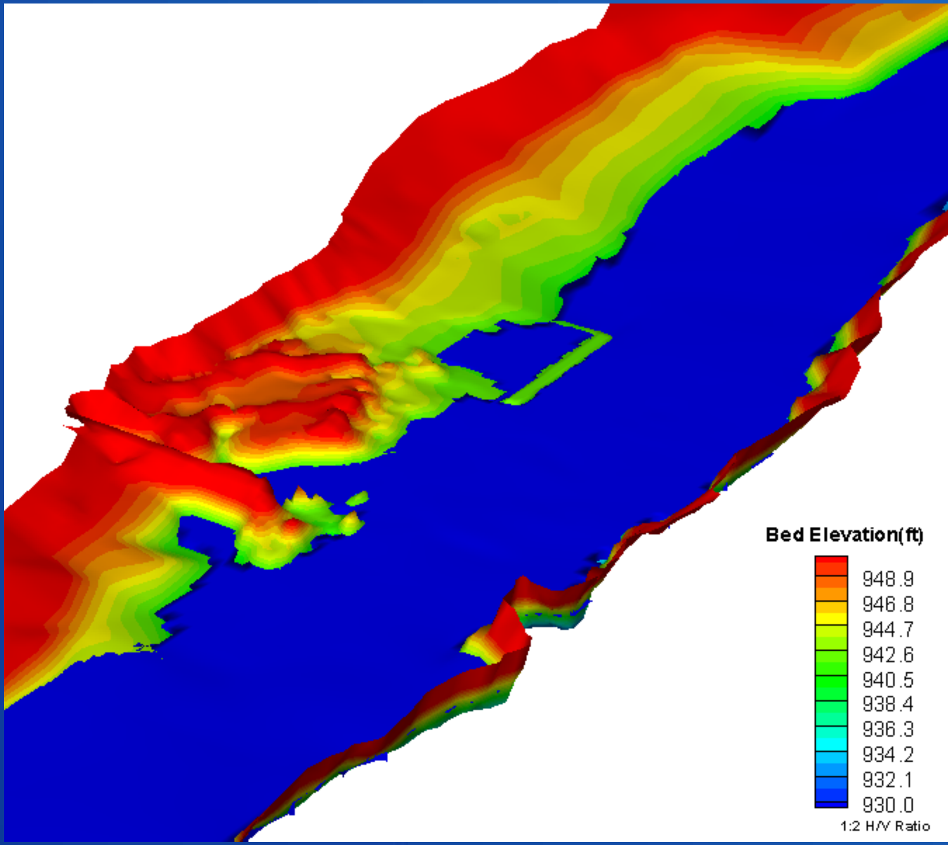
Left Cofferdam Design



After Dam Removal Inundation

900cfs **8,390cfs**

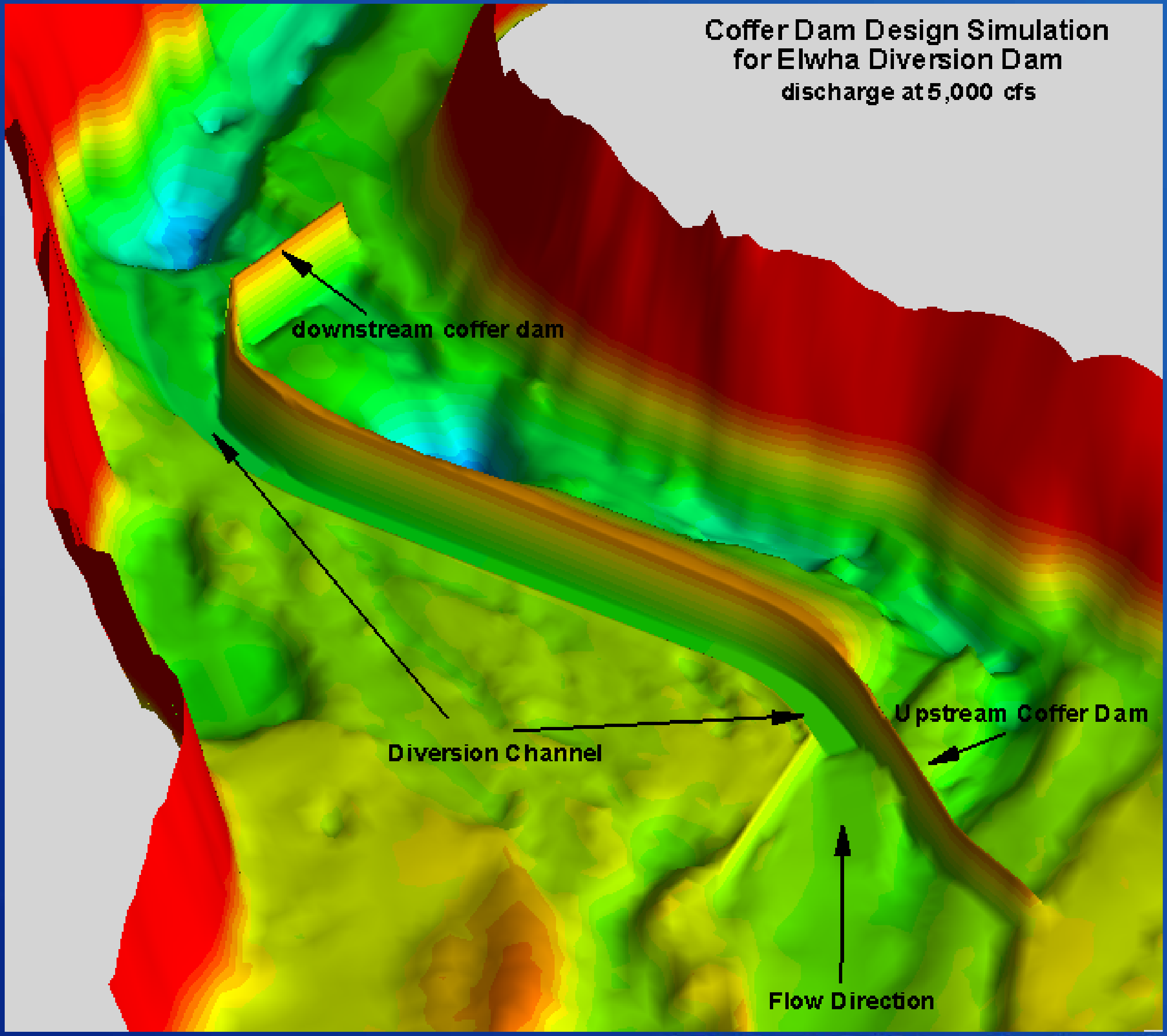




Elwha Surface Diversion Project

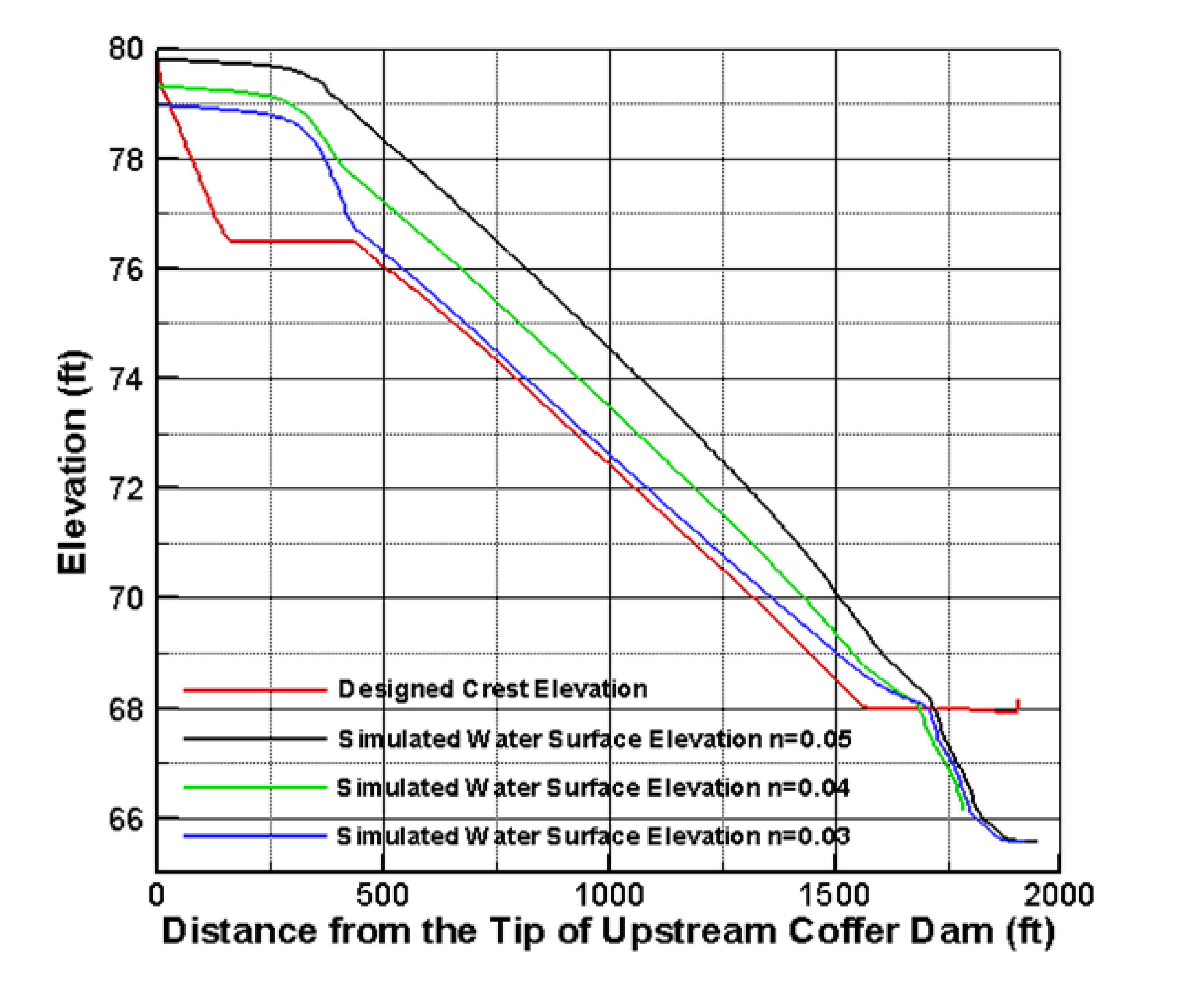
RECLAMATION

Topography by Mesh



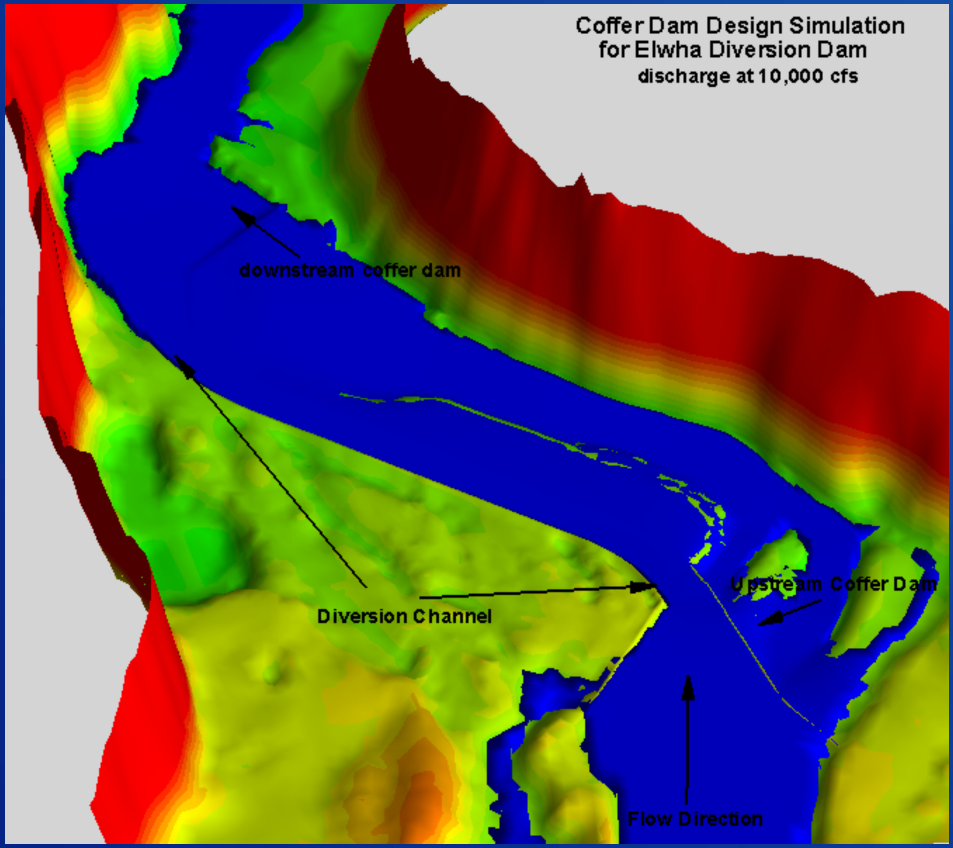
RECLAMATION

Cofferdam Design & Inundation at Q=5,000cfs

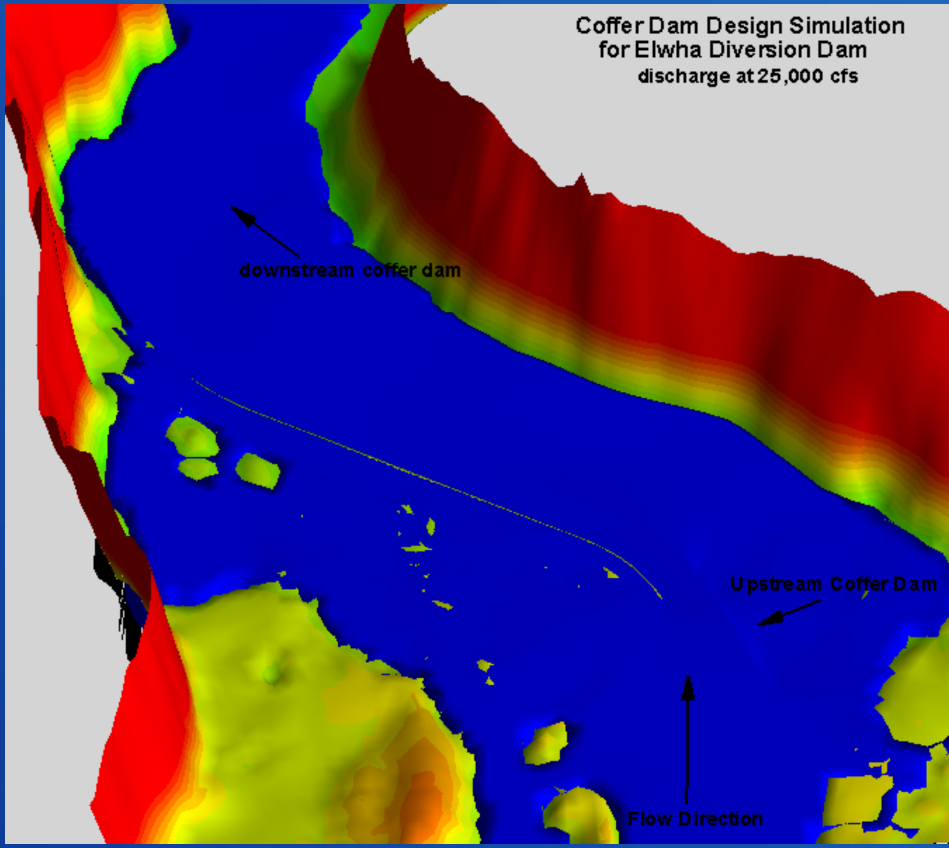


Flood Inundation

10,000cfs



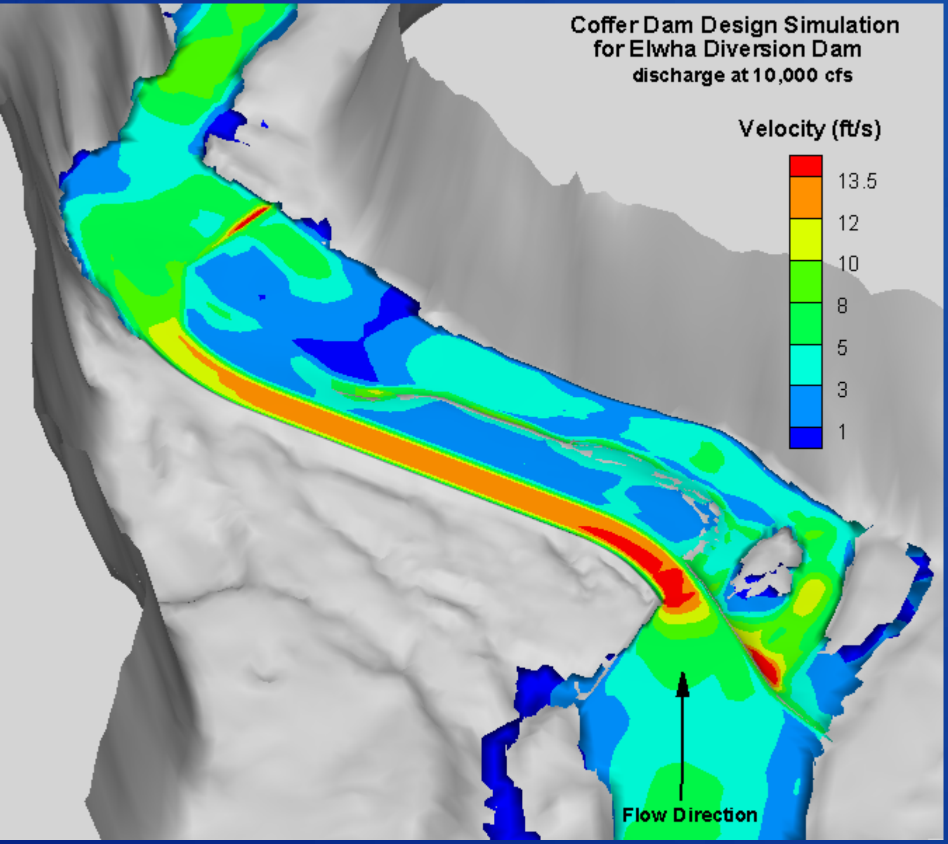
25,000cfs



RECLAMATION

Velocity

10,000cfs



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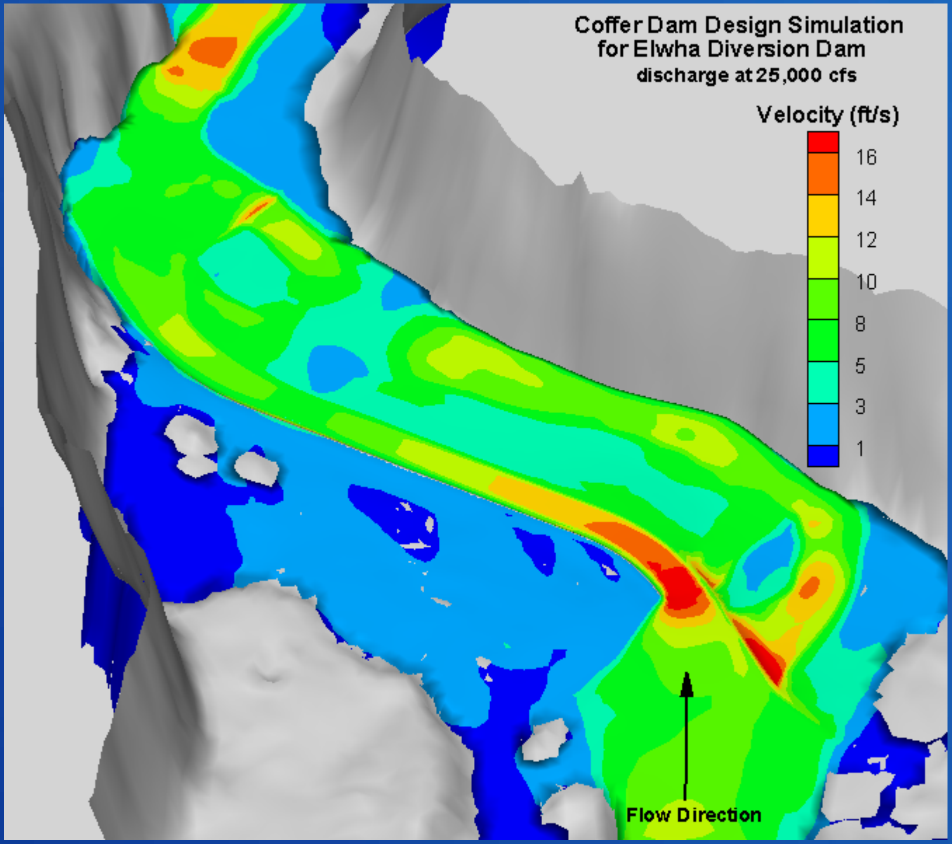
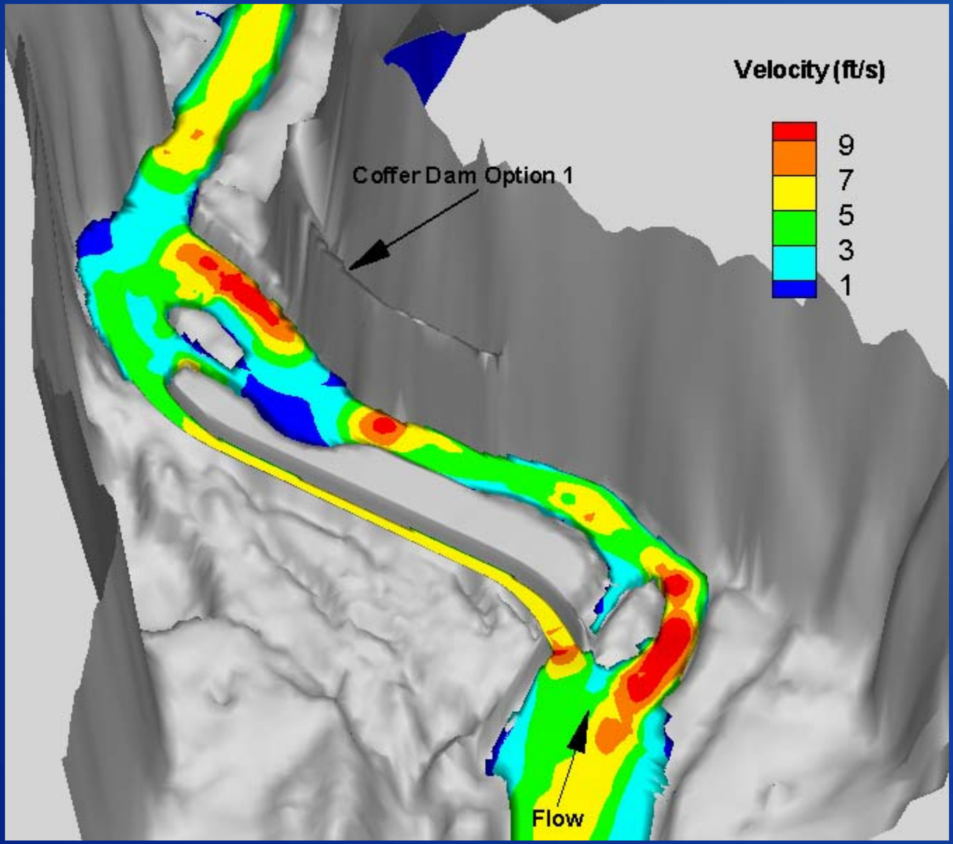
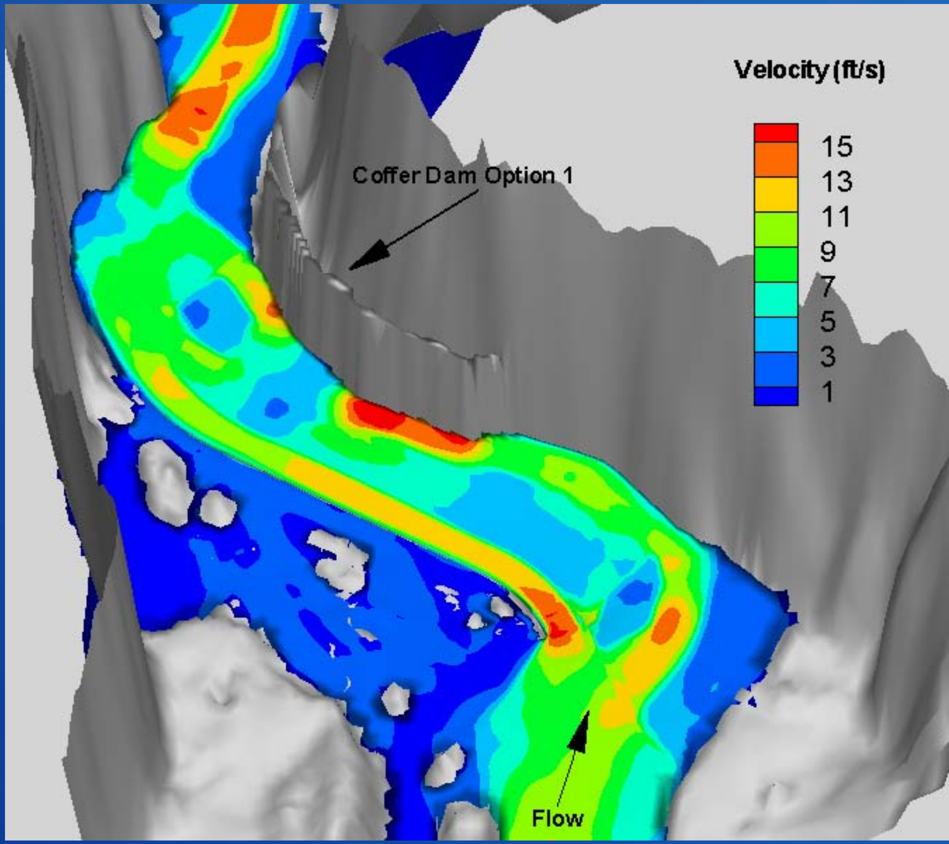


RECLAMATION

Intake Cofferdam Design

5,000cfs **25,000cfs**

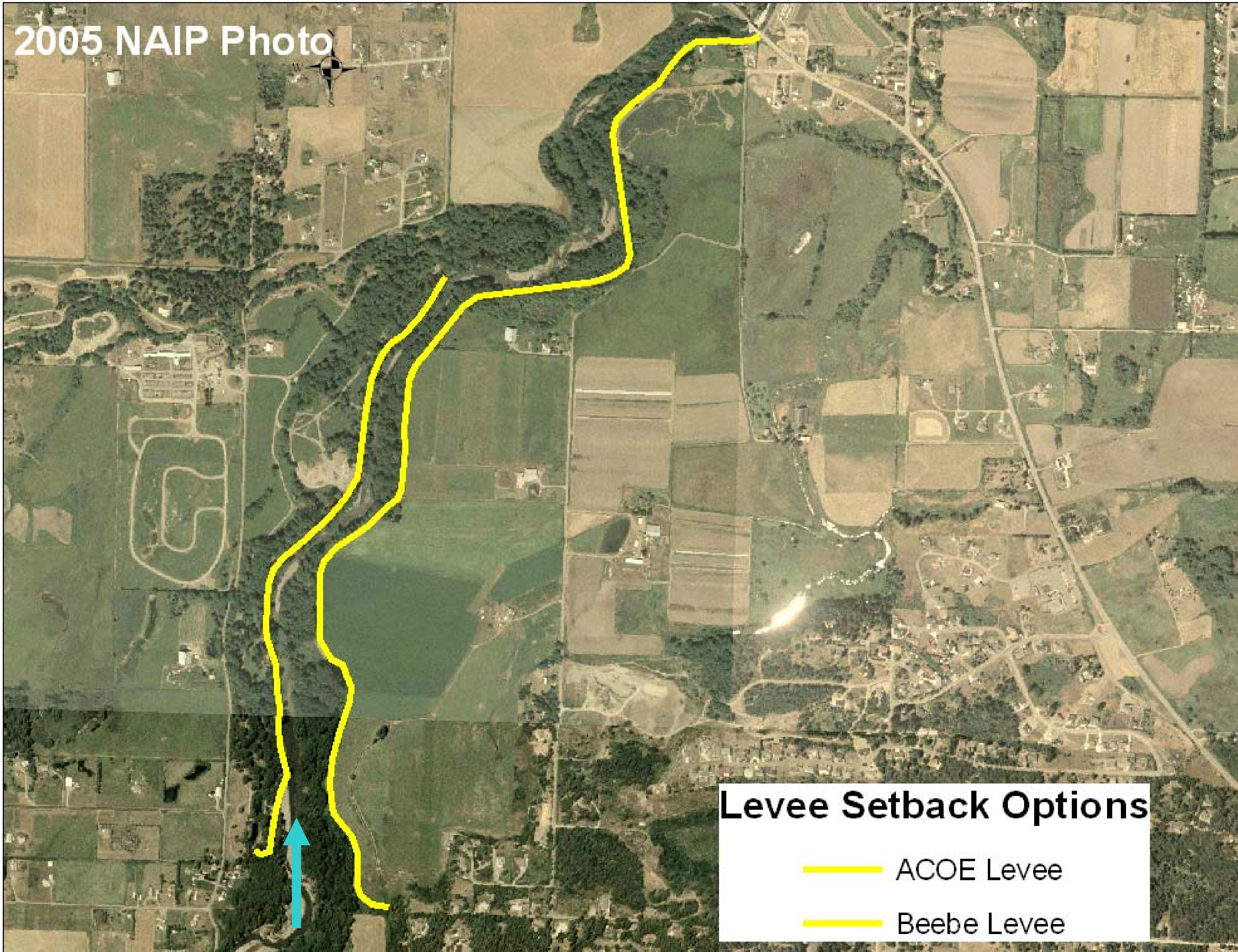


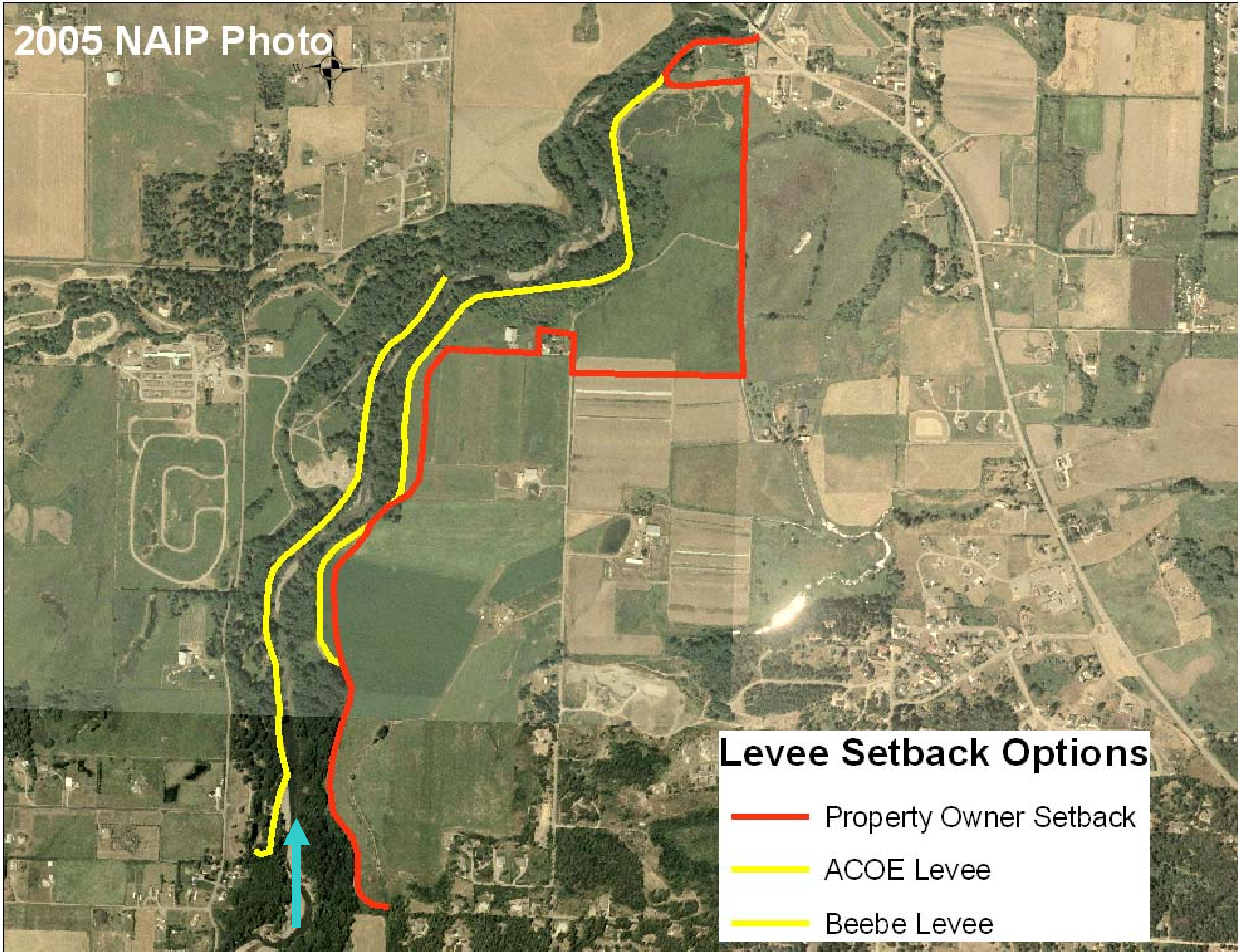


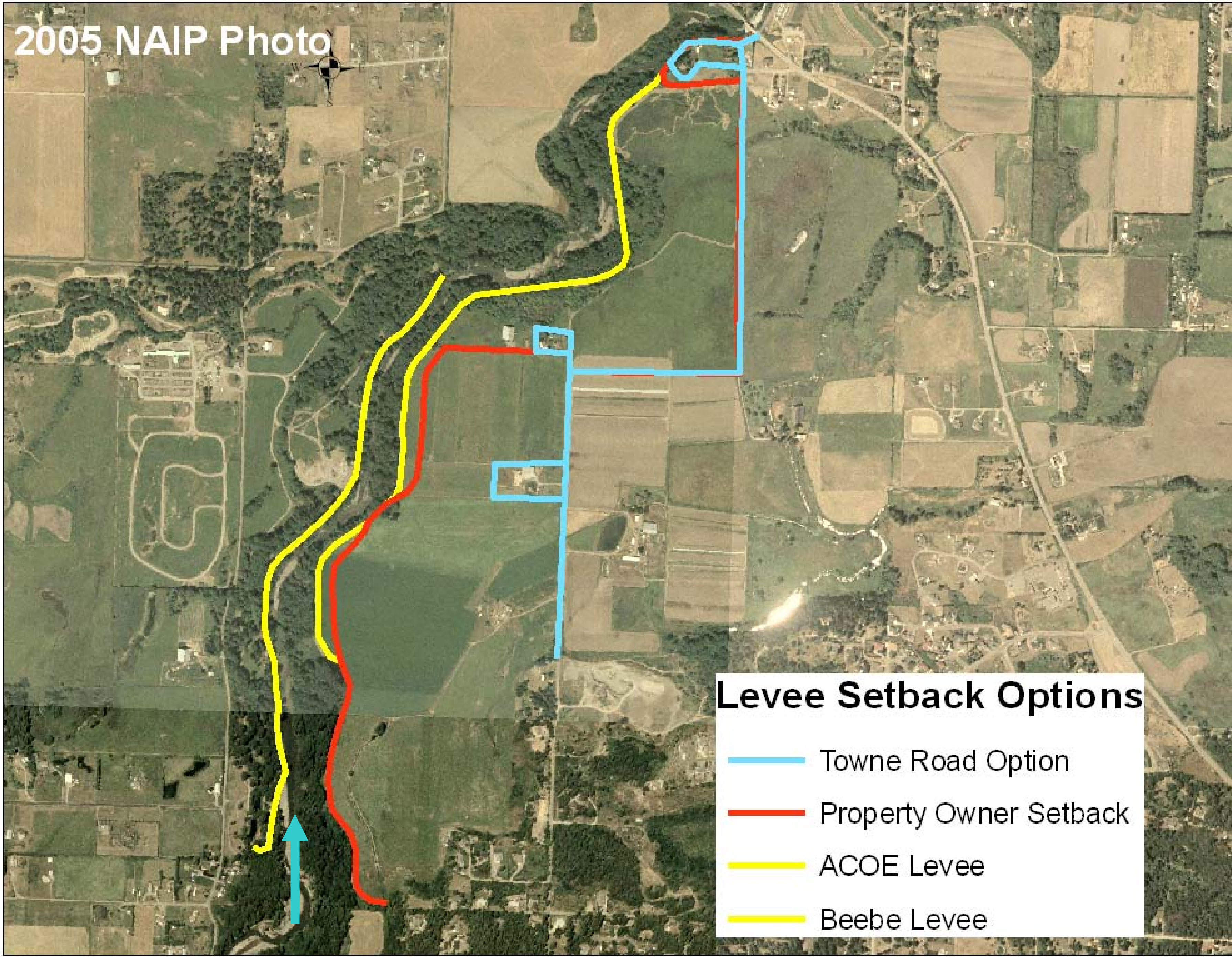
RECLAMATION

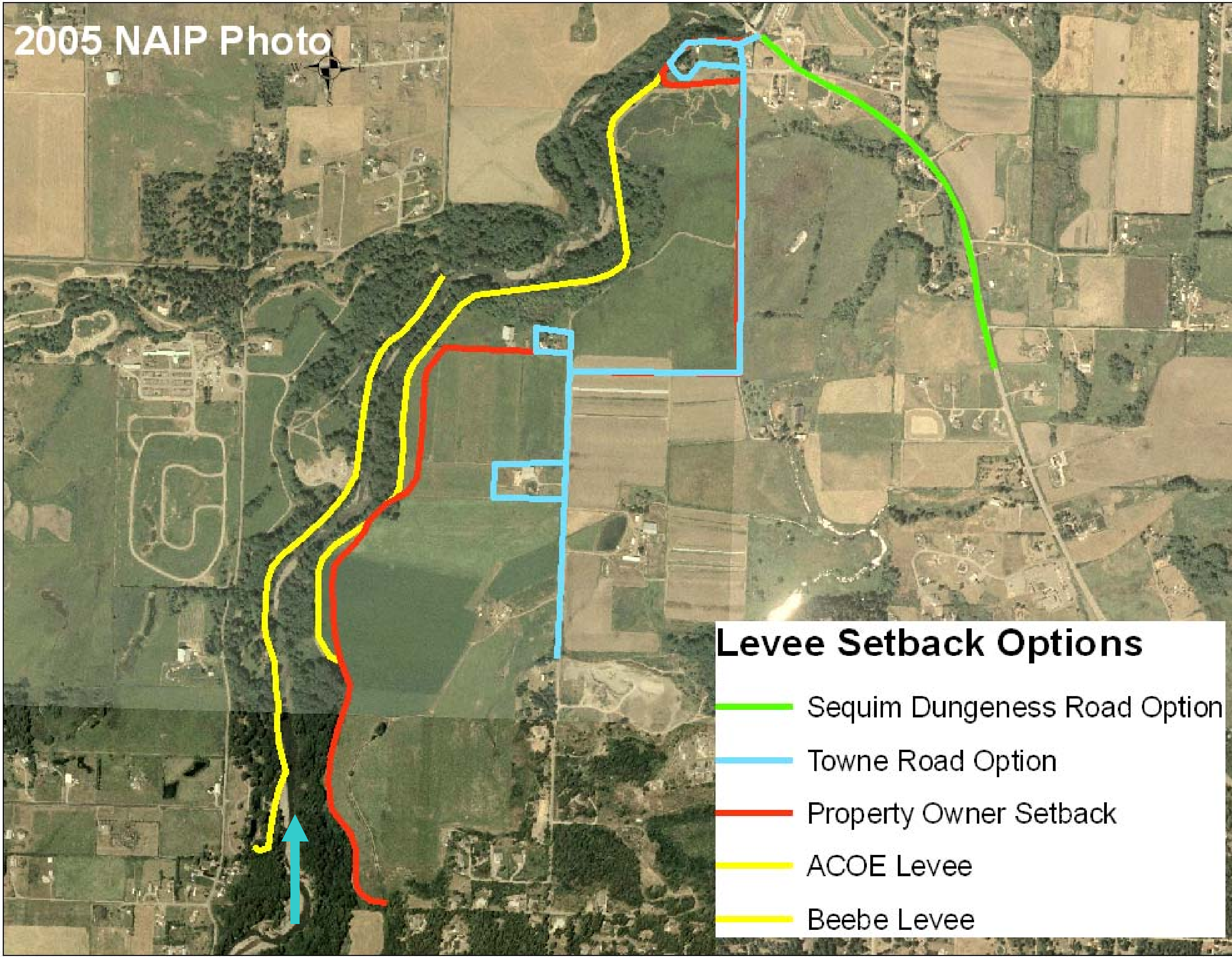
Lower Dungeness Levee Setback Study

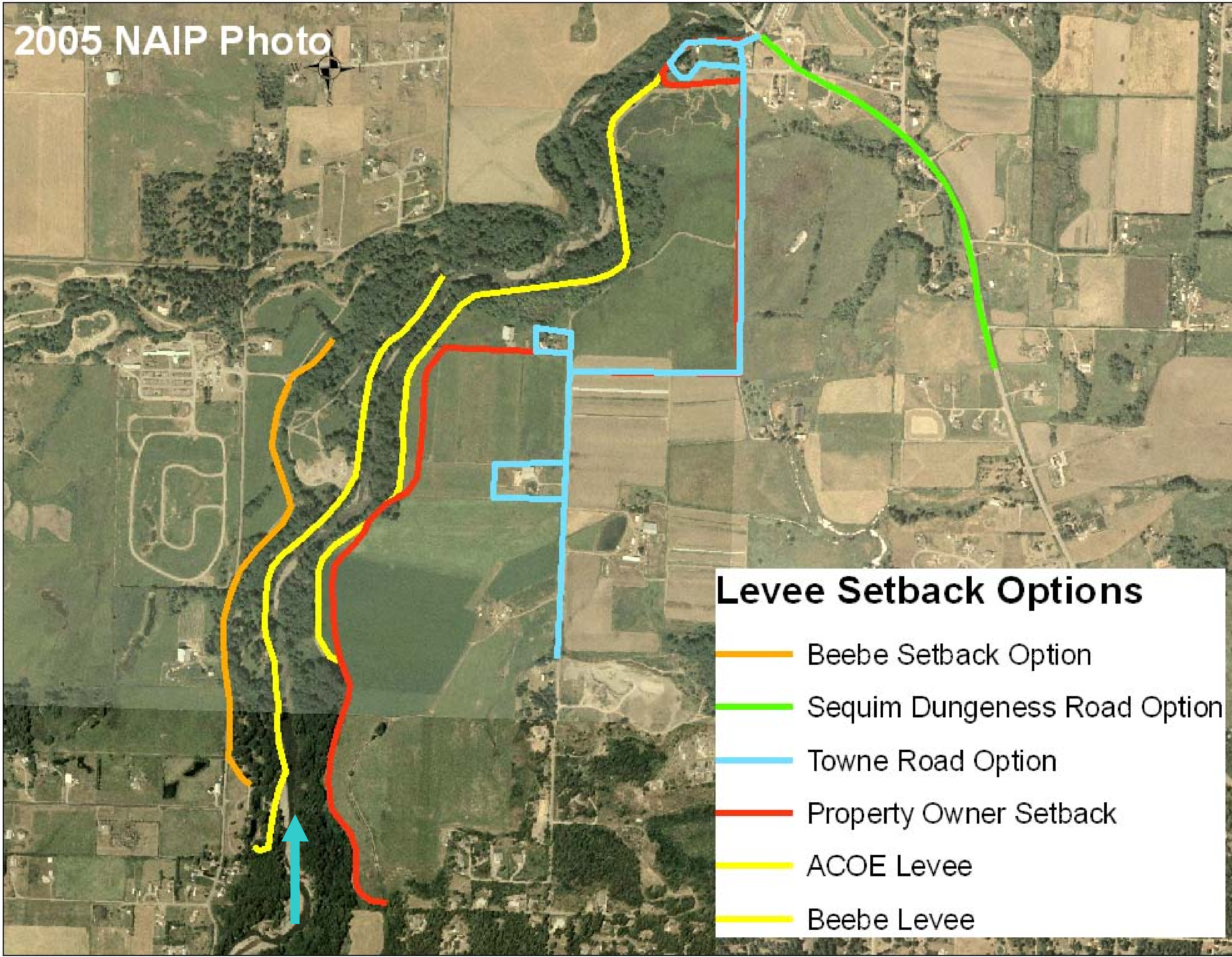
RECLAMATION

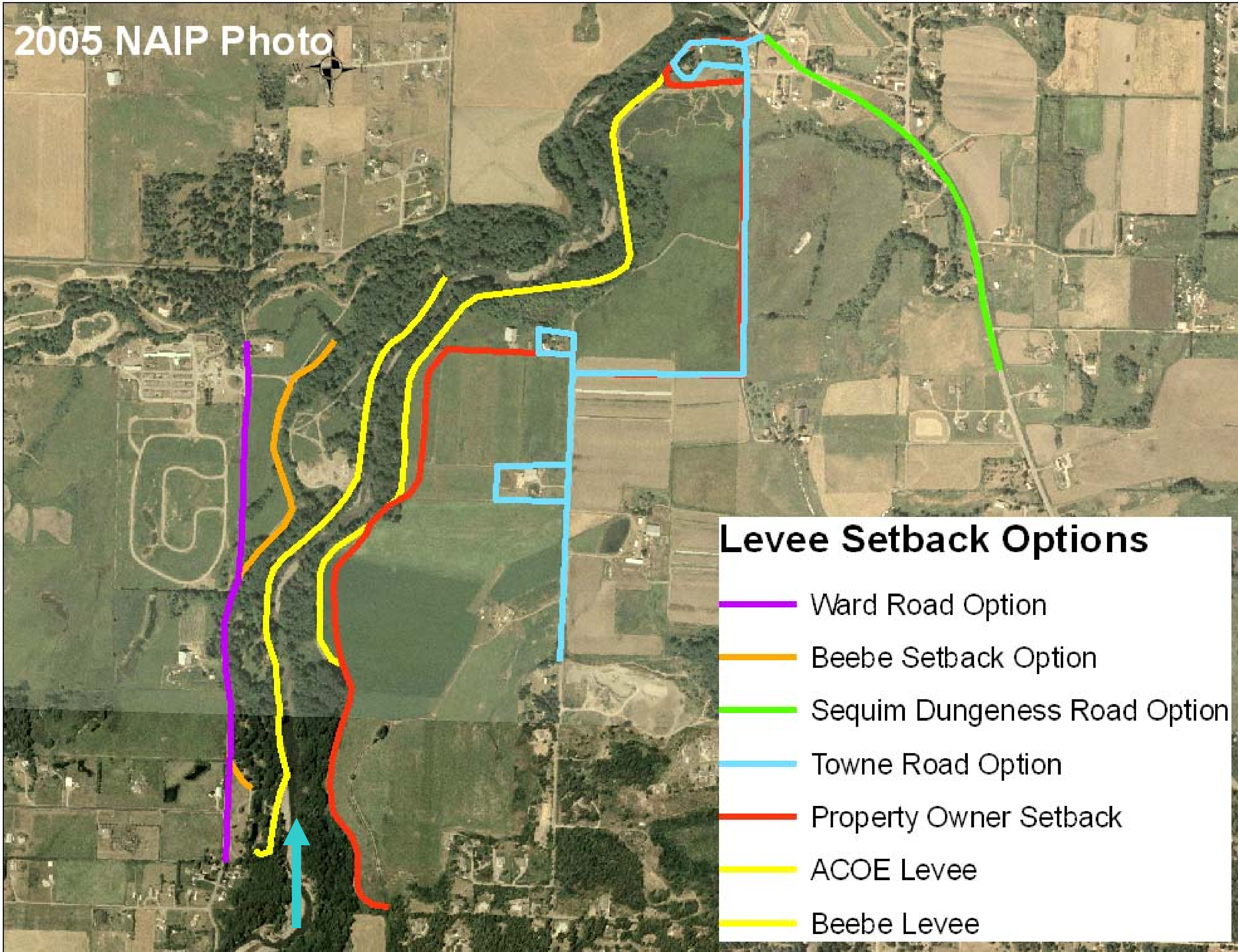

2005 NAIP Photo
Levee Setback Options
ACOE Levee
Beebe Levee


2005 NAIP Photo
Levee Setback Options
Property Owner Setback
ACOE Levee
Beebe Levee

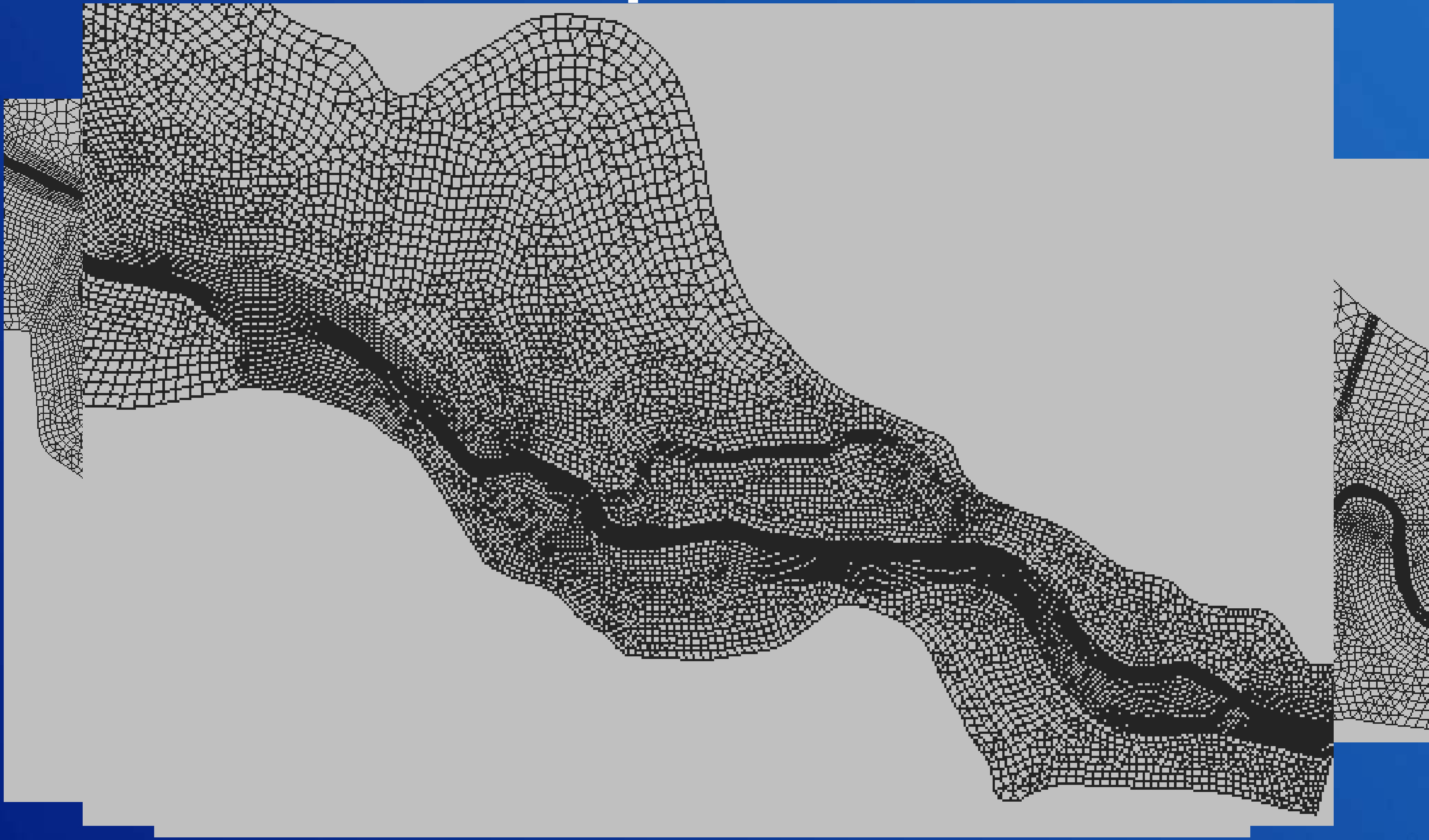

2005 NAIP Photo
Levee Setback Options
Towne Road Option
Property Owner Setback
ACOE Levee
Beebe Levee


2005 NAIP Photo
Levee Setback Options
Sequim Dungeness Road Option
Towne Road Option
Property Owner Setback
ACOE Levee
Beebe Levee

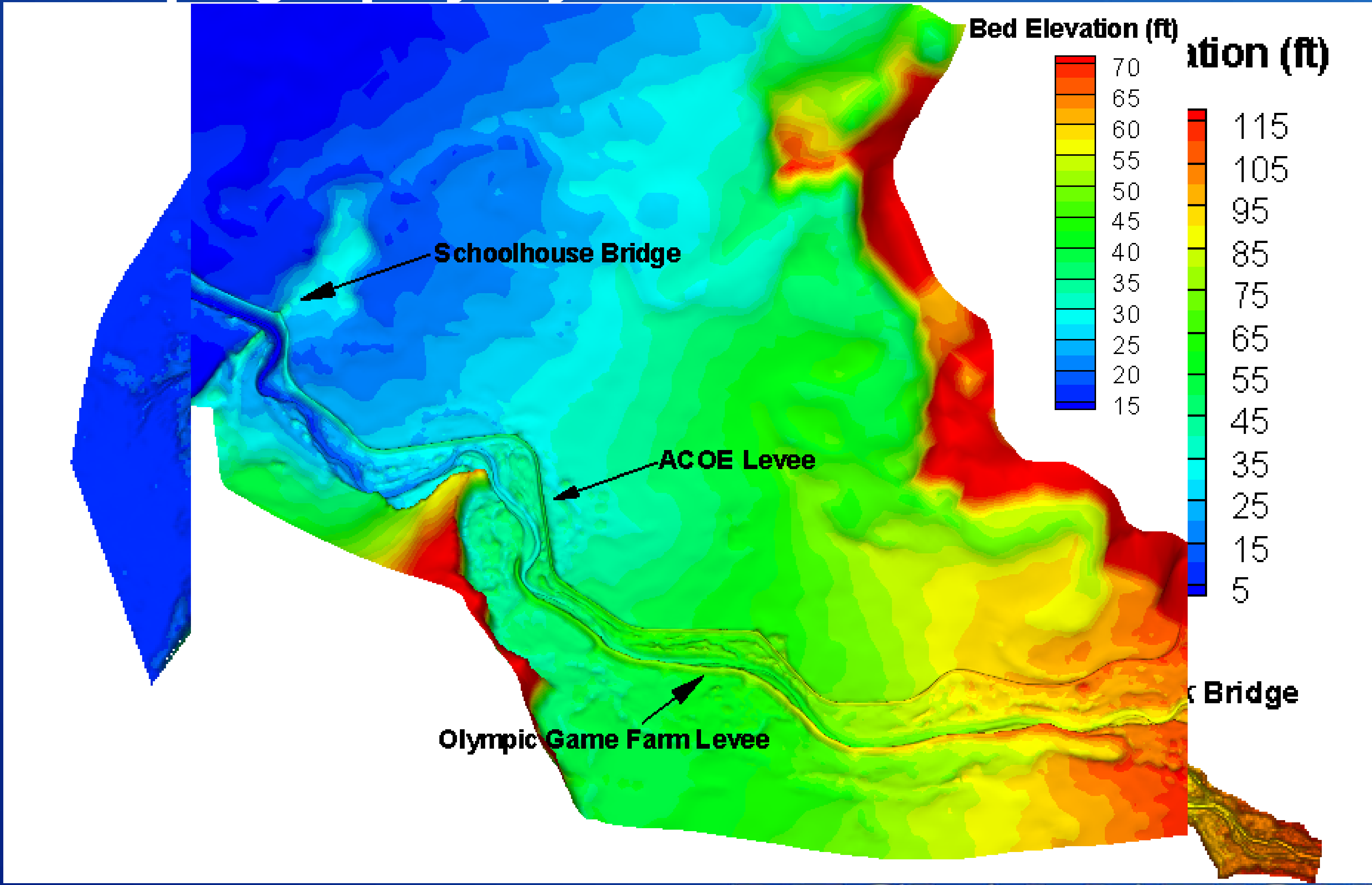

2005 NAIP Photo
Levee Setback Options
Beebe Setback Option
Sequim Dungeness Road Option
Towne Road Option
Property Owner Setback
ACOE Levee
Beebe Levee


2005 NAIP Photo
Levee Setback Options
Ward Road Option
Beebe Setback Option
Sequim Dungeness Road Option
Towne Road Option
Property Owner Setback
ACOE Levee
Beebe Levee

Mesh: ~ 50,000 points

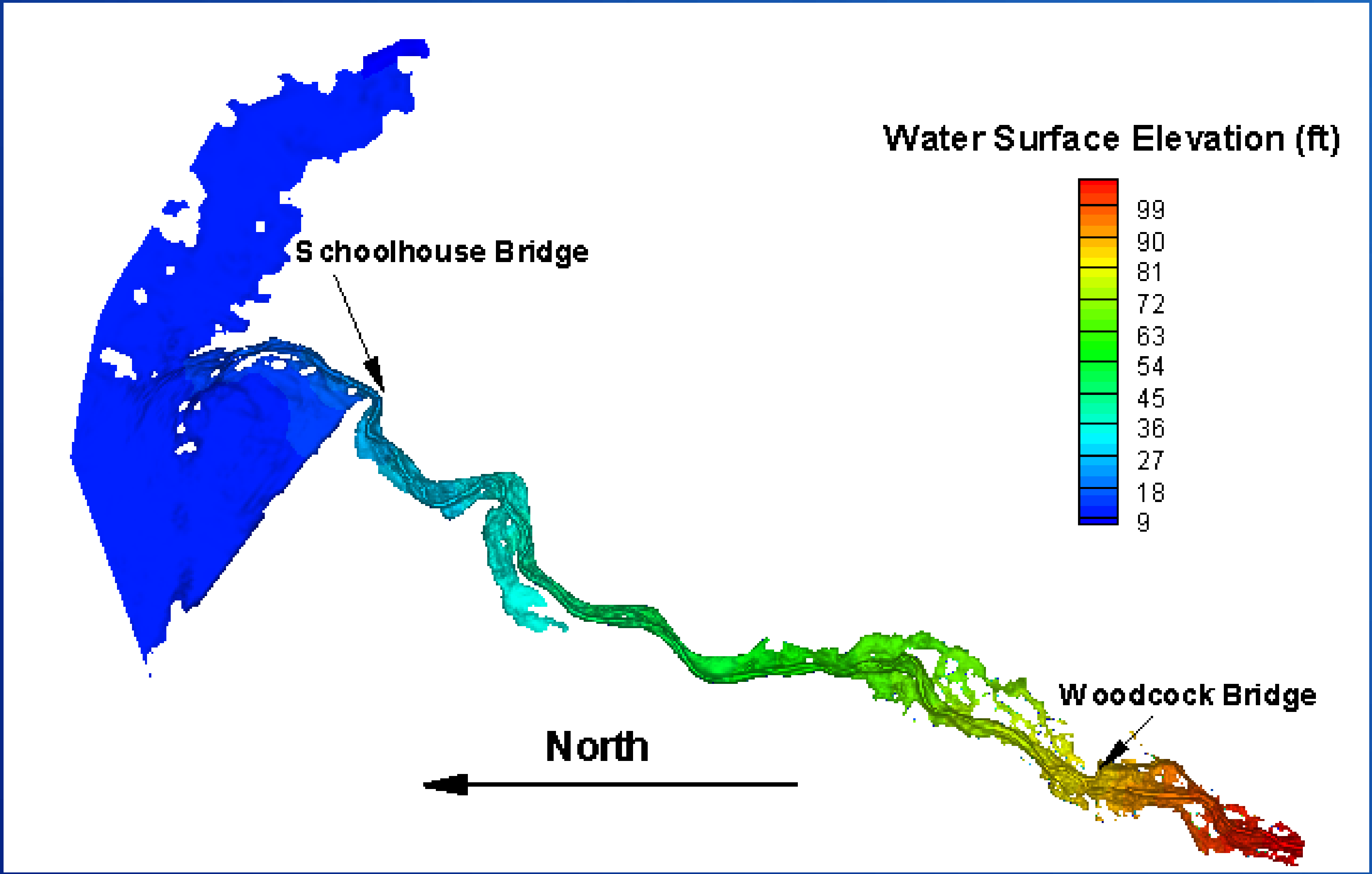


Topography by Mesh

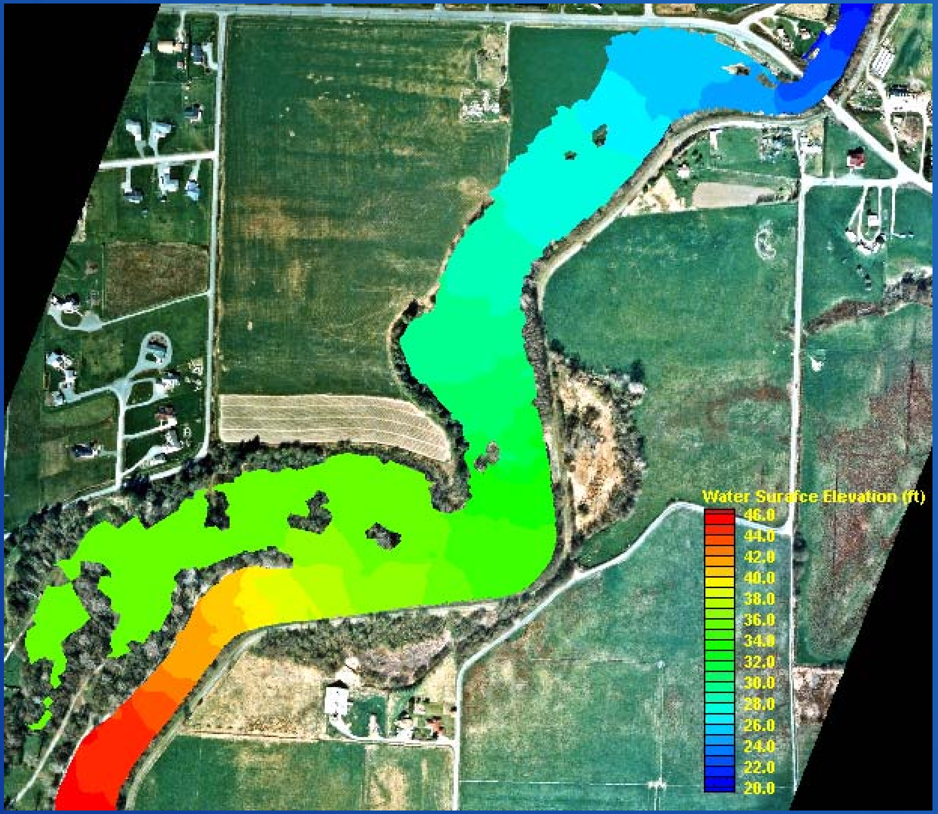


RECLAMATION

2002 Flood Simulation (6,280cfs)

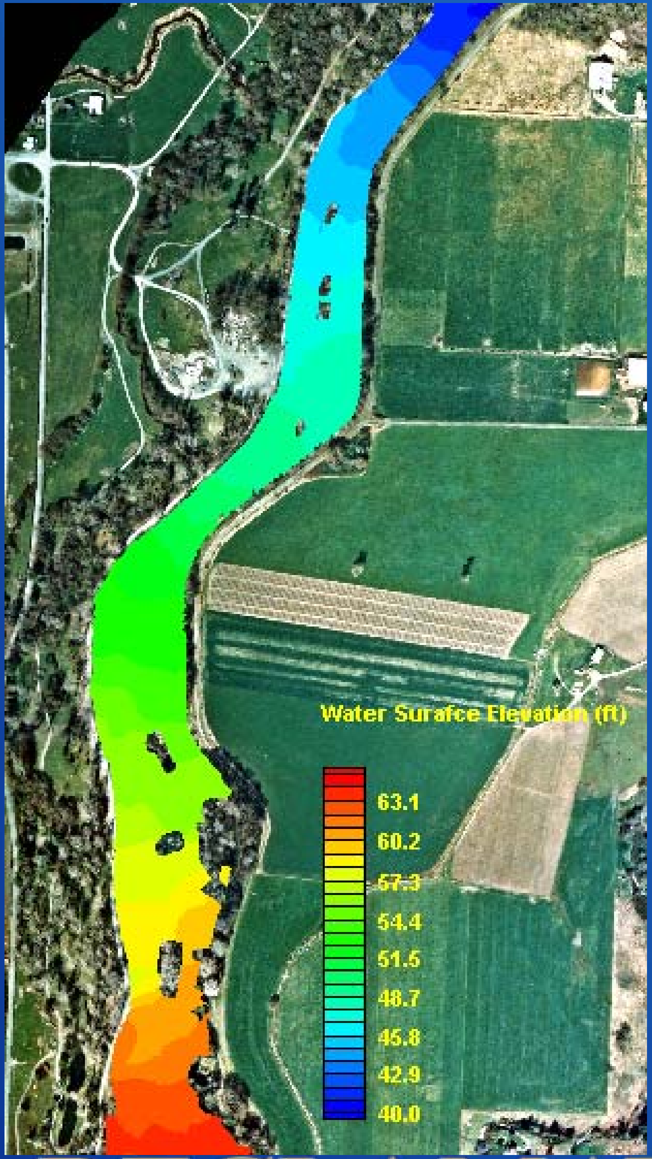


Comparison of Inundation



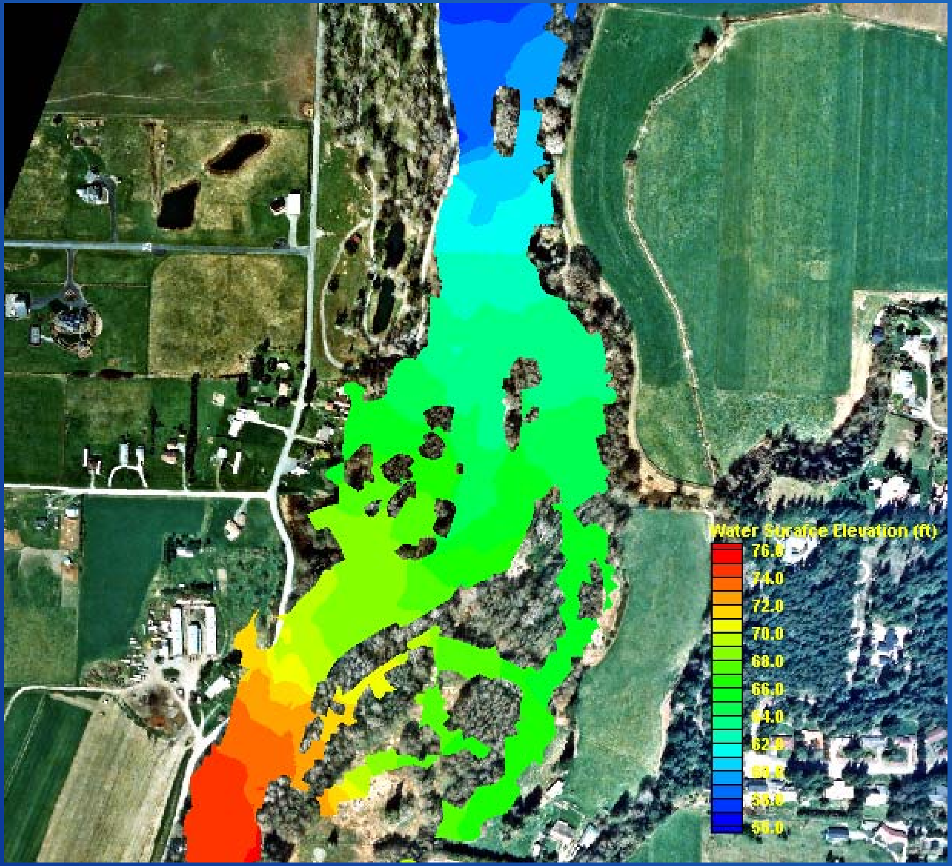
RECLAMATION

Comparison of Inundation



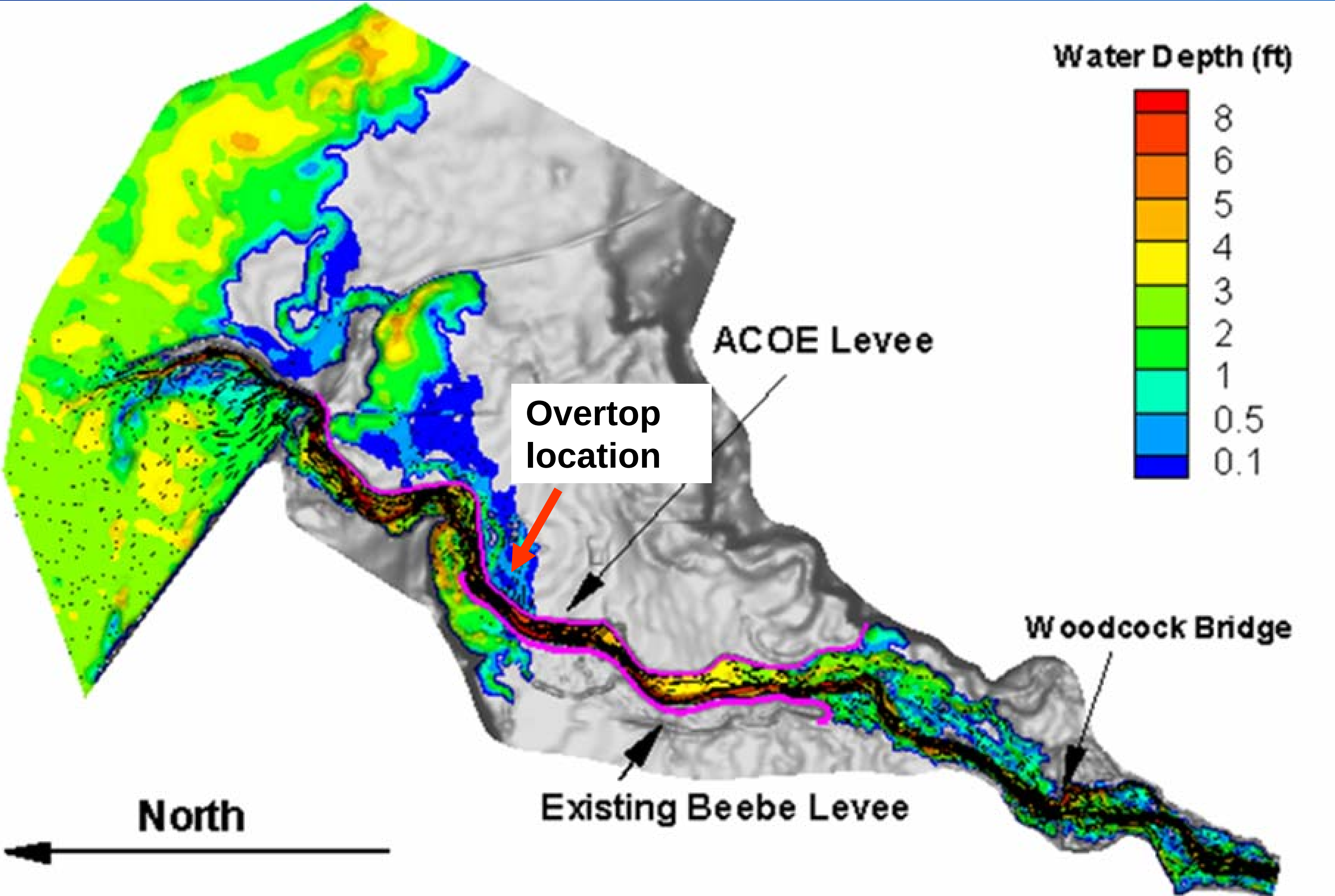
RECLAMATION

Comparison of Inundation



RECLAMATION

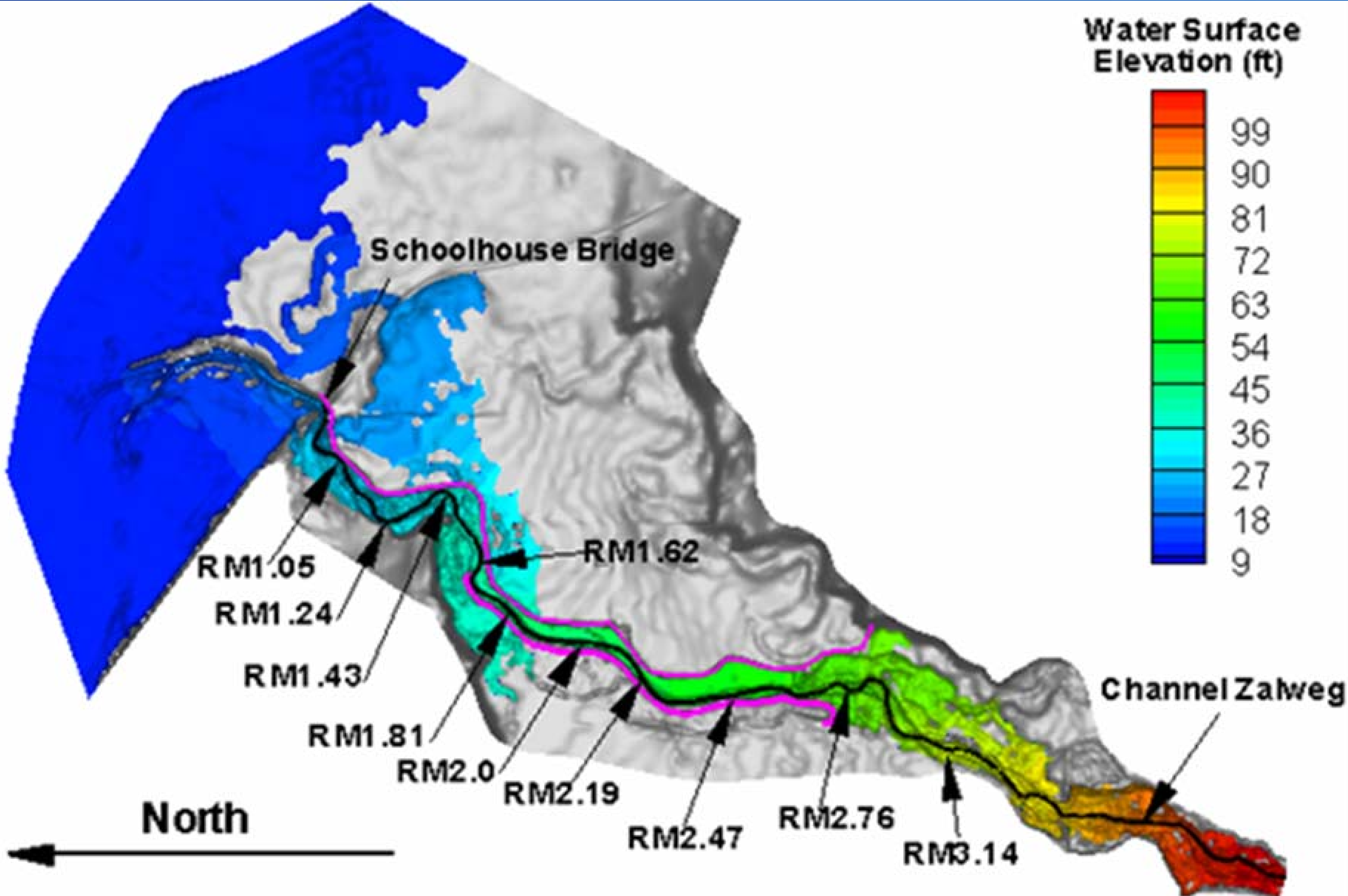
Existing Conditions 100-Year Flood



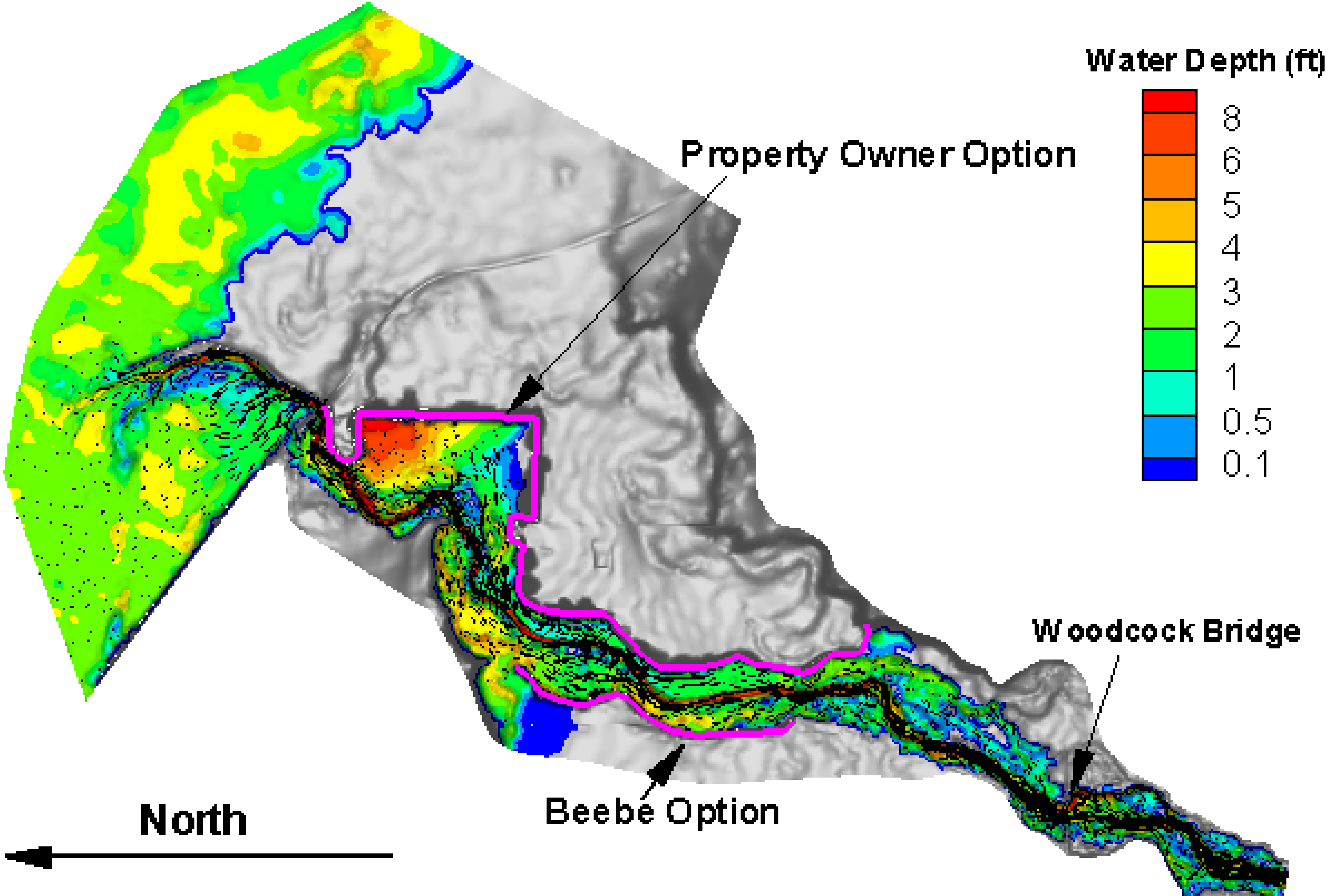
100-Year Flood Inundation Conclusions

- The Sequim-Dungeness and Ward Road setback options provide the closest match to the pre-levee inundation condition

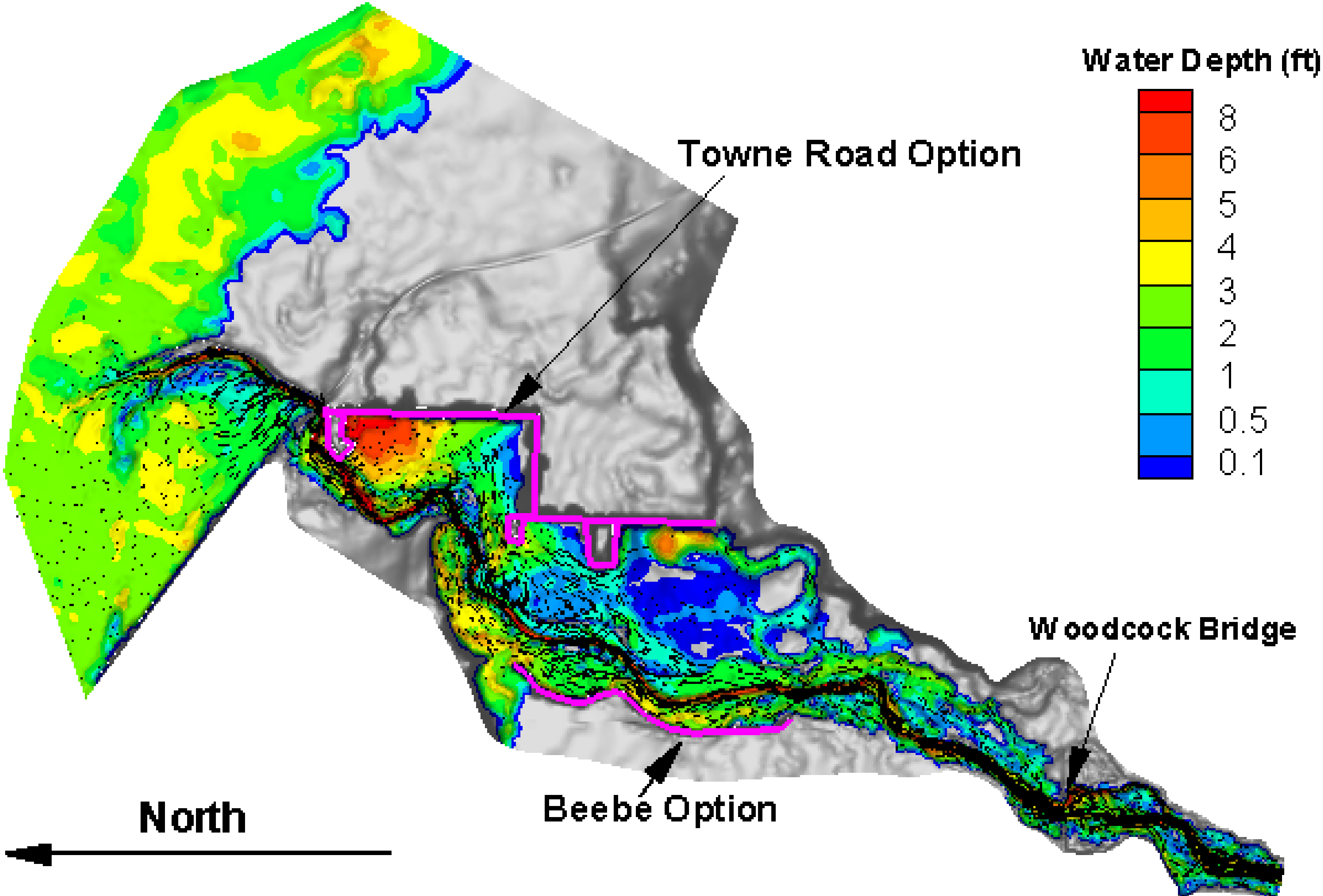
100-year flood depths and velocity vectors for Existing Conditions



100-year flood depths and velocity vectors for ACOE levee-setback alternatives



100-year flood depths and velocity vectors for ACOE levee-setback alternatives



100-year flood depths and velocity vectors for ACOE levee-setback alternatives