Use of Two-Dimensional Hydraulic Models in Ecosystem Restoration Planning, Upper Mississippi River

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US Army Corps of Engineers
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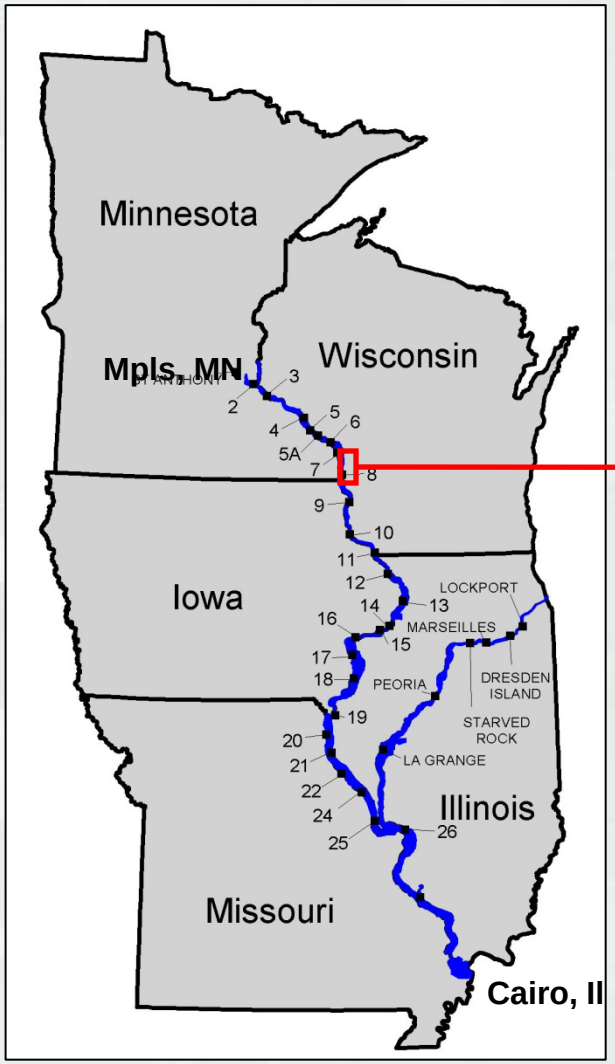
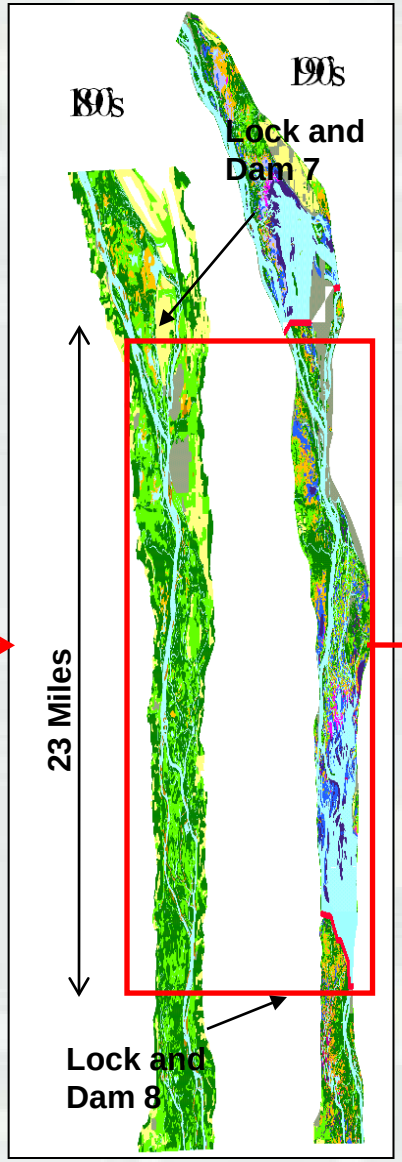
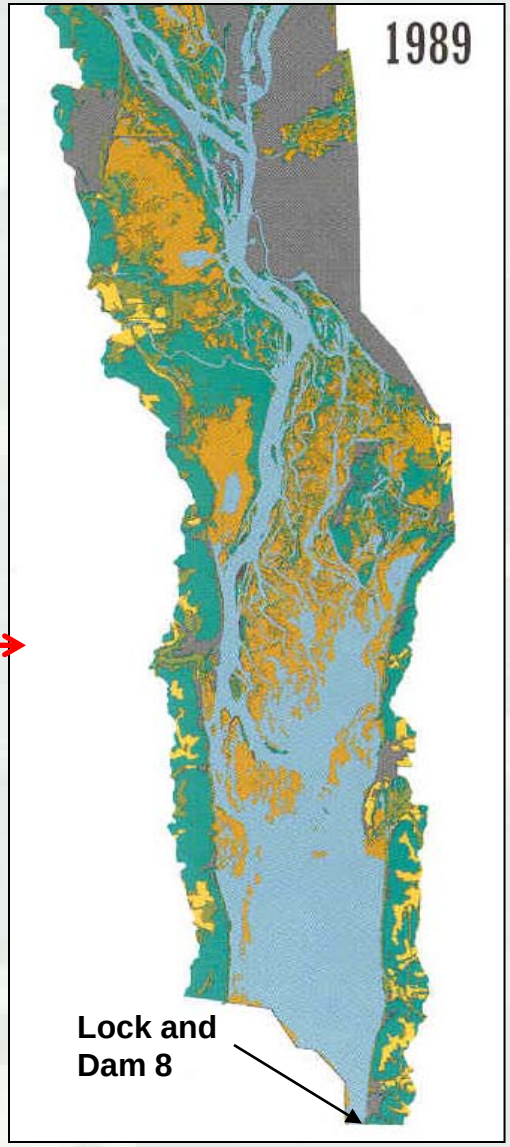
Topics Covered

- Upper Mississippi River System (UMRS) Basics
- Hydraulic Models: One-Dimensional (1D) versus Two-Dimensional (2D)
- Model Development & Model Uses.
- 2D modeling in support of the ecosystem restoration planning
- Future Directions

Location Map







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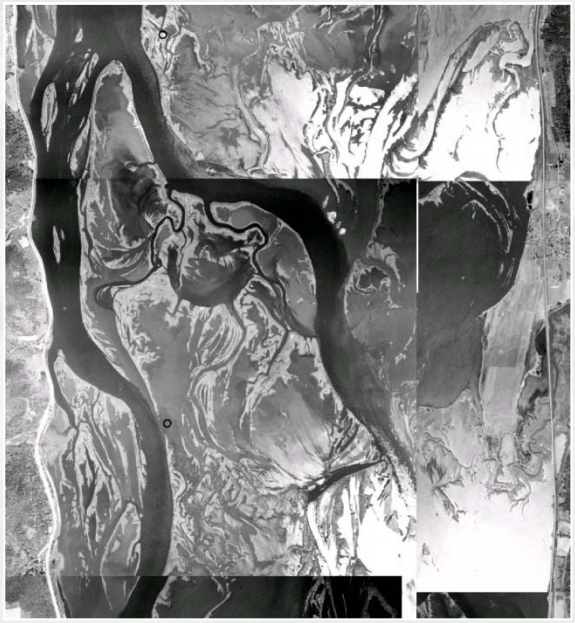
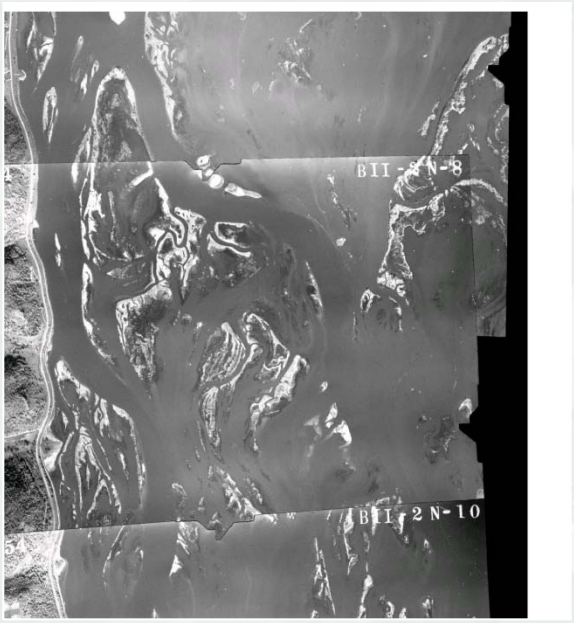
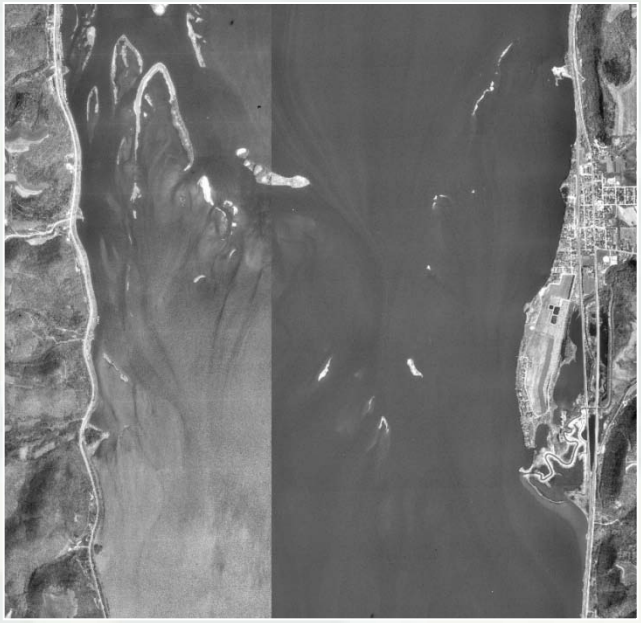
Need for Hydraulic Models

1. Hydraulics is the underlying foundation for processes affecting water quality, geomorphology, habitat, biota.
2. Many of the long-term changes that have occurred on the river have altered hydraulic parameters (see change in land mass over time in lower pool 8 below).
3. Many of the management actions that river managers use alter hydraulic parameters.

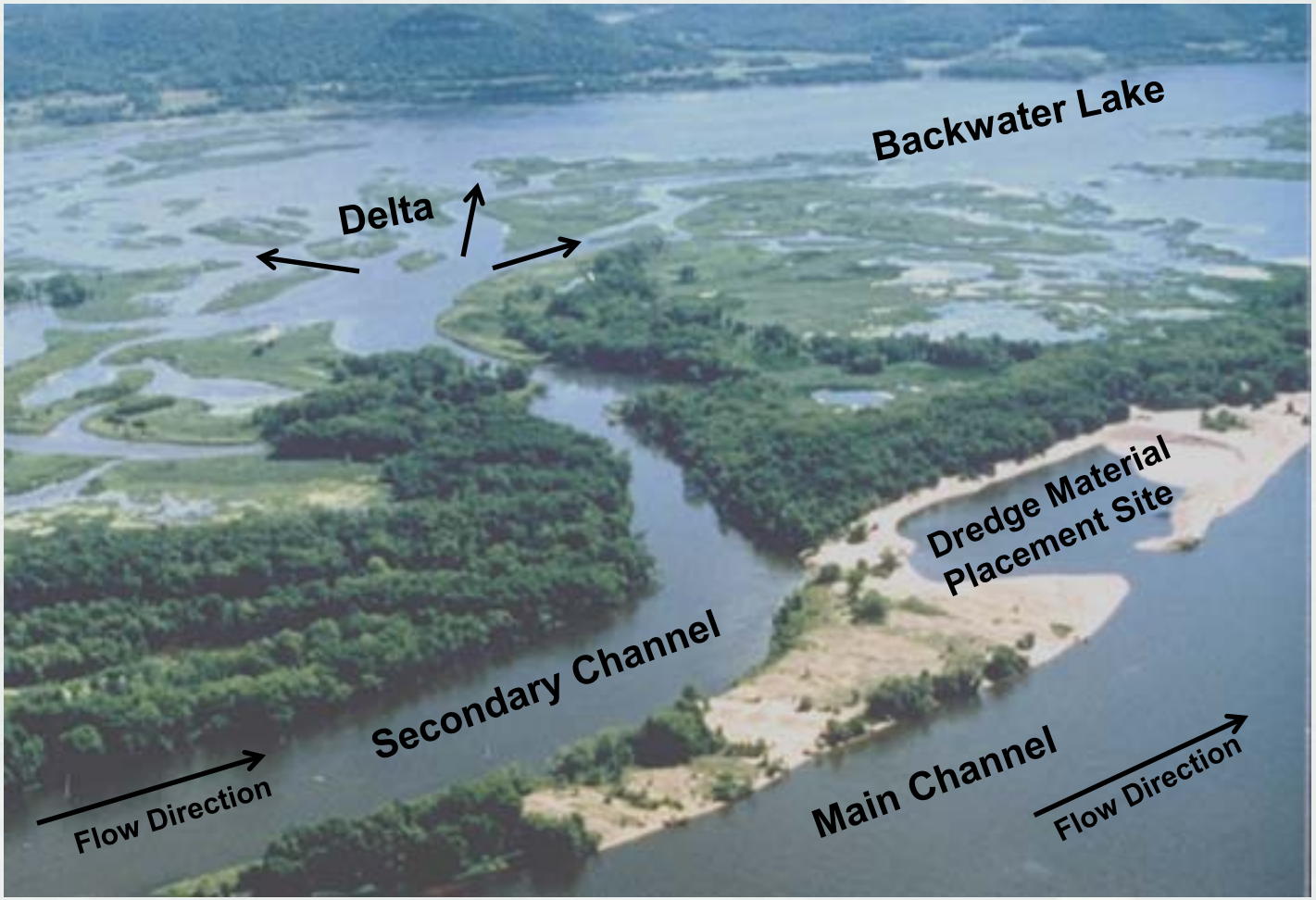
1954 1991







Multiple Flow Paths Require Two-Dimensional (2D) Models

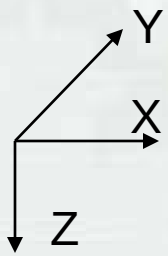


Two-Dimensional (2D) Hydraulic Models on the UMRS :

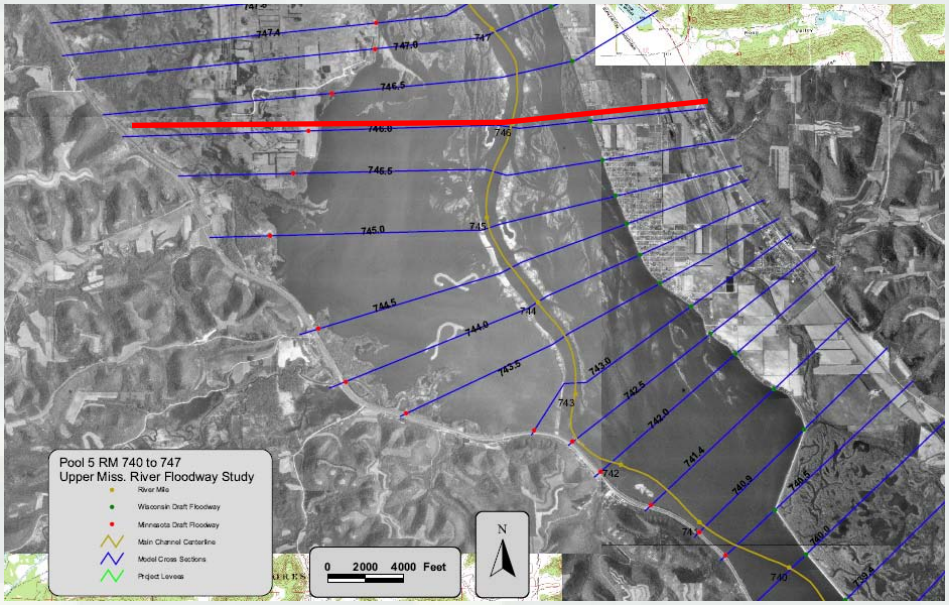
- Simulations of hydraulic parameters in the longitudinal and lateral directions.
- Provides information on water surface and velocity given a flow rate, boundary conditions, geometry, and surface roughness.
- Model output for existing conditions, historic conditions, and alternatives provides information for PDT decision making.
- Have been in use for over two decades on the UMRS.

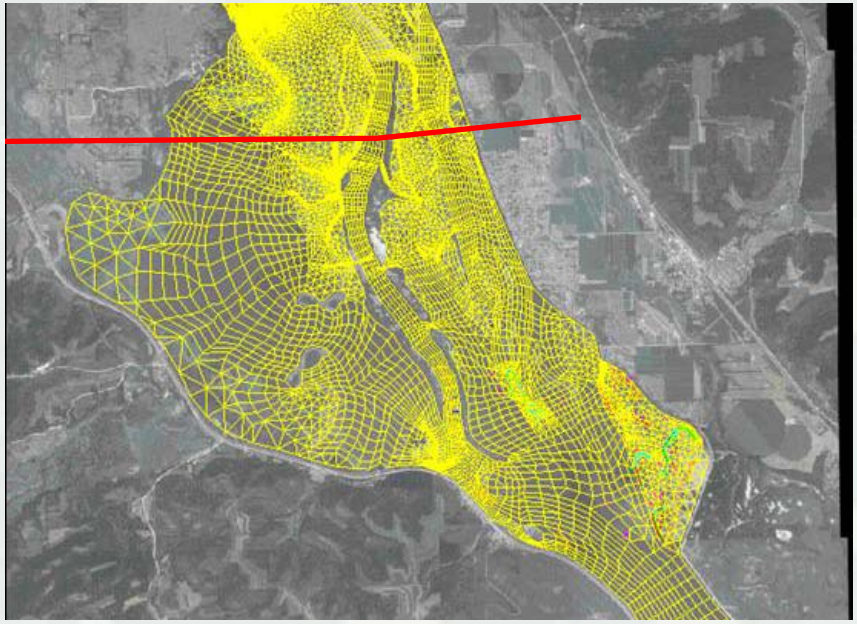
Adaptive Hydraulics (ADH)

- Over the last 5 years, the Adaptive Hydraulics Model (ADH) developed at ERDC through the SWWRP has become the 2D model of choice for PDTs on the Upper Miss.
- ADH includes:
  - A library of routines for sediment that are reusable in most hydrodynamic codes
  - Grid Adaption to improve model accuracy when needed
  - Long term simulation capabilities
  - Water Quality Library connection
  - Ecological modeling capabilities
- http://chl.erdc.usace.army.mil/



1D versus 2D

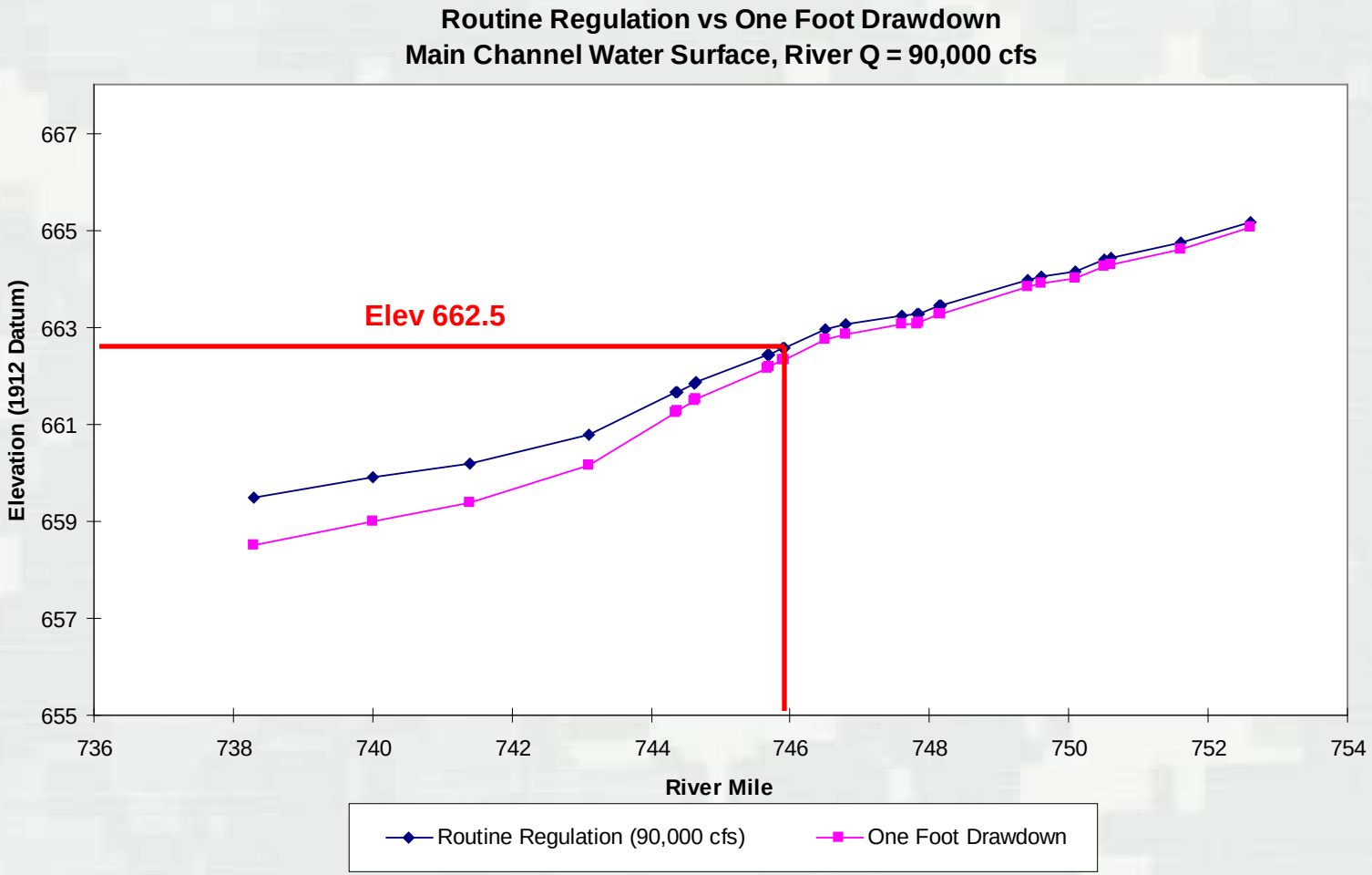


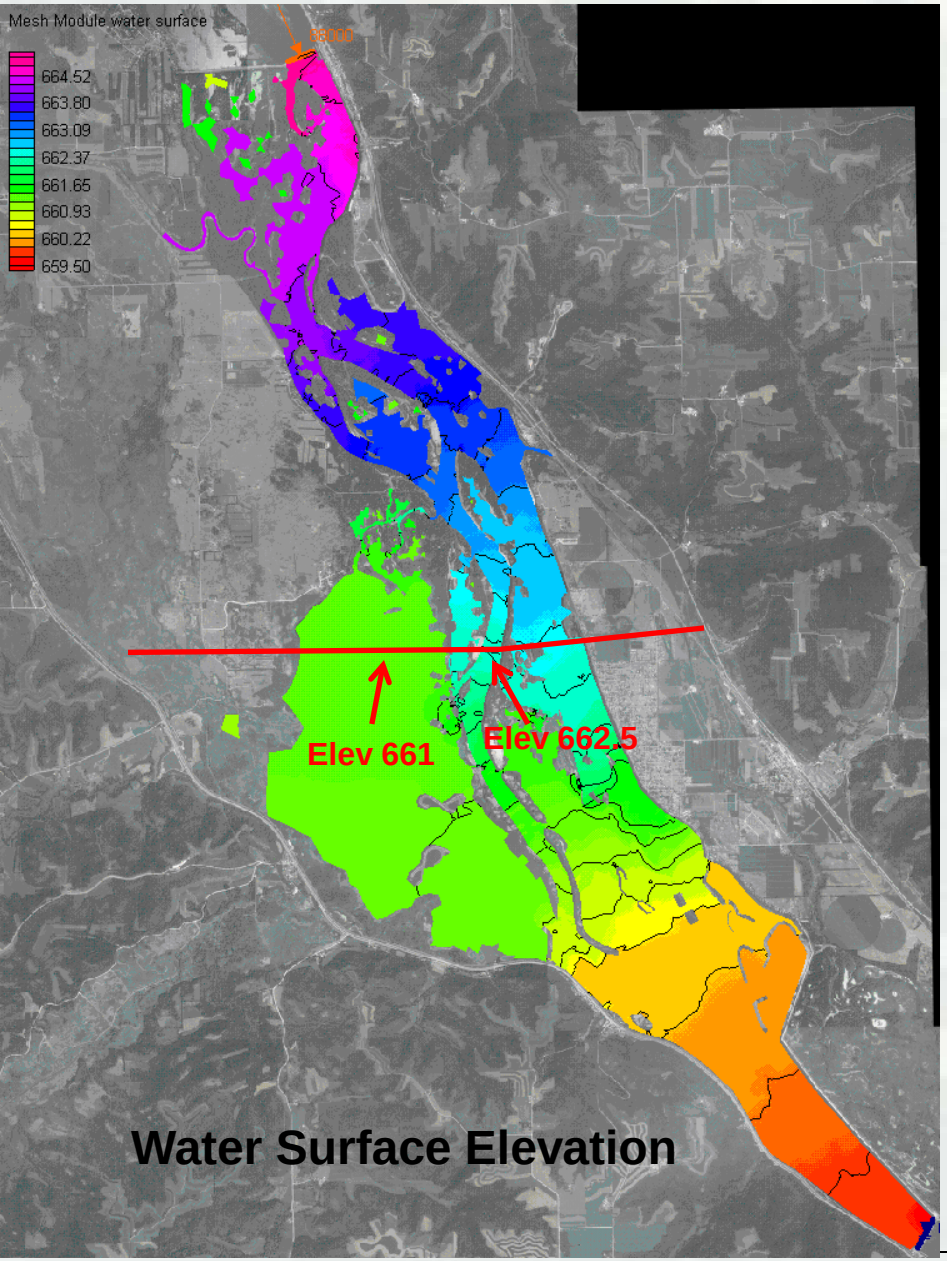


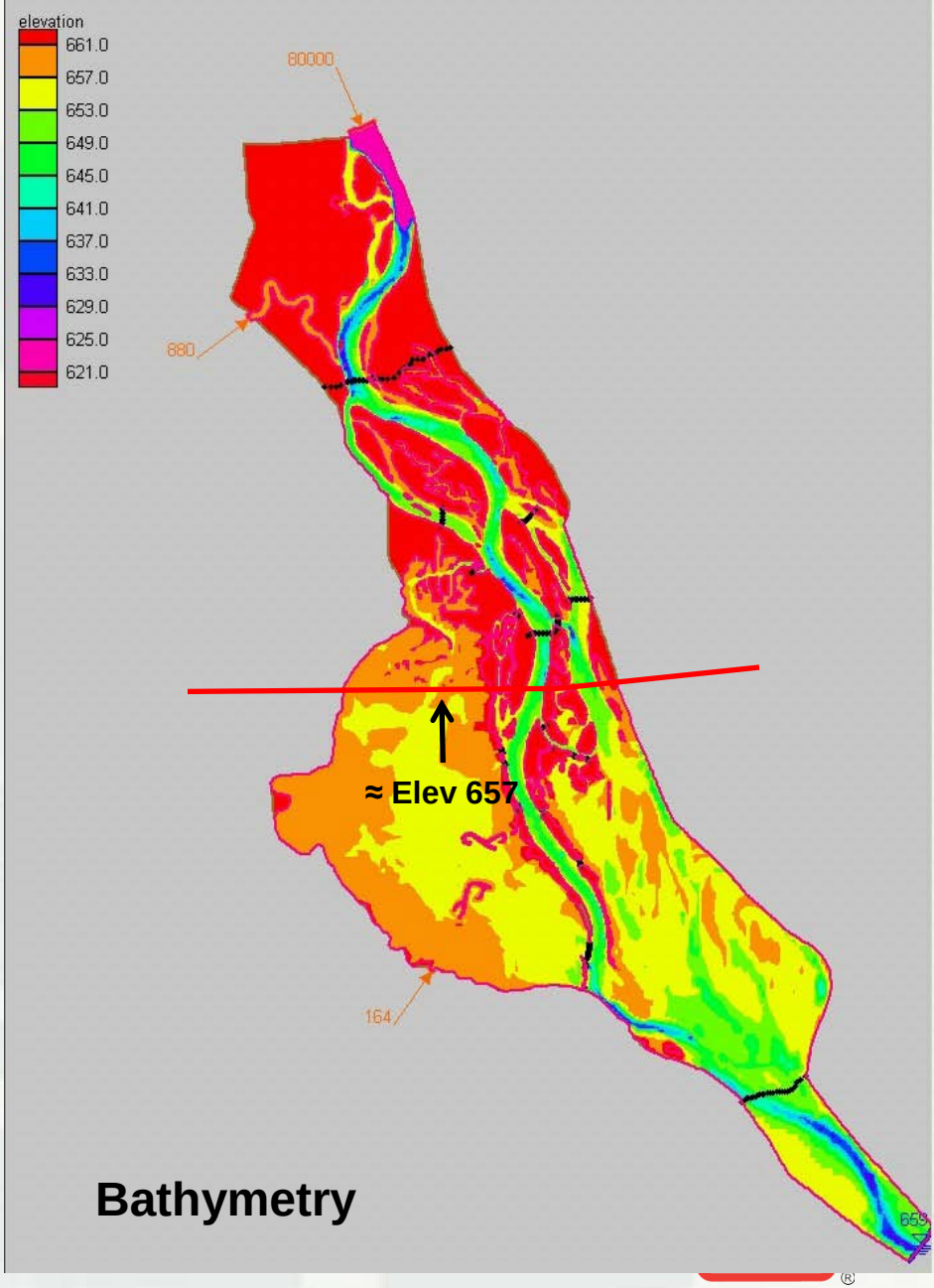
One-dimensional (1D) models simulate the change in parameters in one direction (e.g. downstream to upstream)

Two-dimensional (2D) models simulate the change in parameters in two directions (e.g. downstream to upstream and from one side of the channel or river valley to the other)

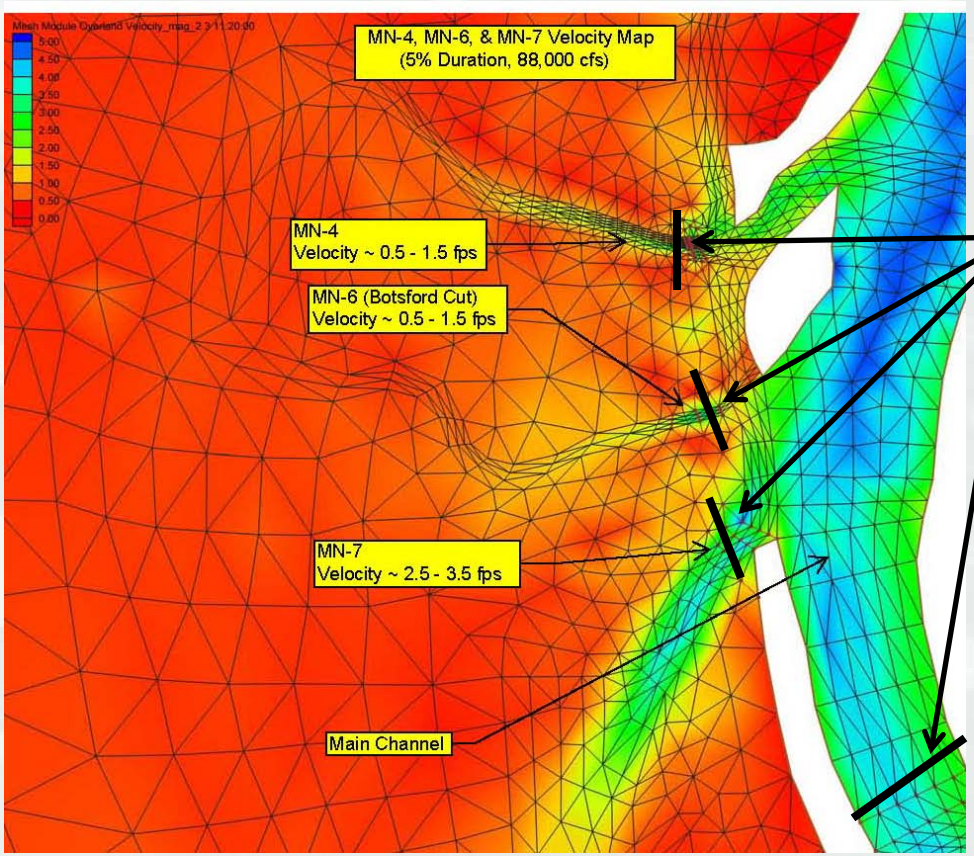
1D Model of Water Surface, Pool 5, Upper Miss




Mesh Module water surface
664.52
663.80
663.09
662.37
661.65
660.93
660.22
659.50
80000
Elev 661
Elev 662.5
Water Surface Elevation


elevation
661.0
657.0
653.0
649.0
645.0
641.0
637.0
633.0
629.0
625.0
621.0
80000
880
≈ Elev 657
164
Bathymetry

2D models provide information beyond monitoring sites



Monitoring Sites:
Discharge measurements have been collected at the four sites shown by the black lines.

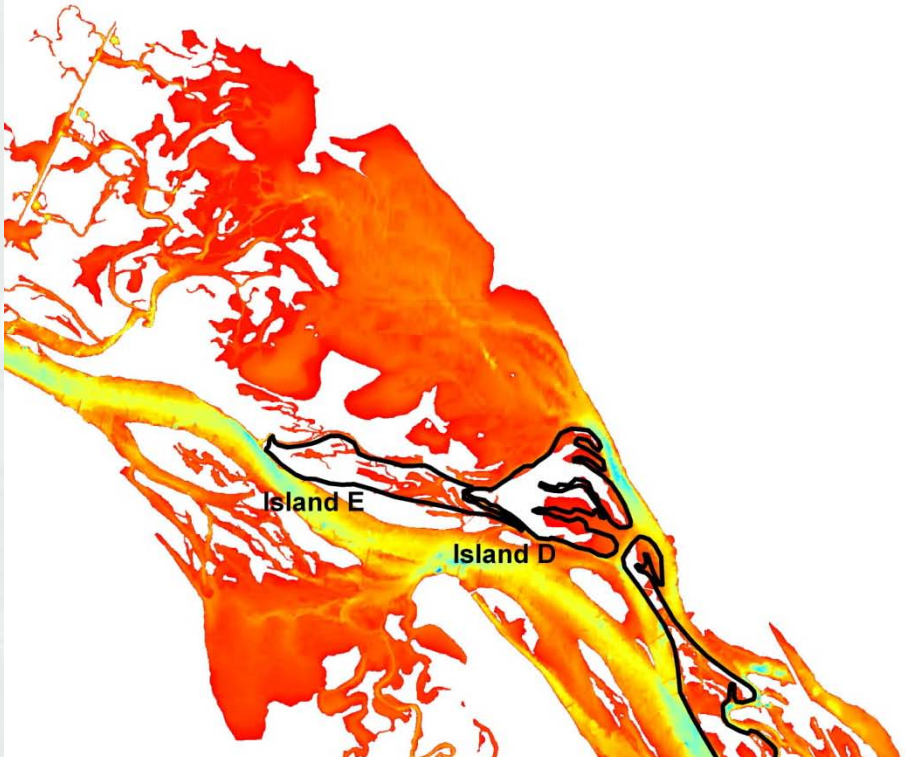
A 2D model calibrated to match the flow measurements provides information on velocity, water surface elevation, and flow rates throughout the area of interest. This can be brought into a GIS data base.

Lower Pool 4 Island E, D, & B Analysis

2D models provide information for the full range of conditions including extreme events like floods or droughts.

This image and table illustrate a simulation of the 1% chance flood in lower pool 4 to determine the impacts of proposed islands on water surface elevations.

The model was calibrated and verified using data for much lower flow events.



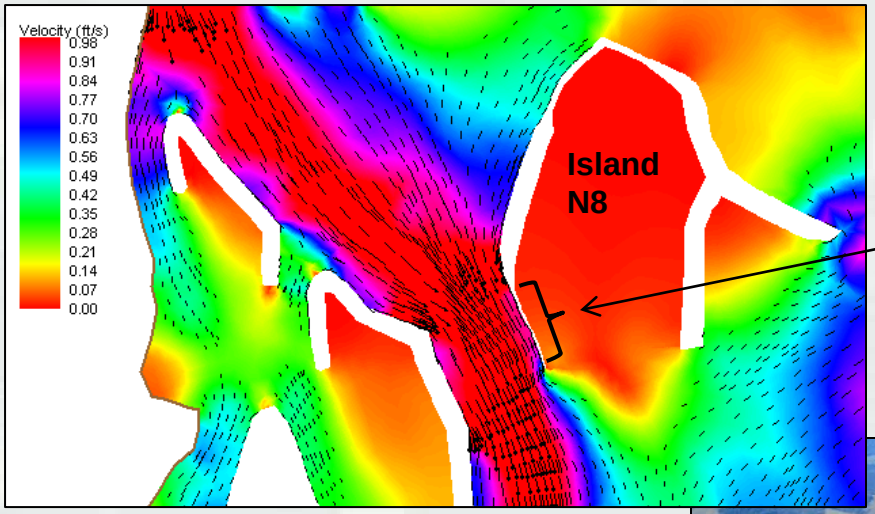
1% (100-year) Flood WSEL change due to Islands E, D, & B

Island Elevations are 2 & 4 feet above Low Control Pool (LCP); Approx. Elevation 668.2 & 670.2

A Two-Dimensional Model (ADH) was used for the analysis

River Mile	Landmark	Island E		Island D		Island B		Islands E&D		Islands E&B		Islands D&B		Islands E,D&B	
		LCP + 2'	LCP + 4'	LCP + 2'	LCP + 4'	LCP + 2'	LCP + 4'	LCP + 2'	LCP + 4'	LCP + 2'	LCP + 4'	LCP + 2'	LCP + 4'	LCP + 2'	LCP + 4'
765.103	Lake Pepin	0	0	0.06	0.09	0.07	0.09	0.07	0.12	0.08	0.1	0.14	0.18	0.15	0.21
760.759	U/S Waba Limits	0.01	0.01	0.15	0.22	0.17	0.21	0.17	0.27	0.19	0.23	0.32	0.42	0.34	0.46
760.181	Wabasha Bridge	0.01	0.02	0.17	0.24	0.2	0.23	0.19	0.29	0.21	0.25	0.36	0.46	0.38	0.51
759.17	D/S Waba Limits	0.01	0.02	0.17	0.24	0.22	0.25	0.19	0.29	0.23	0.27	0.37	0.47	0.39	0.52
758.299	U/S Isl. E	0.01	0.01	0.16	0.22	0.23	0.27	0.18	0.24	0.24	0.28	0.38	0.47	0.4	0.49
757.105	D/S E; U/S D	-0.01	-0.02	0.09	0.09	0.24	0.28	0.08	0.07	0.24	0.27	0.32	0.36	0.31	0.34
756.373	D/S D; U/S B	0	0	0	0	0.18	0.21	0	0	0.18	0.21	0.19	0.22	0.19	0.22
754.204	D/S Isl B	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0
752.823	L/D 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2D models help team members communicate during planning & design



This leg on island N8 was extended at the request of fisheries biologists to prevent flows from entering the interior of island N8

Some Important Points

1. Use the simplest model that helps the team answer questions. A 1D model might be adequate, however 2D models:
   - are getting easier to create and drive other models that simulate things like sediment transport, fish movement, mussel habitat, aquatic plant growth.
   - 2D models may provide more information and learning opportunities
2. 2D models are only one tool that help the team make decisions during project planning. There are many other factors like constructability, funding levels, regulatory issues……
3. Calibrate and verify models to field data (water surface elevation, and flow distribution).
4. Boundary conditions are very important. If the wrong starting water surface elevation is given, the model will still give you output – it will just be wrong.
5. Sensitivity testing should be done to determine effects of mesh size and boundary conditions.
6. Long-term simulations of parameters like sediment or nutrients might be limited with multi-dimensional models due to computational requirements.

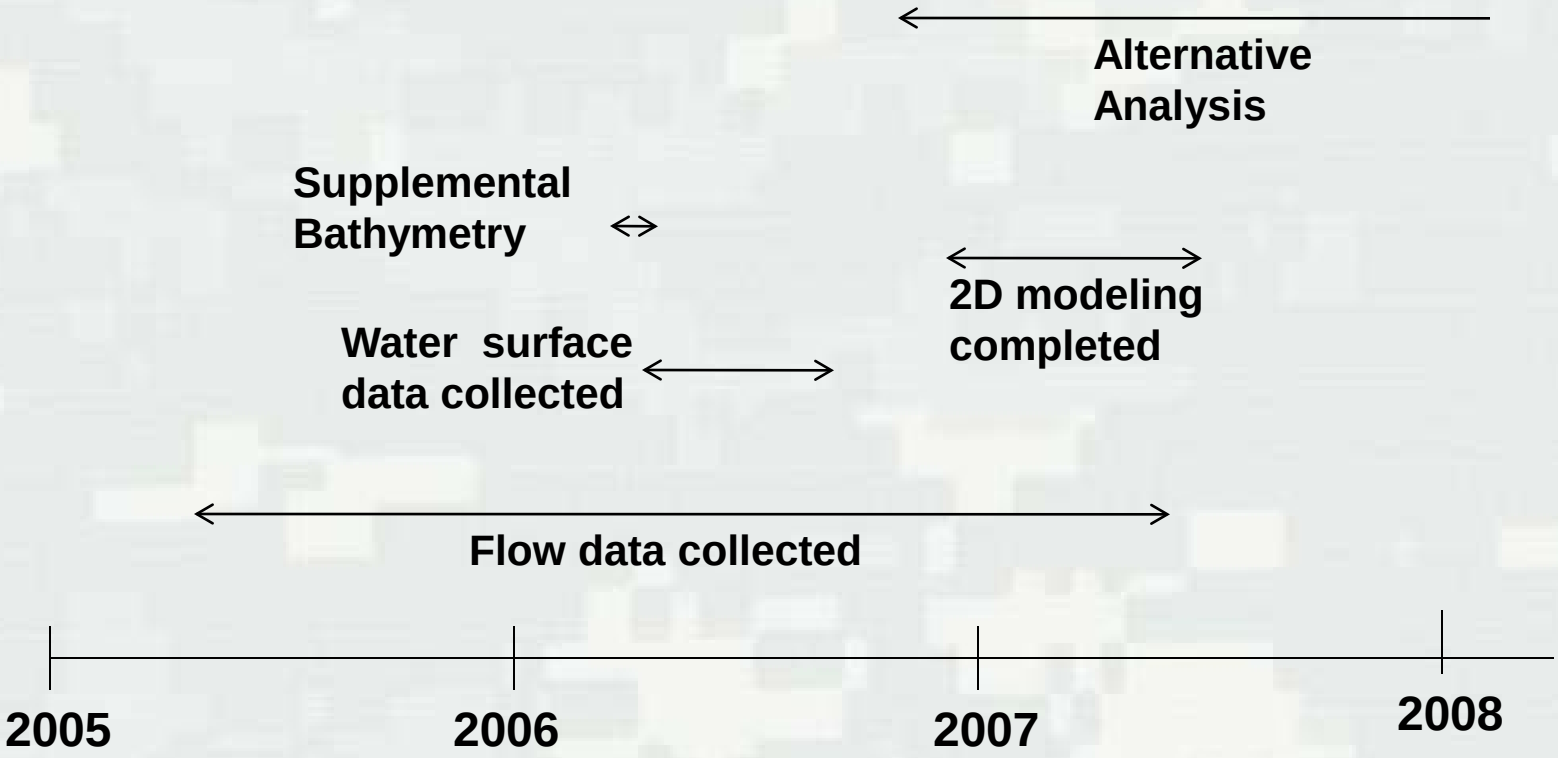
Some Data Needs

- Bathymetry/Topography (Consistent horizontal and vertical datums)
- Structure elevations (roads, culverts, etc.)
- Water Surface Elevation rating curves at boundaries (same datum as bathymetry)
- Flow Distribution Data
- Vegetation Patterns on geo-referenced photos
  - Information on seasonal changes
- Desired range of hydraulic conditions for target species or habitat
- Sediment Information
  - Bed sediment gradation to expected scour depth.
  - Suspended sediment quantity and gradation
- Water Quality Parameters

When Do You Start Modeling

- Early in the study so that model results can aid decision making
- Monitoring needed to develop and calibrate models begins even earlier
- Parallel modeling and monitoring tracks is often a reality
  - ►In some cases, modeling may help inform monitoring plans

Timeline for Reno Bottoms 2D Model



Model Time and Cost
Model Review

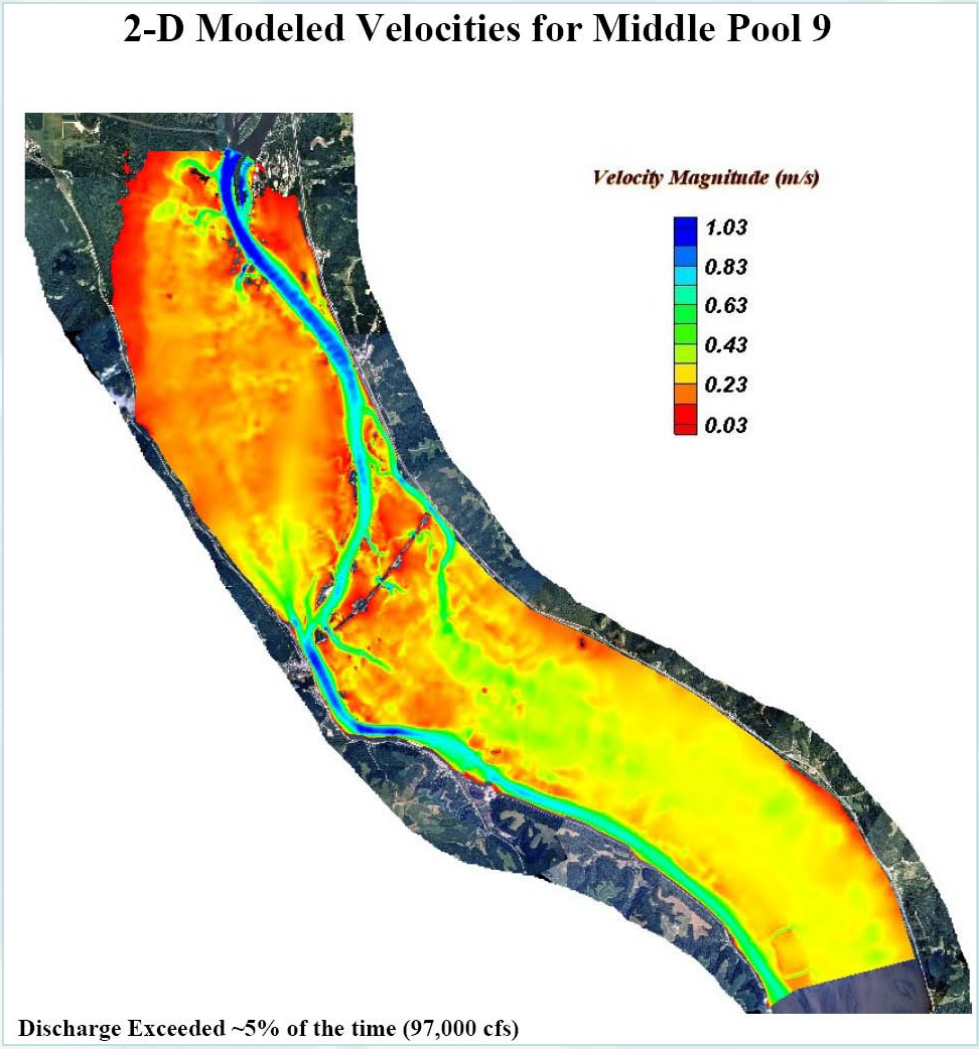
- Time and Cost to do the modeling
  - Many factors can influence this, but 3 to 4 months and 50K (in-house labor) is good starting point for UMRS Hydraulic models.
  - Model costs are about 1% of a typical project cost
- Model Review
  - Usually a District Quality Control Function
  - The number of available reviewers is limited.

2D Model Use in Planning Steps

Inventory Existing Conditions

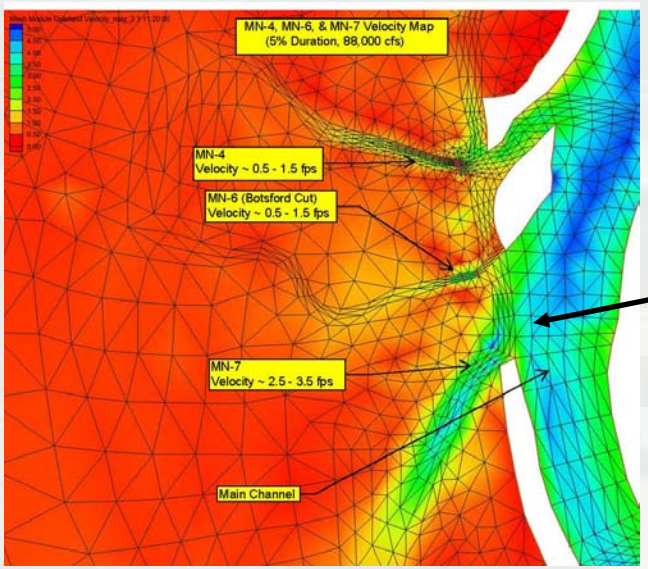
2D models which are built on existing bathymetric data, calibrated to flow and water surface data can be used to interpret habitat conditions for biota for large areas.

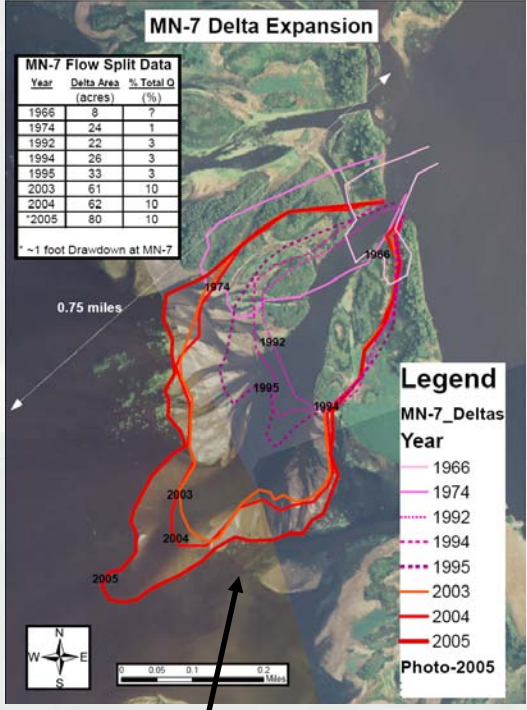
Velocity and water surface data is available throughout the 16 mile long by 2.5 mile wide area depicted here.

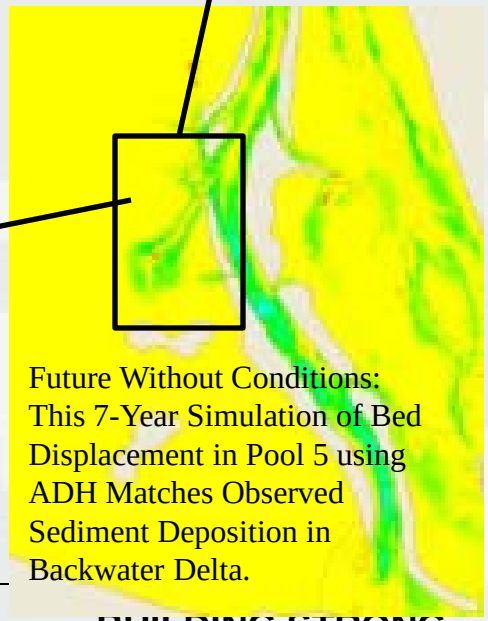


Forecast Future Without-Project Conditions

2D models are evolving to the point where patterns of erosion and deposition can be predicted. This allows the user to interpret future conditions given various hypothetical flow conditions. The effects of large floods can be analyzed also.







Future Without Conditions: This 7-Year Simulation of Bed Displacement in Pool 5 using ADH Matches Observed Sediment Deposition in Backwater Delta.

Modeling1930 Reference Conditions, Reno Bottoms

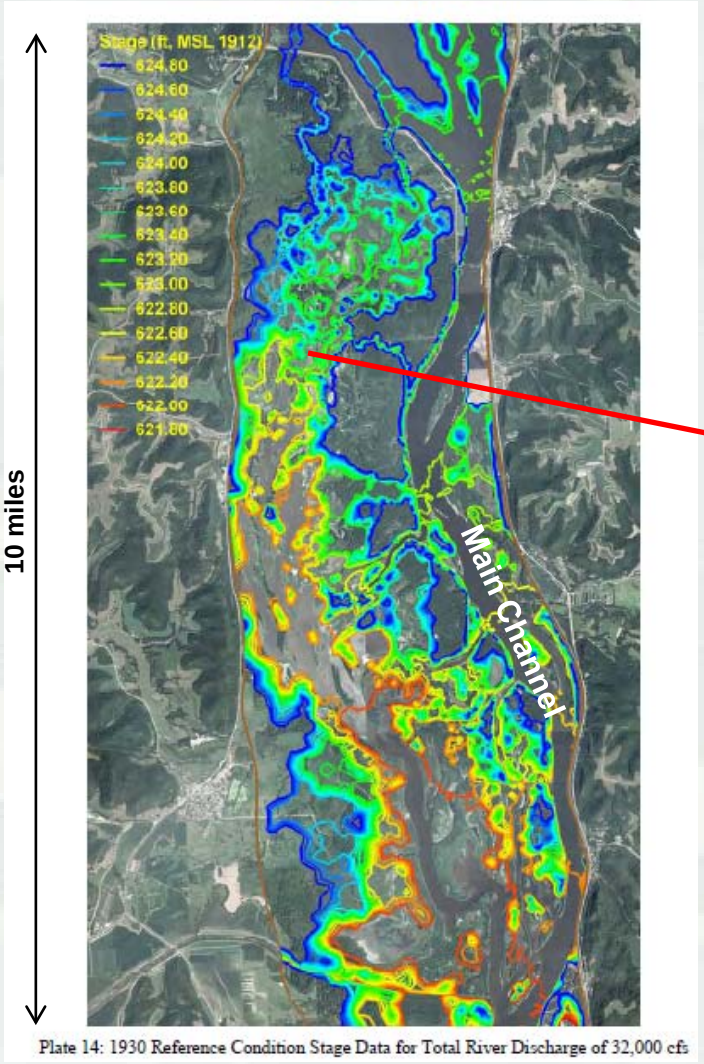
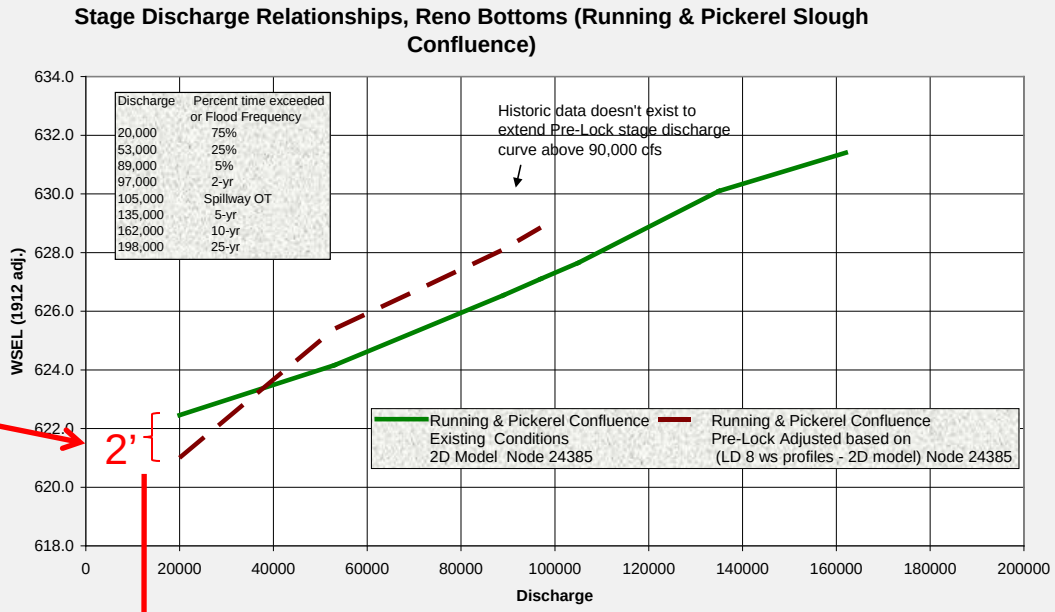


Plate 14: 1930 Reference Condition Stage Data for Total River Discharge of 32,000 cfs

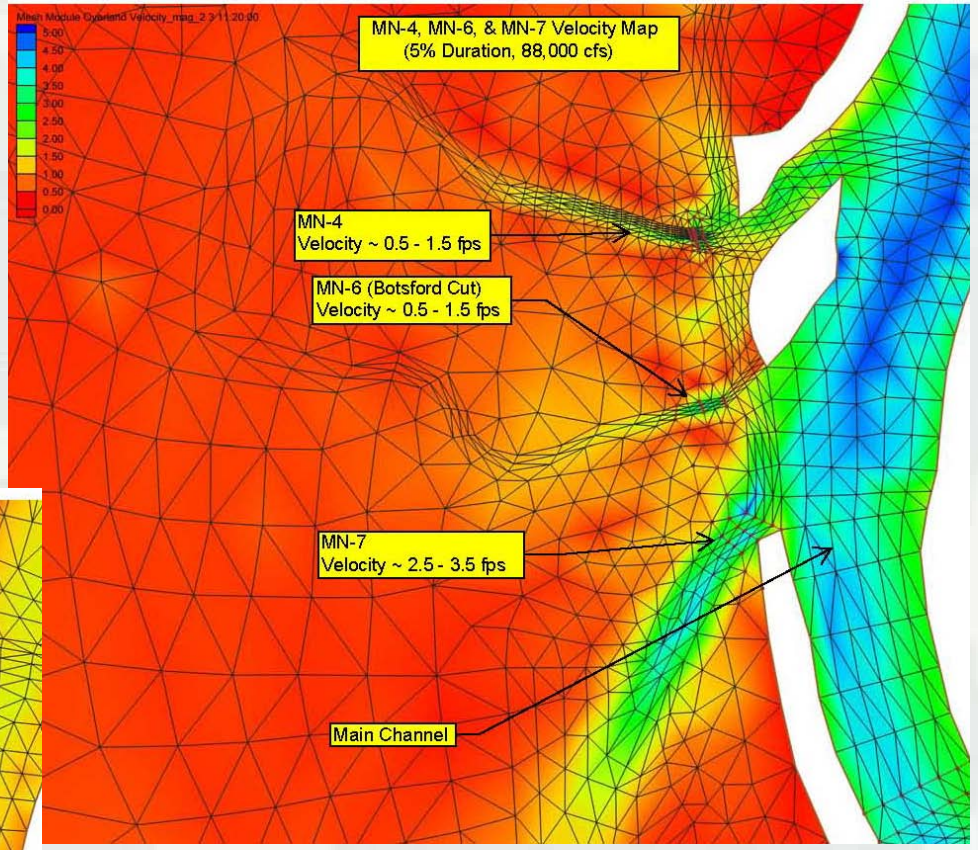


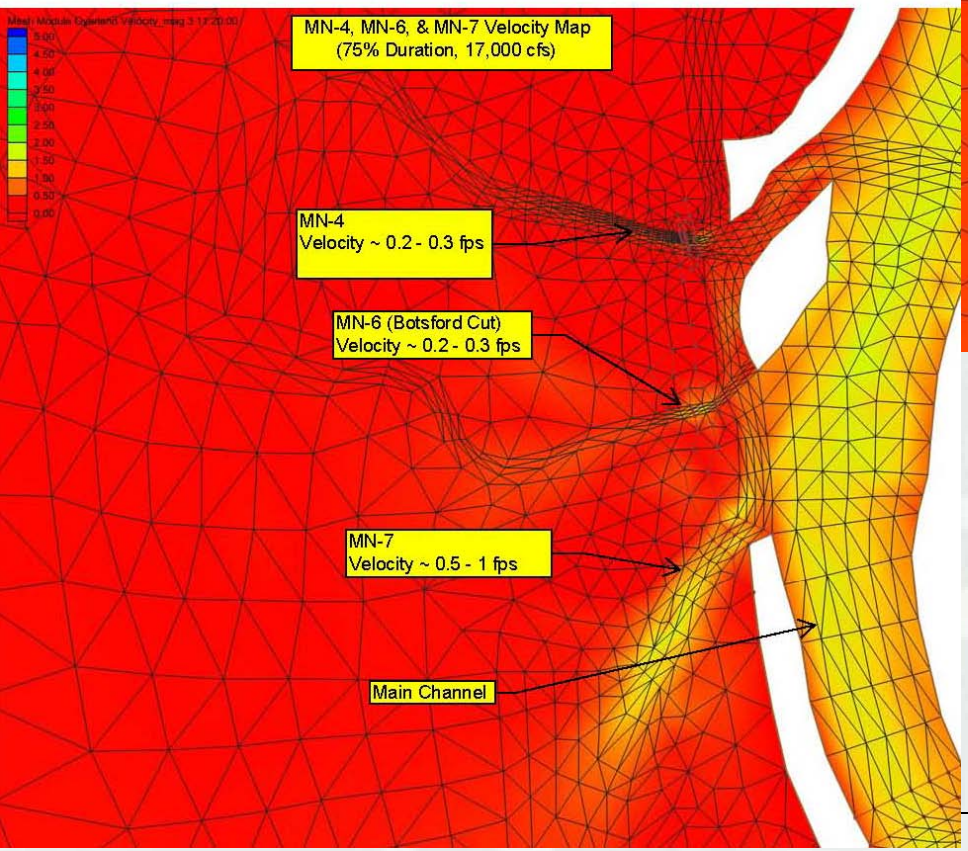
The current floodplain forest distribution is two feet higher in elevation than during pre-Lock and Dam periods.

Interestingly, the stage-discharge relationships at the low discharge of 20,000 cfs are also 2 feet higher than pre-Lock and Dam periods.

Apparently, current water management is responsible for shifting the FF distribution about two feet higher in most of Reno Bottoms.

2D models can be used to refine objectives and performance criteria





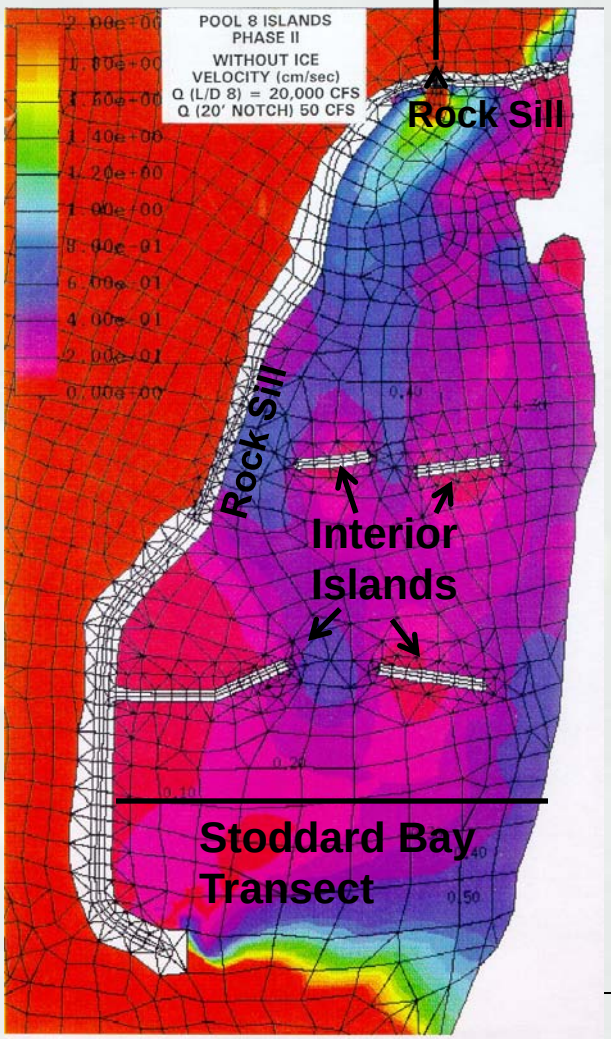
Performance Criteria for Secondary Channels:

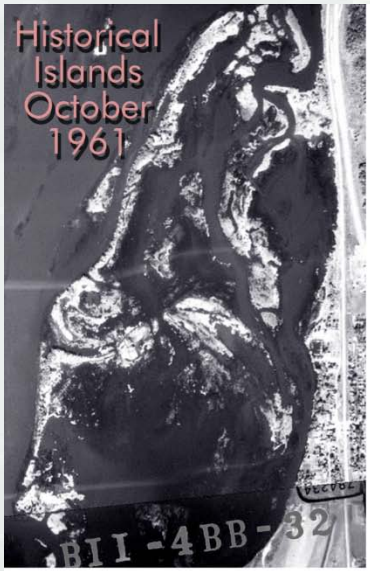
- **2 < vc < 3 fps for 5% duration event**
- **.5 < vc < 1.5 fps for 75% duration event**

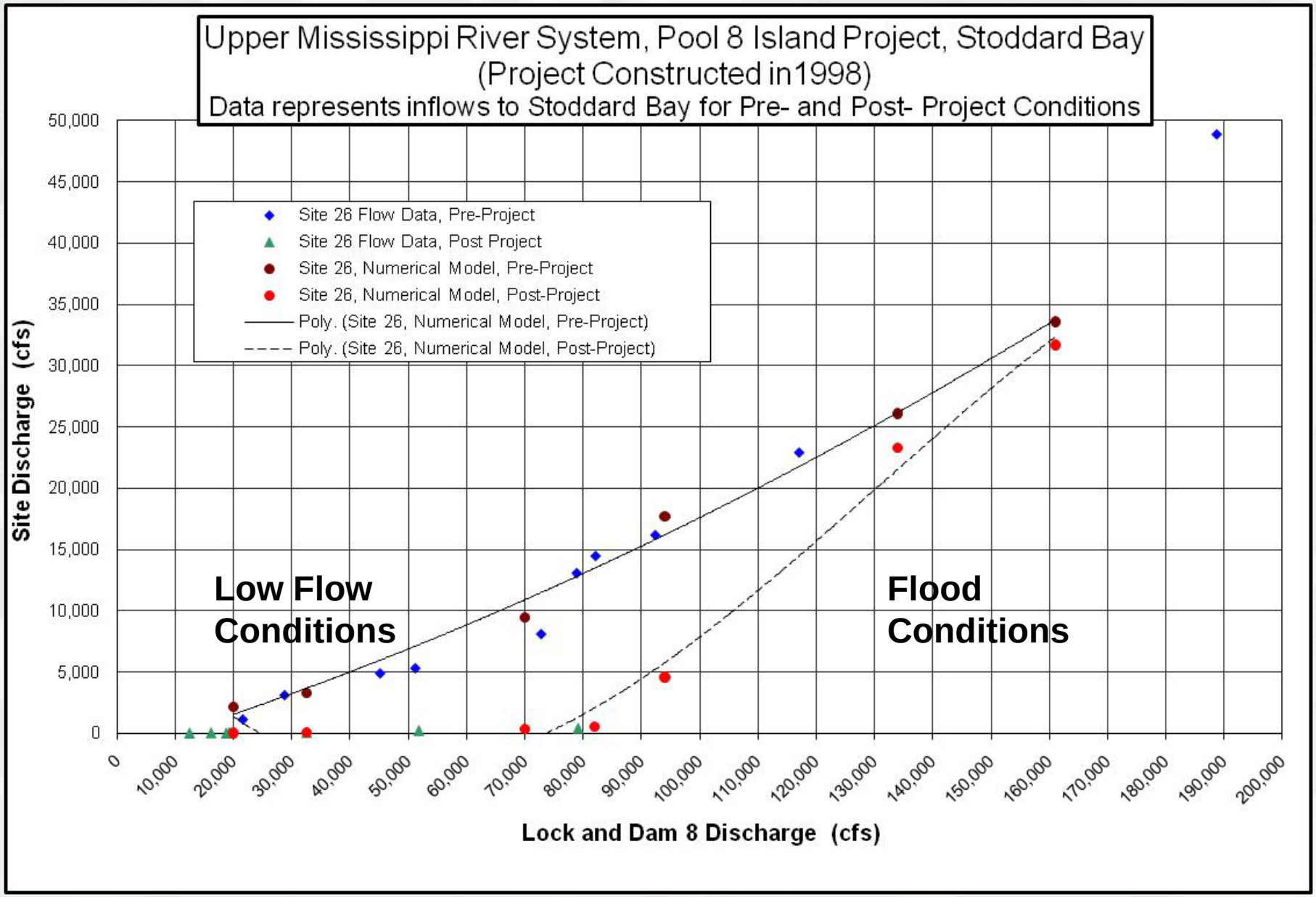
Formulate, Evaluate, Select Alternative Plans

- 2D model results provide information used in alternative development and analysis.
- However, other factors such as opportunities, constraints, constructability, funding, regulatory issues….affect alternatives also.
- 2D model results are used to refine designs, evaluate constraints, communicate, visualize, and estimate habitat outputs.

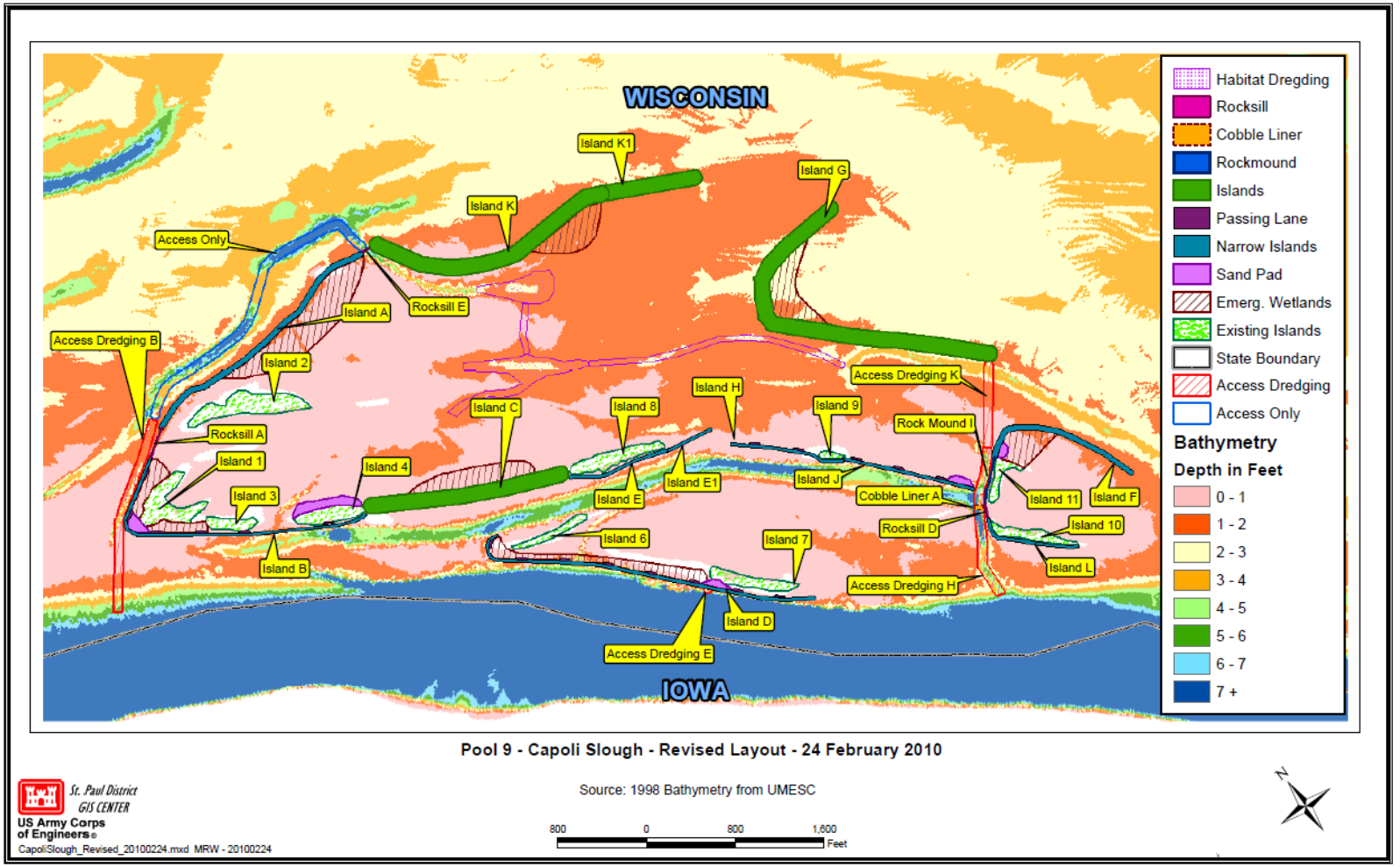
Pool 8 Islands, Phase II (Stoddard Bay)






Upper Mississippi River System, Pool 8 Island Project, Stoddard Bay
(Project Constructed in1998)
Data represents inflows to Stoddard Bay for Pre- and Post- Project Conditions
Site 26 Flow Data, Pre-Project
Site 26 Flow Data, Post Project
Site 26, Numerical Model, Pre-Project
Site 26, Numerical Model, Post-Project
Poly. (Site 26, Numerical Model, Pre-Project)
Poly. (Site 26, Numerical Model, Post-Project)
Low Flow Conditions
Flood Conditions
Site Discharge (cfs)
Lock and Dam 8 Discharge (cfs)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
110,000
120,000
130,000
140,000
150,000
160,000
170,000
180,000
190,000
200,000

Capoli Slough, Pool 9



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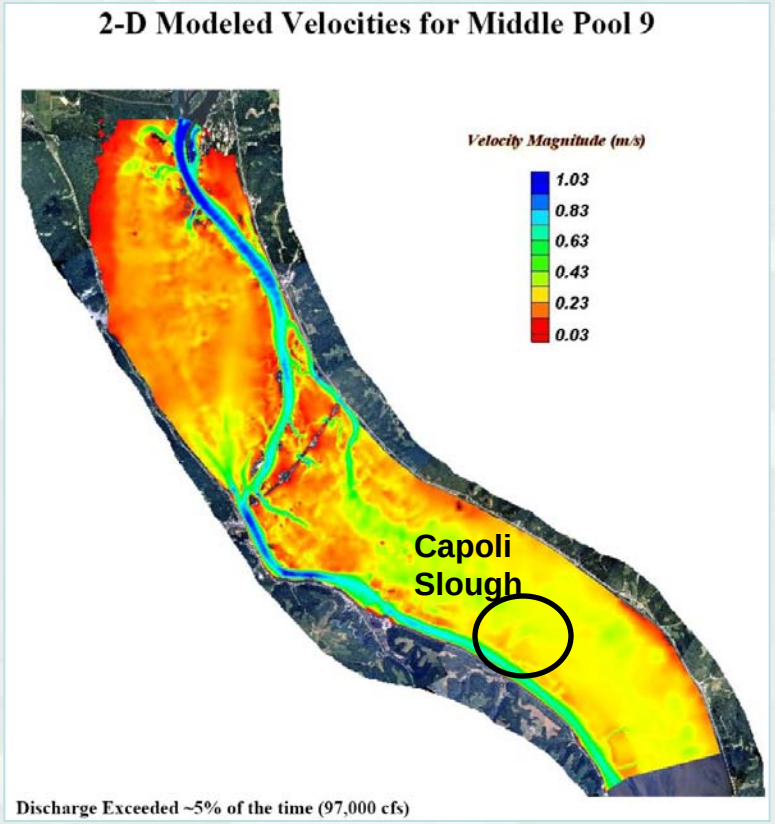
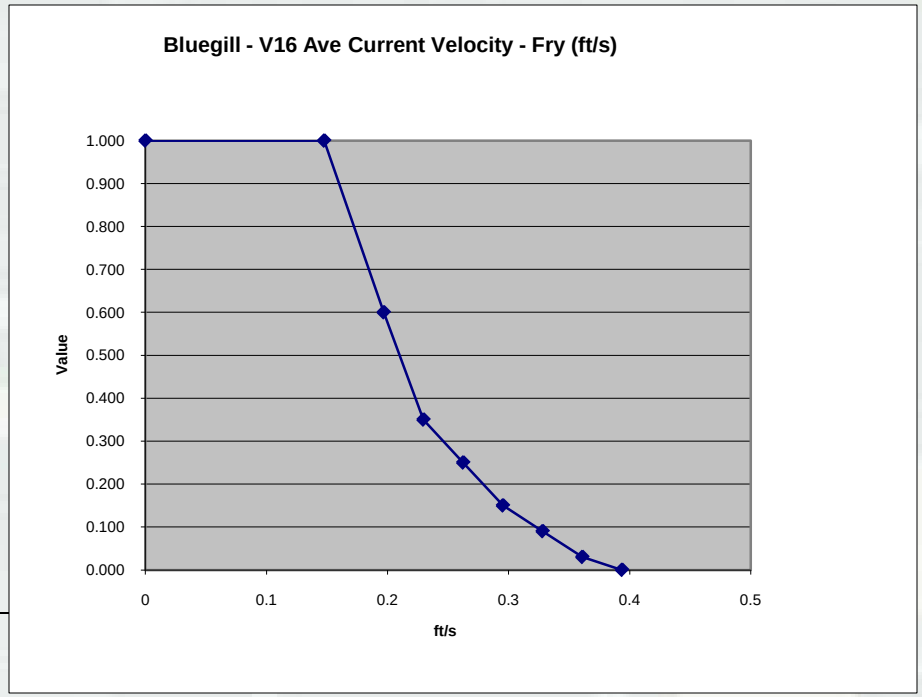
Capoli Slough, Pool 9

- 2D model average flow velocities were used to establish:
  - Baseline Conditions
  - Project Alternative conditions
  - Criteria for meeting project goals
- Spatial organization was by cover types: open water, SAV, RFV, EAV within different areas of the project.



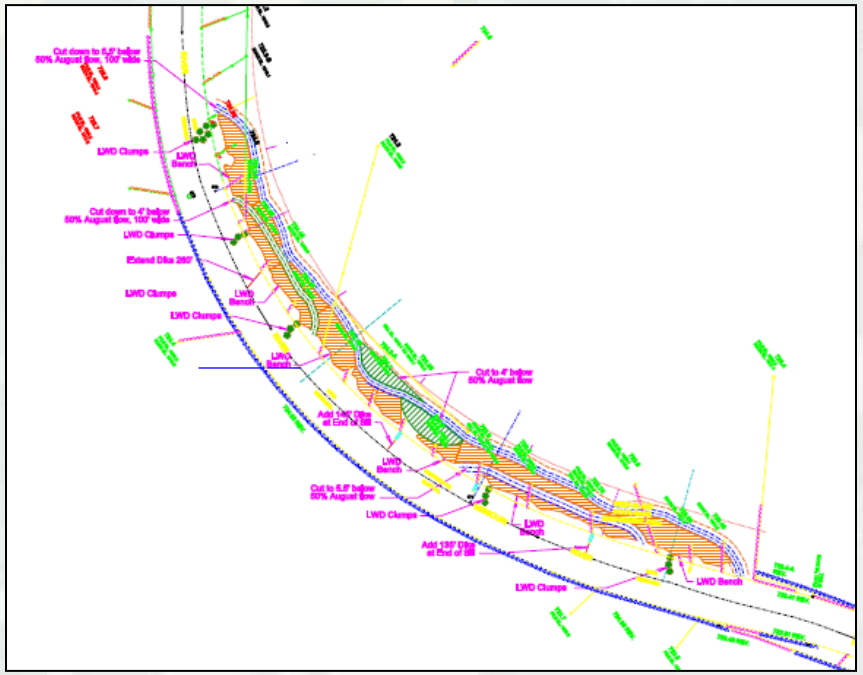
Capoli Slough, Pool 9

- Model velocities were compared to blue book curves for smallmouth bass and bluegill considering:
  - ► Habitat components (food, cover, spawning)
  - ► Life Stages (fry, fingerling, juvenile, adult)
- HEAT software was used to calculate AAHUs for different alternatives



Alternative Analysis - Lower Little Sioux Bend, Missouri River

- Shallow water habitat for Pallid Sturgeon can be constructed at significant cost.
- Question is how long will the habitat last and how significant are the maintenance requirements due to sedimentation?
- Shallow water habitat criteria
  - Depth < 5’
  - Velocity < 2 fps



Lower Little Sioux Bend, Missouri River

- Unsteady ADH model for sediment transport. 31,000 elements.
- Model is being used to optimize hydraulics and sediment transport in the navigation channel and off-channel shallow water habitat
- Very sensitive to sediment boundary conditions
- Run time is 10 to 12 hours on ERDC supercomputer for a 300 day simulation

5.1 HYDRODYNAMICS

The computed depth and velocity data for the August 50% duration flow was analyzed using an ArcGIS script to determine the areas which would meet the SWH criteria. The results for the seven alternatives are shown on Figures 13-19. Light green areas meet the SWH habitat criteria (aquatic areas having a flow depth of less than 5 feet and a velocity of less than 2 ft/sec for the August 50% duration flow).

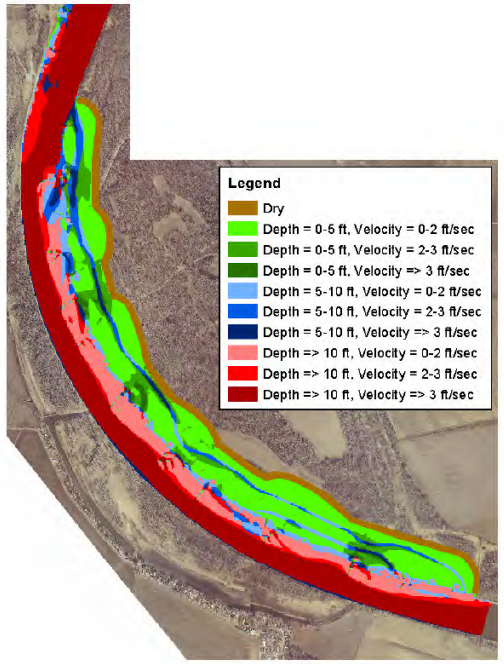


Figure 13: Depth/Velocity Zones for the August 50% Duration Flow, dmaxpx

Lower Little Sioux Bend, Bed Displacement

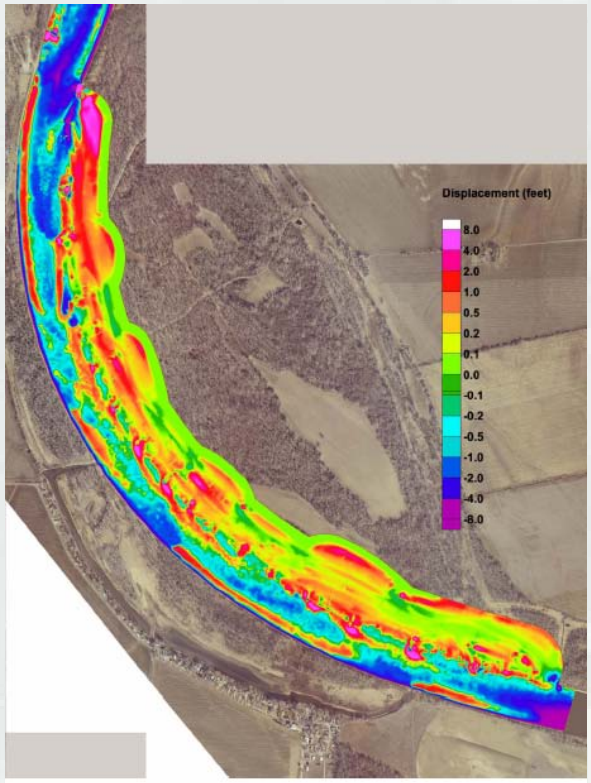


Figure 38: Bed Displacement for the 1997 Hydrograph, Option A

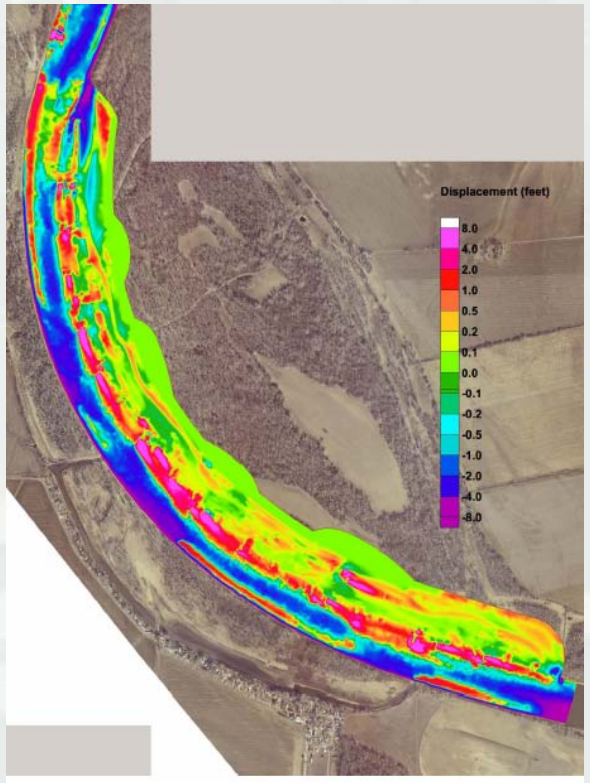


Figure 47: Bed Displacement for the 1997 Hydrograph, Option D

The unsteady ADH model is being used to optimize hydraulic and sediment transport in the navigation channel and in off-channel areas.

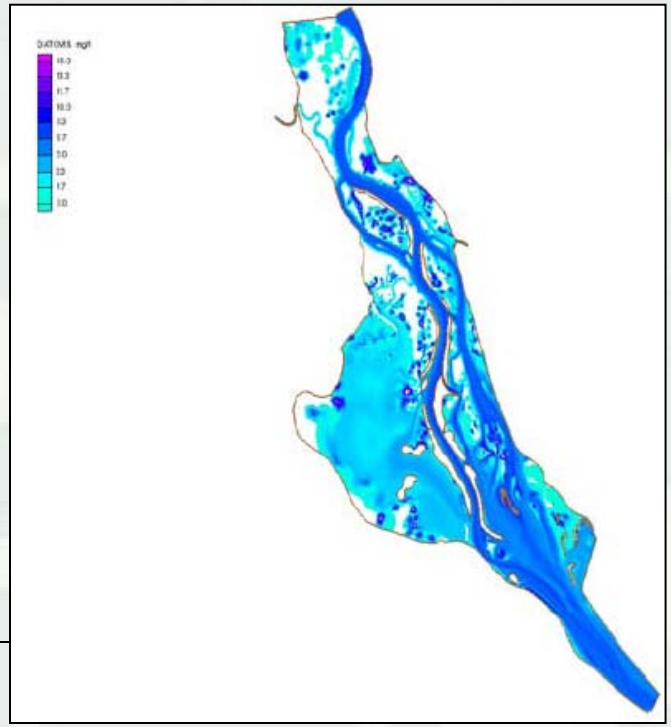
SWWRP

System Wide Water Resources Program

- A CE program to build modeling tools to assist districts
  - Provides model development and integration support for hydraulic, watershed, sediment, and ecological models
  - Establishes data management, model integration, and model structuring protocols
  - Provides data management tools
  - Provides visualization tools
  - https://swwrp.usace.army.mil/DesktopDefault.aspx

ADH-CASM

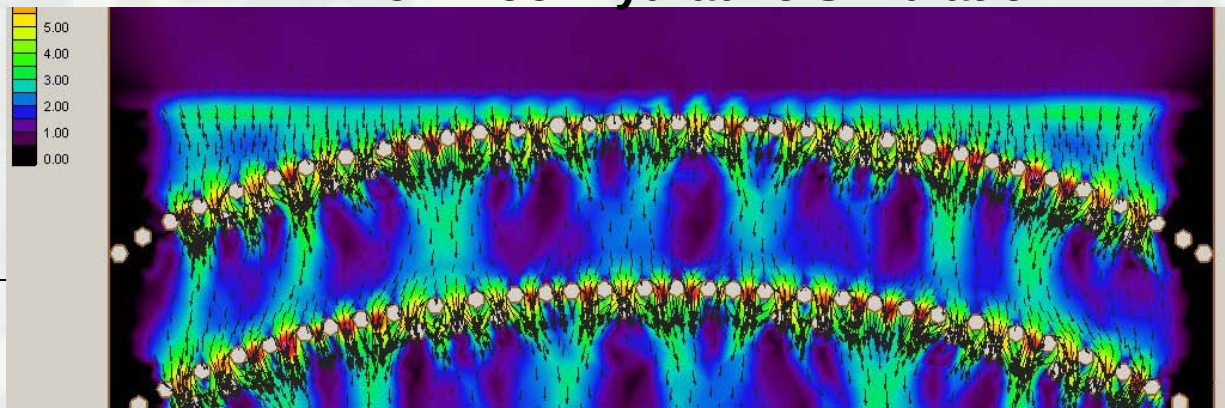
- CASM stands for the Comprehensive Aquatic Systems Model
- Has been used to look at alternatives in Pool 5 UMRS
- Calculates daily changes in biomass and water quality
- In Pool 5, at each node, model depth and velocity is provided to aquatic food web algorithms.
  - Predicts Vallisneria Growth
- CASM Uses in USACE Planning
  - Baseline Conditions
  - Future Without
  - Alternatives
  - Implications of variability



ADH-ELAM

- ELAM (Eularian Lagrangian Agent Method)
- Being used to look at Fish Passage alternatives on the UMRS
- Was developed in the Pacific Northwest for Salmon projects
- Forecasts responses of highly mobile aquatic biota
- Limited by knowledge of fish response to hydraulic stimulus
- ELAMs offer a way to more closely couple ecosystem response to physical conditions
- ADH model describing flow field was used for Lock and Dam 22 Fish Passage simulations

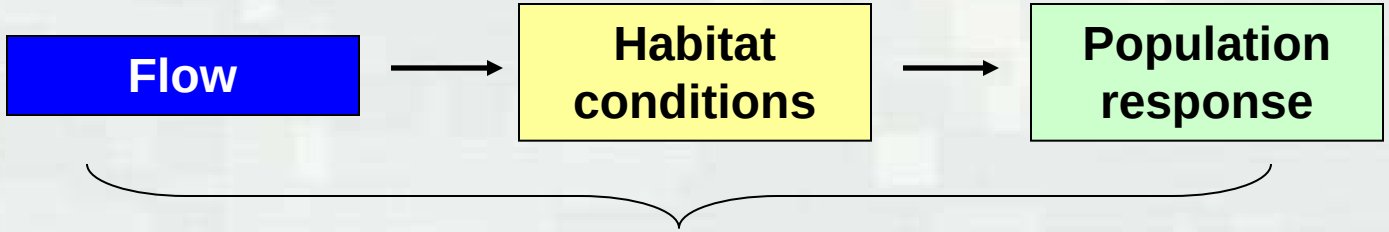
Riffle – Pool Hydraulic Simulation



HydroMussel:

Flow-based Ecological Modeling Software

ADH User Group Workshop



- **Hydraulic model** – describes physical environment
- **Habitat model** – describes use and function (*niche)*
- **Population model** – describes biological response

Summary

- 2D hydraulic models have been tool of choice for a couple decades on the UMRS due to the complex flow patterns, which are adequately represented by these models.
- ADH (developed through the SWWRP) is the latest 2D model.
- Model costs are about 1% of project costs.
- 2D models provide H&H information
  - at un-gauged locations across the river valley, which can be incorporated into a GIS data base.
  - For the entire flow regime
  - For extreme events, which we usually don't have data for

Summary

- 2-D hydraulic models have been used in ecosystem restoration planning on the UMR to:
  - ► Inventory existing conditions
  - ► Provide information for alternative analysis
- More recent applications include:
  - ► Simulating future without project geomorphic change
  - ► Simulating historic reference conditions
- Future directions:
  - ► Link H&H simulations directly to ecosystem response