Hydrodynamic Models as Tools for Ecological Restoration on the Upper Mississippi River Pool 8: A Tale of Two Models—Historic and Modern

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Abstract

The Upper Mississippi River System (UMRS), located in the north-central United States, supports a diverse and dynamic ecosystem, forming the upper part of the third longest river in the world. However, as a result of over 150 years of navigation improvements, human impacts, and development the UMRS has been drastically altered from its original state. Significant changes were caused by the construction of the lock and dam system beginning in the 1930s. The resulting increase in water levels caused many backwater areas to be flooded year round, with a loss of natural islands and decreasing side channels on the flood plain.

It is often difficult to fully understand pre-inundation or reference conditions on how to best restore ecosystems on the UMRS. Typically, scientists, engineers and water managers are faced with the difficult decisions of determining what the reference conditions were like and how to best measure the effectiveness of river restoration projects. The goal of this study is the application of two dimensional hydrodynamic modeling to compare physical conditions of original, pre-inundation conditions from historic and modern conditions in the same location of Pool 8 of the UMRS near La Crosse, WI. With a better understanding of the effect of islands on both past and current pool scale hydrodynamics, river managers can make more informed decisions to help meet their habitat restoration goals.

Background

The Upper Mississippi River System (UMRS), of the north-central United States, is a diverse and dynamic ecosystem that includes the main stem river channel, side channels, backwater floodplains and lakes, islands, wetlands, grasslands, and floodplain forests. The hydrology of this rich ecosystem is one of the key drivers for physical chemical and biological processes. However, as a result of over 150 years of navigation improvements, human impacts, and development, the hydrologic and hydraulic characteristics of many parts of the UMRS have been drastically altered from their original state. The resulting increased water levels caused many backwater areas to be flooded year round, with a loss of natural islands and a decoupling of the river from the broader flood plain. informed decisions to help meet their habitat restoration goals.

Prior to the construction of the present lock and dam system, a majority of the modifications to the navigation channel were made by the construction wing dams and closing dams, and through the use of dredging. All of these projects have had an impact on the hydrology and habitat of the Mississippi River System.

Objectives

- Simulate historic hydrodynamics of Upper Mississippi River near what is now Pool 8.
- Demonstrate the effectiveness of 2-D modeling in helping river managers assess change in hydrodynamics from pre-impoundment to current conditions.
- Bridge knowledge gaps between ecologists, scientists, and river engineers.

Model Framework

Governing Equations—St. Venant Equations

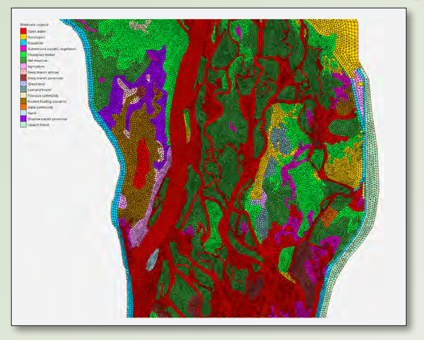
Continuity: $\frac{\partial h}{\partial t}+\frac{\partial hU}{\partial x}+\frac{\partial hV}{\partial y}=0$

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

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

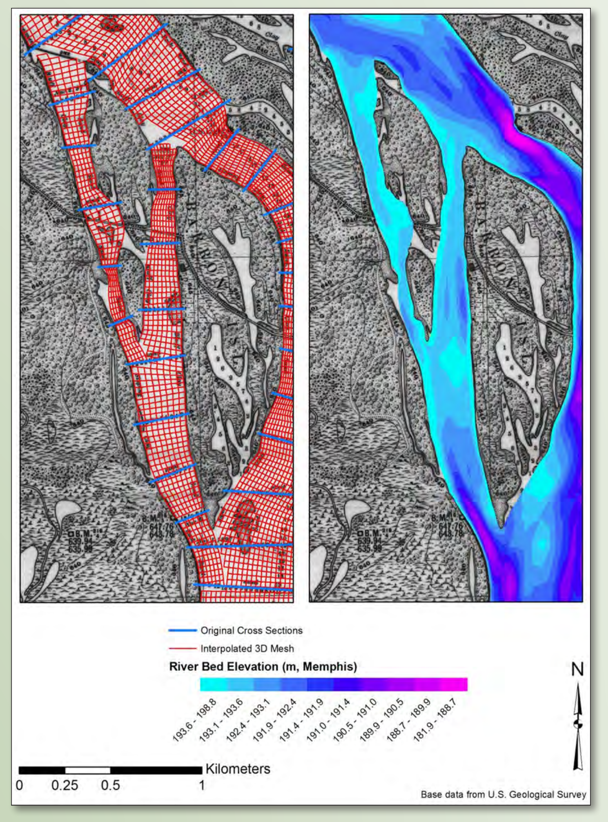
The study uses SRH-2D, a two –dimensional hydraulic model developed by the Bureau of Reclamation. SRH-2D is a physics based model that solves the 2-D dynamic wave equations, also known as the depth-averaged St. Venant equations, using finite-volume numerical methods.

Mesh and Material Types



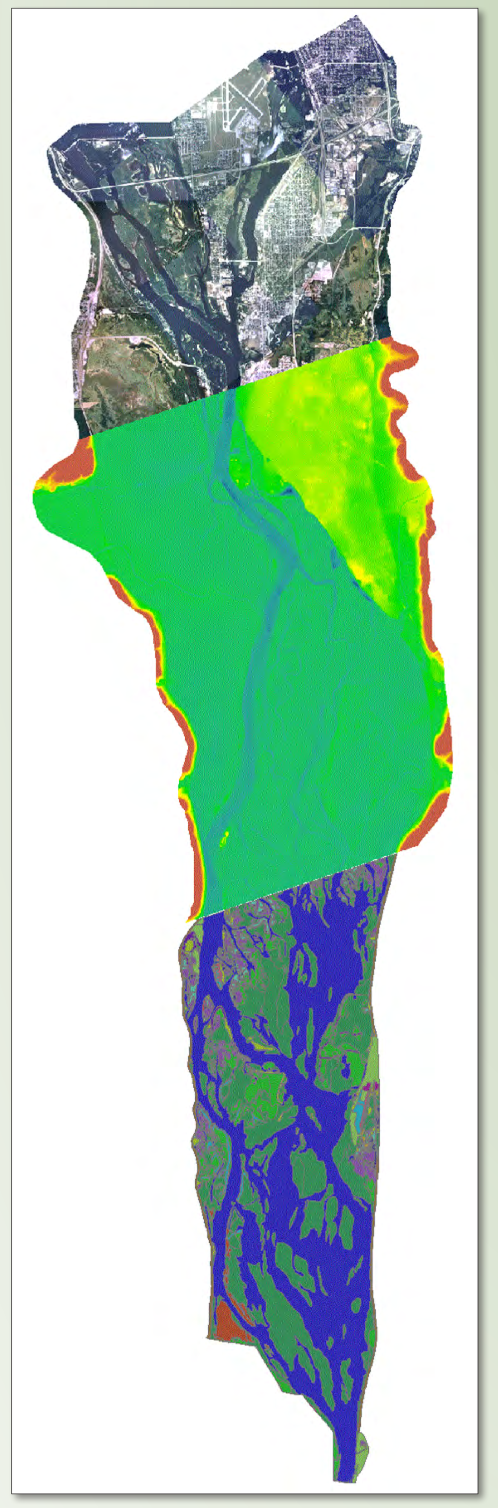
A hybrid mesh was used in this study with a structured rectangular mesh in the main channel and unstructured mesh in the floodplain. Material types based on Manning's Roughness Coefficient can be assigned to individual cells.

Historic Flow Conditions

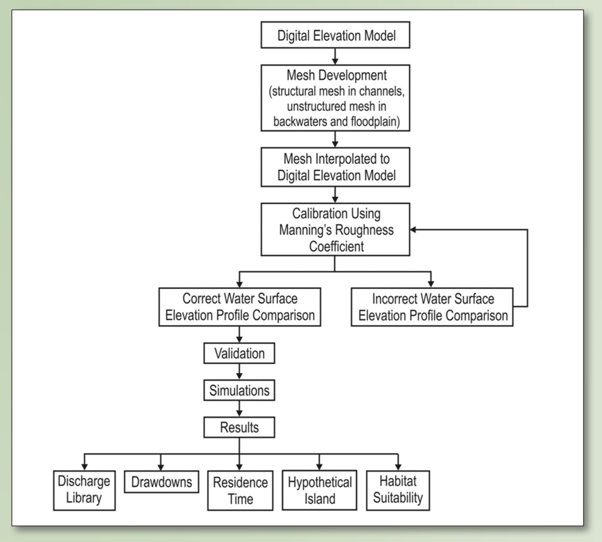


The 1890 river survey map (provided by the U.S. Geological Survey) was geo-referenced and digitized (above, and top right). The DEM (Digital Elevation Model) was made from contours and bathymetry points using inverse distance weighted interpolation with points brought together in a TIN (triangulated irregular network). Section of the 1890 Pool 8 map on right illustrating bathymetric mesh and resulting TIN.

Modern Flow Conditions



Model Development Process

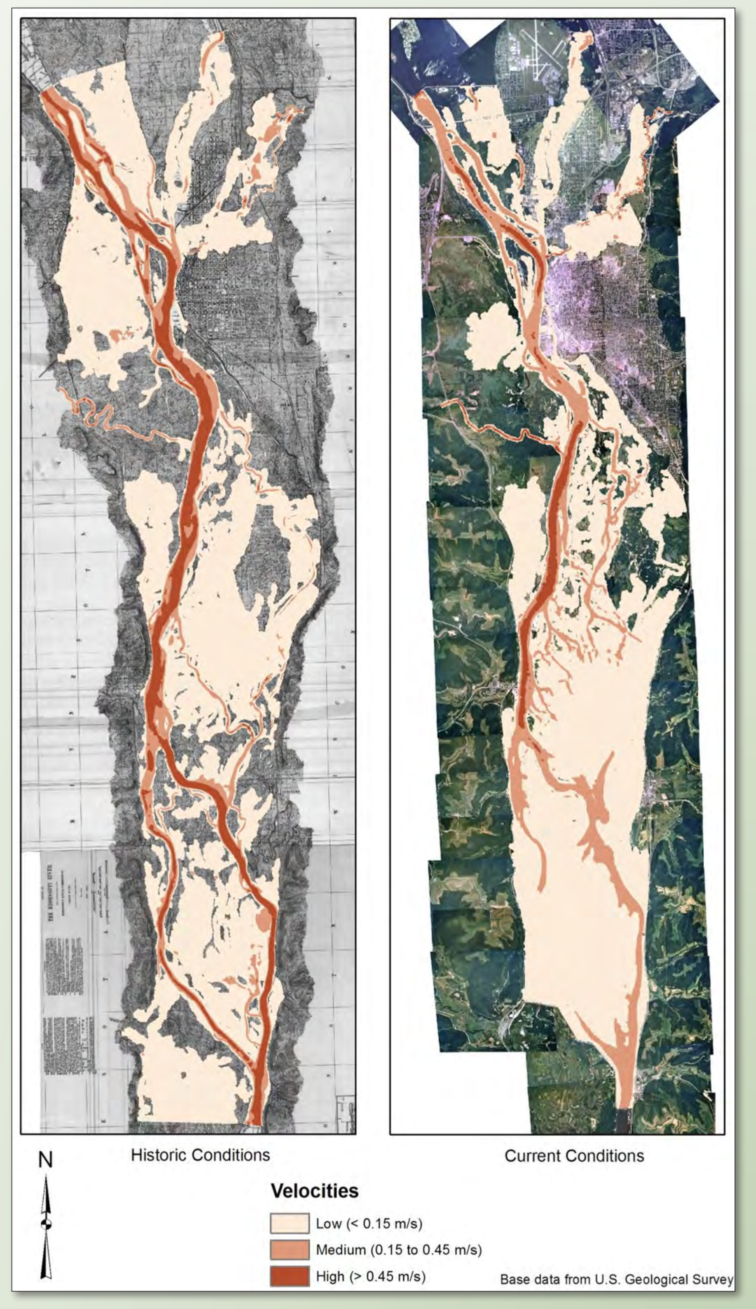


Model Boundary Conditions

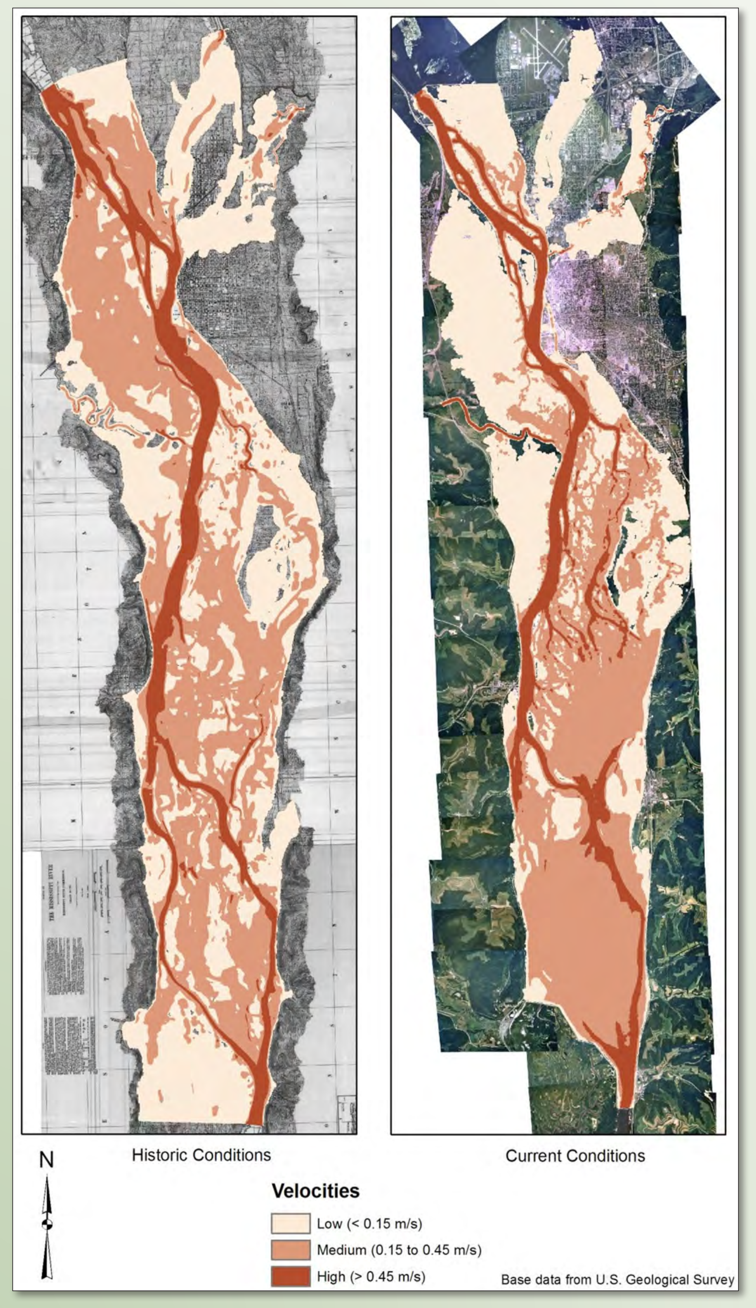
Calibration Flow Conditions		Validation Flow Conditions	
Inlet	**Discharge (m^3/s)**	**Inlet**	**Discharge (m^3/s)**
Lock and Dam 7	1127.0	Lock and Dam 7	770.2
French Island Spillway	8.6	French Island Spillway	2.8
Onalaska Dam	51.0	Onalaska Dam	21.9
Lacrosse River	8.9	Lacrosse River	8.6
Root River	33.4	Root River	20.5
Exit	**Discharge (m^3/s)**	**Exit**	**Discharge (m^3/s)**
Reno Spillway	0	Reno Spillway	0
Hastings Spillway	0	Hastings Spillway	0
Exit	**Elevation (m)**	**Exit**	**Elevation (m)**
Lock and Dam 8	191.87	Lock and Dam 8	191.85

The water development process for current conditions utilized a LiDAR derived water surface profile for calibration. Once the roughness coefficients were finalized a validation simulation was run and the results were compared with ADCP measurements for 17 transects of the pool. The mean difference was 0.01 m, with SD of 0.04 m. Historic conditions were calibrated to the 1864 low water profile with mean difference of 0.2 m at the upstream end and 0.01 mat the downstream end.

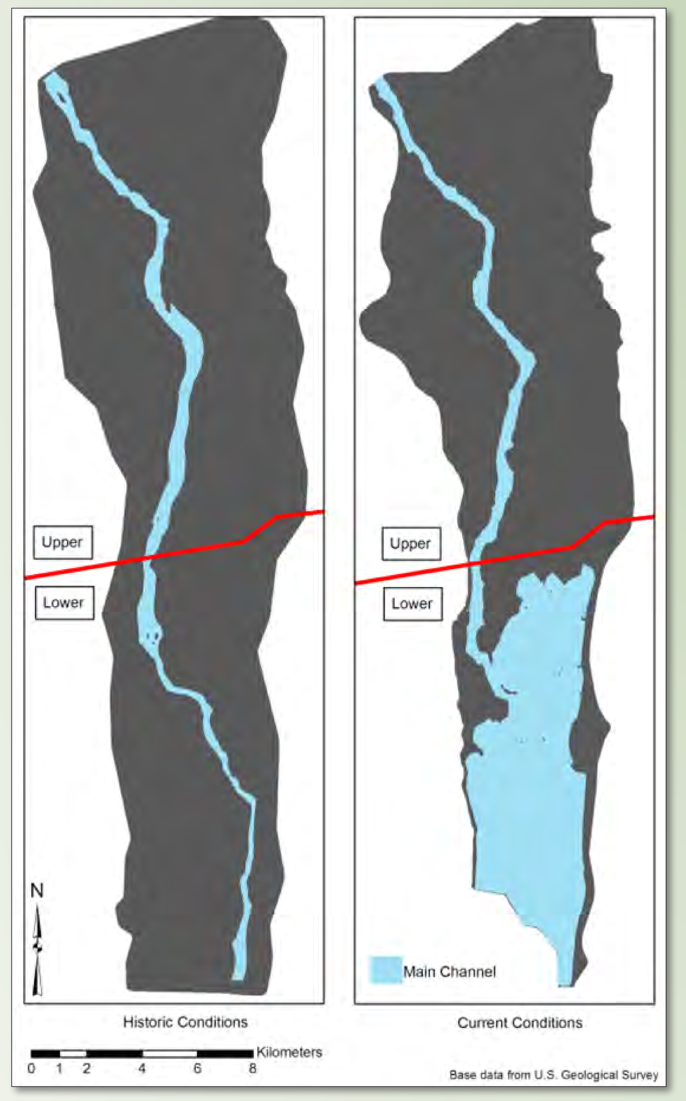
Selected Results & Products

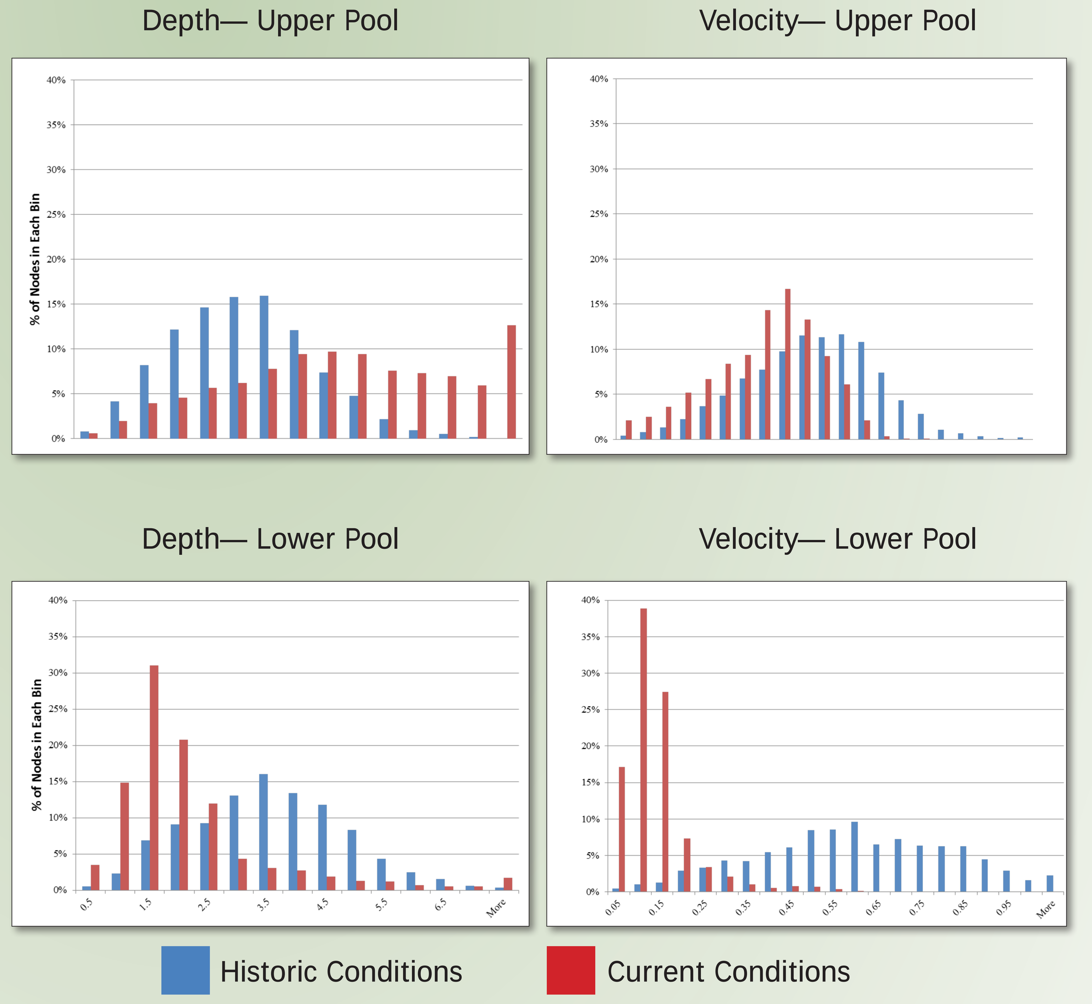


Velocity Map of Pool 8 –Simulated discharge of ***30,000 cfs.***
Historic conditions (left) and current conditions (right).



Velocity Map of Pool 8 —Simulated discharge of ***90,000 cfs.***
Historic conditions (left) and current conditions (right).





Map showing historic and current conditions for upper and lower Pool 8 with histograms at the right showing changes in depth and velocity distributions.
Note the broader distribution of depths and velocities for historic conditions for the lower pool 8 (pre-impoundment).

Other products include sediment grain size maps, habitat suitability plots for emergent vegetation, critical shear stress, and input into other models:

- 3-D models of select areas
- Ecological models