Post-dam removal river hydraulics and the influence of derelict industrial logging infrastructure on modern aquatic habitat

Nick Richmond[1], Peter Koons[1,7], Lauren Ross[3], Sean Smith[1,2], Samuel Roy[2], Gayle Zydlewski[4], Joe Zydlewski[5,6]

[1]University of Maine, School of Earth and Climate Sciences, Bryand Global Sciences Center, Orono, Maine
[2]University of Maine, Senator George J. Mitchell Center, Norman Smith Hall, Orono, Maine
[3]University of Maine, Department of Civil and Environmental Engineering, 308A Boardman Hall, Orono, Maine
[4]University of Maine, School of Marine Sciences, 360 Aubert Hall University of Maine Orono, ME 04469-5706
[5]University of Maine, Maine Cooperative Fish and Wildlife Research Unit, 5755 Nutting Hall, Orono, Maine
[6]University of Maine, Department of Wildlife Fisheries and Conservation Biology, 5755 Nutting Hall, Orono, Maine
[7]University of Maine, Climate Change Institute, Sawyer Research Building, Orono, Maine

Abstract

Following the 2013 removal of the Veazie Dam in the lower Penobscot River, the reappearance of remnant logging structures ("boom islands") in the former dam impoundment raises questions about what should be done, if anything, with the derelict structures. Knowledge about the impacts of the boom islands on federally-protected diadromous fish species will help to inform decision-making efforts about dam removal projects involving remnant infrastructure. Detailed knowledge of the water flow velocity conditions around boom islands is central to assessing the impact of logging industry infrastructure on fish habitat, but there are challenges associated with direct measurements and numerical approaches to predicting their hydraulic effects. While detailed velocity measurements are possible with Acoustic Doppler Velocimetry, collecting measurements over a range of flow conditions in large rivers reaches is impractical. Traditional approaches to numerical modeling of river hydraulics are able to perform 1D and 2D simulations in reach-scale domains, but they are unable to capture the effects of the boom islands due to constraints on dimensionality and resolution. Three-dimensional (3D) computational fluid dynamics (CFD) solutions accelerated by High-Performance Computing make it possible to capture the 3D effects of the boom islands on river velocity at the scale of the boom island structures. By using 3D velocity measurements with an Acoustic Doppler Current Profiler (ADCP) to augment and constrain 3D CFD solutions calculated using Smoothed Particle Hydrodynamics (SPH), we will capture detailed information about flow kinematics in the Penobscot River to inform decision-making efforts related to aquatic habitat restoration.

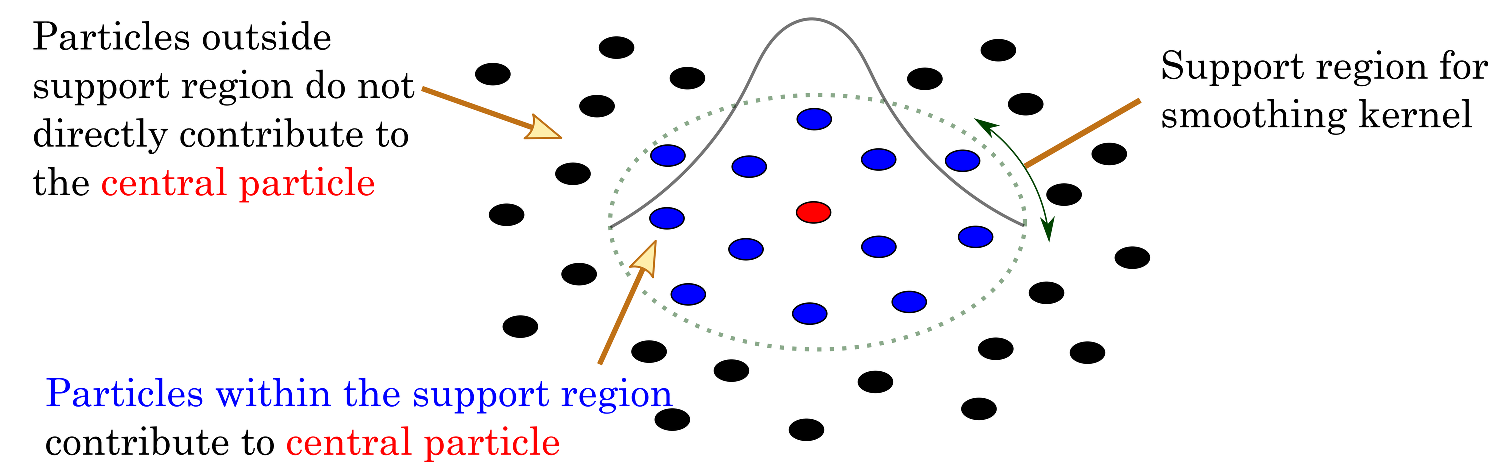
How Does SPH Work?

The physics of motion for fluids (Navier-Stokes [N-S] equations, shown below in simplified notation) are solved for each particle at every timestep.

$$\rho \frac{\partial \vec{v}}{\partial t} = \nabla P - \rho g + \mu \nabla^2 \vec{v}$$

For a given particle (shown below as the red "central particle," the N-S equations are locally integrated using the position and motion information of neighbor particles. A smoothing kernel weights the influence of the neighbor particles on the central particle such that the closest neighbors have the greatest influence on the central particle.

Figure 1: A Basic SPH Smoothing Kernel (after Karekal, Das, Mosse, & Cleary,



SPH is able to handle the fluid accelerations very well, which allows for robust solutions of the inertial N-S term and realistic simulation of fluid-structure interaction. Simulation of millions of particles with DualSPHysics (Crespo et al., 2015) enables investigation of the forces and kinematics associated with flow past hetergeneous boundaries in three dimensions.

3D Hydraulic Modeling with SPH

"Boom Islands" (Figure 2) are relict structures used for logging operations on Maine's Penobscot River. These structures became unsubmerged after the 2013 removal of Veazie Dam, and the flow obstruction may create dynamic habitats which are favorable to protected species such as Shortnose Sturgeon.

Figure 2: Relict Logging Structures in the Penobscot River

Figure 3: Flow Around a Single Boom Island

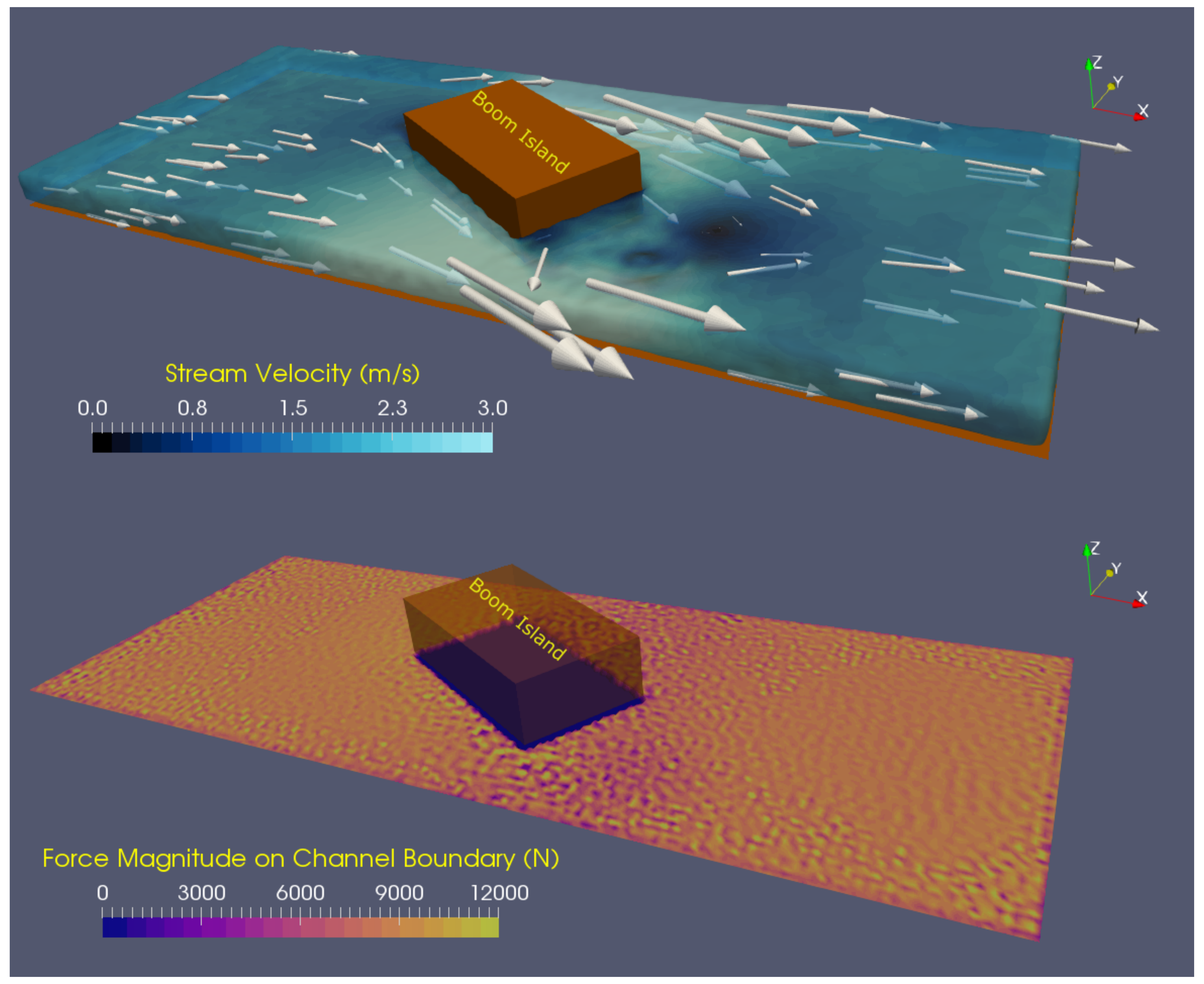


Figure 3 shows a SPH solution for flow past an idealized boom island. A distinct low-velocity zone (top panel) and zone of low forces acting on the channel bed (bottom panel) on the down-stream end of the boom island may provide favorable breeding conditions for shortnose sturgeon.

Figure 4 shows a SPH flow past a cluster of boom islands with an arrangement that is akin to real boom island clusters shown in Figure 2. By scaling up numerical flow solutions calibrated with field measurements to spatial scales which aren't easily measured in the field, we may evaluate whether a zone of cumulative influence of the boom islands on the 3D velocity field exists at various river discharges.

Figure 4: Flow Around a Boom Island Cluster

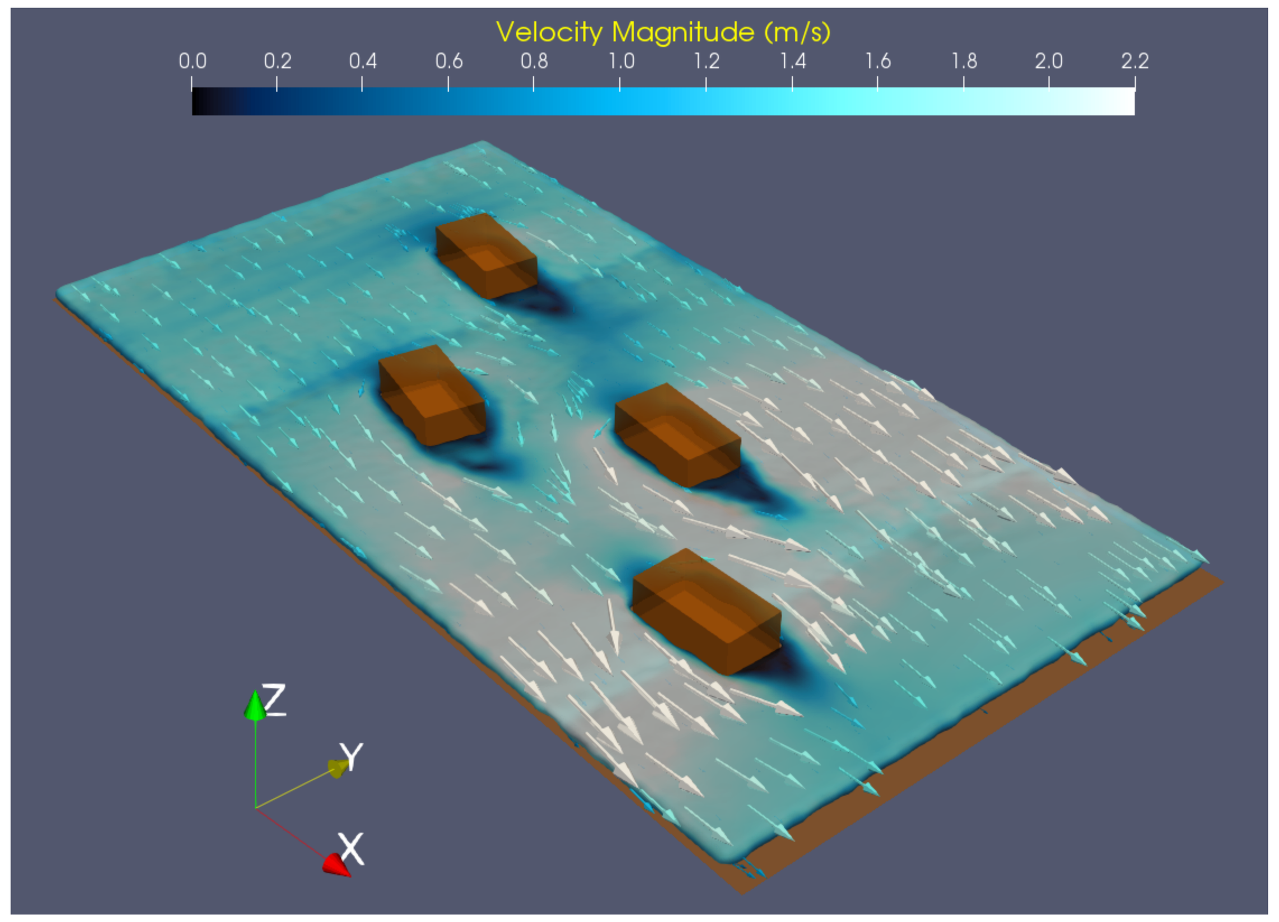
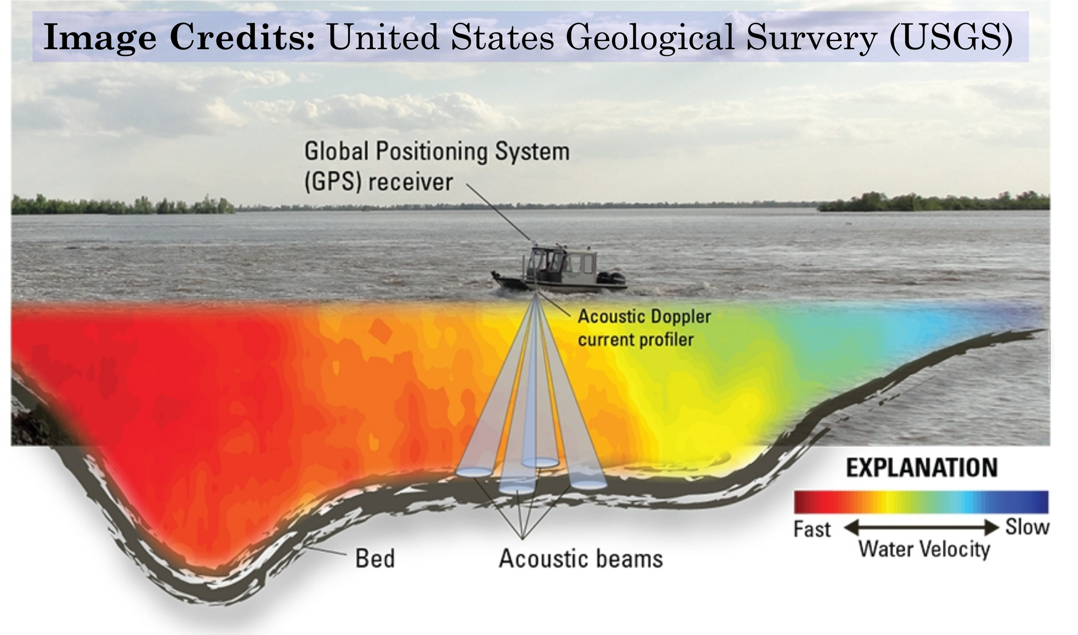


Figure 5: Acoustic Doppler Velocimetry



Field observations of 3D water velocity in the Penobscot River will be made in Summer 2018 using an Acoustic Doppler Current Profiler (ADCP), which estimates velocity in 3D space using the characteristics of acoustic signals transmitted and received by transducers. These velocity measurements will be used to calibrate the SPH model and to directly evaluate the role of Boom Islands on the velocity structure of the Penobscot River.

Acknowledgements

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Discussion

This investigation directly builds on the work of Johnston (2016), who used numerical modeling to produce 2D depth-averaged velocity estimates for the Penobscot River in order to evaluate the impacts of dam removal on shortnose sturgeon. By increasing the dimensionality of simulated flows (from 2D to 3D) and by calibrating the simulated results to high-resolution 3D hydraulic velocity measurements, we will be able to address questions which require a detailed knowledge of the hydraulic conditions of the Penobscot River. Through these detailed measurements and modeling results, we expect to resolve the influence of relict logging structures on the hydraulic conditions which impact aquatic habitat for federally-protected diadromous fishes.