Decoding and Forecasting 3-D Fish Movement Behavior using a Eulerian-Lagrangian-Agent Method (ELAM)

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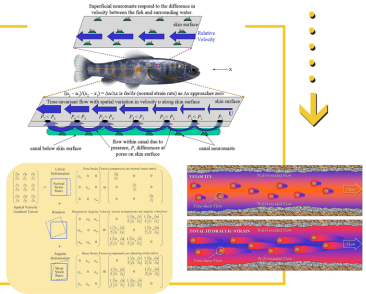
Results: Numerical Fish Surrogate (NFS) forecasts generally match observed passage proportions with goodness of fit (slope/R-square) decreasing from spillway (0.95/0.85), bypass (1.07/0.80), to powerhouse (1.15/0.61). The reduced goodness of fit for the powerhouse reflects the difficulty of maintaining constant operation of the powerhouse during testing. Spillway operation is held constant during a test and therefore meets the steady-state assumption of the computational fluid dynamics (CFD) model. Bypass system operation is also held constant, but its location nearer the powerhouse than the spillway for most cases reduces its goodness of fit. The "rules off" case represents passive transport. The substantial improvement in goodness of fit provided by the "rules on" case represents the contribution of the behavioral rules to the quality of the forecast.

Findings: The "traffic rule" used by out-migrating fish is based on a river geomorphology concept that spatial flow pattern results from flow resistance. Flow resistance imposes pattern on bulk flow once it is set into motion by the force of gravity. Spatial variation in velocity induces (1) linear deformation, (2) rotation, and (3) angular deformation mechanisms. Defining total flow field distortion as the sum of these mechanisms (i.e., all fluid motion mechanisms other than simple linear translation), the spatial velocity gradient tensor embodies all of the information needed to define a 'total distortion metric' we call "total hydraulic strain". Since subcutaneous canals of the mechanosensory lateral line system of fish are oriented differently over the body, it is plausible a fish can detect each spatial velocity gradient separately and at a near instantaneous interval. With little-to-no guidance on how, or if, fish may assemble and respond to the instantaneous spatial velocity gradients describing flow field distortion, we assemble them into a hypothetical scalar distortion metric "total hydraulic strain" using the simplest way possible - we sum the absolute values of each spatial velocity gradient.



Flow field distortion may then be generally described as either (1) friction resistance producing wall-bounded flow occurring when a solid boundary (e.g., river channel) exerts friction force on moving water and (2) form resistance producing free-shear flow occurring when an obstruction in the flow (e.g., stump or rock outcrop) produces a local constriction in flow area. Information contained in the total hydraulic strain and velocity fields is sufficient to separate structures producing friction resistance and form resistance flows. Wall-bounded flow gradients, associated with friction resistance, exhibit increasing total hydraulic strain and decreasing water velocity towards the friction source. Free-shear flow gradients, associated with form resistance, exhibit increasing total hydraulic strain and water velocity towards the friction source until localized boundary effects very near the source are encountered.

Total hydraulic strain and velocity provide cues to out-migrating fish about spatial distortion in the flow field allowing them to navigate efficiently. By minimizing total hydraulic strain, an out-migrating fish can consistently locate itself in the part of the river channel exhibiting the highest mean downstream water velocity.

Alternative Exits for Out-migrating Fish

Problem: Water resources development impounds, diverts, or regulates streams and rivers. These alternations dramatically alter natural processes and seriously impact river biota. These impacts must be managed to prevent degradation in ecosystem health so future generations can use and enjoy the world's streams and rivers.

The Opportunity: Sophisticated engineering tools forecast temporal and spatial patterns in water delivery and water use to support water resources planning and management. These high-resolution, multi-dimensional tools could be used to support ecological studies by providing valuable, detailed environmental information. In this way, high-fidelity engineering tools can be used to develop plans that ensure sustainable water resources development and minimize benefits foregone.

Approach: High-resolution CFD models create an accurate virtual reality in which design or operational alternatives can be assessed. In the real world, acoustically tagged fish are released into the forebay and their paths through 3-D time-space are recorded as tracks that are overlaid on the model mesh. A fish swim path selection algorithm added to a particle tracker (forecasts passive transport of neutrally buoyant particles) creates a "smart particle" or NFS. The NFS can forecast fish x, y, z, time, swim speed, and swim orientation in the vertical and horizontal planes. The underlying "traffic rule" used by fish to hydraulically navigate complex hydrodynamic fields can be discovered by recursively reducing differences between observed and forecasted paths. The NFS used one design/operation for calibration and 19 different designs/operations across three dams and two rivers for validation. Forecasted and observed passage summaries are compared to determine the utility of this tool.

Numerical Fish Surrogate NFS

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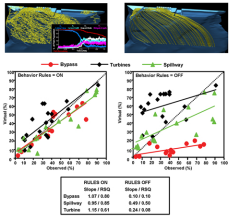
How Well Does the NFS Work?



	RULES ON: Slope / RSQ	RULES OFF Slope / RSQ
Bypass	1.07 / 0.80	0.70 / 0.10
Spillway	0.95 / 0.85	0.49 / 0.50
Turbine	1.15 / 0.61	0.24 / 0.08

Two Significant Findings From This Work:

1. CFD modeling and the NFS can accurately forecast performance of different dam designs and operations for fish passage and other issues. This allows engineers to design bypass systems and take management actions to minimize impact of water resources development on migrating fish.

2. In free flowing rivers there is a dynamic equilibrium between flow field and bed form. Unfortunately, flow pattern at dams is determined by size, orientation, and operation of gates, valves, and orifices and not a dynamic equilibrium between discharge and channel bed form. Dams should incorporate "natural hydrodynamic signals" to reduce impact on fish. By so doing, the hydraulic "foot print" of the dam can be minimized, perhaps even made invisible, to migrating fish with attendant benefits to society.