Hydraulic complexity metrics and brook trout (*Salvelinus fontinalis*) habitat

Biological Systems Engineering

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Abstract

Hydraulic complexity and flow structure (i.e. eddies) were modeled based on hydraulic engineering principles including circulation, vorticity, and kinetic energy gradients. Weighted usable area (WUA) for each sub-reach was also calculated using velocity, depth, and channel substrate preferences for brook trout. Both the hydraulic complexity metrics and the WUA calculated by the model were compared to spatially distributed fish data (every 10-20 m) to evaluate relationships between fish location, flow complexity and traditional methods of evaluating habitat.

The research goal is to improve stream habitat restoration design

Interest in river and stream restoration has increased dramatically over the last two decades. Conservative estimates place river restoration costs for the continental US in excess of $14 billion since 1990.[1] Traditionally, engineers concerned primarily with flood mitigation eliminated flow complexity from streams; however, aquatic organisms often inhabit and utilize complex flow patterns such as eddies, transverse flows and velocity gradient (fig. 1).

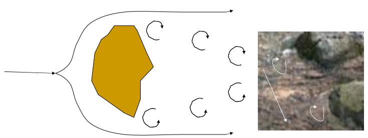

Figure 1. Plan view schematic of qualitative trends observed in the wake of a natural boulder.

Specifically, the objectives include:

1. Evaluate the relationship between flow complexity and fish habitat preferences;
2. Develop and field test metrics to predict hydraulic complexity characteristics and hydraulic habitat preferences from stream topography and flow; and
3. Evaluate flow complexity created by in-stream structures.

Flow Complexity Metrics

Flow complexity metrics including *vorticity*, *circulation*, and *kinetic energy gradients* can describe hydraulic conditions with potential biological importance such as areas in the wake of boulders[2].

Kinetic Energy Gradient

$$\left|\frac{\partial}{\partial x}\frac{V^2}{2}\right| \cong \left|2V_{ave}\frac{\frac{V_2-V_1}{\Delta x}}{V_1^2}\right|$$

Vorticity

$$\xi = \left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)k$$

Modified Circulation

$$|\xi|_{ave} = \frac{\int\int_{A_{tot}}|\xi|dA}{A_{tot}}$$

Where V = velocity
v = velocity in x direction
u = velocity in y direction
k = unit vector in the vertical direction
A_{tot} = total area

Brook Trout in the Staunton River, Shenandoah National Park

The Staunton River is a headwater stream originating on the eastern slope of the Blue Ridge Mountains in Shenandoah National Park (SNP), VA. The channel consists of pools separated by step pool cascades, small (<2 m) waterfalls, and bedrock slides.[3] In 1995, the site was affected by a catastrophic 500 year flood and debris flow affecting the lower half of the study reach (fig 2). This study modeled two 80-m sub-reaches, one within the affected area, and one directly upstream. Brook trout were captured by electrofishing within each habitat complex (10-20 m reach encompassing several pools and riffles and terminating at potential low-flow barriers)[3].

Figure 2. Habitat complexes where brook trout were sampled within the Staunton River.

Hydraulic Modeling

River2D is a 2-dimensional, depth averaged, finite element model for use on natural streams and rivers. This model was used to calculate the spatial distribution of hydraulic parameters in the stream. Model input included stream bed topography, flow discharge, and bed roughness (figs 4 and 5).

Detailed topographic surveys using a total station were conducted on provide insight into the structural complexity within this stream and were used to create a three-dimensional stream bed model to account for local flow obstructions.

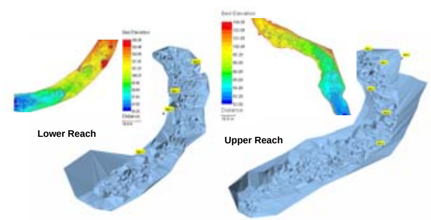

Figure 4. Relative elevation and triangulated surface of study reaches.

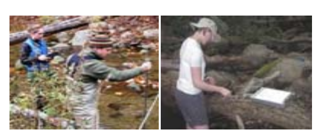

Figure 4. Field work in Shenandoah National Park.

Discharge and distributed velocity measurements were been taken at 2 flows for use in model. Bed roughness and substrate size were quantified using pebble counts.

Evaluating Habitat using WUA

Velocity, depth, and weighted usable area (WUA) were calculated using a single flow (0.5 m^3/s). WUA was calculated from velocity, depth and substrate habitat suitability indices for adult brook trout.[4] Results indicate no relationship between WUA and brook trout location.

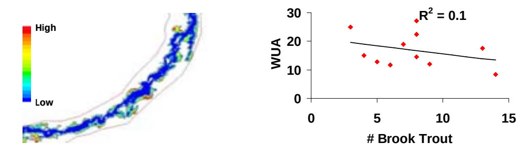

Figure 6. Distribution of WUA within lower reach and comparison of WUA to brook trout distribution at 0.5 m^3/s.

Evaluating Habitat using Hydraulic Complexity Metrics

Modified (area weighted) circulation describes the flow complexity within a defined area. For 0.5 m^3/s there was no relationship between the area weighted modified circulation metric and the density of brook trout (fig 6).

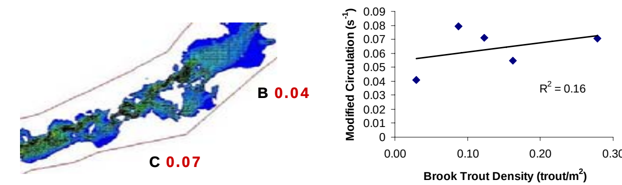

Figure 6. Habitat complexes B and C illustrating flow around obstructions and comparison of the modified circulation metric and the density of brook trout within the lower reach.

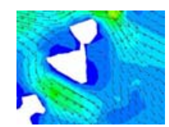

Figure 7. Example from upper reach: KEG = 35.8 m^{-1}.

Kinetic energy gradients (KEG) can be used to evaluate areas of potential biological importance (fig 7). Brook trout have been found in areas with KEG of 4-14 m^{-1}.[2]

Future Work

- Metrics will be evaluated for different flow regimes.
- Individual circulation zones will be identified within each habitat complex.

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