Spatially explicit hydraulic analysis of the effects of whitewater parks on fish passage

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SPATIALLY EXPLICIT HYDRAULIC ANALYSIS OF THE EFFECTS OF WHITEWATER PARKS ON FISH PASSAGE

Tim Stephens, Brian Fox, Nell Kolden, & Brian Bledsoe

Department of Civil and Environmental Engineering

Colorado State University
Outline

- Site Description
- Suppression of Movement
- Current Knowledge Base
- Objectives
- Qualitative Hydraulic Assessment
- Quantitatively Describing the Flow Field
- Results
- Conclusions
Fish Tracking Data

- North St. Vrain River, Lyons, CO
- 14 months of fish tracking data
- 3 WWP structures and 3 natural reaches

(Fox, 2013; Kolden, 2013)
Hydraulic Modeling

Numerical Modeling Results
(Software: FLOW-3D)

- North St. Vrain River, Lyons, CO
- 3 WWP structures and 3 natural reaches
- Modeled 7 discharges
- Model Resolution: approximately 3 inch mesh size
- Post processing using EnSight 10.03

(Fox, 2013; Kolden, 2013)
Outline

- Site Description
- **Suppression of Movement**
- Current Knowledge Base
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Suppression of Movement (Fox, 2013)
Passage Success

- Varies among the three WWP structures

- Varies among size classes of fish at each individual structure

- The fraction of observed movements among the 3 WWP structures varies with discharge
Spatial and Temporal Hydraulic Heterogeneity

WWP 1

30 CFS

150 CFS

WWP 2

30 ft³/s

150 ft³/s

WWP 3

30 ft³/s

150 ft³/s

Velocity (ft/s)

10
7.5
5
2.5
0
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Fish Swimming Abilities

- Fish body length is correlated with swimming ability (Castro-Santos et al., 2012).

- High levels of turbulence pose a stability challenge for fish (Tritico and Cotel, 2010).

- At high current speeds, turbulence can reduce a fish’s swimming ability (Lupadin, 2005; Pavlov et al., 2000).

(Lupandin, 2005)
Quantifying Hydraulics

- 3-D field studies are limited to point measurements that are not spatially continuous.
- Additional field studies are limited by a 2-D analysis and averaging over larger spatial scales.
- Laboratory studies that continuously quantify hydraulics in 3-D are limited in transferability (Lacey et al, 2012).
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- Site Description
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Objectives

- Provide a continuous and spatially explicit description of velocity, vorticity, and TKE along the flow field at a scale meaningful to a fish.

- Compare the magnitude and structure of velocity, vorticity, and TKE among the Lyons WWP structures.

- Determine the influence of velocity, vorticity, TKE, and depth on the suppression of movement of upstream migrating trout.
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Velocity Barrier

All velocities below 10 ft/s

All velocities above 10 ft/s
Hydraulic Interaction

Velocity

Vorticity

TKE
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Defining the Flow Field Dimensions

- Establish a physical criteria for the upstream and downstream boundary
- Must be equally comparable across flows at each structure
- Must be equally comparable across all structures
- Incorporate the full length of potential hydraulic barriers
Continuous and Spatially Explicit Description

Emit “n” particle traces through the flow field

\[ n \approx 10,000 - 20,000 \]
(encompass all features of the flow field)
Encompassing the Entire Flow Field
Encompassing the Entire Flow Field
Hydraulic Descriptors

- Incorporate a directional component of velocity based on the upstream direction
- Cost along a trace
  \[ Cost = \sum v_{rms}^2 \times d \]
- Ratio of water velocity to burst swimming speed
  \[ \frac{v_{water}}{v_{burst}} \]
- Fraction of usable cross-sectional area based on a usable minimum flow depth
- Sum of vorticity along a trace
- Sum of TKE along a trace
Outline

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## Hydraulic Descriptors

### Fish Size Class (mm)

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<th>125</th>
<th>150</th>
<th>175</th>
<th>200</th>
<th>225</th>
<th>250</th>
<th>275</th>
<th>300</th>
<th>325</th>
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<td>0.20284</td>
<td>0.11712</td>
<td>0.071758</td>
<td>0.01794</td>
<td>0.01794</td>
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<td>0.54333</td>
<td>0.046467</td>
<td>0.005163</td>
<td>0.003746</td>
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<tr>
<td>WWP3</td>
<td>0.99987</td>
<td>0.75633</td>
<td>0.34351</td>
<td>0.009666</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>

**Fraction of Traces Where $V_{water}/V_{burst} >= 1$**

- WWP1: 0.88762, 0.20284, 0.11712, 0.071758, 0.01794, 0.01794, 0, 0, 0, 0, 0, 0, 0
- WWP2: 0.84914, 0.11123, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
- WWP3: 1, 0.072575, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

**30 cfs**

- WWP1: 0.98927, 0.89847, 0.099289, 0.033678, 0.030186, 0.004241, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118
- WWP2: 1, 0.75988, 0.61974, 0.15062, 0.002828, 0, 0, 0, 0, 0, 0, 0, 0
- WWP3: 1, 0.90052, 0.50491, 0.003821, 0, 0, 0, 0, 0, 0, 0, 0, 0

**150 cfs**

- WWP1: 0.96295, 0.54333, 0.046467, 0.005163, 0.003746, 0.003746, 0.003746, 0.003746, 0.003746, 0.003746, 0.003746, 0.003746, 0.003746
- WWP2: 1, 0.97627, 0.22859, 0.028296, 0.00184, 0, 0, 0, 0, 0, 0, 0, 0
- WWP3: 0.99987, 0.75633, 0.34351, 0.009666, 0, 0, 0, 0, 0, 0, 0, 0, 0

**300 cfs**

- WWP1: 0.98927, 0.89847, 0.099289, 0.033678, 0.030186, 0.004241, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118
- WWP2: 1, 0.75988, 0.61974, 0.15062, 0.002828, 0, 0, 0, 0, 0, 0, 0, 0
- WWP3: 1, 0.90052, 0.50491, 0.003821, 0, 0, 0, 0, 0, 0, 0, 0, 0

**CDF**

- Cost (ft³/s²)
  - 0 to 500
  - 500 to 1000
  - 1000 to 1500
  - 1500 to 2000
  - 2000 to 2500

**15 cfs**

- WWP1: 0.88762, 0.20284, 0.11712, 0.071758, 0.01794, 0.01794, 0, 0, 0, 0, 0, 0, 0
- WWP2: 0.84914, 0.11123, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
- WWP3: 1, 0.072575, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

**150 cfs**

- WWP1: 0.98927, 0.89847, 0.099289, 0.033678, 0.030186, 0.004241, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118, 0.003118
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- WWP3: 1, 0.90052, 0.50491, 0.003821, 0, 0, 0, 0, 0, 0, 0, 0, 0

**300 cfs**

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- WWP3: 0.99987, 0.75633, 0.34351, 0.009666, 0, 0, 0, 0, 0, 0, 0, 0, 0

**CDF**

- Cost (ft³/s²)
  - 0 to 500
  - 500 to 1000
  - 1000 to 1500
  - 1500 to 2000
  - 2000 to 2500
Hydraulic Descriptors

30 CFS

150 CFS

CDF

Vorticity (s⁻¹)

0 2000 4000 6000 8000 10000

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

TKE (ft²/s²)

WWP 1

WWP 2

WWP 3

CDF

Vorticity (s⁻¹)

0 2000 4000 6000 8000 10000

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

TKE (ft²/s²)

WWP 1

WWP 2

WWP 3
Stepwise Regression

- Fraction of traces where \( \frac{v_{\text{water}}}{v_{\text{burst}}} > 1 \) for 25-BLS and 10-BLS for each individual fish
- 5\(^{\text{th}}\), 16\(^{\text{th}}\), 50\(^{\text{th}}\), 84\(^{\text{th}}\), & 95\(^{\text{th}}\) percentiles of cost
- 50\(^{\text{th}}\) percentile of the sum and Maximum Vorticity along each trace
- 50\(^{\text{th}}\) percentile of the sum and Maximum TKE along each trace
- Fraction of usable cross-sectional area based on minimum depth criteria

Significant

- \( \frac{v_{\text{water}}}{v_{\text{burst}}} > 1 \) for 25-BLS
- \( \frac{v_{\text{water}}}{v_{\text{burst}}} > 1 \) for 10-BLS
- 16\(^{\text{th}}\) percentile of cost
- 50\(^{\text{th}}\) percentile of the sum of vorticity
- 50\(^{\text{th}}\) percentile of the maximum vorticity
- 50\(^{\text{th}}\) percentile of the sum of TKE
- Depth criteria
Logistic Regression

**Inclusion**

- $v_{\text{water}} / v_{\text{burst}} > 1$ for 25-BLS
- Depth criteria
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Conclusions

- A continuous and spatially explicit description of the flow field highlights the difference in the magnitude and distribution of velocity, vorticity, and TKE among the WWP structures and across a range of discharges.

- The variation in the magnitude and distribution of the water velocity relative to the burst swimming ability of a fish is reflective of relative passage success at each structure.

- Logistic regression shows a statistically significant influence of velocity and depth on passage success.

- These results might be transferable to other WWPs and can help inform future projects; however, additional WWPs of various sizes and hydrologic regimes must be investigated.

- These results have implications for native fishes with lesser swimming abilities.
Questions?