Jun 21st, 3:30 PM - 3:50 PM

An Investigation of the Hydraulics in a Prototype Pool-and-Chute, Vortex Weir Fishway for Anadromous Fish Passage

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_Michael Love & Associates_

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Foster, Brendan; Lang, Margaret PhD, PE; Cashman, Eileen; and Love, Michael PE, 'An Investigation of the Hydraulics in a Prototype Pool-and-Chute, Vortex Weir Fishway for Anadromous Fish Passage' (2017). International Conference on Engineering and Ecohydrology for Fish Passage. 19.  
https://scholarworks.umass.edu/fishpassage_conference/2017/June21/19
An Investigation of the Hydraulics in a Prototype Pool-and-Chute, Vortex Weir Fishway for Anadromous Fish Passage.

Brendan Foster; Margaret Lang, PhD, PE; Eileen Cashman, PhD; Michael Love, PE
Outline

Introduction
Research Objectives
Velocity and Turbulence Characteristics
Preliminary Passage Model
Summary
Questions
Standard Pool-and-Chute & Vortex Weir Fishways

Photo: Michael Love & Associates

Photo: M. Lang
Installation Types

Fully Spanning
Photo: Brendan Foster

Partially Spanning
Photo: Michael Love & Associates

Bypass
Photo: [http://www.fao.org/docrep/004/Y2785E/y2785e03.htm](http://www.fao.org/docrep/004/Y2785E/y2785e03.htm)
Research Objectives

1. Measure the hydraulic conditions throughout the proposed fishway at three flows spanning the fish passage flow range
   - velocity magnitudes and directions
   - turbulent kinetic energy (TKE)

2. Identify the potential migration pathways for Steelhead and Coho Salmon

3. Determine percent fatigue (F%) and ascension times for adult Steelhead and Coho salmon passage through the prototype fishway

4. Estimate a theoretical maximum length for the prototype fishway
New Hybrid Design

Model: Length = 9.6 ft, Width = 2 ft

Prototype: Length = 144 ft, Width = 30 ft
Experimental Conditions

Three fish passage design flows

<table>
<thead>
<tr>
<th>Flow Name</th>
<th>Model Flow Rate (cfs)</th>
<th>Prototype Flow Rate (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Flow</td>
<td>0.21</td>
<td>181</td>
</tr>
<tr>
<td>Medium Flow</td>
<td>0.17</td>
<td>144</td>
</tr>
<tr>
<td>Low Flow</td>
<td>0.12</td>
<td>107</td>
</tr>
</tbody>
</table>

8% Slope

1:15 scale model of proposed fishway
Flow Regimes

Streaming Flow

Transitional Flow

Plunging Flow

Recreated from Ead et al. (2004)
ADV Data Collection

Plan View

Side View

Flow

Orifice

Orifice

Orifice

Orifice

h / 2

h

Top

Middle

Bottom

Top

Middle

Bottom

14

14

14

1

1

1

1
Velocities – High Flow (181 cfs)

- **Surface**
  - Streaming flow width = ~8 ft

- **Middle**
  - Transitional and plunging flow width = ~22 ft

- **Bottom**
  - Streaming flow width = ~8 ft
TKE – High Flow (181 cfs)
Velocities – Medium Flow (144 cfs)

<table>
<thead>
<tr>
<th>Length (ft)</th>
<th>Width (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
</tr>
</tbody>
</table>

- **Surface**
  - 0 15 30
- **Middle**
  - 0 15 30
- **Bottom**
  - 0 15 30
TKE – Medium Flow (144 cfs)
Velocities – Low Flow (107 cfs)

Surface

Middle

Bottom

Transitional

Plunging

Wetted Edge
TKE – Low Flow (107 cfs)
Preliminary Passage Model

1. Estimate passage efficiency as percent fatigue (F%) and ascension time
   - Two species: steelhead and coho salmon
   - Two swim pathways: straight and long
   - Two flow rates: medium and high

2. Estimate theoretical maximum length for the prototype fishway
Model Assumptions

1. Fish swim continuously
2. Fish use burst swim mode to go over weirs, prolonged swim mode while swimming in pools
3. Sufficient depth exists throughout pools and over significant portions of the weirs under the three flow rates considered
4. Fish enter the fishway with 0% fatigue
5. Fish are highly motivated - no behavioral delays are considered
6. Fish lengths and water velocities are normally distributed
7. Weir velocities are calculated as the average velocity over the plunging flow cross section
8. Pool water velocities are the depth-averaged middle and surface velocities scaled up to prototype values
Two Pathways Chosen to get a Range of F% Values and Ascension Times

- **Straight Path**
- **Long Path**

Burst speed over weirs
Prolonged speed in pools
Model Calculations

Percent Fatigue (F%) calculated as (Castro-Santos, 2006):

\[
F\% = 100 \times \sum \frac{t_{UsTotal}}{T_{UsTotal}} = \frac{\text{time swum}}{\text{time to fatigue}}
\]

\[
F\% = 100 \times \sum \left( \frac{t_{UsProlonged}}{T_{UsProlonged}} + \frac{t_{UsBurst}}{T_{UsBurst}} \right)
\]
Model Calculations

The fish swim speed ($U_s$) was calculated as (Castro-Santos, 2005):

$$U_s = U_g - U_w$$
Summary of Calculations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{U_s}^{Prolonged}$</td>
<td>$U_{G-opt}$ calculated using equations asserted by Castro-Santos (2005) and data from Paulik &amp; Delacy (1957) by Love &amp; James (2016)</td>
</tr>
<tr>
<td>$t_{U_s}^{Burst}$</td>
<td>Weaver (1963)</td>
</tr>
<tr>
<td>$T_{U_s}^{Burst}$</td>
<td>Hunter and Mayor (1998)</td>
</tr>
<tr>
<td>$T_{U_s}^{Prolonged}$</td>
<td>Love &amp; James (2016), data from Paulik &amp; Delacy (1957)</td>
</tr>
</tbody>
</table>
Calculation of $T_{Us}^{Total}$

$T_{Us}^{Burst}$

Steelhead Burst Swim Speed Equation from Hunter and Mayor (1998):

$$V_s = 12.3L^{0.62} T_{Us}^{Burst^{0.51}}$$

Coho Burst Swim Speed Equation from Hunter and Mayor (1998):

$$V_s = 13.3L^{0.52} T_{Us}^{Burst^{0.65}}$$

Swim speed versus fatigue time for steelhead trout swimming at prolonged speeds, developed from data presented in Paulik and Delacy (1958) (Love & James, 2016).
F% for 1000 Steelhead under the Medium Flow Rate, along the Short and Long Path

Short Path

Long Path

~8%
Summary of mean $F\%$ for all As-Designed Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Steelhead</th>
<th>Coho</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med Short</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Med Long</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>High Short</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>High Long</td>
<td>55</td>
<td>55</td>
</tr>
</tbody>
</table>

Legend:
- Steelhead
- Coho
Summary of Findings

Velocities and TKE

Does not appear to be energetically limiting

Prototype fishway could extend 37.5 ft without a single fish reaching 100 F%

Future model improvements
  - Use observed swim speeds within full-scale pool-and-chute fishways
  - Incorporate behavioral delays entering and within fishways
  - Quantify error from scale effects
## Acknowledgements

<table>
<thead>
<tr>
<th>Committee</th>
<th>Michael Love &amp; Associates</th>
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<tbody>
<tr>
<td>Dr. Margaret Lang, HSU Engineering</td>
<td>Michael Love, PE</td>
</tr>
<tr>
<td>Dr. Eileen Cashman, HSU Engineering</td>
<td>Travis James, PE</td>
</tr>
<tr>
<td>Dr. Mark Henderson, HSU Fisheries</td>
<td></td>
</tr>
</tbody>
</table>

| HSU College of Natural Resources Technicians   | HSU Environmental Resources        |
|                                               | Engineering Undergraduates         |
| Marty Reed                                     | Mathew Nyberg                      |
| Colin Wingfield                                | Brian Draeger                      |
|                                               | Brian Weekly                       |
|                                               | Neftali Eunice Romero              |


Questions?

"That guy thinks like a fish."
Possible Occurrence

Photo: Brendan Foster
Model Calculations

The fish swim speed \((U_s)\) was calculated as (Castro-Santos, 2005):

\[
U_s = U_g - U_w
\]

\(U_w\) - water velocity

- Prolonged (in pools): depth averaged over the surface and middle depths, sampled for each nodal distance using Monte Carlo simulations
- Burst (over weirs): calculated using a dimensionless discharge approach following equations from Bates & Love (2010), which were reproduced from Ead et al. (2004)

\(U_g\) - ground speed

- Prolonged (in pools): Assumed values from Love & James (2016), calculated using equations asserted by Castro-Santos (2005) and data from Paulik and Delacy (1958)
- Burst (over weirs): Assumed values from (Weaver, 1963)
Calculation of $t_{U_sProlonged}$

$t_{U_sProlonged}$: Nodal distances in pools (ft) / Pool swim speed (BL(ft)/s)

$= (4 \text{ or } 5.9 \text{ ft}) / (\text{sampled } U_w + \text{distance-optimizing ground swim speed } (U_{G-opt}))$


Steelhead: $U_{G-opt} = \frac{1}{0.487} = 2.05$ BL/s

Coho Salmon: $U_{G-opt} = \frac{1}{0.595} = 1.68$ BL/s
Calculation of \( t_{Us,Burst} \)

\( t_{Us,Burst} \): Weir thickness (ft) / weir swim speed (BL(ft)/s)

\[
= (0.67 \text{ ft}) / (U_w \text{ over weir (calculated)} + U_g \text{ for Burst speed})
\]

- \( U_g \) for Burst speed assumed to be 2.5 BL/s for steelhead and 3.1 BL/s for coho (Weaver, 1963)