Jun 25th, 4:30 PM - 4:50 PM

Concurrent Sessions C: Multi-Dimensional Modeling and Fish Passage Restoration - Some Aspects of Fish Behaviour and Hydraulics Which May Affect Passage Effectiveness

Christos Katopodis
Katopodis Ecohydraulic s Ltd.

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Some aspects of fish behaviour and hydraulics which may affect passage effectiveness

Christos Katopodis, Katopodis Ecohydraulics Ltd.
KatopodisEcohydraulics@shaw.ca
Winnipeg, MB, CANADA

International Conference on Engineering & Ecohydrology for Fish Passage
Oregon State University, Corvallis, June 25-27, 2013
Fish passage developments

- Trial and error & empiricism characterized early efforts to develop fish passage systems.

- Often there still is a mindset that fishways are too expensive or some species do not use them and fish passage systems should not be considered.

- To keep costs low, fishways of steepest possible slopes, shortest lengths, smallest dimensions and simplest designs were usually built, often targeting single “valuable” species and compromising passage effectiveness.
Fish passage effectiveness

- Often a passage system type is ineffective, because its hydraulic characteristics are a poor match for the needs and behaviour of each fish species.

- Often fish passage systems are introduced well after barriers are built and only after fish populations have declined appreciably, challenging recovery efforts and effectiveness.

- Flow is a key factor in attracting and guiding fish, yet frequently fish passage has low priority or is essentially neglected in flow management decisions.
Fish move laterally or sideways if channels are connected.

Ecology, Hydrology, Biology, Morphodynamics & Hydraulics are all important for fish movements & habitat use, yet frequently not all ecohydraulic aspects are considered.

Fish move upstream - downstream, or longitudinally.

www.river2d.ualberta.ca
Katopodis spearheaded model development.

Fish may use ground water connections.
Fish passage effectiveness

Characteristics of highly effective *upstream* or *downstream* fish passage systems:

1. Use is compelled by the **migratory needs** of specific species and availability of suitable habitat *upstream* or *downstream* of a barrier

2. Are **easy to locate** by the migratory fish community as they offer topographical and flow conditions that species *seek rather than avoid*

3. Combine morphological features and hydrodynamic conditions which match fish biomechanical capabilities and are suitable for **efficient transport**
Fish passage effectiveness

These factors relate to:

1. **Species motivation** *(required versus tentative movements)* and availability of suitable habitat

2. **Attraction efficiency** *(probability that fish will locate the upstream fishway entrance or be actively guided downstream)*; *depends more on biological factors*

3. **Passage efficiency** *(probability fish will move through passage system)*; *depends more on passage system design features*

**NOTE:** *Any one of these factors* or any combination of the three may limit overall system passage effectiveness.
Hell’s Gate, BC, Canada: Challenges for fish to locate fishway entrances

Attraction efficiency: 73-78%

Arrows indicate multiple fishway entrances for upstream migrants

Flow
Attraction efficiency

Mactaquac fish lift, St. John River, NB Power, Canada:

Challenges for fish to locate collection gallery and fish lift entrance
Fairford Fishway, Manitoba

Fishway entrance

Attraction water flume

Fairford Dam Plain Denil Fishway, Fish Passage in 1987

<table>
<thead>
<tr>
<th>Fish Type</th>
<th>Number Passing (Spring 1987)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Sucker</td>
<td>5032</td>
</tr>
<tr>
<td>Walleye</td>
<td>2313</td>
</tr>
<tr>
<td>Sauger</td>
<td>907</td>
</tr>
<tr>
<td>Cisco</td>
<td>352</td>
</tr>
<tr>
<td>Shorthead Redhorse</td>
<td>175</td>
</tr>
<tr>
<td>Common Carp</td>
<td>79</td>
</tr>
<tr>
<td>Other</td>
<td>13</td>
</tr>
</tbody>
</table>

Katopodis, Derksen, and Christensen 1991

Lac Portneuf, Quebec
Attraction water

Captures des omble de fontaine et des meuniers noirs dans la cage de montaison

Brook trout (navy blue)
White sucker

Captures quotidienne d'ombles de fontaine et de meuniers noirs dans la cage de montaison

Sur le lac Portneuf, M. et. Simard 2005

Kapopodis

Ecohydraulics Ltd.
Passage efficiency
Nature-like fishways

Lower Churchill River Weir (2300 m wide)

Goose Creek Culvert Fishway

Beaver River, Thornbury, Ontario, Canada

Culvert installed in 1979, Liard Highway, N.W.T., Canada

River Flow

Near the Arctic coast of Manitoba, Canada
Bar racks or Trashracks

Katopodis, Lemke and Ghamry 2011
Tsikata, Katopodis and Tachie 2009

Fish screens
Helical or Alden turbine (DOE-EPRI 2011)

Archimedes screw & Kaplan turbine (DWA 2005)

High fish survival turbines

Modified Kaplan turbine Columbia River dams
<table>
<thead>
<tr>
<th>Fishway (u/s)</th>
<th>Species</th>
<th>Attraction efficiency</th>
<th>Passage efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand River, Ontario, Denils of 10% &amp; 20% slope, (Bunt, Katopodis &amp; McKinley, 1999)</td>
<td>White sucker</td>
<td>50% and 59%</td>
<td>55% and 38%</td>
</tr>
<tr>
<td></td>
<td>Smallmouth bass</td>
<td>82% and 55%</td>
<td>36% and 33%</td>
</tr>
<tr>
<td>Big Carp River, Ontario, Vertical slot trap &amp; sort, (Pratt et al. (Katopodis) 2009)</td>
<td>White sucker</td>
<td>97-98%</td>
<td>36-88%</td>
</tr>
<tr>
<td></td>
<td>Rock bass</td>
<td>26-33%</td>
<td>0-14%</td>
</tr>
<tr>
<td>Cobourg Brook, Ontario Vertical slot trap &amp; sort, (Pratt et al. (Katopodis) 2009)</td>
<td>White sucker</td>
<td>82-85%</td>
<td>6-9%</td>
</tr>
<tr>
<td></td>
<td>Rainbow trout</td>
<td>12-58%</td>
<td>12-25%</td>
</tr>
<tr>
<td>Pool-and-orifice, Scotland, (Gowans et al. 1999)</td>
<td>Atlantic salmon</td>
<td>-</td>
<td>100%</td>
</tr>
<tr>
<td>Pool-and-overfall, Scotland, (Gowans et al. 2003)</td>
<td>Atlantic salmon</td>
<td>-</td>
<td>72%</td>
</tr>
<tr>
<td>Vertical slot, Australia, (Stuart et al. 2008)</td>
<td>Common carp</td>
<td>-</td>
<td>81%</td>
</tr>
<tr>
<td>Vertical slot, Australia, (White et al. 2011)</td>
<td>Bony herring</td>
<td>-</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>Silver perch</td>
<td>-</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Golden perch</td>
<td>-</td>
<td>11%</td>
</tr>
<tr>
<td>Hell’s Gate, Fraser River, B.C., Original vertical slots, (Hinch and Bratty 2000)</td>
<td>Sockeye salmon</td>
<td>73-78%</td>
<td>100%</td>
</tr>
<tr>
<td>Columbia River pool and weir fishways over 6 consecutive dams (Muir &amp; Williams 2012)</td>
<td>Chinook salmon</td>
<td>Average through 6 dams Per-project survival</td>
<td>84% 97%</td>
</tr>
</tbody>
</table>
Dunvegan Hydro Project

One of 10 Bypasses for downstream migrants; Bypasses also serve as spillways.

Guide wall and submerged conduits for directing attraction flows provided after water used for power production.

Fishway for upstream migrants generating nature-like flow features; one on each river bank.

50% Exceedence Discharge
CFD models are capable of simulating fishway hydraulics quite well as long as they are verified with laboratory or field data.

**FLUENT**

3-D Reynolds-averaged Navier-Stokes equations (RANS); $k - \varepsilon$ turbulence model; models *free surface* (air-water interface) with volume of fluid method.
Turbulence – shear stress and eddy size

Iberian barbel
*Luciobarbus bocagei*

- E1, E2, E3 - offset orifices (preferred)
- E4, E5 - straight orifices
- E6, E7 - straight orifices with a bar

Bar helped smaller fish but not larger fish

*Silva, Katopodis, Santos, Ferreira, and Pinheiro 2012*
Barbel behaviour observed: eddy size/fish length ($L_e/TL$)

e) $Le/TL_{lf} \approx 1$ (£)

Straight orifices with a bar

- large fish lost body stability and were seen to spread their pectoral fins in an attempt to stabilize body position

- most large fish were dragged to d/s pool

Silva, Katopodis, Santos, Ferreira, and Pinheiro (2012)
Proportions of upstream movements for each species by opening type and flow regime. BP – Barbel in plunging flow regime; BS – Barbel in streaming flow regime; CP – Chub in plunging flow regime; CS – Chub in streaming flow regime.

Branco, Santos, Katopodis, Pinheiro and Ferreira (2013)
Vianney-Legendre vertical slot fishway, Quebec

Lake sturgeon (n=88) 
*(Acipenser fulvescens)*

White sucker

Silver red horse

Atlantic salmon

Walleye

Entrance pool

First turning basin

Second turning basin

Thiem et al. (Katopodis) 2011; 2013
### Fish passage efficiencies

<table>
<thead>
<tr>
<th>Fishway (u/s)</th>
<th>Species</th>
<th>Passage efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vianney-Legendre Vertical slot, Richelieu River, Quebec. (Thiem et al. (Katopodis) 2011 and 2013)</td>
<td>Acipenseridae Lake sturgeon (<em>Acipenser fulvescens</em>)</td>
<td>36.4%</td>
</tr>
<tr>
<td></td>
<td>Catostomidae Longnose sucker (<em>Catostomus catostomus</em>)</td>
<td>48.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>White sucker (<em>Catostomus commersoni</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silver red horse (<em>Moxostoma anisurum</em>)</td>
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<tr>
<td></td>
<td></td>
<td>River red horse (<em>Moxostoma carinatum</em>)</td>
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<tr>
<td></td>
<td></td>
<td>Shorthead red horse (<em>Moxostoma macrolepidotum</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Greater red horse (<em>Moxostoma valenciennes</em>)</td>
</tr>
<tr>
<td></td>
<td>Cyprinidae Common carp (<em>Cyprinus carpio</em>)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Centrarchidae Smallmouth bass (<em>Micropterus dolomieu</em>)</td>
<td>63.6%</td>
</tr>
<tr>
<td></td>
<td>Ictaluridae Channel catfish (<em>Ictalurus punctatus</em>)</td>
<td>52.8%</td>
</tr>
<tr>
<td></td>
<td>Percidae</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Sauger (<em>Sander Canadensis</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Walleye (<em>Sander vitreus</em>)</td>
</tr>
<tr>
<td></td>
<td>Salmonidae Atlantic salmon (<em>Salmo salar</em>)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Sciaenidae Freshwater drum (<em>Aplodinotus grunniens</em>)</td>
<td>66.7%</td>
</tr>
</tbody>
</table>

**NOTE:** Lake sturgeon were placed in the fishway; some spawn *d/s* & may not need to move *u/s*; this may have affected passage efficiency.
Turning pools - Vianney-Legendre fishway

Existing turning pool - Large eddies may confuse sturgeon more than other fish

Added baffle wall - Reduces large eddies

Velocity magnitudes and directions at a plane 0.5 the turning pool depth.
ANSYS CFX; 3-D Reynolds averaged Navier-Stokes equations (RANS); models free surface (air-water interface) with volume of fluid method; \( k - \varepsilon \) turbulence model

Marriner et al. (Katopodis) 2013 (submitted)
Conclusions

- Management decisions, as well as biological and physical factors affect fish passage effectiveness; several of these factors lack careful study for many species.

- Fish attraction and guidance aspects are the most challenging, highly site- & species-specific, and may dominate overall effectiveness.

- Adapting passage systems to species-specific biological needs and behaviour, as well as providing suitable hydraulic conditions remain the most critical aspects for effectiveness.
Classical Hellenic thinking:

«Γηράσκω αεί διδασκόμενος»

“I grow older ever in a state of learning”

Do your best to “think like a fish”… but remember that fish have the last word!

Thank you! Questions?