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

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

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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.

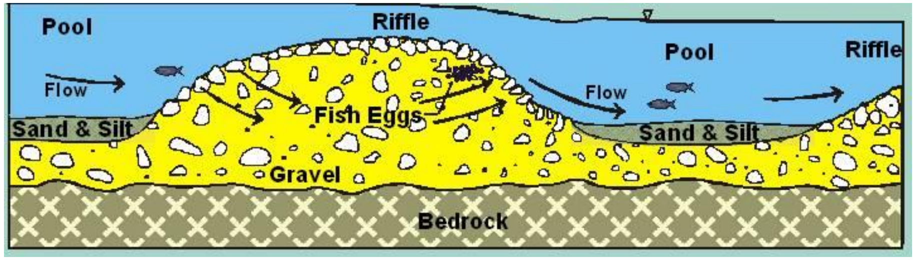
Ecology , Hydrology, Biology, Morphodynamics & Hydraulics ***are all important for fish movements & habitat use, yet frequently not all ecohydraulic aspects are considered.***

Fish move upstream - downstream, or longitudinally

www.river2d.ualberta.ca

Katopodis spearheaded model development

Fish move laterally or sideways if channels are connected



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.

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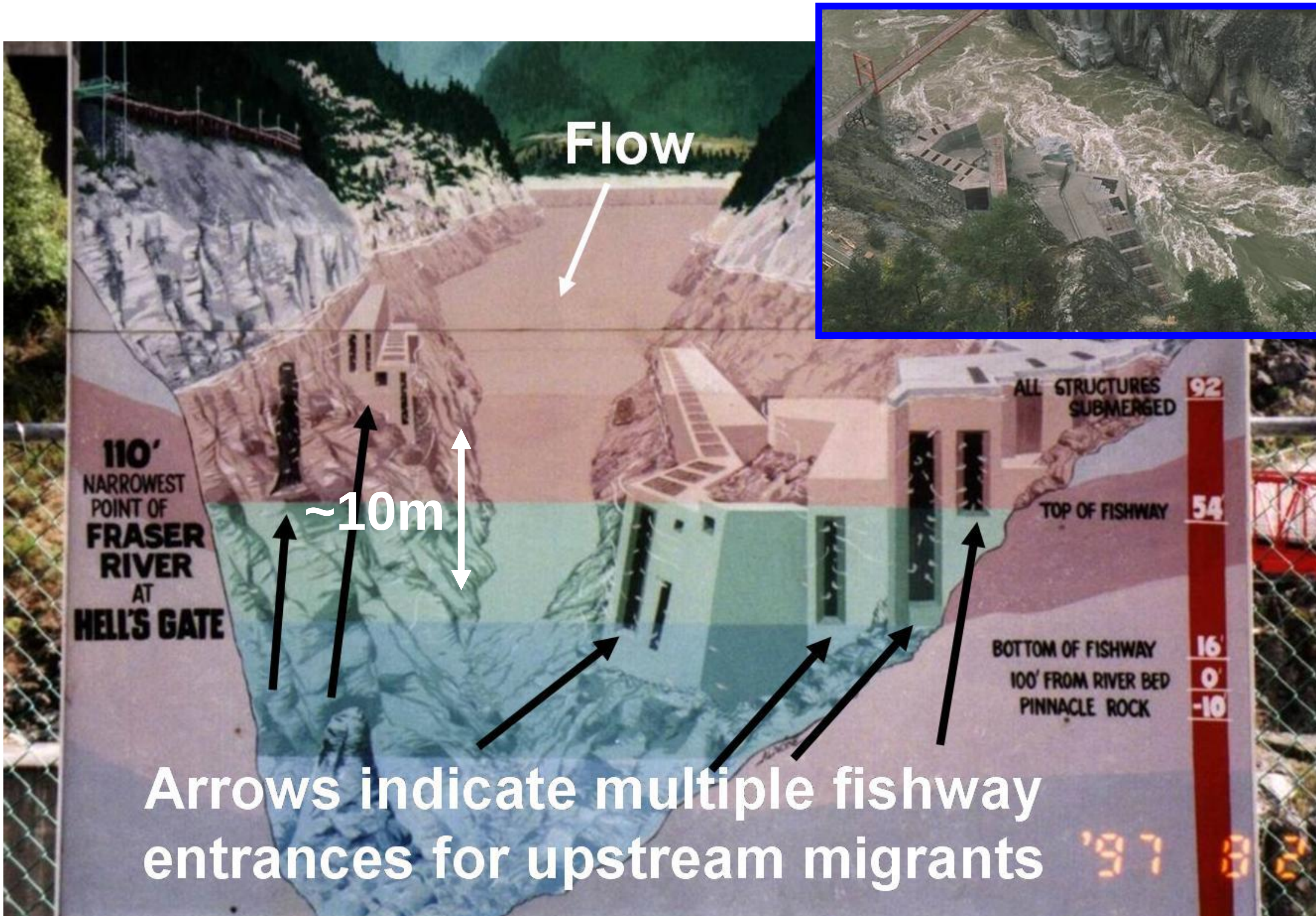
Hell's Gate, BC, Canada: Challenges for fish to locate fishway entrances

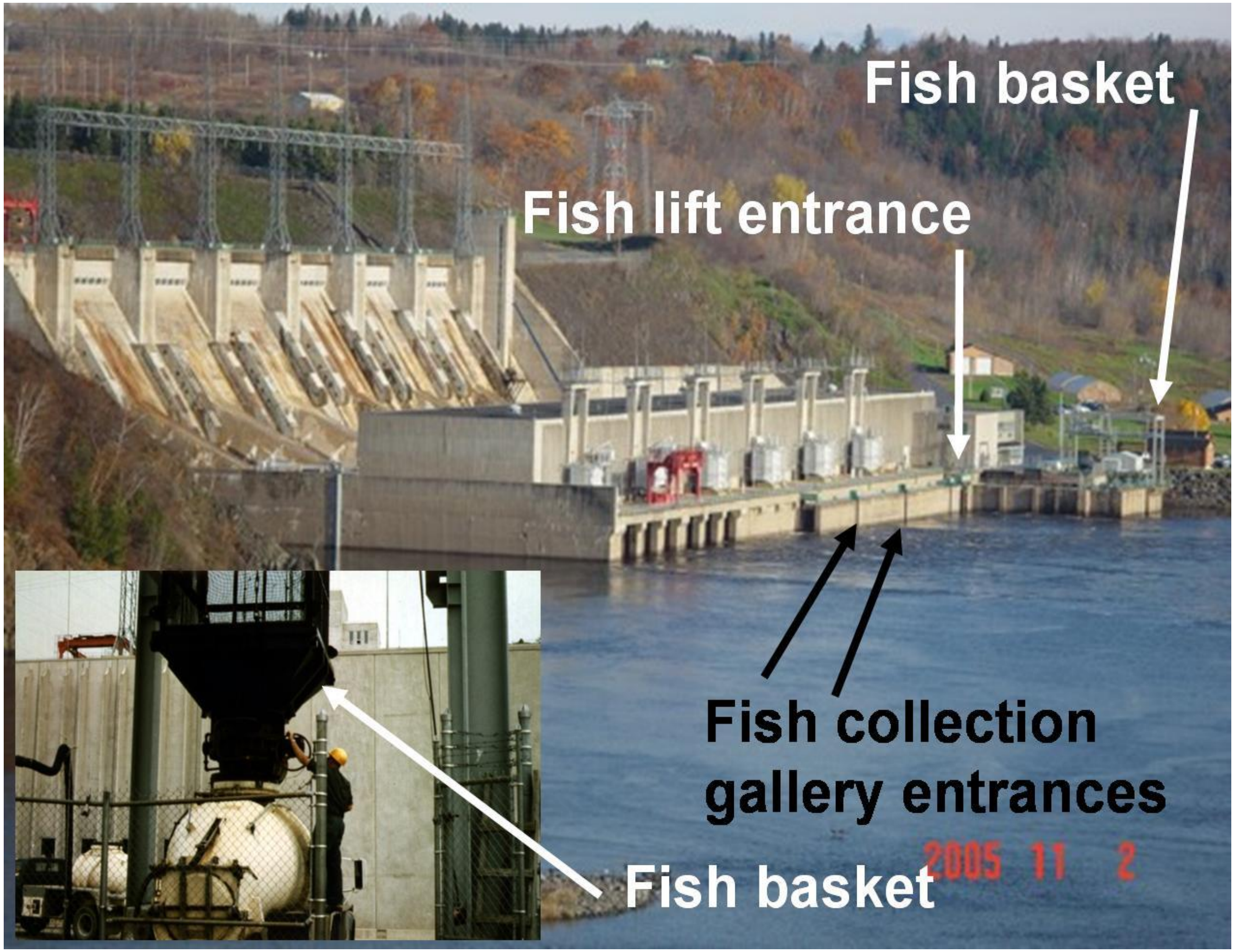
Attraction efficiency
73-78%



Attraction efficiency

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

Challenges for fish to locate collection gallery and fish lift entrance



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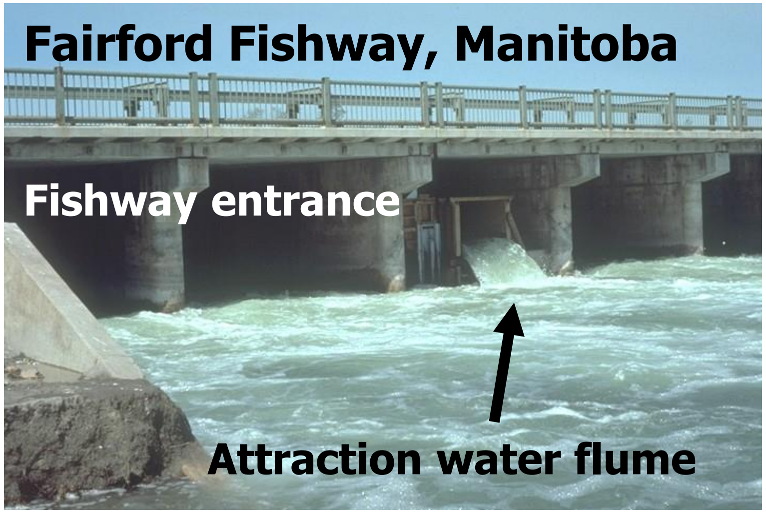
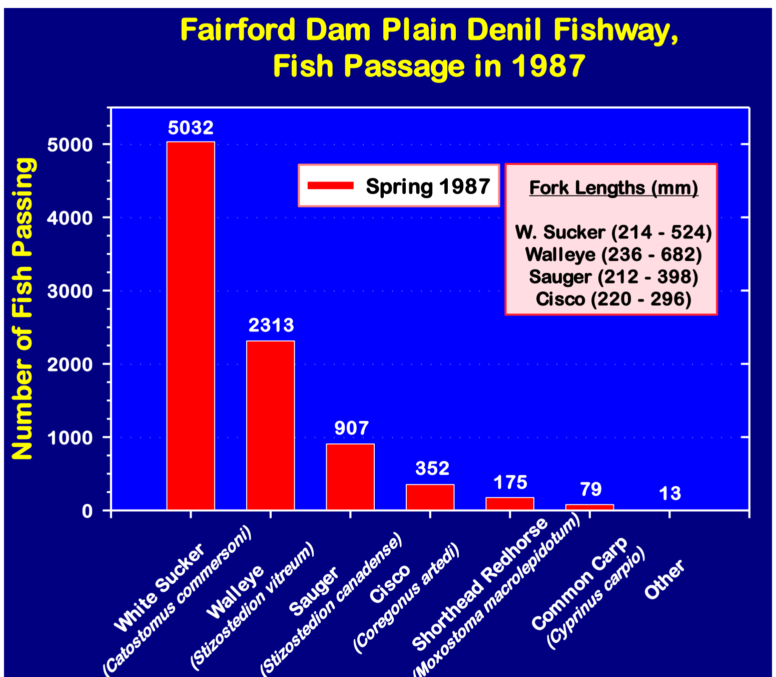
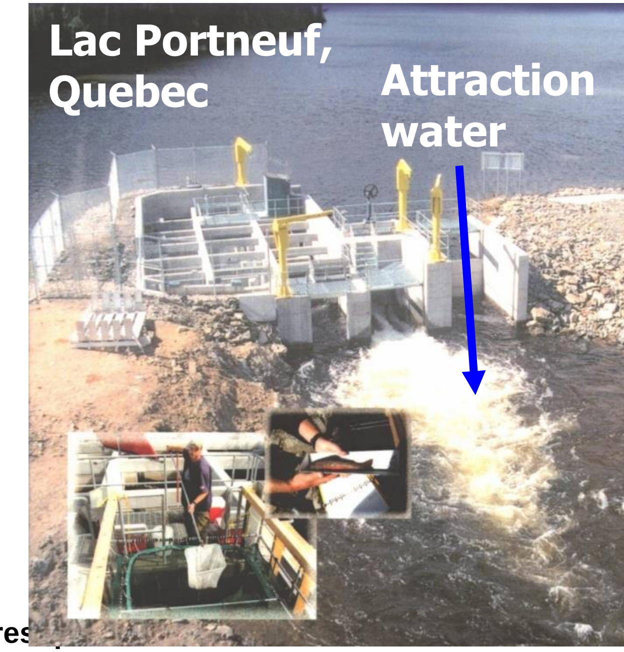
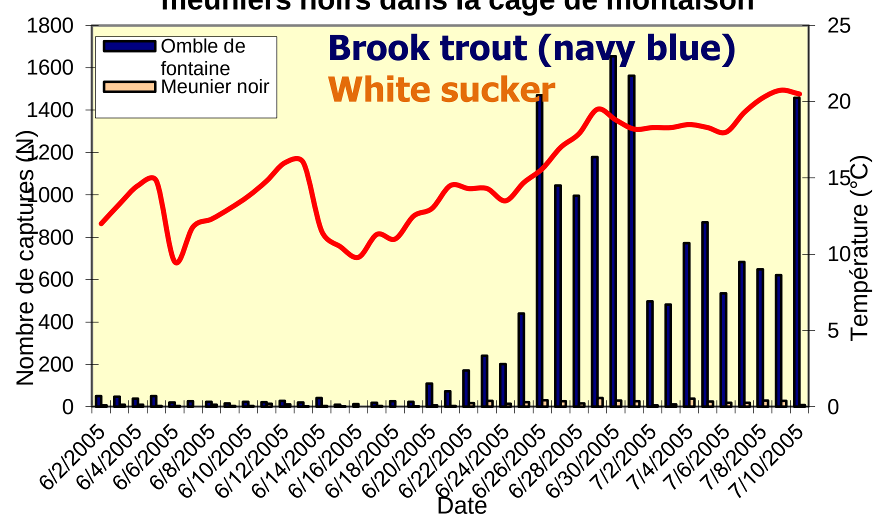
Katopodis, Derksen and Christensen 1991





Belles-Isles, M. et I. Simard 2005





Passage efficiency

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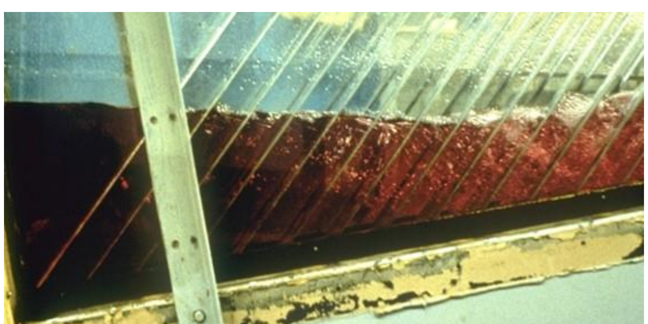

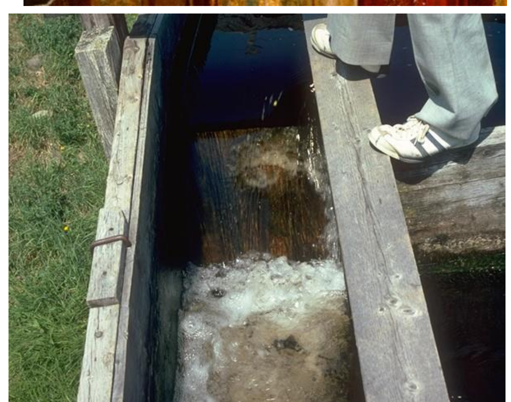

Culvert installed in 1979,
Liard Highway, N.W.T., Canada

Photo: 10 Sept. 2008

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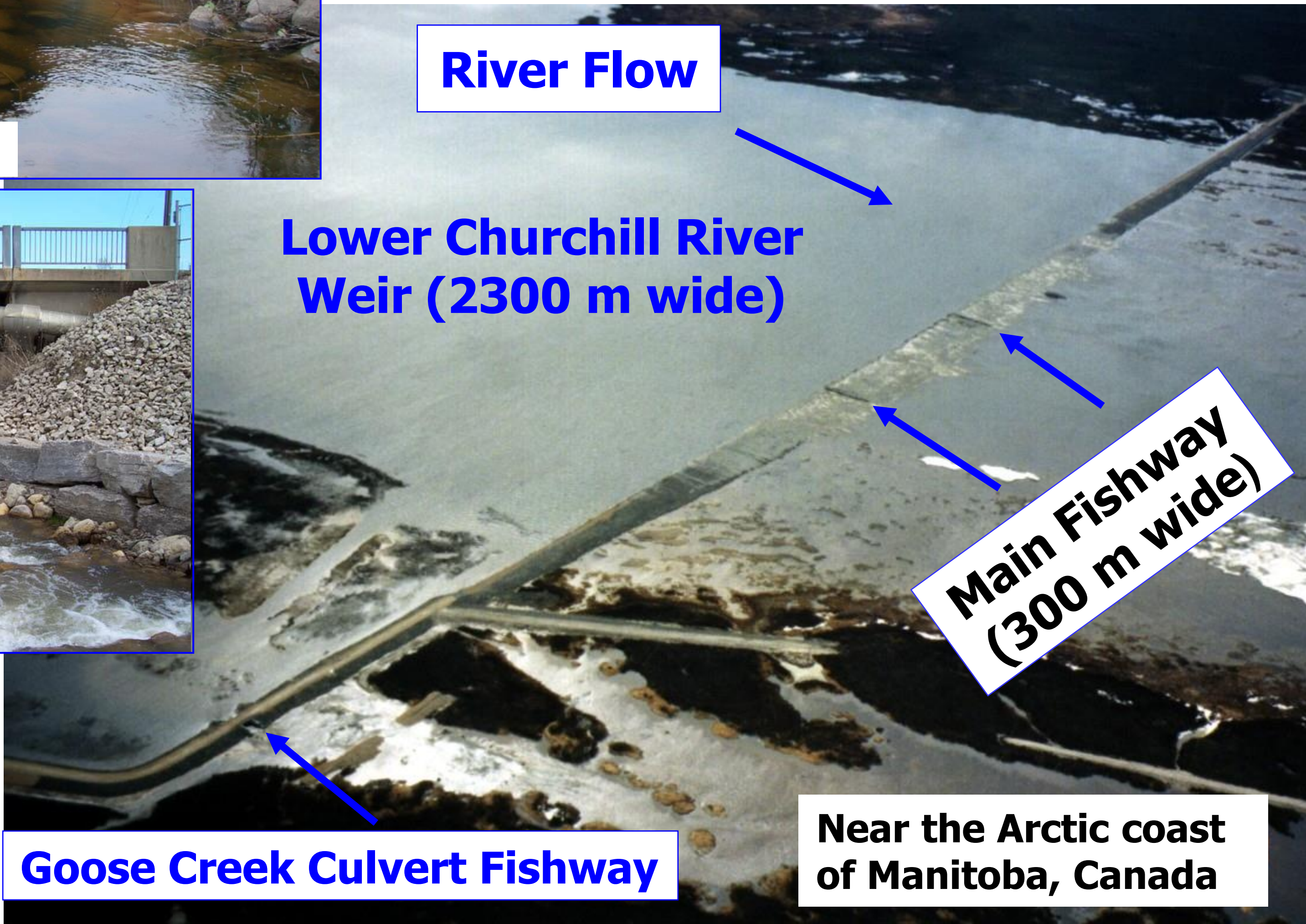
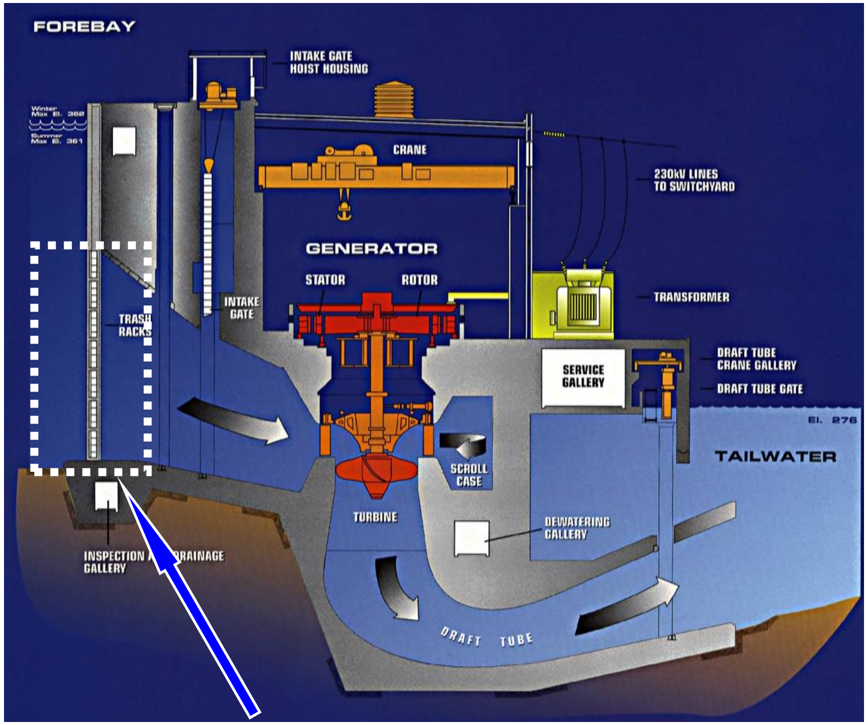
Nature-like fishways

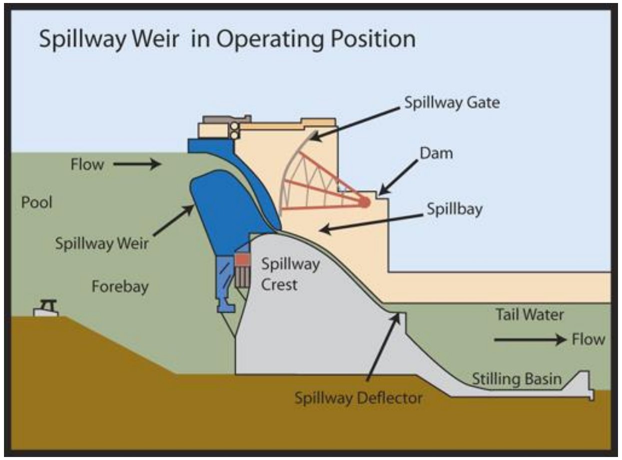
Beaver River, Thornbury, Ontario, Canada

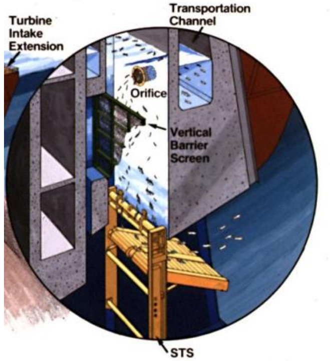


Near the Arctic coast of Manitoba, Canada



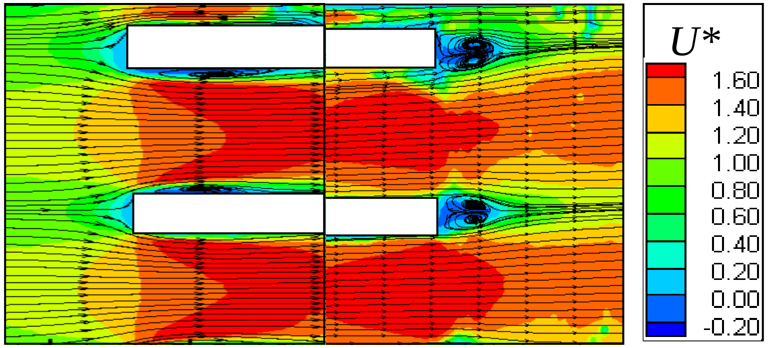
Bar racks or Trashracks

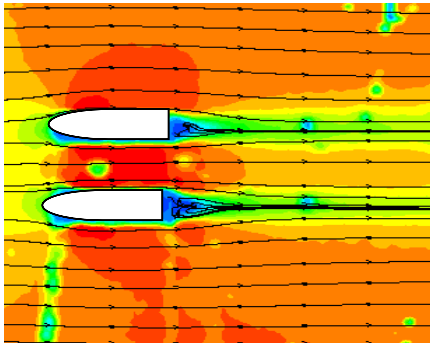




Fish screens

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





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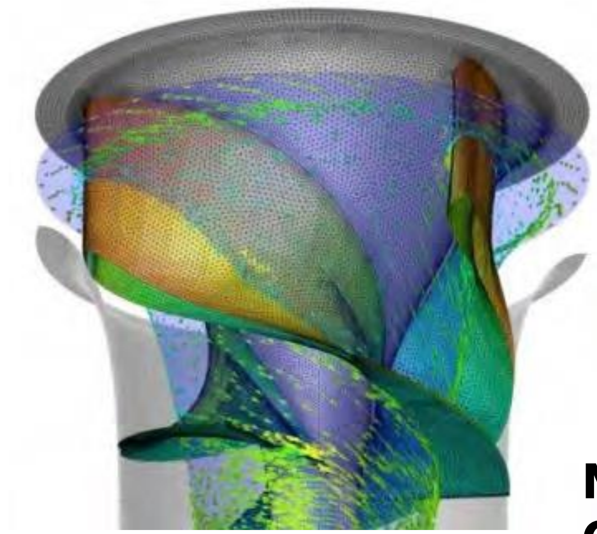
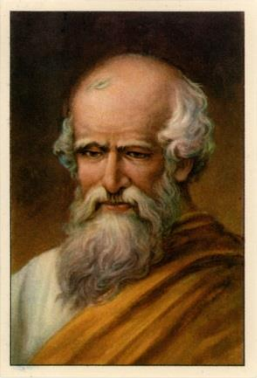
High fish survival turbines

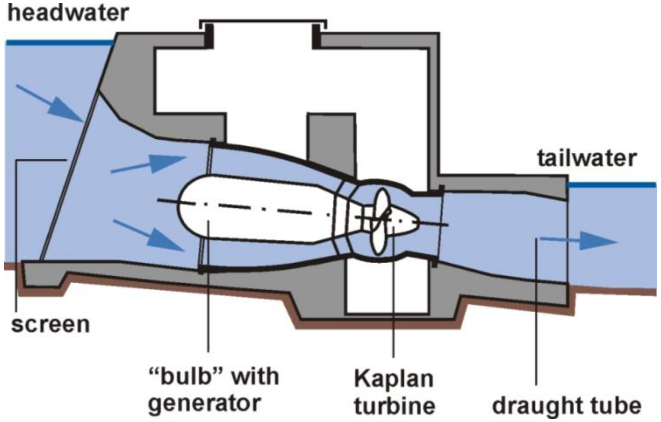


Helical or Alden turbine (DOE-EPRI 2011)

Modified Kaplan turbine
Columbia River dams

Archimedes screw & Kaplan turbine (DWA 2005)





Attraction & fish passage efficiencies

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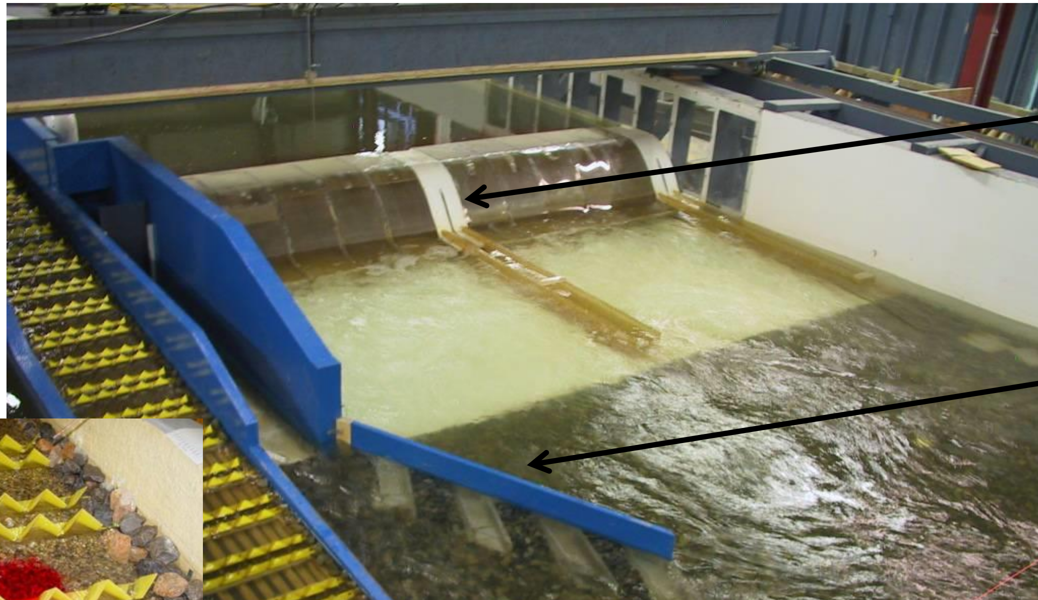
Fishway (u/s)	Species	Attraction efficiency	Passage efficiency
Grand River, Ontario, Denils of 10% & 20% slope, (Bunt, Katopodis & McKinley, 1999)	White sucker	50% and 59%	55% and 38%
	Smallmouth bass	82% and 55%	36% and 33%
Big Carp River, Ontario, Vertical slot trap & sort, (Pratt et al. (Katopodis) 2009)	White sucker	97-98%	36-88%
	Rock bass	26-33%	0-14%
Cobourg Brook, Ontario Vertical slot trap & sort, (Pratt et al. (Katopodis) 2009)	White sucker	82-85%	6-9%
	Rainbow trout	12-58%	12-25%
Pool-and-orifice, Scotland, (Gowans et al. 1999)	Atlantic salmon	-	100%
Pool-and-overfall, Scotland, (Gowans et al. 2003)	Atlantic salmon	-	72%
Nature-like fishways, Europe, (Aarestrup et al. 2003; Calles and Greenberg 2005)	Salmonids	-	39-52%
Vertical slot, Australia, (Stuart et al. 2008)	Common carp	-	81%
Vertical slot, Australia, (White et al. 2011)	Bony herring	-	26%
	Silver perch	-	15%
	Golden perch	-	11%
Hell's Gate, Fraser River, B.C., Original vertical slots, (Hinch and Bratty 2000)	Sockeye salmon	73-78%	100%
Columbia River pool and weir fishways over 6 consecutive dams (Muir & Williams 2012)	Chinook salmon Average through 6 dams Per-project survival		 84% 97%

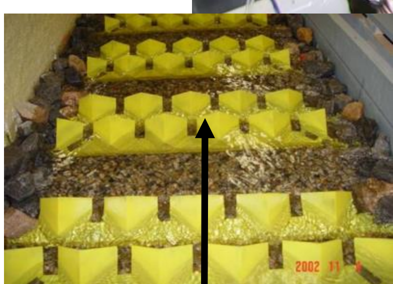
Dunvegan Hydro Project



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

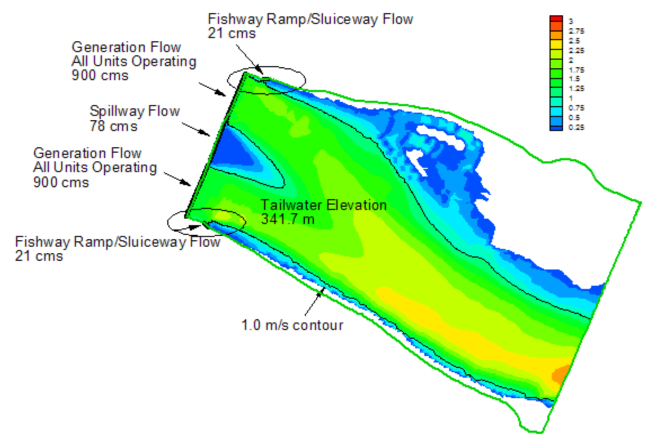
Guide wall and submerged conduits for directing attraction flows provided after water used for power production.

Flow



Flow

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

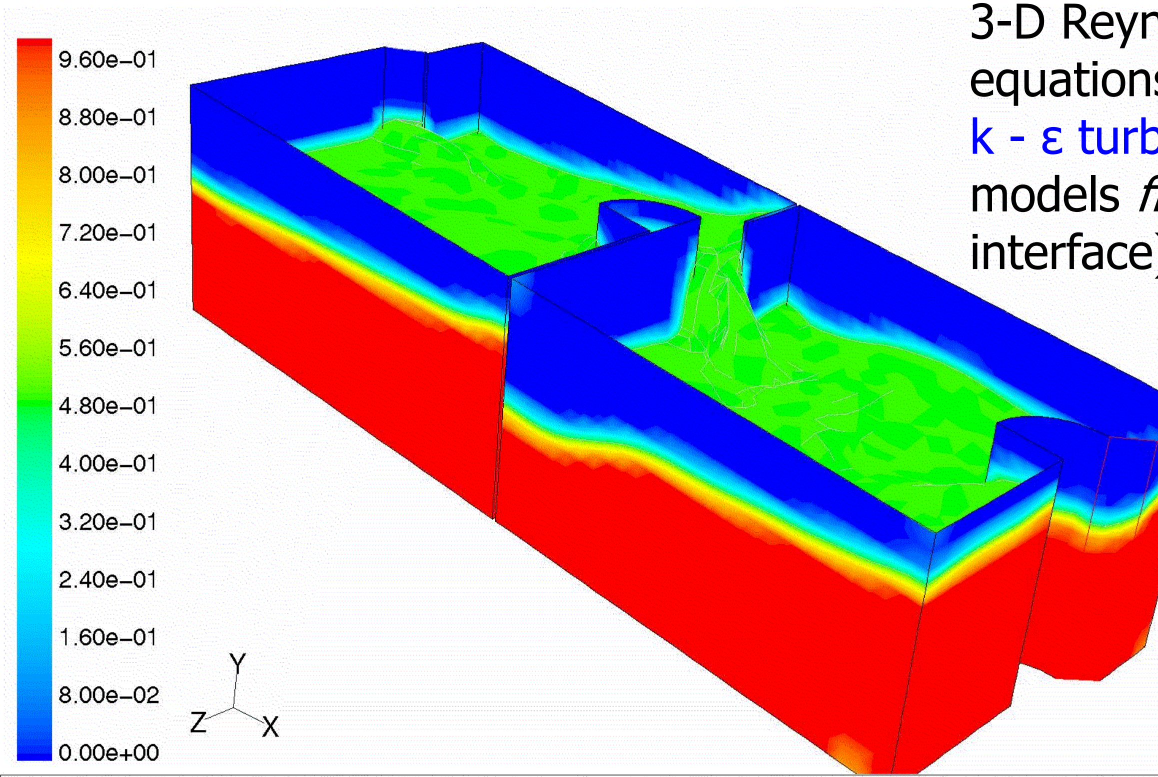


50% Exceedence Discharge

CFD modeling

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 - ε turbulence model;
models *free surface* (air-water interface) with volume of fluid method



Contours of Volume fraction of water−liquid (Time=2.9403e+01) Jan 29, 2002
FLUENT 5.5 (3d, segregated, rngke, unsteady)

Barton, Keller & Katopodis (2002 AFS, 2008 & 2009)

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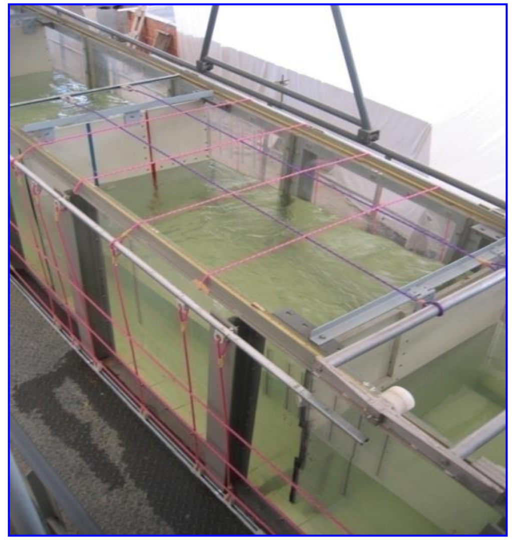
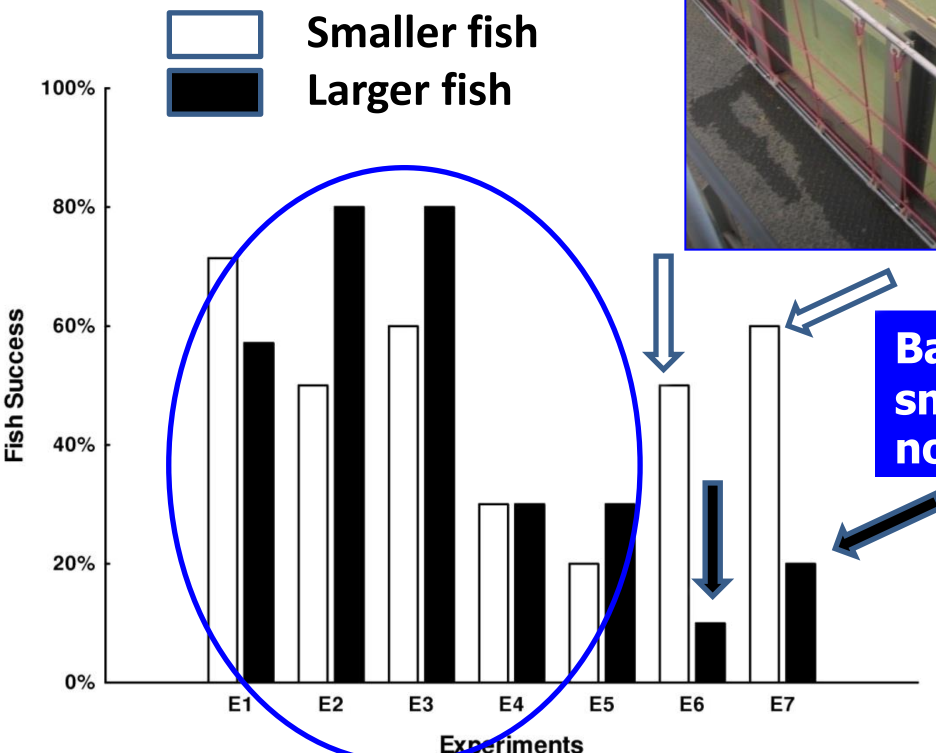
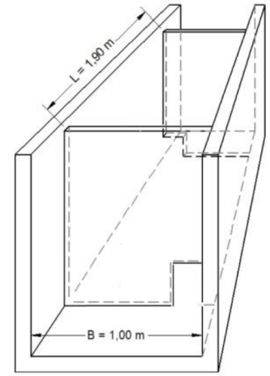
Turbulence – shear stress and eddy size

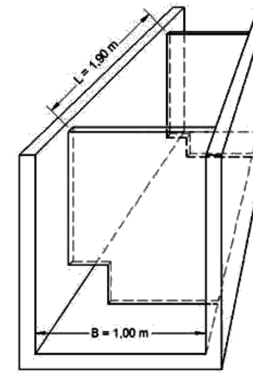
Iberian barbel
Luciobarbus bocagei

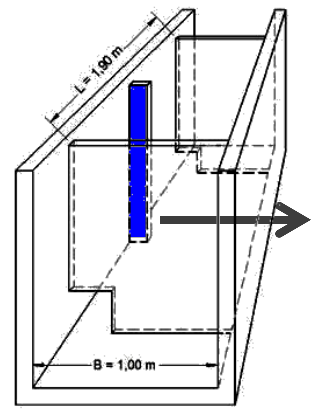




Bar helped smaller fish but not larger fish





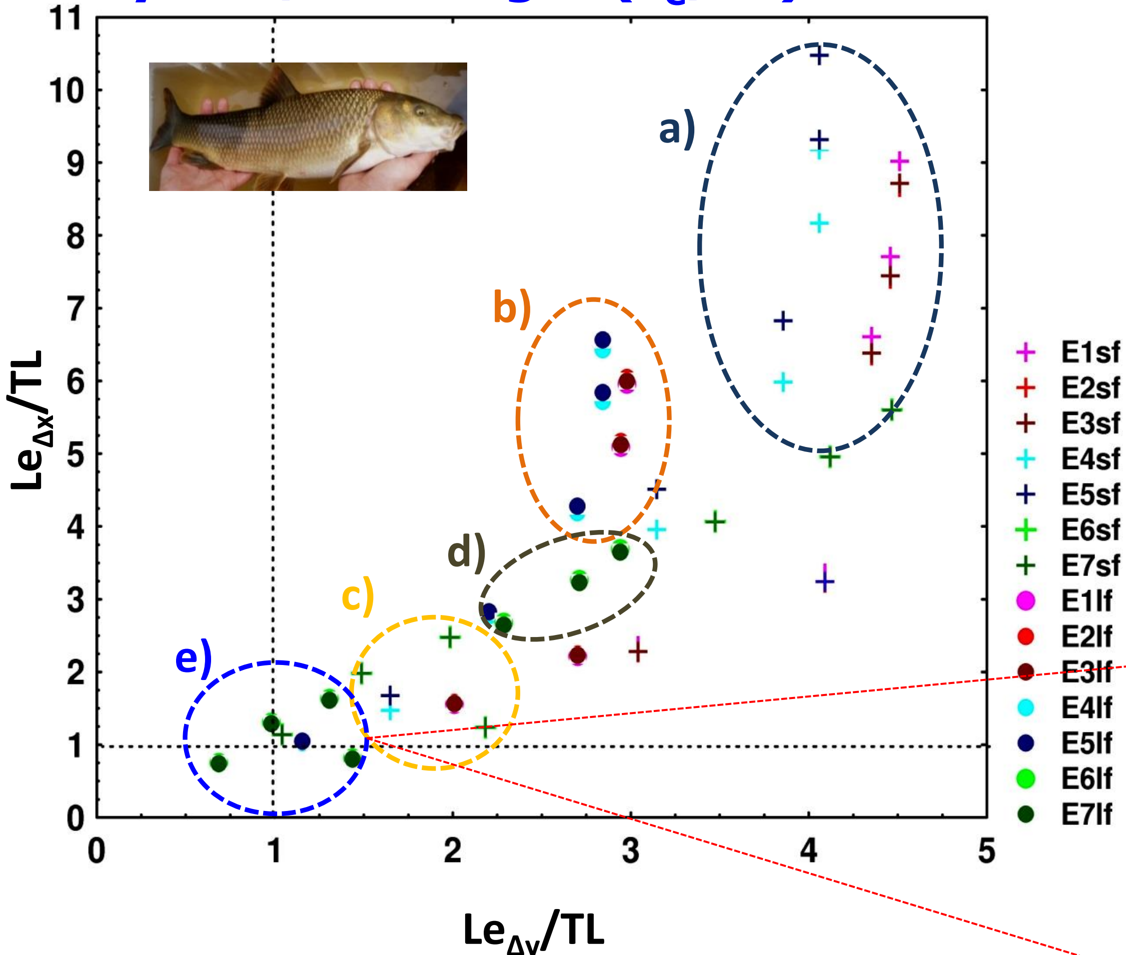


$0.5b_o$; 0.2L

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

Silva, Katopodis, Santos, Ferreira, and Pinheiro 2012

Barbel behaviour observed: eddy size/fish length (L_e/TL)

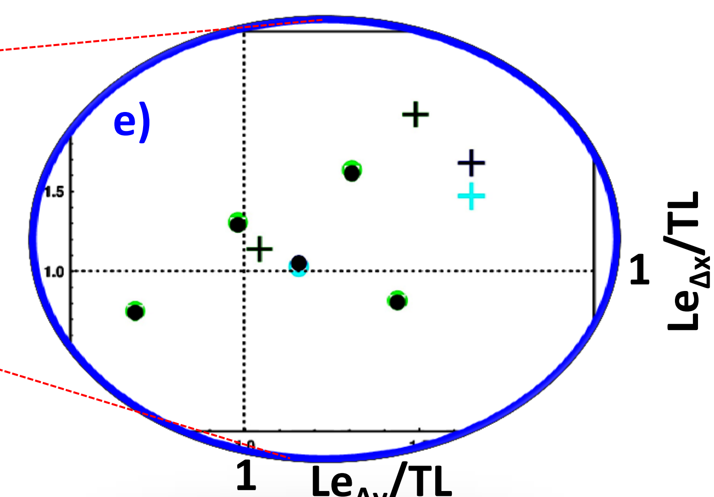


e) $Le/TL_{lf} \approx 1$ (●)

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)

Bottom orifice vs surface notch
Plunging vs streaming flow

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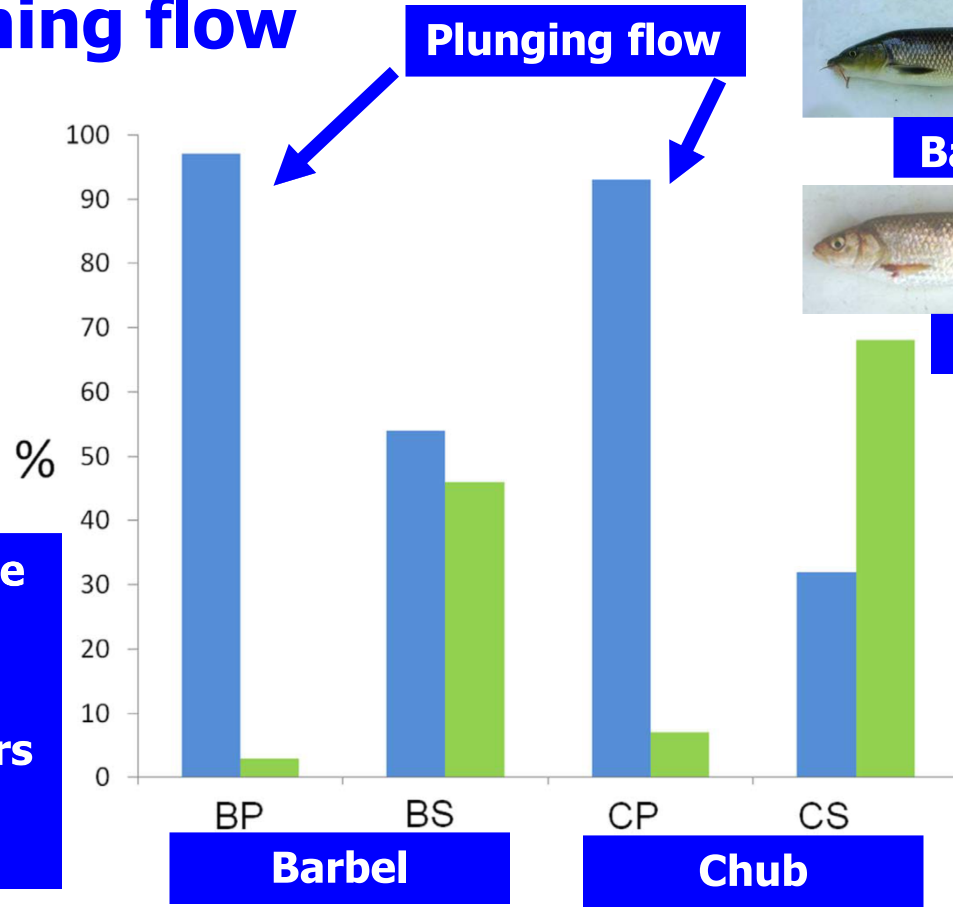
Iberian barbel (*Luciobarbus bocagei*) – potamodromous, large-bodied, bottom oriented

Iberian chub (*Squalius pyrenaicus*) – resident, small-bodied, water-column

In plunging flow, bottom orifice strongly preferred by both species;

In streaming flow, chub prefers surface orifice, while barbel uses both orifice & notch



Barbel

Chub

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)

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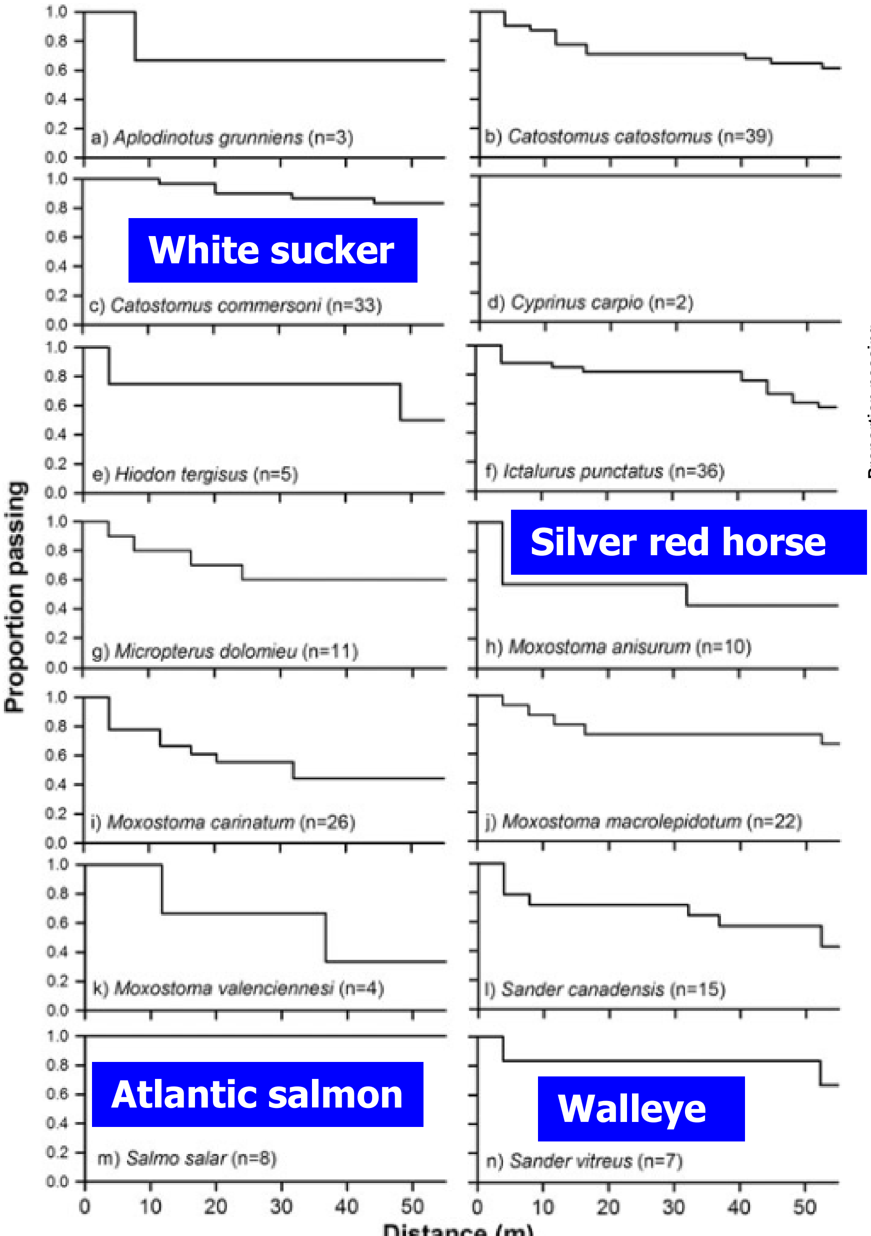
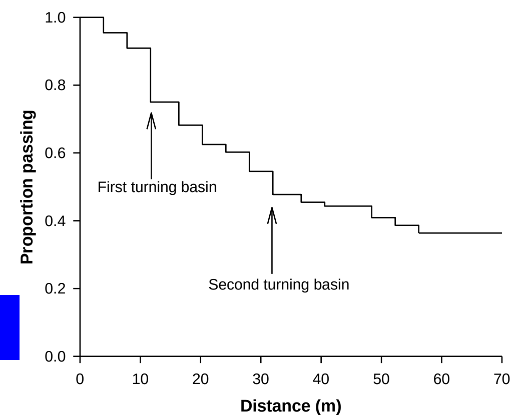


Vianney-Legendre vertical slot fishway, Quebec



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

Thiem et al. (Katopodis) 2011; 2013

Fish passage efficiencies

Fishway (u/s)	Species		Passage efficiency
Vianney-Legendre Vertical slot, Richelieu River, Quebec. (Thiem et al. (Katopodis) 2011 and 2013)	Acipenseridae		
		Lake sturgeon (*Acipenser fulvescens*)	36.4%
	Catostomidae		
		Longnose sucker (*Catostomus catostomus*)	48.7%
		White sucker (*Catostomus commersoni*)	75.8%
		Silver red horse (*Moxostoma anisurum*)	30.0%
		River red horse (*Moxostoma carinatum*)	30.8%
		Shorthead red horse (*Moxostoma macrolepidotum*)	45.5%
		Greater red horse (*Moxostoma valenciennesi*)	25.0%
	Cyprinidae	Common carp (*Cyprinus carpio*)	100%
	Centrarchidae	Smallmouth bass (*Micropterus dolomieu*)	63.6%
	Ictaluridae	Channel catfish (*Ictalurus punctatus*)	52.8%
	Percidae		
		Sauger (*Sander Canadensis*)	40.0%
		Walleye (*Sander vitreus*)	57.1%
	Salmonidae	Atlantic salmon (*Salmo salar*)	100%
	Sciaenidae	Freshwater drum (Aplodinotus grunniens)	66.7%

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

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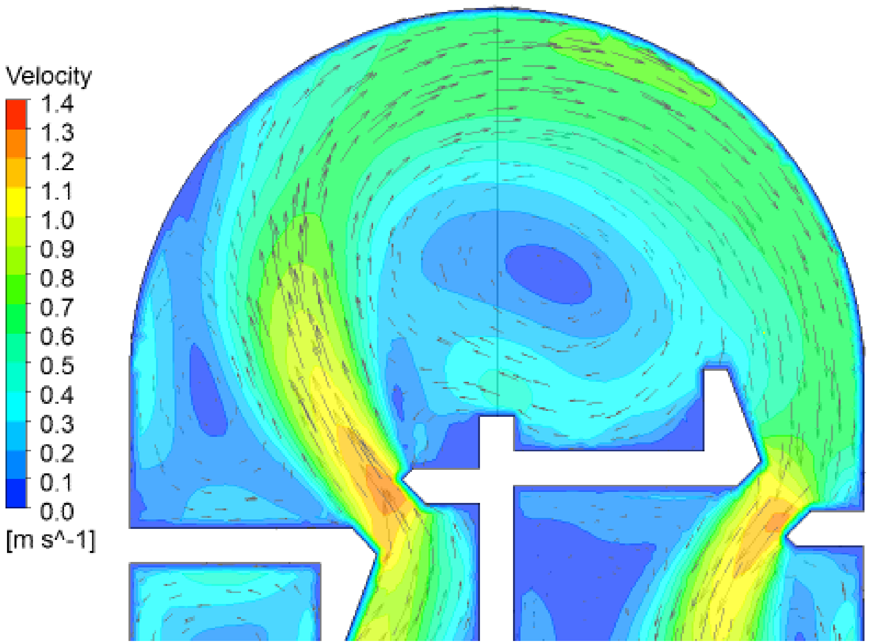
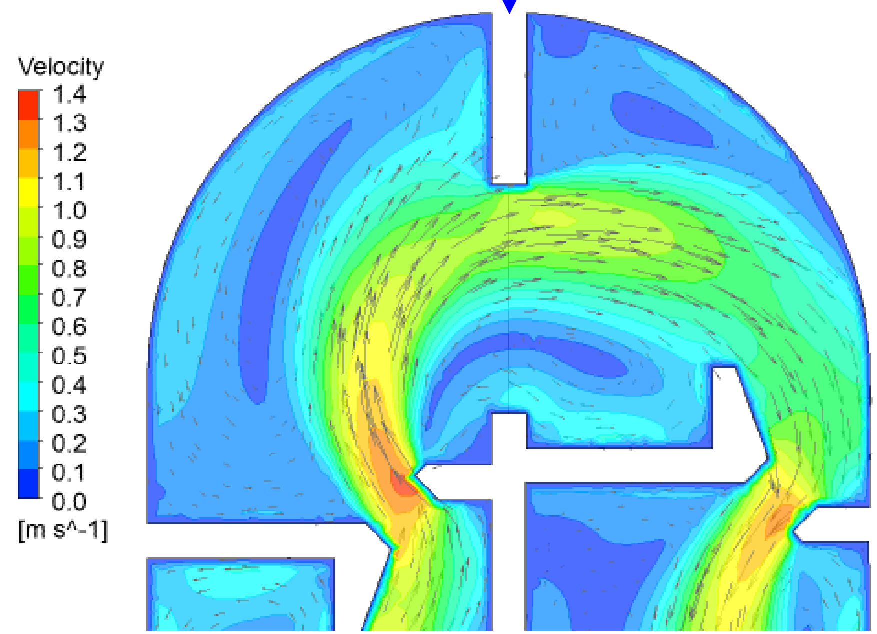
Turning pools - Vianney-Legendre fishway

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 - ε 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

Do your best to "think like a fish"... but remember that fish have the last word!

Classical Hellenic thinking:

«Γηράσκω αεί διδασκόμενος»

"I grow older ever in a state of learning"

Thank you! Questions?