Fish Passes: A brief Introduction

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Webinar Outline

1. **Why** do we need fish passes?

2. **Types of Fish Passes –** one size does not fit all

3. **Design & Construction challenges**

4. **Monitoring & Maintenance –** keeping them working

5. **Lessons learned & conclusions**

1. Why do we need Fish Passes?

4 H's threaten fish biodiversity:

Harvest

Habitat

Hatcheries (AIS)

Hydro (Obstacles)

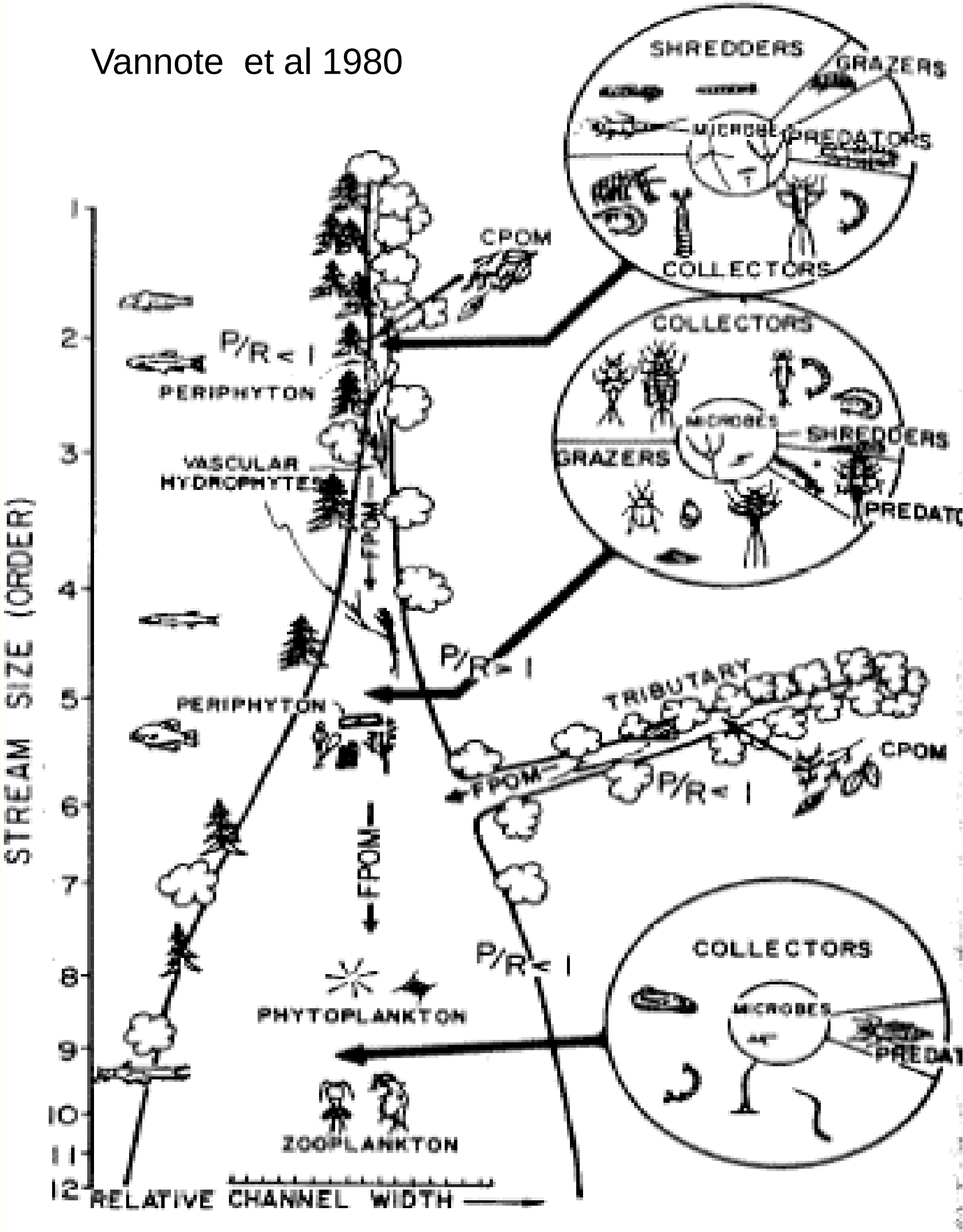
Why is River connectivity important?

Many reasons:

1. Healthy rivers = Flowing rivers

River continuum underpins structural and functional integrity of rivers

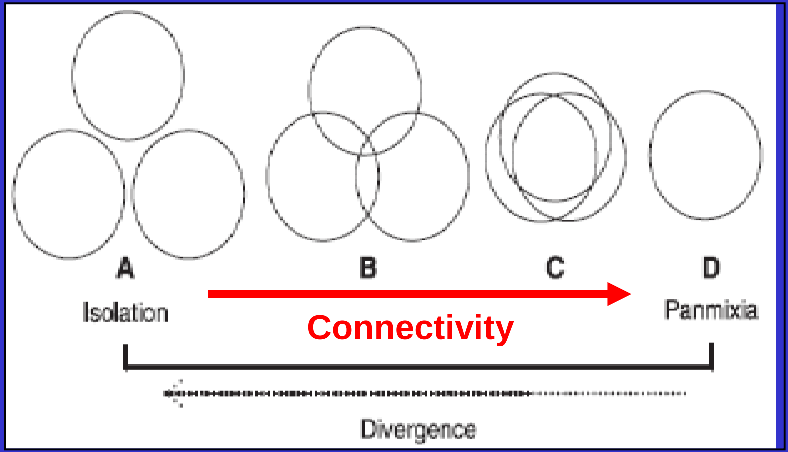
Vannote et al 1980



Why is river connectivity important?

2. Movement = fish reaction to adversity

- Individual fitness
- Metapopulation
- Resilience
- Portfolio effect



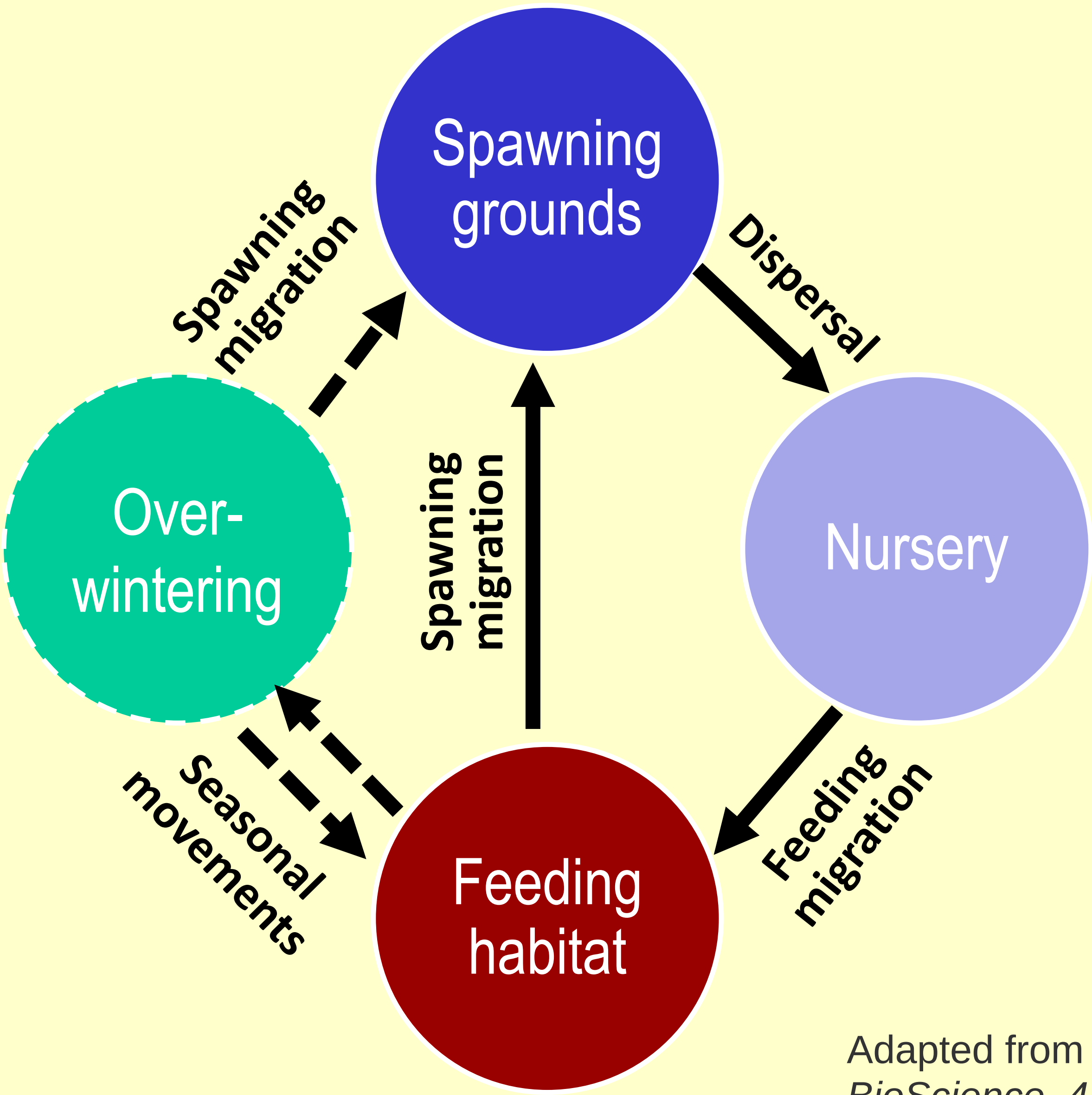
Recommendations of the meeting of the European Platform for Biodiversity Research Strategy

Brdo, Slovenia, 15th -18th January 2008

WATER FOR LIFE: RESEARCH PRIORITIES FOR SUSTAINING FRESHWATER BIODIVERSITY

- Assess effect of connectivity of freshwater systems on biodiversity & resilience

But it is not just 'migratory' fish that need to move



Adapted from Schlosser (1991) *BioScience*, *41*(10), 704-712.

…and what happens if they don't?

Hydrobiologia **483:** 55–69, 2002.
E.B. Thorstad, I.A. Fleming & T.F. Næsje (eds), Aquatic Telemetry.

The impact of small physical obstacles on upstream movements of six species of fish

Synthesis of a 5-year telemetry study in the River Meuse basin

Michaël Ovidio & Jean-Claude Philippart

most fish migrate during or outside the spawning period; some small obstacles can significantly disrupt and/or obstruct their movements

Ecology, 83(1), 2002, pp. 1–13

RESTRICTED MOVEMENT IN STREAM FISH: THE PARADIGM IS INCOMPLETE, NOT LOST

MARCO A. RODRÍGUEZ[1]

Hydrobiologia (2008) 609:83–96
DOI 10.1007/s10750-008-9397-x

EIFAC 2006: DAMS, WEIRS AND FISH

Weir removal in salmonid streams: implications, challenges and practicalities

Carlos Garcia de Leaniz

Considerable intra- and interspecific heterogeneity in the extent of movement; potential importance of the mobile component to population processes.

Importance of seasonal migrations and seasonal activity underestimated

Journal of Applied Ecology 1996, **33**, 1345–1358

Seasonal movements and behaviour of adult barbel *Barbus barbus*, a riverine cyprinid fish: implications for river management

MARTYN C. LUCAS and EMMA BATLEY
University of Durham, Department of Biological Sciences, Science Laboratories, South Road, Durham DH1 3LE, UK

Journal of Animal Ecology 2004 **73**, 353–366

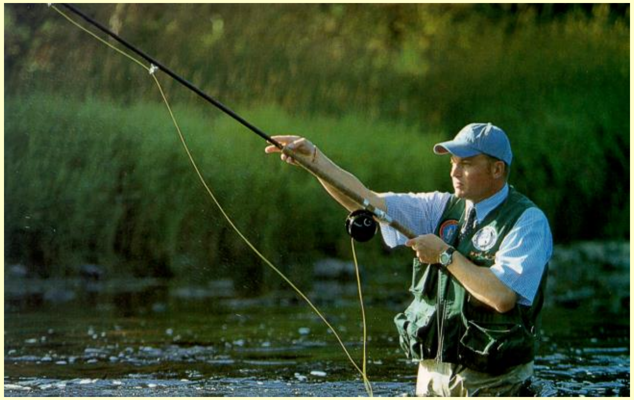
Is the home range concept compatible with the movements of two species of lowland river fish?

Impacts of barriers on fish

Direct impacts

- **Block, disrupt & delay movements**
  - Reduction in carrying capacity
  - Allee effects
  - Artificial selection

- **May increase mortality & reduce fitness**
  - hydro turbines; screens
  - over-exploitation
  - predation;
  - crowding stress
  - infectious diseases

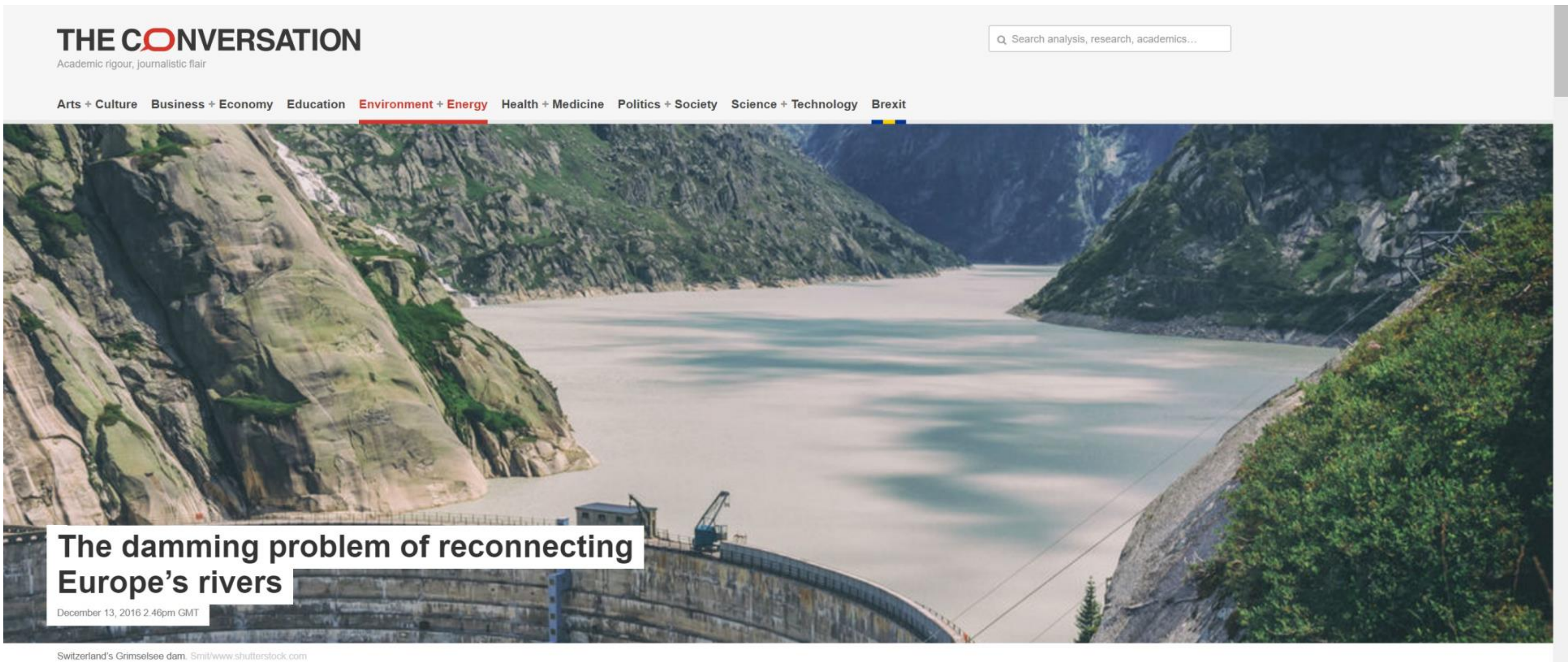


Impacts of barriers on fish

Indirect impacts

- **Habitat**
  - upstream (impoundment, silting, erosion)
  - downstream (less flow, sediment-starved, erosion)
  - Water quality (temp, nutrients)
- **Hydrological cycle**
  - Water balance
  - Changes in flow regime (hydropeaking, ecological traps)

So… what can we do?



https://theconversation.com/the-damming-problem-of-reconnecting-europes-rivers-69913

Reconnecting Europe's Rivers the Smart Way

AMBER

www.amber.international

Funded by the Horizon 2020 Framework Programme of the European Union

AMBER
LET IT FLOW

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 689682.

Adaptive Management of Barriers in European Rivers

H2020, €6.2 M, 20 partners, 11 countries 2016-2020

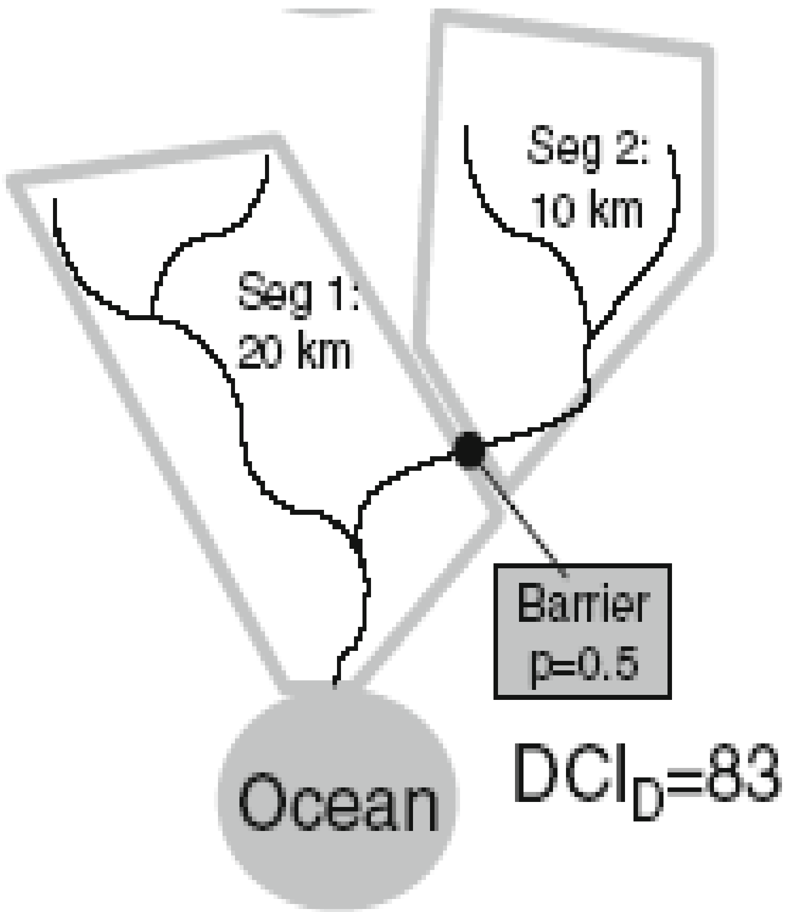
8 Universities - Swansea, Durham, Highlands & Islands, Southampton, Cork (Ireland), Oviedo (Spain), Milan (Italy), DTU (Denmark).

4 Industrial partners - hydropower – EDF (France), IBK (Germany), Innogy (Germany), Sydkraft (Sweden)

4 NGOs (WFMF (Netherlands), WWF (Switzerland), CNSS (France), AEMS (Spain)

4 Government organisations - IFI (Ireland), ERCE (Poland), SSIFI (Poland), Joint Research Centre (Italy)

Better **decision & prioritization tools** are needed



Dendritic connectivity index

Cote et al (2009)

Barrier Impacts

- No of barriers
- Location of barriers
- Passability

Barrier Mitigation

- Costs
- Opportunities
- Benefits

Options

- Remove the barrier
- Overcome the barrier (build a fish pass)

Advantages of dam removal/breaching over other solutions:

1. Solves upstream AND downstream fish passage

2. Typically cheaper than any fish pass

3. Achieves direct, integral stream restoration

4. Addresses other problems (e.g. structural safety)

5. Does not hinder future options

Garcia de Leaniz (2008)

Limitations of dam removal /breaching :

1. Not always practical or feasible

2. Short-term mobilization of sediments, potentially toxic

3. Limited experience in Europe (compared to fish pass)

4. Societal & cultural issues, historical value of some weirs

5. Paperwork and red-tape: may take a long time to do it

Garcia de Leaniz (2008)

OK so we opt for a fish pass, but which one?

One size does not fit all….

1. **Barriers differ**



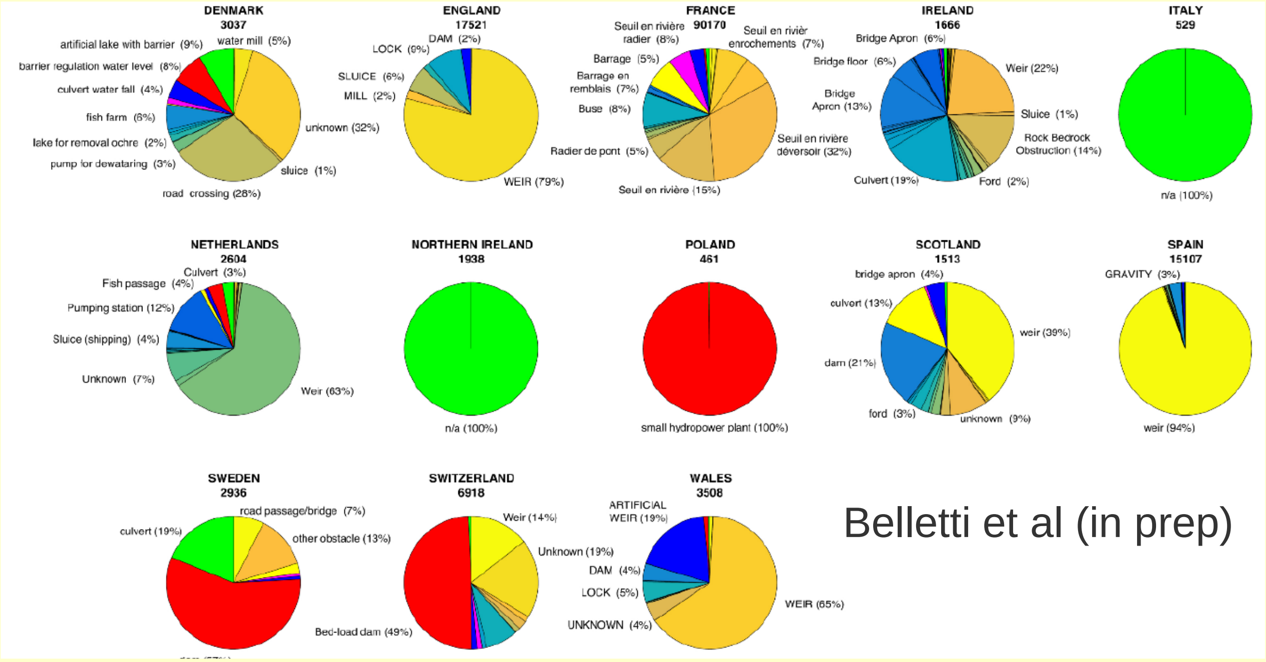
2. **Fish differ**



3. **No single fish pass is best under all conditions**

Barrier typology

- Barriers are not just dams. Over **290 different barrier types** found in Europe!



- They differ in **size**, **location**, **use**, area **impounded**, **water abstraction, construction, age**, and **state of conservation.** All these can affect impacts on fish

Large hydroelectric dams

Palombera dam
R. Nansa (Height 20 m).

Garcia de Leaniz (2008)

Small hydro developments

Brufao (2006)

Weirs for water mills and irrigation

Channelization & flood defences

Extreme, Hard engineered Flood defences

R. Deva tributary (Spain). Inside a 'National Park'

Culverts

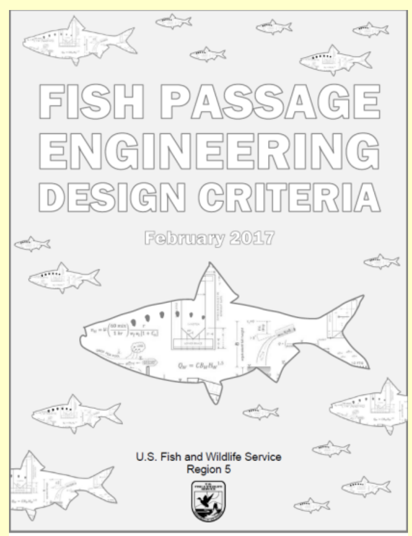
No water : no passage

R. Pas (Spain). A ‘salmon’ river but no water

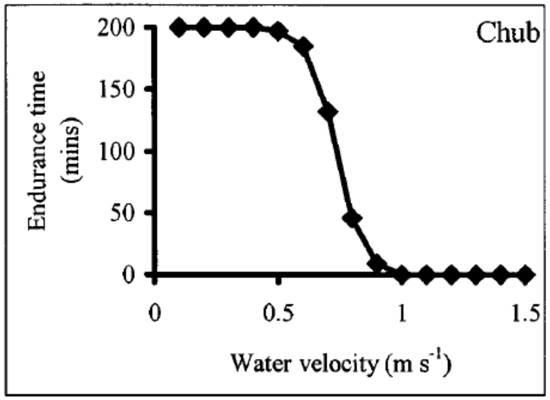
Not all fish are the same

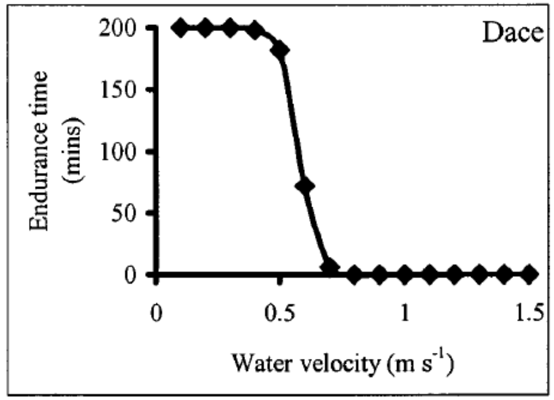
A lot is known about **upstream salmonid** passage, but relatively little about:

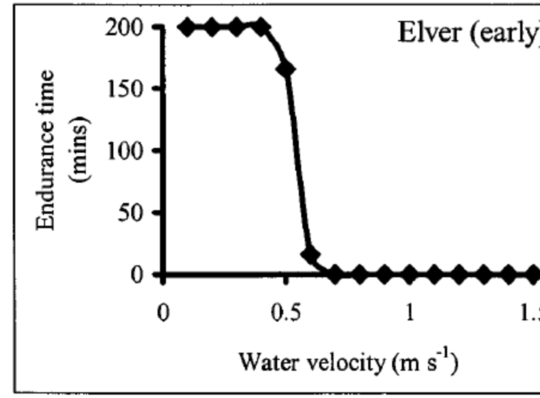
- Most other fishes, many of which are **weak swimmers**
- **Downstream** fish passage
- **Aquatic Invasive Species**

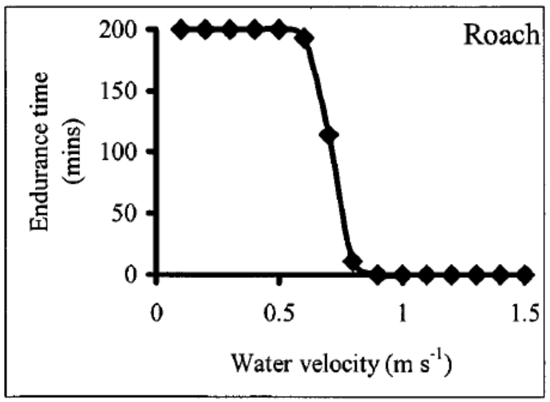


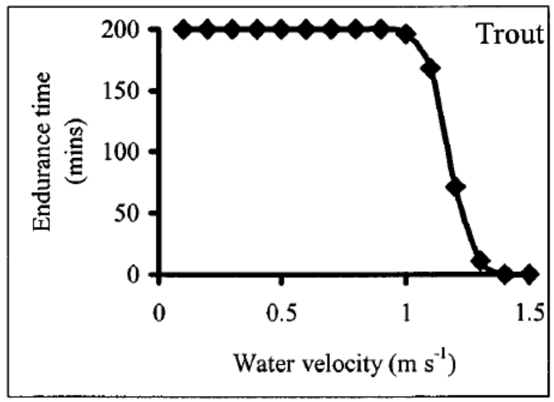
topmouth gudgeon









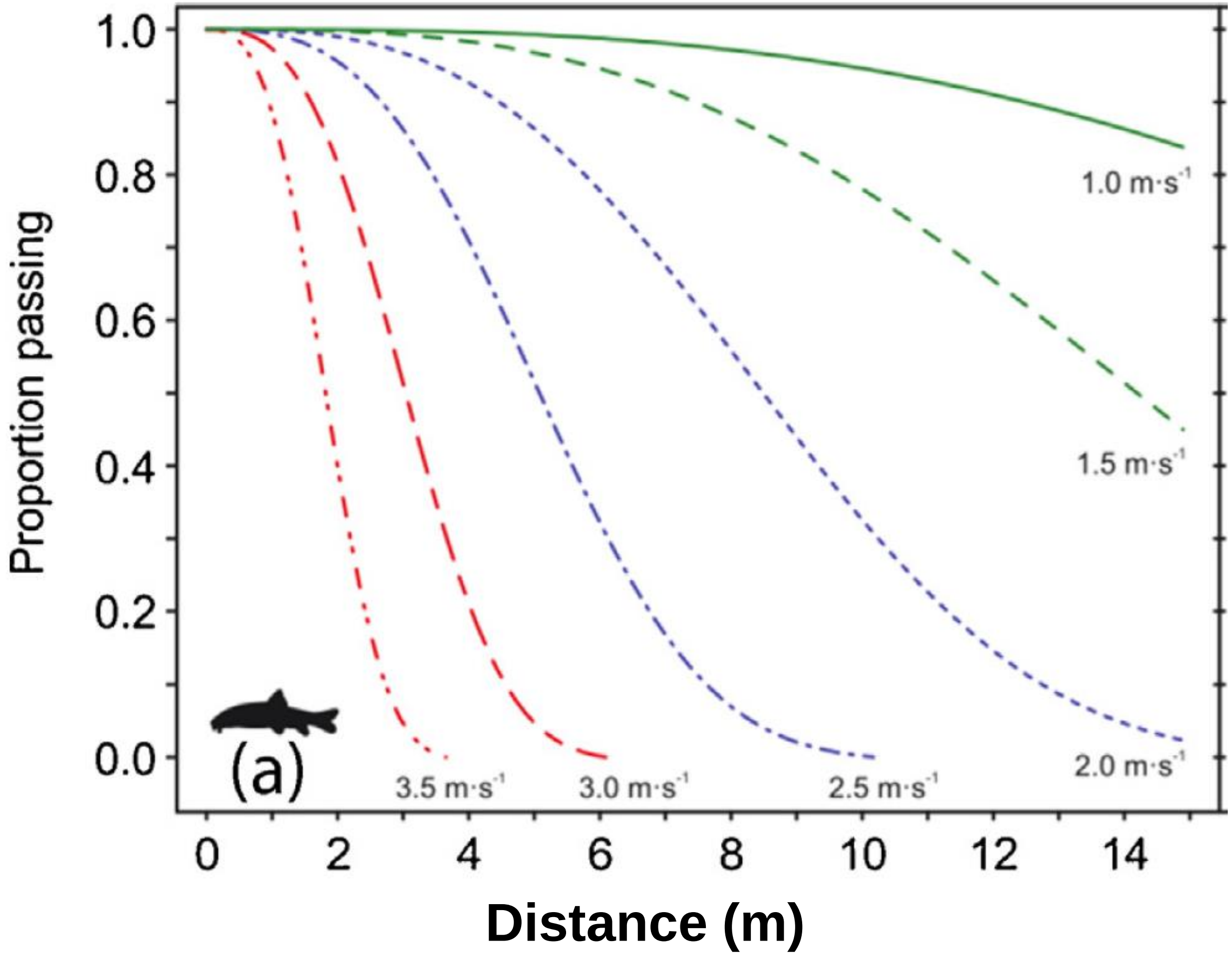


Endurance of 5 freshwater fish (15 cm) at 10C

Clough & Turnpenny 2001

Swimming endurance

1. Is **not a linear function** of water velocity
2. Differs widely among **species**
3. Differs with **fish size** and **water temperature**



Ascent distance of barbel at various flow velocities

Sanz-Ronda et al. 2015

The distance that fish can swim diminishes quickly at high velocities

Fish Pass Design & construction: an introduction

Fish Pass©
Lego

Timeline of developments in fish passes

1500 1600 1700 1800 1900 2000

1 2 3 4 5 6 7 8-9,10-13 14 15

1. 1500. Need for upstream fish passage documented in China, end of Ming Dynasty.
2. 1650. 1st rough fishway (France), bundles of branches used to create steps & bypass
3. 1678. Map showing salmon stockades R. Pas (Spain), legislation to allow fish upstream
4. 1700s, City of Falmouth (MA) v. dam owner, fishway required
5. 1776 - Dam owners in the New World required to provide fishways
6. 1790, MA passed legislation requiring fish passage
7. 1837 Fishway patent by Richard McFarlan (NB, Canada) to bypass lumber mill
8. 1850s, MA required fish passage in charter to Essex Company
9. 1852–1854, Ballisodare Fish Pass (Co Sligo, Ireland) to draw salmon into an empty river
10. 1872, Holyoke Company v. Lyman, U.S. Supreme Court, fishway required
11. 1879, IL passed legislation requiring fishways at dams
12. 1880, first fishpass built in Rhode Island (US), on Pawtuxet Falls Dam.
13. 1884, Parker v. Illinois, State Supreme Court, fishway required
14. 1910, Mr. Denil, a civil engineer from Belgium, develops the first baffle fish pass
15. 1983, Larinier describes a simplified Denil fishpass with low floor baffles & clean walls

Types of fish passes

The ideal fish pass:

- Does not hinder volitional movement
- It works for all species and under all flows
- It works both upstream and downstream
- It is cheap to build and easy to maintain...

.....it does not yet exist!

Types of fish passes

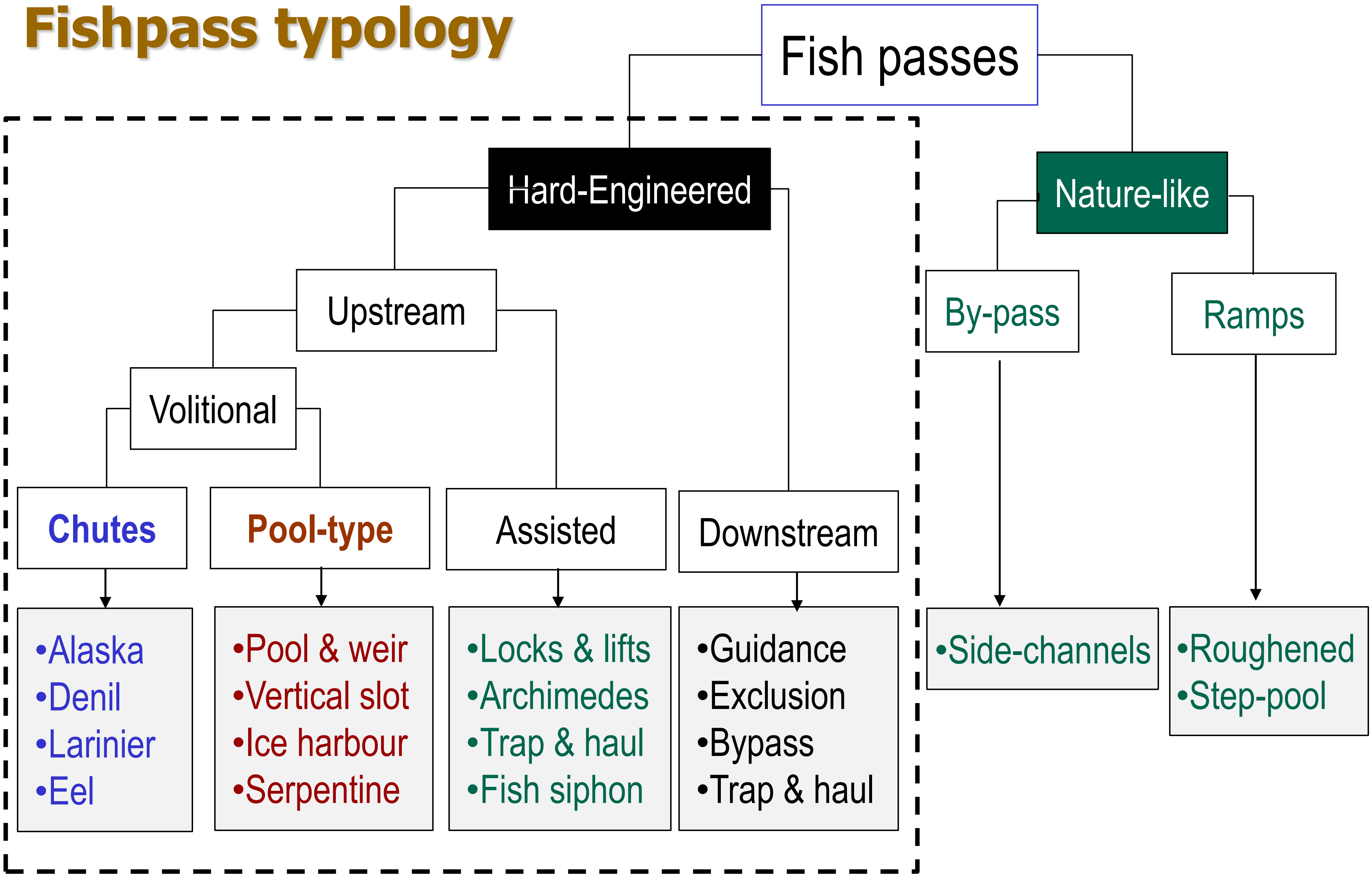
Six basic types – but many variations

- Pool & weir
- Vertical slot
- Chutes (ramps) with baffles
- Fish lifts & locks
- Nature-like
- Fish siphon

Can be classified according to:

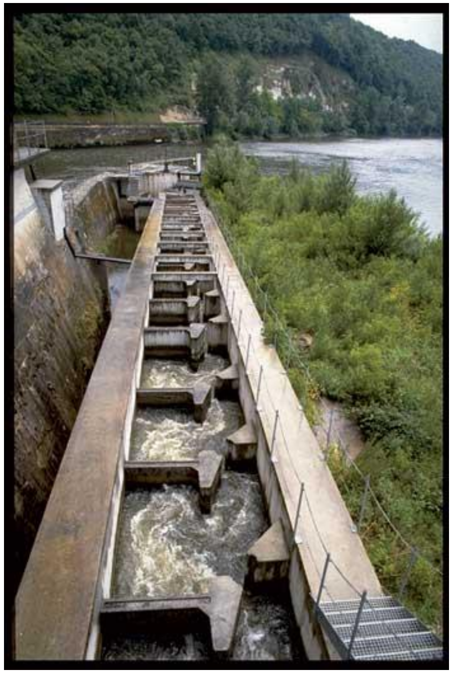
- Hard **Engineered** vs **Nature-like**
- **Upstream** vs **Downstream** passage
- **Volitional** vs **Assisted** passage
- **Flow** (**Plunging** vs **Streaming**)
- Those that **seldom** work vs those that work **sometimes…**

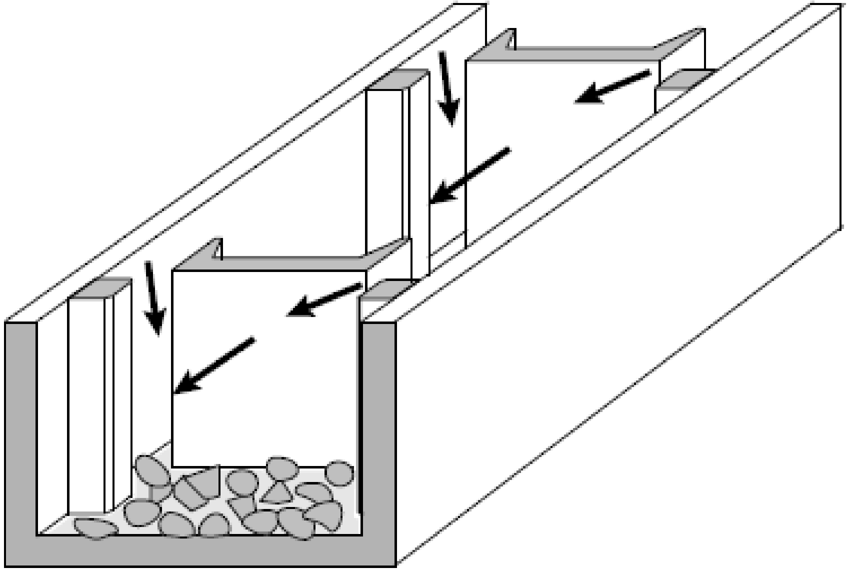
Fishpass typology



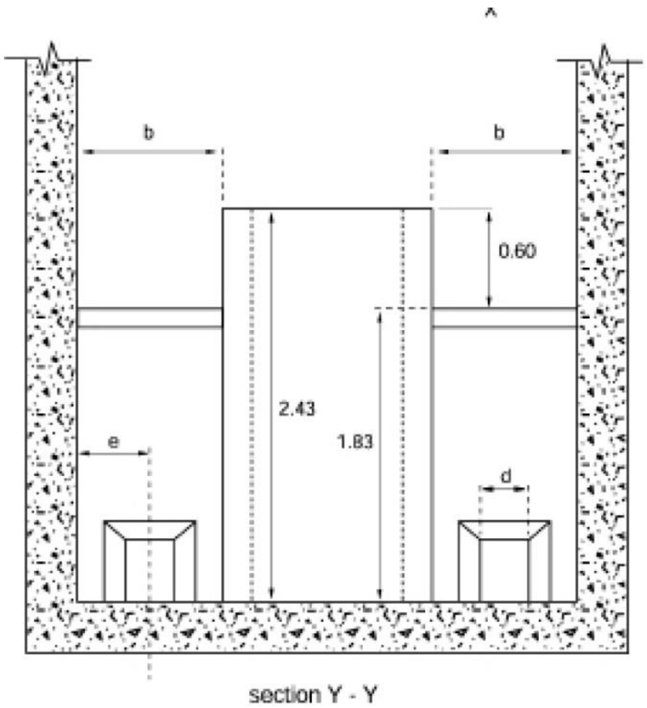
Pool-type: Poor & Weir

Pool-type: Vertical slot

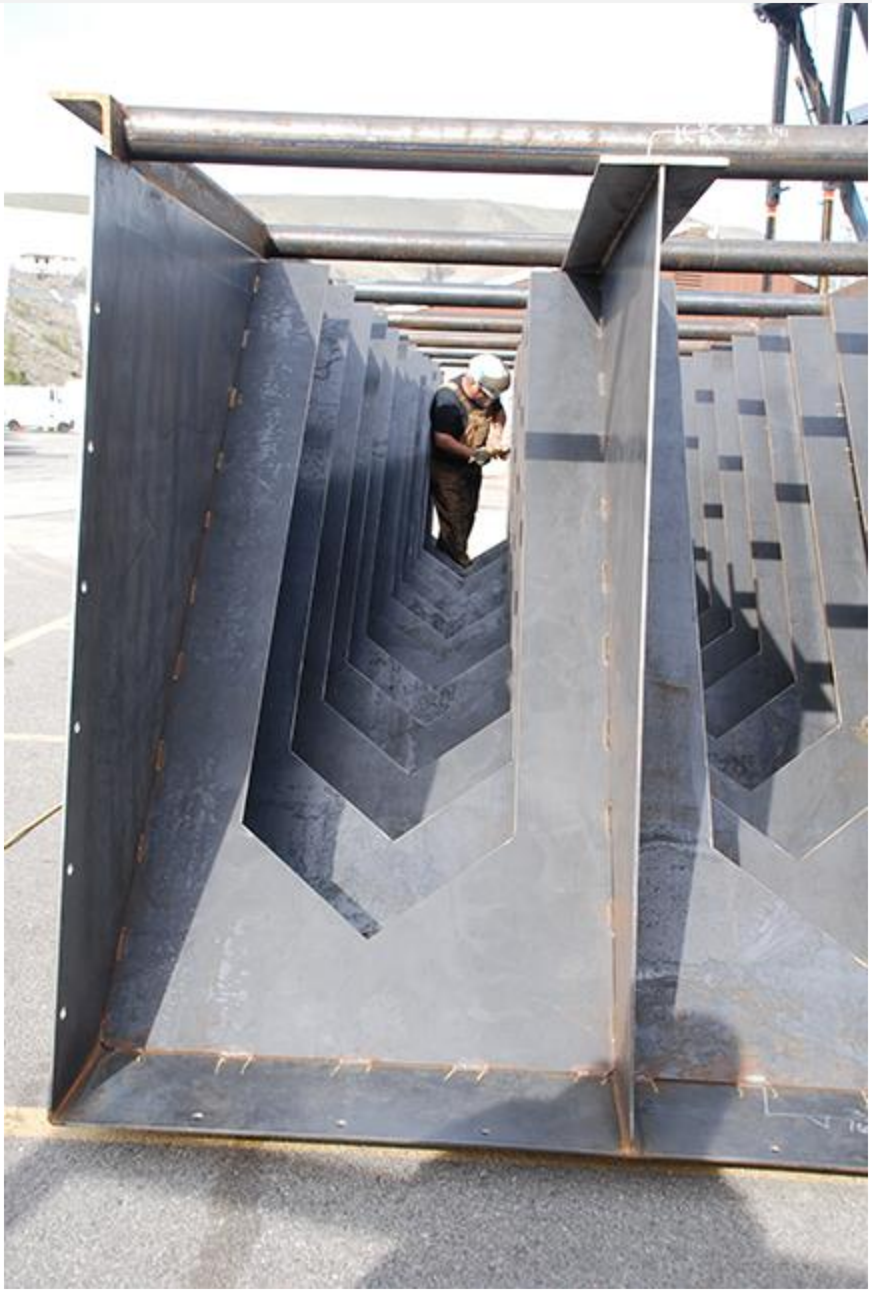




Pool-type: Ice-harbor type



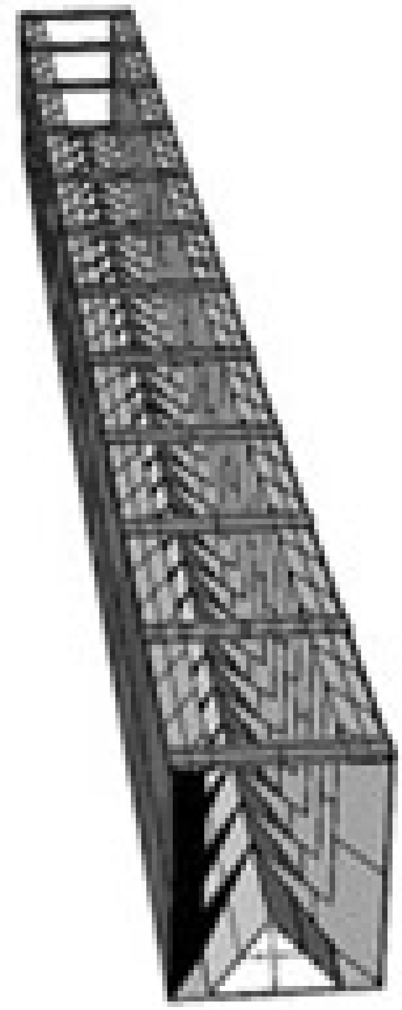
Chutes - baffle systems



Denil fish pass

Chutes- baffle systems

Larinier Super Active Baffle



Alaska type

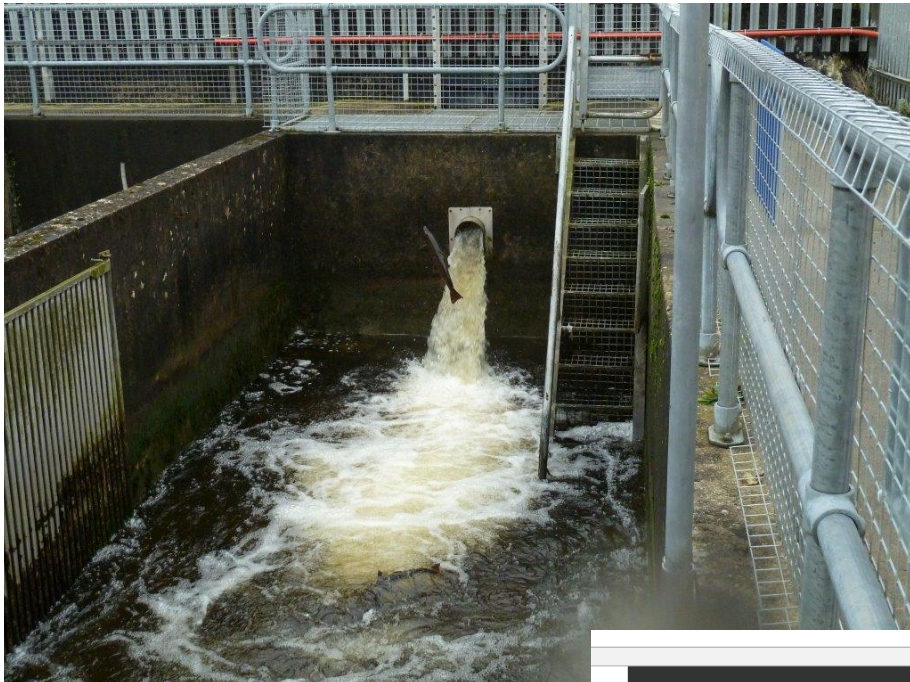
Chutes - baffle systems

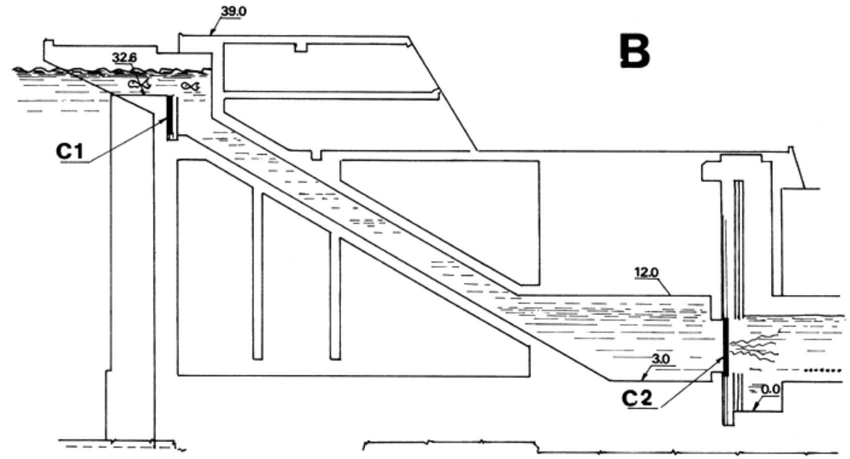
Active baffles (Larinier)

- Uninterrupted fish movement
- Allows sediment transport

Eel fish pass

Assisted fishways : Fish lifts and fish locks





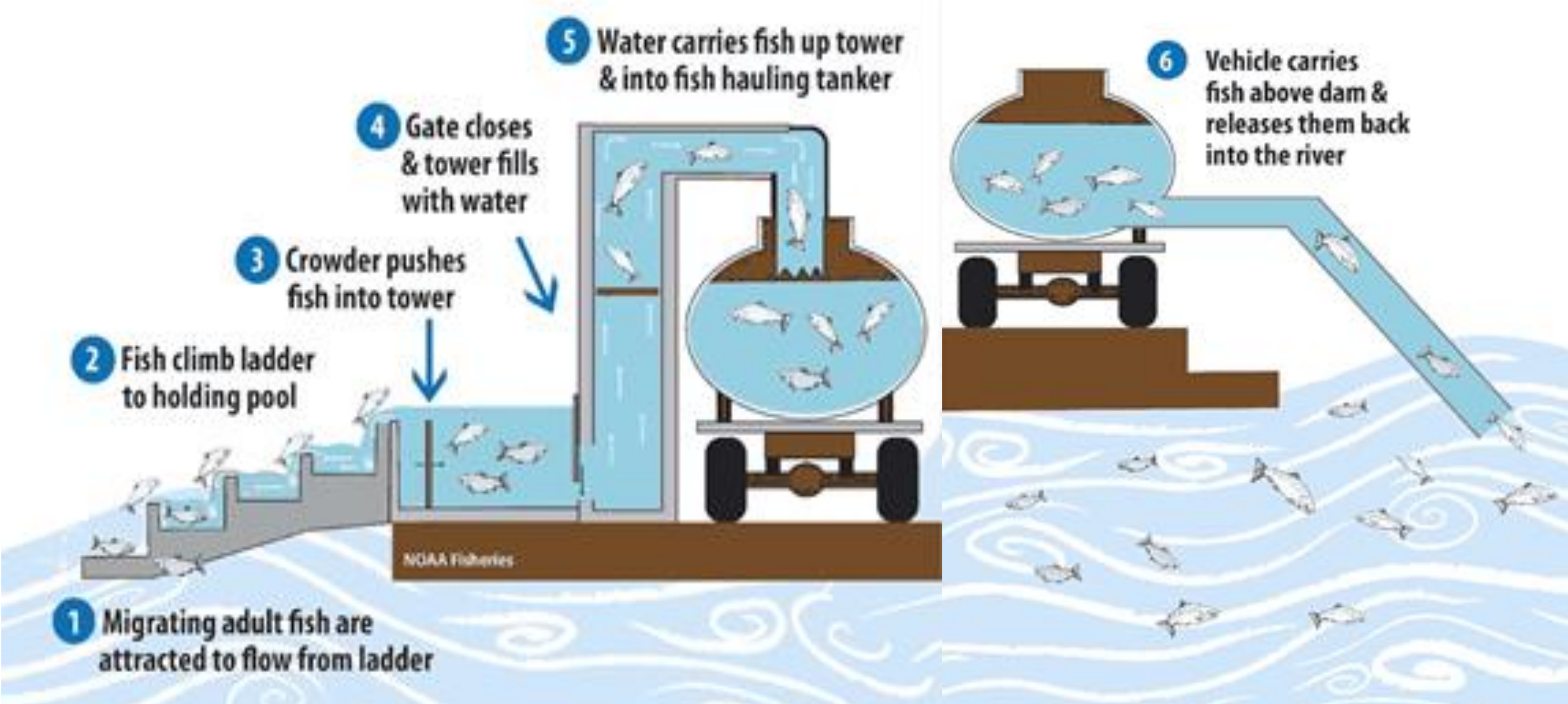
Borland (fish lift)

THE FAILURE OF THE ARDNACRUSHA FISH-LIFT

July 14, 2013 · by Dr. William O'Connor · in Ardnacrusha, Atlantic salmon, Fish passage, Shannon scheme. ·

> *Although at least 49,000 salmon should be passing upstream on the River Shannon each year if the river was reaching its "conservation limit", in reality only a few hundred salmon pass upstream here each year*

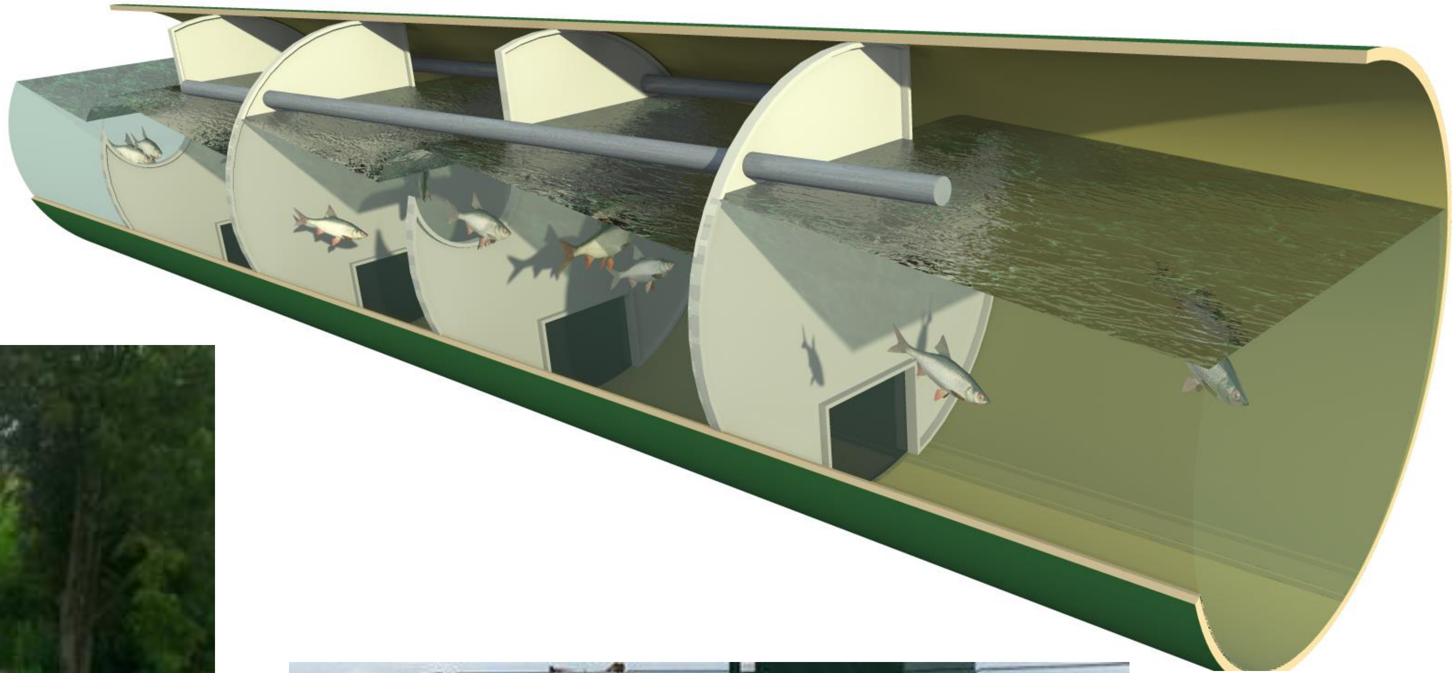
Assisted fishways : trap & haul



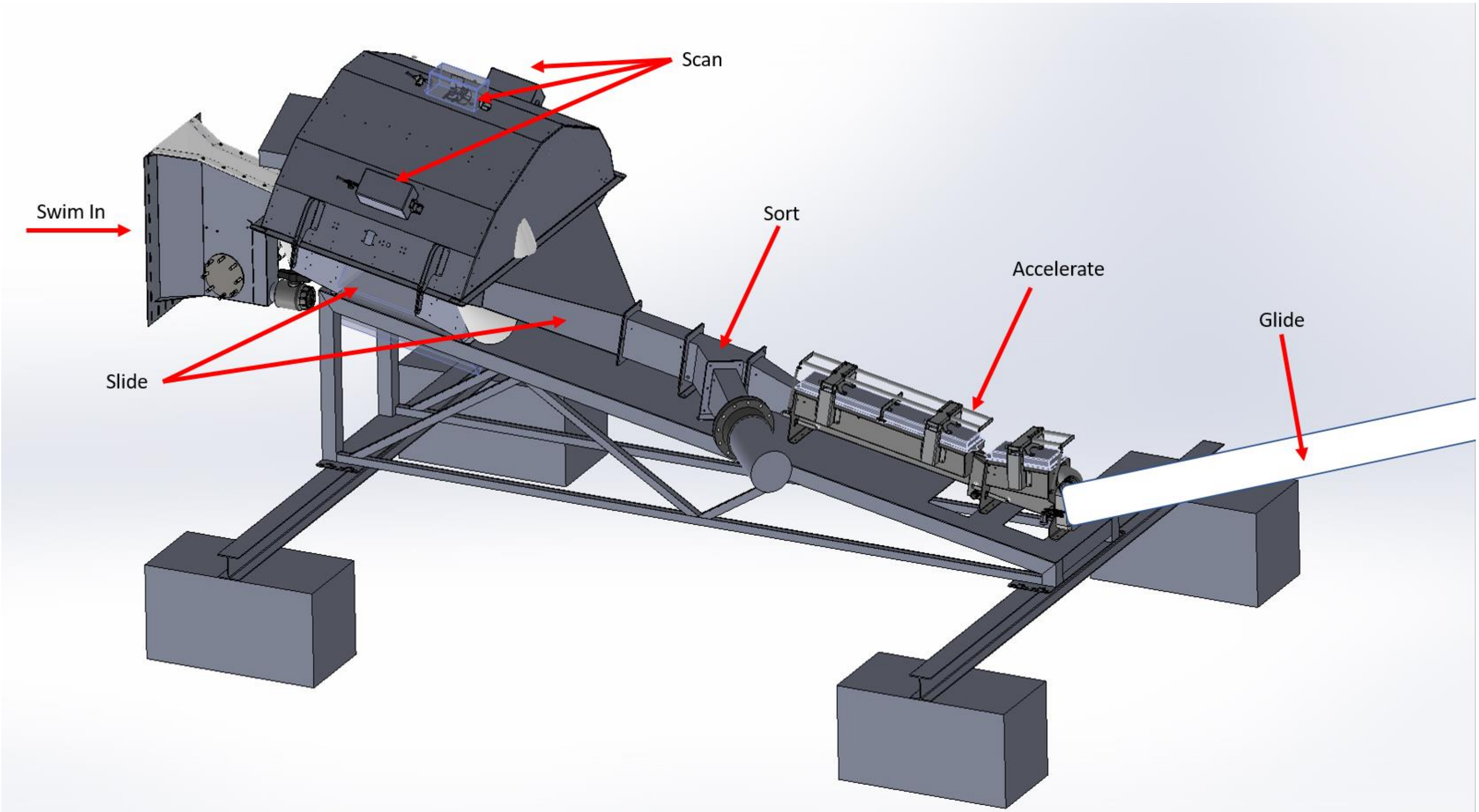
Assisted fishways : Archimedes screws

Slow rotating Archimedes screws

Assisted fishways : siphon



Assisted fishways : air vacuum

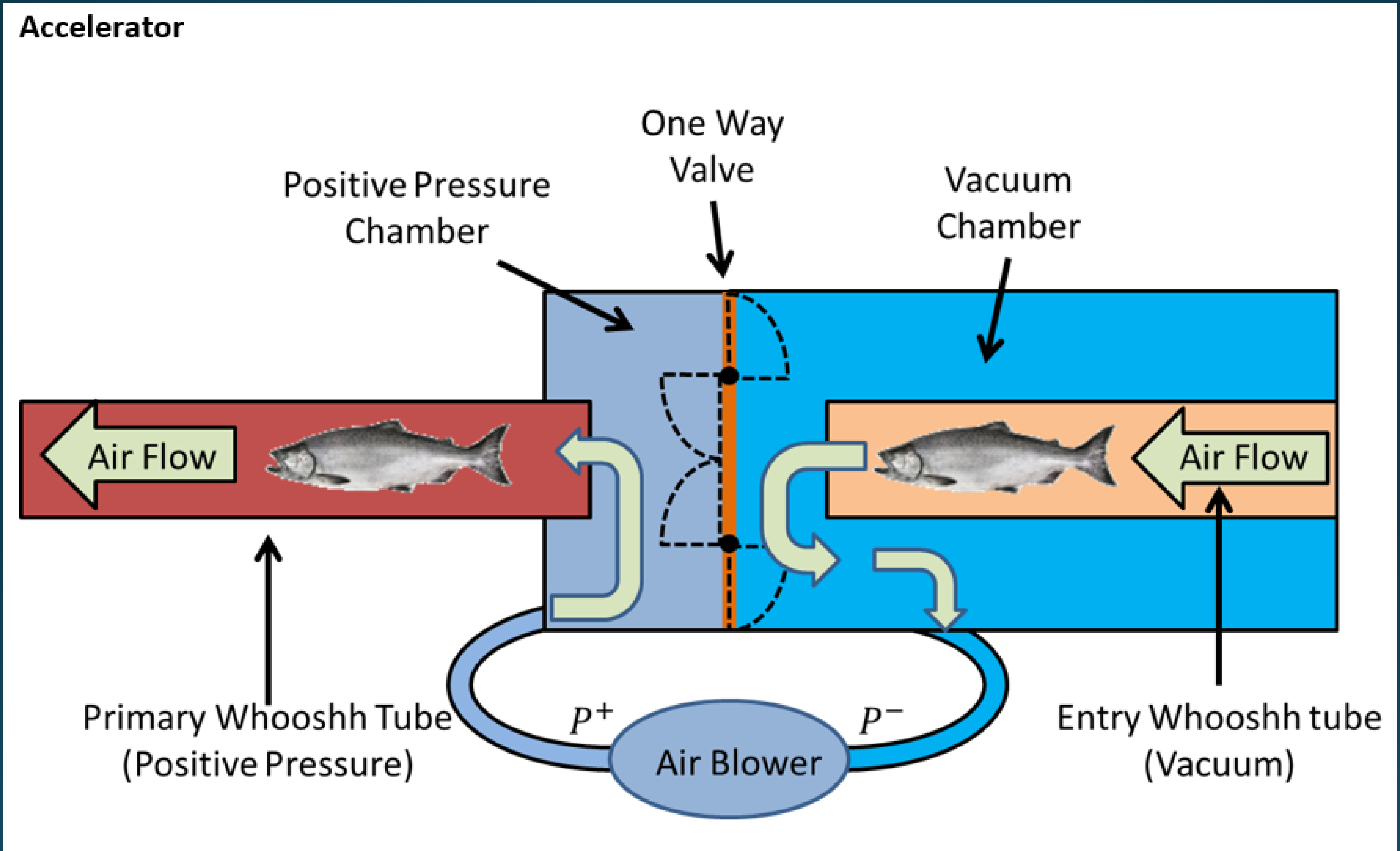


Whooshh Innovations

Fish Transport Solutions

see videos at https://www.whooshh.com/

How Does It Work?



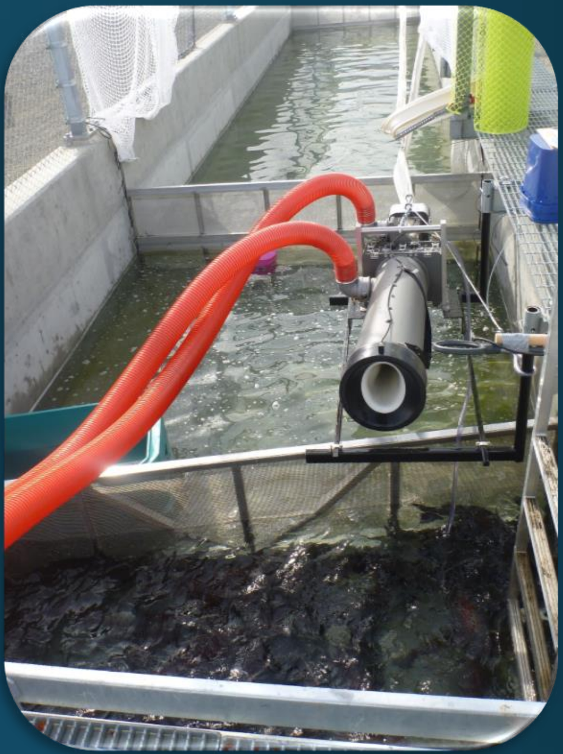
Inside

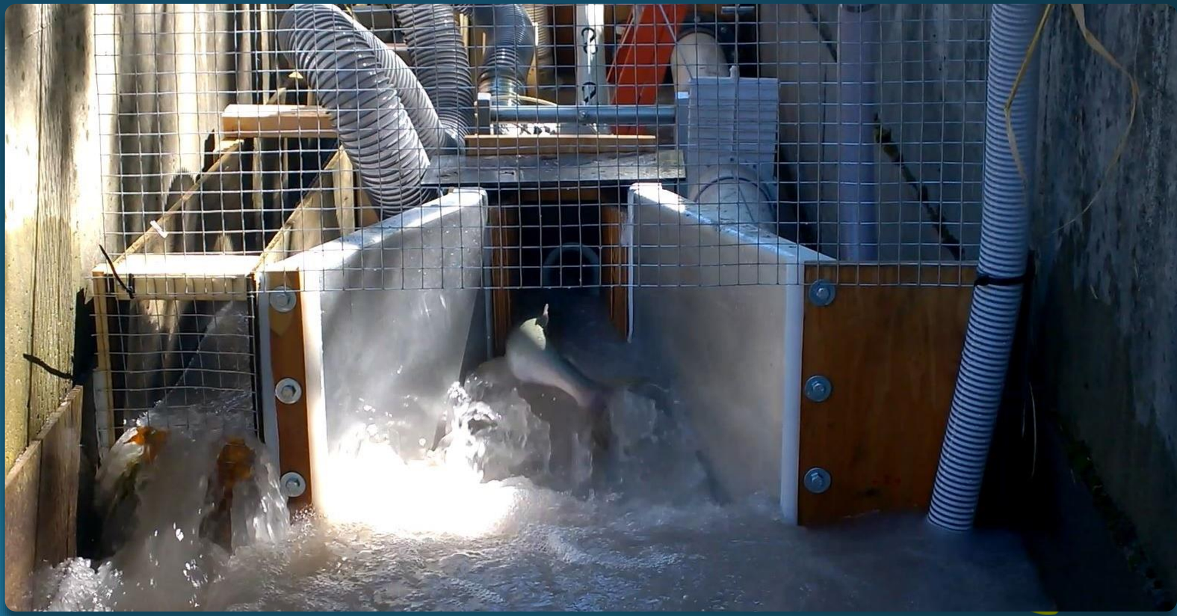
- Low pressure wet air ~6800 Pascals
- No loss of slime, scales or eye damage
- No change to reproduction or migration
- 5 tube sizes (0.5 - 15kg fish)

Species moved to date

Pink salmon
Chinook salmon
Sockeye salmon
Coho salmon
Chum salmon
Steelhead
Atlantic salmon
Asian Carp
Common Carp
Rainbow trout
Steelhead
Brown Trout

Lake Sturgeon
Gizzard Shad
American Shad
Large Mouth Bass
Northern Pike
Common White Sucker
Longnose Sucker
Walleye



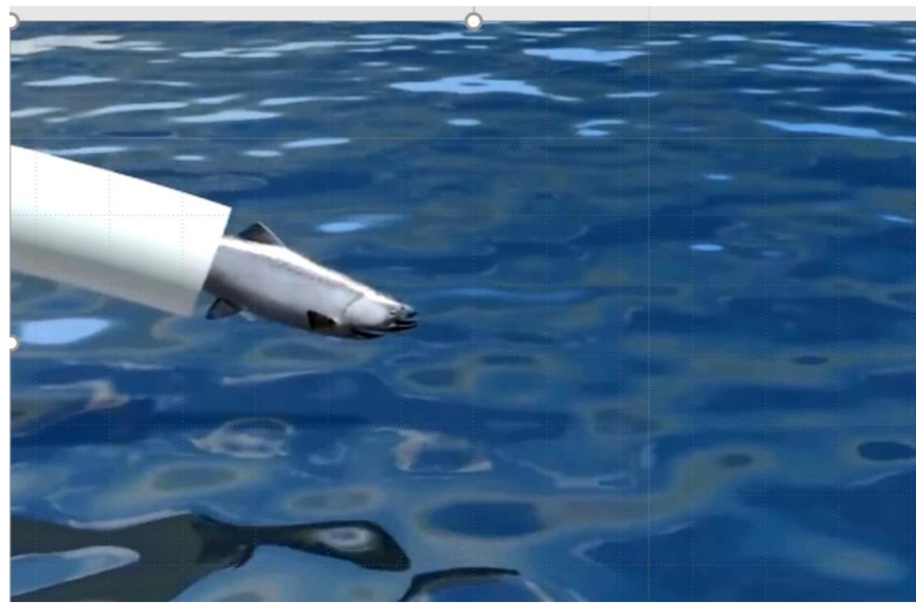


Swim-in system

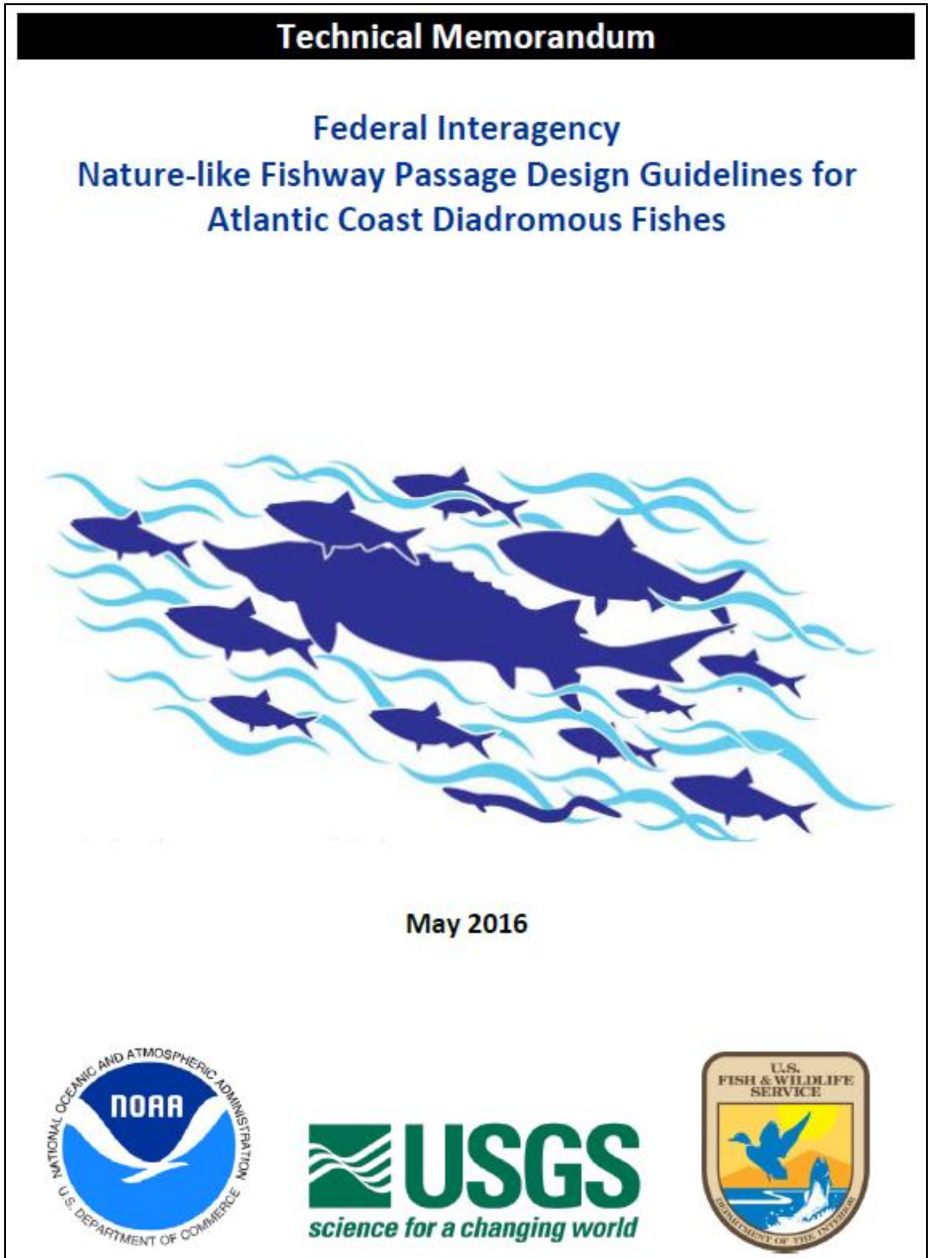
Installation in Washington State

530 m length, 50 m high
< 60s tailrace to lake



Nature-like fishways


Technical Memorandum

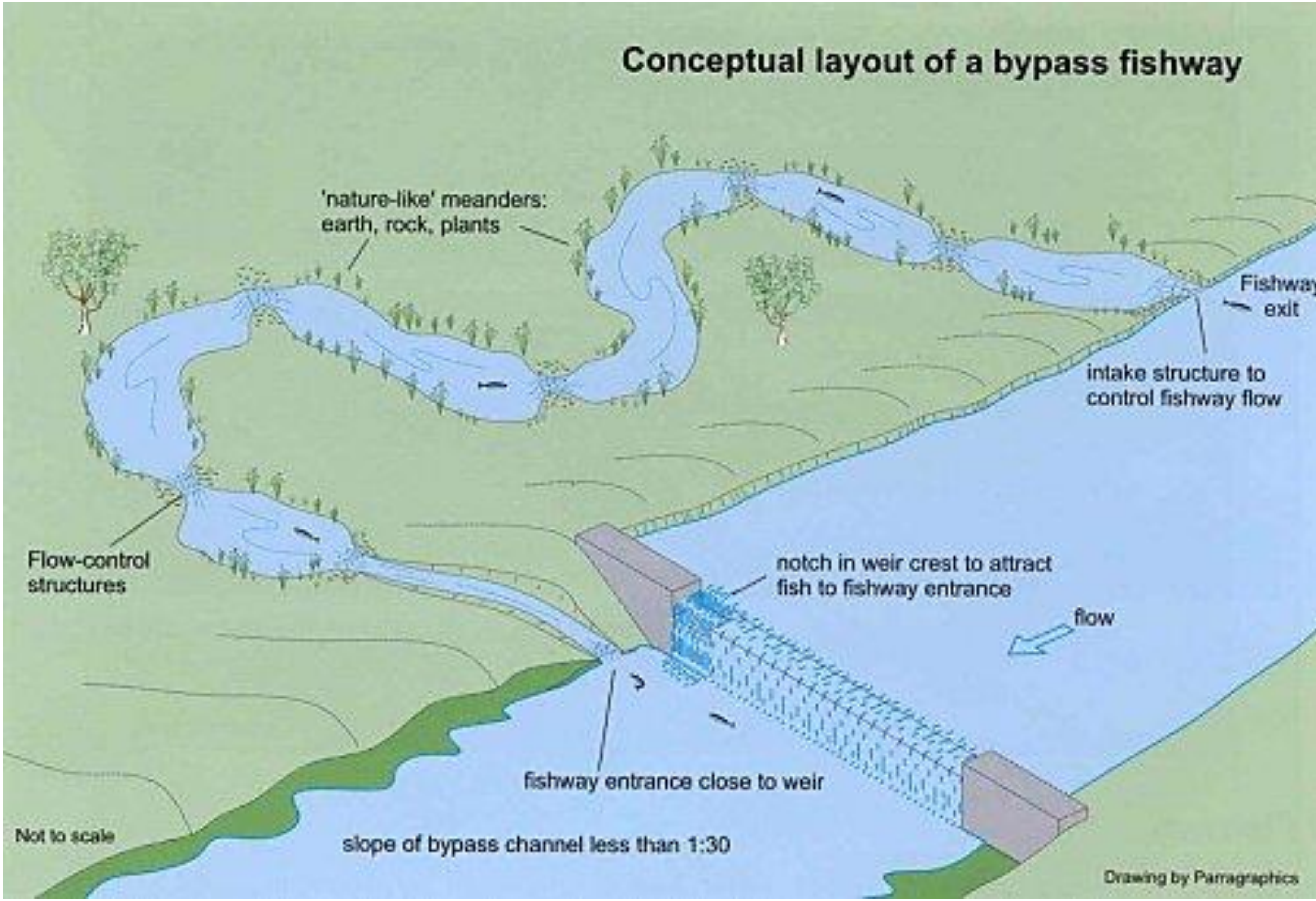
Federal Interagency
Nature-like Fishway Passage Design Guidelines for
Atlantic Coast Diadromous Fishes

May 2016

- Roughened ramps
- Step-pools
- Side channels

Nature-like: roughened ramps and step-pools

Nature-like: side channels



https://www.dpi.nsw.gov.au/fishing/habitat/rehabilitating/fishways

Nature-like: side channels

Bypass, Gave de Pau (France) to overcome a 5.5 m high dam

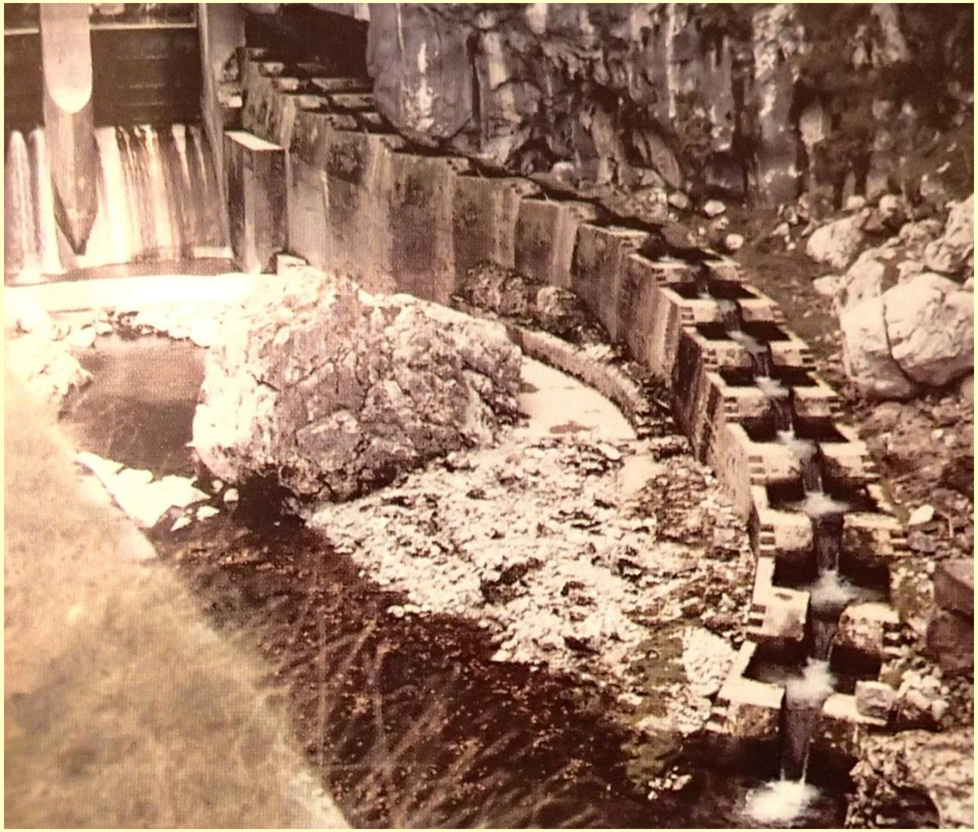
(Ravichandran & Semwa, 2016)

Nature-like: side channels

Nature-like: side channels

General steps on fish pass design & construction

- Topographic survey
- Flow measurements
- Target species
- Hidrauylic considerations
- Choosing the best option
- Building phase
- Monitoring



General steps on fish pass design & construction

We have decided to build a fish pass, we now need to:

1. Determine **minimum size** and **cost** of fishway that will pass the expected maximum run with the least possible delay.
2. **Delays** can occur in two major areas: (a) fishway entrance, and (b) during passage

3. Decide best location, and then focus on passage.

4. Need to match hydraulic conditions with swimming capacities of target species (speed and turbulences)

5. Also need to calculate pool volume to accommodate run peaks

General steps on fish pass design & construction

Before starting to think about **where** and **how**, we need to have information on :

1. Local topography
2. Flows and water levels
3. Target species and fish behaviour

Where? best location for the pass should also consider ease of access for both construction and maintenance

How? This will depend on (a) flow requirements,
(b) resting pools, (c) auxiliary attraction discharge,
(d) protecting the pass against river debris,
(e) monitoring needs (gates, trapping devices, etc.)

General steps on fish pass design & construction

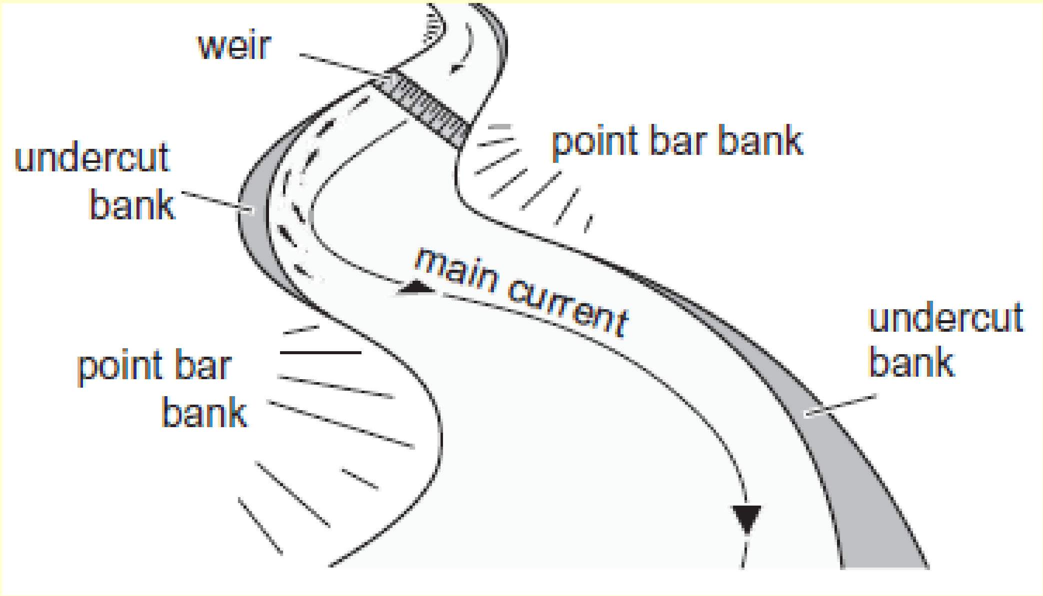
Also need to consider

1. Legal permits and licences
2. Access
3. Working a river without water … a difficult challenge!
4. Avoiding toxic leaks from working areas that could impact on fauna
5. Building challenges, weather, and delays
6. Risk and Safety Management: prepare for the unexpected

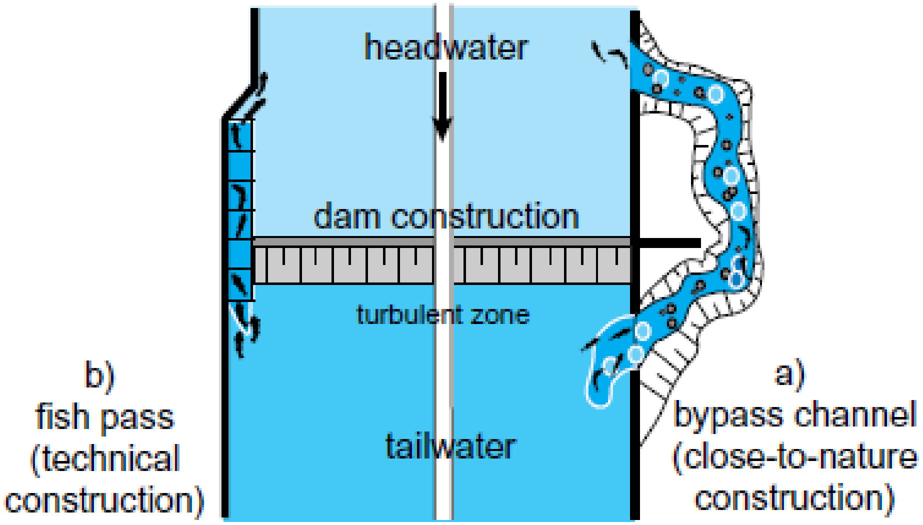
Designing the fishpass: the survey

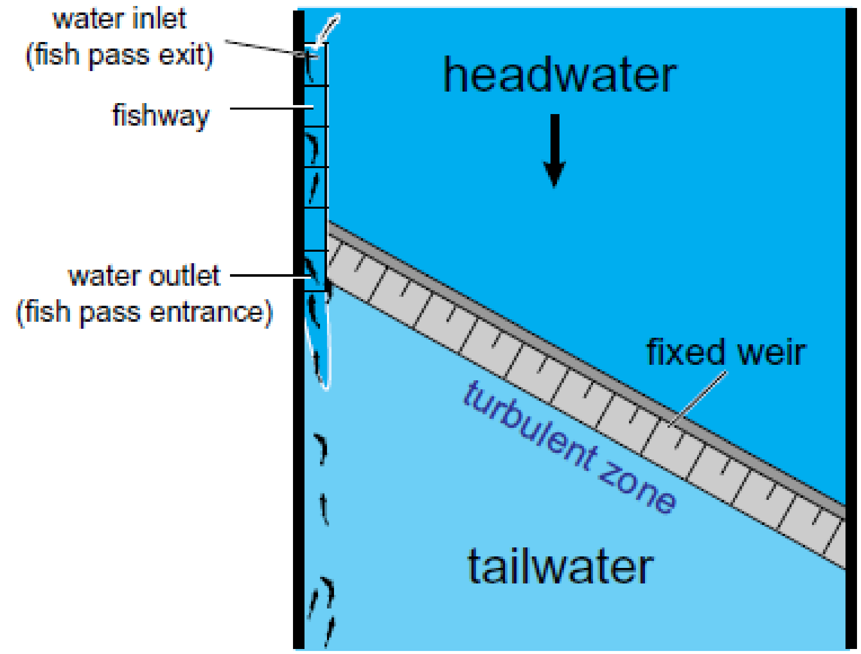
We need a **topographic survey** to:

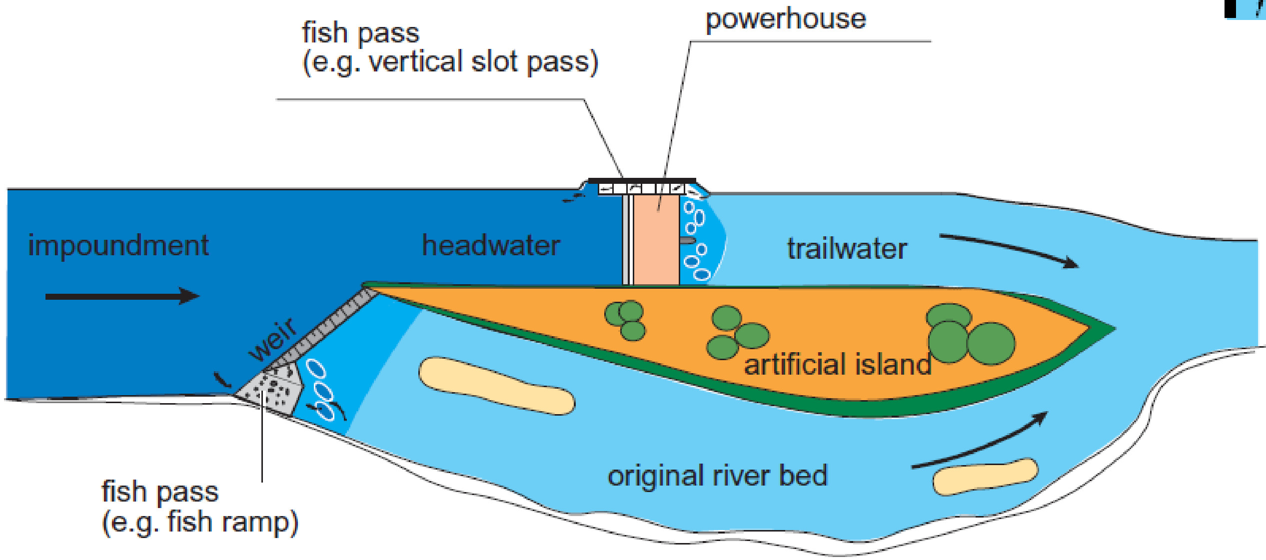
1. Know the characteristics of the river and the barrier in order to develop a plan (one or more fishpasses may be needed)
2. Determine the deep and shallow ends
3. Plan a route of access for heavy machinery into the building site



Designing the fishpass: where?

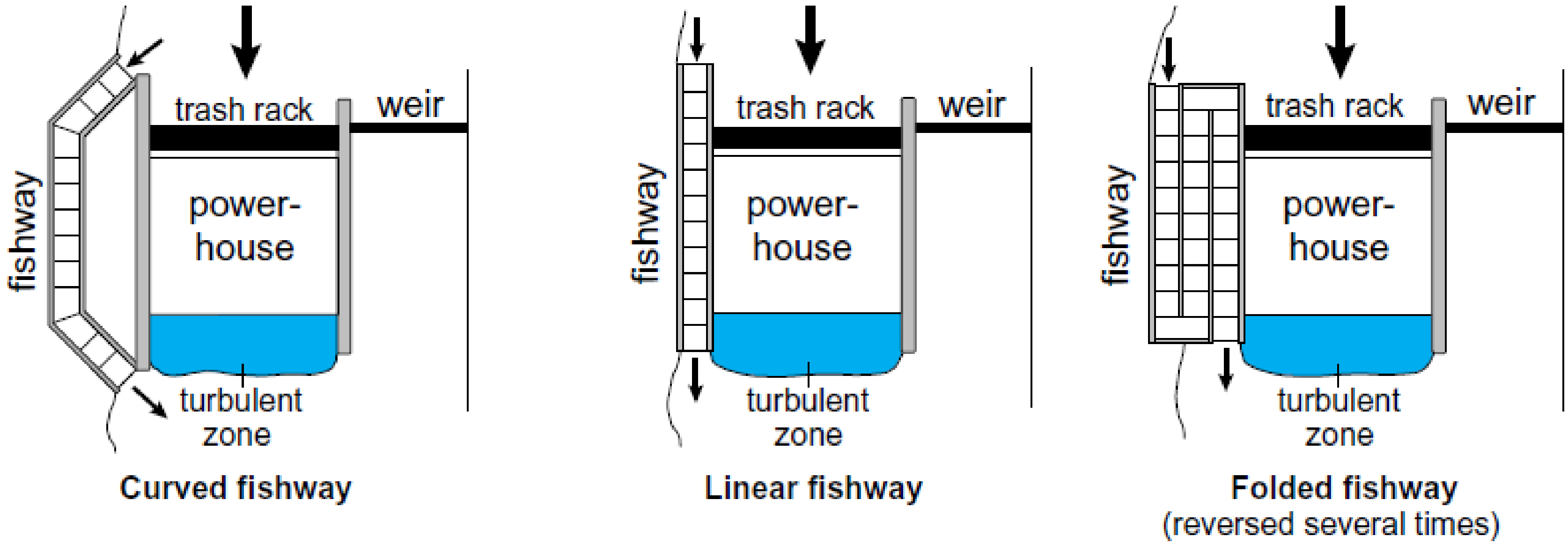






Welcomme (2002)

Designing the fishpass: where?



- Fishpass entrance: must be foud quickly to avoid migration delays
- Consider: need for attraction flow, fishway capacity (to avoid crowding), exit
- Salmonids and other homing fish **swim upstream**

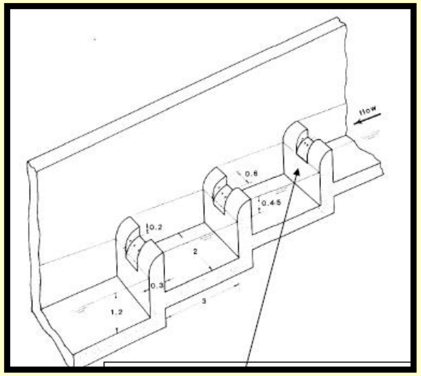
Welcomme (2002)

Designing the fishpass: flows and fish behaviour

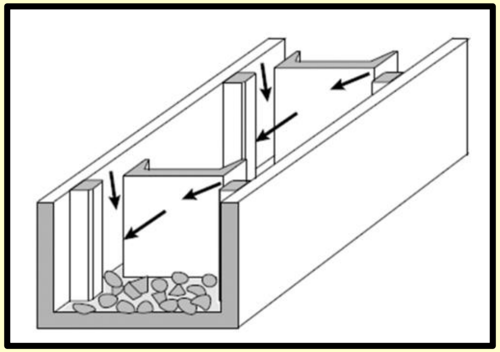
- We need information on flows & water levels, the points where fish attempt to leap and resting areas
- Are there any predators taking advantage around the obstacle?
- Where are the turbulent areas?

Fish pass Design criteria

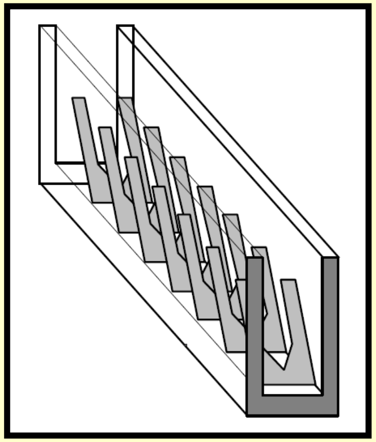
1. Pool & Weir



2. Vertical slot



3. Denil fish pass



Fishpass selection criteria

		Pool-type			Assisted		Chutes		
		Pool & weir	Vertical slot	Pool & orifice	Fish lock	Fish lift	Denil	Larinier	Chevron
Species	Salmonids								
	Fast coarse								
	Slow coarse								
	Alosa								
	Eel								
Slope	<5%								
	5-10%								
	10-20%								
	20-25%								
	>25%								
Debris resilience	High								
Head range	Large								

Target species and hydraulic considerations

Table 4 Some simple guidelines for basic parameters of pool, and baffle, fish passes

Pass Parameters		SPECIES			
		Coarse fish	Brown trout	Sea trout	Salmon
POOL PASS	Max Vel (ms^{-1})	1.4-2.0	1.7-2.4	2.4-3.0	3.0-3.4
	Head drop (m)	0.1-0.2	0.15-0.3	0.3-0.45	0.45-0.6*
BAFFLED PASS	Mean Vel (ms^{-1})	1.1-1.3	1.2-1.6	1.3-2.0	1.3-2.0
	Length (m)	8-10	8-10	10-12	10-12

Welcomme (2002)

Criteria for choosing a fishpass depending on target species, flow variation, barrier height, and river width (Galicia, Spain)

Species	Small flow variation	Large flow variation	Barrier height < 2 m	Barrier height > 2 m	River width < 30 m	River width > 30 m
Salmonids	Pool & weir; bafles	Vertical slot	Baffles	Pool & weir, Vertical slot	Pool & weir; Baffles	Vertical slot, several barriers
Lamprey	Baffles	Vertical slot	Baffles	Vertical slot	Baffles	Vertical slot
Cyprinids	Pool & weir	Vertical slot	Pool & weir	Vertical slot	Pool & weir	several barriers
Other aquatic fauna	Partial lowering/breaching of barrier					

Pool & Weir

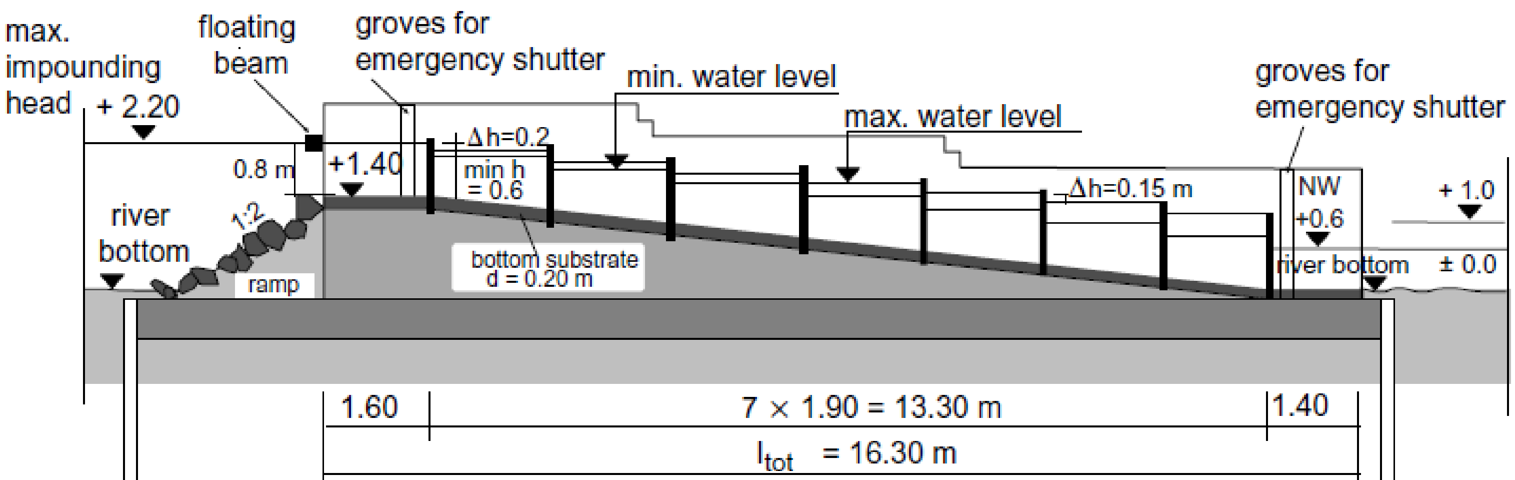
Pros	Cons
• Relatively low water requirements, between 0.05 and 0.5 m3/s for normal orifice dimensions	• Very sensitive to variations in headwater levels
• Well suited to leaping fish, such as salmonids	• Does not work well for non-leaping species
• Relatively easy to build	• Regular maintenance required, clogging can greatly affect performance
• Tried and tested, lots of experience	• It needs more space than chute-type fishways

Recommended dimensions for pool passes

Fish species to be considered	Pool dimensions[1)] in m: length l_b	Pool dimensions[1)] in m: width b	Pool dimensions[1)] in m: water depth h	Dimensions of submerged orifices in m: width b_S	Dimensions of submerged orifices in m: height h_S[2)]	Dimensions of the notches[3)] in m: width b_a	Dimensions of the notches[3)] in m: height h_a	Discharge[4)] through the fish pass m^3/s	Max. difference in water level[6)] Δh in m
Sturgeon[5)]	5 – 6	2.5 – 3	1.5 – 2	1.5	1	-	-	2.5	0.20
Salmon, Sea trout, Huchen	2.5 – 3	1.6 – 2	0.8 – 1.0	0.4 – 0.5	0.3 – 0.4	0.3	0.3	0.2 – 0.5	0.20
Grayling, Chub, Bream, others	1.4 – 2	1.0 – 1.5	0.6 – 0.8	0.25 – 0.35	0.25 – 0.35	0.25	0.25	0.08 – 0.2	0.20
upper trout zone	> 1.0	> 0.8	> 0.6	0.2	0.2	0.2	0.2	0.05 – 0.1	0.20

Welcomme (2002)

Design example for cyprinids and other weak swimmers



Calculations

1. Water level differences between headwater and tailwater= 2.20-0.60= 1.60
2. Pool dimensions from the table above: width= 1.4 m; depth= 0.6; cuadrangular orifice, 0.30m; weir thickness=0.10 m
3. Jump= 0.20 m. Number of jumps= 1.60/0.20= 8. Number of pools= 8-1=7; with higher tailwater levels, the water level difference falls to 2.20-1.00= 1.20 m (0.15 m leap)
4. Flow speed= $\sqrt{2g * 0.20} =$ 1.98 m/s< 2.00. If we used the higher tailwater levels, flow speed= $\sqrt{2g * 0.15} =$ 1.71 m/s
5. Orifice dimensions= bs = hs = 0.3 m; section= 0.09 m^2
6. Discharge (using a discharge coefficient-Ψ- of 0.75, between 0.65-0.85)
   Qmax= Ψ*section*flow speed= 0.75*0.09*1.98= 0.134 m^3/s; Q min= 0.75*0.09*1.71= 0.115 m^3/s
6. To calculate the length of each pool, we use power density equation: Power/Volume
   power density= density*gravity*pool jump*discharge/ volume; volume= power/power density

The maximum of power density allowed to avoid turbulence is 150 W/m^3; V= 1000*9.81*0.20*0.134/150= 1,75 m^3
We consider that only a half of the leap between pools is contributing to disipate energy; pool volume= width*length*depth= 1.40*l*(0.60+0.20/2); l= 1.75/1.40*0.70= 1.79 m. Important to add to this length, weir thickness= 0.10; l+d= 1.89 m

Adapted from Welcomme (2002)

Vertical slot

Pros	Cons
• Well suited to a range of species, including small fish and weak swimmers	• Need more space to overcome the same height than chute-type fishways
• Can accommodate varying headwater levels	• Generally more expensive to build than other types
• Unaffected by varying tailwater levels	• Regular maintenance required
• Can cope with varying discharges from just over 100 l/s to several m3/s	• Optimal design of slots is critical to avoid undesired turbulences

Vertical slot: minimum dimensions

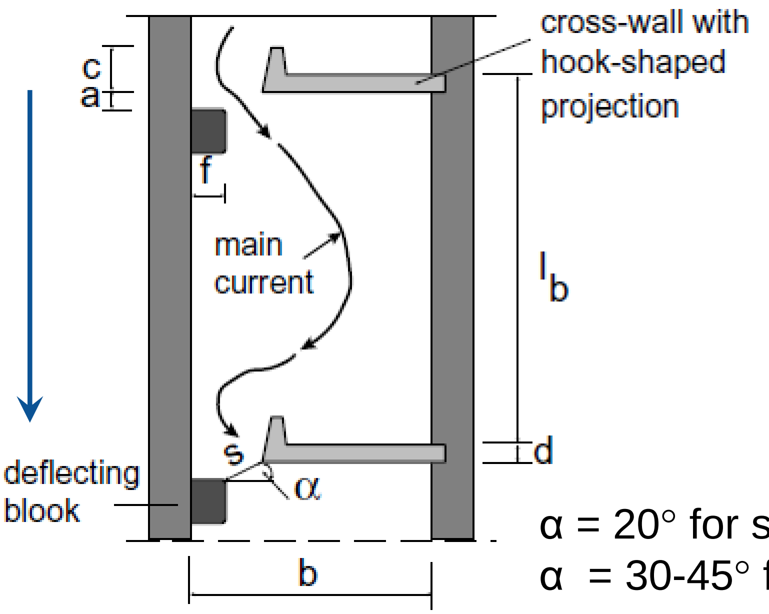
Fish fauna to be considered		Grayling, bream, chub, others		Sturgeon
		Brown trout	Salmon, sea trout, huchen	
Slot width	s	0.15 – 0.17	0.30	0.60
Pool width	b	1.20	1.80	3.00
Pool length	l_b	1.90	2.75 – 3.00	5.00
Length of projection	c	0.16	0.18	0.40
Stagger distance	a	0.06 – 0.10	0.14	0.30
Width of deflecting block	f	0.16	0.40	0.84
Water level difference	h	0.20	0.20	0.20
Min. depth of water	h_{min}	0.50	0.75	1.30
Required discharge[1]	Q in m^3/s	0.14 – 0.16	0.41	1.40

[1] calculated for $\Delta h = 0.20$ m and h_{min}

Welcomme (2002)

Vertical slot: minimum dimensions

The aim is to avoid a straight flow from one pool to the next



α = 20° for small pools

α = 30-45° for large pools

Welcomme (2002)

- Slot ensures uniform vertical velocity profile
- Bottom substrate should ideally be the same as natural substrate
- Bottom substrate facilitates ascend for benthic fauna and reduces flow velocities

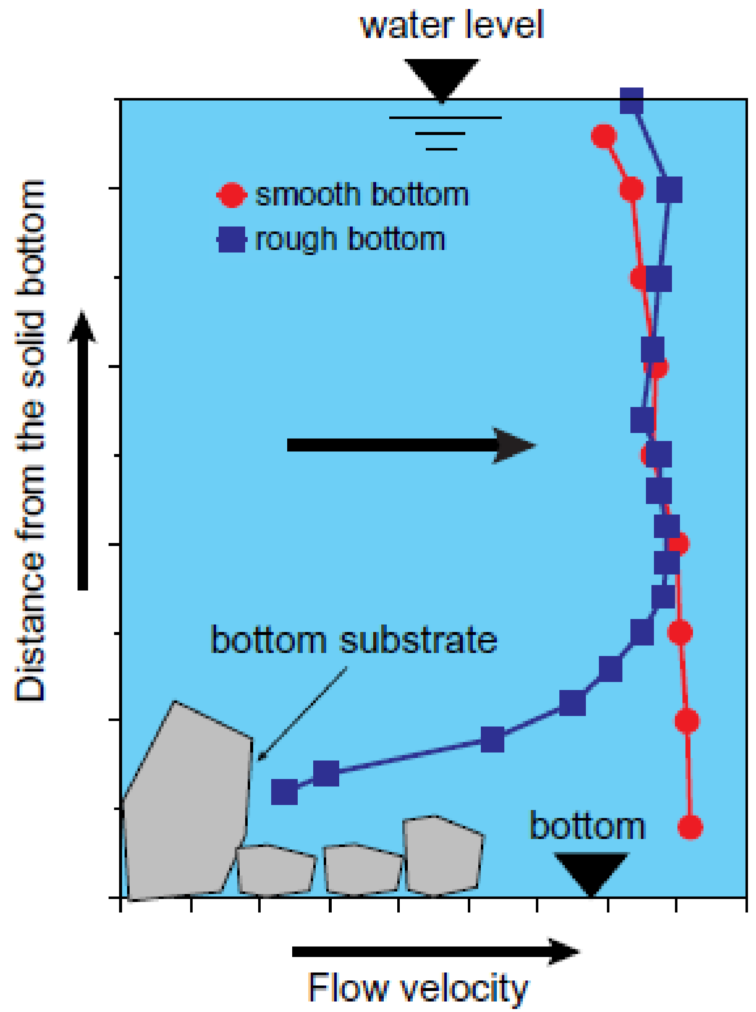


Fig. 5.17: Flow velocity distribution in the slot, comparison between smooth and rough bottom (after GEBLER, 1991).

Welcomme (2002)

Designing the vertical slot: how to calculate *Q*

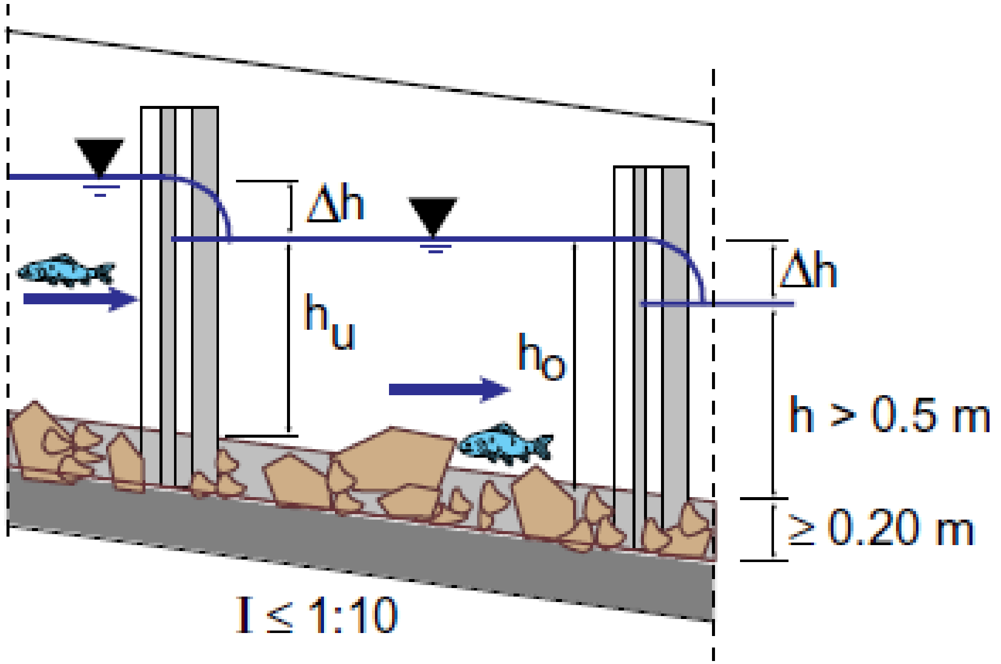
Speed at the slot comes from

$$v_s = \sqrt{2g\Delta h}.$$

To calculate the discharge flow,

$$Q = \frac{2}{3}\mu_r s \sqrt{2g}\, h_o^{3/2}$$

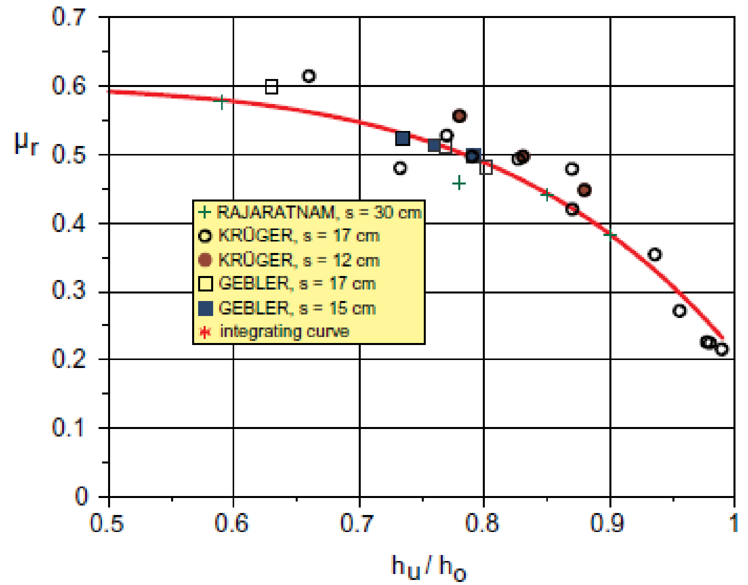
where $\mu_r = f(h_u/h_o)$



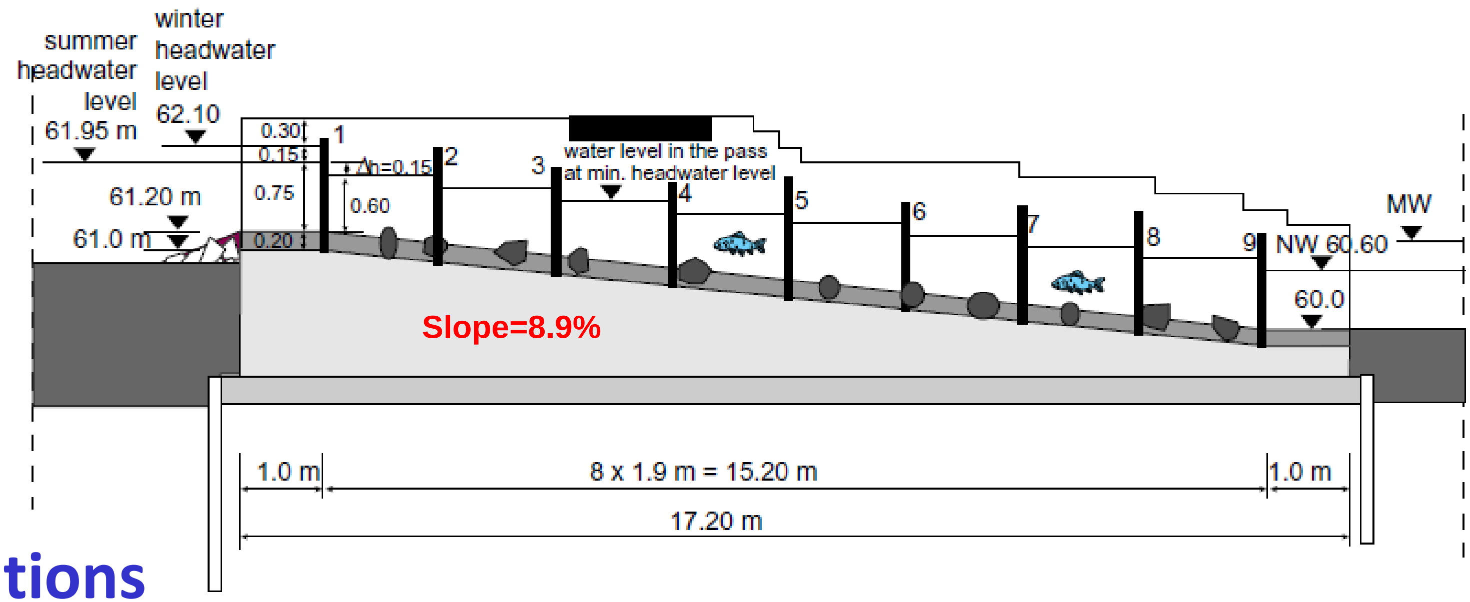
1. Estimate discharge Flow (Q) using mean diff between tailwater and headwater levels

2. The headwater depth $\mathbf{h_o}$ can be found step-by-step for each crosswall, starting from the last downstream cross-wall

3. At the end, the upper $\mathbf{h_o}$ has to be equal to the headwater level; if not, we iterate again until this is achieved



Designing the vertical slot fishpass: dimensions



Calculations

- Starting considerations: No larger salmonids; slot width= 0.17 m; pool length= 1.90 m; pool width= 1.40 m.
- Discharge, flow velocity and turbulence conditions determined for minimum and maximum headwater levels (62.10-60.60= 1.50 m)
- Step = 0.20 m. No. of steps= 1.50/0.20= 7.5. No. of pools= 8-1=7; with higher tailwater levels, the water level difference falls to 61.95-60.60= 1.35 m (0.15 m leap).
- To be safe we will use 9 pools to reach a 0.15 m leap (9*0.15= 1.35 m), corresponding to summer water levels

Designing the vertical slot fishpass

- Flow speed= $\sqrt{2g * 0.20} = 1.98$ m/s< 2.00. If we used the summer headwater level, flow speed= $\sqrt{2g * 0.15} = 1.71$ m/s
- Section= 0.75*0.17= 0.128 m2; Discharge coefficient from chart above ; h_u/h_0=0.6/0.75=0.8, μ=0.49)
- Discharge Qmax= 2/3* μ *width*$h_0^{3/2}$ *$\sqrt{2g}$=0.66*0.49*0.17*$0.75^{3/2}$ *$\sqrt{2g}$=0.16m^3/s
- Pool length using power density equation: Power/Volume; power density= density*gravity*pool jump*discharge/volume; volume (V)= power/power density
- Maximum power density allowed to avoid turbulence is 150 W/m^3; V= 1000*9.81*0.15*0.16/150= 1.57 m^3 (we consider leap = 0.15 m)

Designing the vertical slot fishpass

- Assume only half of the leap between pools disipates energy; pool volume= width*length*depth= 1.40*l*(0.60+0.15/2);
- l= 1.57/1.40*0.675= 1.66 m. We could take 1.70.
- Remember to add wall thickness to the pool length = 0.10; l+d= 1.80 m. This is a minimum, in the example they took 1.90 instead of 1.80 m.
- For winter highwater level, h_0 = 0.90 m, and 0.75 m for h_u. This changes μ to 0.46, and h_0 to 0.90, and the discharge would be: $Q= 0.66*0.46*0.17*0.90^{3/2} *\sqrt{2g}$=0.197 m3/s
- The power density is: 1000*9.81*0.197*0.15/1.8*1.4*(0.75+0.15/2)= 139.4 W/m^3

Baffle Fish passes

Pros	Cons
• Steep slopes possible, low space required	• Much affected by variations in headwater (max 20 cm)
• Can be prefabricated; easily retrofited into existing dams	• Easily clogged by debris
• Largely unaffected by variations in tailwater level	• Regular maintenance required
• Good attraction flow	• High discharge per head difference compared to other passes

Designing the Denil fishpass

- Channel is always straight, bends are not allowed as they impact on flow; changes of direction achieved with intermediate pools.
- Fish must ascend in one episode of continuous swimming, they cannot rest
- Channel length must be chosen in accordance with the swimming performance of fish with low stamina.
- A resting pool is built every 6-8 m for cyprinids or every 10-12 m for salmonids (it depends also on the height of each flight, 1 m for cyprinids, 2 m for salmonids)
- The volumetric power dissipation (power density for conversion of hydraulic energy) of the resting pools should be less than $E = 25\text{-}50\ W/m^3$.

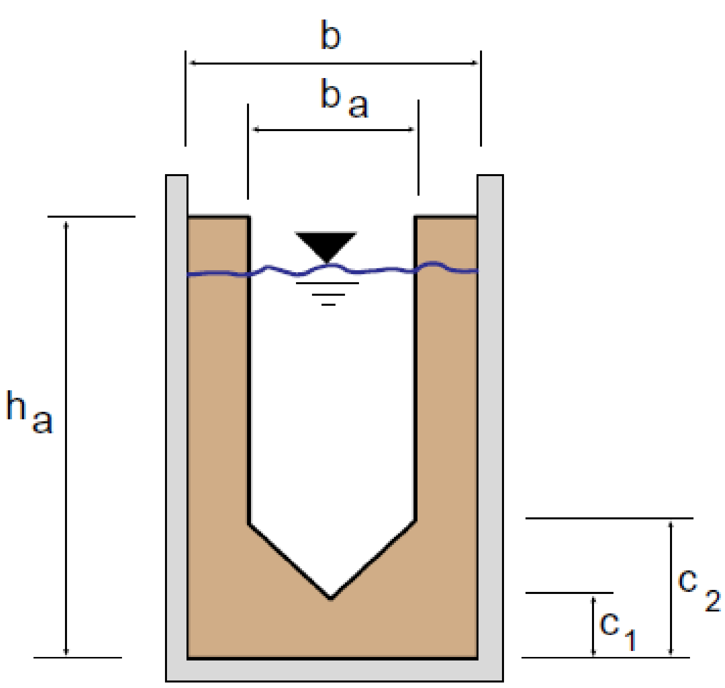
Designing the Denil fishpass

- Channel width (b) = 0.8-1.2 m for large salmomids and 0.6-0.9 m for brown trout and cyprinids
- Baffles edges should be well rounded to avoid fish injuries
- Baffles are inclined 45° upstream and have a U-shaped section that is triangular in its lower part.
- Baffle dimensions depend on channel width and can only vary slightly as deviations impact on optimal flow pattern
- Water flow should always reach the inlet (fish pass exit) from the direction that represents an upstream prolongation of the channel axis.
- There should be some means to close off the flow to allow fishpass maintenance

Designing the Denil fishpass

Table 5.5: Guide values for the design of baffles in a Denil pass depending on the selected channel width, after LONNEBJERG (1980) and LARINIER (1992b)

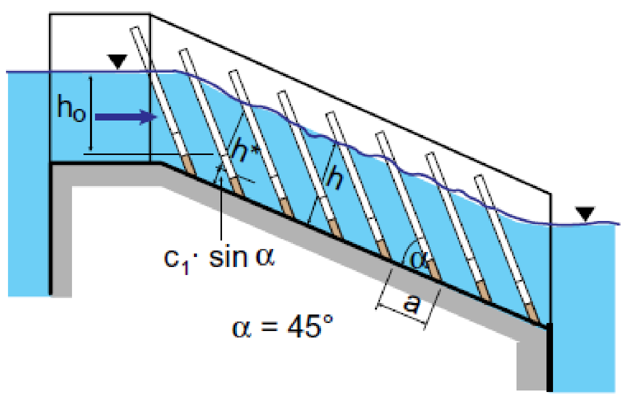
		Tolerance range	Recommended guide values
Baffle width	b_a/b	0.5 – 0.6	0.58
Baffle spacing	a/b	0.5 – 0.9	0.66
Distance between the lowest point of the cutout and the bottom	c_1/b	0.23 – 0.32	0.25
Depth of the triangular section	c_2/c_1	2	2

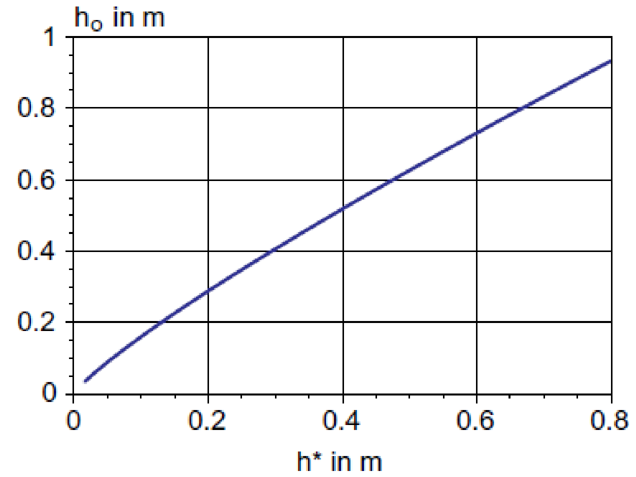


Designing the Denil fishpass

Table 5.4: Guide values for channel widths and slopes in Denil passes (LARINIER, 1983)

Fish fauna to be considered	Channel width b in m	Recommended slopes I as %	1 : n	Water discharge[1)] Q in m^3/s for $h^*/b_a = 1.5$
Brown trout, Cyprinds and others	0.6	20.0	1 : 5	0.26
	0.7	17.0	1 : 5.88	0.35
	0.8	15.0	1 : 6.67	0.46
	0.9	13.5	1 : 7.4	0.58
Salmon Sea trout and Huchen	0.8	20.0	1 : 5	0.53
	0.9	17.5	1 : 5.7	0.66
	1.0	16.0	1 : 6.25	0.82
	1.2	13.0	1 : 7.7	1.17





IMPORTANT

Ensure:

$h^* > 0.35$ m and

$h^*/ba = 1.5$ to 1.8

at max discharge

Designing the Denil fishpass

- Denil channel must project sufficiently far into the tailwater that the outlet (fish pass entrance) so that it is at least at the level of water in the channel even at low water.
- During high tailwater levels, the backwater influence is displaced further into the channel, without having any great effect on the current patterns in the fish pass.
- The most important thing is to check, before making the decision to chose this fishpass, if the down level goes down faster than the high one; if this is the case, one should not use a Denil fishpass.

Designing the Denil fishpass

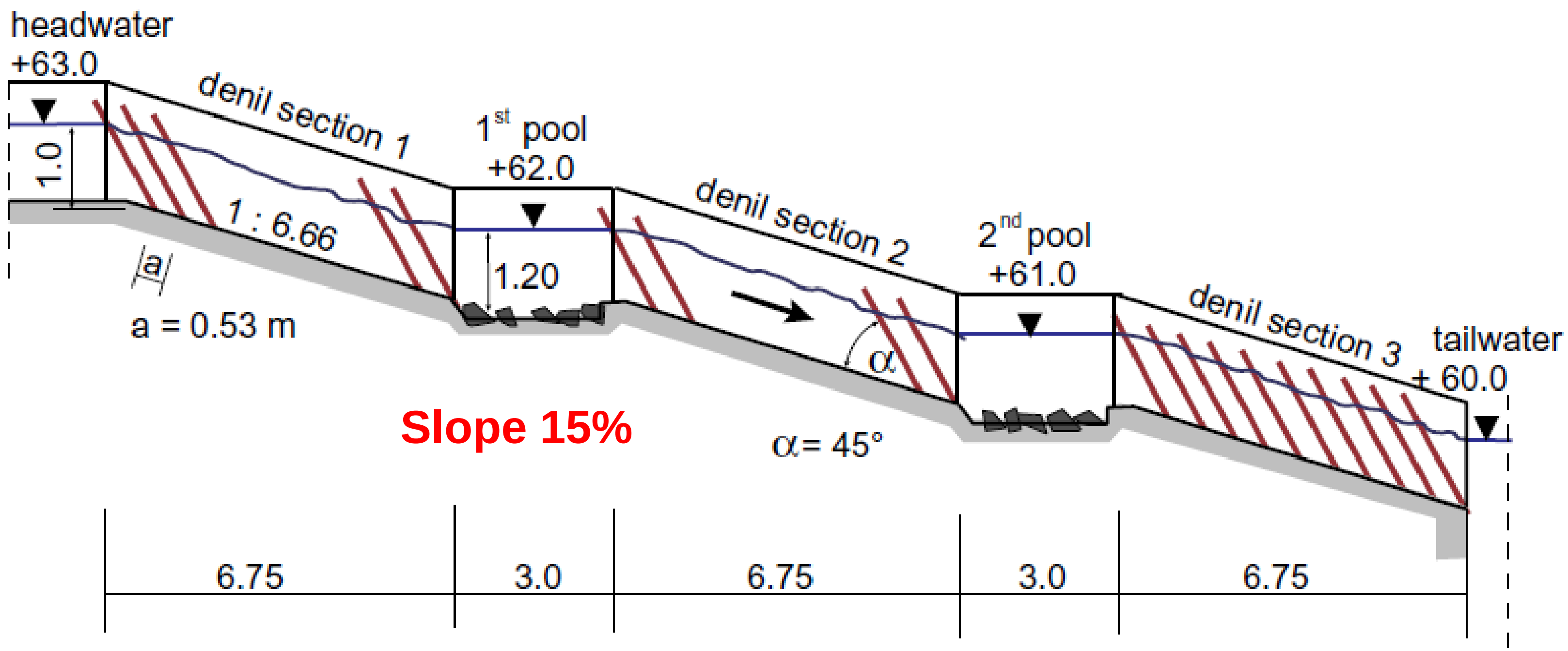
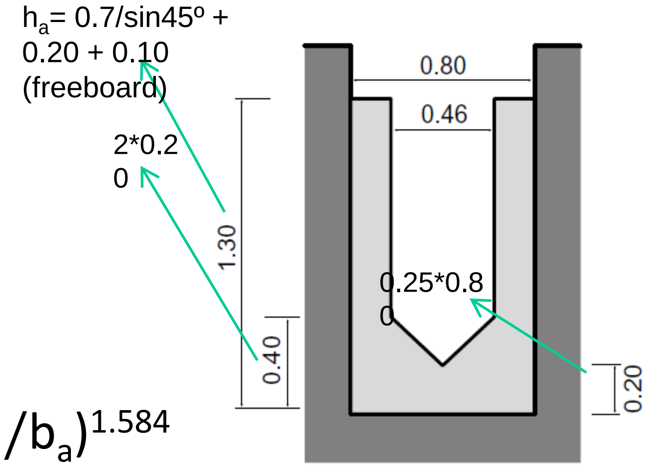


Figure 5.34: Longitudinal section of the fish pass

Calculations

- Max. difference in water level (headwater-tailwater) = 3.0 m
- Fish pass fitted in slope, width and discharge flow at a time (see table)
- We chose width = 0.8 m and as a result, 15% slope and discharge = 0.46 m^3/s

Designing the Denil fishpass



Hydraulic calculations (I)

1. Calculate desired discharge using tables above as a function of slope and channel width

2. Kruger's equation (1944): $Q = 1.35 * b_a^{2.5} * \sqrt{gS} * (h^* / b_a)^{1.584}$

3. We need to divide these 3 m in several flighs to accommodate weak swimmers

4. Each ramp can overcome a maximum of 6-8 m and 1 m height. So we will divide into 3 x 1 m high flights; Using the chosen slope , 6.67 m is required for one of the three channels, that we will get to 6.75 m

5. We will set a resting pool between two ramps, using the equation:

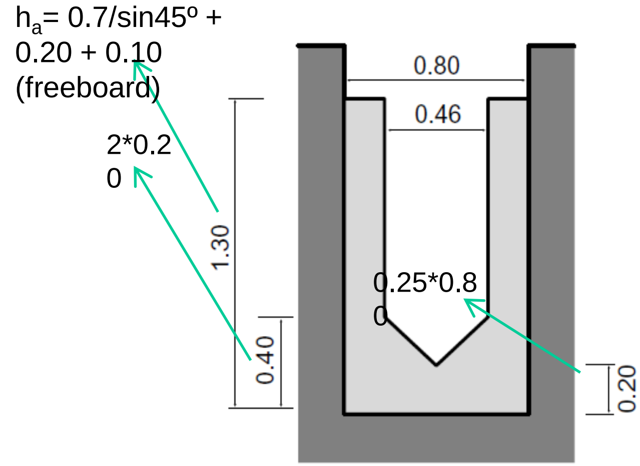
$$E = \frac{\frac{\rho}{2} Q v^2}{b_m h_m l_b} < 25 \text{ to } 50 \text{ W/m}^3 \qquad (5.11)$$

where b_m, h_m, l_b are the mean width, water depth and length of the resting pools and $v = Q/(h^* \cdot b_a)$.

6. Baffle spacing would be: a=0.66*0.8= 0.53 m, and the other dimensions will be taken from the recommended ones; h^*/b_a= 1.5; so as at the same time, b_a/b=0.58; b_a=0.8*0.58= 0.46 m. Now we can calculate h^* = 1.5* b_a= 0.70 m and rest of dimensions

Designing the Denil fishpass

Hydraulic calculations (II)



7. To finish, we need to design the resting pools using the previous equation about power dissipation, to be sure that the power density is less than the required 35 W/m3 (25-50 W/m3)

$$Q = 1.35 \cdot b_a^{2.5} \cdot \sqrt{gS_*} \cdot (h_*/b_a)^{1.584} = 1.35 \cdot 0.46^{2.5} \cdot \sqrt{9.81 \cdot 0.15} \cdot (0.7/0.46)^{1.584} = 0.457 \text{ m}^3/\text{s}$$

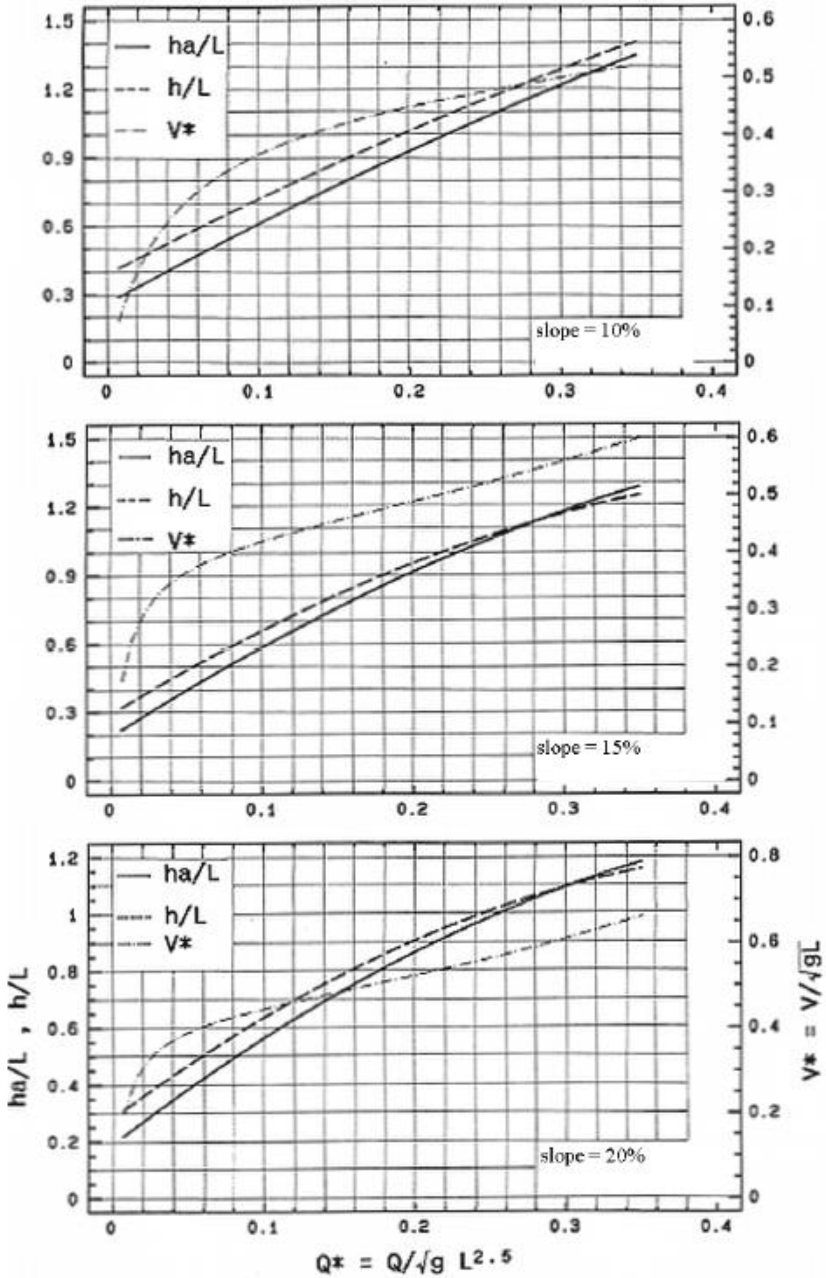
8. The dimensions of the resting pools (depth= 1.20 m) can be found with E = 35 W/m3 and the flow velocity: $v = Q/A \approx Q/(b_a \cdot h_*) = 1.42$ m/s

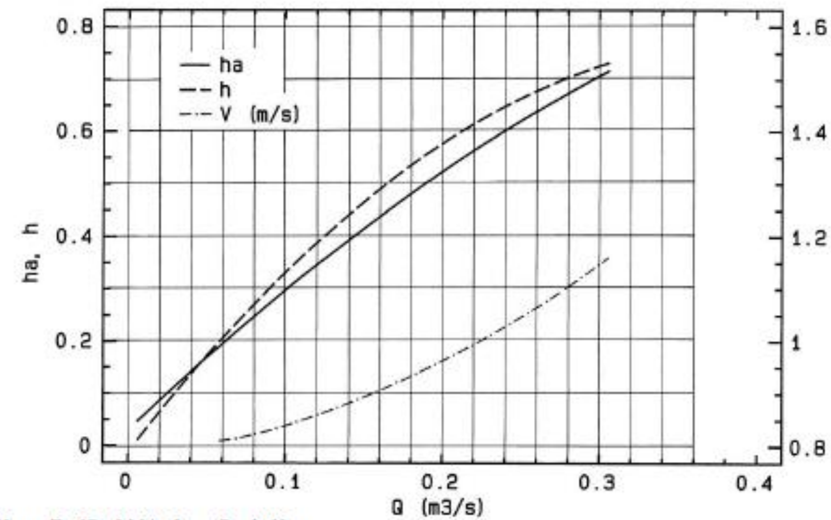
9. So we would need an area (A_{nec}) of: $A_{nec} = l_b \cdot b_m = (\rho/2 \cdot Q \cdot v^2)/(h_m \cdot E) =$

$= (1000/2 \cdot 0.457 \cdot 1.42^2)/(1.20 \cdot 35) = 10.97$ m2

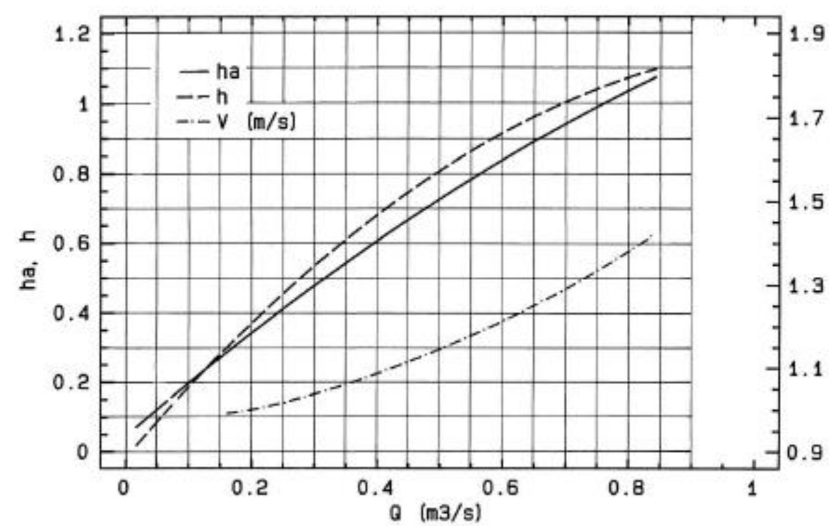
10. We could choose a length (l_b) of 3 m and a width of 4 m

Designing the Denil fishpass





Plane Baffle 20% slope L=0.60m



Plane Baffle 20% slope L=0.90m

From Clay (1995)

Monitoring & maintenance

Blocked Migration: Fish Ladders On U.S. Dams Are Not Effective

Fishways on rivers in the U.S. Northeast are failing, with less than 3 percent of one key species making it upriver to their spawning grounds, according to a new study. The researchers' findings provide a cautionary tale for other nations

Helping hand. Maryland's Conowingo Dam has a fish lift. Edward J. (

Commons

Published online 17 January 2008 | Nature | doi:10.1038/news.2008.445

News

Fish ladders of doom

Attempts to help river-spawning fish in Brazil may have led to their decline.

Matt Kaplan

Throughout much of South America, fish 'ladders' designed to help fish swim up-river to breeding grounds are actually sending the animals to their death, with no chance of escape. That's the conclusion of a review of river conditions by two researchers in Brazil.

Catfish might go up a fish ladder to

Fish Ladders and Elevators Not Working

By **Jill U Adams** | Jan. 25, 2013 , 3:30 PM

What's the Dam Problem

Why it's so hard to design a fish ladder that works

INTERNATIONAL RIVERS people • water • life

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THE BASICS | SOLUTIONS | WHERE WE WORK | LEARN MORE | GET INVOLVED

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Do Not Pass Go: The Failed Promise of Fish Ladders

By: Lori Pottinger

Date: Tuesday, March 19, 2013

The future of fish passage science, engineering, and practice

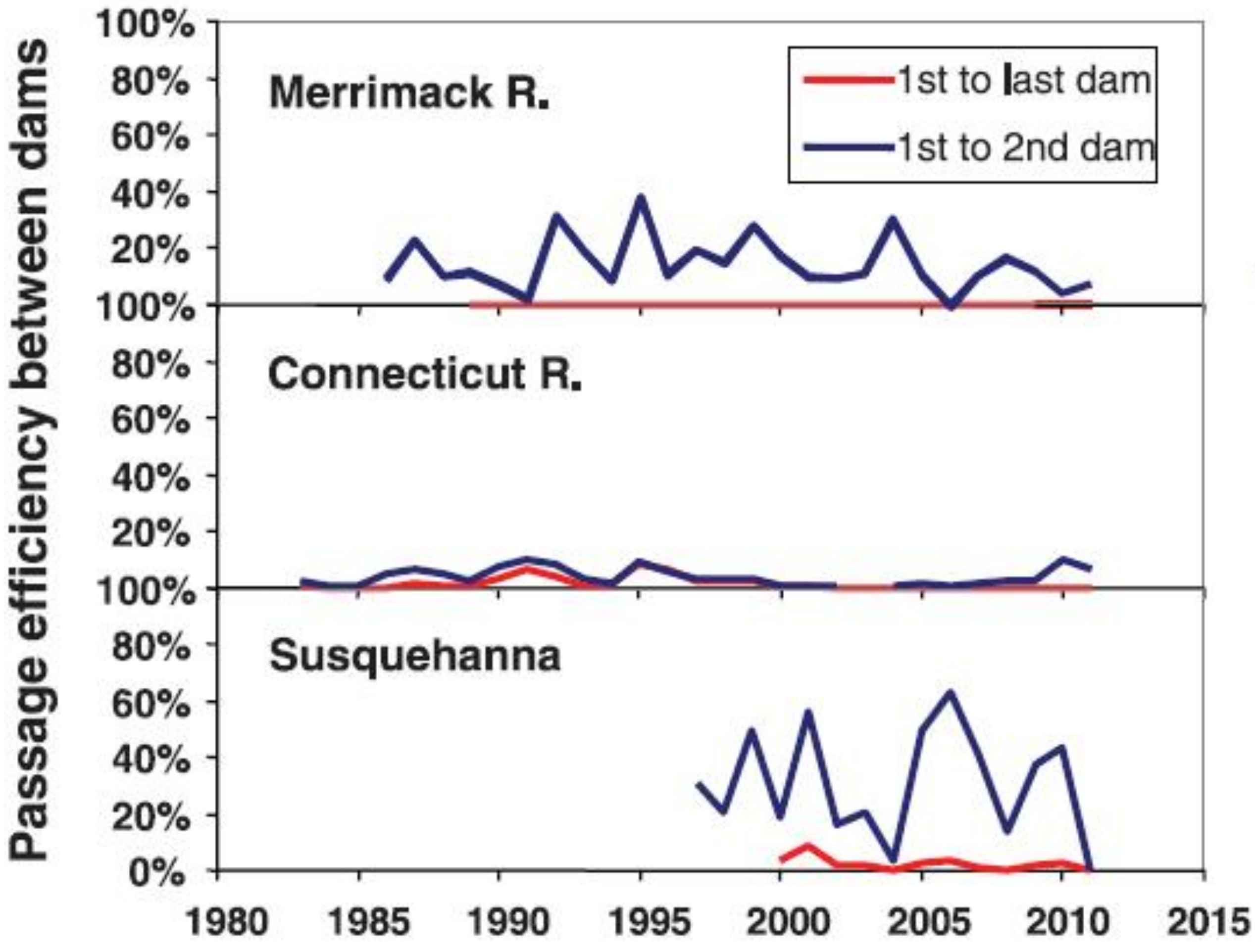
Ana T. Silva[1,2] | Martyn C. Lucas[3] | Theodore Castro-Santos[4] | Christos Katopodis[5] Lee J. Baumgartner[6] | Jason D. Thiem[7] | Kim Aarestrup[8] | Paulo S. Pompeu[9] | Gordon C. O'Brien[10] | Douglas C. Braun[11,12] | Nicholas J. Burnett[11] | David Z. Zhu[13] | Hans-Petter Fjeldstad[14] | Torbjørn Forseth[1] | Nallamuthu Rajaratnam[13] | John G. Williams[15] | Steven J. Cooke[2]

Conservation Letters 6:4 July/August (2013) 280–286

POLICY PERSPECTIVE

Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies

J. Jed Brown[1], Karin E. Limburg[2], John R. Waldman[3], Kurt Stephenson[4], Edward P. Glenn[5], Francis Juanes[6], & Adrian Jordaan[7]



American shad
(Alosa sapidissima)

Fish passes: review of evidence

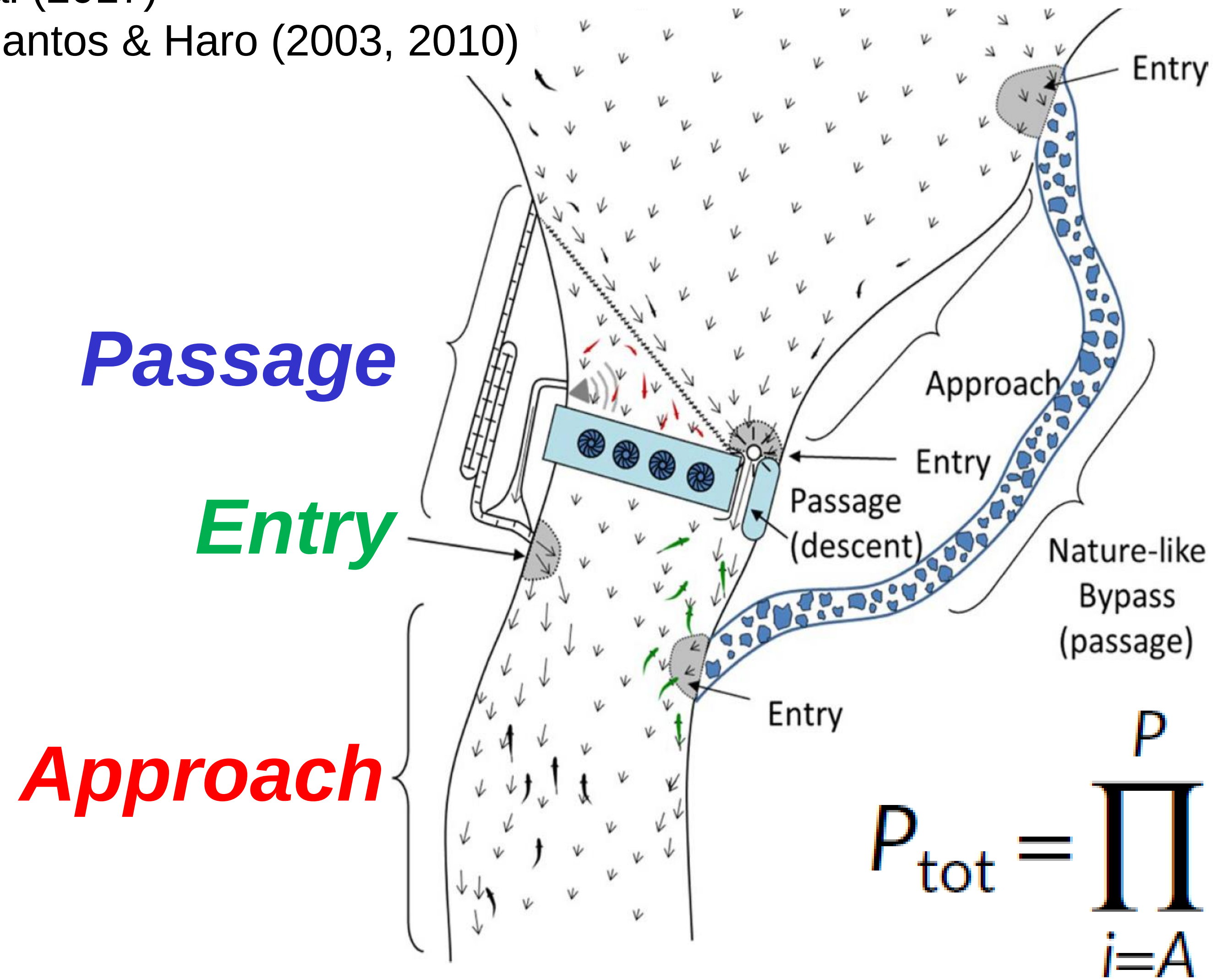
FISH and FISHERIES, 2012, **13**, 450–464

A quantitative assessment of fish passage efficiency

Michael J Noonan, James W A Grant & Christopher D Jackson

- Downstream passage efficiency = 69%,
- Upstream efficiency = 42%
- Salmonids were more successful (62-75%)
- Non-salmonids least successful (21-40%)
- Most ‘traditional’ fish passes **don’t work** and don’t fully mitigate for stream fragmentation

Silva et al (2017)
Castro-Santos & Haro (2003, 2010)



$$P_{tot} = \prod_{i=A}^{P} P_i$$

Total Probability of Passage (P_{tot}):
p(*Approach*) x p(*Entry*) x p(*Passage*)

Marine and Freshwater Behaviour and Physiology
Vol. 42, No. 5, October 2009, 307–313

Taylor & Francis
Taylor & Francis Group

Fish ladders select fish traits on migration – still a growing problem for natural fish populations

Gilson Luiz Volpato[a,b*], Rodrigo Egydio Barreto[a,c], Ana Lúcia Marcondes[b], Paula Sueli Andrade Moreira[b] and Magali Fátima de Barros Ferreira[b]

Table 1. Effects of a fish ladder on physiological traits of upstream migrating curimbatá, *P. lineatus* (Valenciennes 1836), at Porto Primavera hydroelectric power station, River Paraná, São Paulo state, Brazil.

					Statistics					
	Females		Males		Sex × Local		Sex		Local	
Biological traits	Bottom	Top	Bottom	Top	*F*	*P*	*F*	*P*	*F*	*P*
Body weight (kg)	1.3 ± 0.8 (8)	2.4 ± 0.5 (15)	1.5 ± 0.6 (8)	2.0 ± 0.5 (8)	3.39	0.07	0.02	0.88	22.03	**0.0001**
Standard body length (cm)*	35.4 ± 5.7 (8)[a]	46.8 ± 4.0 (15)[b]	38.5 ± 5.4 (8)[a]	43.6 ± 3.5 (8)[b]	4.87	**0.034**	0.07	0.80	31.57	**0.0001**
HSI	0.55 ± 0.3 (8)	0.47 ± 0.1 (15)	0.67 ± 0.1 (8)	0.55 ± 0.1 (8)	0.27	0.61	4.68	**0.038**	3.01	0.09
GSI*	0.86 ± 1.6 (8)[a]	6.90 ± 5.2 (15)[b]	0.54 ± 0.4 (8)[a]	0.55 ± 0.3 (8)[a]	8.60	**0.006**	8.79	**0.005**	9.95	**0.003**
Plasma glucose (mg dL^{-1})	26.0 ± 5.7 (7)	38.7 ± 16.4 (11)	42.1 ± 18.1 (7)	58.4 ± 21.8 (7)	0.03	0.87	9.28	**0.005**	6.05	**0.020**
Hematocrit (%)	41.8 ± 3.8 (8)	39.1 ± 4.8 (8)	43.7 ± 3.0 (6)	40.0 ± 3.4 (6)	0.10	0.76	0.88	0.36	4.31	**0.049**
Leucocrit (%)	1.4 ± 0.5 (8)	0.9 ± 0.8 (8)	0.8 ± 0.8 (6)	0.8 ± 1.2 (6)	0.54	0.47	1.53	0.23	1.60	0.22
Muscle fiber diameter (μ)**										
Red	28.0 ± 6.2 (8)	28.3 ± 3.8 (5)	32.3 ± 7.8 (8)	32.8 ± 5.9 (6)	0.0001	0.99	3.07	0.09	0.05	0.82
White	45.1 ± 4.3 (7)	59.1 ± 7.6 (5)	53.5 ± 17.4 (7)	67.6 ± 23.5 (5)	0.013	0.91	1.71	0.21	6.12	**0.022**
Intermediate	38.6 ± 8.3 (8)	46.6 ± 9.2 (4)	41.0 ± 7.0 (8)	45.2 ± 10.1 (6)	0.33	0.57	0.27	0.87	2.94	0.10

Fish that successfully **ascended** the fish pass were: **larger**, **heavier**, had larger **muscle fibres**, **higher glucose** and **lower haematocrit**

Lessons learned and conclusions

1. Adaptive monitoring (learning what works and does not work) is key
2. Fish passes must be routinely checked and kept in working order: standard operating manuals and spot checks are needed
3. View fishways as **BBS** (**B**est of a **B**ad **S**ituation), stop-gap solutions; barriers remain and the problem has not gone away
4. Even if we had a perfect solution for fish passage we are not addressing ecosystem connectivity, and the lager the barrier the more true this is

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Useful websites and videos

Websites

https://amber.international/
https://www.dpi.nsw.gov.au/fishing/habitat/rehabilitating/fishways
https://www.whooshh.com/
http://www.fithydro.eu
http://damremoval.eu/

Videos

Whooshh system

https://www.youtube.com/watch?v=nopg9JSTTzg

Plunging flow in a pool and weir fishway

https://www.youtube.com/watch?v=A7K90e4pu3o

Vertical slot flow simulation

https://www.youtube.com/watch?v=pt0RNJNB_EQ
https://www.youtube.com/watch?v=JF0sTRC49_8
https://www.youtube.com/watch?v=Q6XyTrhaGxc

Vertical slot simulation Australia

https://www.youtube.com/watch?v=os1Y0S6s3fs

Thank you for listening
Any Questions?

AMBER website
http://www.amber.international/

AMBER in Facebook
https://www.facebook.com/AMBERtools/

AMBER in Linkedin (River Connectivity Network)
https://www.linkedin.com/groups/1215847/profile