Fish Passes: A brief Introduction

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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:
- **H**arvest
- **H**abitat
- **H**atcheries (AIS)
- **H**ydro (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

Brdlo, 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

...and what happens if they don’t?

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

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

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

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

Importance of seasonal migrations and seasonal activity underestimated

Weir removal in salmonid streams: implications, challenges and practicalities
Carlos Garcia de Leaniz

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
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?

Reconnecting Europe’s Rivers the Smart Way

www.amber.international
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

**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)

Dendritic connectivity index

Cote et al (2009)
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
• Barriers are not just dams. Over 290 different barrier types found in Europe!

Belletti et al (in prep)

• 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’
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**

[Image of fish and ruler showing tompmouth gudgeon]
Endurance of 5 freshwater fish (15 cm) at 10°C

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
The distance that fish can swim diminishes quickly at high velocities

Ascent distance of barbel at various flow velocities

Sanz-Ronda et al. 2015
Fish Pass Design & construction: an introduction
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

Fish passes

Hard-Engineered

Upstream

Volitional

Chutes
- Alaska
- Denil
- Larinier
- Eel

Pool-type
- Pool & weir
- Vertical slot
- Ice harbour
- Serpentine

Assisted
- Locks & lifts
- Archimedes
- Trap & haul
- Fish siphon

Downstream
- Guidance
- Exclusion
- Bypass
- Trap & haul

Nature-like

By-pass
- Side-channels

Ramps
- Roughened
- Step-pool
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 ARDNACRUSHASHA 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

1. Migrating adult fish are attracted to the flow from the ladder.
2. Fish climb the ladder to the holding pool.
3. Crowder pushes fish into the tower.
4. Gate closes, and the tower fills with water.
5. Water carries fish up the tower and into the fish hauling tanker.
6. Vehicle carries fish above the dam and releases them back into the river.

NOAA Fisheries
Assisted fishways: Archimedes screws

Slow rotating Archimedes screws
Assisted fishways: siphon
Assisted fishways: air vacuum

- Swim In
- Slide
- Scan
- Sort
- Accelerate
- Glide
Fish Transport Solutions

see videos at https://www.whooshh.com/
How Does It Work?

- **Accelerator**
  - Positive Pressure Chamber
  - One Way Valve
  - Vacuum Chamber

- **Air Flow**
  - Primary Whooshh Tube (Positive Pressure)
  - Air Blower
  - $p^+$
  - $p^-$
  - Entry Whooshh Tube (Vacuum)
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  Lake Sturgeon
Chinook salmon  Gizzard Shad
Sockeye salmon  American Shad
Coho salmon  Large Mouth Bass
Chum salmon  Northern Pike
Steelhead  Common White Sucker
Atlantic salmon  Longnose Sucker
Asian Carp  Walleye
Common Carp
Rainbow trout
Steelhead
Brown Trout

Swim-in system
Installation in Washington State

530 m length, 50 m high
< 60s tailrace to lake
Nature-like fishways

- Roughened ramps
- Step-pools
- Side channels
Nature-like: roughened ramps and step-pools
Nature-like: side channels

Conceptual layout of a bypass fishway

- 'nature-like' meanders: earth, rock, plants
- Flow-control structures
- Notch in weir crest to attract fish to fishway entrance
- Fishway entrance close to weir
- Fishway exit
- Intake structure to control fishway flow
- Slope of bypass channel less than 1:30

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
- Hydraulic considerations
- Choosing the best option
- Building phase
- Monitoring
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
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 found quickly to avoid migration delays
- Consider: need for attraction flow, fishway capacity (to avoid crowding), exit
- Salmonids and other homing fish swim upstream

Welcombe (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

<table>
<thead>
<tr>
<th>Species</th>
<th>Pool-type</th>
<th>Assisted</th>
<th>Chutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonids</td>
<td>Pool &amp; weir</td>
<td>Fish lock</td>
<td>Denil</td>
</tr>
<tr>
<td>Fast coarse</td>
<td>Vertical slot</td>
<td>Fish lift</td>
<td>Larinier</td>
</tr>
<tr>
<td>Slow coarse</td>
<td>Pool &amp; orifice</td>
<td></td>
<td>Chevron</td>
</tr>
<tr>
<td>Alosa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pool-type</th>
<th>Assisted</th>
<th>Chutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>Head range</td>
<td></td>
</tr>
<tr>
<td>&lt;5%</td>
<td>Large</td>
<td></td>
</tr>
<tr>
<td>5-10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;25%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Debris resilience</th>
<th>Head range</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Large</td>
</tr>
</tbody>
</table>
Target species and hydraulic considerations

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

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

Welcomme (2002)
Criteria for choosing a fishpass depending on target species, flow variation, barrier height, and river width (Galicia, Spain)

<table>
<thead>
<tr>
<th>Species</th>
<th>Small flow variation</th>
<th>Large flow variation</th>
<th>Barrier height &lt; 2 m</th>
<th>Barrier height &gt; 2 m</th>
<th>River width &lt; 30 m</th>
<th>River width &gt; 30 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonids</td>
<td>Pool &amp; weir; baffles</td>
<td>Vertical slot</td>
<td>Baffles</td>
<td>Pool &amp; weir, Vertical slot</td>
<td>Pool &amp; weir; baffles</td>
<td>Vertical slot, several barriers</td>
</tr>
<tr>
<td>Lamprey</td>
<td>Baffles</td>
<td>Vertical slot</td>
<td>Baffles</td>
<td>Vertical slot</td>
<td>Baffles</td>
<td>Vertical slot</td>
</tr>
<tr>
<td>Cyprinids</td>
<td>Pool &amp; weir</td>
<td>Vertical slot</td>
<td>Pool &amp; weir</td>
<td>Vertical slot</td>
<td>Pool &amp; weir</td>
<td>several barriers</td>
</tr>
<tr>
<td>Other aquatic fauna</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Partial lowering/breaching of barrier</td>
<td></td>
</tr>
</tbody>
</table>
Pool & Weir

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

<table>
<thead>
<tr>
<th>Fish species to be considered</th>
<th>Pool dimensions in m</th>
<th>Dimensions of submerged orifices in m</th>
<th>Dimensions of the notches in m</th>
<th>Discharge through the fish pass m³/s</th>
<th>Max. difference in water level Δh in m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>length $l_b$</td>
<td>width $b$</td>
<td>water depth $h$</td>
<td>width $b_S$</td>
<td>height $h_S$</td>
</tr>
<tr>
<td>Sturgeon</td>
<td>5 – 6</td>
<td>2.5 – 3</td>
<td>1.5 – 2</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Salmon, Sea trout, Huchen</td>
<td>2.5 – 3</td>
<td>1.6 – 2</td>
<td>0.8 – 1.0</td>
<td>0.4 – 0.5</td>
<td>0.3 – 0.4</td>
</tr>
<tr>
<td>Grayling, Chub, Bream, others</td>
<td>1.4 – 2</td>
<td>1.0 – 1.5</td>
<td>0.6 – 0.8</td>
<td>0.25 – 0.35</td>
<td>0.25 – 0.35</td>
</tr>
<tr>
<td>upper trout zone</td>
<td>&gt; 1.0</td>
<td>&gt; 0.8</td>
<td>&gt; 0.6</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Welcombe (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; quadrangular 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 = \(\sqrt{2g \cdot 0.20} = 1.98 \text{ m/s} < 2.00\). If we used the higher tailwater levels, flow speed = \(\sqrt{2g \cdot 0.15} = 1.71 \text{ m/s}\)
5. Orifice dimensions = bs = hs = 0.3 m; section = 0.09 m²
6. Discharge (using a discharge coefficient-Ψ- of 0.75, between 0.65-0.85)
   \[ Q_{\text{max}} = \Psi \cdot \text{section} \cdot \text{flow speed} = 0.75 \cdot 0.09 \cdot 1.98 = 0.134 \text{ m}^3/\text{s}; \quad Q_{\text{min}} = 0.75 \cdot 0.09 \cdot 1.71 = 0.115 \text{ m}^3/\text{s} \]
6. To calculate the length of each pool, we use power density equation: Power/Volume
   \[ \text{power density} = \text{density} \cdot \text{gravity} \cdot \text{pool jump} \cdot \text{discharge} / \text{volume} \]; volume = power/power density
   The maximum of power density allowed to avoid turbulence is 150 W/m³; \(V = 1000 \cdot 9.81 \cdot 0.20 \cdot 0.134 / 150 = 1.75 \text{ m}^3\)
   We consider that only a half of the leap between pools is contributing to disipate energy; pool volume = width \cdot length \cdot depth = 1.40 \cdot 1 \cdot (0.60 + 0.20 / 2); \ l = 1.75 / 1.40 \cdot 0.70 = 1.79 \text{ m}. Important to add to this length, weir thickness = 0.10; l+d = 1.89 m

Adapted from Welcomme (2002)
# Vertical slot

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

<table>
<thead>
<tr>
<th>Fish fauna to be considered</th>
<th>Grayling, bream, chub, others</th>
<th>Sturgeon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brown trout</td>
<td>Salmon, sea trout, huchen</td>
</tr>
<tr>
<td>Slot width</td>
<td>s</td>
<td>0.15 – 0.17</td>
</tr>
<tr>
<td>Pool width</td>
<td>b</td>
<td>1.20</td>
</tr>
<tr>
<td>Pool length</td>
<td>lb</td>
<td>1.90</td>
</tr>
<tr>
<td>Length of projection</td>
<td>c</td>
<td>0.16</td>
</tr>
<tr>
<td>Stagger distance</td>
<td>a</td>
<td>0.06 – 0.10</td>
</tr>
<tr>
<td>Width of deflecting block</td>
<td>f</td>
<td>0.16</td>
</tr>
<tr>
<td>Water level difference</td>
<td>h</td>
<td>0.20</td>
</tr>
<tr>
<td>Min. depth of water</td>
<td>h_{min}</td>
<td>0.50</td>
</tr>
<tr>
<td>Required discharge(^1)</td>
<td>Q in m(^3)/s</td>
<td>0.14 – 0.16</td>
</tr>
</tbody>
</table>

\(^1\) calculated for \(\Delta h = 0.20\) m and \(h_{min}\)

Welcombe (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).
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,

$$Q = \frac{2}{3} \mu_r s \sqrt{2gh_o^{3/2}}$$

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 $h_o$ can be found step-by-step for each crosswall, starting from the last downstream cross-wall

3. At the end, the upper $h_o$ 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= $\sqrt{2g \times 0.20} = 1.98 \text{ m/s} < 2.00$. If we used the summer headwater level, flow speed= $\sqrt{2g \times 0.15} = 1.71 \text{ m/s}$

- Section= $0.75 \times 0.17 = 0.128 \text{ m}^2$; Discharge coefficient from chart above; $h_u/h_0=0.6/0.75=0.8$, $\mu=0.49$)

- Discharge $Q_{\text{max}}= \frac{2}{3} \mu \times \text{width} \times h_0^{3/2} \times \sqrt{2g} = 0.66 \times 0.49 \times 0.17 \times 0.75^{3/2} \times \sqrt{2g} = 0.16 \text{ m}^3/\text{s}$

- 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$^3$; $V= 1000 \times 9.81 \times 0.15 \times 0.16/150 = 1.57 \text{ m}^3$ (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 \( \mu \) to 0.46, and \( h_0 \) to 0.90, and the discharge would be:
  \[ Q = 0.66 \times 0.46 \times 0.17 \times 0.90^{3/2} \times \sqrt{2g} = 0.197 \text{ m}^3/\text{s} \]

- The power density is:
  \[ 1000 \times 9.81 \times 0.197 \times 0.15/1.8 \times 1.4 \times (0.75+0.15/2) = 139.4 \text{ W/m}^3 \]
# Baffle Fish passes

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Steep slopes possible, low</td>
<td>• Much affected by variations in headwater</td>
</tr>
<tr>
<td>space required</td>
<td>(max 20 cm)</td>
</tr>
<tr>
<td>• Can be prefabricated;</td>
<td>• Easily clogged by debris</td>
</tr>
<tr>
<td>easily retrofited into</td>
<td></td>
</tr>
<tr>
<td>existing dams</td>
<td></td>
</tr>
<tr>
<td>• Largely unaffected by</td>
<td>• Regular maintenance required</td>
</tr>
<tr>
<td>variations in tailwater</td>
<td></td>
</tr>
<tr>
<td>level</td>
<td></td>
</tr>
<tr>
<td>• Good attraction flow</td>
<td>• High discharge per head difference</td>
</tr>
<tr>
<td></td>
<td>compared to other passes</td>
</tr>
</tbody>
</table>
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 $E = 25-50 \, \text{W/m}^3$. 
Designing the Denil fishpass

- Channel width (b) = 0.8-1.2 m for large salmonids 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)

<table>
<thead>
<tr>
<th></th>
<th>Tolerance range</th>
<th>Recommended guide values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baffle width</td>
<td>$b_a/b$</td>
<td>0.5 – 0.6</td>
</tr>
<tr>
<td>Baffle spacing</td>
<td>$a/b$</td>
<td>0.5 – 0.9</td>
</tr>
<tr>
<td>Distance between the lowest point of the cutout and the bottom</td>
<td>$c_1/b$</td>
<td>0.23 – 0.32</td>
</tr>
<tr>
<td>Depth of the triangular section</td>
<td>$c_2/c_1$</td>
<td>2</td>
</tr>
</tbody>
</table>

![Diagram of Denil fishpass](image)
Designing the Denil fishpass

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

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

IMPORTANT

Ensure:

\( h^* > 0.35 \) m and \( h^*/b_a = 1.5 \) 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

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 m³/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): \( Q = 1.35 \cdot b_a^{2.5} \cdot \sqrt{gS} \cdot (h^*/b_a)^{1.584} \)

3. We need to divide these 3 m in several flights 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:

\[
E = \frac{\rho}{2} \frac{Qv^2}{b_m h_m l_b} < 25 \text{ to } 50 \text{ W/m}^3 \quad (5.11)
\]

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: \( a = 0.66 \cdot 0.8 = 0.53 \) m, and the other dimensions will be taken from the recommended ones; \( h^*/b_a = 1.5 \); so as at the same time, \( b_a/b = 0.58 \); \( b_a = 0.8 \cdot 0.58 = 0.46 \) m. Now we can calculate \( h^* = 1.5 \cdot b_a = 0.70 \) 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)

\[ Q = 1.35 \times b \times a^{2.5} \times \sqrt{gS \times (h/2a)} \]

\[ = 1.35 \times 0.46^{2.5} \times \sqrt{(9.81 \times 0.15) \times (0.7/0.46)} \]

\[ = 0.457 \text{ m}^3/\text{s} \]

8. The dimensions of the resting pools (depth= 1.20 m) can be found with \( E = 35 \text{ W/m}^3 \) and the flow velocity: \( v = Q/A \approx Q/(ba \times h) = 1.42 \text{ m/s} \)

9. So we would need an area (Anec) of: \( \text{Anec} = lb \times bm = (\rho/2 \times Q \times v^2)/(hm \times E) \)

\[ = (1000/2 \times 0.457 \times 1.422)/(1.20 \times 35) = 10.97 \text{ m}^2 \]

10. We could choose a length (lb) of 3 m and a width of 4 m
Designing the Denil fishpass

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.

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

The future of fish passage science, engineering, and practice

Ana T. Silva1,2 | Martyn C. Lucas3 | Theodore Castro-Santos4 | Christos Kapodistis5
Lee J. Baumgartner6 | Jason D. Thiem7 | Kim Aarestrup8 | Paulo S. Pompeu9
Hans-Petter Fjeldstad14 | Torbjørn Forseth1 | Nallamuthu Rajaratnam13 | John G. Williams15 | Steven J. Cooke2

Do Not Pass Go: The Failed Promise of Fish Ladders

By: Lori Pottinger
Date: Tuesday, March 19, 2013
Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies

J. Jed Brown, Karin E. Limburg, John R. Waldman, Kurt Stephenson, Edward P. Glenn, Francis Juanes, & Adrian Jordaan

American shad (Alosa sapidissima)
Fish passes: review of evidence

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
Total Probability of Passage ($P_{\text{tot}}$):
$p(\text{Approach}) \times p(\text{Entry}) \times p(\text{Passage})$
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 (Best of a Bad Situation), 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 larger the barrier the more true this is


Useful websites and videos

Websites
https://amber.international/
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
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