RETROFITTING FISH PASSES: INTERNATIONAL BEST PRACTICE, CURRENT RESEARCH AND FORESEEABLE DEVELOPMENTS

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ABSTRACT

Worldwide there is a growing movement to remove dams which no longer serve any useful purpose or where the environmental and other costs outweigh the benefits. However, in cases, the environmental impacts of such impassable structures may be mitigated by retrofitting fishways and/or operating the dams in a fish-friendly manner.

The issues associated with upstream fish passage are relatively well understood and a broad range of fishway solutions are available. It is possible to design fish passes that facilitate multi-species passage.

This paper describes the three main determinants of fish pass efficiency: a) attraction, b) passage, and c) operation time. It provides an overview of fishway solutions for medium and high head structures, summarizes the advantages and disadvantages of non-volitional fishways (fish locks and fish lifts), outlines existing knowledge gaps and ongoing multi-disciplinary research, and depicts foreseeable developments in fishway engineering.

INTRODUCTION

Physical barriers in rivers may be natural or anthropogenic. Anthropogenic barriers can take many forms, such as impassable weirs or dams, and have primarily been constructed for hydropower generation, navigation, flood protection and water supply. These barriers are known to have adverse impacts on natural migration patterns of aquatic organisms (Bergkamp et al., 2000; Larinier, 2000; Nilsson et al., 2005) and thus on the composition, distribution and abundance of aquatic species. Particularly, there have been large reductions in the populations of diadromous fishes (i.e. species that migrate through fresh- and saltwater ecosystems) in river basins worldwide.

The deleterious effects on fish migration can be mitigated through dam removal, and a variety of fish pass and protection technologies. Fish passes (also known as fishways and fish ladders) are structures on or around barriers that primarily facilitate fishes' upstream migration. They can also enable downstream passage if the downstream migrating fish encounter the exits, or if bypasses (for downstream movement) were designed into the fish passes.

Fish passes have been installed worldwide for over 300 years (Clay, 1995) and increasingly been retrofitted at barriers during the last decades. In the past, fisheries management and thus fishway engineering focused on economically or indigenously

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important fish species, specifically salmon and trout in the US and Europe (Figure 1), and sturgeon in Russia (Larinier, 2000; Pavlov, 1989). The first concerted efforts to develop scientifically based fishways for upstream migrant fish began in the early 1900s in Europe with field and laboratory testing of different fishway designs. These were followed by extensive efforts beginning in the 1940s in North America (Katopodis & Williams, 2012).

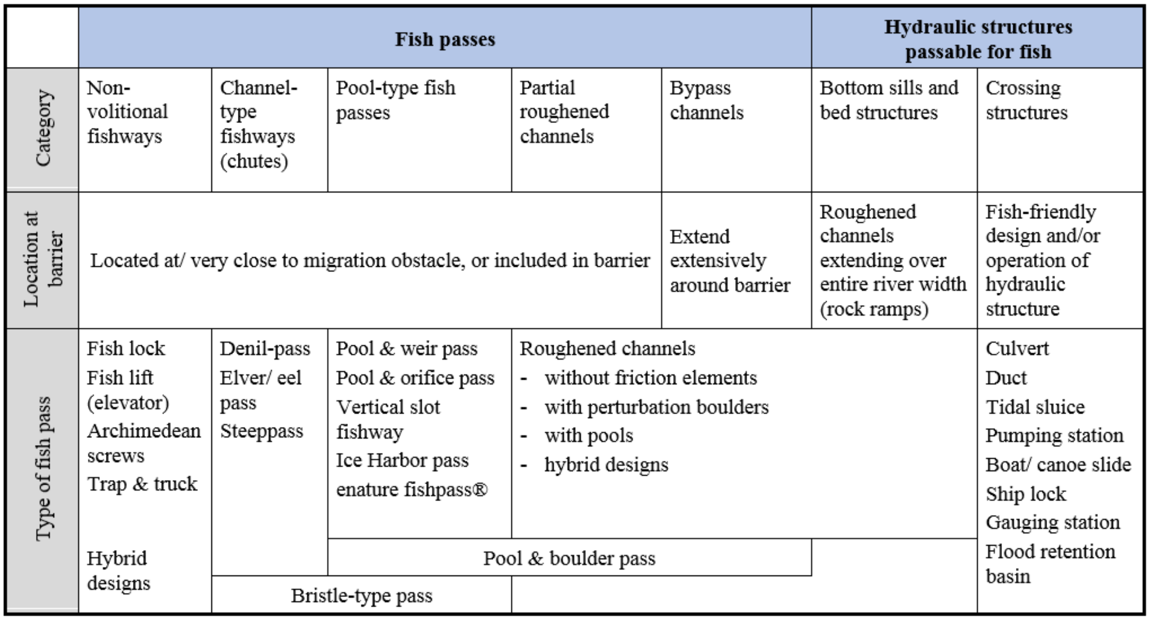
Figure 1. Pool & traverse fish pass (72 pools, 28.5 m head) at Cathaleen's Fall Hydropower Station, River Erne, Ireland. Designed and built for Salmon in the 1940's, with each pool 7.62 m long by 3.66 m wide with a 0.46 m drop between each pool. (Photo: Redeker)

FISH PASSAGE ENGINEERING ADVANCEMENTS

The last three decades have seen an increase in global awareness of the need for all fish species to migrate to fulfil successful life cycles. For example in Europe, since 1992, three pieces of European Union (EU) legislation have forced the focus of fisheries management and fish protection to expand beyond the commercially relevant salmonids to include course fish (i.e. non-salmonids), namely (a) the Habitats Directive (92/43/EEC), (b) the Water Framework Directive - WFD (2000/60/EC), and (c) the Regulation establishing measures for the recovery of the stock of European eel (EC/1100/2007). The free passage of all migratory fish is a key requirement of the WFD and is used as an indicator for assessing whether water bodies are meeting the so-called 'Good Ecological Status' (the main objective of the WFD in all freshwater and coastal water bodies by 2027). In general, the necessity for free movement of both diadromous and potadromous fishes (i.e. species that require movement through freshwater systems to complete their lifecycle) is now readily acknowledged (Kroes et al., 2006; Brink et al., 2018).

In principle, a fish pass is a water passage around or through an obstruction. For it to be effective, it must (a) be possible for all fish to locate and access it almost year-round, without excessive delay or energy loss and (b) provide hydraulic and geometric conditions suitable for fish to pass the obstruction into the headwater without undue stress or injury (DWA, 2014).

Today, the issues associated with upstream fish passage are relatively well understood and a broad range of fishway solutions are available (Figure 2). It is possible to design fish passes so that they facilitate the passage of all species of indigenous fish fauna (i.e. multi-species fish passes) and almost all age/size stages of migratory fish.



<table>
<tr><th></th><th colspan="5">Fish passes</th><th colspan="2">Hydraulic structures passable for fish</th></tr>
<tr><td>Category</td><td>Non-volitional fishways</td><td>Channel-type fishways (chutes)</td><td>Pool-type fish passes</td><td>Partial roughened channels</td><td>Bypass channels</td><td>Bottom sills and bed structures</td><td>Crossing structures</td></tr>
<tr><td>Location at barrier</td><td colspan="4">Located at/ very close to migration obstacle, or included in barrier</td><td>Extend extensively around barrier</td><td>Roughened channels extending over entire river width (rock ramps)</td><td>Fish-friendly design and/or operation of hydraulic structure</td></tr>
<tr><td rowspan="3">Type of fish pass</td><td rowspan="3">Fish lock
Fish lift (elevator)
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Elver/ eel pass
Steeppass</td><td>Pool & weir pass
Pool & orifice pass
Vertical slot fishway
Ice Harbor pass
enature fishpass®</td><td colspan="3">Roughened channels
- without friction elements
- with perturbation boulders
- with pools
- hybrid designs</td><td rowspan="3">Culvert
Duct
Tidal sluice
Pumping station
Boat/ canoe slide
Ship lock
Gauging station
Flood retention basin</td></tr>
<tr><td colspan="3">Pool & boulder pass</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Bristle-type pass</td><td colspan="2"></td></tr>
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Figure 2. Upstream fishway types (translated from DWA, 2014)

Fish passes can be categorized into volitional or non-volitional systems. The distinction refers to whether passage relies upon motivation, performance and behavior of the fish to ascend over the barrier. Volitional fishways rely on fish motivation, performance and/or behavior, and include pool-type, channel-type and rock ramp designs. Non-volitional fishways include fish lifts (elevators) and fish locks.

FISH PASSAGE BEST PRACTICE

Recommended Practice for Fish Pass Design

Several countries have developed fish pass guidelines (e.g. Environment Agency, 2010; Larinier et al., 2002; Lebensministerium, 2012; NMFS, 2015). These represent the state of the art in knowledge and technology for the correct design, construction and operation of fish passes and fish-passable structures in the respective countries or regions.

Recent fish pass guidelines (e.g. DWA, 2014; USFWS, 2017) follow a design philosophy introduced by *Gerhard* in 1912 where the "fishway design is based on the fish one intends to guide". These guidelines include geometric and hydraulic criteria for fish passes based on body size/proportions (incl. movement/orientation mechanism) and swimming performance of fishes.

At a European level, the European Committee for Standardization (CEN) is currently developing a CEN fish pass monitoring standard that will become compulsory for the EU member States. Similarly, hydropower associations (amongst others) have established international best practice in managing the ecological impacts of hydropower schemes which comprise restoration and mitigation measures, including fishways (IHA, 2018).

Determinants of Fish Pass Effectiveness and Efficiency

In principle, three factors determine the effectiveness and efficiency of fish passes (DWA, 2014). These are

- fish attraction to the pass (attraction);
- the environment within the pass (passage); and
- operation (and maintenance) of the pass (operation).

While passage depends on the details of the construction and conditions within the fish pass, the (ease of) attraction depends on the layout, design and hydraulic conditions at the fish pass entrance. Typically, the accessibility and functionality of the pass entrance is the key factor in determining the effectiveness and success of a fish pass (Noonan et al., 2011; Bunt, et al., 2012).

Particularly important factors in relation to attraction to the fish pass are:

- The large-scale location of the fish pass in the water body, taking into account the site-specific water use(s);
- The position of the fish pass entrance and thus the integration into the environment downstream of the barrier;
- The design of the entrance, e.g. adaptation to fluctuating tailwater levels and connection to the river bed; and
- The attraction flow should be of such velocity, discharge and angle that it is perceptible to and attracts fish.

The movement of fish through the pass depends on the design as well as hydraulic conditions within the pass. Thus, the environment within the pass (passage) is largely determined by:

- Hydraulics, i.e. flow velocities, flow patterns and discharge, and
- Geometry, i.e. water depths, pool/shaft dimensions, and slot sizing that allow maneuverability of fish.

Modern fish pass guidelines (e.g. German Guideline DWA-M 509 (2014) and USFWS Fish Passage Engineering Design Criteria (2017)) instruct that the geometric criteria should accommodate an adult fish of the largest prevailing or target species. The maximum flow velocity in a fish pass, e.g. in notches/slots/orifices, is selected based on the swimming performance of the species concerned. The hydraulic criteria are designed to accommodate the weakest swimming prevailing or target species. Table 1 gives an overview of typical parameters of pool-type passes (vertical slot passes) for a number of prominent fish species, as well as coarse fish.

Table 1. Guidelines for basic parameters of pool-type passes (vertical slot passes)

Country: Guideline **parameters**	**Coarse fish**	**Pike**	**Brown trout**	**Sea trout & Salmon**
***Germany**: DWA-M 509 (2014)*				
max. velocity	1.4 - 1.7 m/s	1.4 - 1.7 m/s	1.8 - 2.2 m/s	1.8 - 2.2 m/s
max. drop	0.1 - 0.15 m	0.1 - 0.15 m	0.17 - 0.25 m	0.17 - 0.25 m
min. pool dimensions (LxW)	2.45 x 1.85 m	3.0 x 2.25 m	1.95 x 1.5 m	3.0 x 2.25 m
min. slot width	0.15 - 0.3 m	0.3 m	0.2 m	0.35 m
max. power density*	100 - 150 W/m^3	100 W/m^3	200 - 225 W/m^3	200 - 250 W/m^3
***United Kingdom**: Fish Pass Manual (2010)*				
max. velocity	1.4 - 2.0 m/s		1.7 - 2.4 m/s	2.4 m/s
drop	0.1 - 0.2 m		0.15 - 0.3 m	0.3 m
pool dimensions (LxW)			2.0 x 1.6 m	3.0 x 2.4 m
slot width	0.2 - 0.3 m		0.2 m	0.3 m
max. power density*	100 - 150 W/m^3		100 - 150 W/m^3	150 - 200 W/m^3
***France**: Larinier et al. (2002)*				
max. velocity				
max. drop	0.15 - 0.2 m		0.2 - 0.3 m	0.3 - 0.4 m
min. pool dimensions (L)				L = 2.5 - 3.5m
min. slot width	0.2 - 0.3 m		0.2 m	0.3 - 0.4 m
max. power density*	<150 W/m^3		<150 W/m^3	<200 W/m^3
***USA**: USFWS (2017)*				
max. velocity			1.0 m/s	1.0 / 2.4 m/s
drop	0.12 - 0.2 m			<0.3 m
pool dimensions (LxW)	**		**	4.5 x 3.6 m
slot width				>0.45 m
max. power density*			<111 W/m^3	<141 W/m^3

Notes:

* Power density (strictly: power dissipation per unit volume) is a measure used to describe the turbulence in a volume of water. It is the potential energy per unit time spread throughout a known volume of water in a pool.

** The dimensions are in relation to the slot width (s). At each site, the sizing and arrangement of the slot is influenced by hydraulics, discharge, and the biological needs of fish. The dimensions of a standard vertical slot fishway with one slot per baffle acc. to Larinier et al. (2002) are: clear pool length L = 8.1 - 8.35 x s, pool width W = L x 0.75.

In relation to its operation, a fish pass should:

- Have almost year-round attraction and functional efficiency (e.g. between Q_{30} - Q_{330} or $Q_{95\%}$ - $Q_{5\%}$ [2]),
- Operate 24 hours a day, seven days a week, and
- Require minimal maintenance.

Current Best Practice Versus Former Fish Pass Design

In general, international recommendations with regards to fish pass attraction have not changed considerably over the years. However, today there is a better understanding of:

- Attraction flow velocities for different fish species, and
- Attraction discharge flow rates.

Fish passes which were built in the 20th century were mostly designed for the passage of high-performance and high-value species, e.g. Atlantic and Pacific salmon, brown trout/ sea trout and shad. The conditions in these "traditional" fishways are unsuitable for small or weak-swimming fishes (i.e. for many potamodromous species) because migrating fish traversing velocity barriers are forced to swim at speeds greater than their maximum sustained speed. These fishway designs generally do not provide passage for a wide spectrum of species or novel species. Therefore, recent guidelines promote multi-species fishway designs with species-specific (passage) criteria. In pool-type fish passes, the recommended vertical drop at baffles has reduced in recent years for both salmonid and multi-species fish passes that include course fish.

FISHWAYS FOR MEDIUM AND HIGH-HEAD STRUCTURES

Pool-type and non-volitional fish passes (fish lifts and fish locks) are the most common fishways for medium and high-head dams.

Pool-Type Fish Passes

Pool-type fish passes work by dividing the total height to be ascended (head) into several small drops in a series of pools. The passage of water from one pool to the next is through openings situated in the baffle (wall) separating the two pools. The passage of water from one pool to the next is through either:

- Surface overflow,
- One or more submerged opening(s), or
- One or more notches or slots.

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[2] Q_{30} - Q_{330} = low flow and high flow, respectively, that are not exceeded on 30/330 days per annum.
In the USA, the operating range "Low Design Flow" (=$Q_{95\%}$) to "High Design Flow" (=$Q_{5\%}$) is used, meaning the nominal lower/upper limits of river flows that can achieve safe, timely, and effective fish passage. Fish passage design flows, and associated exceedance probabilities, are developed using daily average river flows recorded during the fish passage season over a sufficiently long period of record (i.e., 10 to 30 years). High (5%) and low (95%) design flows can be compared to station capacity.

The critical parameters of pool-type passes are the dimensions of the pools and the geometric characteristics of the cross-walls separating the pools (shapes, dimensions and heights of the weirs, notches, slots and orifices). These geometric characteristics, together with the water levels upstream and downstream of the facility (i.e. gradient), determine the hydraulic behavior of the pass i.e. the flow discharge, the difference in water level from one pool to another, and the flow pattern within the pools.

In principle, the lower the vertical drop between pools, the easier it is for the fish to pass. However, there is an inverse relationship between the vertical drop and the number of pools required. Therefore, the drop cannot be reduced too much as the number of pools required would become prohibitive.

Yet, there is no clear (biological) limit on the maximum permissible number of pools, the length of pool-type fishways, or on the maximum total head of pool-type fishways. Several pool-type fish passes have been constructed at medium head dams (head ~10-20 m) (Figures 3 and 4). However, there is some evidence from medium head fish passes monitored in Scotland and in the US that fish may discontinue their upstream migration and turn downstream in pool-type fishways of long distance or excessive drops between pools (Scottish and Southern Energy, 2001; Castro-Santos, 2012).

Figure 3. Nature-like bypass channel at Harkortsee Hydropower Station, Ruhr River, Germany. Left: Aerial view (Photo: Ruhrverband); Right: Pool section (Photo: Redeker). Designed for course species: Total length = 375 m, 57 pools, 2 slots per boulder row ~0.35 m wide, max. 0.13 m drop per pool, discharge = 0.7 m^3/s plus 0.5 m^3/s auxiliary flow.

Figure 4. Enature Fishpass at Schwabeck Hydropower Station, Drau River, Austria. Designed for coarse species: 158 pools (LxW = 3.0 x 2.17 m), slot 0.4 m wide, max. 0.13 m drop per pool, discharge = 0.45 m³/s (Photos: Verbund).

The rule of thumb is that non-volitional fishways should be considered where the head is greater than 10-15 m (30-50 feet). In such cases, fish locks and lift designs are more economic due mainly to their smaller footprint relative to large volitional passage designs.

Non-volitional Fishways

Fish locks

The principle of a fish lock was originally suggested in 1890 (Aitken et al., 1966). The first "hydraulic pressure locks for the ascent of fish" were constructed in the USA in the 1930s. In Europe, a Scottish Engineer named J.H.T. Borland, developed the so-called "Borland fish lock" and the first pass of this type was constructed at the Leixlip Dam (River Liffey, Dublin, Ireland) in 1949 (Figure 5). Following construction of Leixlip Dam fish lock, the North of Scotland Hydro-Electric Board and Electricity Supply Board Ireland built several Borland fish locks in Scotland and Ireland in the 1950s and 1960s that are still in operation today.

A Borland fish lock consists of a lower chamber and upper pool connected by a shaft. The chamber is equipped with a sluice gate, and the pool typically with a falling gate in order to fill or drain the lock. The cross-section of the shaft may either be circular or rectangular. Whereas the shaft of a Borland lock is inclined (parallel to the downstream face of the dam, Figure 5), the shafts of more recent fish lock designs tend to be vertical.

Figure 5. The first Borland fish lock at Leixlip Dam (Photo: Redeker)

Fish locks and lifts differ from the “classic” fish passes in that their operation is multi-phase, consisting of four phases:

1. Fishing (attraction) phase
2. Filling phase (lock) / crowding and raising phase (lift)
3. Exit phase (lock) / releasing phase (lift)
4. Draining phase (lock) / lowering phase (lift)

During the fishing phase the downstream gate is open and the upstream sluice controls the flow into and through the lock. The water flows out of the lower chamber into the tailwater and its current attracts the fish into the lower (holding) chamber. After the attraction period the downstream sluice closes and the lock fills up. The fish follow the water in the conduit, rising and reaching the upper pool when the lock is full. The fish are encouraged to pass into the headpond by opening a bypass in the lower chamber, which induces an attraction flow across the partially lowered upstream sluice. After a specified period of time, the upstream sluice is closed. The lock is gradually emptied by means of the still open bypass, and when emptying is almost complete the downstream sluice is re-opened.

Fish lifts

The first fish lift facility was constructed at Hadley Falls Station (Connecticut River, USA) in 1955. Further fish lifts were constructed from the 1960’s in Canada, the USA and Russia (Clay, 1995; Pavlov, 1989). In Europe the first fish lift was retrofitted at the Tuilières Hydropower Station (Dordogne River, France) in 1985.

In principle, a fish lift is a mechanical system that first traps the migrating fish in a suitably sized tank of water (so-called hopper) located at the base of an obstruction, and then raises and empties it upstream.

Typically, the lift (shaft) is vertical, but two inclined fish lifts have been built in Australia in recent years.

An auxiliary flow attracts the migrating fish into a trapping (or holding) pool. In some large fish lifts the auxiliary flow is provided by mini hydro plants. Fish are trapped in a wire mesh cage fitted with an inscale (non-return device or V-trap), and with a lower section which forms the transport tank. Immediately downstream from the trap is a mechanized vertical screen that is operated as a portcullis to prevent other fish from entering the chamber during the phase when the tank is being lifted.

If there are a lot of fish to be moved upstream, or if the fish cannot tolerate confinement (e.g. shad), a device is used in which the trapping, holding and raising functions are separated. The fish are trapped and held in a holding pool, the entrance to which is fitted with an inscale. The hopper is embedded into the floor at the upstream extremity of the holding pool. Immediately before lifting, the fish are crowded and pushed by a vertical screen on a trolley that moves horizontally (mechanical crowder), confining them in the space above the hopper. The same screen generally serves to trap the fish (panels positioned open to form the trap inscale), and to crowd them together (panels closed to form a flat screen). This principle was first used at the Hadley Falls Station and has since been used successfully for lifts in France (Larinier et al., 2002). Alternatively, a couple of fish pass pools can be installed below the hopper, which is mostly done at sites with distinct tailwater level fluctuations.

Operation of fish locks and lifts

The cycle of operations is normally automatic. The timing of the phases, total cycle time and rota number may be varied to best suit the movements of fish at any period of the year. The total cycle time of fish locks usually varies between 2 and 4 hours (Redeker & Stephen, 2006) but may be as short as 20 minutes for fish lifts (USFWS, 2017).

It is very important that a fish lock maintains flow into and attraction flow out of the lock into the tailwater during all four phases, i.e.

- During the fishing phase: attraction flow through the main entrance and via the bypass pipe(s);
- During the filling and exit phase: attraction flow via the bypass pipe(s); and
- During the draining phase: outflow via the bottom sluice gate and bypass pipe(s).

Similarly, continuous attraction flow is required at fish lifts during all four phases at the entrance and in the holding pool respectively.

Appraisal of fish locks and fish lifts

Fish locks and fish lifts have been in operation for decades. They can be effective means of passage for specific target species (mainly diadromous species) at high weirs and dams, especially at sites with confined space. Despite this, their overall numbers are low compared with regular fish passes (Table 2). Fish lifts predominate in France, Switzerland and North America, whereas fish locks prevail in Ireland, Scotland, Portugal, Russia and Australia. Germany and Austria have only one fish lift each. Fish locks have predominantly been placed at low to medium head barriers (up to 20 m), whereas fish lifts have mostly been applied to medium to high head dams (up to 45 m in Brazil), especially in the last two to three decades. Guidance on design criteria and recommendations for operation for fish locks and lifts is sparse. As a result, existing structures vary and each fish lift and fish lock is unique.

Table 2. Overview of fish locks and fish lifts around the world (Redeker, 2015 updated)

	Fish locks	**Fish lifts**
Number of facilities world-wide	81	46
Three highest facilities (in operation)	1. Ardnacrusha Dam, River Shannon, Ireland (head 30.6 m) 2. Salto Grande Dam, Rio Uruguay, Uruguay, 2 Borland fish locks (head 30 m) 3. Iniscarra Dam, River Lee, Ireland (head 29.4 m)	1. Funil Dam, Rio Grande, Brazil (lift height 45 m) 2. Tallowa Dam, Shoalhaven River, Australia (lift height 43 m) 3. Pedrogão-Dam, Guadiana River, Portugal (lift height 43 m)

Fish locks and fish lifts are generally criticized for their intermittent operation and lack of suitability for a range of different species. Their efficiency depends on several variables and both systems require additional elements to function well, e.g. inscale (V-trap), holding pool with crowder, and auxiliary flow system.

Fish lifts have advantages relative to fish locks and are therefore currently perceived as the superior technology. One of the main advantages of fish lifts relative to fish locks is, fish lifts have a shorter duration of phases 2 to 4 (typically only a couple of minutes) and can therefore rapidly resume the fishing phase, i.e. the duration for which fish cannot enter the hopper is comparatively short. Fish must actively swim through fish locks, possibly inducing fatigue or disorientation, whereas fish are moved passively through fish lift systems. All fish from fish lifts are released into the headwaters, i.e. total passage efficiency approximates 100%. Fish lifts are well suited for large headwater fluctuations and there are no pressure fluctuations in fish lifts.

However, fish locks have a number of advantages relative to lifts, namely, they (1) can be used for downstream passage, (2) are structurally more adaptable to existing barrier structures/geometries and (3) are more maintenance-friendly and energy efficient.

To help mitigate issues deriving from the dearth of design criteria and guidance on operation available for fish locks and fish lifts, Redeker (2015) proposed a few recommendations:

- The target fish species and their requirements need to be determined prior to design;
- The design should allow for operational adaptations, e.g. automation, cycle time, filling, flow control, etc.;
- Particular attention should be given to the variables (e.g. diurnal rhythm, season, temperature, lighting) during design and operation; and
- Function checks and biological evaluation should be carried out immediately after start-up to evaluate fishway effectiveness and efficiency. This information should be used to optimize the operation (e.g. by means of Programmable Logic Control settings) and hydraulic conditions for the fish, or to undertake structural adaptations.

KNOWLEDGE GAPS, CURRENT RESEARCH AND FORESEEABLE DEVELOPMENTS

Today, our understanding of the impacts of river barriers on fish migration and dispersal is much better than historically, with the result that research and development around fish passage engineering, technology, and evaluation has advanced immensely in the recent decades, and particularly in the last 20 years. As previously noted, in recent years, efforts have turned to developing multi-species fishways.

Nevertheless, fishway science, engineering and practice are still evolving and fish passage is not yet an entirely proven technology (and likely may never be). Once dominated by an engineering-focused approach, fishway science today involves a wide range of disciplines, from fish behavior to socioeconomics. Results of past research and implementation suggest that the development of effective fish passes requires biological knowledge of fish behavior when encountering variable flows, velocity and turbulence, combined with hydraulic and civil engineering knowledge and expertise to develop facilities that provide suitable hydraulic conditions for fish. Where knowledge of the behavior of (target) fish species does not exist, it requires considerable financial resources for biological and hydraulic testing as well as engineering design. Today 3D-CAD and computational fluid dynamics models assist engineers to investigate flow patterns during fish pass design and to optimize nonstandard fishway components, e.g. gated entrances, auxiliary water systems (Figure 6) and turning pools. Using this technology, it is possible, for example, to assess whether adequate flow velocities will prevail in the migration corridor in all flow and tailwater level conditions.

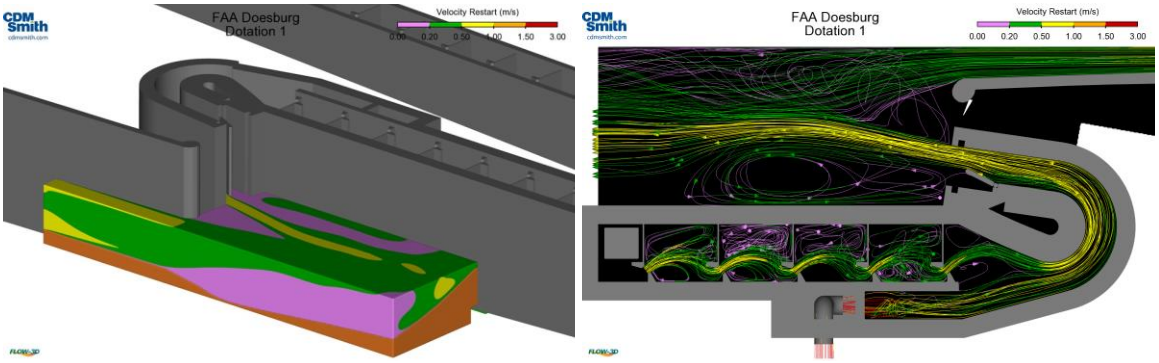

Figure 6. CFD model of a gated fishway entrance with auxiliary attraction water system (Redeker & Heimerl, 2018)

Biological understanding of the requirements of fishway design lags behind the engineering advances and specific ecological issues are still being investigated, e.g. biomechanisms, energetics and population dynamics. In recent years a new bioengineering science discipline "ethohydraulics" has evolved (Adam & Lehmann, 2011; Figure 7). The aim of this discipline is to derive guidelines for a more environmentally compatible hydraulic engineering practice based on the research and understanding of the needs of the aquatic fauna, especially fish.

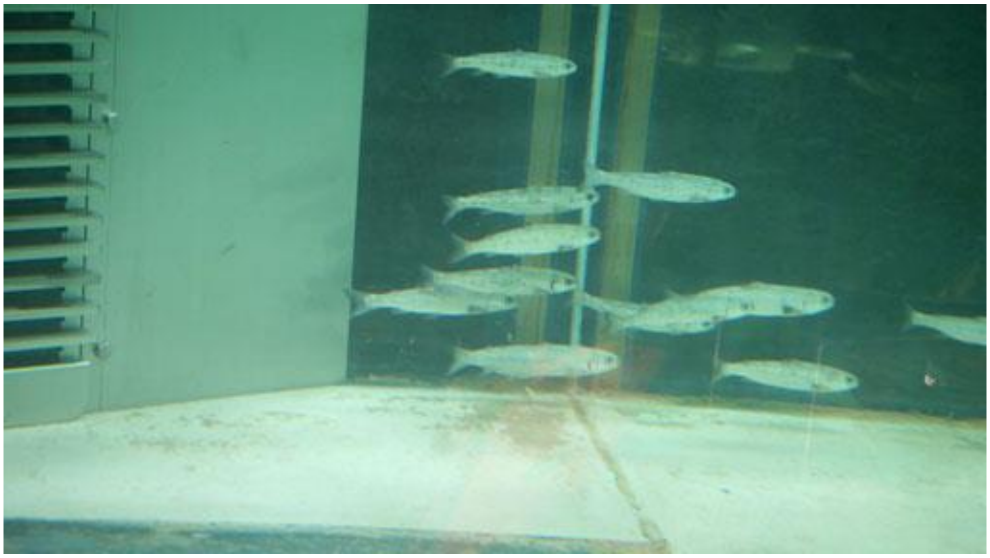

Figure 7. Ethohydraulic laboratory investigations of a school of fish in front of a horizontal bar intake screen (Photo: www.swr.de/blog/diedurchblicker/2016/05/19)

Where biological or engineering knowledge (or both) is absent, development of effective passage facilities could take on a trial and error approach that would likely require years to attain success. Given that fish passage provisions remain a priority worldwide, it appears more sensible to adopt an adaptive management approach to the design and construction of fishways. By means of laboratory investigations and in-situ evaluations with sophisticated technology that determine fishway performance, a better understanding of the relationship between fish pass design and performance may emerge.

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