

8 References

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9 Table of symbols and signs used

Symbol	Unit	Used for
a	m	Distance between baffles in Denil passes; stagger distance of the deflecting block relative to the cross-wall in slot passes
A	m^2	Area, flow section
A_{tot}, A_{ges}	m^2	Total flow section
A_o	m^2	Base area
A_s	m^2	Cross-section of submerged orifice in pool passes; wetted area of an immersed object (e.g. a perturbation boulder)
a_x, a_y	m	Distance between perturbation boulders, (a_x) in longitudinal direction and (a_y) in lateral direction
b	m	Width, channel width
b_a	m	Width of baffle section in Denil passes; width of notches in pool passes
b_m	m	Mean width
b_s	m	Width of submerged orifice in pool passes; width of gaps (for discharge) in a boulder sill (cascaded ramp)
b_{So}, b_{bot}	m	Bottom width
b_{Sp}	m	Width of waterbody at its surface
c	m	Length of hook-shaped projection in slot passes
c_1, c_2	m	Height of triangular section of baffles in Denil passes
c_w	-	Form drag coefficient
d	m	Thickness, e.g. of substrate layer; thickness of wall in pool and slot passes
d_s	m	Boulder or stone diameter
d_{90}	m	Grain diameter for 90% mass sieving
E	W/m^3	Volumetric power dissipation
f	m	Width of deflecting block in slot passes
Fr	-	Froude number
g	m/s^2	Acceleration due to gravity, $g = 9.81 m/s^2$
h	m	Height or water depth, generally the minimum water depth
h^*	m	In Denil passes: distance from the deepest point of the cutout section of the baffle to the bottom of the channel, measured perpendicular to the bottom
h_a	m	Height of notches in pool passes; height of baffles in Denil passes
h_E	m	Energy level
$h_{E,min}$	m	Minimum energy level
h_F	m	Fall head
h_{gr}	m	Limiting depth, water depth for discharges with minimum energy level
h_m	m	Mean water depth
h_o	m	Water depth above a dam, or above a cross-wall or sill (be aware of reference level!)
h_s	m	Height of submerged orifice in pool passes (measured from bottom surface or substrate surface)
h_u	m	Water depth below a dam, or below a cross-wall or sill (be aware of reference level!)
$h_{\bar{u}}$	m	Weirhead (sometimes as $h_{weirhead}$)
h_v	m	Losses in energy level caused by discharges
h_w	m	Height of cross-walls in pool passes
I	-	Slope
k	m	Absolute roughness
k_s	m	Equivalent sand roughness

Symbol	Unit	Used for
l	m	Length, distance
l_b	m	Pool length
l_u	m	Actual length of the wetted channel cross-section
n	-	Number of pools
Q	m^3/s	Discharge or flow
Q_a	m^3/s	Discharge through the notches in pool passes
Q_s	m^3/s	Discharge through the submerged orifices in pool passes
r_{hy}	m	Hydraulic radius, $r_{hy} = A / l_u$
s	m	Slot width in slot passes
V	m^3	Volume
v	m/s	Flow velocity
v_{gr}	m/s	Flow velocity at critical flow depth
v_m	m/s	Mean flow velocity
v_{max}	m/s	Maximum flow velocity
v_s	m/s	Maximum flow velocity in the slot or in the submerged orifice
w	m	Height of weir, height of sill
x, y, z	-	Axes in Cartesian coordinate system
α	°	Angle
Δh	m	Water level difference, e.g. between pools
ϵ_v	-	Volume ratio
ϵ_o	-	Area ratio
λ	-	Resistance coefficient in Darcy-Weisbach flow law
$\lambda_{tot}, \lambda_{ges}$	-	Total resistance coefficient
λ_o	-	Resistance coefficient due to bottom roughness
λ_s	-	Resistance coefficient due to perturbation boulders or similar objects
μ	-	Spillway coefficient for calculating spillover
μ_r	-	Discharge coefficient in slot passes
ρ	kg/m^3	Density (of water), $\rho = 1000 \text{ kg/m}^3$
ρ_s	kg/m^3	Density of stone, $\rho_s \approx 2700 \text{ kg/m}^3$
σ	-	Backwater coefficient, takes account of the influence of the tailwater level
ψ	-	Outflow coefficient
ζ	-	Loss coefficient

Hydrological information and abbreviations

Abbreviation	Meaning
OW	Headwater: water level above a dam
UW	Tailwater: water level below a dam
MNW, MNQ	Mean low-water level and mean low-water discharge
MW, MQ	Mean water level and mean discharge
MHW, MHQ	Mean high-water level and mean high-water discharge
HW, HQ	High water level and high water discharge
$\underline{n}W, \underline{n}Q$	Water level/discharge not reached on n days in the year
$\bar{n}W, \bar{n}Q$	Water level/discharge exceeded on n days in the year
HHW, HHQ	Highest known water level, highest known discharge

10 GLOSSARY

Abiotic factors: Non-living chemical and physical factors, e.g. geology, temperature, water balance, that influence biological systems and biocoenoses. – See: *biotic factors*.

Adult: An organism from the time it reached sexual maturity.

Allochthonous: Living organisms or dead material that is exotic to the environment from which it was sampled. – See: *autochthonous*.

Autochthonous: Living organisms or dead material that is indigenous to the environment from which it was sampled. – See: *allochthonous*.

Autotrophic: Characterizing the physiological mechanism of green plants and many microorganisms, whereby the organism grows using photosynthesis to convert inorganic matter (minerals, CO₂, NH₄) to organic matter.

Benthic zone: Bottom of a body of water. Benthic organisms live on or in the bottom. The biocoenosis of this habitat is termed “benthos”; the biocoenosis of bottom-dwelling invertebrate species is termed “benthic invertebrate fauna”.

Biocoenosis: Living community of plants and animals of a specific living space (biotope). – See: *ichthyocoenosis*.

Biotic factors: Factors pertaining to the living environment, e.g. nutrition, competition, parasites etc., that influence biological systems. See: *abiotic factors*.

Biotope: Space (habitat) occupied by a living community (biocoenosis) of plants and animals with its own specific environmental conditions.

Bypass: A means of conducting water and organisms around the main channel. In these Guidelines often used in the sense of a means to supply additional attraction current.

Bypass power station, synonym with channel power station: A bypass power station is a hydroelectric power station that lies on a bypass channel (water is deviated from the main channel into an artificial turbine canal. In general, the river course is artificially shortened by the bypass in order to achieve a greater fall or head for the generation of electricity. Water is extracted from the main channel by means of the bypass and conveyed to the hydroelectric power station.

Critical discharge: Water volume per unit of time, which is decisive for defining the dimensions of a fish pass. Unit: [m³/s].

Directional current: Current without cross-currents.

Diversional hydropower station: A hydroelectric power station where the exploitable fall or head, as existing at the dam structure, is increased as a result of the diversion.

Draft tube: Funnel-shaped opening that constitutes the connection from the turbine rotor to the tailwater in reaction turbines of hydropower stations and that delays the water coming out of the turbine, thus reducing its flow velocity.

Energy dissipation: The withdrawal of potential and/or kinetic energy from the water discharge energy and its transformation into heat. – See: *volumetric power dissipation*.

Eurytypic: Organisms that can tolerate very different environmental conditions and thus changes in their living space (habitat). – See: *stenotypic*.

Flow transition: Change of water depths from turbulent to laminar flow or conversely. The transition from laminar to turbulent is always steady, while the change from turbulent to laminar always shows a disturbance in the surface water level in the form of a hydraulic jump.

Gabions: Cuboid wire baskets filled with stones that are mainly used for revetting riverbanks above and below water.

Habitat: The normal living space occupied by a species of plant or animal within an ecosystem.

Ichthyocoenosis: Community of living fish. – See: *biocoenosis*.

Interstitial: Water-filled spaces within the river sediments forming the river bottom or adjacent to it.

Invertebrates: Collective term for animals without backbones.

Invertivorous fish: Fish species that feed on invertebrates, whether aquatic, flying or terrestrial. – See: *invertebrates*.

Kelts: Salmon returning to the sea after spawning.

Olfactory orientation: Orientation of many fish species results from a highly developed sense of smell.

Parr: A young salmon living in freshwater.

Phytoplankton: Small to very small algae that live passively in fresh or salt water and manufacture their own nutrition by photosynthesis (i.e. they are autotrophic).

Piscivorous fish: Fish species that feed on other fish.

Planktivorous fish: Fish species that feed on plankton.

Population: The totality of all individuals of one species in a specific living area that reproduce sexually with one another over many generations and are thus genetically linked.

Sluice: Device for relief, flushing or emptying the impoundment behind a dam.

Sluice gate: Constructional, adjustable element installed at weirs, reservoirs and hydroelectric power stations to regulate the flow of water. Sluices are generally made of rectangular steel plates sliding or rolling in lateral guide grooves.

Smolts: Young salmon, with typical silvery colour, migrating to the sea.

Spillover jet: A water jet passing over a real spillway, either falling free or flowing along the spillway back as a gushing jet

Stenotypic: Stenotypic species are very sensitive to changes in their living conditions. – See: *eurypic*.

Stock: Genetically distinct community of individuals of one species in a specific living area.

Volumetric power dissipation: Amount of energy per unit of volume that is dissipated in the pools of a fish pass. The hydraulic energies are no longer available for further discharge. It is a measure of the turbulence conditions in a pool. Unit: [W/m³ pool volume]. – See: *energy dissipation*.

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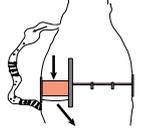
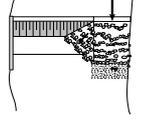
Baumann, A.:	Figure 4.2
BAWAG:	Figures 4.21, 4.26, 4.45
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Stolzenburg, H.:	Figure 2.14
Surhoff, P.:	Figures 4.22, 4.36, 5.3
Touschek, A.:	Figure 4.13

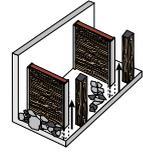
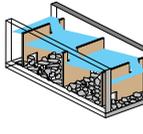
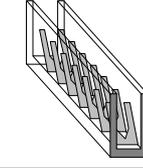
Graphic design by Krüger, F. and Schaa, W.

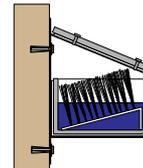
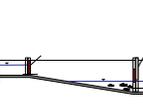
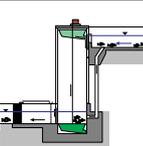
Appendix: Overview of the most frequently used construction types of fish passes

The various fish passes are classified by functional and ecological aspects, but no account is taken of local geographical factors that may limit the use of some structures.

*Where measurements are given, they are only minimum requirements.

Close-to-nature types of structures						
Type	Sketch	Principle	Dimensions* and discharge	Range of application	Advantages and disadvantages	Effectiveness
Bottom ramps and slopes (sect. 4.1)		Ramps and slopes are structures that have a rough surface and extend over the entire width of the river. Loose rockfill constructions and dispersed constructions are favoured.	The ramps are as wide as the river ($b = \text{width of river}$), their slope normally $< 1:15$. If the main body of the ramp is steeper, then at least the marginal areas must be less steep. Height $h > 0.2$ m. Discharge must be $q > 100$ l/s m. Construction in several layers and with secured downstream bottom.	Recommended where a previous use has been abandoned and where the headwater level needs no longer be regulated. Used for the modification of steep drops and fixed (very steep) weirs, as a protective sill to hinder erosion.	There is a danger of drying out at low discharge, so sealing may be necessary. Relatively low costs. They blend well into the landscape, look natural, require little maintenance. No problems with attraction currents, so can easily be found by fish.	They are passable in both directions by all aquatic fauna. Long term silting of the impoundment restores also upstream the typical flow velocities and substrate conditions.
Bypass channels (sect. 4.2)		Offer an alternative route round a dam with a natural-looking stream bypassing the impoundment.	$b > 1.2$ m; $h > 0.20$ m; $< 1:20$. The bypass should extend up to the upstream limit of the backwater. Discharge must be at least $q = 100$ l/s m.	Suitable for all barriers and heads if there is sufficient space, particularly useful for retrofitting existing installations. They are not suitable when impounding heads vary; in the latter case, inlet constructions for water regulation might be necessary.	Their financial cost is low, their demand for space high! Deep cuts into the surrounding terrain may be necessary or combination with other technical structures. Bridges or underpasses are often required.	They are passable for all aquatic fauna, provide living space for rheophilic species, are the only fish pass that can bypass the whole area of the dam and the impoundment, blend well into the landscape.
Fish ramps (sect. 4.3)		Ramps with gentle slopes and a rough surface; integrated into the weir structure. Their body may be of rockfill, with perturbation boulders or boulder sills to reduce flow velocities.	$b > 2.0$ m; $h > 0.3$ to 0.4 m; $= 1:20$ or less. Necessary discharge q approximately 100 l/s m.	They can be used to overcome heights not greater than about 3 metres. Used at fixed weir sills, and at multi-bay weirs as a substitute for a weir bay. They are not suitable for variable impounding heads.	Their construction is often technically demanding, with a need for high structural stability. There is a danger of drying out at low water, therefore sealing may be necessary. Require little maintenance; good self-cleaning during floods. Good attraction current.	They are passable for all aquatic fauna in both directions, i.e. upstream and downstream.

Technical structures						
Type	Sketch	Principle	Dimensions* and discharge	Range of application	Advantages and disadvantages	Effectiveness
Slot passes (sect. 5.2)		Slot passes are generally concrete channels with cross-walls of concrete or wood and with one or two vertical slots that extend over the whole height between the cross-wall and the lateral bounds.	Pool dimensions: $l_p > 1.90$ m; $b > 1.20$ m; $h > 0.5$ m; Slot width: $s > 0.17$ m. Discharge can be from $Q = 140$ l/s up to several cubic metres per second.	Used for small and medium heads, suitable for variable impounding heads. Can be used for small streams and large rivers. The minimum tailwater depth must be $h > 0.5$ m.	Relatively high discharges can be sent through, thus good attraction currents can form. More reliable than conventional pool passes because of the lower risk of clogging of the slots.	They are currently the best type of technical fish pass, being suitable for all species of fish and are passable for invertebrates if a continuous bottom substrate is built in.
Pool passes (sect. 5.1)		Are generally concrete channels with cross-walls of wood or concrete which are fitted with submerged orifices and top notches on alternate sides.	Pool dimensions depend on the river zone; $l_p > 1.4$ m; $b > 1.0$ m; $h > 0.6$ m. Submerged orifices: $b_s/h_s > 25 \cdot 25$ cm Discharge $Q = 80$ to 500 l/s.	Used for small and medium heads, at melioration dams and at hydroelectric power stations.	Only relatively low discharges allowed; there is great risk of clogging with debris.	Suitable for all species of fish if the dimensions of the pools and orifices are chosen as a function of the fish size that can be expected to occur. There might not be sufficient attraction current at low discharges.
Denil passes (sect. 5.3)		Wooden or concrete channel with sectioned baffles (usually of wood) that are U-shaped, and are set at an angle of 45° against the flow direction.	Channels: $b = 0.6$ to 0.9 m; $h > 0.5$ m; $< 1:5$; $Q > 250$ l/s. Channel lengths can be 6 to 8 metres; resting pools are required for heights > 1.5 to 2 m.	Suitable for small heads, particularly for retrofitting of old middams when there is not much space.	Relatively high discharges; should not be used for variable headwater levels; not sensitive to varying tailwater levels; need little space; cheap; good formation of attraction current.	According to present knowledge, less suitable for weak swimmers or small fish. Selective. Benthic fauna cannot pass.

Special constructions						
Type	Sketch	Principle	Dimensions* and discharge	Range of application	Advantages and disadvantages	Effectiveness
Eel ladders (sect. 5.4)		Generally, eel ladders are small channels with brush-type fittings, layers of brushwood or gravel, with water just trickling through them; also "eel pipes" that are led through the weir body and are filled with brushwood or brush-type material.	Channel: $b = 30$ to 50 cm; $h = 15$ to 25 cm. Slopes usually $1:5$ to $1:10$, but can be steeper.	Often used as a bypass in pool passes, but only useful where migration of glass eels and elvers occurs; in general not strictly necessary if there is another fish pass.	Low construction costs, only little space required, only low discharges needed.	Only suitable for glass eels and elvers. Eel pipes are not proven satisfactory because of their tendency to become clogged and the difficulty in maintenance. On their own, they are not sufficient to connect upstream and downstream habitats and cannot guarantee free passage for all fish.
Fish locks (sect. 5.5)		A pit-shaped chamber with controllable closures at headwater and tailwater openings. The attraction current is formed by controlling the sluice gate openings or by sending water through a bypass.	Their dimensions can vary, with minimum chamber width and water depth being similar to those in a pool pass. Water quantity requirements depend on chamber size, cycle intervals for lock operation and required intensity of attraction current.	Used for high heads, and where space or available water discharge is limited.	Planning and construction is often technically demanding. Require high efforts in maintenance and operating, high construction and service costs, low water consumption. Useful where very large fish (e.g. sturgeon) are to be taken into consideration.	According to present knowledge, suitable for salmonids and fish with weak swimming capacities. Less suitable for bottom-living and small fish.
Fish lifts (sect. 5.6)		Lifting device with transport trough and mechanical drive to hoist fish from tailwater to headwater; connection to headwater through a channel; water sent through a bypass creates attraction current.	Dimensions variable, volume of transport trough about 2 to 4 m ³ . Continuous flow through a bypass needed to create attraction current.	Used for same situations as fish locks, but often the only type of pass that can be built for heights greater than 10 metres, e.g. at high dams.	Need little space. Planning and construction is often technically demanding. Require high efforts in maintenance and operating, high construction and service costs.	According to present knowledge, suitable for salmonids and fish with weak swimming capacities. Less suitable for bottom-living and small fish. Not suitable for macrozoobenthic fauna or for downstream migration of fish.

Many fish species undertake more or less extended migrations as part of their basic behaviour. Amongst the best known examples in Europe are salmon (*Salmo salar*) and sturgeon (*Acipenser sturio*), which often swim several thousands of kilometres when returning from the sea to their spawning grounds in rivers. In addition to these long-distance migratory species other fish and invertebrates undertake more or less short-term or small-scale migrations from one part of the river to another at certain phases of their life cycles.

Fish passes are of increasing importance for the restoration of free passage for fish and other aquatic species in rivers as such devices are often the only way to make it possible for aquatic fauna to pass obstacles that block their up-river journey. The fish passes thus become key elements for the ecological improvement of running waters. Their efficient functioning is a prerequisite for the restoration of free passage in rivers. However, studies of existing devices have shown that many of them do not function correctly. Therefore, various stakeholders, e.g. engineers, biologists and administrators, have declared great interest in generally valid design criteria and instructions that correspond to the present state-of-the-art of experience and knowledge.

Fishways can be constructed in a technically utilitarian way or in a manner meant to emulate nature. Bypass channels and fish ramps are among the more natural solutions, while the more technical solutions include conventional pool-type passes, slot passes, fish lifts, hydraulic fish locks and eel ladders. Comprehensive monitoring is crucial.

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