Aspects of Design and Monitoring of Nature-Like Fish Passes and Bottom Ramps

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ISSN 1437-3513

ISBN 978-3-940476-10-4

Berichte des Lehrstuhls und der Versuchsanstalt für
Wasserbau und Wasserwirtschaft

Herausgegeben von Prof. Peter Rutschmann
Ordinarius für Wasserbau und Wasserwirtschaft, TU München

Druck und Einband: Meissner Druck GmbH, Oberaudorf

TO MY PARENTS,
FISH,
AND THE WORLD

Preface

In recent decades engineering concerning environmental issues has been developing rapidly through the world. Hydraulic engineering, dealing essentially with water, in particular plays an important roll in contributing to the mitigation of conflicts between human beings and the other species. This dissertation presents the research results on fish passage problems and is trying to bridge the gap between engineering and biology, as well as civilization and a balance of nature.

For the successful completion of this work, I am especially indebted to my doctoral supervisor, Univ.-Prof. Dr.-Ing. Theodor Strobl, for the immense scientific opportunities, his insights and encouragement; to Univ.-Prof. Dr. rer. nat. Harald Horn for his engagement in the examination committee; to Univ.-Prof. Dr.-Ing. Peter Rutschmann for being the chairman of the examination committee.

I am grateful to Dr. Christian Göhl for his borther-like help. Without his wealth of knowledge and suggestions, this work would not have been possible; to Dr. Arnd Hartlieb, for his scientific help in the laboratory; to Mr. Albert Sepp, for his tremendous amount of discussions, patience and assistance.

I am also thankful to DAAD, German Academic Exchange Service, for providing me the three-year-doctoral-scholarship.

Finally, individuals without whom I might never have complete this work: Richard, Albert, Hubert, Manfred for the model test; Franz, Peter, Stefan (for both) for the fieldwork; Christine and Georg for the administrative assistance. To all my sweet Obernach colleagues and the Blockhaus flatmates, in particular dear Valli, with you there was not only a work in Obernach, but also a life.

WANG Ruey-wen

Poitiers
September, 2008

Abstract

Fish free passage problems in inland waters have long been reported. Many fishways were built to re-establish corridors for fish movement, in particular in Germany a highlight of nature-like fish passes are emphasized.

The first part in this research presents the results of the hydraulic model test about mean flow patterns and turbulence structures in nature-like pool-type fish passes and the comparison with conventional technical type. The frequently applied quantitative scalar of turbulence, energy dissipated rate, is discussed and a more precise term, turbulent kinetic energy, is recommended to represent the scale of turbulent fluctuations and its influence on fish swimming performance.

The second part presents the fieldwork for assessing the effectiveness of two bottom ramps and two fish ramps for fish migration by geometrical and hydraulic as well as biological investigations during low flow, mean flow and high flow conditions. Adequate design principles and standard operating procedures of monitoring work are developed.

Zusammenfassung

Über Probleme bei der Durchwanderbarkeit von Fließgewässern für Fische wird schon seit langem berichtet. Zahlreiche Fischpässe wurden errichtet, um die Durchgängigkeit wiederherzustellen. In Deutschland wird besonderer Wert auf eine naturnahe Bauweise gelegt.

Im ersten Teil dieses Berichts werden die Ergebnisse hydraulischer Modellversuche zur Erfassung der Strömungs- und Turbulenzstrukturen einerseits in einem naturnahen Beckenpass und andererseits in einem in technischer Bauweise ausgeführten Fischpass dargestellt. Als ein wesentliches Ergebnis werden zwei unterschiedlich definierte Größen zur quantitativen Beschreibung der Turbulenz, nämlich die Turbulenzintensität und die turbulente kinetische Energie bestimmt. Zur Beurteilung des Einflusses der Turbulenz auf die Fischwanderung hat sich dabei die turbulente kinetische Energie als geeigneter erwiesen.

Im zweiten Teil werden die Felduntersuchungen an zwei aufgelösten Rampen und zwei Fischrampen im Flusssystem der Mangfall in Oberbayern beschrieben, bei denen die hydraulischen Randbedingungen für niedrigen, mittleren und hohen Abfluss messtechnisch erfasst und hinsichtlich der potentiellen Durchwanderbarkeit überprüft wurden. Aus den Ergebnissen der Untersuchungen wurden Ausführungsrichtlinien für die generelle hydraulische Funktionskontrolle von Rampen und Fischrampen hinsichtlich der potentiellen Durchwanderbarkeit entwickelt.

摘要

內陸水域之魚類迴游問題引起關切已有時日。魚道為一重建魚類自由移動廊道之工法並已廣為應用，在德國尚有其特殊發展出之近自然工法魚道。

本研究之第一部分提出近自然水池式魚道之水工試驗結果，以展示其流場與紊流結構，並與傳統型態魚道比較之。目前魚道設計最常用之紊流量化指標為能量散失率，本研究建議以紊流動能作為紊流強度之指標，以更精確量化紊流尺度並作為設計指標之用。

第二部分為 Mangfall 流域四處不同型態之近自然固床工現場調查結果。調查項目包括其結構型態、尺度與水理特性，並於高、中、低三種不同流量時期進行測量。由調查結果以評估各近自然固床工提供之魚類洄游效能，並以建立監測近自然固床工之魚類洄游廊道重建效能之標準作業程序。

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1. Introduction

1.1. Background

During the 19th and 20th centuries in Europe, river regulations were introduced for various purposes such as land use, water supply, navigation, hydropower and flood mitigation. Therefore weirs, dams and artificial channels were built for the benefit of humans. However, such constructions pose as obstacles and interrupt the longitudinal connectivity of a river so that unhindered passage for aquatic organisms is no longer ensured (DVWK 232/1996). This, together with other factors such as water pollution, leads to a decrease in the population of certain species of fish, e.g. salmon, trout, sturgeon, sometimes even bringing them close to extinction (DVWK 232/1996).

Fish passes are structures that facilitate the upstream or downstream migration of fish over such obstructions. For a fish pass to be considered effective, fish should find the entrance and negotiate it without delay, stress or injury that might prejudice the success of their upstream migration (Larinier 2002). The design of a fishway should take into account certain aspects of the behaviour of migratory species. In particular, its effectiveness is closely linked to water velocities and flow patterns in the facility (Larinier 2002).

The conventional types of upstream fish passes include Denil, pool-type, and vertical-slot (the latter two are sometimes jointly referred to as a single type of pool-type fish pass) fishways and facilities that require mechanical operations such as fish locks and fish lifts.

In the past decades, in Germany and Austria, nature-like fish passes, which are also called near-nature or close-to-nature (FAO and DVWK 2002) fish passes, have become a very common type of fish migration facilities. These fish passes resemble natural river rapids or brooks very closely, and are supposed to be less species selective, which implies that they are supposed to provide passages for both adult migratory fish as well as small and juvenile fish. In Germany the Guidelines (DWVK 1996) “Fish Passes–Design, Dimensions and Monitoring,” defines three constructions as nature-like fish passes: bottom ramps, bypass channels, and fish ramps.

Although the development of nature-like solutions on restoration of fish migration route has been more than two decades and many different types of bottom ramps, bypasses, fish ramps or nature-like pool-type or vertical-slot fishways were built. Most of them are however constructed by experiences or as an imitation of existing examples. The flow patterns in such nature-like fishway facilities are not systematically analyzed and leave unknown. The effectiveness of the fish passes are sometimes assessed via hydraulic or biological field investigations which are conducted only one time during mean flow condition and can not provide a convincing proof whether such fish passes works well under various flow conditions, in particular during low flow period, and will not dry out.

1.2. Purposes of study

In this study it consists of hydraulic model test and field investigations on various nature-like solutions for improvement of fish free passage problems in running waters under different flow conditions. In Chapter 3 the hydraulic model test relevant to mean flow and turbulence structures in a nature-like pool-type fish pass are studied and compared with conventional technical type. The frequently applied quantitative scalar of turbulence, the energy dissipated rate, is discussed and a more precise quantitative term, turbulent kinetic energy, is introduced and recommended to represent the scale of turbulence flow and its influence on fish performance. The design principles for nature-like fish passes are then suggested.

In Chapter 4 the field investigations on two bottom ramps, Kolbermoor in the river Mangfall and Plackermühle in the brook Kalten, as well as two fish ramps, Schwaig in the river Mangfall and Leitner in the brook Leitzach, were studied in detail on their geometries and hydraulics during low flow, mean flow and high flow conditions. Adequate design principles for such ramps and standard operating procedures of monitoring work on how to evaluate the effectiveness of ramps are suggested to ensure satisfactory ecological function of ramps, in particular during low flow period.

Nowadays, humans seem to promise fish a future. In the next decade, we will see how humans keep their word.

2. Principles of fish passes and nature-like fish migration facilities

2.1. Fish behaviour and fish migration

Rheoreaction, which is an inherent behavioural response of fish to swim upstream, underlies fish behaviour in the flow (Fig. 2.1.1, Pavlov 2006). All other features of behaviour in the stream have to be seen against a background of this particular reation. Rheoreaction has two components of behaviour: orientational and locomotor. Organs of vision, touch, equilibrium (horizontal labyrinth channels) and neuromast help fish find its way against the current. Locomotor activity of fish in the stream can be described by several functional indices: threshold flow rate (its value sets the lower limit of flow rate for fish rheoreaction to develop), critical flow velocity (its value defines the upper limit of velocity interval, within which fish retention in the stream is possible), burst speed and swimming capacity (duration of fish motion at different flow velocities).

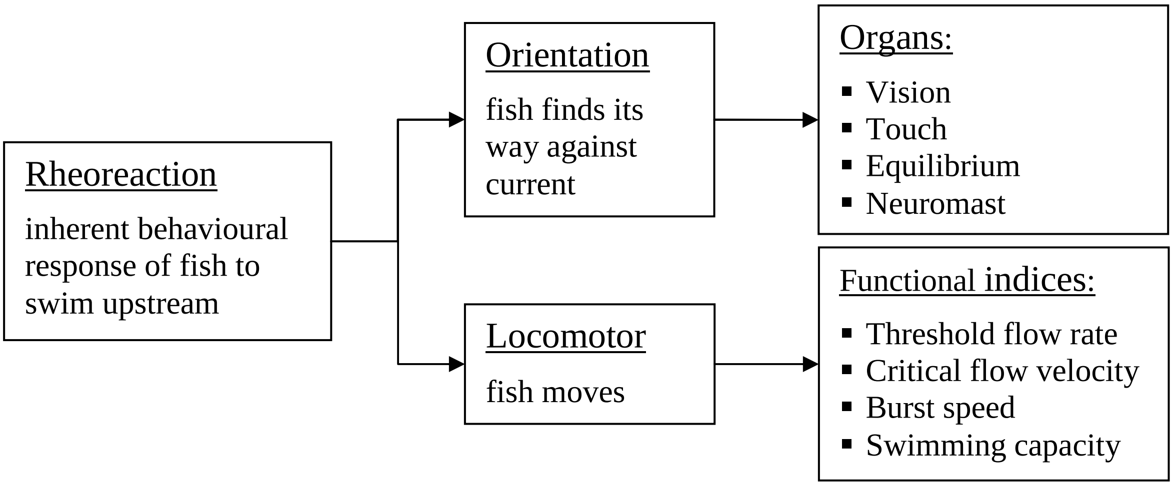


Fig. 2.1.1: Mechanism of rheoreaction responses of fish to swim upstream (after Pavlov 2006)

Fish populations are highly dependent upon the characteristics of the aquatic habitat which supports all their biological functions. This dependence is most marked in migratory fish which require different environments for the main phases of their life cycle which are reproduction, production of juveniles, growth and sexual maturation. The species has to move from one environment to another in order to survive (FAO 2001). Fish can be categorized by their migration behaviour and it includes potamodromous, diadromous and amphidormous species as shown in Fig. 2.1.2.

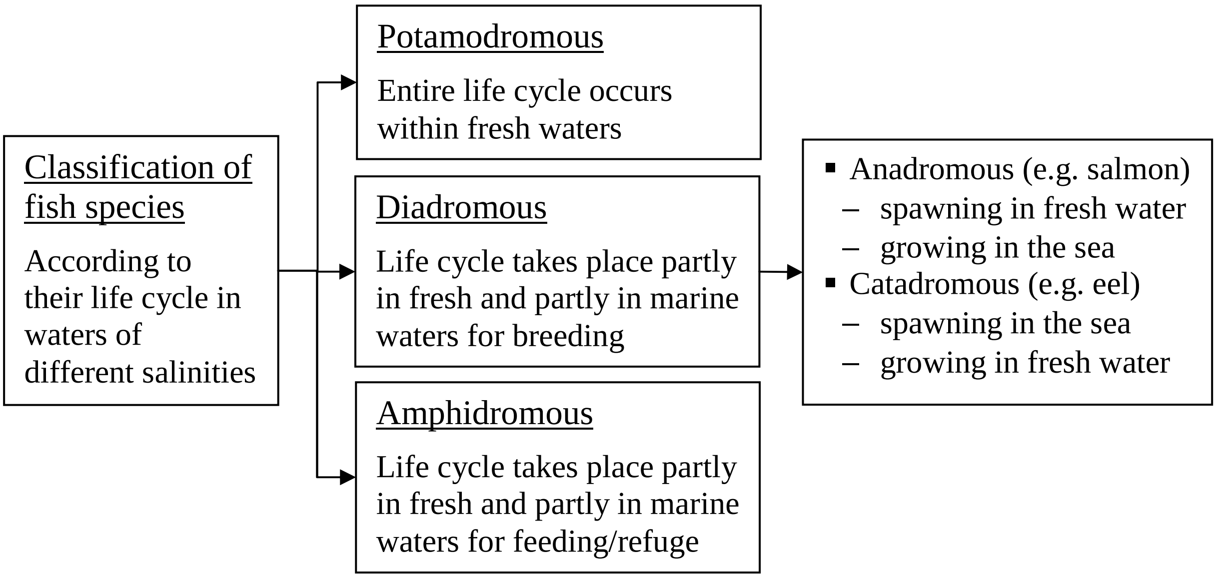


Fig. 2.1.2: Classification of fish migration behaviour (after FAO 2001)

2.2. Fish passes

2.2.1. General principles (from Larinier 2002)

The aim of a fish passage facility is to attract migrants to a specified point in the river, downstream of the obstruction, and then to induce them, or even make them, pass upstream. This is achieved either by opening a waterway or else by trapping them in a tank and lifting them upstream.

For a fish pass to be considered effective, fish should find the entrance and negotiate it without delay, stress or injury that might prejudice the success of their upstream migration. The design of a fishway should take into account certain aspects of the behaviour of migratory species. In particular, its effectiveness is closely linked to water velocities and to patterns of flow in the facility. The water velocities in the fishway must be compatible with the swimming capacity of the species concerned, and the fishways should permit passage for all individuals and not only the athletes.

Some species are very sensitive to particular flow regimes or conditions. These include water level differences between pools that are too large, excessive aeration or turbulence, existence of large eddies, and water velocities that are too low. All of these can act as a barrier for fish.

In addition to hydraulic factors, fish are sensitive to other environmental parameters (level of dissolved oxygen, temperature, noise, smell, etc.) which can have a deterrent effect. This is particularly true if the quality of the water feeding the fishway is different to that passing across the dam (low oxygen levels, differences in temperature, etc.).

Fish also have requirements or preferences with respect to ambient light intensity. Light conditions at the entrance to and inside the fishway which are very different from those at the obstruction (too steep lighting gradient at the entrance, insufficient illumination in the fish facility or on the contrary illumination during the night for lucifugous species) may have a detrimental effect.

The influence of most of these parameters on the behaviour of migratory species is, however, poorly documented at present, and any information usually comes from local observations. This is why it is not easy to specify design criteria for engineers.

2.2.2. Different types of fish passes

Fish passes include the frequent pool type, vertical slot type and Denil fishways as well as special constructions such as eel ladders, fish locks and fish lifts as shown in Fig. 2.2.1. They function either to attract fish to pass through the construction itself, or to transport them mechanically or by trap-and-truck. In Germany, the Guidelines “Fish Passes – Design, Dimensions and Monitoring” (DVWK 232/1996) have a particular emphasis on nature-like solutions for fish migration facilities which are introduced in Chapter 2.3.

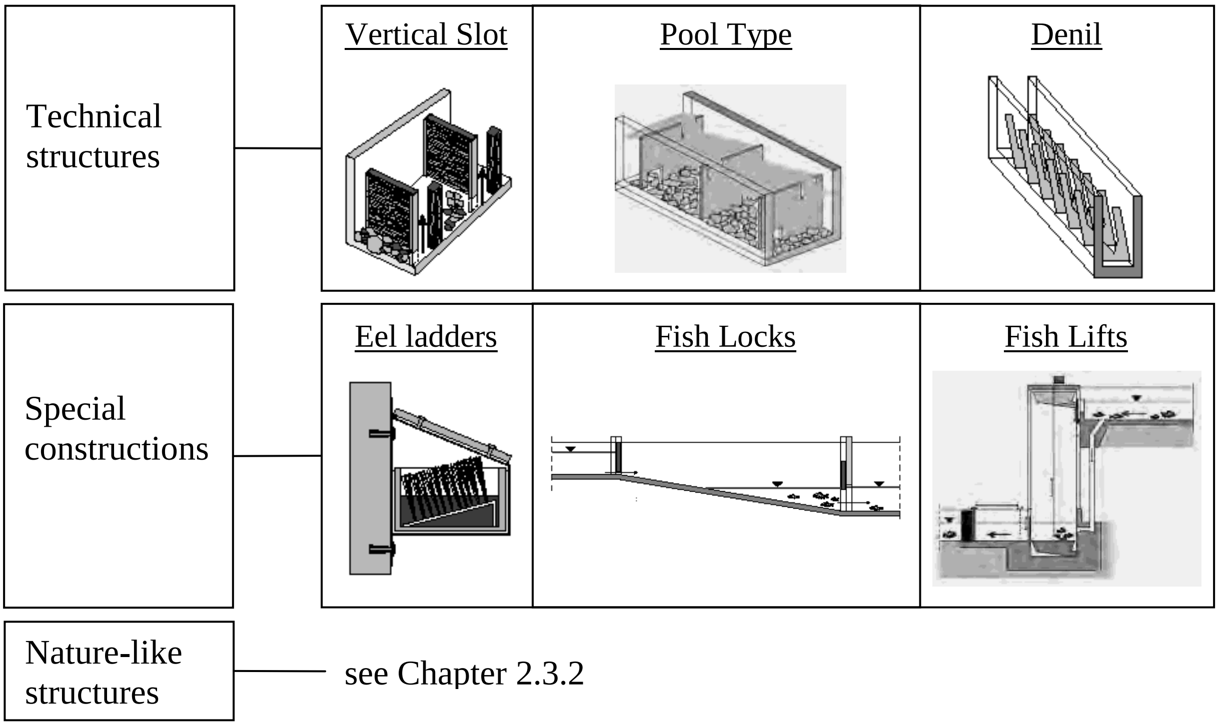


Fig. 2.2.1: Different types of fish passes categorized in the Guidelines DVWK 232

2.3. Ramps – from bottom protection structures to fish friendly constructions

In the Guidelines DVWK 232 it consists of three different types of nature-like fish passes: bottom ramps, bypass channel and fish ramps. Bottom ramps are originally kinds of river bottom protection structures for mitigation of streambed erosion. An overview of bottom protection structures and their further considerations with reference to providing ecological improvement in the aquatic environment are introduced in this chapter. The structures, general requirements and other construction principles of bottom ramps, bypass channel and fish ramps will then be discussed in detail.

2.3.1. Bottom protection structures (DIN 19661-2)

2.3.1.1. Drop structures and ramps

Bottom protection structures consist of drop structures and ramps as well as sills according to the German standard of hydraulic structures DIN 19661-2 (Fig. 2.3.1). They change the longitudinal section so that the streambed slopes upstream and downstream of the bottom drops are milder and the difference in level is therefore overcome by the constructions.

Drop structures and ramps cause changes of flow type during higher discharge conditions. On the bottom constructions there should be twice flow changes: from subcritical flow to supercritical and then back to subcritical flow. By the second flow change, significant energy dissipation occurs on the construction within short section with Froude number $Fr \geq 1.7$ in front of the hydraulic jump and with $Fr \geq 0.5$ right after (DIN 19661-2) the jump. However the values are adequate as criteria for drop structures but not adequate for milder rough ramps (DVWK 1997).

Drop structures and ramps which create no hydraulic jumps under significant discharges, cause erosion at mobile bed below the constructions. Bottom drops only slightly disturb the bed load transport. At high discharges the flow velocities are about the same as for a continuous bottom slope without drops. The height of drop structures and ramps is in principle upward unlimited, however downward there is a limitation on the hydraulic effectiveness (DIN 19661-2).

2.3.1.2. Sills

Sills are one of bottom protection structure for shelter against erosion without changing the existing bed slope and consist of three types: firm sills, ground sills and bottom sills, in which firm sills should raise the upstream water stage to the level that the energy slope will be reduced and the shear stress and velocity will not exceed the limit values (DIN 19661-2). Scour occurring around sills are usually unavoidable.

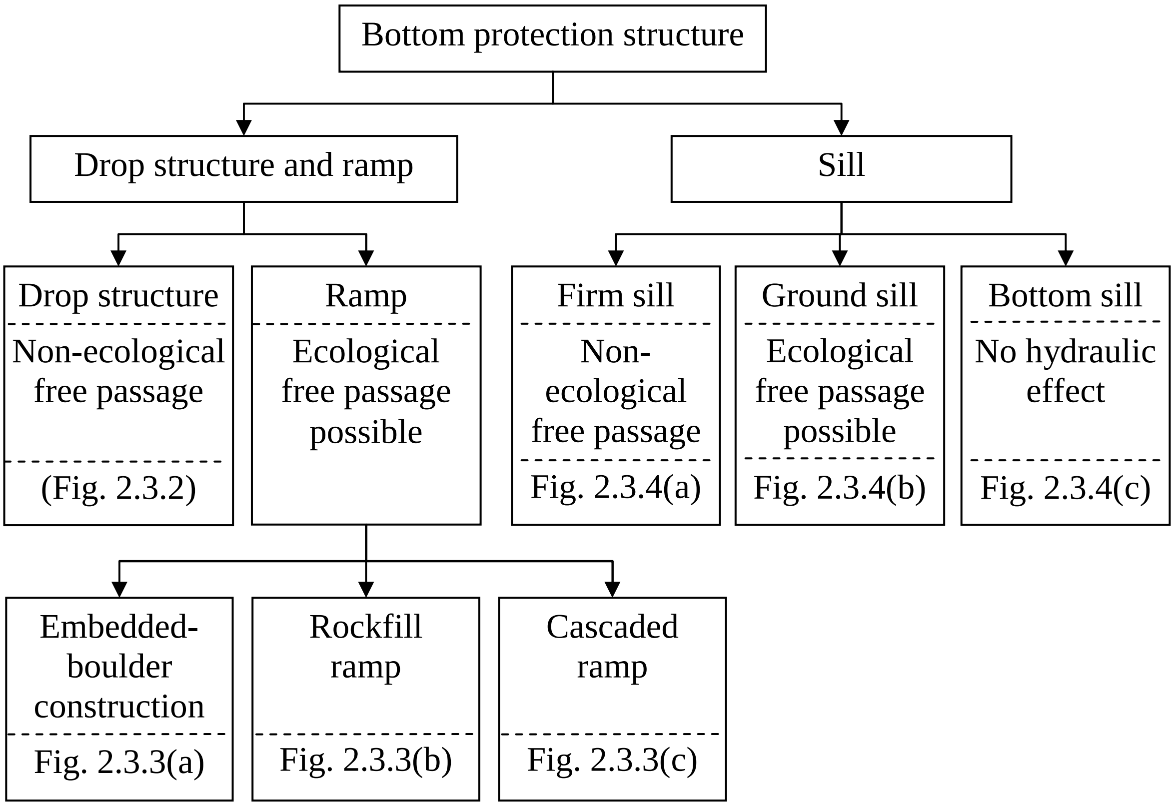


Fig. 2.3.1: Classification of bottom protection structures according to DIN 19661-2 and DVWK 232/1996 (German terms see App. C)

2.3.2. Nature-like fish migration facilities

Nature-like fish migration facilities have been well known in Germany and Austria for decades. In the Guidelines of fish passes DVWK 232, the constructions “Bottom ramp”, “Bypass channel” and “Fish ramp” are defined as nature-like types of fish passes.

Ramps are originally developed as a method to prevent from further erosion of river bed. Flow changes and hydraulic jumps are designed to occur on the constructions for energy dissipation so that the length, slope, stone size and arrangement of stones as a factor to represent roughness and form of the ramp as well as discharges and water levels are considered for a better controlled bottom stabilization work.

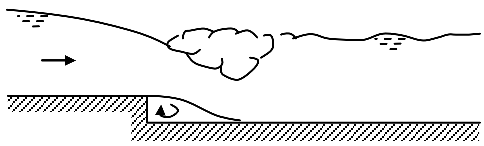
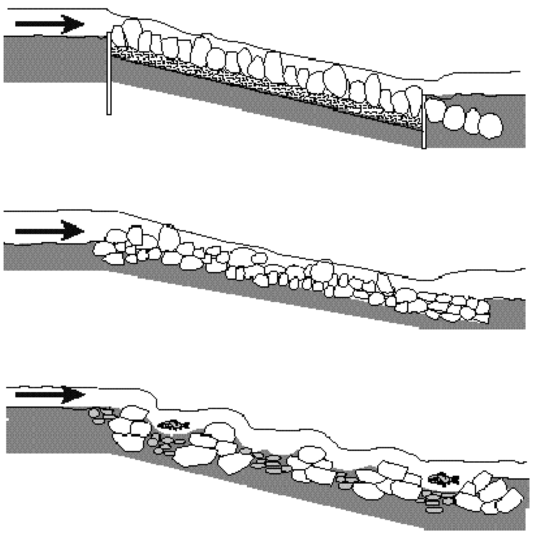


Fig. 2.3.2: Sketch of drop structures, DIN 19661-2



(a) Embedded-boulder construction

Single layer structure with filter layer, boulders are set clamped to each other, uniform roughness, rigid structure

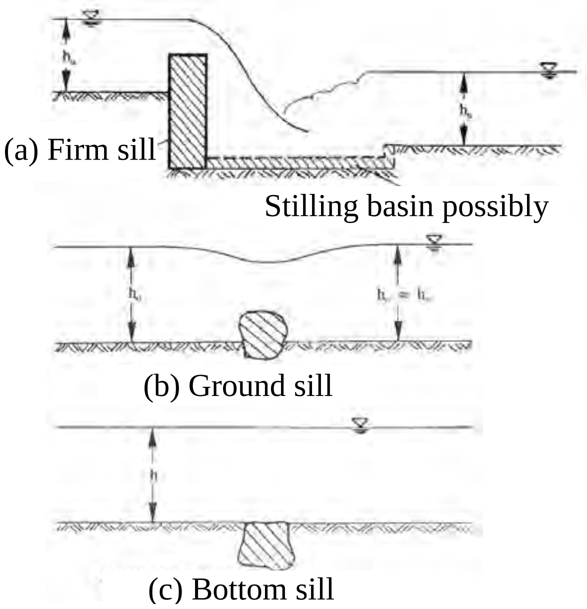
(b) Rockfill construction

Loose multilayer rockfill, scour protection below necessary, elastic structure, diverse roughness, filter layer necessary

(c) Cascaded construction

Cascaded structure forming by boulder sills, high structural variety, flow dynamics develops in basins

Fig. 2.3.3: Sketch of ramps, DVWK 232 and 118



(a) Firm sill

Functioning similar to a weir that over the crown of the sill, the flow changes and the energy slope upstream becomes milder.

(b) Ground sill

Only a small part of the sill projects from the bed and are applied only when slope of the mobile bed is allowed to be exceeded slightly or raise of water level for low flow period.

(c) Bottom sill

Inserted into bed for local stability of bed.

Fig. 2.3.4: Definition of sills (DIN 19661-2 and DVWK 118)

However when it comes to carry the function on reestablishment of fish free passage, the design principles should be modified to reach the requirements for fish and other organisms. For example ramps with slope of 1:5 to 1:10 cause significant energy dissipation but are too steep and result in high flow velocity, shallow water depth and very turbulent region at the downstream side of constructions for fish to migrate. In addition, more detailed in the flow patterns, including turbulence structures should also be studied.

In Chapter 2.3.2 nature-like fish passes are introduced based on the fish pass Guidelines DVWK 232.

2.3.2.1. Bottom ramp

As mentioned in Chapter 2.3.1, bottom ramps are one of the bottom protection structures used for streambed stabilization since flow changes between subcritical and critical flow occuring on constructions and energy significantly dissipates. In addition, they represent, advantageous method for the restoration of a river continuum as they imitate the conditions of a river stretch naturally rich in structural diversity and gradient.

According to DIN 19661-2, such constructions can be furthermore categorized as bottom ramps (Sohlrampen) and bottom slopes (Sohlgleiten) based on slopes of the structures. Bottom ramps are such constructions with slope between 1:3 and 1:10 while bottom slopes are with slope between 1:10 and 1:30. In the Guidelines DVWK 232 it is suggested that for an appropriate possible free passage for fish migration, the slope of such constructions should be 1:15 or milder. The criteria will be examined later in Chapter 4 based on the results of field investigations. The term of such structures will be fixed as bottom ramp with no more mention to bottom slope.

Bottom ramps can also be considered as a substitution for removal of out-of-service weirs in rivers. It takes advantage for restoration of longitudinal continuity in running waters not only for fish or other aquatic organisms but also for sediment transportation.

(a) Embedded-boulder construction

Embedded-boulder constructions are generally limited to ramps with slopes of approximately 1:10. The ramp is constructed by setting boulders in size of 0.6 to 1.2 m and attached to each other. Under the ramp there must be a filter layer to maintain the structural stability. The dimension of filter layer is in accordance with conventional rules. The top and bottom boulders are usually secured by steel sheet piles or similar securing elements. Protection against scour below ramps must be designed for about 3 to 5 meters in longitudinal direction. If there is a potential on formation of scour, further erosion protection, e.g. rock fills, must be considered.

(b) Rockfill construction

From an ecological point of view, rockfill ramp, or bottom ramp with perturbation boulders, are assessed to be more favourable than embedded-boulder constructions. The main body consists of a multi-layered rockfill where the thickness of the layers is at least twice the maximum diameter of the biggest boulders used. The bottom roughness is increased by individual boulders. A cascaded design using rock sills is also possible with main purposes to keep adequate water depth during low flow period and to enhance the structural diversity. The rockfill ramp can be additionally secured by wooden pile roles or steel reinforced bars. For a constantly erosive streambed it is unnecessary to consider a further scour protection at the transition zone to downstream side and the rockfill ramp is extended with the same slope until it is below the level of the tail water river bottom with a short erosion protection of about 3 to 5 meter in longitudinal direction. On the contrary, for rivers throughout plain with non-constantly erosive streambed or sandy or silty substrate, there should be scour basin build as transition zone and the protection construction should be extended as well.

The embankments along the ramp and the erosion protection zone must be secured with rockfill over the mean high water level (MHW). Planting the embankments with appropriate vegetation enhances their resistance against erosion and keeps the main flow axis in the center of the river during floods.

(c) cascaded construction

Cascaded bottom ramps mainly consist of a number of boulder bars, or called boulder sills, with stone size of 0.6 to 1.2 m. To enhance stability of boulder sills, they can be arranged in arches, so that the boulders will lean against to each other. For streambed with less erosion potential, stony or gravel bed such as in mountain streams, boulder sills should be embedded to 2.5 m deep and additionally be secured by piles or steel reinforced bars. Another alternative of construction type is to provide a filter layer below the boulder sills for structural stability and the embedded depth will be then unnecessary so deep as 2.5 m.

Boulder sills create pools which are filled with gravels, cobbles or even sands typical for plain, and will yield its specific flow dynamics. The materials may be removed during high flow conditions but will be compensated by deposit of sediment when flow decreases.

The interval between boulder sills and the arrangement of boulders should be designed to provide water level differences between adjacent pools not over 20 cm.

Cascaded bottom ramps with boulder sills are sometimes hardly to be recognized as artificial constructions because of its diversity of structure. To plan and to construct such ramps remain however highly experienced, in particular comparing with other nature-like fish migration constructions.

- **Plane view**

Boulder sills are constructed with a spatial curvature as shown in Fig. 2.3.5 in rivers with bottom width $b_0 > 15$ m and the crest profile has a pitch of 0.3 to 0.6 m in cross section. In smaller rivers a curved arch is not required and a linear crest is constructed instead. The scour protection zone below the ramp provides stability security against erosion. A low flow channel, or thalweg, should be arranged to provide adequate water depth and migration corridor for drought or low flow periods.

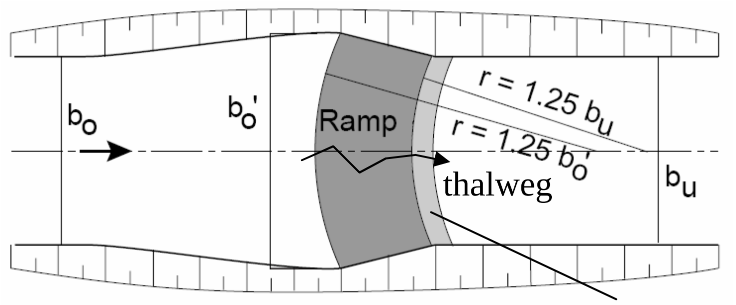


Fig. 2.3.5: Plan view of a curved bottom ramp (DVWK 232, modified)

- **Longitudinal section**

In principle embedded bottom ramps are designed with slopes of 1:8 to 1:10. Rockfill ramps and cascaded ramps are with mild slopes of 1:15 to 1:30. Flow velocities at embedded bottom ramps with slope of 1:10 are estimated to be too high for most fish and benthos but a proper zone may be created nearby riverbanks to produce low velocity area in the margins.

An averaged water depth of 0.3 m to 0.4 m should be retained even for low flow conditions. Big boulders and deep basins forming resting pools make it easier for fish to ascend and give a very varied and also optically attractive flow pattern, especially for cascaded bottom ramps with boulder sills can best reach such criteria.

- **Overall assessment**

Rough bottom ramps with mild slopes can be considered as most favourable construction to restore free passage for fish in rivers which are disturbed by different obstacles. In which rockfill ramps and cascaded ramps with boulder sills are preferable to embedded ramps. The amount of concrete for a stable structure should be minimized.

The construction principles of rockfill ramps or cascaded ramps with boulder sills can be also applied for modification of drops or regulable weirs.

Maintenance is relatively little and can be combined with occasional removal of drift and floating waste as well as regular check for possible damages in particular after flooding.

It should be possible for the entire aquatic fauna to pass through such constructions in both upstream and downstream directions.

2.3.2.2. Bypass channel

The artificial river, or “natural bypass channel”, is a mild slope channel mimicking a natural watercourse and linking the forebay and tailbay of an obstacle without structural modification of the obstacle itself (DVWK 232, Larinier 2002) as shown in Fig. 2.3.6. The velocity in the channel is reduced and the energy is dissipated by the roughness of the bottom, the banks, and by a series of constrictions and expansions of the flow created by blocks, groynes and weirs positioned more or less regularly throughout the channel (Larinier 2002).

Bypass channel is taken to be “environmentally-friendly passage” and can be multi-purposes. It may form a fish passage facility and habitat for migratory fish and a white-water course for canoes, kayaks or rafts (Larinier 2002).

The slope of such bypass channel is low with gradient of a few percent, from less than 2% to a maximum of 5% (DVWK 232, Larinier 2002), which means the channels are very long and needs relative large area for the construction. This will be the main disadvantages for its application.

- **Fundamental requirements**

Slope	1:100 to max. 1:20
Bottom width	Min. 0.8 m
Mean water depth	0.2 m
Mean flow velocity	0.4 to 0.6 m/s
Maximum flow velocity	1.6 to 2.0 m/s
Bottom	Rough, locally available substrate is preferable
Shape	Sinuous or straight, possibly meandering, with pools and rapids
Cross-section	Various, bank protection, big boulders or boulder sills to break the slope
Specific discharge	$q > 0.1$ m³/s/m

- **Entrance**

Similar to other fish passes, the entrance of the bypass channel (i.e. the downstream entrance for the fish) must locate very close to the weir or other obstacles. The bypass channel sometimes must turn back by 180° right after entrance to ensure appropriate location of entrance and slope of the channel.

- **Various forms of bypass channel**

Bypass channels can be a mimic artificial river or other forms such as pool-type passes that consist of a series of pool-shape sections using boulder sills or “porous” weirs. Bypass channels can also form with groynes, large blocks like perturbation boulders to remain adequate water depth and to dissipate energy (DVWK 232, Larinier 2002).

2.3.2.3. Fish ramp

Removal of a weir with replacement of a bottom ramp can be considered only when water levels are not required to be controlled and there is also adequate discharge available. However due to the water needs such as hydroelectric power generation, flood mitigation, agriculture or fish farms, the requirements are hardly to meet and a rough ramp of reduced width, i.e. the so-called fish ramp, can be introduced to replace a portion of a weir as shown in Fig. 2.3.7. The purpose of the obstacle and water uses can be remained and a free passage for aquatic fauna can also be rebuilt.

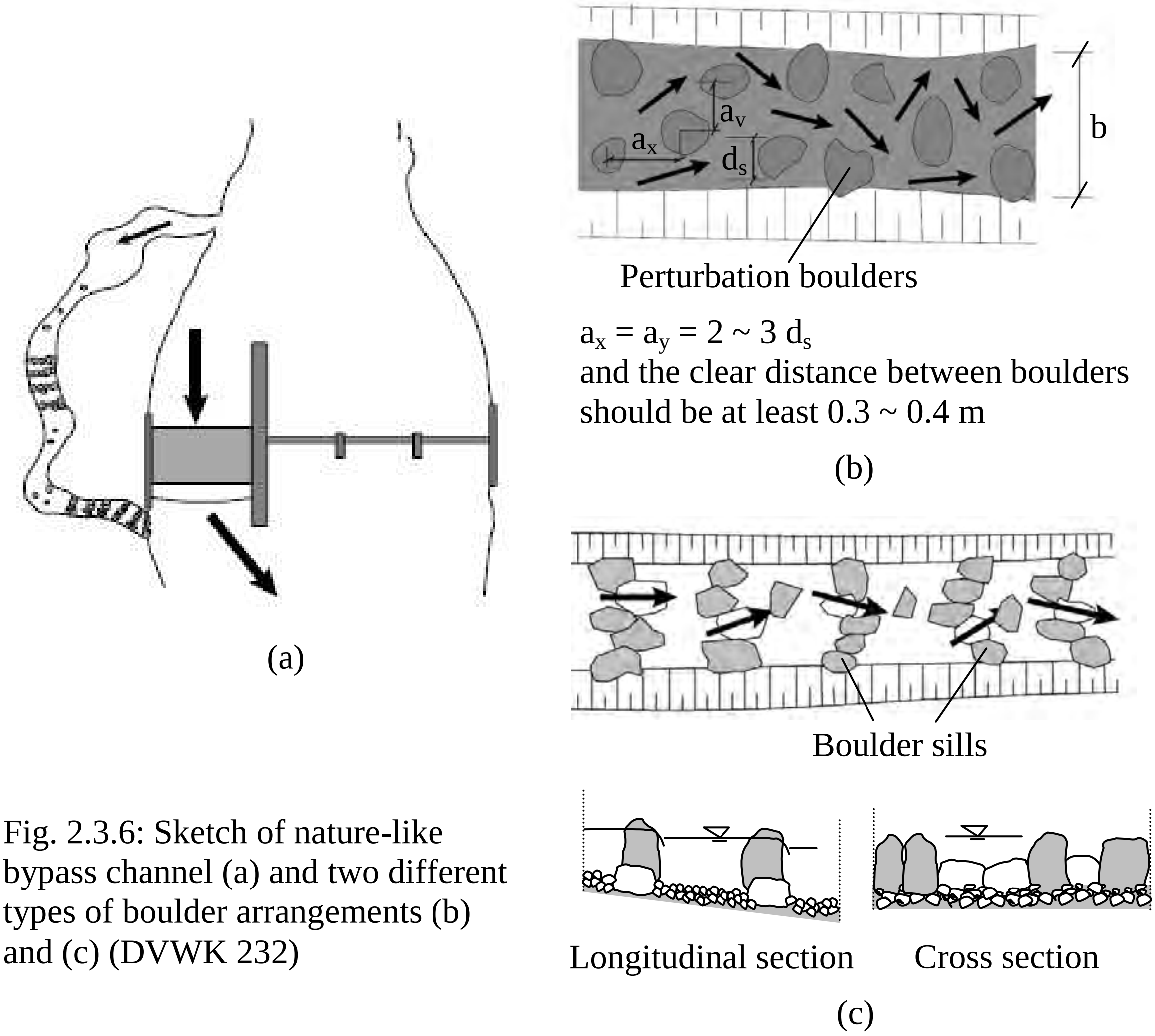
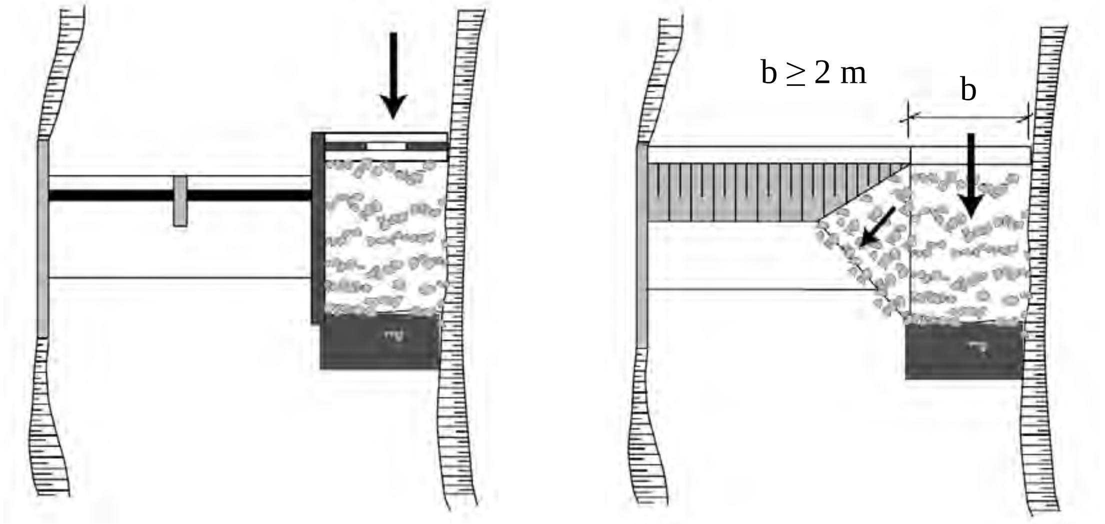


Fig. 2.3.6: Sketch of nature-like bypass channel (a) and two different types of boulder arrangements (b) and (c) (DVWK 232)

The model for designing a fish ramp is also derived from nature. The primary objective of fish ramp design is to mimic the structural variety of natural river rapids or streams with more or less steep slopes.

A fish ramp is normally integrated directly in the weir construction, and concentrate, as far as possible, the total discharge available at low and mean water level. At off-line power stations, for example, the necessary residual discharge can be sent through the fish ramp and water only spills over the weir crest during floods. Big boulders or boulder sills are arranged to form cascades on the fish ramp to ensure the water depths and flow velocities required to allow upstream migration of fish.



(a) at movable weir (b) at fixed weir

Fig. 2.3.7: Applications of fish ramps (DVWK 232)

The width of the ramp is mainly defined by the discharge during fish migration period. The efficiency of ramps for facilitating upstream migration might be reduced when discharges are high, as in the case of flooding. Dimensioning of the fish ramp is essential for structural stability during floods.

- **Fundamental requirements**

Slope	1:20 ~ 1:30 or milder
Bottom width	At least 2 m
Mean water depth	30 ~ 40 cm
Maximum flow velocity	1.6 ~ 2.0 m/s
Bottom	Many interstitial gaps, rough
Shape	Shelters, deep zones and resting pools to facilitate upstream migration
Specific discharge	The whole instream flow need (residual flow) should be derived to pass through fish ramp. Water flow over weir only at high discharge conditions

As a rule, fish ramps are set nearby riverbanks which receiving the greater portion of the current. The upper, acute angle should be selected for the construction of the fish ramp at submerged weirs standing obliquely in the river. An existing empty evacuation channel or abandoned sluiceway can often be used for the construction of a fish ramp.

Fish ramps installed at fixed weirs with very steep slopes, at obstacles with vertical drops or at weirs equipped with movable shutters often have to be confined on one side by a solid wall (partition wall in Fig. 2.3.7(a)); fish ramps at gently sloping weirs can also be given an inclined lateral filling as shown in Fig. 2.3.7(b), to prevent the formation of dead corners.

The width of the ramp should be a function of the available discharge, but should not be less than 2.0 m. Longer sections with milder slopes and with deeper resting pools are recommended, particularly in the case of ramps longer than 30 m.

- **Body of the ramp**

The construction types usually used for the bottom ramps, i.e. rockfill constructions, embedded-boulder constructions and cascaded constructions, can also be transposed to fish ramps, with occasional slight modifications.

Problems can arise with rockfill ramp bodies when the river carries little water, as water may be lost through seepage through the rockfill. In extreme cases this may lead to the ramp crest running dry, so that the ramp is unable to function as a fish pass. In rivers that carry a lot of sedimentary material, and where the ramp crest is at the level of the headwater bottom, self-sealing takes place relatively quickly through washed-in sediments. Self sealing may take a very long time if the ramp crest is high and no sedimentary material is carried by the water, in which case sand and gravel can be artificially washed-in to fill the gaps.

A wedge-shaped or parabolic cross-section is recommended for ramps where there are varying discharges. This cross section concentrates the small discharges during low-water periods, while allowing, at times of high discharges, shallower regions to form at the sides where flow velocities are then correspondingly lower.

- **Perturbation boulders and boulder sills**

Despite a rough bottom, with the usual mild ramp slopes of 1:20 and 1:30 the flow velocities can not be assured to be below maximum permissible limits. For this reason, additional elements that reduce flow velocity and increase water depth are incorporated into the body of fish ramps. Again, large boulders are the most suitable materials for this purpose.

- **Overall assessment**

Fish ramps are nature-like constructions and are believed to be characterised by the following features (DVWK 232):

- They are suitable for retrofitting of low fixed-weir installations.
- They can be passed even by small fish and fry and by the benthic invertebrates.
- They are also suitable for downstream migration of fish.
- They have a natural-looking, visually attractive design.
- They require little maintenance in comparison with other constructions.
- They are not easily clogged; deposits of flotsam and flood debris do not immediately affect the efficiency of the installation.
- Their guide currents are satisfactory and easily located by fish.
- They offer habitat for rheophilic species.

Their disadvantages are:

- Sensitivity to fluctuating headwater levels.
- The large discharges necessary for their operation.
- The large amount of space they occupy.

The features will be however examined according to the results of fieldwork on assessment of effectiveness of ramps in Chapter 4.

2.3.3. Structural recommendations on constructions of nature-like bottom ramps

For construction safety on a required long life for bottom ramp, there are six important rules to be accounted for based on the experiences from Water Resources Bureau Rosenheim (Barnikel 2003):

- **Secured scour basin below the ramp**

There must be a secured sufficient long riprap constructed downstream of the ramp to prevent from scour below the ramp. In particular it should pay attention that such riprap area-widely reaches the bank and the banks at this region are also secured. At the transition zone between ramps and scour basins, structural safety can be secured by implanting steel sheet piles.

- **Integrated long enough into river bank**

At cascaded constructions with boulder sills, each sill must be integrated into river bank very carefully. When it is about cascaded type ramps, the whole length of the ramp integrate enough into the embankment at the bank region. There is a reason that is to avoid the ramp to be washed away. If water flows over the ramp at the bank side, the boulders at the side might be washed and may move down during flood. There would be more and more boulders transported downstream at next flood events which will lead to collapse of the whole ramp.

- **The ramp should be deeply founded at the upstream side of the ramp**

It is usually carried out through a multi-layered riprap. If there was an old existing construction, e.g. a weir, usually it can be used as a foundation. Besides steel sheet piles or other reinforced bars are also recommended for structural safety.

- **The river banks must be secured with riprap at both sides in the region where hydraulic jump occurs**

Because at bottom ramps flow changes occur one or more times companying with higher or lower velocities and result in wave attack. With different water level, such wave attack was generated at various power. The strongest hydraulic jump occurs usually at flows over annual mean flow or a small scale flood, and then the bank will be affected by such flow. However by flood usually the water flows wavy but there is no hydraulic jump occurs and the banks are not attacked strongly. Based on this reason, banks should be secured until the flow decreases back to normal status. It means, embankments must be secured from the beginning of the ramp till the end of the scour basin. For safety reason it is recommended to construct riprap till altitude of the 1-year-return-period flow. Above the level usually there will be planting with bushes or trees.

- **A filter layer under the construction is essential**

At sandy, gravel or stony streambed area the criteria is automatically fulfilled. However streambed which is not in this case, a filter layer must be constructed according to guidelines of filters. It should pay attention that the ramp is sealed, e.g. use cohesive grains, at the bottom to prevent from dry up during drought event. The application of geotextile should not be use if possible, because the biological exchange with the underground will be prohibited.

- **Sizes of boulders must be examined for structural stability**

The resistance to the load resulted by flow flushing primarily depends on stone weight and slightly partly covered by the joggle-effect. But the joggle-effect depends on the form of stones and how they are inserted. Each case is different from each other and therefore it is very difficult to evaluate (joggle-effect should therefore be neglected).

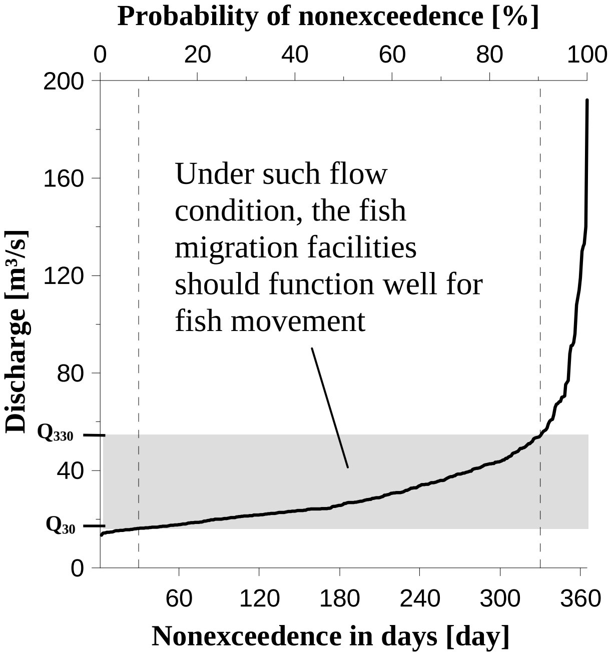
Generally the sizes of boulders are calculated by experimental formula derived by Whittaker & Jäggi and are cited in chapter 3.1.2.

2.4. Definition of criteria on evaluation of fish pass effectiveness

In the new German experts' report "Monitoring of fish upstream migration facilities (DWA-Themen 2006: Funktionskontrolle von Fischaufstiegsanlagen)" it is believed that the monitoring of fish migration facilities can reach the goals of the investigation only when all the questions about the effectiveness of a fish migration facility are essentially answered and the assessment are conducted according to the standards, to ensure the assessments can be traced back and comparisons of different monitoring work can be made. In this report based on 212 reports of monitoring work, the necessary parameters of monitoring work are suggested, which can also be specified as parameters which are important for assessment of fishways and parameters which are necessary only for scientific research. The parameters include site characteristics, technical and biological parameters to support the assessment. In Chapter 4 shows the procedures and results of evaluation of fish pass effectiveness and Appendix F shows some selected parameters in table form.

2.4.1. Geometric / hydraulic criteria

To develop a free fish passage for all species in the river, it is necessary to provide the flow conditions which are adequate to fish for at least 300 days/year at the appropriate cross section (MUNLV 2005, Schwevers 2006, Dumont 2006, Görlach 2006, DWA-Themen 2006). Under this condition the biological field work would be carried out for three times: while the discharge in the river corresponding to 30-days-nonexceedence-discharge (Q_{30}) and 330-days-nonexceedence-discharge Q_{330} to illustration the flow conditions in the ramps within the 300 days/year range and to mean annual flow (MQ) to check the average flow condition as the key foundation for analysis. The concept of the 300 days per year migration potential is shown in Fig. 2.4.1. Furthermore from the statistics of historical hydrological data it shows that the Q_{30} is similar to mean low flow (MNQ) and Q_{330} is about double of mean annual flow (MQ), which can be taken as replacements if the nonexceedence discharges are difficult to obtain. The statistics of suggested values for the fieldwork is shown in Table 2.4.1. Further discussion in detail is attached in Appendix D.



Probability of nonexceedence, P_r
$P_r[Q \leq Q_{p\%}] = P$ %

Nonexceedence in days, D_r
$D_r[Q \leq Q_{days}] = $ Days

Q_{30}: 30-days-nonexceedence-discharge
Q_{330}: 330-days-nonexceedence-discharge

Fig. 2.4.1. Concept of the 300 days/year possibility of free passage for fish in fish migration facilities

Table 2.4.1: The three concerned statistics of discharge at the corresponding gauging stations in the river system of Mangfall [unit: m³/s]

Ramp	Kolbermoor	Schwaig	Plackermühle	Leitner Mühle
River	Mangfall		Kalten	Leitzach
Gauging station	Rosenheim Mangfall		Hohenofen	Stauden
Data year	1966 – 2000		1999 – 2004	1941 – 2002
Q_{30}	3.06		1.33 [a]	2.25
MQ	17.40		2.65	4.66
Q_{330}	36.90		4.24 ~ 5.3 [b]	7.83

[a] Q_{30} = MQ / 2.0 (estimated by ratio of Q_{30} and MQ from adjacent stations)
[b] Q_{330} = MQ × 1.6 ~ MQ × 2.0 (estimated by ratio of Q_{330} and MQ from adjacent stations)

A resting pool works when volumetric dissipated power (volumetric energy dissipated rate), $E < 150$ to 200 W/m^3 and for $E > 150$ to 200 W/m^3 some fish passages are no more suitable for some species (Larinier et al. 2002, DVWK 232). Other discussions about the E values are also suggested. However the volumetric dissipated power, E, is suggested by Larinier as estimation for dimensions of pools in pool-type fish passes. By Dumont (2006, MUNLV 2005) is used as estimated mean energy dissipated rate for different running water regions. The suitability and application of such volumetric energy dissipated rate is an important index and will be discussed in detail in Chapter 3 as well as in the results of fieldwork in Chapter 4.

$$E = \frac{\rho g \Delta h Q}{\overline{V}} \quad [\mathrm{W/m^3}] \qquad \text{(Eq. 3.12)}$$

where ρ: density of water [kg/m³]
g: acceleration of gravity [m/s²]
Δh: water level difference between two adjacent pools [m]
Q: discharge [m³/s]
$\overline{V}$: volume of water in the pool [m³]

Table 2.4.2: Estimated mean of the volumetric dissipated power for different running water regions (MUNLV 2005, Dumont 2006)

Running water region	Maximum bed slope		Energy dissipated rate, E
Upper trout zone	5 %	1:20	150 – 400 W/m³
Lower trout zone	1.5 %	1:66	100 – 150 W/m³
Grayling zone	0.75 %	1:133	50 – 100 W/m³
Barbel zone	0.30 %	1:300	10 – 50 W/m³

2.4.2. Biological criteria

- Target species: no specific target fish species
- Efficiency: no constraint as a min. efficiency for number of upstream migrating fish
- Investigation period: no constraint of a certain period or results of migration, i.e. the facilities must work at least 300 days a year

One of the main criteria for the fish passage is critical flow. The overcoming velocities for fish should be distinguished between burst speed, prolonged speed and sustained speed (Turnpenny 2006, Beamish 1978). Fish reach the burst speed to jump through a barrier (e.g. a weir), reach prolonged speed to swim over the rapids and reach the sustained velocity to keep staying in resting pools. For small and near bottom fish species the criteria are even restricted.

The maximum flow velocity for fish which can pass through is different from various species and is depend on the fish body length. With regard to the field investigation on evaluation of the effectiveness of fish passage at fish migration facilities, the flow velocity is a matter of particular interest to provide a migration passage that is possible to pass through without harm on fish. Such flow velocity is designated as critical velocity. There are some different criteria on critical velocity for different fish species.

Table 2.4.3: Critical velocity, Gebler, 1989. (Vogel, 2003)

Fish species	Critical velocity, v_{max}
Trout and other Salmonids	2.0 m/s
cyprinids (bad swimmer)	1.5 m/s
Juvenile and small fish	1.0 m/s

Table 2.4.4: Critical velocity by LfU, 1999. (Vogel, 2003)

River zone		Fish species	Body length [cm]	Critical sustained velocity [m/s]	Maximum spring velocity [m/s]
Rhitral	Trout – grayling region	Salmon	50-100	3.20-	4.60-7.00
		Trout	20-35	0.80-1.00	3.50
		Rainbow trout	10-35	0.90	4.50
		Bullhead	2-4	0.20-0.35	–
		Loach	2-4	0.25-0.45	–
Potemal	Barbel – bream region	Bream	30-50	0.8-1.15	2.10
		Perch	5-12	0.40-0.50	1.50
		Eel	7-15	1.20	1.50
		Roach	15-30	1.15	1.50
		Gudgeon	12	0.55	–

Table 2.4.5: Target fish species and the criteria for small fish (origin: LfW Nr. 79)

Fish species		Bullhead, Eurasian minnow, stone loach
Body length [cm]		4 ～ 13
Recommendations for migration rate ≥ 70 %	Flow velocity (v)	$v \leq 0.5$ m/s
	Water depth (h)	$10 \leq h \leq 20$ cm
	Substrate 16 mm	$v \leq 0.5$ m/s
	Substrate 32 mm	$v \leq 0.5$ m/s
	Height of the sills on river bed (h_s) t_s:water depth over the sills	max. $10 \leq h_s \leq 15$ cm *and* $v_s \leq 0.5$ m/s *and* min. $10 \leq t_s \leq 20$ cm
	Water depth over the sills on river bed ($h_ü$)	min. $10 \leq h_ü \leq 20$ cm
	Flow velocity over the sills on river bed (v_s)	$v_s \leq 0.5$m/s
	Drop height (Δh) V_A:flow velocity upstream t_A:water depth upstream	$\Delta h < 5$ cm *and* $v_A \leq 0.5$ m/s *and* min. $10 \leq t_s \leq 20$cm

Table 2.4.6: Distribution of fish species and the adequate flow velocity (origin: DVWK Merkblatt 204/1984)

Region	Main fish species	Substrate	Flow velocity
1. Trout zone	All trout species	boulder, cobble	Very high rush over stones > 1 m/s
2. Grayling zone	Grayling and trout species, e.g. brook trout	cobble, gravel	High 0.5 ~ 4.0 m/s
3. Barbel zone	Barbel	gravel, sand (silty)	0.5 m/s
4. Bream zone	Bream	sand, silt	0.3 m/s
5. Ruffe-flounder zone	Ruffe, flounder	sand, silt	Flow direction changes

The body shapes of both fish and benthic invertebrates are optimally adapted to the flow regimes of their respective habitats. Fish in fast flowing upper reaches of streams have torpedo-shaped bodies and thus only offer low resistance to the current (e.g. brown trout, *Salmo trutta f. fario*, or minnow *Phoxinus phoxinus*), while high-backed fish such as bream (*Abramis brama*) and carp (*Cyprinus carpio*) colonize waters with more gentle currents (DVWK 232, see Fig. 2.4.2)

In the nature-like fish migration facilities, the possible passages are usually offered by the gaps or openings between the nature-like structure or materials. These gaps and openings should supply a geometry which is appropriate for fish to pass through. The criterion is based on the fish body form and should be about three times in height and in width of the fish body (Fig. 2.4.3), so that fish will not get abrasion when they try to pass through a small slot.

The exports’ report of monitoring of fish upstream migration facilities in Germany was published in 2006. Processes of monitoring work and some selected criteria for assessment in this report are listed in Appendix F.

2.4.3. Criteria on assessment

There are numerous factors which contribute influences on the performance of fish migration facilities. For an assessment in practice, simple and quantitative criteria should be given to make it possible on evaluation of the effectiveness of the construction. Following is the summarized criteria based on the German experts’ report of monitoring of fish upstream migration facilities, DWA-Themen 2006 “Funktionskontrolle von Fischaufstiegsanlagen” (also see App. F).

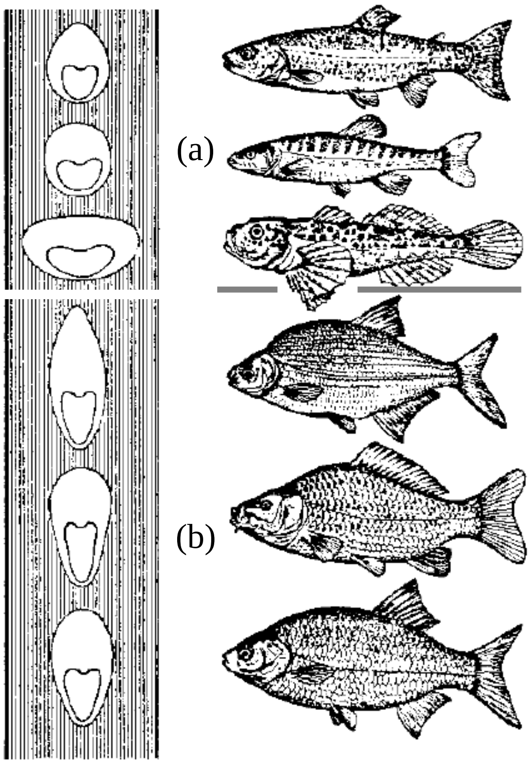


Fig. 2.4.2: Adaptations of body forms of fish to different flow velocities (from DVWK 232/1996 after Schua 1970)

(a) Species occurring in the fast flowing upper reaches of streams: brown trout, minnow, bullhead;

(b) Species occurring in slow flowing river regions: bream, carp, rudd.

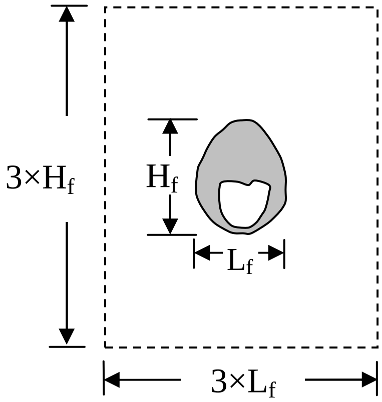


Fig. 2.4.3: Possible passage for fish: the geometry should be with height at least 3-fold of the fish body height and with width at least 3-fold of the fish body width.

Fish are categorized in groups as shown in Table 2.4.7 and are assigned to different dimensional criteria in Table 2.4.8.

Table 2.4.7: Fish categories for the corresponding criteria on assessment of fish pass performance

Species	Description
Brown trout (*Salmo trutta f. fario*)	Representative of the fish species in the upper and lower trout zones with body length up to 40 cm
Grayling (*Thymallus thymallus*) Dace (*Leuciscus leuciscus*) Chub (*Leuciscus cephalus*) Roach (*Rutilus rutilus*)	Representative of the fish species with body length up to 60 cm
Barbel (*Barbus barbus*) Bream (*Abramis brama*) Pike-perch (*Sander lucioperca*) Salmon (*Salmo salar*) Sea trout (*Salmo trutta f. trutta*) Northern pike (*Esox lucius*)	Representative of the fish species with body length up to 120 cm, in particular appear in freshwater or anadromous salmonids which migrate till grayling zone.
Sturgeon (Acipenser sturio)	Representative of the fish species with body length up to exceed 300 cm of the largest local species, which is currently missing in Nordrhein-Westfalen.

Table 2.4.8: Assessment of effectiveness in fish migration facilities: level of assessment = B

	Brown trout	Grayling, Dace	Barbel, pike
Min. water depth [m]	0.4	0.45	0.5
Width of notches and narrow slots [m]	0.2 ~ 0.4	0.4 ~ 0.6	0.6
Max. water level difference [m]	0.2	0.15	0.13
Max. flow velocity in notches and narrow slots [m/s]	2.0	1.7	1.6

Note: The level of assessment B corresponds to “good” status, the other levels also see App. F.

3. Mean Flow and Turbulence Distribution in Nature-Like Pool-Type Fishways

Many examples of nature-like type fish passes are presented in the DVWK Guidelines of fish passes; however, only rare fundamental model tests were conducted to study the flow pattern in detail. Gebler (1991) conducted a hydraulic model test to investigate the existence of a biological free passage in a rockfill ramp of slope = 1:10, flume width = 0.6 m, flume length = 4.5 m, and specific discharge = 75 l/s/m. The experiments were conducted 10 days continuously combining biological test with brown trout (*Salmo trutta fario*, body length = 10 ~ 28 cm), stone loach (*Barbatula barbatula*, body length = 4 ~ 10 cm), bullhead (*Cottus gobio*, body length = 5 ~ 10 cm) and hundreds of amphipods[1] as substitutes for invertebrate released at downstream division of the test flume. The velocity at gaps between boulders was about 0.2 ~ 0.5 m/s. Approximate half the samples of the small fish was found in the upstream division. Based on the result it was stated that a qualitative proof of the existence of free passage was shown that individual fish species could move upstream through the gaps between big boulders and passed through the ramp, even for small fish species and amphipods.

Vogel (2003) conducted experiments to study the construction stability of cascaded bottom ramps and has proposed a relationship between specific discharges and boulder sizes for cascaded ramps with slope between 1:10 and 1:30. However, in Vogel’s study, the flow velocity and flow pattern were not investigated, indicating that these ramps have not been studied in detail.

The design instructions for such nature-like fish passes in the Guidelines are suggested based either on calculations and parameters pertaining to the technical type of fish passes or on engineers’ experiences. In addition, there will be apparent deviation while using deterministic hydraulic calculations on nature-like constructions consisting of irregular materials and cross-sections that create diverse flow patterns, in particular in the maximum velocity, cross sectional velocity distributions around passage slots, and levels of turbulence, which should be statistically analyzed. Therefore many current nature-like fish passes do not function effectively as expected and it takes a lot of money and effort afterwards to improve them.

Nature-like fish passes are recently a common type of fish migration facilities. In this chapter the hydraulic model test of a nature-like pool-type fish pass on the mean and turbulence flow are presented. Sills made of boulders (boulder sills) were used as cross-walls to separate pools in the fish pass and to build the nature-like constructions.

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[1] Amphipoda (amphipods) is an order of animals that includes over 7,000 described species of small, shrimp-like crustaceans.

Around the sill, the streamwise velocity at the cross sections was measured to examine whether it is possible for fish to ascend. The near bottom velocity measurements were made to study the migration possibility for small or juvenile fish. The turbulence structure in the pools was obtained by using Acoustic Doppler Velocimeter (ADV) to measure the three components of velocity. An appropriate parameter to describe and to represent the scale and the influence of turbulence flow on fish swimming performance is also discussed by comparing energy dissipated rate, turbulence intensity and turbulent kinetic energy. The vortices at the streamwise-vertical plane were obtained by using Particle-Image-Velocimetry (PIV) and were discussed on the development under different overflow conditions. Two slopes of 1:30 and 1:15 and three specific discharges of 150, 200 and 250 l/s/m were studied in this test. As a comparison, the flow in the pools which were separated by sills of technical type was also investigated under the same boundary conditions. Results are shown to give a systematic study of nature-like pool-type fish passes and to provide a better understanding for designing. The design processes in the German Guidelines were examined to check the variances between the suggested design algorithms and the varieties in the natural-like design. A best quantitative term, turbulent kinetic energy, is suggested to describe the scale of turbulence flow and to bridge the relationship of the influence of turbulent flow pattern on fish behaviour.

3.1. Materials of design algorithms and turbulence

For nature-like hydraulic constructions, similar to conventional technical designs, hydraulic calculation are suggested in the Guidelines DVWK 232 to examine the requirements for structural stability and free movement for fish species in running water bodies. A fundamental introduction of turbulence, eddy and vortex is presented before discussing turbulent flow in fish passes to clarify the frequently confused terms in fluid mechanics.

3.1.1 Dimensional design and calculation of hydraulics in nature-like channel with boulder sills

The hydraulic calculation processes of nature-like bypass with boulder sills or pool-type fish passes with boulder sills are suggested in the Guidelines DVWK 232 as in Fig. 3.1.1.

To apply the weir equation (Poleni Formula) for calculation of rough channel with boulder sills, the two coefficients, submerged overflow reduction factor σ and weir coefficient μ need to be calibrated. The submerged overflow reduction factor is between 0 and 1.

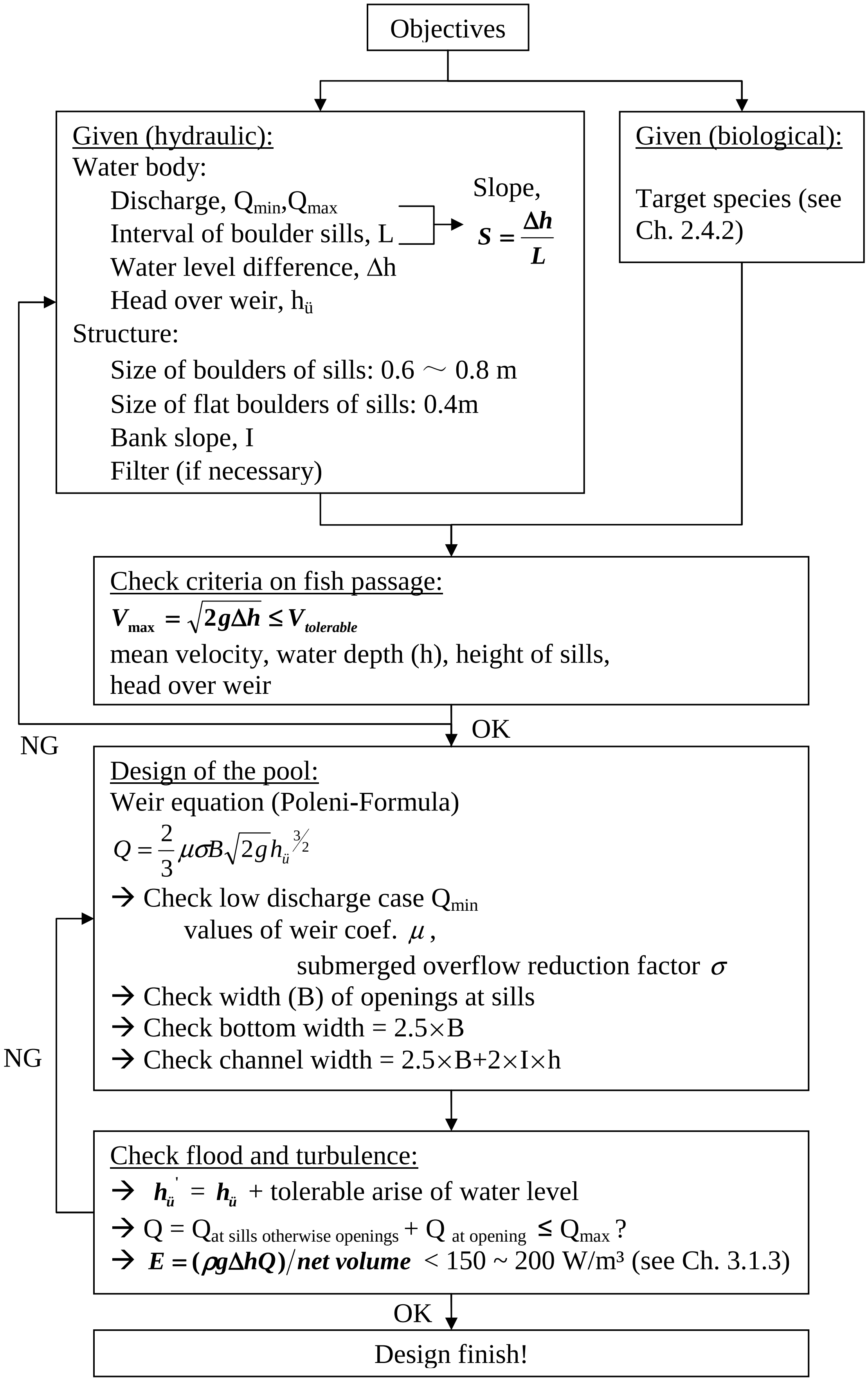


Fig. 3.1.1: Hydraulic calculation processes of nature-like bypass / pool-type fish passes with boulder sills

For round shape sills, submerged overflow reduction factor, σ, can be obtained in related to the ratio of upstream/downstream head over weir (Schröder 1994, DVWK 232, Patt et. al. 1998) as shown in Fig. 3.1.2. The weir coefficient, μ, can be obtained experimentally under different constructions and flow conditions. In the Guidelines DVWK 232 it is recommended as follows:

$\mu \approx 0.5 \sim 0.6$ wide sharp-edged rocks, crushed material,

$\mu \approx 0.6 \sim 0.8$ rounded stones, e.g. fieldstones,

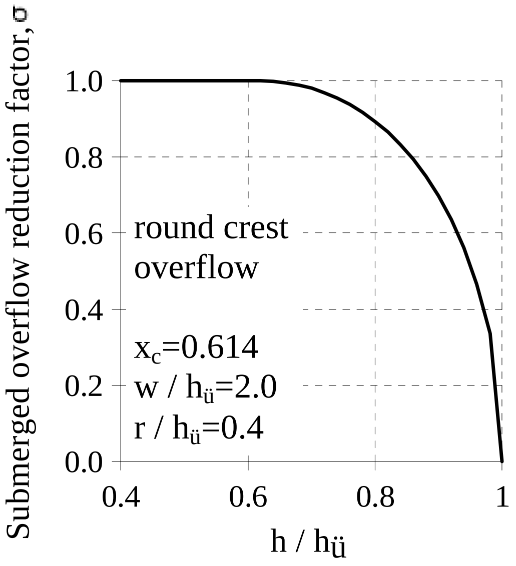
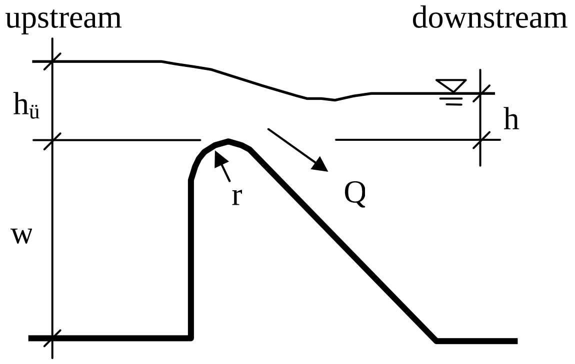


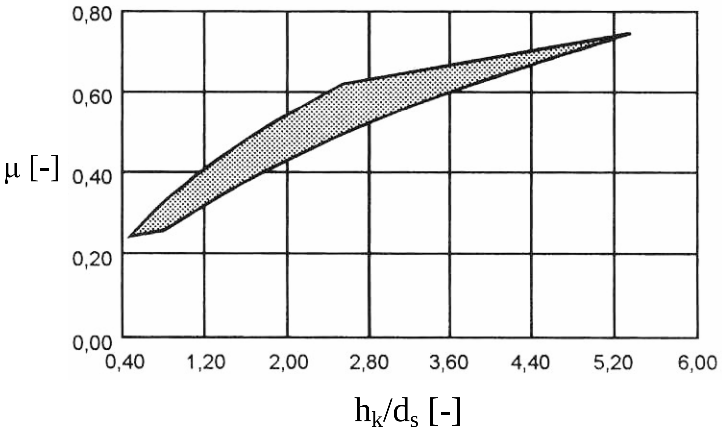
Fig. 3.1.2: Submerged overflow reduction factor (Schröder 1994)



Overflow at round crest below backwater

$h_ü$: head over weir, upstream
h: head over weir, downstream
w: weir height
Q: discharge
r: radius of round crest
x_c: critical value of $h/h_ü$

Hassinger suggested the weir coefficient by the results of model test as shown in Fig. 3.1.3.



h_k: head over ramp crest [m]
d_s: boulder size [m]

Fig. 3.1.3: Weir coefficient, μ, for bottom ramps (after Hassinger 1992 by Patt 1998)

Here according to the design processes suggested in the German Guidelines DVWK 232, rough channels with boulder sills should follow the calculation referred as in Fig. 3.1.1. The criteria for assessing the critical velocity by calculating maximum velocity were examined in chapter 3.4.1. The design of the rough channel bases on minimum (Q_{min}) and maximum (Q_{max}) discharges and therefore the bottom width is calculated and assigned. Q_{min} and Q_{max} should be however replaced by Q_{30} and Q_{330} and the whole calculation processes should also be revised. Some ramps seem to perform well during mean flow condition but inadequately during low flow, which is one of the main tasks to be investigated in this study. To avoid such problem, a more reasonable calculation process of rough ramps will be suggested in this study.

3.1.2 Stability of bottom ramps

For stability of bottom ramps, the sizes of boulders selected to build up ramps are analyzed based on results of various hydraulic model tests. The criteria of stability for bottom ramps in rockfill constructions according to Whittaker and Jäggi (1986) can also be applied to ramps in cascaded constructions with boulder sills (DVWK 118, Wieprecht 1997):

$$\boldsymbol{q_{crit}} = \mathbf{0.257}\sqrt{\frac{\rho_s - \rho_w}{\rho_w} \cdot g} \cdot S^{-7/6} \cdot d_{65}^{3/2} \qquad [\mathrm{m^3/s/m}] \qquad \text{(Eq. 3.1)}$$

where $d_{65} = d_s / 1.06$

q_{crit} : critical specific discharge [m^3/s/m)

ρ_s : density of stone [kg/m^3)

S : slope of ramp [-]

d_{65} : diameter through which 65% of soil passes [m)

d_s : equivalent spherical diameter [m)

3.1.3 Turbulence, eddy and vortex

It is common use to apply the volumetric dissipated power, E, as an index to discuss turbulent flow in a pool-type fish pass. However as an averaged magnitude of energy dissipation in a pool of a fish pass, it can not exactly describe the spatial variation of turbulence. In addition, when biologists and engineers mention about turbulence in fish migration facilities, there are many misunderstandings on what exactly turbulence means, how to quantify features of turbulent flow, what are eddies or vortices and their influences on fish migration performances. These technical terms must be clarified and make it accordant between biologists and engineers.

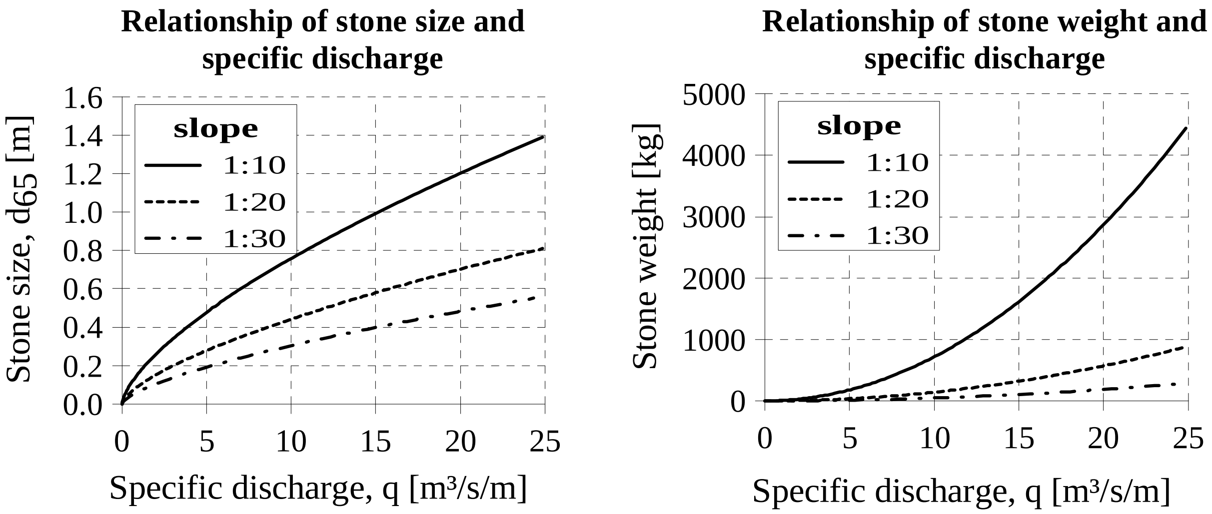


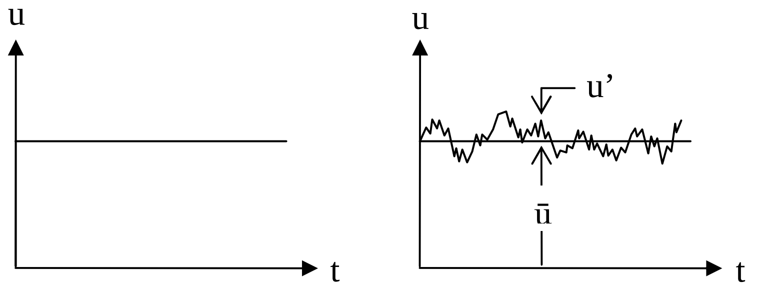
Fig. 3.1.4: Critical condition of structural stability for bottom ramps in cascaded constructions according to Whittaker and Jäggi (1986)

- **Turbulence**

Flow structure in the turbulent regime is characterized by random, three-dimensional motions of fluid particles in addition to the mean motion. The behaviour of turbulent flow is due to small, high-frequency velocity fluctuations superimposed on the mean motion of a turbulent flow (Fox 1992) and the velocity can be written as:

$$\boldsymbol{u} = \bar{\boldsymbol{u}} + \boldsymbol{u}' \qquad \text{[m/s]} \qquad \text{(Eq. 3.2)}$$

where $\bar{\boldsymbol{u}}$ is the average value and $\boldsymbol{u}'$ is the fluctuation.



(a) Laminar flow (b) Steady turbulent flow

Fig. 3.1.5: Variation of axial velocity with time.

Turbulence remains an unsolved problem and its motion is chaotic and has the following distinguishing characteristics (Narayana and Seetharamu 2005):

- Irregularity: turbulent motion is random, cannot be assigned a definite value, statistical averages can be taken.
- Diffusivity: turbulent flow has more diffusivity than molecular diffusivity.
- Generally observed when Renolds number is high.
- Motion is rotational and three-dimensional
- Has wide spectrum: Turbulent fluctuations can be thought of as superposition of several waves of different amplitudes and frequencies. The turbulent motion has a wide frequency spectrum.
- The motion is dissipative: In a turbulent flow, the energy from the mean motion is converted into fluctuating motion and is finally dissipated in the form of heat.
- Turbulence is a feature of flow and not a fluid property.

Turbulence is also defined by Davidson (2004) as:

Incompressible hydrodynamic turbulence is a spatially complex distribution of vorticity which advects itself in a chaotic manner in accordance with the vorticity equation (Eq. 3.3). The vorticity field is random in both space and time, and exhibits a wide and continuous distribution of length and time scales.

$$\frac{D\vec{\zeta}}{Dt} = (\vec{\zeta} \cdot \nabla)\vec{u} + \nu\nabla^2\vec{\zeta} \qquad \text{(Eq. 3.3)}$$

where $\vec{\zeta}$ is the vorticity and ν the viscosity.

- **Eddy**

There has been a longstanding tradition in turbulence of studiously avoiding any formal definition of what we mean by a "turbulent eddy", or for that matter "turbulence"; it is almost as if we fear that, as soon as we try to define an eddy, the entire concept will melt away (Davidson 2004). An Eddy can be interpreted as a blob of vorticity and the turbulence comprises of a sea of eddies (Davidson 2004).

The largest of these eddies have a size comparable with the characteristic geometric length scale of the mean flow (diameter in Fig. 3.1.6). However, most of the eddies are much smaller than this. The size of the smallest eddies depends on the Reynolds number of the turbulence. At any instant, there is a broad spectrum of eddy sizes within fully developed turbulence. There exists a broad spectrum of eddy sizes, and the dissipation of mechanical energy is associated predominantly with the smallest eddies. The largest eddies, which are created by instabilities in the mean flow, are themselves subject to intertial instabilities and rapidly break-up or evolve into yet smaller vortices (eddies). Thus, at each instant, there is a continual cascade of energy from the large scale down to the small. The whole process is essentially driven by inertial forces. The cascade comes to a halt, however, when the eddy size becomes so small that *Re*, based on the size of the smallest eddies, is of order unity. At this point the viscous forces become significant and dissipation starts to become important (Davidson 2004).

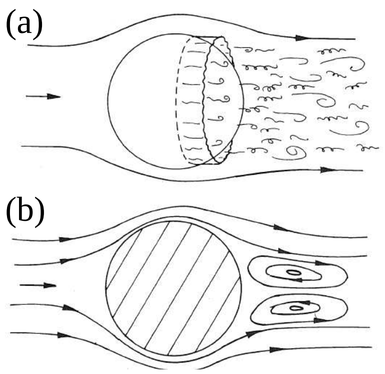


Fig. 3.1.6: Schematic representation of flow over a sphere
(a) snapshot of the flow
(b) time-averaged flow pattern (Davidson 2004)

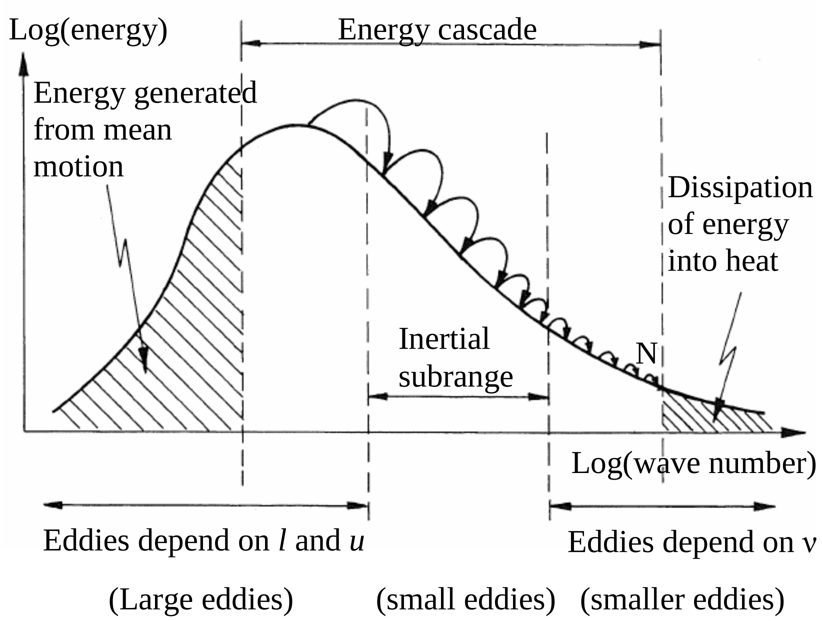


Fig. 3.1.7: Schematic representation of the energy cascade (Davidson 2004, modified)

- **Vortex**

A flow pattern in which the streamlines are concentric circles is known as a circular vortex. If the fluid particles rotate as they revolve around the vortex centre, as they do in a rotating cup of water, the vortex is said to be rotational or “forced”; if the particles do not rotate, the vortex is irrotational or “free” (Vallentine 1967).

To describe vortices quantitatively they can be expressed by intensity, such as rotation or vorticity, and by size.

The rotation, $\vec{\omega}$, of a fluid particle is defined as the average angular velocity of any two mutually perpendicular line elements of the particle. Rotation is a vector quantity. A particle moving in a general three-dimensional flow field may rotate about all three coordinate axes (Fox 1992). Thus, in general,

$$\vec{\omega} = \hat{i}\,\omega_x + \hat{j}\,\omega_y + \hat{k}\,\omega_z = \frac{1}{2}\left[\hat{i}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right) + \hat{j}\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right) + \hat{k}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)\right]$$

$$= \frac{1}{2}\nabla \times \vec{V} \qquad [\mathrm{s}^{-1}] \qquad \text{(Eq. 3.4)}$$

The factor of ½ can be eliminated in Eq. 3.4 by defining a quantity called the vorticity, $\vec{\zeta}$, to be twice the rotation,

$$\vec{\zeta} \equiv 2\vec{\omega} = \nabla \times \vec{V} \qquad [\mathrm{s}^{-1}] \qquad \text{(Eq. 3.5)}$$

The vorticity is a measure of the rotation of a fluid element as it moves in the flow field.

The circulation, Γ, is defined as the line integral of the tangential velocity component about a closed curve fixed in the flow,

$$\Gamma = \oint_C \vec{V} \cdot d\vec{s} \qquad [\mathrm{m}^2/\mathrm{s}] \qquad \text{(Eq. 3.6)}$$

where $d\vec{s}$ is an elemental vector, of length *ds*, tangent to the curve; a positive sense corresponds to a counterclockwise path of integration around the curve (Fox 1992). A relationship between circulation and vorticity can be obtained by (Vallentine 1967)

$$\Gamma = \oint_C \vec{V} \cdot d\vec{s} = \int_A 2\omega_z dA = \int_A \left(\nabla \times \vec{V}\right)_z dA \qquad \text{(Eq. 3.7)}$$

Thus the circulation around a closed contour is the sum of the vorticity enclosed within it (Fox 1992), or in another word, vorticity is equal to the circulation around an element surface divided by the area of the surface (Narayana et al. 2005)

The circulation calculated around a streamline of an irrotational vortex is a measure of the intensity of the vortex. It is

$$\Gamma = v_\theta \oint ds = 2\pi r v_\theta = 2\pi C = K \qquad \text{(Eq. 3.8)}$$

which is independent of r. Hence the circulation around all streamlines of the vortex is constant and equal to the strength of the vortex (Vallentine 1967).

3.1.4 Previous studies of effects of turbulence on fish

Turbulence and shear stress are believed to be harmful to fish at high levels (Odeh et al. 2002). Biologists have observed the effect of turbulence on the swimming behavior of fish and have conducted significant research in the past 20 years. Lupandin (2005) used TI—defined as the standard deviation of flow velocity divided by the mean velocity—to describe the effect of turbulence on critical flow velocity with respect to the fish body length. According to his study, the longer the body of the fish, the higher is the turbulence required to decrease the critical flow velocity. The TI in this study ranges between 0.03 and 0.15. The critical flow velocity were affected in 61–90-mm long fish for TI greater than 0.10 and in 91–120-mm long fish for TI greater than 0.12.

Enders et al. (2003) used the standard deviation of flow velocity to represent the level of turbulence for assessing the swimming cost (oxygen depletion on fish over time) of juvenile Atlantic salmon (*Salmo salar*) in turbulent flows. Four different conditions were tested formed from the two streamwise mean flow velocities (18 and 23 cm/s) and two turbulences (5 and 8 cm/s). Individual discussions on the turbulences were conducted on the basis of the turbulence in streamwise, lateral, and vertical directions.

Meanwhile, engineers have also been conducting experiments to study the turbulence distribution in fish passes. Chorda et al. (2004) showed that the TI increased with the concentration of roughness elements in a fish pass. Larinier (1992) and Larinier et al. (2002) used volumetric dissipated power (or called energy dissipation rate), $E = \rho \cdot g \cdot \Delta h \cdot Q/\overline{V}$, where ρ, g, Δh, Q, and $\overline{V}$ indicate the density of water, gravitational acceleration, difference in the water levels between two adjacent pools, discharge, and volume of water in a pool, respectively, to estimate the pool size in pool-type fish passes. E is frequently used in the design of fish passes in Europe and North America as a tool for estimating pool sizes. Sometimes E is used as the “specific power input” to specify the level of turbulence in different running water regions (MUNLV 2005 and Dumont 2006). However, the flow pattern in each pool of a given fish pass is spatially diverse; therefore, it is not feasible to use an average energy dissipation rate to quantify the level of turbulence in a pool. Owing to the development of measurement instruments such as an acoustic Doppler velocimeter (ADV), Larinier and Travade (2006) suggested the use of turbulent kinetic energy (TKE) to represent fluctuations in a given flow.

Odeh et al. (2002) adopted the definition of TI proposed by Gordon et al. (1992), wherein TI is the root-mean-square (RMS) of the turbulent fluctuations about the mean, and used the resultant TI to refer to the magnitude of turbulence in a given flow. They conducted experiments under two turbulence conditions and observed that turbulence had significant effects on salmon and hybrid bass; however, no observable effects were found on rainbow trout. Liu et al. (2006) used the normalized TKE per unit mass, TI along each axis (x-, y-, and z-axis or jet centerline) and the average energy dissipation rate to represent the turbulence structure in vertical slot fish passes. Nikora et al. (2003) used TKE and the ratio of its square root to the streamwise mean velocity to represent the relative turbulence intensity. The values of the TKE in their test ranged between 0 and 80 cm^2/s^2; however, this result stated that the effects of turbulence on the swimming performance of inanga (*Galaxias maculatus*) appeared to be negligible, which was contrary to that obtained in some of the previous studies.

From the abovementioned research results, we know that to study the effect of turbulent flow on the swimming behavior of fish, we could quantify the level of turbulence in the flow by using TI, E, or TKE. TI can be obtained from TKE by using the relation $TI = \sqrt{1/3 \cdot \left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)} \Big/ \overline{U} = \sqrt{2/3 \cdot TKE} \Big/ \overline{U}$, where u', v', and w' indicate the fluctuating velocity components in the x-, y-, and z-directions, respectively, and $\overline{U}$ is the time-averaged velocity. However, some researchers used the resultant of the fluctuating velocity components to define TI as $TI = \sqrt{\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)} \Big/ \overline{U}$. Moreover, as an alternative expression, TI is multiplied by 100 to express it as a percentage (Odeh 2002). The previous studies are also listed in Table 3.1.1.

This chapter presents the hydraulic model test of a nature-like pool-type fish pass on the mean and turbulence distribution of flow. As a comparison, the flow in the pools, which were separated by technical-type sills, was also investigated under the same boundary conditions. The results enable a systematic study of nature-like pool-type fish passes and provide a better understanding of their design. This article includes a special discussion on the representation of turbulence. E, TKE, and TI are studied and discussed in order to obtain the best quantitative term for describing the level of turbulence and to propose a relationship between the level of turbulence and fish behavior.

Table 3.1.1: Different metrics of turbulence by biologists and engineers in experiments of fish passes

Name	Term	Description
Biologists		
Lupandin, 2005	Turbulence number, K	▪ Def: standard deviation of flow velocity / mean velocity ▪ turbulence, critical flow rate, fish body length ▪ K was observed only in a certain range ▪ 61-90 mm fish, K > 0.10; 91-120 mm fish, K > 0.12 → observe V_{cr}
Enders, 2003	-	▪ Def: standard deviation of flow velocity ▪ swimming costs (juvenile Atlantic salmon) increased as turbulence increased ▪ two mean streamwise flow velocities (18 & 23cm/s), two streamwise turbulence conditions (5 & 8cm/s)
Odeh et al. 2002 (with engineers)	Turbulence intensity	▪ Adopted the definition of turbulence intensity by Gordon et al. (1992): turbulence intensity, root mean square of the turbulent fluctuations ▪ turbulence had significant effects among salmon and hybrid bass
Engineers		
Larinier, 1992, 2006	Volumetric dissipated power (E)	▪ $E = \frac{\rho g \Delta h Q}{volume}$ ▪ an averaged value in a pool
	Turbulent kinetic energy (TKE)	▪ $TKE = \frac{1}{2} \cdot \left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2} \right)$ ▪ can be calculated using data obtained by ADV etc. lately
Liu, 2006	Normalized turbulent kinetic energy	▪ Def: square root of TKE / mean velocity ▪ The normalized turbulent kinetic energy profile has a similar property to the longitudinal turbulence intensity.
	Normalized energy dissipation rate	▪ Def: modified equation for specific design ▪ The normalized energy dissipation rate shows some similarity and has a maximum value on the center of the jet
Chorda, 2004	Turbulence level	▪ Def: RMS (velocity fluctuations) / local mean flow ▪ turbulence level increased with concentration of roughness elements in a fish pass
Nikora 2003 (with ecologists)	Total turbulence energy	▪ Def: $K = 0.5(\sigma_u^2 + \sigma_v^2 + \sigma_w^2)$, σ is std. of velocity components
	Relative turbulence intensity	▪ Def: $\boldsymbol{\sigma_u / \overline{U}}$, $\boldsymbol{\sigma_v / \overline{U}}$, $\boldsymbol{\sigma_w / \overline{U}}$ and $\boldsymbol{K^{0.5} / \overline{U}}$

3.2. Experimental arrangements and methods

This experiment was conducted in a rectangular flume (length: 12 m; width: 50 cm), as shown in Figs. 3.2.1(a) and (b), along with the coordinate system (x, y, z) used. The model scale is 1:5 according to the Froude number similarity. Fourteen boulder sills were used as cross-walls to separate the pools on the rough flume bed of gravel with a diameter of 4–8 mm (Figs. 3.2.2(a) and (b)). The length and width of each pool were 40 cm and 50 cm, respectively. The boulder sills consisted of two different stone sizes: stones measuring approximately 10.2 cm in height brought the sills to the desired height, and smaller stones measuring approximately 3.4 cm provided an opening to ensure a free passage under low discharge conditions (Fig. 3.2.1(d) and Fig. 3.2.2(b)). The openings were located in a crisscross manner to prevent a strong concentrated flow on one side (Fig. 3.2.1(c)). Conventional technical-type fish passes were also introduced in the model test for comparison with the nature-like pass and for studying the differences in the flow velocity and flow patterns between these two types of passes. The impermeable technical-type sill (T1, Fig. 3.2.1(e)) and permeable technical-type sills (T2, Fig. 3.2.1(f)) would replace the boulder sills at the same positions (see Fig. 3.2.1(b) for position description,) under the same boundary conditions. To compare and examine the streamwise velocity distribution with the critical velocity, a T1-type sill, which was similar in geometry to the nature-like sill, was used. For the 3D turbulent structures, T2-type sills were applied to simulate the permeable structure of the boulders in nature-like sills. The nature-like pool-type fish pass was tested for two slopes of 1:30 and 1:15 and three discharges, Q_m, of 6.71, 8.94, and 11.18 L/s, which correspond to the specific discharges in prototype scale, q_p, of 150 (the suggested lower limit for fish passes in the DVWK Guidelines), 200, and 250 l/s/m. Table 3.2.1~2 shows the details of the experiments.

To study the cross-sectional velocity distribution, only the streamwise velocity was measured, for the reason that around the opening at cross-section C (labeling of cross-sections shown in Fig. 3.4.2), water jet developed, and the streamwise velocity was considerably higher than the other two velocity components. The measurements of the streamwise velocity around boulder sill S8 were obtained by using a propeller-type current meter (Type: MC20, propeller diameter: 18 mm, precision: 0.01 m/s) for q_p = 150, 200, and 250 l/s/m to examine the maximum velocity in flows. The sampling density was 48–56 points separated by 2.5~3 × 4 cm in the y- and z-directions respectively, at cross-sections A, B, D, and E, as well as 1.5 × 1 cm at cross-section C. Later, S8 was replaced by the technical-type sill T1, and the streamwise velocity and the near-bottom velocity for q_p = 150 l/s/m were measured. ADV was not considered suitable to be used for streamwise measurements owing to its restrictions when sampling near boundaries.

The measurements of the three-dimensional velocity components were performed in the pools between the sill pairs S4–S5, S6–S7, and T2–T2 by using an ADV to study the turbulence distribution. The sampling time of the ADV was set to be 90 s, and the sampling frequency was 25 Hz. The sampling volume was obtained at a depth of 5 cm from the tip of the probe. The standard sampling volume is a cylinder of water with a diameter of 4.5 mm and a height of 5.6 mm. The spacing of each measured point in the measured planes was approximately 5–7 cm in the x- and y-directions; in the condition of slope = 1:15, only 6–10 points could be measured in the pool between sill pair T2–T2. In the z-direction, because of the "velocity hole" (Martin et al. 2002), which was approximately 2.5–3.5 cm above the gravel bottom, the measurements were performed at only one or two different water depths. ADV measurements were used for analysis if the data filtered by the 50% correlation (COR) cutoff and phase-space despiking algorithm (Goring and Nikora 2002; Wahl 2003) were 50% or more of the original retained; the filtered samples were not replaced. A 70% COR cutoff is recommended by the manufacturer, which is appropriate for mean flow measurements. In highly turbulent flows, because of the random movement of the water particles, therefore, using a 70% COR cutoff would result in the underestimation of the level of the turbulence. Fig. 3.2.3 shows the comparison between the RMS of V_x' obtained with the filter of 70% COR cutoff plus despiking method and that obtained with different filters. The RMS of V_x' obtained using 50% COR plus despiking method was consistent with that obtained using 70% cutoff plus despiking method and the retained data obtained using 50% COR plus despiking was more than that obtained using 60% COR cutoff plus despiking.

TKE values were compared among the two nature-like sills, S4–S5 and S6–S7, and the technical-type sills, T2–T2, with a one-way ANOVA using mean flow velocity and its standard deviation as variables with the 95% confidence intervals.

Table 3.2.1: Dimensions of the experimental flume (in model scale)

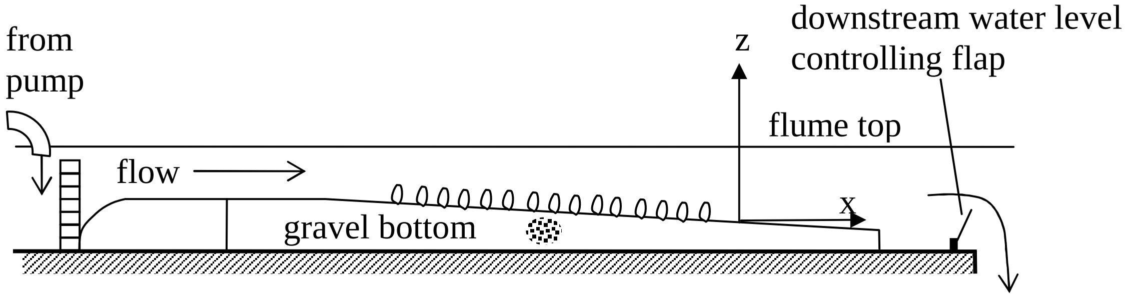
Experimental flume		**Boundary conditions**	
Width	0.5m	Boulder size	ca. 10.2 ± 0.9 cm
Depth	0.6m	Flat stone size	ca. 3.4 ± 0.6 cm
length	12 m	Substrate	4 – 8 mm
Specfic discharge, q [l/s/m]	150, 200, 250	Slope	1:15 1:30
		Spacing between boulder sills	40 cm

Measuring plan		
Measuring plane	**Objective**	**Method**
Surface	To study the flow pattern	PIV
Cross section	To check v_{crit}	Propeller current meter
Near bottom	To check v_{crit} for small and juvenile fishes	Propeller current meter
Longitudinal section	To study the flow pattern and circulation	PIV
Water depth	To check $h_{\ddot{u}}$, Δh, and min. depth	Water level gauge
Pool	To study the turbulence structure	ADV

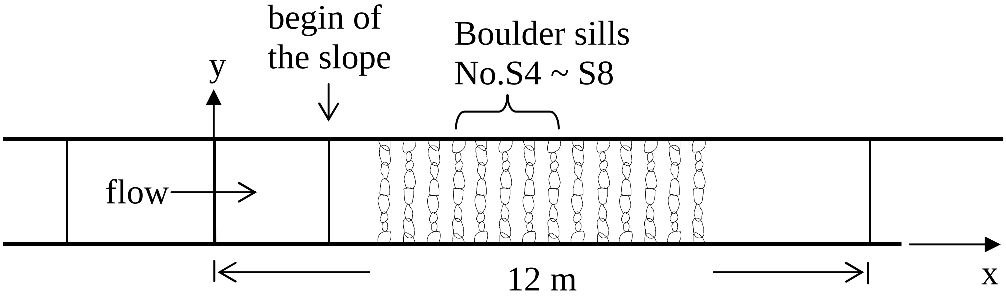
Table 3.2.2: List of experiments

S [%]	q_p [l/s/m]	Q_m [L/s]	Measured section	Velocimeter	Measured plane
3.33 (1:30)	150	6.71	S4–S5, S6–S7, T2 S4–S5, S6–S7, T2 S8, T1	ADV PIV propeller	z = 12.5 ~ 22.5 cm longitudinal sec., surface cross sec., near bottom
3.33 (1:30)	200	8.94	S4–S5, S6–S7, T2 S4–S5, S6–S7, T2 S8	ADV PIV propeller	z = 12.5 ~ 22.5 cm longitudinal sec., surface cross sec., near bottom
3.33 (1:30)	250	11.18	S4–S5, S6–S7, T2 S4–S5, S6–S7, T2 S8	ADV PIV propeller	z = 12.5 ~ 22.5 cm longitudinal sec., surface cross sec., near bottom
6.67 (1:15)	200	8.94	S4–S5, S6–S7, T2	ADV	z = 12.5 ~ 15 cm
6.67 (1:15)	250	11.18	S4–S5, S6–S7, T2	ADV	z = 15 cm

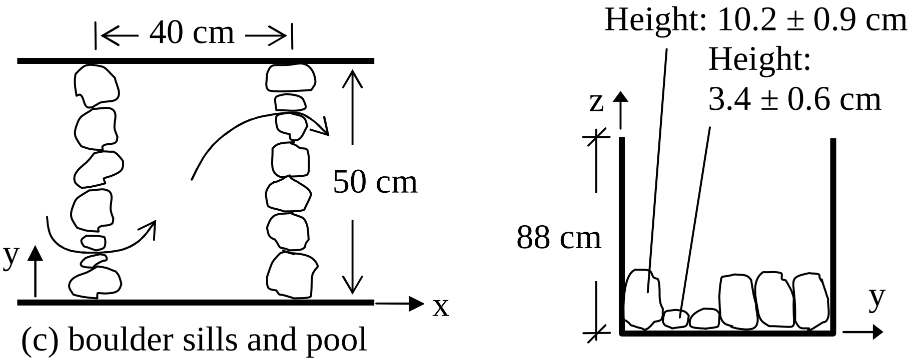
Note: q_p indicates specific discharges in prototype scale; Q_m indicates discharge in model scale



(a) side view

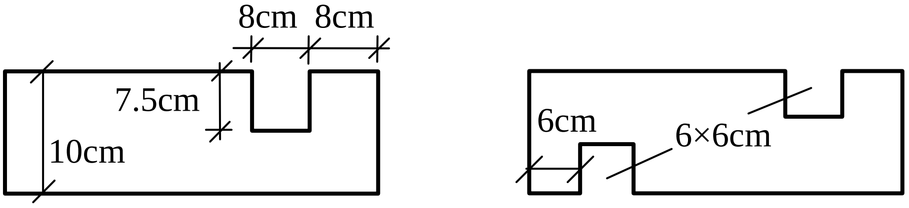


(b) plan view



(c) boulder sills and pool

(d) permeable, nature-like

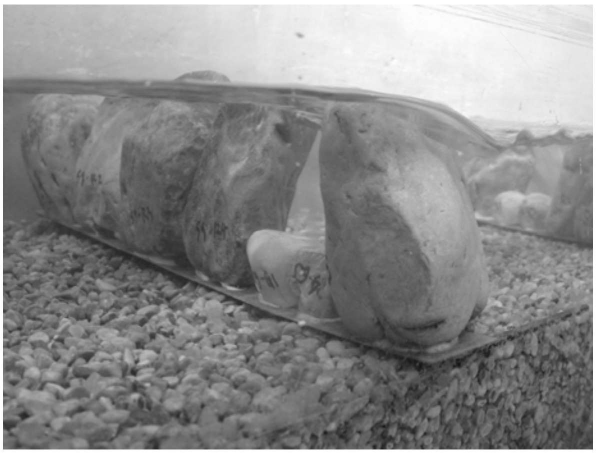


(e) impermeable,
technical type (T1)
(thickness: 1 cm)

(f) permeable,
technical type (T2)
(thickness: 4 cm)

Fig. 3.2.1: Experimental flume of the nature-like pool-type fish pass with boulder sills: (a) side view; (b) plan view; (c) detail of boulder sills, plan view; (d) detail of boulder sills, front view; (e) Technical type T1, front view (f) Technical type T2, front view (dimensions are in model scale; not to scale)

(a) The rough channel with boulder sills, view from downstream



(b) View of boulder sills

(c) Measurements of near bottom velocity using micro-propeller current meter

Fig. 3.2.2: Experimental flume of the nature-like pool-type fish pass with boulder sills

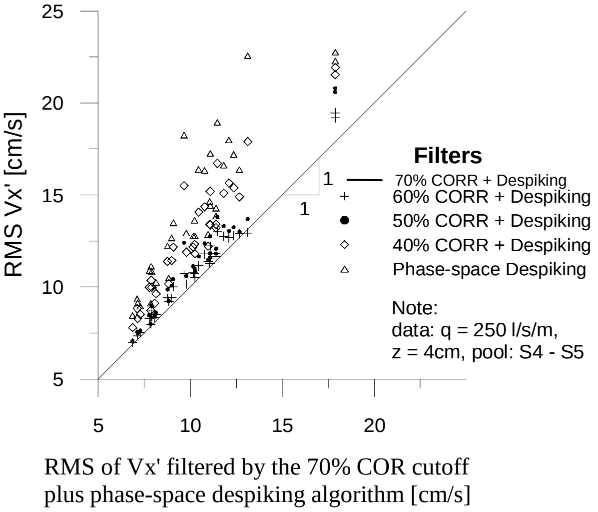


Fig. 3.2.3: Comparison of various COR filters with respect to 70% COR cutoff and phase-space despiking method.

3.3. Measurement Methods

- **Micro-propeller current meter**

The micro-propeller current meter (Type: MC20, propeller diameter: 18 mm, precision: 0.01 m/s) is used to measure the near bottom velocity. The nearest measure point is 1.07 cm from the bottom.

- **Particle-Image-Velocimetry (PIV)**

Particle Image Velocimetry (PIV) is a non-intrusive optical technique for the measurement of flow velocities. Velocity vector components are measured simultaneously over a two-dimensional plane or three-dimensional volume in flow.

The PIV technique follows an intuitive principle: particles in motion, suspended in the flow, are imaged digitally at two points in time close to each other. These points are defined precisely using short pulse illumination to “freeze” particle motion on each of the two images. In the time interval between light pulses, the particles move a short distance. Their displacements are then calculated statistically over a grid, for each grid cell area. Knowing the pulse separation and the image scale, the displacement field can be converted into a velocity vector field. The result is an immediate snapshot of the flow.

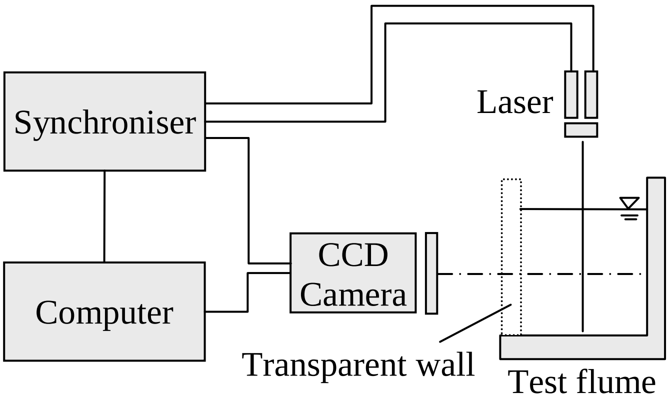


Fig. 3.3.1: Sketch of PIV instrument and the measurement principle

- **Acoustic Doppler Velocimeter (ADV)**

– **Principles of ADV Techniques**

The Acoustic Doppler Velocimeter measures the velocity of water using a physical principle called the Doppler effect. The ADV instrument uses one transmitter and three acoustic receivers. The transmitter generates a short pulse of sound at a known frequency, which propagates through the water along the axis of its beam. As the pulse passes through the sampling volume, the acoustic energy is reflected in all directions by particulate matter (e.g., sediment, small organisms, bubbles). Some portion of the reflected energy travels back along the receiver axis, where it is sampled by the ADV instrument and processed by the electronics to measure the change in frequency. The Doppler shift measured by one receiver is proportional to the velocity of the particles along the bistatic axis of the receiver and transmitter. The location of the sampling volume is 5 cm from the tip of the probe. The size of the ADV instrument sampling volume is determined by the sampling configuration used. The standard sampling volume is a cylinder of water with a diameter of 4.5 mm and a height of 5.6 mm. The MicroADV records nine values with each sample: three velocity values (one for each component), three signal strength values (one for each receiver), and three correlation values (one for each receiver). Naturally, the velocity data are of foremost interest; signal strength and correlation are used primarily to determine the quality and accuracy of the ADV velocity data.

– ADV settings

An ADV was used to measure the three velocity components in one of the pools at the fish pass to study the mean flow and turbulence flow structure. The sampling frequency and sampling time were set to 25 Hz and 90 seconds, respectively.

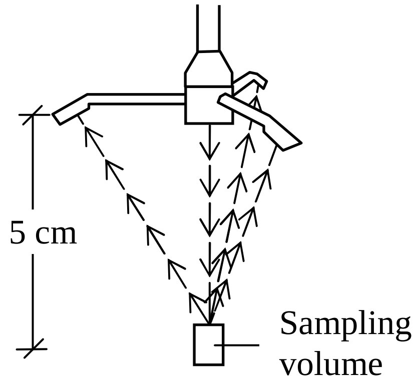


Fig. 3.3.2: ADV transmitter, receiver and sampling volume

3.4. Results

3.4.1 Streamwise velocity distribution at the cross sections

- **Examination of the maximum velocity**

The magnitudes of the results are all in prototype scale for a better connection to the requirements for fish migration in fish passes. The maximum velocity appearing near the boulder sills are governed by the difference in water level, Δh, and amount to,

$$V_{\max} = \sqrt{2g\Delta h} < V_{crit} \qquad [\text{m/s}] \qquad (\text{Eq. 3.9})$$

where V_{crit}: critical velocity in related to fish swimming performance (Ch. 2.4.2)

According to the trial runs of nature-like bypass channels and rough ramps in the Guidelines DVWK 232, the following planning targets should be checked in particular:

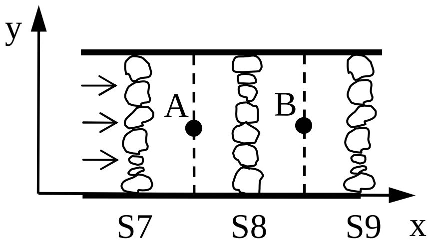
- Flow patterns and water depths: very shallow sections, areas with very high turbulence, short-circuit flows and detached jets must be avoided.
- The maximum flow velocities should not exceed 2.0 m/s, particularly at the critical locations (i.e. narrow cross-sections, submerged boulder sills)
- Differences of water level at drops and sills: $\Delta h \leq 20$ cm.

A fishway is designed with a certain value of Δh depending on the burst speed of the fish that would use this fishway (Liu et al. 2006). For example, according to the above equation, if the critical flow velocity for the fish to pass through is selected to be 2.0 m/s, then Δh must not exceed 20 cm.

$$\Delta h \leq \frac{V_{crit}{}^{2}}{2g} = \frac{2.0^{2}}{2 \times 9.81} = 0.204\,(m) \cong 20\,cm$$

However, Δh varies with the discharge, but this is not represented dynamically in the equation. To study this difference, velocity and water level difference were calculated and measured.

The difference of water levels at the center of the pools between sill pairs S7 – S8 and S8 – S9 is defined as Δh_b (Fig. 3.4.1). The boulder sill S8 was selected to examine the maximum velocity so that the measurements about water level or water depth were also conducted surrounding S8.



Δh_b = difference of water level between position A and B

Fig. 3.4.1: Definition of Δh_b

The data shown in Table 3.4.1 indicates that the measured Δh and velocity values are different from the designed values. Here, two reduction factors—k_1 and k_2—are introduced to study this difference.

$$V_{\max} = k_1 \times \sqrt{2g(k_2 \cdot \Delta h)} \le V_{crit} \qquad \text{[m/s]} \qquad \text{(Eq. 3.10)}$$

where V_{crit} : critical flow velocity

k_1: ratio of measured $V_{\max}$ to theoretical $V_{\max}$

k_2: ratio of measured water level difference to designed water level difference

Adjusting the factors of reduction of measured values to theoretical value, the designed water level difference can be modified by

$$\Delta h \le \frac{1}{2g \cdot k_2}\left(\frac{V_{crit}}{k_1}\right)^2 \qquad \text{[m]} \qquad \text{(Eq. 3.11)}$$

Table 3.4.1: List of calculated and measured maximum velocity, $V_{\max}$ (slope = 1:30)

Specific discharge, q_p	Water depth, h [1)]	Water level difference: designed, Δh_a	$V_{\max,\,a} = \sqrt{2g\Delta h_a}$	Water level difference: measured, Δh_b [2)]	$V_{\max,\,b} = \sqrt{2g\Delta h_b}$	$V_{\max,\,m}$: measured	$k_1 = \frac{V_{\max,m}}{V_{\max,a}}$	$k_2 = \frac{\Delta h_b}{\Delta h_a}$
[l/s/m]	[cm]	[cm]	[m/s]	[cm]	[m/s]	[m/s]	–	–
Boulder sill								
150	47.0	6.67	1.144	4.65	0.955	1.09	0.953	0.698
200	51.8	6.67	1.144	4.20	0.908	1.14	0.997	0.630
250	57.3	6.67	1.144	5.55	1.044	1.26	1.102	0.833
Technical sill, T1								
150	50.3	6.67	1.144	12.85	1.588	1.50	1.310	1.928

Note: [1)] Water depth was measured in the middle of a pool

[2)] The difference of water levels at the center of the pools between sill pairs S7 – S8 and S8 – S9 is defined as Δh_b.

[3)] Δh_a = slope × length of a pool

For example if we use the case of nature-like boulder sill with the channel bottom slope of 1:30, the maximum difference of water level can be calculated as:

$$\boldsymbol{\Delta h \le \frac{1}{2\times 9.81\times 0.698}\left(\frac{2.0}{0.953}\right)^2 = 0.322\,m \cong 32\,cm}$$

From the values of k_1 and k_2 listed in Table 3.4.1, k_1 is approximately 1.0, which indicates that the measured V_{max} values are similar to their theoretical values; hence, k_1 should be ignored. We only require k_2 to adjust the water level difference according to the selected critical flow velocity. Hence, Δh can be obtained by

$$\boldsymbol{\Delta h \le V_{crit}{}^2 / (2g\cdot k_2)} \qquad [\mathrm{m}] \qquad (\text{Eq. } 3.12)$$

where k_2 is suggested to be 0.75 from the average of the k_2 values listed in Table 3.4.1.

The upper limit of water level difference will be overestimated in such nature-like design because of its irregular cross section of the boulder sills. The overestimation can however be taken as a safety factor.

$$\Delta h \le \frac{1}{2\times 9.81\times 0.75}\times 2.0^2 = 0.272\,\mathrm{m} \cong 30\,\mathrm{cm}$$

From the detailed measurements show that the v_{max} is a good estimation to roughly illustrate the upper range of velocity distribution but on the other hand, it is slightly too strict as a design criteria. Using the revised equation (Eq. 3.11) with the factor, k_2, we can obtain a better reference for the upper limit of difference of water level in adjacent pools for design.

Examination of the maximum velocity is to study the application of the theoretical maximum velocity in a nature-like type fish pass. The variation of discharges is emphasized in particular for nature-like fish passes under the requirement of at least 300 days/year effective migration corridor in Germany. The idea is that, when we have to consider the dynamic variation of flow in river and its corresponding discharge in fish passes, the factors k_1 or k_2 should be taken into consideration. If the discharge can be controlled at the range of about 150 l/s/m, the elevation between adjacent pools can be 30 cm instead of 20 cm while applying nature-like fish passes, since the form of separating sills result in smaller water level difference comparing with technical type under same boundary conditions. If high discharge condition should be taken into account, then the magnitude of k_2 must be selected carefully.

In fact the calculation process in the Guidelines DVWK 232 must be clarified: first of all, if we choose $v_{crit} = 2.0$ m/s while applying $V_{\max} = \sqrt{2g\Delta h} < V_{crit}$, that means Δh must be less or equal to 20 cm, under which restriction of Δh, the slope of the fish pass and the interval of separating walls are chosen. There is however no need to examine maximum velocity.

If we have to examine the maximum velocity during different discharge conditions, then the factor k_2 should be studied to know if there is significant influence of flow variation on the maximum velocity.

The adjustment of the k_2 factor implies that the difference of elevations between two adjacent pools can be designed larger while applying nature-like type than that in technical-type. This study was conducted with initial discharge value being the minimum value required, $q_p = 150$ l/s/m, for the fish pass design. The overtopping conditions on the sills changed as the discharge increased, and therefore, expressing k_2 as a function of other variables, such as discharge or bottom slope, still remains a challenge.

- **Streamwise velocity distribution**

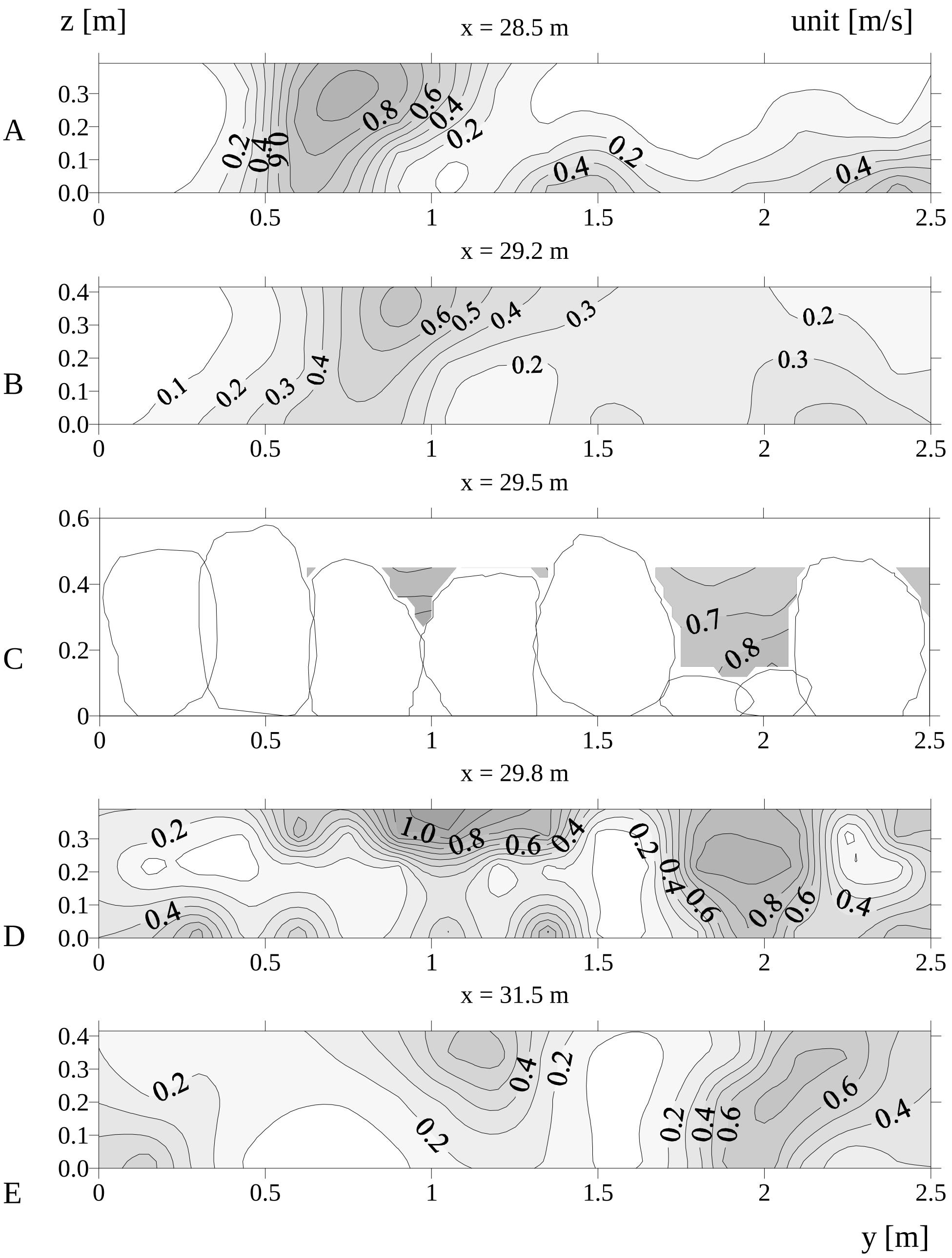
Fig. 3.4.2 illustrates the results of the streamwise velocity distributions at the cross-sections near the boulder sill S8 and the technical sill T1. The specific discharge values of q_p were 150, 200, and 250 l/s/m for S8 and 150 l/s/m for T1, with which S8 was later replaced. Here, for studying the streamwise velocity under the same upstream and downstream conditions and for focus on the differences in the velocity and flow pattern caused by the geometry of the separate wall, only one boulder sill S8 was replaced by a T1 sill. The sill S8 located is at x = 29.5 m (section C); cross-sections A (x = 28.5 m) and E (x = 30.5 m) are in the middle of the pools between sill pairs S7–S8 and S8–S9.

In Fig. 3.4.2(a), it is seen that for $q_p = 150$ l/s/m at cross-section A, there is a concentration flow at approximately y = 0.75 m owing to the position of the opening at S7. An apparent low-velocity area (velocity less than 0.2 m/s) can be observed at the upper right of the water zone and on the left side of section A. The concentration of the flow is not as significant in section B as it is in section A; moreover, the velocity is mostly below 0.4 m/s. In section C, where the opening of the sill is located, the flow concentrates again, and the velocity is mostly between 0.6 and 0.85 m/s. In addition, in section C, there is local overtopping at the other parts of the sill. The velocity distribution at section D shows a marked variation and is very uneven. The maximum velocity of the pool is observed in this section, D, where the water jet is located. High velocities are also observed at the location far from the opening of the sill located, because of the local overtopping at the sills. In section E, which is located in the middle of the pool, the velocity distribution becomes similar as that in section A.

As the discharge increases, the cross-sectional velocity distributions for q_p = 150, 200, and 250 l/s/m vary basically similar (Figs. 3.4.2(a)~(d) and Fig. 3.4.3). The overtopping for q_p = 150 l/s/m occurs mainly at the opening and partly at the slots between the smaller boulders in the middle, which can be observed in Fig. 3.4.2(a) in section C. The local overtopping region expands in section C while the discharge increases (Figs. 3.4.2(b) and (c)), which explains why the mean and maximum values of the velocity for q_p = 250 l/s/m are lower than those for q_p = 200 l/s/m (Fig. 3.4.3, section C).

As for the technical T1 sill, the cross-sectional velocity distributions are similar to those at the boulder sill but are more concentrated and even. The still water zone is larger in section E than at the boulder sill.

At S8, the streamwise velocity for q_p = 150 l/s/m ranges from 0.72 (25%-tile) to 0.86 m/s (75%-tile), and the mean value is 0.80 m/s; however, at the T1 sill, it ranges from 0.98 (25%-tile) to 1.22 m/s (75%-tile), with the mean value of 1.07 m/s, as shown in Figs. 3.4.2(a), (d) and Fig. 3.4.3. The mean value at the boulder sill S8 is approximately 25% lower than that at the technical sill T1.



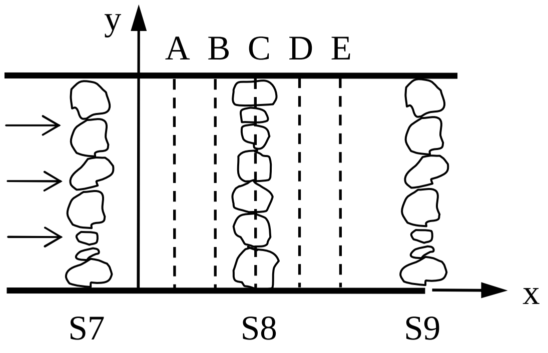
Max.	0.95
75%-tile	0.35
Average	0.29
25%-tile	0.08
Min.	0.04

Max.	0.78
75%-tile	0.33
Average	0.28
25%-tile	0.19
Min.	0.03

Max.	1.03
75%-tile	0.86
Average	0.80
25%-tile	0.72
Min.	0.62

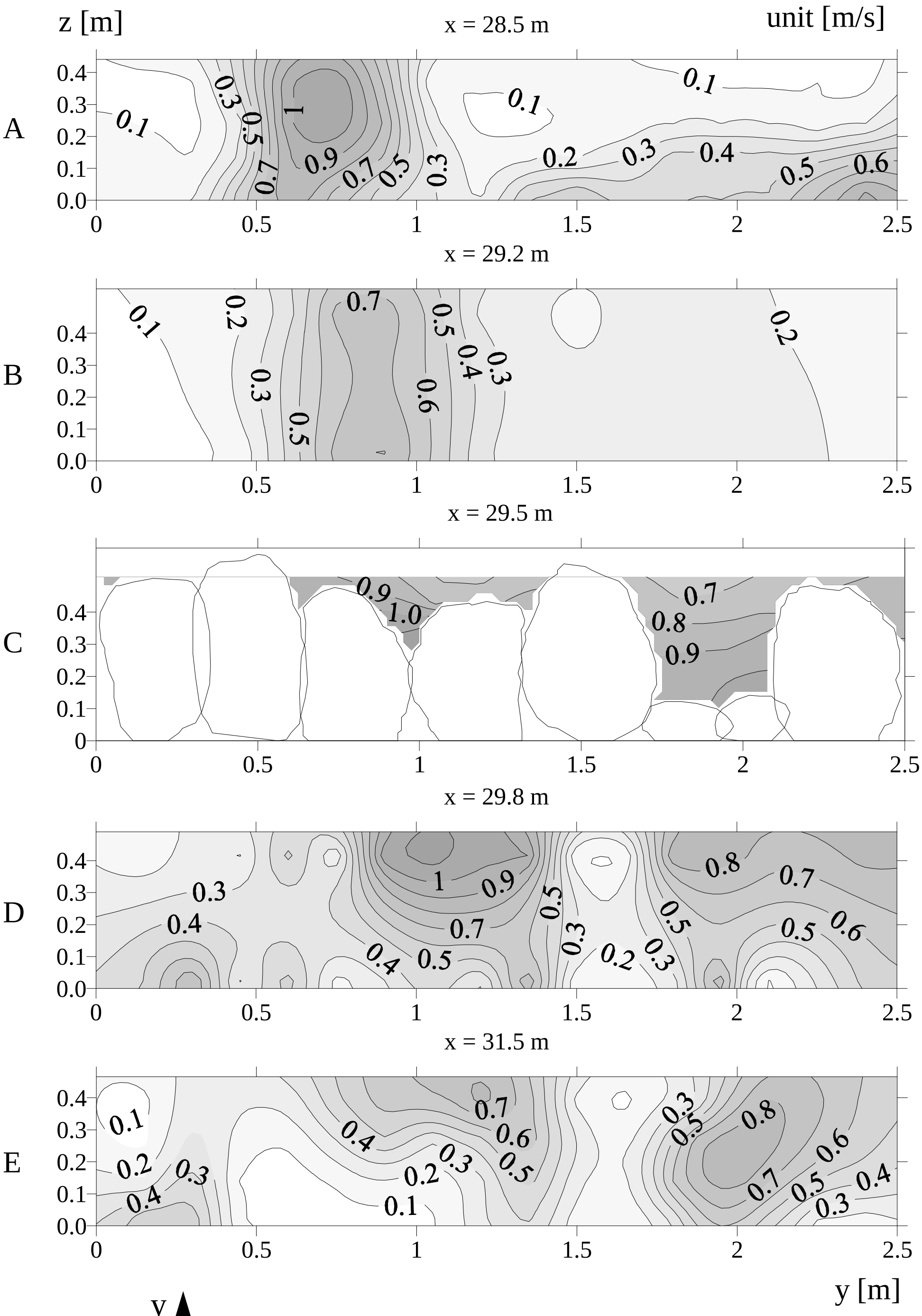
Max.	1.09
75%-tile	0.84
Average	0.47
25%-tile	0.13
Min.	0.05

Max.	0.73
75%-tile	0.53
Average	0.32
25%-tile	0.15
Min.	0.03



measured planes: cross sections A, B, C, D and E

Fig. 3.4.2(a): Streamwise velocity distributions at cross sections near the boulder sill No. S8 at x = 29.5m, q = 150 l/s/m, nature-like, boulder sill



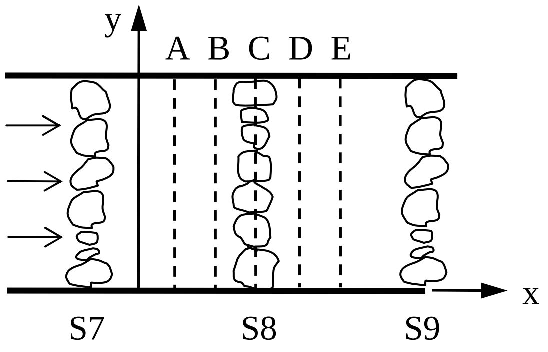
A	
Max.	1.08
75%-tile	0.51
Average	0.37
25%-tile	0.13
Min.	0.08

B	
Max.	0.81
75%-tile	0.34
Average	0.30
25%-tile	0.18
Min.	0.07

C	
Max.	1.17
75%-tile	1.02
Average	0.94
25%-tile	0.87
Min.	0.72

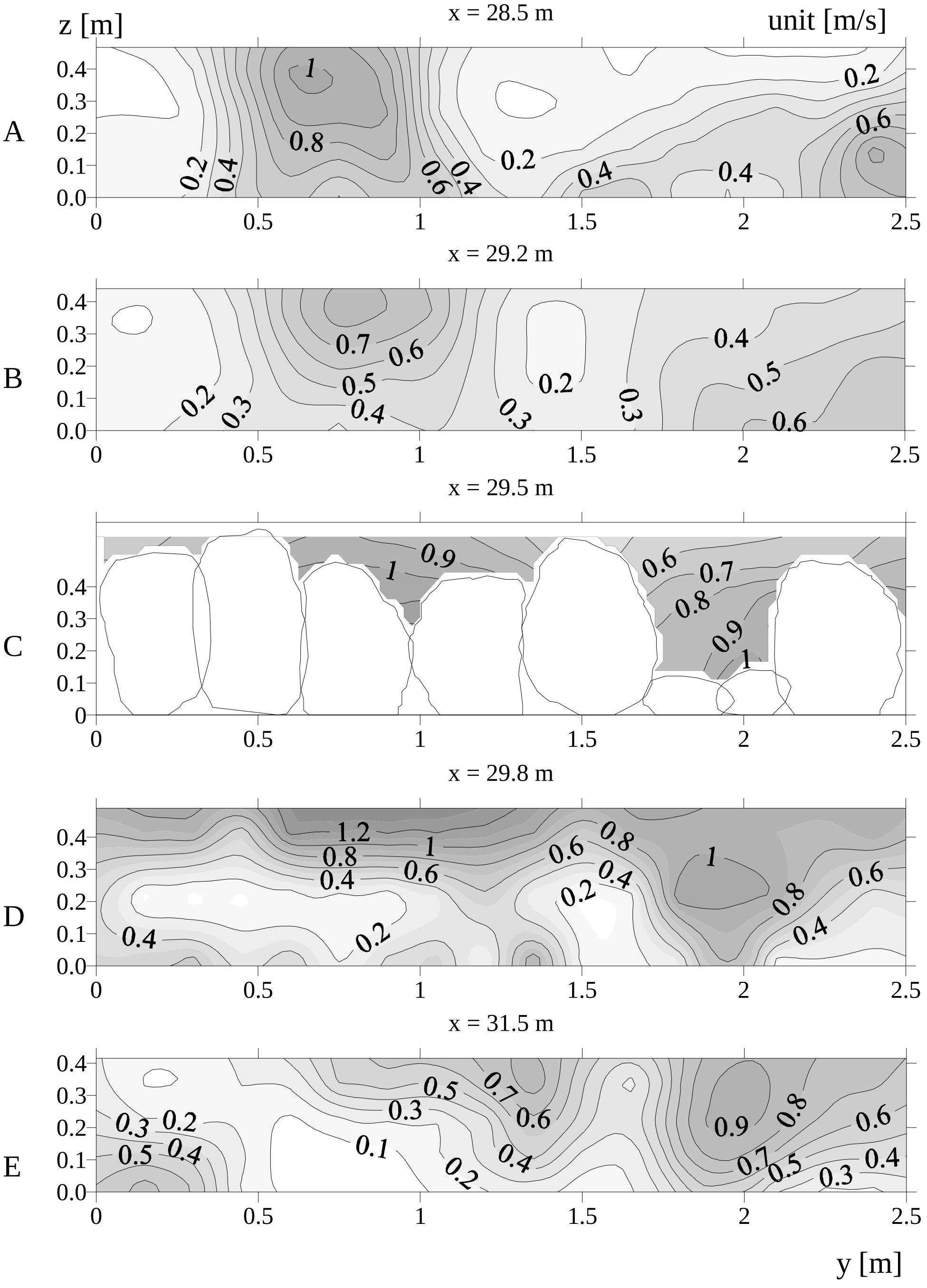
D	
Max.	1.14
75%-tile	0.81
Average	0.52
25%-tile	0.22
Min.	0.07

E	
Max.	0.87
75%-tile	0.59
Average	0.40
25%-tile	0.18
Min.	0.05



measured planes: cross sections A, B, C, D and E

Fig. 3.4.2(b): Streamwise velocity distributions at cross sections near boulder sill No. S8 at x = 29.5m, q = 200 l/s/m, nature-like, boulder sill



A (x = 28.5 m):

Max.	1.02
75%-tile	0.61
Average	0.42
25%-tile	0.17
Min.	0.08

B (x = 29.2 m):

Max.	0.86
75%-tile	0.50
Average	0.40
25%-tile	0.29
Min.	0.09

C (x = 29.5 m):

Max.	1.13
75%-tile	1.00
Average	0.90
25%-tile	0.82
Min.	0.46

D (x = 29.8 m):

Max.	1.26
75%-tile	0.96
Average	0.63
25%-tile	0.21
Min.	0.07

E (x = 31.5 m):

Max.	0.93
75%-tile	0.67
Average	0.45
25%-tile	0.20
Min.	0.05

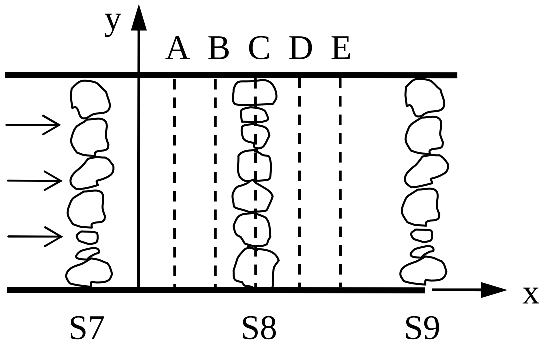
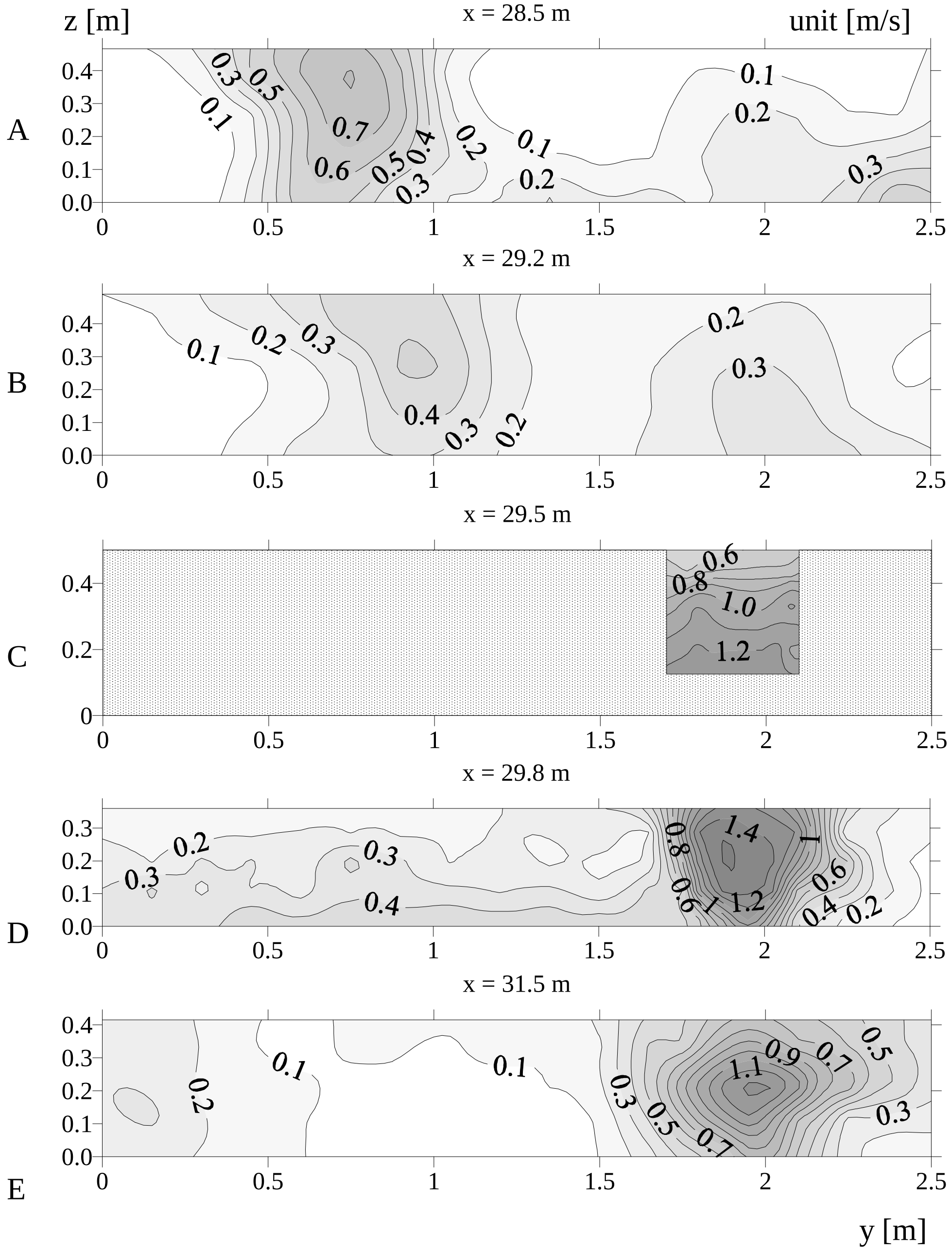


Fig. 3.4.2(c): Streamwise velocity distributions at cross sections near boulder sill No. S8 at x = 29.5m, q = 250 l/s/m, nature-like, boulder sill

measured planes: cross sections A, B, C, D and E



	A
Max.	0.81
75%-tile	0.30
Average	0.25
25%-tile	0.08
Min.	0.04

	B
Max.	0.51
75%-tile	0.28
Average	0.23
25%-tile	0.14
Min.	0.04

	C
Max.	1.31
75%-tile	1.22
Average	1.07
25%-tile	0.98
Min.	0.62

	D
Max.	1.50
75%-tile	0.70
Average	0.55
25%-tile	0.21
Min.	0.11

	E
Max.	1.32
75%-tile	0.66
Average	0.40
25%-tile	0.11
Min.	0.04

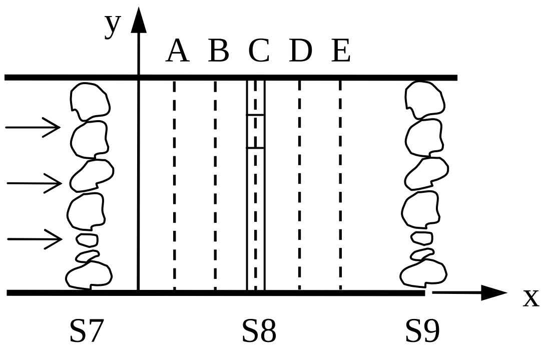


Fig. 3.4.2(d): Streamwise velocity distributions at cross sections near boulder sill No. S8 at x = 29.5m, q = 150 l/s/m, technical type, T1

measured planes: cross sections A, B, C, D and E

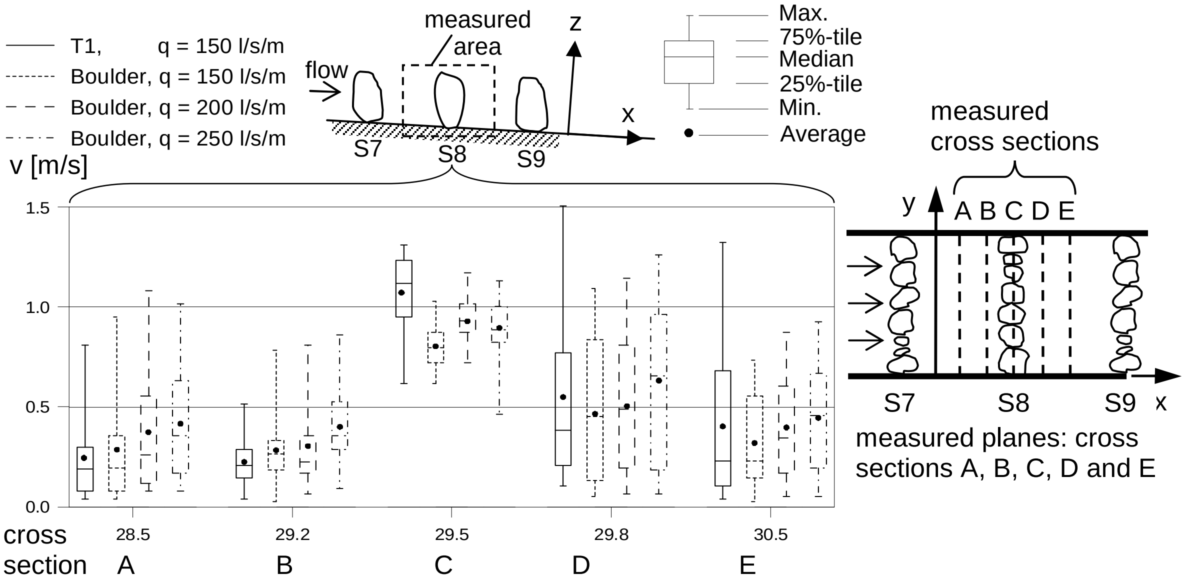


Fig. 3.4.3: Box-Whisker plot of the streamwise velocity distributions at cross sections near to the location S8 at x = 29.5m with boulder sill and T1 sill respectively under various discharge conditions

However, the maximum velocity occurs not at the sills but at the water jet downstream next to the opening in S8 and is represented as section D in this test. The maximum velocities at boulder sill S8 and the technical sill T1 are 1.09 m/s and 1.50 m/s respectively. V_{max} of the water jet at boulder sill is approximately 27% lower than that at the technical sill.

To examine the maximum velocity in a fish pass, velocities of 2.0 m/s (DVWK 1996) and 0.5 m/s (BLW 1999) are recommended for some migrant fish such as trout and for small fish, respectively. For migrant fish species, the maximum velocities in section C at boulder sill S8 for q_p = 150, 200, and 250 l/s/m are 1.09, 1.17, and 1.26 m/s, respectively, which are considerably lesser than 2.0 m/s. For small fish species, the nature-like type proves advantageous because of the low velocity downstream from the sills, which can be observed in Fig. 3.4.3 in section D. However, the flow is still high for small fish to cross the sills, and they may need to use the burst speed to move further. The velocities in the middle of two boulder sills increase when the discharges increase. But exactly at the boulder sill due to the different water depths and overtopping conditions, the flow area changed and might cause the lower flow rate at a higher discharge, as shown in Fig. 3.4.3 section C for boulder sills with q_p = 200 and 250 l/s/m. From the measured velocity distribution, it is seen that there is no clear relation to prove that the nature-like type construction provides a diverse flow pattern, which is closer than that produced by the technical type to that found in nature. For example, in Fig. 3.4.3 in section C, where S8 is located, and in section E, which is the central portion of the pool, the velocity ranges (between 25%-tile and 75%-tile) are higher for the technical sill T1 than for the boulder sill.

From the detailed measurements show that the v_{max} is a good estimation to roughly illustrate the upper range of velocity distribution. On the other hand, it is somehow a bit too strict as a design criterion. From the 75%-tile values of boulder sill at S8, a reduction of 20% of v_{max} will be recommended to examine the hydraulic design in a nature-like fish pass.

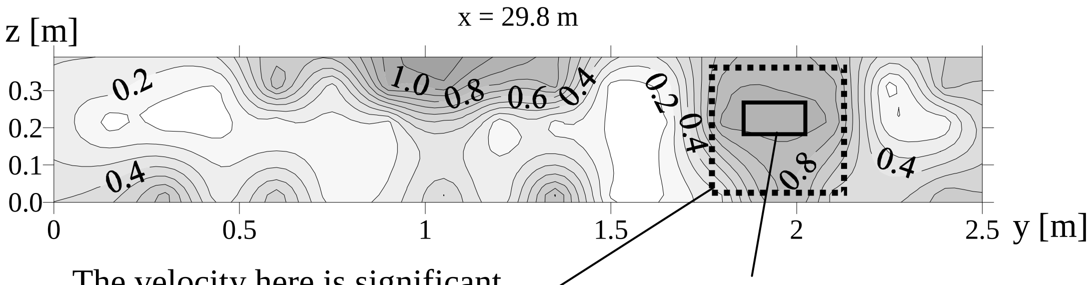
$$\mathbf{\frac{(1.09-0.84)}{1.09} = 22.9\% \cong 20\%}\text{, q = 150 l/s/m, nature-like boulder sill,}$$

where 1.09 and 0.84 m/s are the maximum and 75%-tile of velocity at section D for q = 150 l/s/m around boulder sill S8. The reductions are 28.9% and 23.8% respectively for q = 200 and 250 l/s/m.

$$\mathbf{\frac{(1.14-0.81)}{1.14} = 28.9\% \cong 30\%}\text{, q = 200 l/s/m, nature-like boulder sill,}$$

$$\mathbf{\frac{(1.26-0.96)}{1.26} = 23.8\% \cong 20\%}\text{, q = 250 l/s/m, nature-like boulder sill,}$$

The idea about this discussion is that, if there is a single point at a cross section with velocity over 2 m/s (for example), velocity at the main cross sectional area of high velocity maybe significant lower than the maximum value. Since the average value cannot pick up the high velocity condition, to use 75%-tile velocity to examine the v_{crit} is suggested.



The velocity here is significant lower than the maximum value and is possible for fish to pass through

The velocity here is about the maximum value

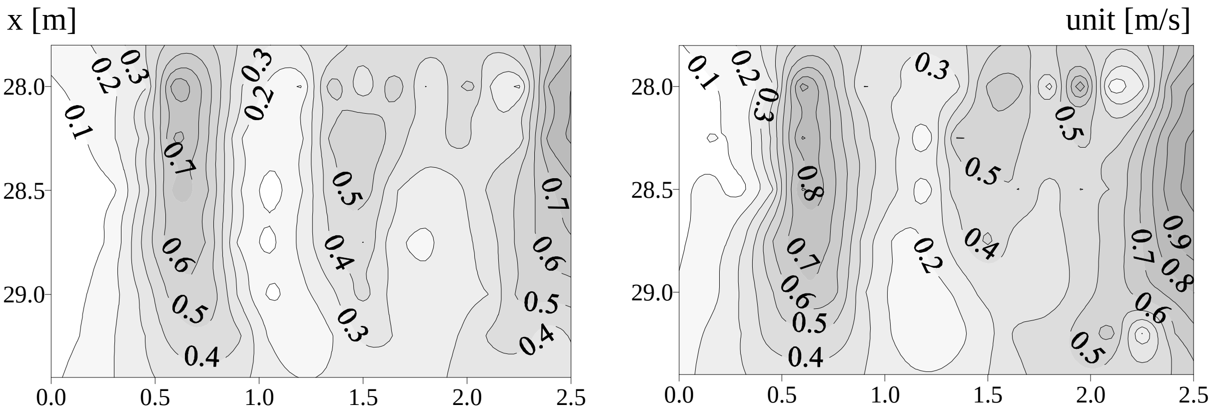
Fig. 3.4.4: The concept of regions of maximum velocity and 75%-tile velocity

3.4.2 Near bottom velocity distributions

The near bottom velocity in the pool between sill pair S7 – S8 with q = 150, 200 and 250 l/s/m and later the technical sill T1 replaced S8 with the same flow condition were measured and shown in Fig. 3.4.5. The near bottom velocity was measured by using micro-propeller (see Fig. 3.2.2(c) in page 36). The measurements were done at about 1.8 cm from the gravel bottom which corresponded to about 9 cm in prototype scale. The velocity distribution at T1 sill could give a reference of the velocity pattern on the rough bottom bed because there are no orifices on the bottom, which exist however at boulder sills due to gaps between boulders. In the cases of boulder sills, the velocities are obviously higher than with sills of no orifices on the bottom. But in comparison with the velocities just at the sill where x = 29.5 m (section C), the near bottom velocities are around one half of them and it would be possible for small fish species to pass through.

The near bottom velocities increase slightly when discharges increase as shown in Fig. 3.4.5(f). Theoretically because of the boundary layer, in particular on rough bottom, velocity decrease when approaching the bottom. The magnitudes of the near bottom velocity were measured and the results prove that the near bottom zone provide low velocity conditions, most are under 0.5 m/s as shown in Fig. 3.4.5(f), even for fish which are not good swimmers to pass through or to remain rest, no matter under low flow or high flow conditions.

9 cm apart from the streambed can be considered as “near bottom” for big fish. For small or juvenile fish it is not “near” enough. However due to the restrictions of the flume and facilities, better results could not be obtained. For small or bottom oriented fish, study of near bottom velocity distribution is recommended to be conducted at model scale of 1:1.

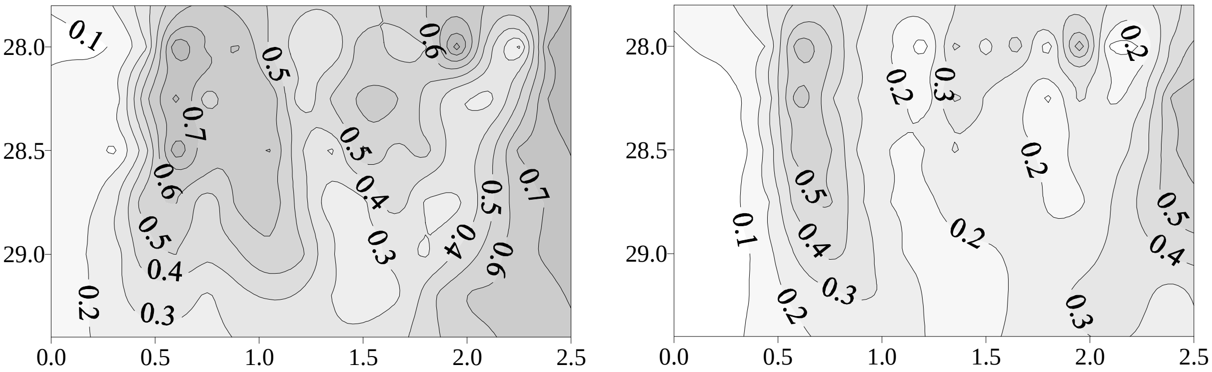


(a) q = 150 l/s/m,
nature-like
boulder sill

Max.	0.90
75%-tile	0.49
Average	0.35
25%-tile	0.20
Min.	0.05

(b) q = 200 l/s/m,
nature-like
boulder sill

Max.	0.98
75%-tile	0.59
Average	0.44
25%-tile	0.26
Min.	0.07

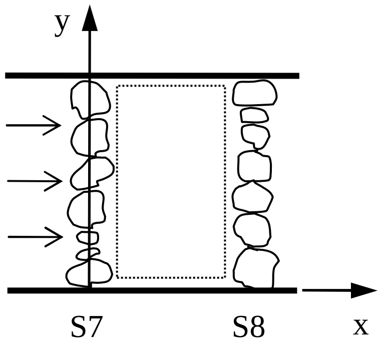


(c) q = 250 l/s/m,
nature-like
boulder sill

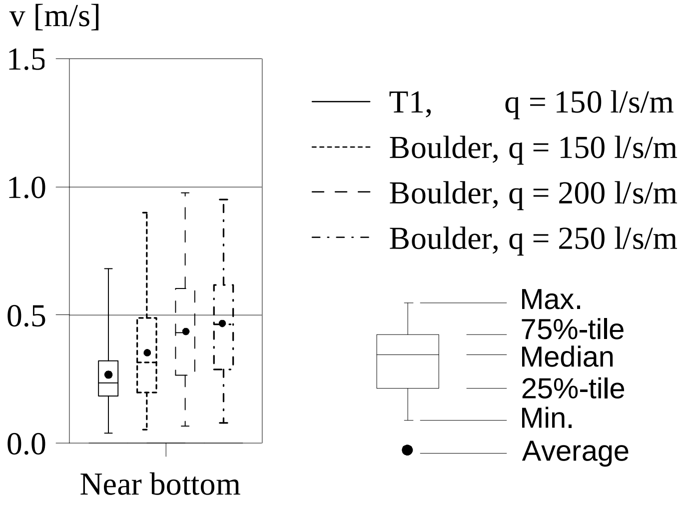
Max.	0.95
75%-tile	0.62
Average	0.47
25%-tile	0.29
Min.	0.08

(d) q = 150 l/s/m,
technical type
T1

Max.	0.68
75%-tile	0.32
Average	0.27
25%-tile	0.18
Min.	0.04



(e) Measured plane: near bottom,
about 9 cm above bottom



(f) Box-Whisker plot of near bottom velocity

Fig. 3.4.5: Near bottom velocity distributions between sill pair S7 – S8

3.4.3 Revise of the calculation processes

In the Guidelines DVWK 232 the calculation processes for rough channel with boulder sills must check the allowable maximum velocity at first comparing with a common used critical velocity 2 m/s. When the designed water level difference is equal or less than 20 cm, theoretically the maximum velocity will be lower than 2 m/s. However according to the results shown in chapter 3.4.1, a reduction factor k_2 can be introduced and the maximum allowable water level difference will be suggested to be 30 cm by which the velocity in the rough channel / ramp will not exceed 2 m/s.

For a bypass channel or rough bottom ramp, to discuss the hydraulics referring to discharge Q can not exactly quantify the flow whether it is high or low flow. Instead of discharge Q, the specific discharge, q, should be used in particular for hydraulic calculation.

The main problem on design of nature-like ramps occur during low flow period as mentioned before which means the channel or river width and the low flow discharged should be evaluated to prevent from too shallow water depth while there is little flow in streambed. Here a revised calculation process is recommended as follows.

As for bottom ramps Q_{30} and Q_{330} should be chosen to replace Q_{min} and Q_{max} respectively for calculation. For rough channel bypass the minimum and donation flow should be Q_{min} and Q_{max} respectively depending on the available discharges.

– Example: the bottom ramp Kolbermoor in the river Mangfall (ref. Ch. 4.4)

Set minimum $h_ü$ to be 15 cm so that,

$$Q = \frac{2}{3}\mu\sigma B\sqrt{2g}\,h_ü^{3/2}$$

$$\boldsymbol{h_ü = \left(\frac{3}{2}\frac{Q}{\mu\sigma B\sqrt{2g}}\right)^{2/3} \geq 0.15}$$

Let μ = 0.5 and σ = 1.0 since for low flow the submerged overflow is not expected.

Using the weir equation, the “net width of openings, B” can be calculated as:

$$\boldsymbol{B \leq \frac{3}{2}\cdot\frac{Q}{\mu\sigma\sqrt{2g}}\cdot\frac{1}{h_ü^{3/2}}} \qquad [m/s] \qquad (Eq.\ 13)$$

here input Q_{30} into the variable Q

$$\boldsymbol{B \leq \frac{3}{2} \cdot \frac{Q}{\mu\sigma\sqrt{2g}} \cdot \frac{1}{0.15^{3/2}} = \frac{3}{2} \cdot \frac{3.06}{0.5 \times 1.0\sqrt{2 \times 9.81}} \cdot \frac{1}{0.15^{3/2}} = 35.7(m)}$$

where 3.06 m^3/s is the Q_{30} at the discharge gauge station downstream of the bottom ramp Kolbermoor. It shows during low flow condition, Q_{30}, the net width of openings should not larger than 35.7 m to prevent from dry out of the construction as a barrage for fish movement.

Here the result of fieldwork at the bottom ramp Kolbermoor is used to explain the definition of B, which is equivalent to the cross sectional width of a boulder sill multiplying the passage ratio (see Chapter 4.4.1) to ensure adequate water depth during low flow condition (i.e. discharge between MQ and Q_{30}).

We should create migration corridor as thalweg to concentrate the river flow during low flow periods. However the flow may spread at the whole river bottom if the thalweg is not a significant deeper channel, but the “net width of openings, B” should not over the value obtained by Eq. 13.

3.4.4. Turbulence distribution in the pools

- **Volumetric Dissipated Power**

Fig. 3.4.6 shows the results of the estimation of the volumetric dissipated power, E, in the pool between position x = 20.5m and x = 22.5m (control volume (a)) as well as between x = 22.5 to 24.5 m (control volume (b)).

The net volume used in the equation of volumetric dissipated power (Eq. 3.14) is the water volume in the pool between sill pairs S4 – S5 or S5 – S6. The control volume is marked upstream side till middle of the adjacent upstream pool because of Δh, which was calculated as the difference of water level at the center of two adjacent pools. Three values of Δh at different longitudinal sections corresponding to three values of E is to do repeating test (to take values at y = 0.625m and 1.85m as repeating samples for y = 1.25m) for catching the feature of irregularity in nature-like forms.

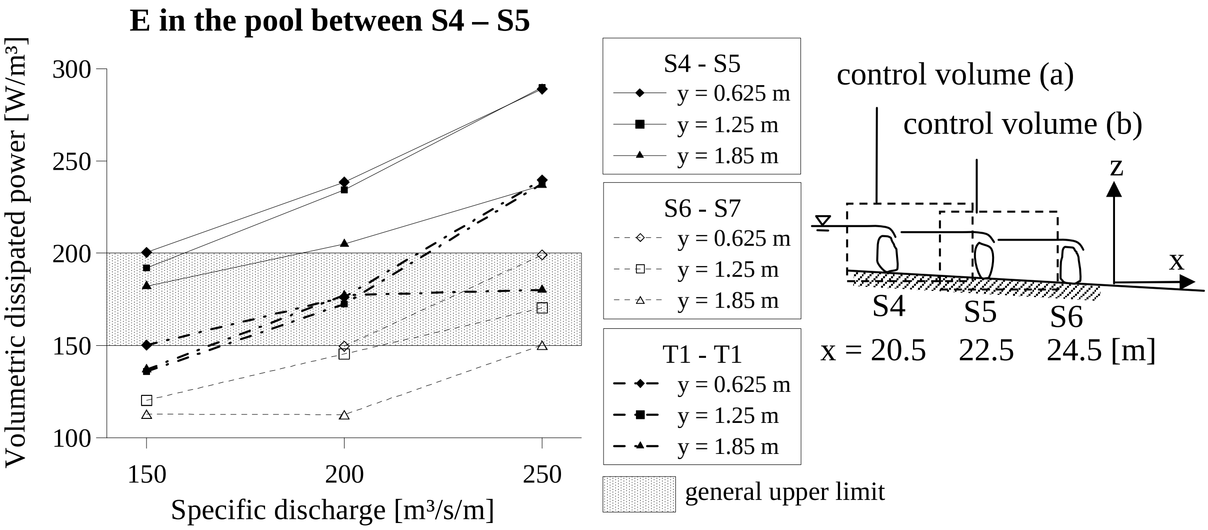
The experiment conducted for the boulder sill pair S6–S7 was a repeat test for the boulder sill pair S4–S5, just as the experiment for the control volume (b) was a repeat test for the control volume (a). There was a marked difference in the calculated values of E between these two still pairs, as shown in Fig. 3.4.6(a). In the case of sill pair S4–S5, most of the E values exceeded the general recommended criterion-E $\leqslant$ 150~200 W/m^3. For sill pair S6–S7, all the E values matched that of the criterion. Moreover, E obtained for technical-type sill pair T2–T2 was in between those obtained for sill pairs S4–S5 and S6–S7, and they did not show whether the nature-like construction provided better energy dissipation than the technical-type construction. E does not illustrate the spatial distribution of turbulence due to different overtopping conditions or flow pattern structures, and it can vary in a wide range under the same flow conditions due to the irregular structures in nature-like facilities.

The result at the measured section S5 in Fig. 3.4.6(b) shows that the energy dissipation for technical sill pair T1 – T1 are most above the criterion of 150 to 200 W/m^3 and that for nature-like sill pairs S4 – S5 and S6 – S7 are most within the criteria and only two measured data points for S6 – S7 are significantly higher than the criteria for q = 250 l/s/m.

From the result it shows, there is no significant difference for energy dissipated rate between nature-like type or technical type design of fish passes at control volume (a). However the specific discharge of 150 l/s/m could better provide the hydraulic condition for fish migration under suggested criteria for energy dissipation. The specific discharge of 200 l/s/m provides condition just around the criteria limit but as for 250 l/s/m, it’s significantly more possible to be over the criteria for energy dissipation and disturbs the performance of fish swimming.

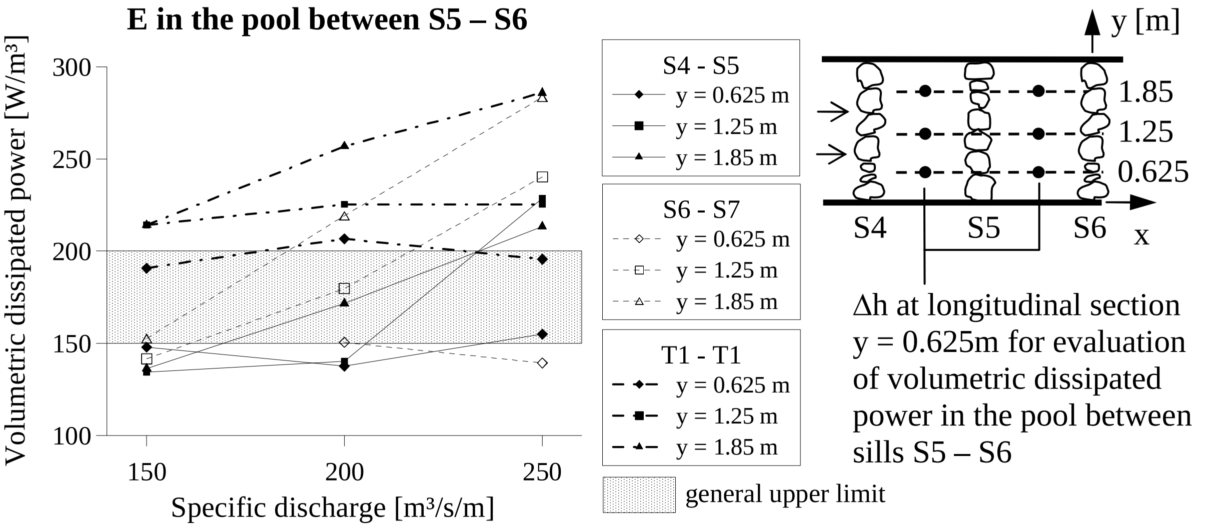
From the equation of energy dissipated rate it is obvious that we can only calculate one value to estimate the degree of turbulence in a pool. However because of the structures of each design, such as slots, notches, orifices, sills and the flow condition of overflow, etc. will result in various flow or jet conditions. An average estimation of the turbulence degree can not illustrate the spatial distribution exactly.

(a) control volume (a)



E in the pool between S4 – S5

(b) control volume (b)



E in the pool between S5 – S6

Fig. 3.4.6: Volumetric dissipated power in the pool between nature-like sill pairs S4 – S5, S6 – S7 and between technical sill pair T1 – T1(S4 – S5 were replaced later by S6 – S7 and T1 – T1 at the same position)

- **Turbulence Intensity**

From the research results, scientists who used TI to describe the influence of turbulent flow on fish swimming performance indicated that they conducted experiments under certain velocities. The mean flow they mentioned is a very important key, which points out that the turbulence intensity is a ratio of turbulence scale comparing with the mean flow. In Fig. 3.4.7 it shows, TI increases rapidly when mean flow velocity decreases; besides, there is no significant difference of the distributions for sill pairs S4 – S5, S6 – S7 and T2 – T2. But there is no physical phenomenon in the relation of mean flow velocity and turbulence intensity and the tendency is only a mathematical result. Since TI is defined as the root mean square of fluctuation divided by mean velocity, when the mean velocity, denominator, decreases, TI increases. Furthermore, because turbulence intensity is used to quantify the relative proportion of turbulence to mean flow, instead an absolute quantification of the scale of turbulence, so that in Fig. 3.4.7 there are also no difference between various sill pairs. Since velocity is also a key parameter while assessing the possibility for fish to migrate in fishway facilities, using turbulence intensity, TI, to describe the scale of turbulence in pool type fishways, it is quite possible to obtain very high TI value at low flow velocity locations. However, such high TI value should not straight refer to high turbulent flow conditions.

- **Kinetic energy of the turbulent flow per unit mass**

As for turbulent kinetic energy per unit mass, TKE, is defined as the summation of the three components of the turbulent kinetic energy, which represent inverse tendency to mean velocity as comparing with the relation for turbulence intensity and mean flow. In Fig. 3.4.8 it shows that when mean flow is lower than about 50 cm/s, TKE increases while mean velocity increases; when mean flow is higher than 50 cm/s, there is no obvious relation of TKE and mean flow and the values of TKE depend basically on the position in the pool. From the result for experiments with flume slope of 1:30, the turbulent kinetic energy in the pools between sill pairs S4 – S5 and S6 – S7 are most under 1000 cm^2/s^2, however, the turbulent kinetic energy in the pool between sill pair T2 – T2 spreads scattered to about 2000 cm^2/s^2 and is obviously higher than the TKE in nature-like type for high mean flow conditions. The different performance of turbulent flow in nature-like or technical pool-type design can not be observed when we introduce energy dissipated rate or turbulence intensity to describe the scale of turbulence.

Using volumetric energy dissipated rate we can only calculate an average value in a pool but it can not reflect the influence of flow perturbation on fish and the spatial variation of turbulence structure. The turbulence intensity should be carefully used to quantify turbulence and with referring to its relevant mean flow velocity, otherwise there will be mathematical misapprehension. TKE can describe spatial variations of turbulence structure and thus using TKE to study the fish swimming performance will be suggested in this study.

Fig. 3.4.9 shows the results of TI, TKE, and resultant velocity V_{xy} in the pool with the boulder sill pair S4–S5 in the plane z = 15 cm (prototype scale) for q_p = 150 l/s/m and slope = 1:30. The distribution patterns of TI and TKE are in sharp contrast to each other. Because of the normalized magnitudes, TI increases when the mean velocity decreases, and singular points with high TI values occur when the velocity approaches zero, where it is the space that the fish might consider as a resting zone in a pool. The use of TI to quantify the level of turbulence appears to produce a contradictory result. It is to be noted that the previous studies on the relation between turbulence and fish behavior were conducted in channels under certain conditions of streamwise mean velocity. When considering the relation between turbulence and fish behavior in pool-type fish passes, the flow pattern in a pool cannot be simplified to be a 1D (e.g., water jet at a slot) or 2D (e.g., vertical-slot fish pass) flow owing to complications in the pool configurations. In addition, behavioral responds of fish to turbulence relate to a relative turbulent level, or to the magnitude of the turbulent level itself, remain uncertain. Therefore, it is inappropriate to use TI for discussions on the spatial variation of turbulence. Nevertheless, the TKE represents the magnitudes of velocity fluctuations without the normalization problem, and it is recommended in this study for the discussion of spatial distribution of turbulence and its effect on fish behavior.

Fig. 3.4.10 shows the box-whisker plot of TKE measured in pools between sill pairs S4–S5, S6–S7, and T2–T2 for three specific discharges (q_p = 150, 200 and 250 l/s/m) and two slopes (S = 1:30 and 1:15). The standard deviation (TKE_{SD}) of TKE in nature-like type pools with q = 250 l/s/m, z = 15 cm and slope = 1:30 is similar between S4–S5 and S6–S7 ($F = 1.69 < 1.904 = F_{95\%}$), characterized by a lower mean value (S4–S5: $t = 5.016 > 2.002 = t_{95\%}$; S6–S7: $t = 7.057 > 2.004 = t_{95\%}$) and smaller standard deviation (S4–S5: $F = 2.336 > 1.867 = F_{95\%}$; S6–S7: $F = 3.947 > 1.867$) of TKE values than that observed for technical-type sills T2–T2. The value of TKE increases slightly in the z-direction, as shown in Fig. 3.4.10(b) and (c). For slope = 1:15 (Fig. 3.4.10(d)) and q_p = 250 l/s/m, the mean values of the TKE could even exceed 2000 cm^2/s^2.

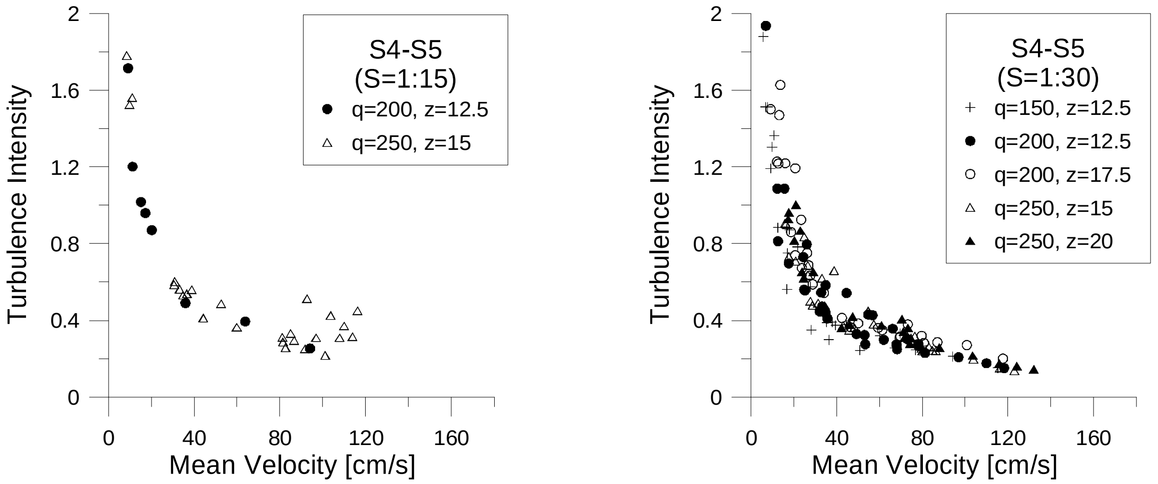
Table 3.4.3 shows the mean values of TKE and the difference between the nature-like and technical-type sills in terms of the reduction ratio. The reduction in the TKE value ranges from 23% to 54% for slope = 1:30 and from 34% to 55% for slope = 1:15, which clearly proves that by using the nature-like sill, the TKE values could be significantly reduced from one-fourth to one-half of those obtained with the technical-type sill. From the results in Fig. 3.4.10 and Table 3.4.2 it shows that not only the levels of the turbulence in the nature-like fish passes are lower than those in the technical-type passes but also shows that the perturbation of the flow is relatively uniform on the whole.

The spatial distribution of the TKE are shown in Fig. 3.4.11 ~ Fig. 3.4.14. For slope = 1:30, as shown in Fig. 3.4.11 ~ Fig. 3.4.13, it shows that in most cases, a high TKE is distributed downstream of the sills and in particular, the TKE value becomes high at both the sides of the wall; moreover, it may influence the movement of the fish whey they try to pass through the opening on the sill, which can be observed in particular in Figs. 3.4.11 and 3.4.12. In Fig. 3.4.13, the TKE value immediately below the middle part of S6 appears to be high. This distribution differs from that for S4–S5 in that there are no apparent high TKE values near the opening of sill S6 and the wall. The difference is supposed to result from the irregular cross section in various distributions; for S6, the boulders at the middle part of the sill are relatively smaller, which resulted in stronger overtopping flow and high turbulence.

The distributions of the TKE for slope = 1:15 are shown in Fig. 3.4.14. Sometimes, due to shallow water depth and turbulent conditions, measurements could be conducted only in a part of the entire horizontal plane (e.g., Fig. 3.4.14(a), (c) and (e)). Comparing the results in Fig. 3.4.14(b) and (e), the TKE distributions are similar to those in Fig. 3.4.11(a)~(d) and 3.4.12(d)~(e) but high TKE values moved closer to the boulder sill.

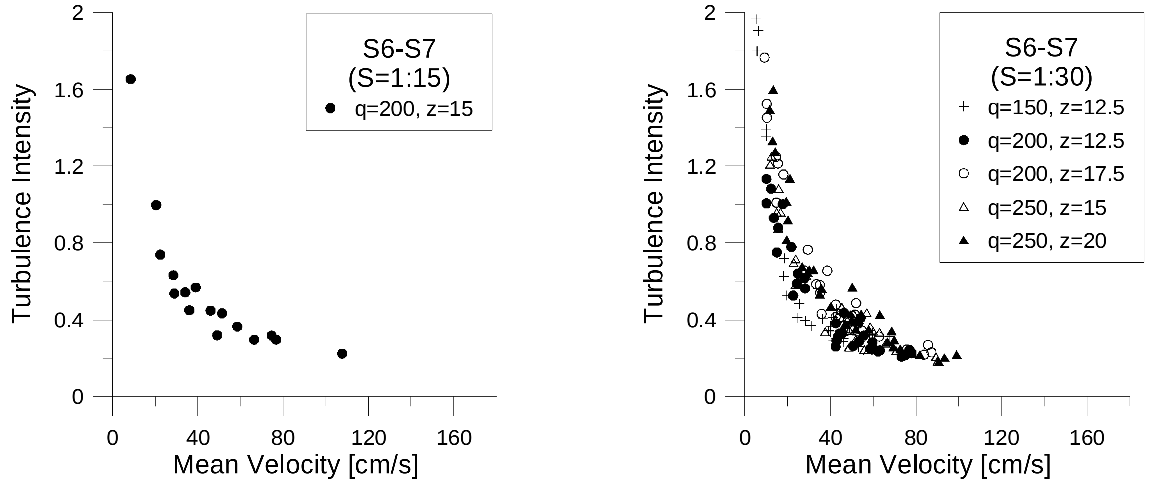
Table 3.4.2: Averages of TKE and the reductions of TKE by technical type (T2) comparing with nature-like type (S4 – S5, S6 – S7) Unit: [cm²/s²]

slope	1:30					1:15	
q_p [l/s/m]	150	200		250		200	250
z [cm]	12.5	12.5	17.5	15.0	20.0	12.5/15.0	15.0
S4 – S5	353.2	477.3	606.8	538.2	619.8	515.0	1146.3
S6 – S7	311.4	353.2	547.9	435.2	603.4	566.2	-
Mean of TKE: nature-like type	332.3	415.3	577.3	486.7	611.6	540.6	1146.3
z [cm]	15.0	15.0	22.5	15.0	22.5	15.0	15.0
T2 – T2	726.2	542.1	965.0	876.2	1173.4	816.0	2562.5
Reduction of TKE: Technical to nature-like type	-54%	-23%	-40%	-44%	-48%	-34%	-55%



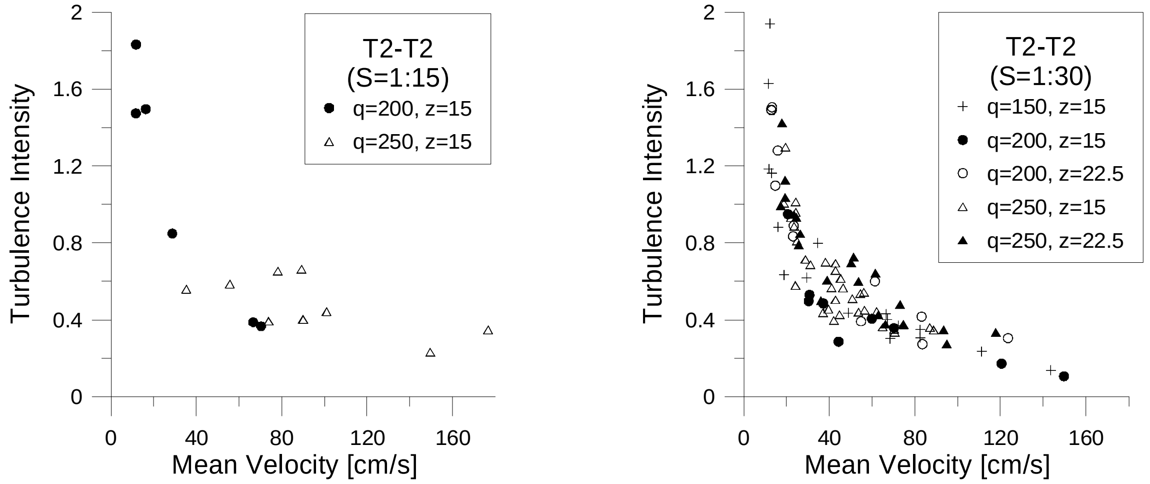
(a) Sill pair: S4 – S5

(b) Sill pair: S4 – S5



(c) Sill pair: S6 – S7

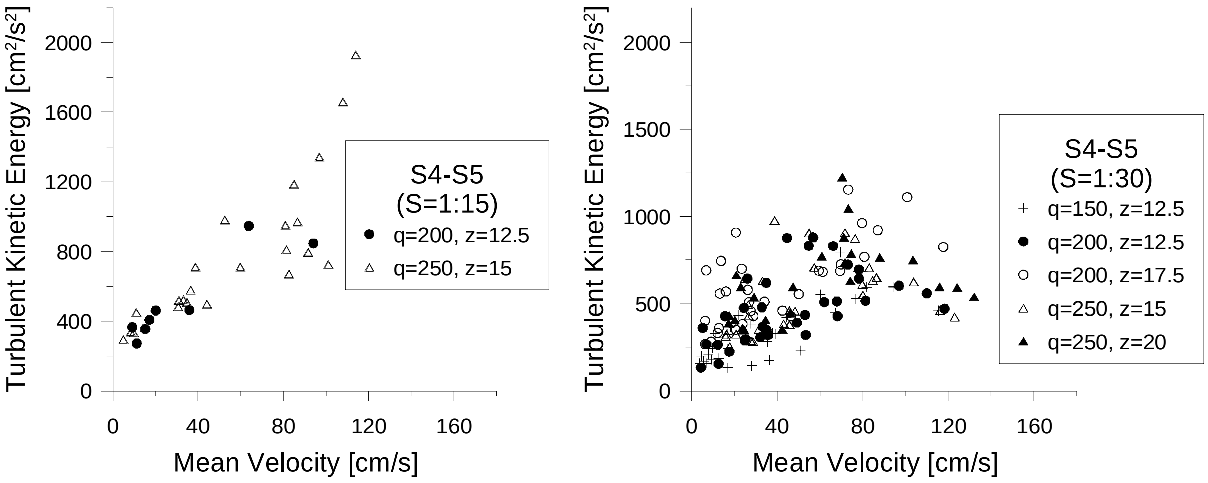
(d) Sill pair: S6 – S7



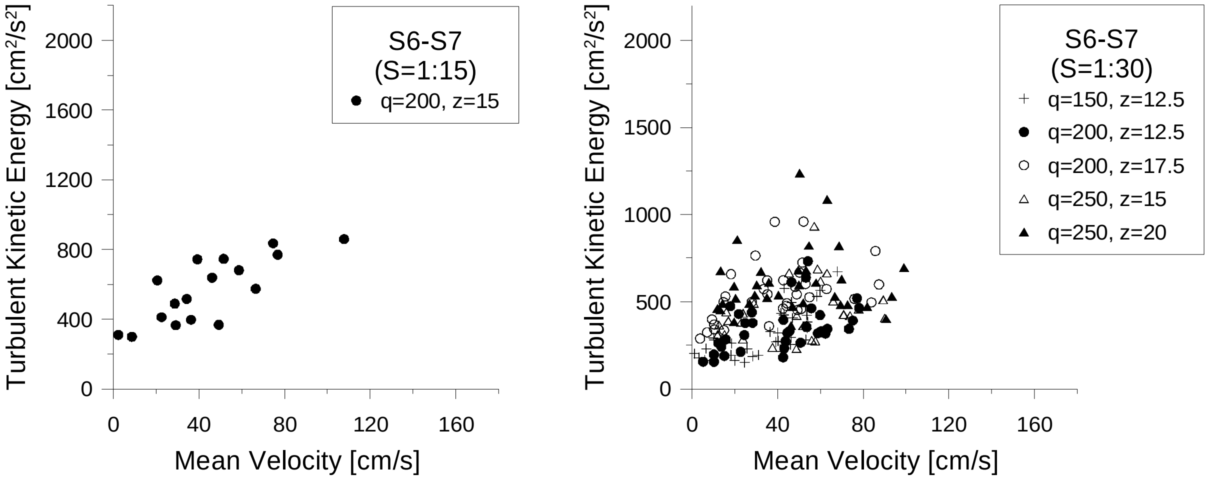
(e) Sill pair: T2 – T2

(f) Sill pair: T2 – T2

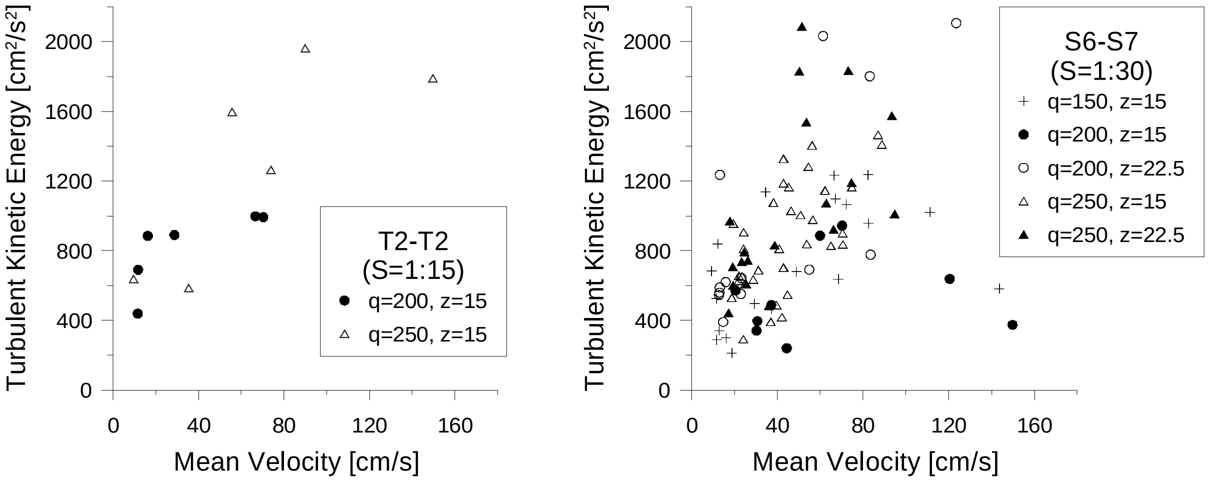
Fig. 3.4.7: Turbulence intensity versus mean velocity (data are plotted for TI < 2.0)



(a) Sill pair: S4 – S5 (b) Sill pair: S4 – S5

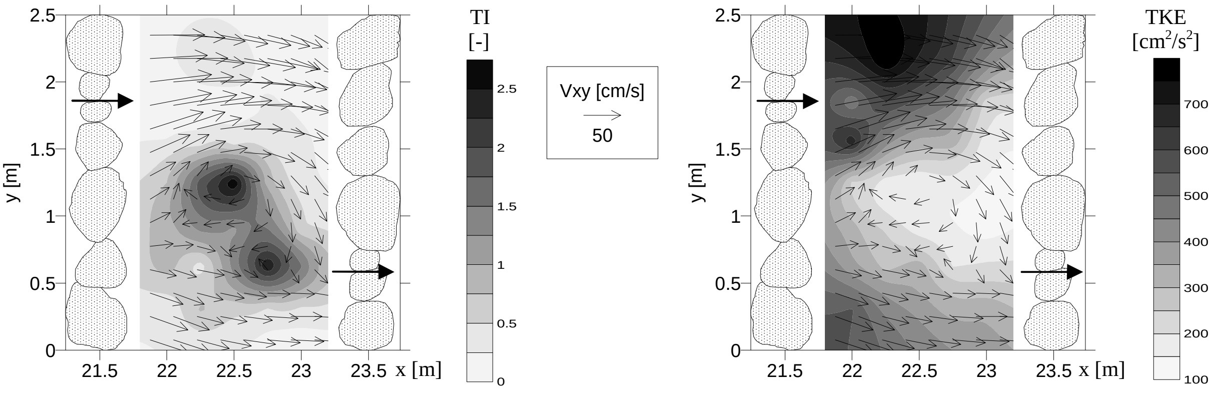


(c) Sill pair: S6 – S7 (d) Sill pair: S6 – S7



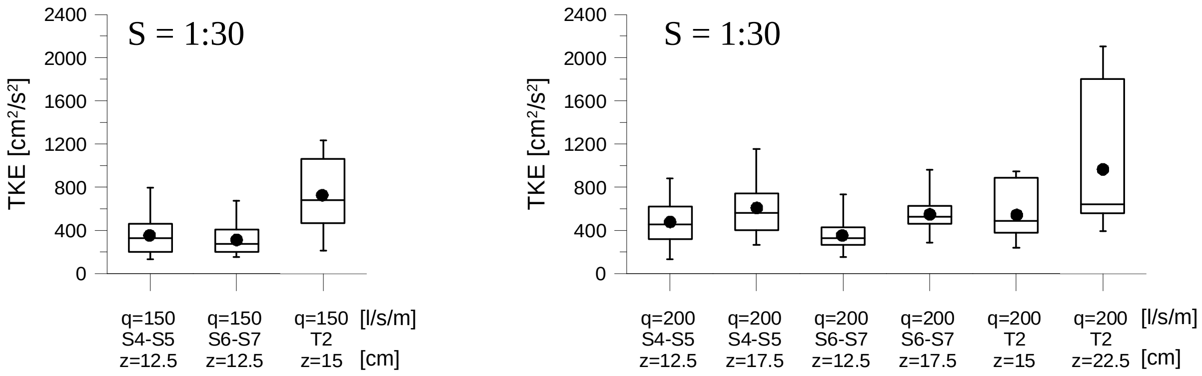
(e) Sill pair: T2 – T2 (f) Sill pair: T2 – T2

Fig. 3.4.8: Turbulent kinetic energy versus mean velocity (data are plotted for TKE < 2000)

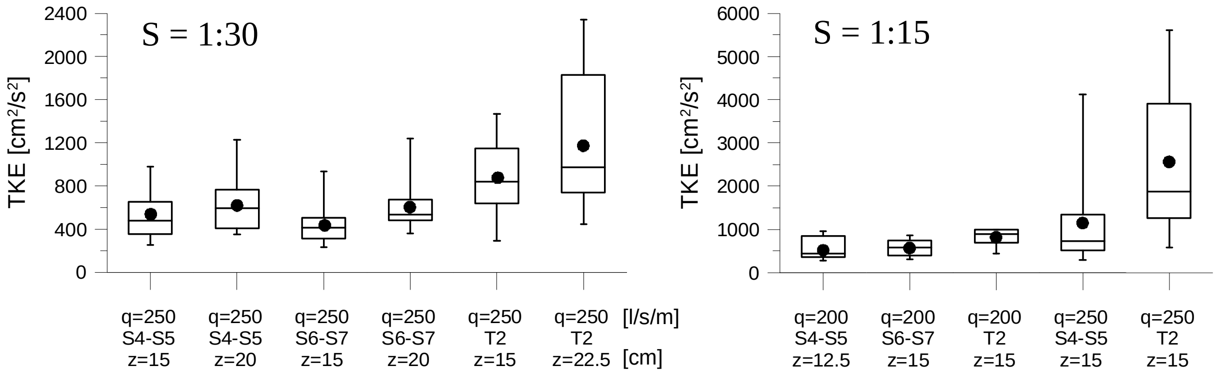


(a): TI vs. V_{xy} (b): TKE vs. Vxy

Fig. 3.4.9: Distribution of turbulence intensity, turbulent kinetic energy and velocity, V_{xy}, in x- and y- direction in the pool between sill pair S4 – S5 (z = 12.5 cm, q_p = 150 l/s/m, slope = 1:30)

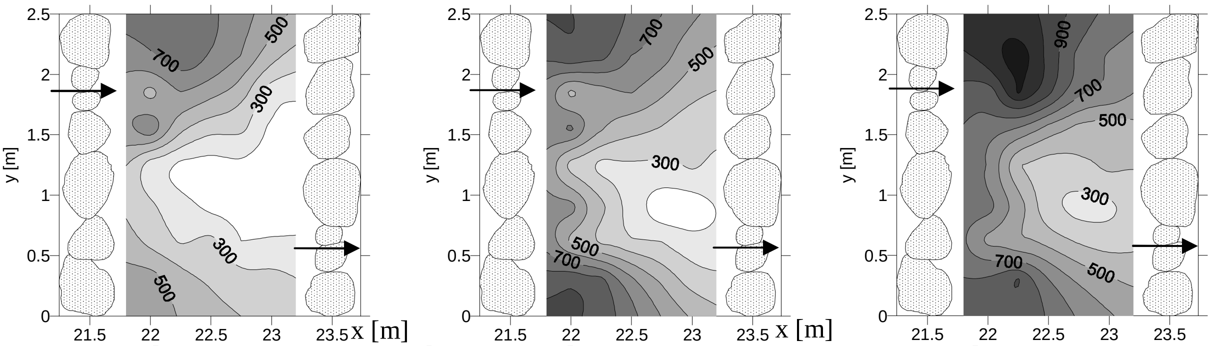


(a) q_p = 150 l/s/m, flume slope = 1:30 (b) q_p = 200 l/s/m, flume slope = 1:30

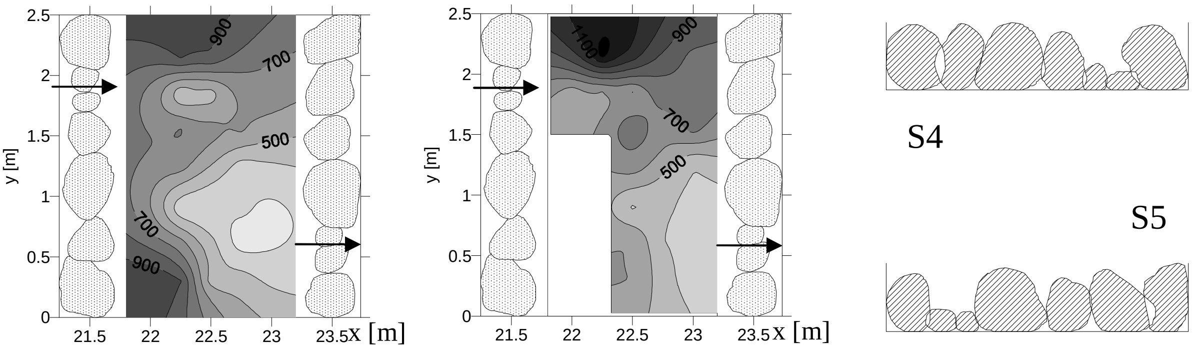


(c) q_p = 250 l/s/m, flume slope = 1:30 (d) q_p = 200, 250 l/s/m, flume slope = 1:15

Fig. 3.4.10: Box-Whisker plots of the turbulent kinetic energy (TKE)

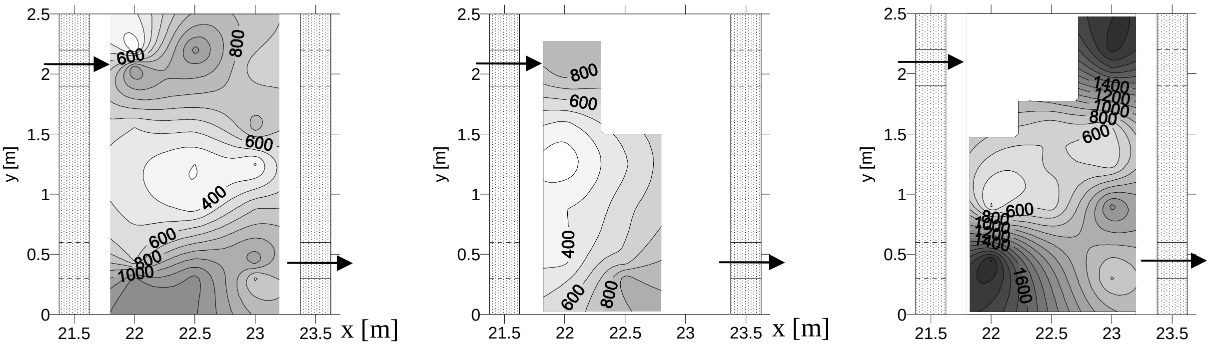


(a) q = 150 l/s/m, z = 12.5 cm (b) q = 200 l/s/m, z = 12.5 cm (c) q = 200 l/s/m, z = 17.5 cm

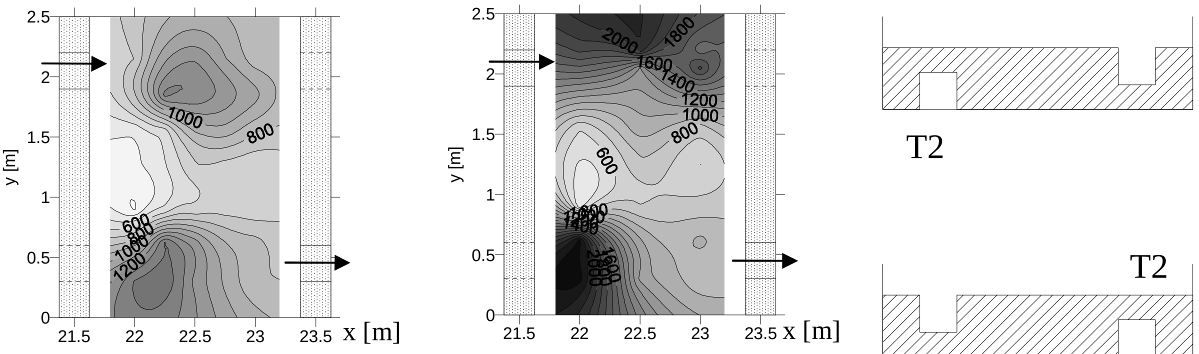


(d) q = 250 l/s/m, z = 15 cm (e) q = 250 l/s/m, z = 20 cm

Fig. 3.4.11: TKE distribution at the pool between sill pair S4 – S5; flume slope = 1:30, unit of TKE: [cm²/s²]; arrows indicate the locations of the openings

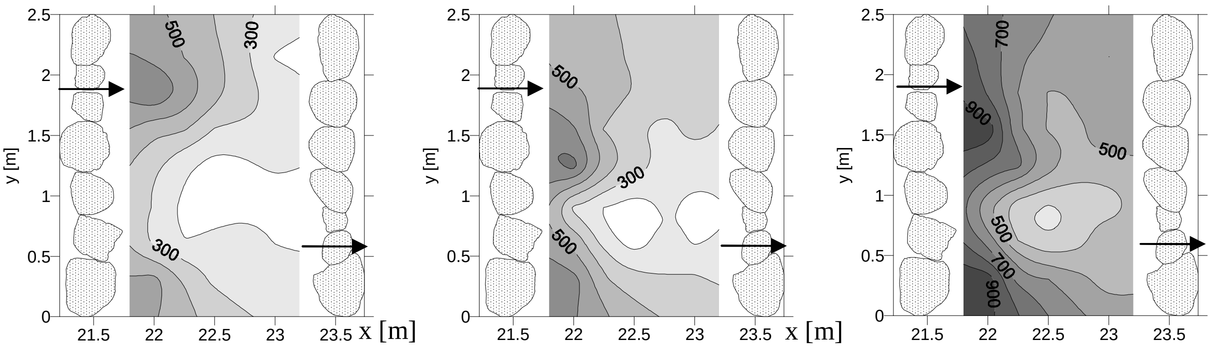


(a) q = 150 l/s/m, z = 15 cm (b) q = 200 l/s/m, z = 15 cm (c) q = 200 l/s/m, z = 22.5 cm

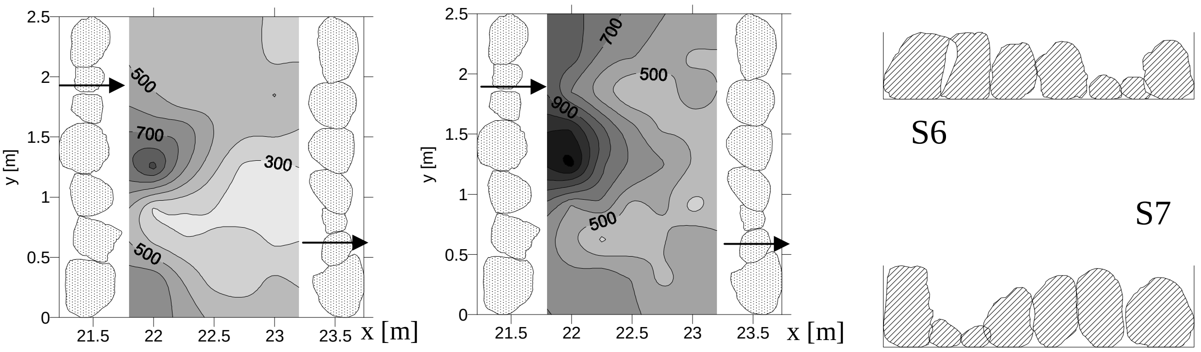


(d) q = 250 l/s/m, z = 15 cm (e) q = 250 l/s/m, z = 22.5 cm

Fig. 3.4.12: TKE distribution at the pool between sill pair T2 – T2; flume slope = 1:30, unit of TKE: [cm²/s²]; arrows indicate the locations of the openings

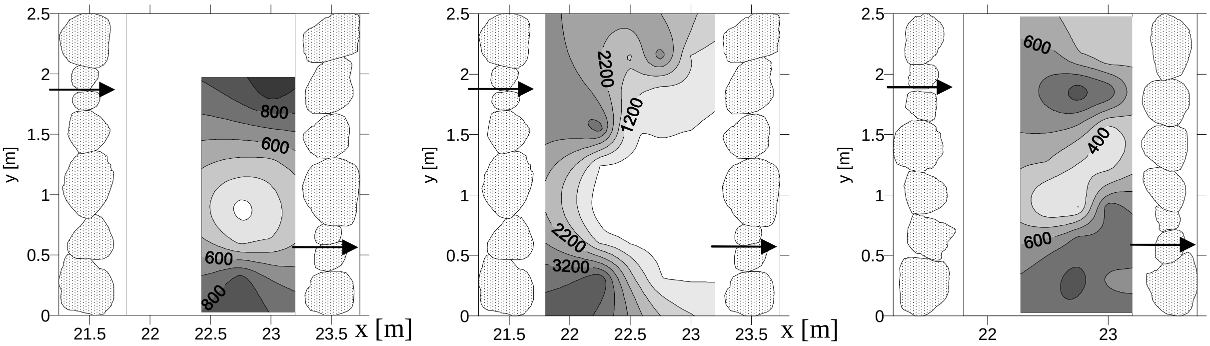


(a) q = 150 l/s/m, z = 12.5 cm (b) q = 200 l/s/m, z = 12.5 cm (c) q = 200 l/s/m, z = 17.5 cm



(d) q = 250 l/s/m, z = 15 cm (e) q = 250 l/s/m, z = 20 cm

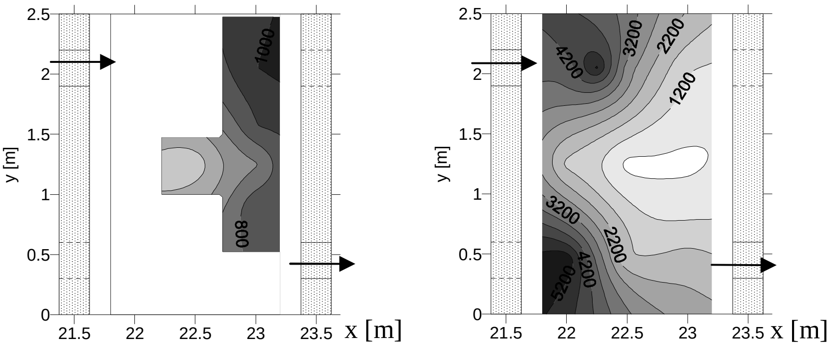
Fig. 3.4.13: TKE distribution at the pool between sill pair S6 – S7; flume slope = 1:30, unit of TKE: [cm²/s²]; ; arrows indicate the locations of the openings



(a) Sill pair: S4 – S5
q = 200 l/s/m, z = 12.5 cm

(b) Sill pair: S4 – S5
q = 250 l/s/m, z = 15 cm

(c) Sill pair: S6 – S7
q = 200 l/s/m, z = 15 cm



(d) Sill pair: T2 – T2
q = 200 l/s/m, z = 15 cm

(e) Sill pair: T2 – T2
q = 250 l/s/m, z = 15 cm

Fig. 3.4.14: TKE distribution, flume slope = 1:15, unit of TKE: [cm²/s²]; ; arrows indicate the locations of the openings

3.4.5. Surface and longitudinal velocity distributions and vortices structures

The experiments of longitudinal velocity distributions were measured between the boulder sill pairs S4 – S5, S6 – S7 as well as between the technical sill pair T2 – T2. The sill pair S6 – S7 is taken as a repeat test of nature-like type for the sill pair S4 – S5. The measurements using PIV method were compared with the measurements using micro-propeller current meter and to verify the results qualitatively and quantitatively. In each pool between the three sill pairs, the water free surface and three longitudinal sections, which located at the openings formed by flat boulders and in the middle (Fig. 3.4.15~16, detail see App. B), were investigated with three specific discharges of q = 150, 200 and 250 l/s/m.

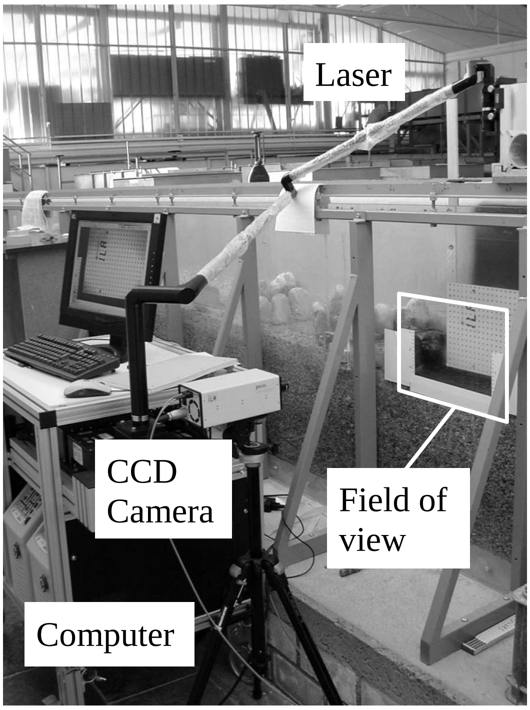
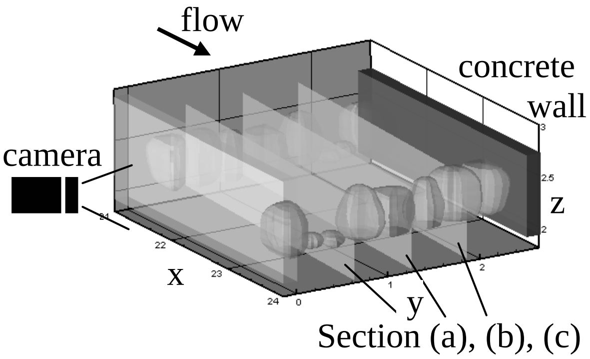
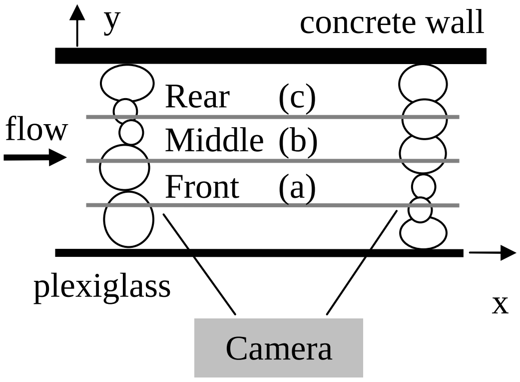


Fig. 3.4.15: Installation of PIV-facilities to measure the longitudinal velocity profiles



Arrangement of laser planes: the front and rear planes locates at y-positions where the openings with smaller boulders of sills are.



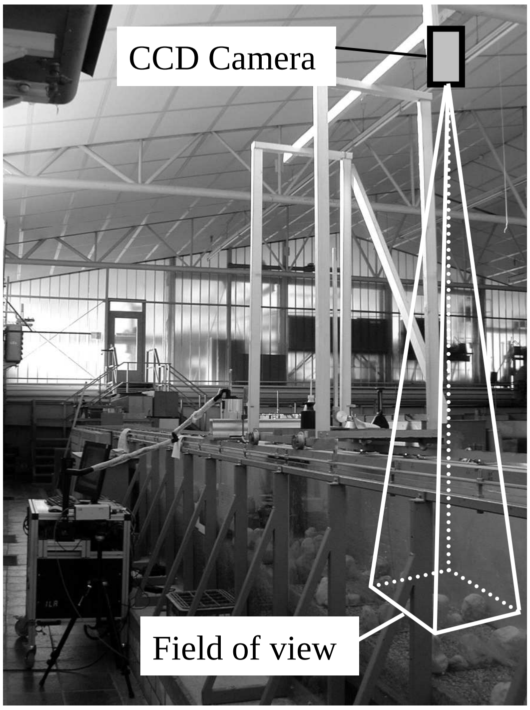


Fig. 3.4.16: Installation of PIV-facilities to measure the surface velocity distributions

- **Velocity fields at the longitudinal sections**

The velocity fields at the longitudinal sections are shown as V_{xz} in Fig. 3.4.17. Arrows show the direction of vector V_{xz} and its magnitude is calculated as:

$$\boldsymbol{V_{xz} = \sqrt{v_x{}^2 + v_z{}^2}} \qquad [\mathrm{m/s}] \qquad (\text{Eq. } 3.17)$$

where v_x: velocity component in the streamwise (x-) direction [m/s]

v_z: velocity component in the vertical (z-) direction [m/s]

The flow patterns in pools between technical type sill pair and nature-like type sill pairs are significant different. At sections (a) and (b) between T2 sill pair, apparently there are vertical vortices below the upstream sill as shown in Fig. 3.4.17(a) and (b) with lower discharge. Vortices decrease and longitudinal flow strengthen when discharge increase and the overflow condition changes. Comparing Fig. 3.4.17(a) and (b) with (c) with q = 150 l/s/m, in Fig. 3.4.17(a) the upwelling flow is strong with magnitude of velocity about 0.3 to 0.45 m/s. For boulder sill pair S4 – S5, vertical vortices occur at section (a) for q = 150 and 200 l/s/m (Fig. 3.4.17 (d) and (e)). The vortices are apparently smaller in sizes and intensity comparing with those between T2 sill pair.

As for the stilling zone providing fish for rest, for example, if we consider rest zone for grayling (adult body length 25 – 30 cm) with dimension of space approximate three times of its body length and height for 80 cm and 25 cm in longitudinal and vertical directions where the flow velocity is under 0.3 m/s. The resting zones between sill pair T2 – T2 with q = 150 l/s/m (Fig. 3.4.17(a)) are 80 cm × 45 cm and 100 cm × 20 ~ 40 cm at section (a) and (b), which are adequate in dimension and velocity for grayling. With q = 200 l/s/m (Fig. 3.4.17(b)), there is no stilling zone at section (b) and at section (a) it is about 100 cm × 35 cm at the upper water column. With q = 250 l/s/m (Fig. 3.4.17(c)), the stilling zones are 140 cm × 35 cm and 120 cm × 20 ~ 30 cm at the lower water column at section (a) and (b), which also provide adequate space.

The resting zones between sill pairs S4 – S5 and S6 – S7 (Fig. 3.4.17(d)~(i)) show that section (a) at both boundary conditions for the three discharges provide good resting zone with flow velocity under 0.3 m/s. Only for condition of sills S4 – S5 with q = 250 l/s/m, there is plunging flow below the sill S4 with velocity between 0.4 to 0.8 m/s. However a stilling zone can still be observed with dimension about 50 ~ 90 cm × 15 ~ 40 cm at the upper water column. At section (b) for the sill pair S4 – S5 with the three discharges, it provides good resting zone, however for the sill pair S6 – S7, due to a larger slot between boulders of upstream sill S6, flow velocity is higher in magnitude of about 0.5 to 0.7 m/s.

In practice, when the variation of flow in fish passes or bypass is significant and can result in negative influences on fish migration behaviour, the results provide a good quantitative and qualitative analysis insight the changes of flow pattern.

The nature-like structure provides flow pattern with lower velocity and larger stilling zone comparing with technical type structure under same flow condition; water depths are however generally shallower and should pay attention to design.

Upwelling flow is believed to perform a negative influence on fish so that vertical vortices should be considered when dealing with upwelling problems near notches or slots in pool type fish passes.

- **Turbulence Intensity (TI), Turbulent Kinetic Energy (TKE) and vorticity profiles with velocity field**

In Fig. 3.4.18 it shows three typical longitudinal flow patterns in this study. Fig. 3.4.18(a) shows an obvious vortex below the upstream sill at about x = 21.9 m; Fig. 3.4.18(b) shows a small vortex below the upstream sill and a strong flow upwards toward downstream side; in Fig. 3.4.18(c) there is no apparent vortex and main flow goes downwards toward downstream side.

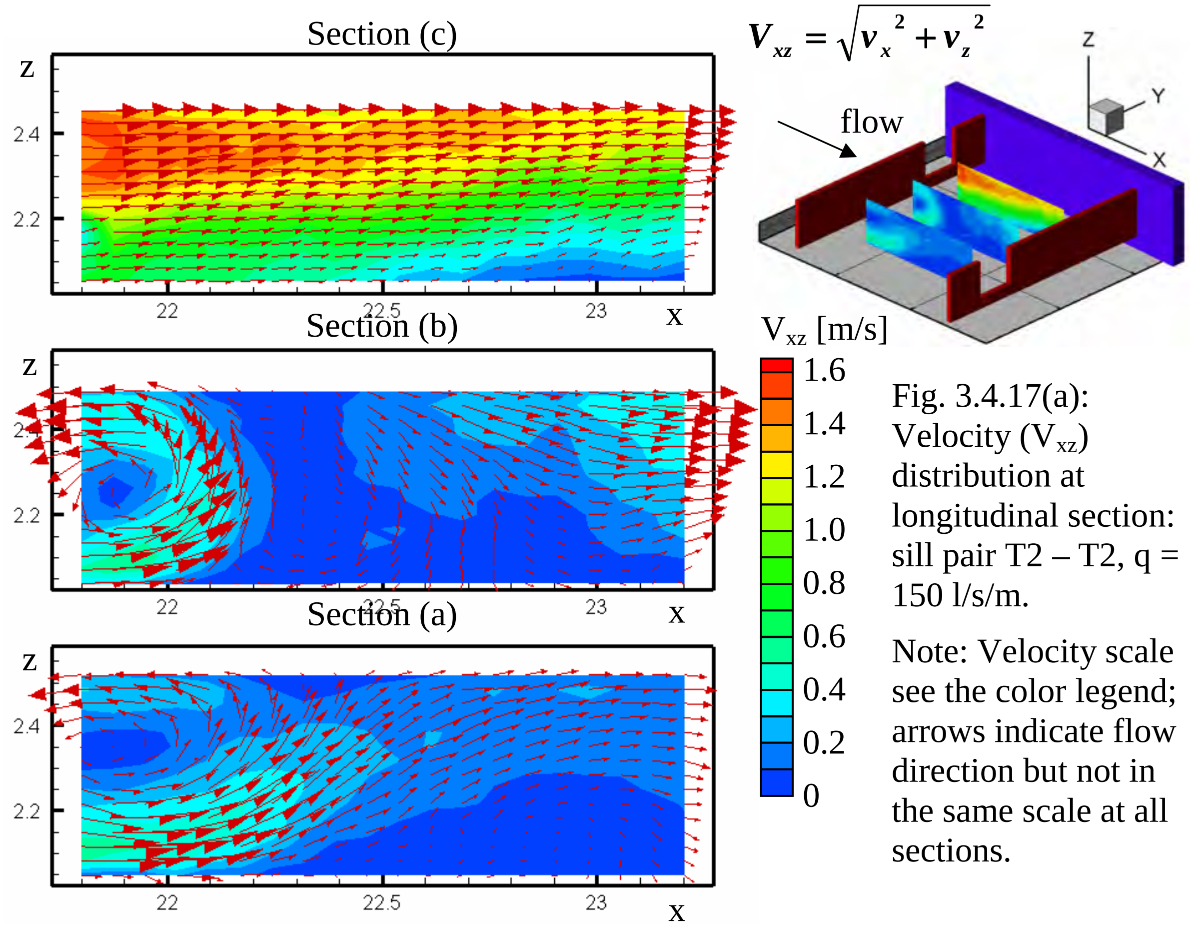


Fig. 3.4.17(a): Velocity (V_{xz}) distribution at longitudinal section: sill pair T2 – T2, q = 150 l/s/m.

Note: Velocity scale see the color legend; arrows indicate flow direction but not in the same scale at all sections.

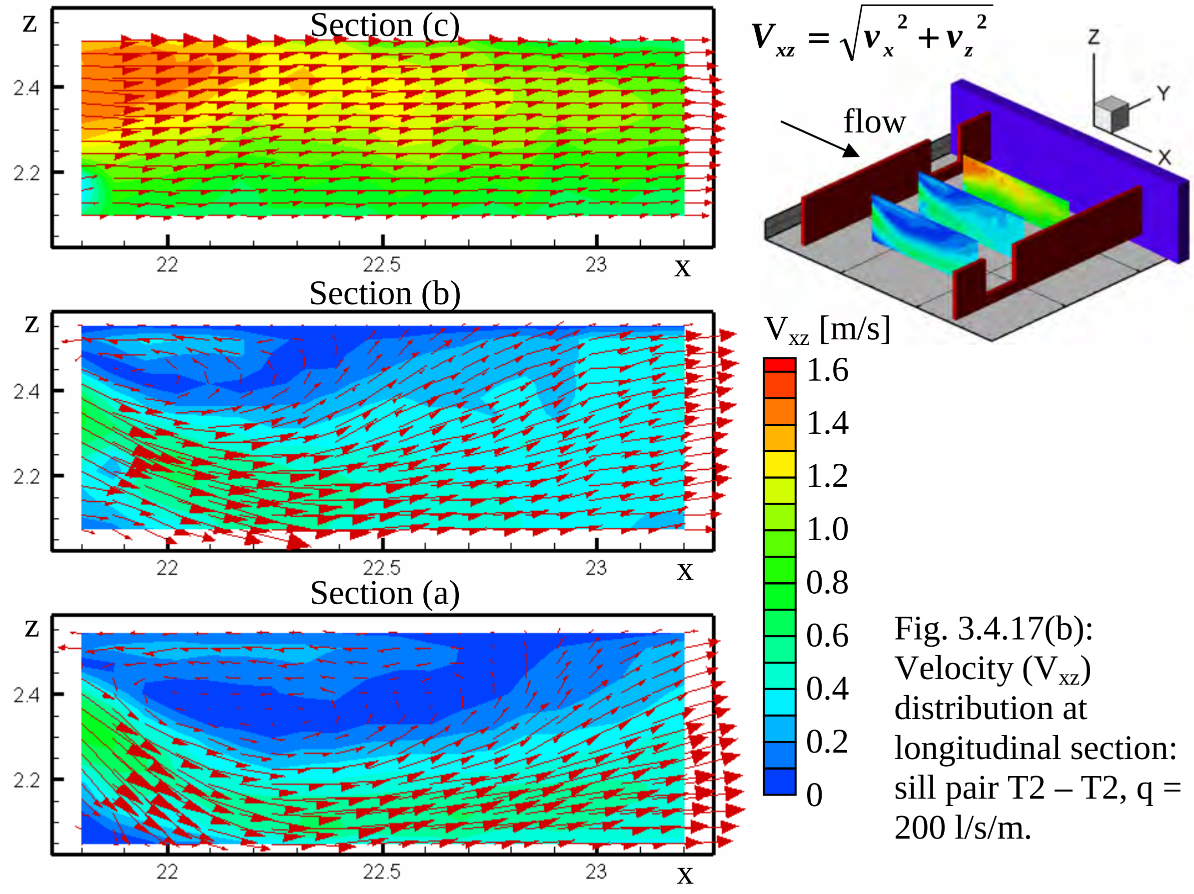


Fig. 3.4.17(b): Velocity (V_{xz}) distribution at longitudinal section: sill pair T2 – T2, q = 200 l/s/m.

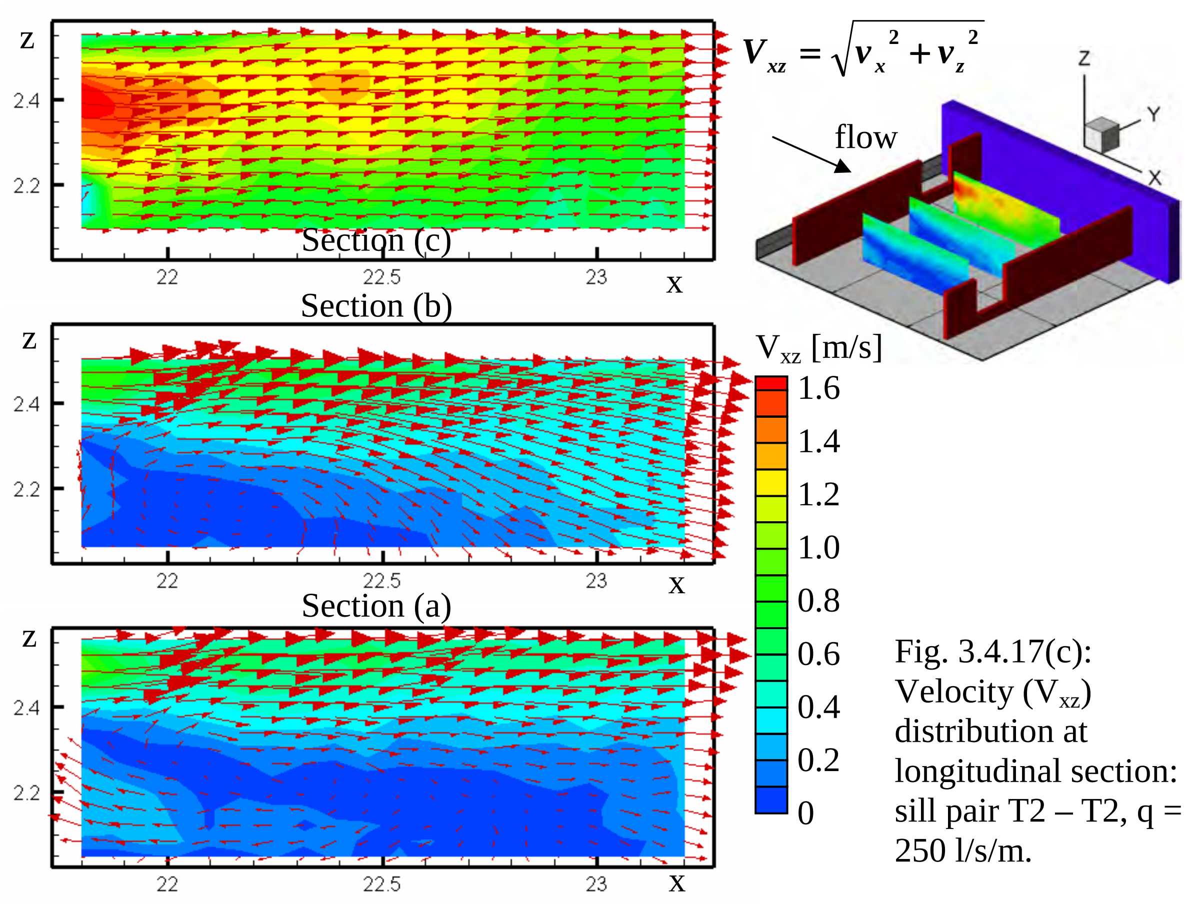


Fig. 3.4.17(c): Velocity (V_{xz}) distribution at longitudinal section: sill pair T2 – T2, q = 250 l/s/m.

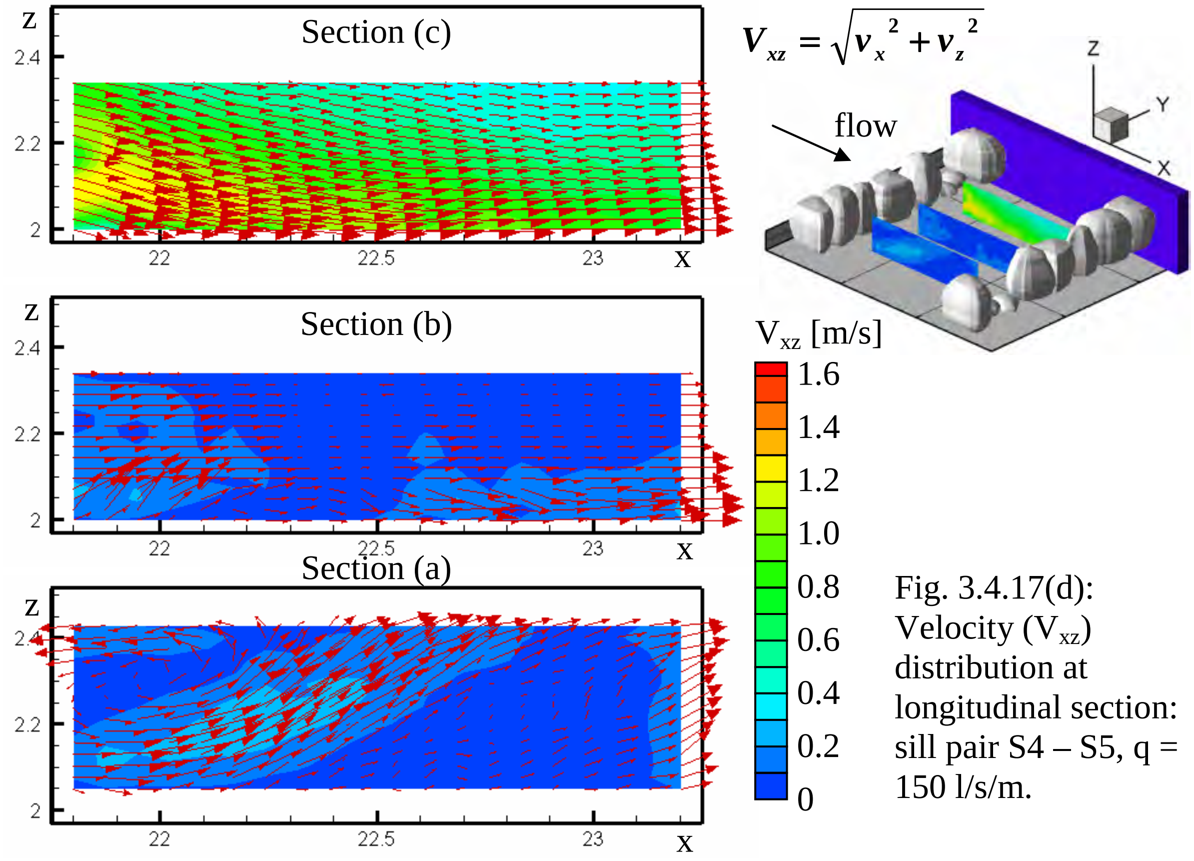


Fig. 3.4.17(d): Velocity (V_{xz}) distribution at longitudinal section: sill pair S4 – S5, q = 150 l/s/m.

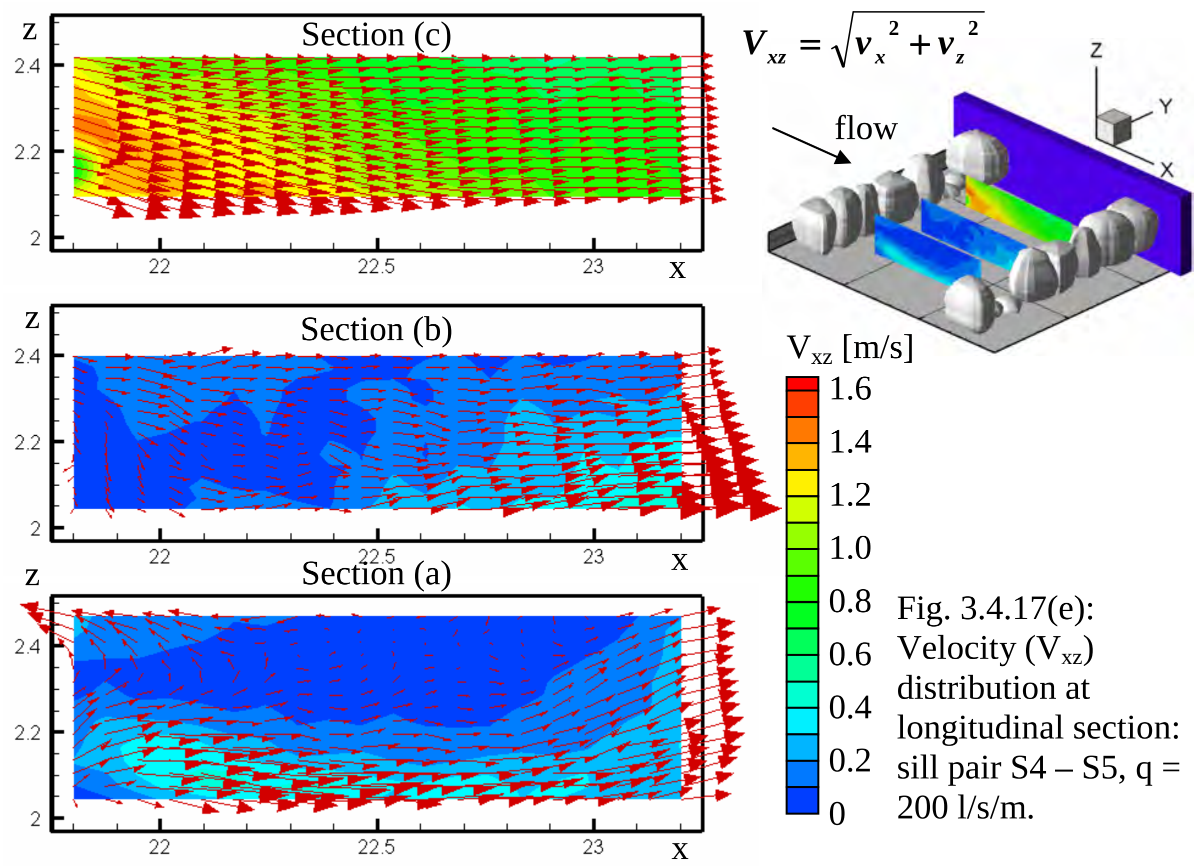


Fig. 3.4.17(e): Velocity (V_{xz}) distribution at longitudinal section: sill pair S4 – S5, q = 200 l/s/m.

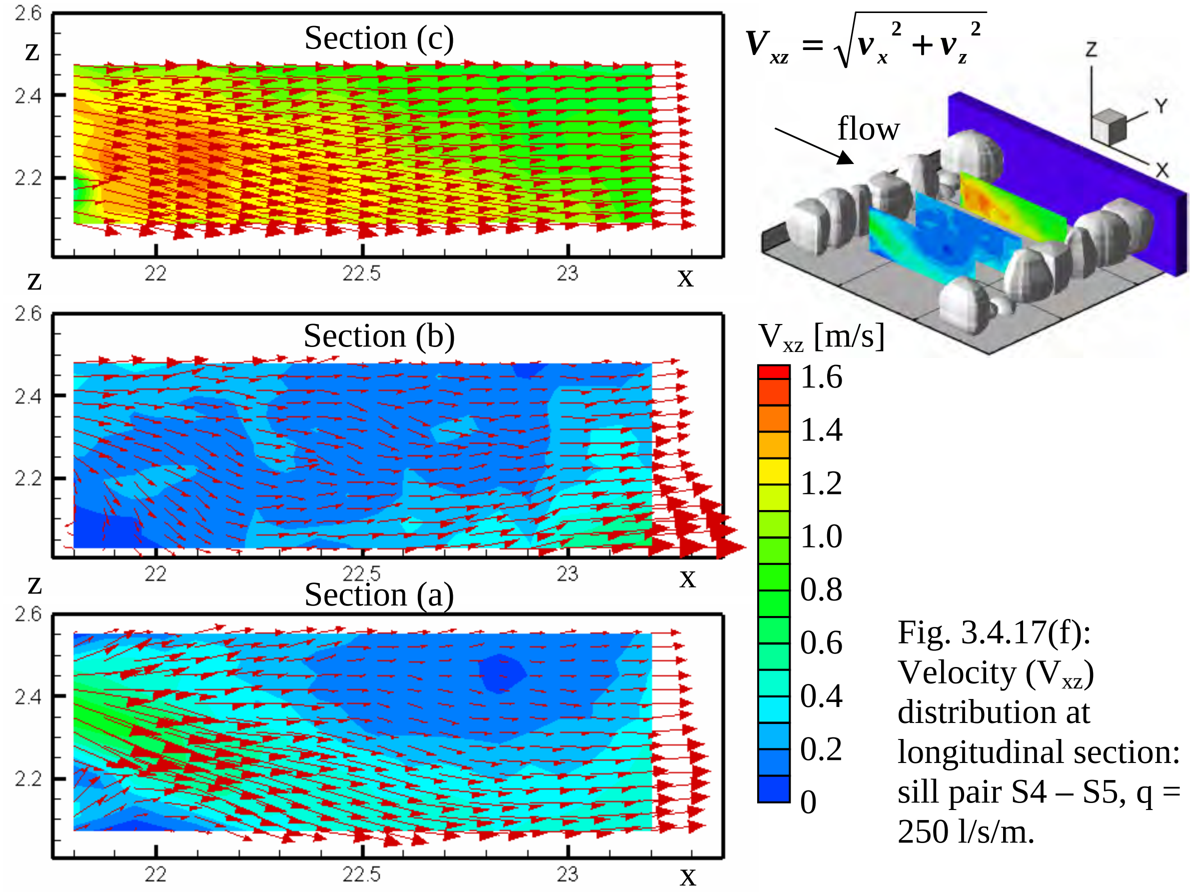


Fig. 3.4.17(f): Velocity (V_{xz}) distribution at longitudinal section: sill pair S4 – S5, q = 250 l/s/m.

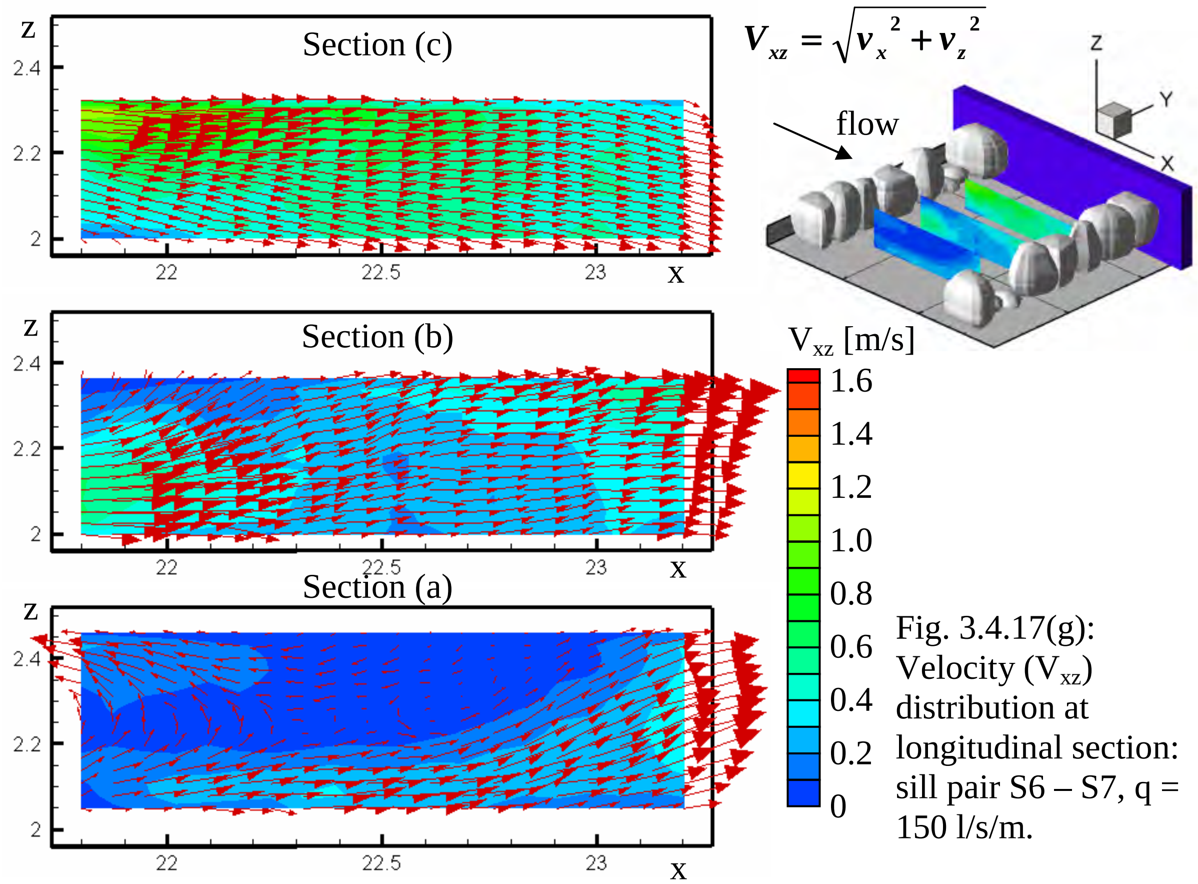


Fig. 3.4.17(g): Velocity (V_{xz}) distribution at longitudinal section: sill pair S6 – S7, q = 150 l/s/m.

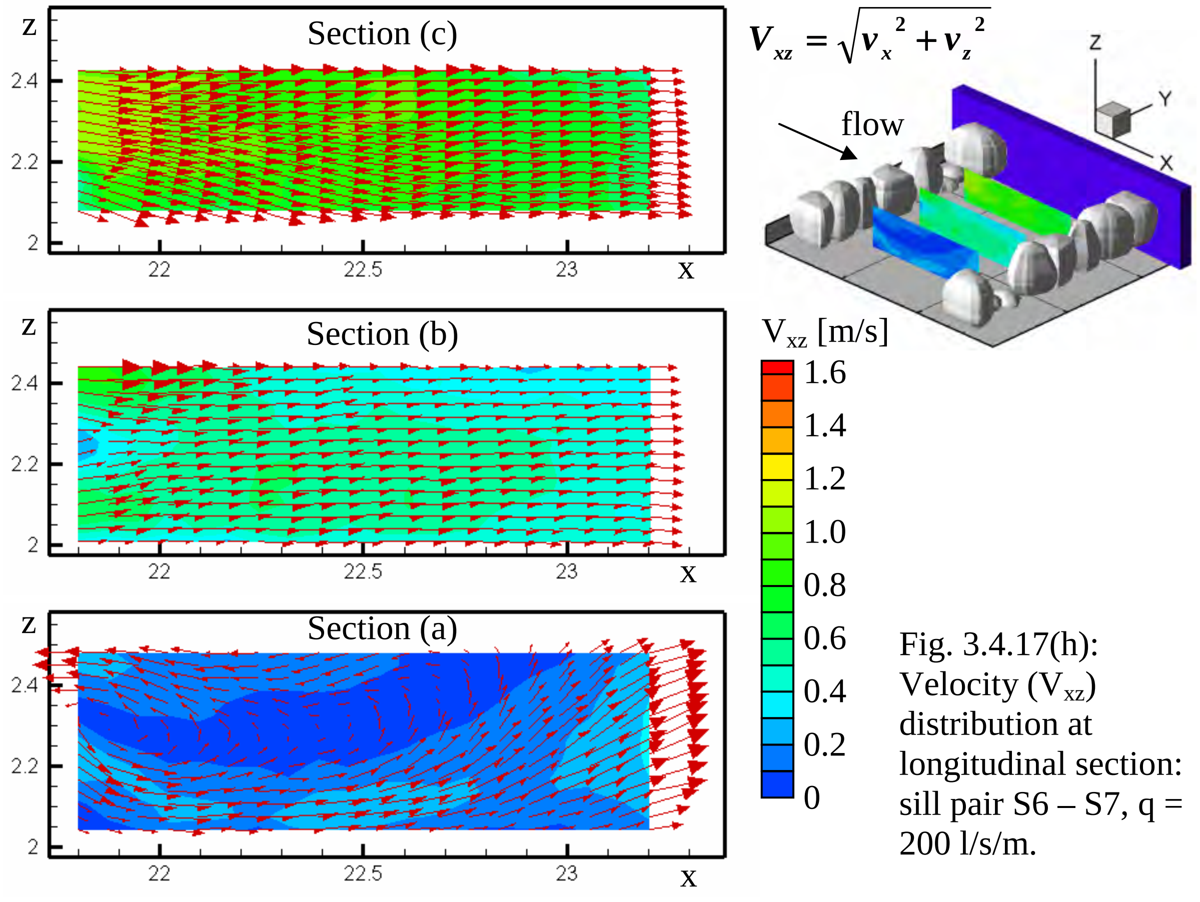


Fig. 3.4.17(h): Velocity (V_{xz}) distribution at longitudinal section: sill pair S6 – S7, q = 200 l/s/m.

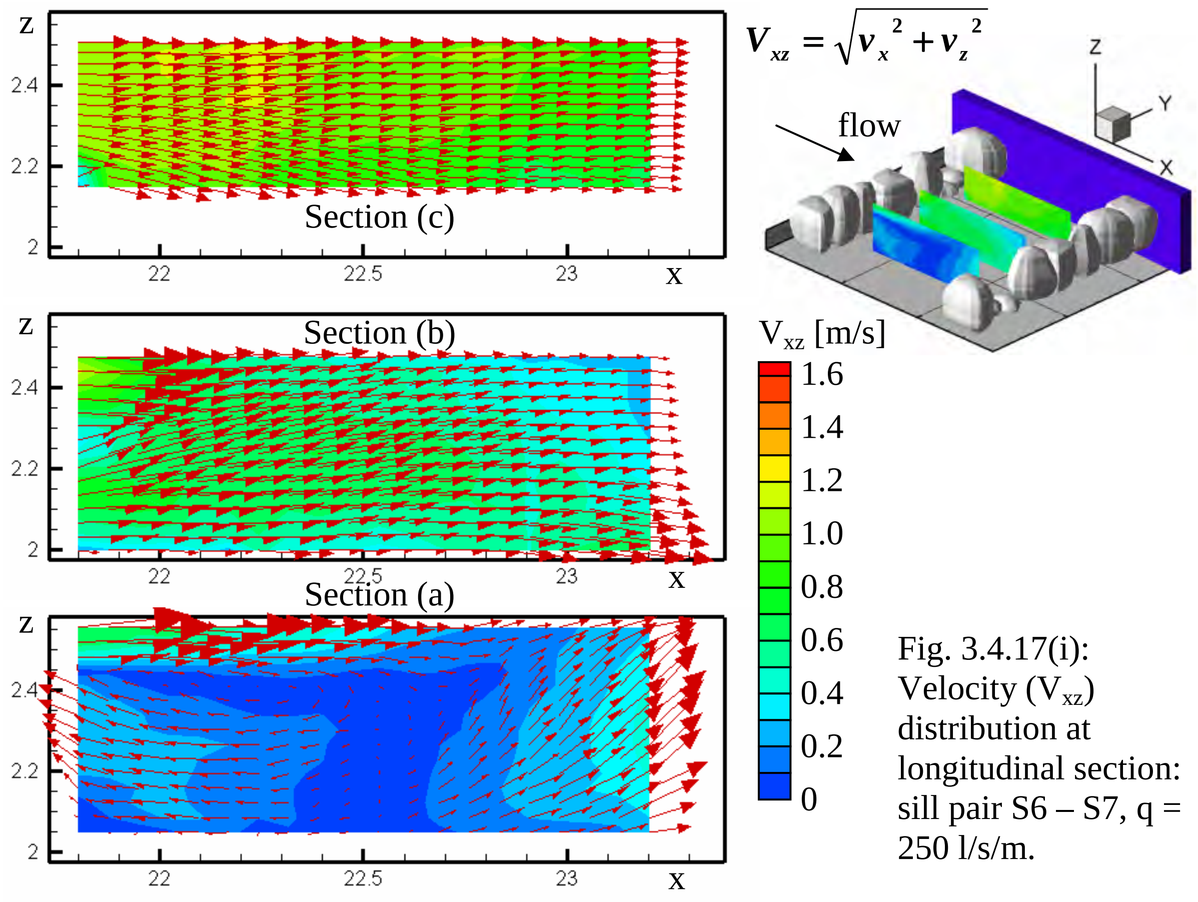


Fig. 3.4.17(i): Velocity (V_{xz}) distribution at longitudinal section: sill pair S6 – S7, q = 250 l/s/m.

As mentioned in Ch. 3.4.4, TI is a magnitude of turbulent flow fluctuation relative to mean velocity. It can reach a very high value if the mean flow approaches zero and leads to a wrong understanding about the intensity of turbulence in flow. In Fig. 3.4.18(a), at the vortex zone (x = 21.9m, z = 2.2 m), TI is very low and the high TI value occurs at x = 22.3 m where flow velocity is about only 0.1 m/s. However the high TKE values distribute around the vortex and the vorticity shows consistent result too.

In Fig. 3.4.18(b) TI shows high values distribute in the stilling zone at x = 22.8 m and z = 2.3 m. However where high TI values are, the TKE values are low and the high TKE values distribute along with main flow. The high vorticity distribute near high TKE value zone but more close to surround the vortex.

In Fig. 3.4.18(c), since there is no obvious vortex, the vorticity shows lower values comparing with in Fig. 3.4.18(a) and (b). TI distribution is quite uniform but from TKE distribution we can recognize where the relative stilling zone is.

Some previous studies (Enders et al. 2003 and Liu et al. 2006) have used the power spectrum of turbulent fluctuations or the Kolmogorov-5/3 law of local isotropic turbulence to estimate the dissipated rate of energy, while some studies (Odeh et al. 2003) have proposed a relationship between the Reynolds' shear stresses and the turbulent flow during the study of turbulence problems in fish passes. However, in this study, for practical purposes, TKE is used to relate turbulence with the swimming performance of fish in a simple manner.

Based on the idea how we observe a resting zone for fish in a pool: a space where the flow velocity is about lower than 0.3 m/s with dimension at least approximate three times of fish body length, width and height, as shown in Fig.3.4.19. By this criterion the overlapped graphs of velocity and TKE values were checked to pick up the area and its corresponding TKE magnitude. Combined the above discussed data, TKE up to 200 cm^2/s^2 for q = 150 l/s/m and TKE up to 400 cm^2/s^2 for q = 250 l/s/m in nature-like fish passes are recommended. The values should be verified by biological tests.

Based on this idea, a resting zone is observed and defined for fish in a pool, i.e., a space where the flow velocity is roughly lower than the upper limit; the dimensions of this resting zone are at least three times the length, width, and height of the fish body, as shown in Fig. 3.4.19.

Here, the grayling species is selected as an example, with a resting velocity of 0.3 m/s and resting zone dimensions of 80 × 20 cm. On the basis of this criterion, the overlap between the plots of velocity and TKE were checked to examine the required rest zone and to determine its corresponding TKE magnitude; the results are shown in Fig. 3.4.20. TKE values of up to 300~400 cm²/s² for q_p = 150 l/s/m and up to 400~500 cm²/s² for q_p = 200 l/s/m or higher in nature-like fish passes with slope = 1:30, as well as a TKE value of up to 500 cm²/s² for slope = 1:15, are recommended. These values should be verified by biological tests entailing the observation of the resting locations.

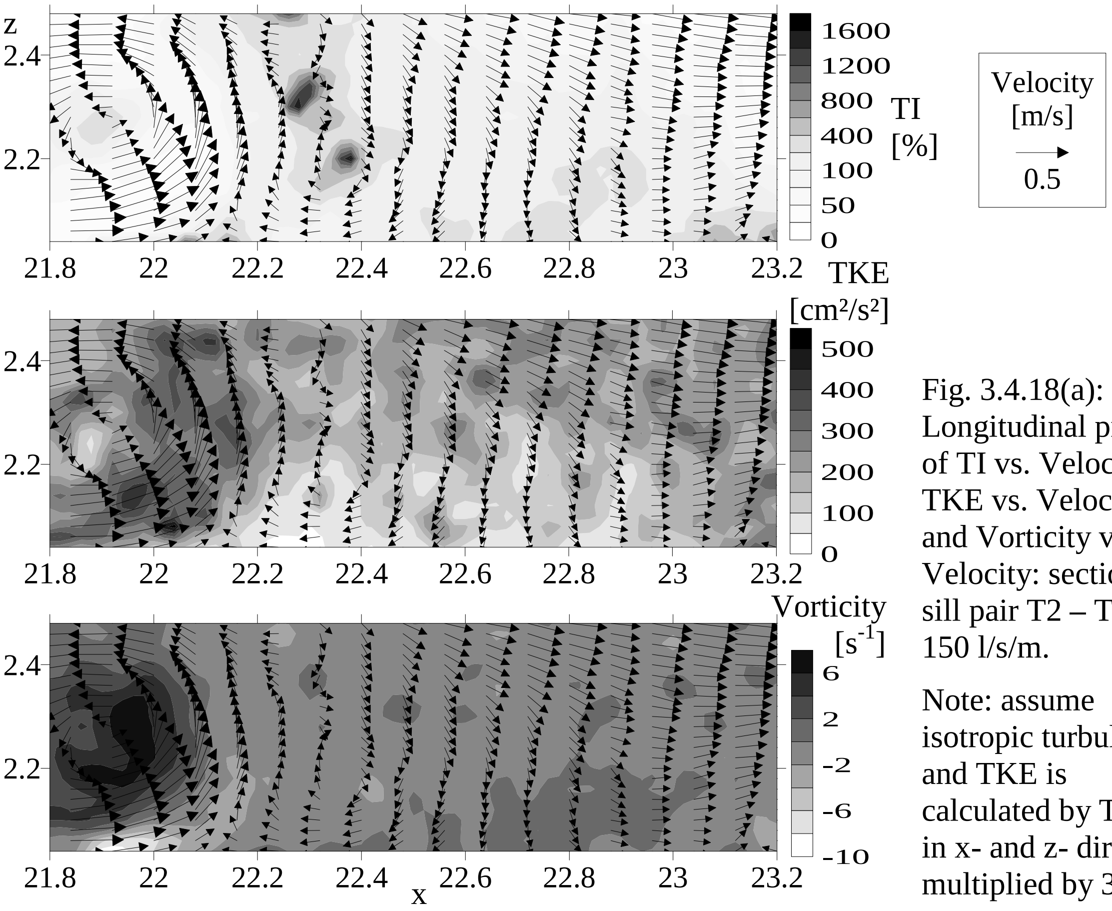


Fig. 3.4.18(a): Longitudinal profiles of TI vs. Velocity, TKE vs. Velocity and Vorticity vs. Velocity: section (b), sill pair T2 – T2, q = 150 l/s/m.

Note: assume isotropic turbulent and TKE is calculated by TKE in x- and z- direction multiplied by 3/2.

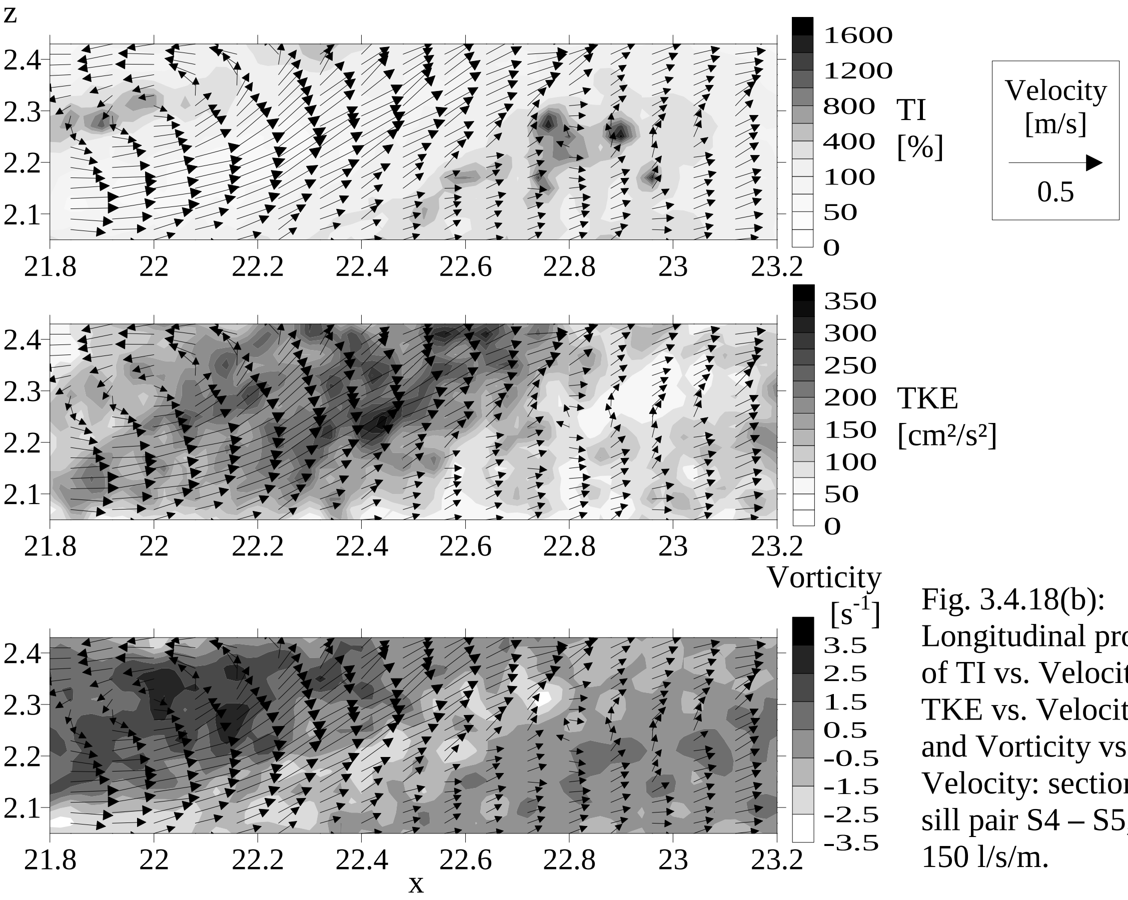


Fig. 3.4.18(b): Longitudinal profiles of TI vs. Velocity, TKE vs. Velocity and Vorticity vs. Velocity: section (a), sill pair S4 – S5, q = 150 l/s/m.

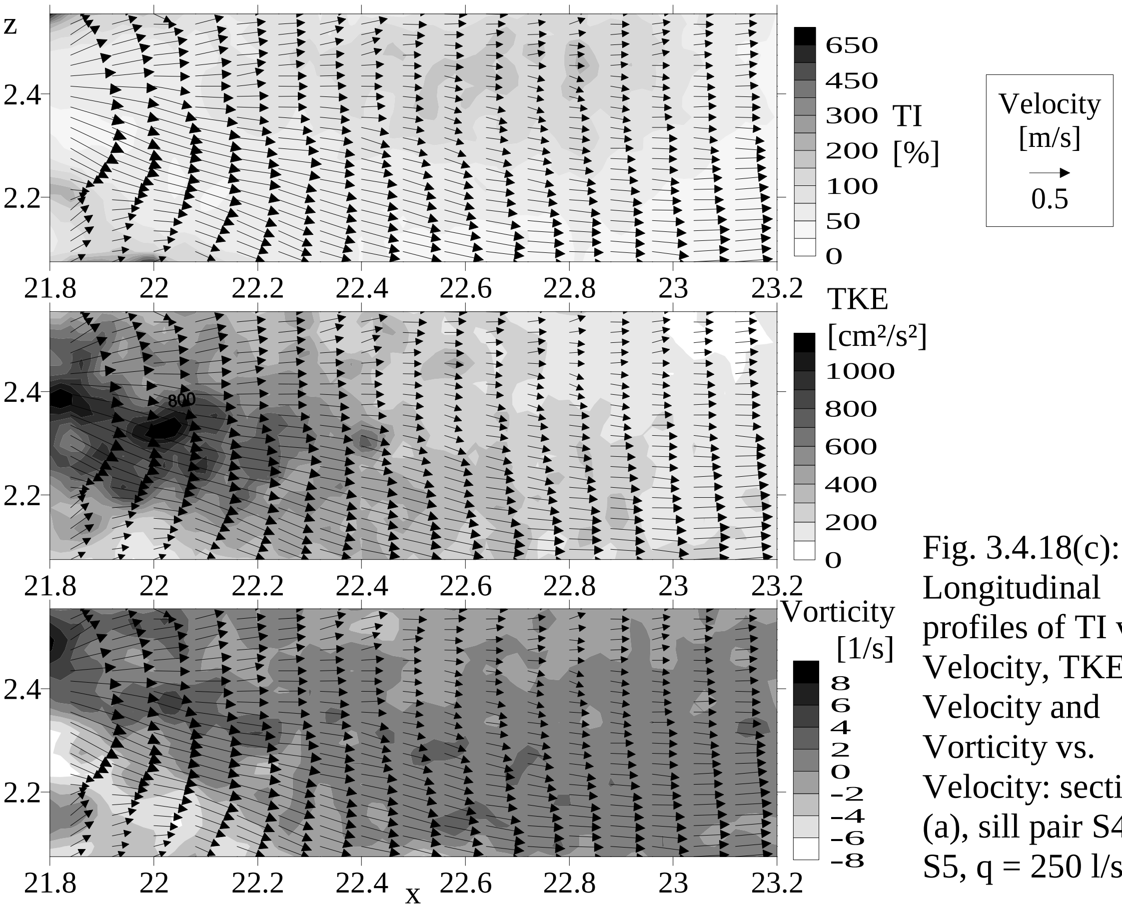
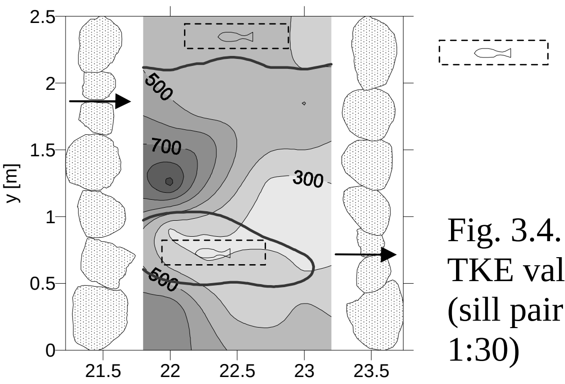


Fig. 3.4.18(c): Longitudinal profiles of TI vs. Velocity, TKE vs. Velocity and Vorticity vs. Velocity: section (a), sill pair S4 – S5, q = 250 l/s/m.



Threefold of fish body in length and width (80 × 20 cm in length and width; select resting velocity = 30 cm/s for grayling)

Fig. 3.4.19: Concept of recommended upper limit of TKE value according to resting zone for fish in a pool (sill pair S6 – S7, z = 15 cm, q_p = 250 l/s/m, slope = 1:30)

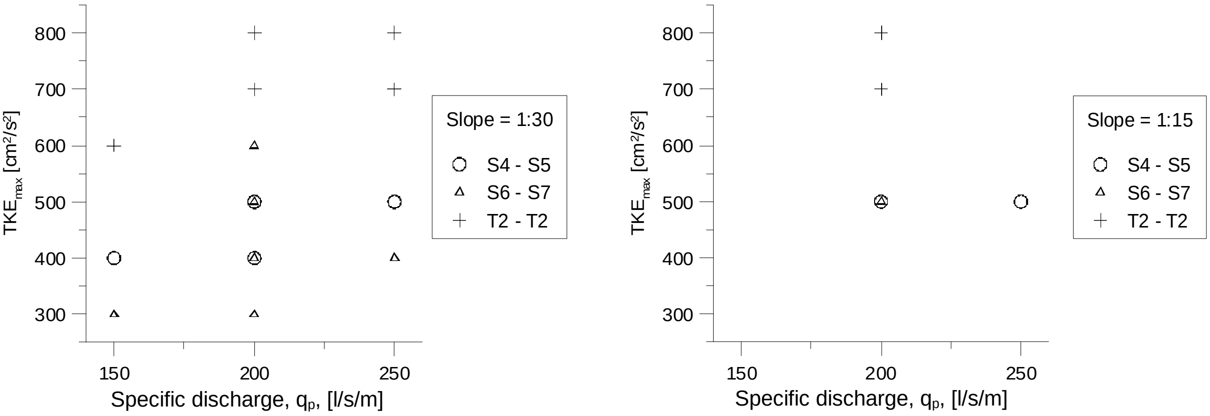
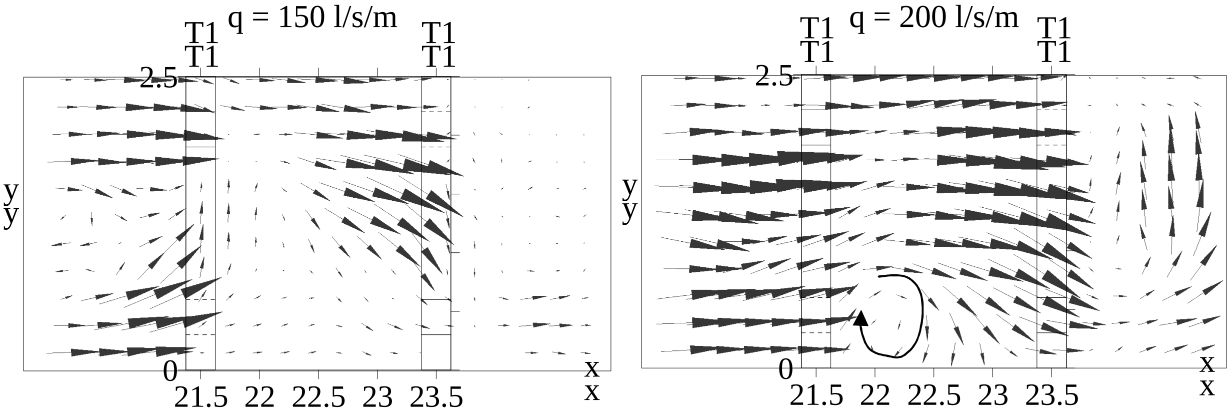


Fig. 3.4.20: Upper limit of TKE values in relation with specific discharge according to resting zone for fish in a pool (select resting velocity = 30 cm/s for grayling with minimum resting zone of dimension threefold of graylings body = 80 × 20 cm in length and width)

- **Velocity field on the free surface**

In Fig. 3.4.21 it shows the velocity fields on the water free surface in pools between technical sill pair T2 – T2 and boulder sill pairs S4 – S5 and S6 – S7 with three specific discharges q = 150, 200 and 250 l/s/m to study the horizontal vortices. Measurements were conducted with floating feeding seeds which are PVC scraps of diameter 5 mm. The feeding scraps would be trapped by sills and resulted in error of velocity calculations. The results of free surface velocity field are only for qualitative discussion.

The results show that vortices on the water surface in pool with technical sill pair T2 – T2 are not significant, however with boulder sill pairs, there are apparent vortices for q = 150 l/s/m. Vortices diminish when discharge increase. When applying nature-like type construction as fish passes, the flow pattern of horizontal vortices should be examined for low flow condition.



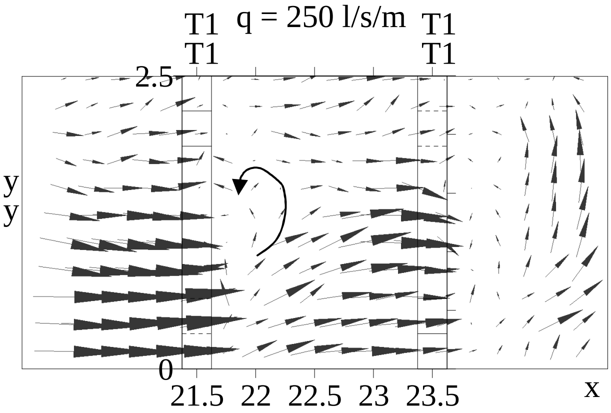
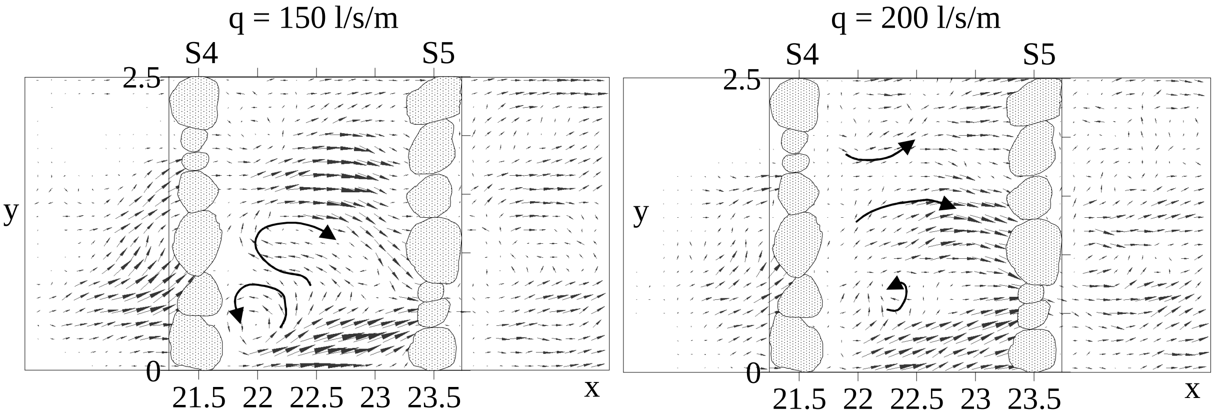


Fig. 3.4.21(a): Velocity profile on the water free surface: sill pair T1 – T1

Note: magnitudes of velocity are not in the same scale. Results of free surface velocity field are only for qualitative discussion.



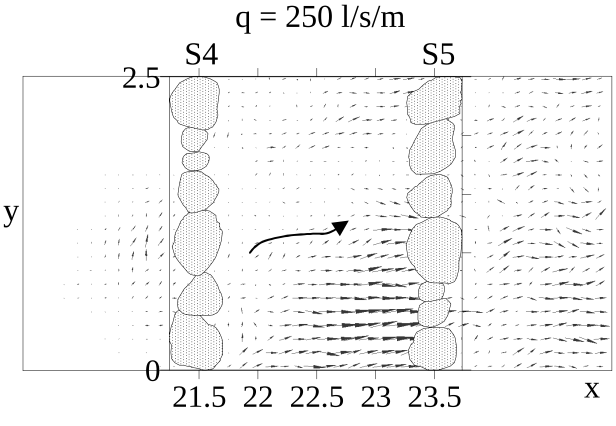
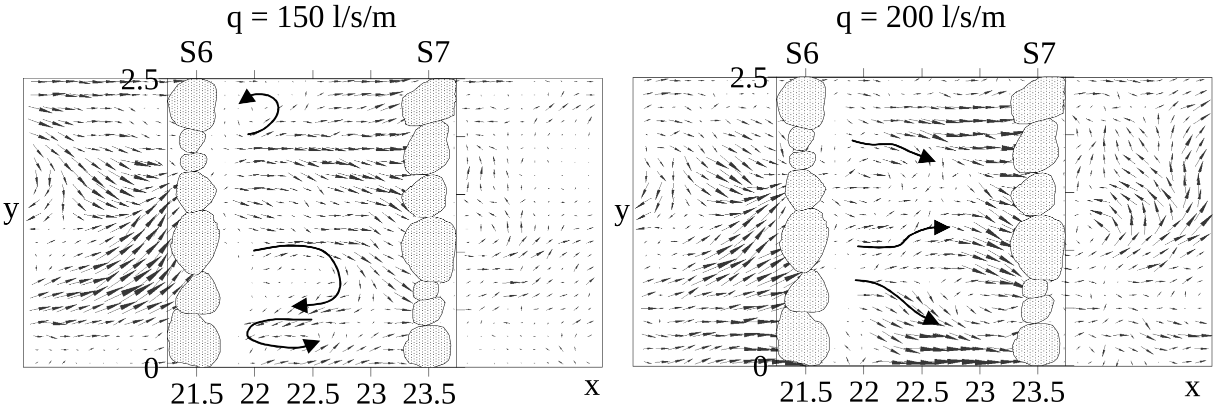


Fig. 3.4.21(b): Velocity profile on the water free surface: sill pair S4 – S5



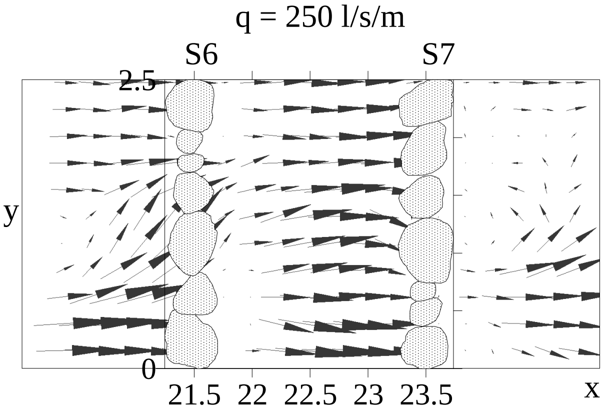


Fig. 3.4.21(c): Velocity profile on the water free surface: sill pair S6 – S7

3.5. Discussions

- From the experimental results of nature-like pool-type fish passes, we get a better idea of the mean flow and turbulence distribution in order to support a quantitative analysis, particularly when comparing nature-like pool-type fish passes with technical-type fish passes. The reduction factor k_2 and the value of 0.75 is introduced to adjust the difference between designed and measured water levels for design of nature-like pool-type fish passes with slope = 1:30. The adjustment of the k_2 factor implies that the difference of elevations between two adjacent pools can be designed larger while applying nature-like type than that in technical-type.

- The idea about the discussion of maximum velocity is that, if there is a single point at a cross section with velocity over 2 m/s (for example), velocity at the main cross sectional area of high velocity maybe significant lower than the maximum value. Since the average value cannot pick up the high velocity condition, to use 75%-tile velocity to examine the v_{crit} is suggested.

- From the experimental results of such nature-like pool-type fish passes, the mean flow and turbulence structures are better known, hence to support a quantitative analysis in particular when comparing with technical type fish passes.

- Some ambiguity suppositions about the flow pattern and critical flow rate in nature-like design could be clarified according to the results. For example, as for the streamwise velocity distribution, the mean value at the nature-like boulder sill is approximately 25% lower than that at the technical-type sill, while the maximum velocities of the water jet at boulder sill is approximately 27% lower than that at the technical sill, i.e. nature-like passes provide high geometrical diversity due to their irregular forms; however, there is no significant difference in the flow fields between the nature-like-type and technical-type passes. Nature-like passes provide lower flow velocity near narrow openings than those observed in technical-type, but not throughout the entire fish pass.

- Clarification on quantitative representations of turbulence

– In the past decade researchers used energy dissipated rate to quantify turbulence in fish passes for discussion on the size of pools and the influences on fish swimming performance. The energy dissipated rate used in pool-type fish passes is however an averaged value and can not represent the spatial variances and distribution of turbulence in a pool. Volumetric dissipated power is used to evaluate the pool size rather than to quantify the level of turbulence.

- Due to the development of 3-D velocimeters, fluctuations of velocity can be measured and turbulence can be therefore precisely described. Turbulence intensity (TI) is often used to discuss the relation between turbulence and the swimming performance of fish under certain mean flow conditions. However, when TI is used in discussions regarding 3D flow patterns in a pool in fish passes, its normalized magnitude can lead to confusion in low mean flow zones, while a very small perturbation of velocity can result in very high TI values.
- Turbulent kinetic energy (TKE) is a non-dimensionless metric and can be used to describe the scale of turbulence without carefully mention about the mean flow conditions. It is recommended to use TKE to study and to develop the relationship and the influences of turbulent flow and fish migration performance for both engineers and biologists on expressions in common.
- Nature-like fish passes can reduce TKE by one-fourth to one-half of the value found in technical-type passes, and the variance of TKE in a natural pool is smaller than that in the technical type under the same conditions.

- Results are shown to give a systematic study of nature-like pool-type fish passes and to provide a better understanding for designing

- Using statistical analysis we can have an overview of the flow pattern in both nature-like and technical type fish passes.

- Whether it forms a proper flow pattern for fish migration in a nature-like channel, the point is on the structure of the construction, which means the arrangement of boulders, instead of calculation. Because the assessment of submerged overflow reduction factor or weir coefficient can hardly be applied in practice for various types of bottom ramps.

- To examine the hydraulic parameter, velocity and water depth, Q_{30} and Q_{330} should be selected as Q_{min} and Q_{max}.

- For conventional type of fish passes such as pool-type or vertical slot type, discharge, Q, is used for calculation of hydraulic condition in design. As for nature-like fish passes, specific discharge, q, should be used instead of discharge, Q, to refer flow at high or low flow condition, since water distributed at the whole width of constructions instead of only at slots or orifices with designed width.

- Some researchers analyze power spectrum of turbulent fluctuations or use Kolmogorov -5/3 law of local isotropic turbulence to estimate the dissipation rate and some other researchers connect relationship between Reynolds number and turbulent flow when they are study the turbulent problems in fish passes. Such attempts should be avoid when the field of interests comes to fish migration problems instead of boundary layer problems. Simpler terms should be developed and to connect the relation with fish swimming performance. Here in this study, turbulent kinetic energy (TKE) is recommended for application.

- The design criterion of TKE is based on the existence of a resting zone for fish in a pool, i.e., a space where the flow velocity is lower than the upper limit, with dimensions at least three times the length, width, and height of the fish body. By selecting the grayling species with a resting velocity of 0.3 m/s as an example, a TKE of value up to 300~400 cm^2/s^2 for q_p = 150 l/s/m and up to 400~500 cm^2/s^2 for q_p = 200 l/s/m or higher in nature-like fish passes with slope = 1:30, as well as a TKE value of up to 500 cm^2/s^2 for passes with slope = 1:15, are recommended.

4. Field investigation in the river system of Mangfall: Effectiveness Assessment of Fish Free Passage at Nature-Like Bottom Ramps and Fish Ramps

4.1. Introduction

For the restoration of free passage for fish and other aquatic species in rivers, nature-like rough ramps and fish ramps are getting more and more importance. In the foothills of the Alps the bed load transportation is very active and there are problems of stream bed erosion. Many weirs and drops were built to mitigate the bed erosion problems. These hydraulic constructions became however barriers for fish to migrate freely in running waters. Therefore some of them were later replaced by bottom ramps, which are expected to provide two functions: to mitigate streambed erosion and to reopen free passage for fish movement.

Bottom ramps are built to cause energy dissipation and to provide lower current velocity and higher water depth in the downstream river section. In the meanwhile, bottom ramps mimic natural pool-riffle structures and are announced that it re-establishes fish migration routes.

The effectiveness of such nature-like ramps and fish ramps on fish migration improvement should be assessed by hydraulic/geometric and biological monitoring. However, an evidence of the biological free passage at bottom ramps in nature are difficult to conduct (Gebler 1991). Many reported field investigations at fish migration facilities or ramps were conducted only one time and were usually during mean annual flow condition. When assessing the effectiveness of fish passes for free passage, investigated flow conditions on the fish migration facilities usually do not correspond to the requirements of the fish at long time scale to reflect the seasonal variation. Such results can hardly demonstrate a convictive proof of the effectiveness under various flow conditions. In regard to fish species, the constructions should be assessed whether there is a strong selectivity regarding to fish species spectrum. Particularly for small fish and benthic fish species, ramps that are not well designed still present as an obstacle for fish movement.

- **Criteria for nonselective performance of ramps**

To develop a free fish passage for all species in rivers, it is necessary to provide the instream conditions which are adequate to fish movement for at least 300 days/year as mentioned in Chapter 2.4. Despite the very high flow and very low flow periods, which are supposed to be about 30 days per year respectively, during the other 300 days in a year, fish migration facilities should be able to provide suitable physical conditions, i.e. flow velocity, water depth, width of passage slots or openings that change themselves in respond to the change in discharge.

- **Investigation work**

In this research field investigations are conducted in two aspects: hydraulic/geometrical investigation and biological investigation. The measurements of hydraulic conditions, including water depth, velocity, levelling for water level difference and slope as well as geometry of the construction, including length, width and slope are measured. The fish mark-capture is conducted for the biological monitoring. Both results will be combined to assess the effectiveness for fish passage and to build up the relationship between hydraulic conditions and fish free passage in reality. From the results of the research, a systematic assessment procedure will be developed and the criteria on an unselective fish passage for such nature-like ramps design will also be suggested.

- **References Study**

Petz-Glechner, R. and *Petz, W.* examined the fish passage at the ramps in the brook Riederbach and Gurtenbach as well as in a pool-type fish pass in the river in Austria. The electrofishing was executed downstream and upstream of the constructions. The study time period took three weeks and the fish recapture rate was between 40% ~ 56%. These data show that it is possible for the marked fish to pass upstream through the ramps and fish migration facilities. At these constructions, no hydraulic measurements of water depth and flow velocity were made.

Eidelsburger reported fourteen fish upstream migration facilities, which include three technical fish passes, five nature-like bottom ramps and six nature-like fish passes. Hydraulic and geometrical investigations were conducted at all the fourteen sites and biological investigation were made only at four sites. At each “sill” the measured maximum and minimum velocity as well as the water level difference was recorded. If the maximum velocity at a sill is lower than selected fish swimming performance criteria, the sill is assessed as “passable”. Such assessment criterion is simple and could be applied to technical fishway facilities, which are principally one-dimensional structure, and fish are constrained to pass through designed slots and orifices. The hydraulic monitoring should be conducted two-dimensionally at bottom ramps and fish ramps, which widely spread at whole or half of the river width.

With the determined overflow velocities and the near-bottom velocities as well as the results of the fishing-recapture a rough criteria (first criteria) for the fish passage at the hydraulic constructions could be evaluated. There are however still numerous questions remained open:

- How to evaluate the influence of the turbulence on the fish passage?
- How to define a „good“ result of fish mark-recapture method in respect to fish passage?
- What are the hydraulic criteria for fish passage? What is the maximal flow velocity and whether it is sufficient when there is at least one place with velocity under the criteria? Or this criteria must be defined via statistics?

4.2. Methodology

4.2.1. Procedures for the evaluation of the effectiveness of fish passes

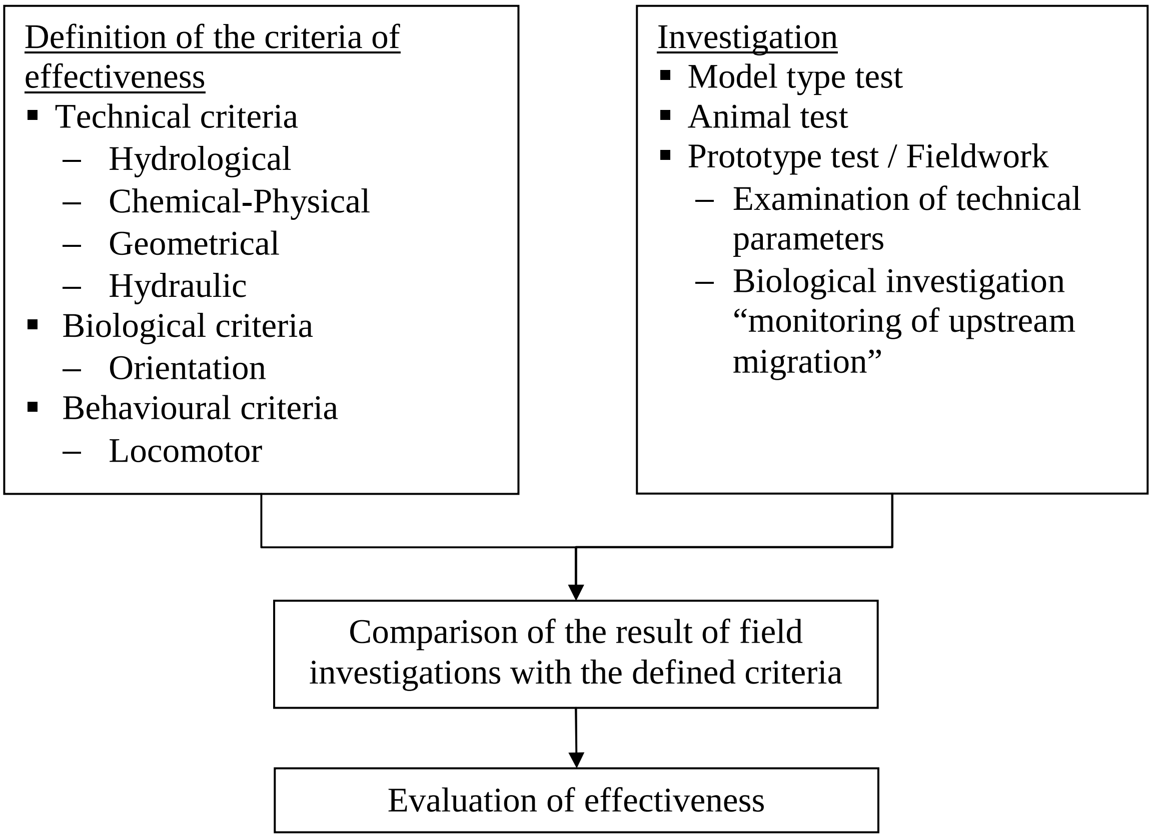


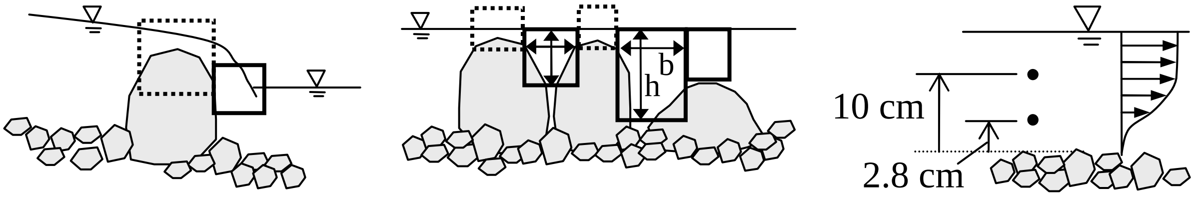
Fig 4.2.1: Procedures for the evaluation of the effectiveness of fish passes

4.2.2. Preparation of field investigation

The geometry of the structures of bottom ramps or fish ramps, the velocity and water depth of the flow in the ramps as well as the differences of the water levels between pools or sills should be measured. The measurements of hydraulics were conducted at four selected ramps under different flow conditions. The flow velocities were measured by midi-propeller current meters (Midi-Flügelmessgerät), which is widely used for field work. The velocity and water depth measurements were conducted at "proper" slots and openings of each boulder sill. Here "proper" means that the cross section of the possible passage at each slot or opening should be at least 15 cm in width and 10 cm in depth. The velocity measurements should be conducted at positions where the highest velocity occurs (see Fig. 4.2.2). Velocities will also be measured in the resting pools if necessary. The differences of the water level upstream and downstream of a boulder sill would be measured.

The results of the geometric/hydraulic measurements are expected to show a wide distributed spectrum, and thus the measurements should be analysed statistically. The investigations on geometries and hydraulics should be connected with the fish-capture results.

In this monitoring investigation, velocities were measured at the near bottom position for the first time fieldwork, which is 2.8 cm above the bottom. A support frame was attached to the current meter at the second time fieldwork so that the current meter can be adjusted to measure velocity at a vertical position 2.8 cm to approximate 40 cm above the bottom. Velocities are measured while the dimension of the possible passage is at least 15 cm wide and 10 cm deep (see Fig. 4.2.2).



Longitudinal cross section | Cross section | Longitudinal cross section

⬚ **Wrong positions** for velocity measurements: overflow above boulders may provide adequate hydraulic conditions for fish migration during high flow, but often fail during mean flow and low flow and should not be counted as possible passages.

☐ **Correct positions** for velocity measurements: slots between boulders form an adequate passage for fish to migrate. Slots with width exceeding 15 cm and depth from free surface exceeding 10 cm will be measured for velocity. The highest velocity occurs at the water jet.

Criteria on possible passage: b ≥ 15 cm and h ≥ 10 cm

Fig. 4.2.2 Positions for velocity measurements

The biological monitoring of fish migration behaviour was conducted by the Bavarian Fishing Association with support of the fish research group in Weihenstephan of the Technische Universität München and the local fishing clubs. Electric-fishing, fish-mark and trapping were used and the investigations were conducted two or three times in summer, autumn and spring respectively.

4.3. Case studies in the river system of Mangfall

The study area is in the river system of Mangfall, which converges into the Inn River, one of the chief tributaries of the Danube and locates at the foot of the Alps in Bavaria. Four bottom ramps / fish ramps in the river Mangfall were chosen for the field investigations. They are a newly constructed bottom ramp “Kolbermoor” and a fish ramp “Schwaig” in the river Mangfall, a bottom ramp “Plackermühle” in the brook Kalten and a fish ramp “Leitner” in the brook Leitzach. All the four ramps constructionally differ from each other apparently. While the cascaded bottom ramp “Kolbermoor” represents a large scale construction in a river at the foot of the Alps with quite active bed load transport; the bottom ramp “Plackermühle” is a small scale construction in a meandering brook with little bed load transport, which is quite interesting to regard different fish habitats and fish species. “Leitner” is a pool-type fish ramp which replaced part of the existing weir and “Schwaig” is another type of fish ramp different from pool-type but with perturbation boulders and has compounded sections to adjust passages under different discharges.

The discharge data for the four selected ramps were adopted by the historical records of the river gauging stations – Rosenheim Mangfall, Hohenofen and Stauden. The statistics of hydrology at the three stations corresponding to the relevant ramps are listed below in Table 4.3.1.

Table 4.3.1: Statistics of discharges at the corresponding gauging stations [unit: m^3/s]

Ramp	Kolbermoor / Schwaig	Plackermühle	Leitner Mühle
River	Mangfall	Kalten	Leitzach
Gauging station	Rosenheim Mangfall	Hohenofen	Stauden
Record period	1966 – 2000	1999 – 2004	1941 – 2002
NQ (lowest flow)	1.02	0.18	1.00
MNQ (mean low flow)	2.43	0.39	1.96
MQ (mean annual flow)	17.40	2.65	4.66
MHQ (mean high flow)	169	35.1	40.5
HQ_1 (flood with a return period of 1 year)	139	-	31.3
HQ (highest flow)	389	40.7	105

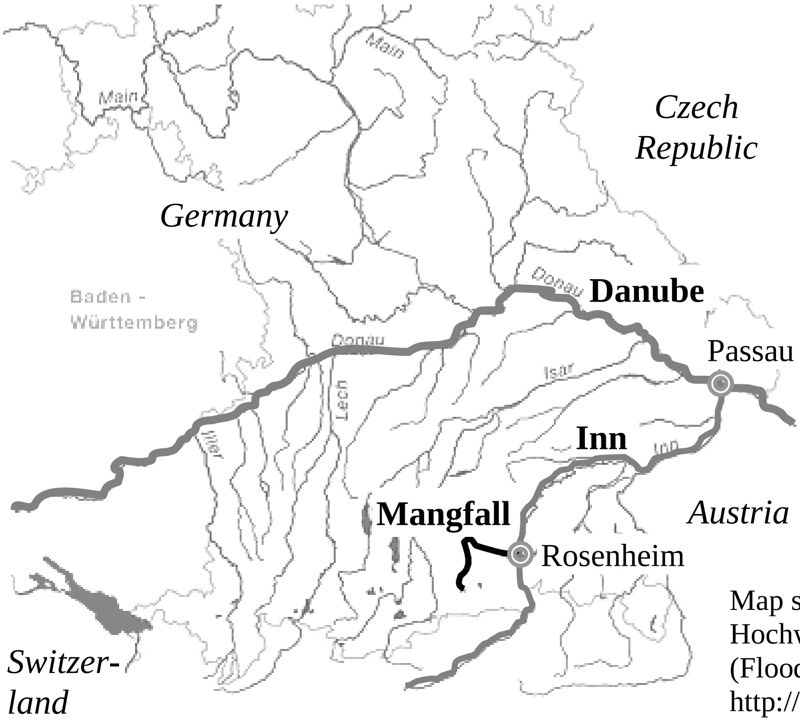
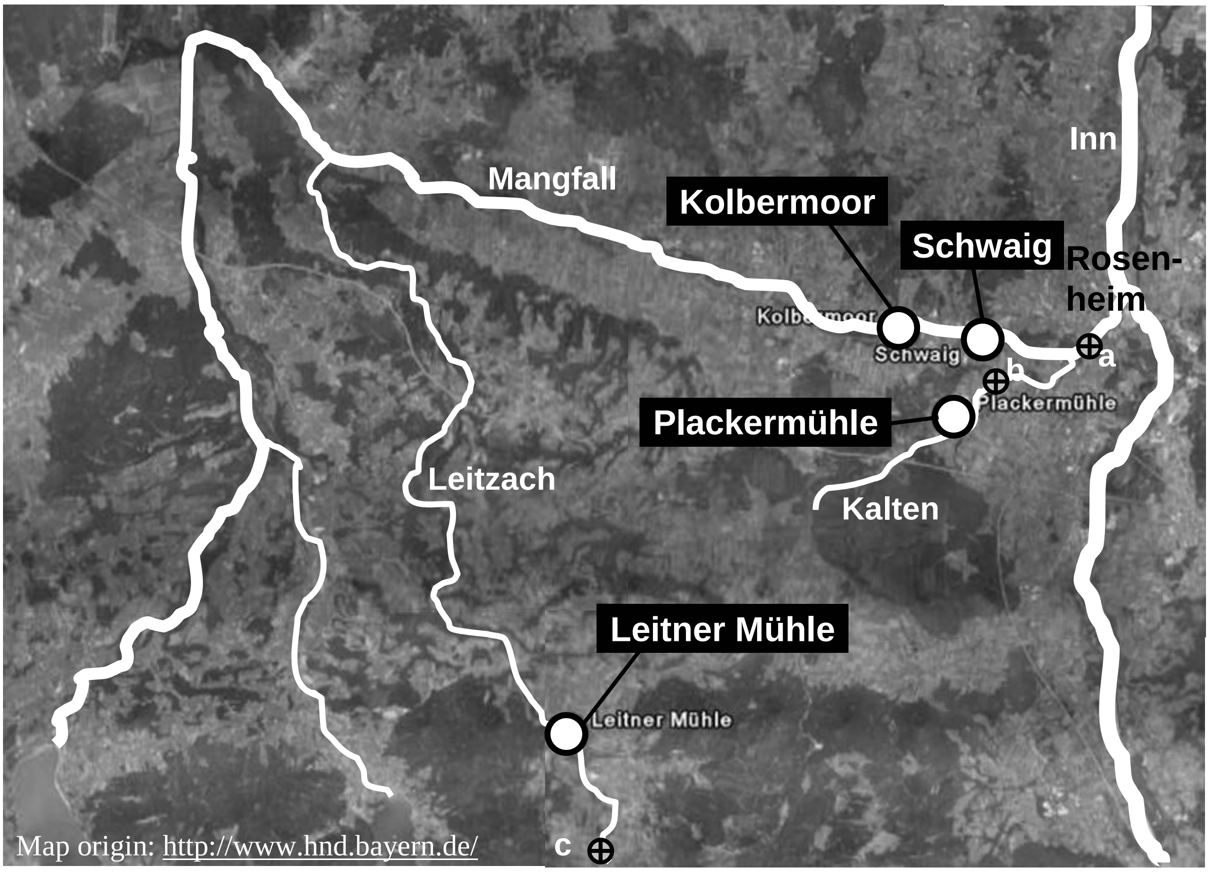


Fig 4.3.1: The river system of Danube, Inn and Mangfall

Map source:
Hochwassernachrichtdienst Bayern
(Flood information service, Bavaria)
http://www.hnd.bayern.de/



Map origin: http://www.hnd.bayern.de/

Fig 4.3.2: Location of the four bottom / fish ramps and the gauging stations
a: Gauging station “Rosenheim Mangfall” in the river Mangfall
b: Gauging station “Hohenofen“ in the brook Kalten
c: Gauging station “Stauden” in the brook Leitzach

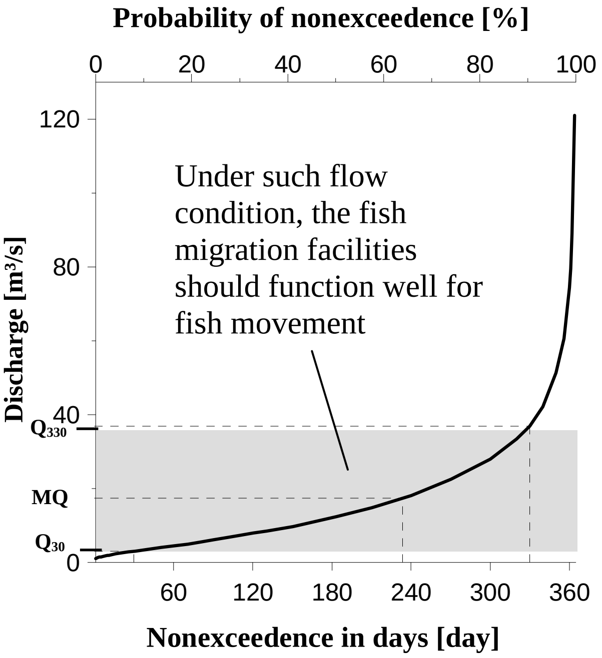
4.4. Case 1: Bottom ramp "Kolbermoor"

The bottom ramp Kolbermoor consists of two nature-like cascaded ramps which are called "naturnahen aufgelösten Rampen" in German. It is part of the integrated flood mitigation project of Kolbermoor. A six meter high spinnery weir was removed during summer 2004 and was replaced by the bottom ramp, which was constructed in June 2005 for preventing the streambed from further erosion. In addition, it can also re-establish the free passage for fish and other aquatic animals (Fig. 4.4.2 ~ 4.4.4).

The upper bottom ramp is about 80 meters long and 45~50 meters wide, formed by 12 boulder sills (Fig. 4.4.3). The lower ramp is about 60 meters long and 33 ~ 42 meters wide, formed by 11 boulder sills. Between the two ramps there is a large resting area, suggested to be created by the local fishery club. The width of the resting zone is decreased by longitudinal sand banks to concentrate the flow in the center of the cross section as well as to create a habitat for fish and the other aquatic animals.

The problems at this cascaded bottom ramp site might be not effective for fish movement during low flow period.

Three field investigations were conducted in May and October 2006 as well as in September 2007 to study various discharge conditions in mean flow (MQ), low flow (30-days-nonexceedence discharge, Q_{30}) and high flow (330-days-nonexceedence discharge Q_{330}).



Probability of nonexceedence, P_r
$P_r[Q \le Q_{p\%}] = P$ %

Nonexceedence in days, D_r
$D_r[Q \le Q_{days}] =$ Days

Q_{30} = 3.06 m³/s
MQ = 17.40 m³/s
Q_{330} = 36.90 m³/s

Fig. 4.4.1. Nonexceedence discharge curve at gauge station Rosenheim Mangfall

Table 4.4.1: General Information of the bottom ramp Kolbermoor

General information of the catchment	
Gauging station	Rosenheim / Mangfall (1966-2003)
River system	Mangfall
Catchment area	1,099.27 km^2
River order (Gewässerordnung)	I
Local authority	WWA Rosenheim
River width	35 ~ 50 m
Hydrological statistics	NQ: 1.02 Q_{30}: 3.06 MQ: 17.40 Q_{330}: 36.90 HQ : 389.00
Geometry of barrier at the site	
Construction type: Weir type, other structures nearby	Past: spinnery weir (removed)
Water use general information, e.g. off-line hydropower station, in-line (run-of-river) hydropower station, navigation lock	
The operation regime of the operational constructions (weir, sluices, hydropower plant)	Intake canal
Powerhouse hydraulic capacity, spillway hydraulic capacity	There is extract water need at this section in Mangfall
Instream flow need	1.3 m^3/s

Characteristics of the ramp:

Construction type of the ramp	Two sets of cascaded bottom ramps
Geometry of the ramp (u: upper ramp, l: lower ramp)	
Length and width of the ramp	Length: 80 m (u) \ 60 m (l) Width: 45 ~ 50 m (u) \ 33 ~ 42 m (l)
bottom slope	1:35 (u) \ 1:53 (l)
Water head	2.34 m (u) \ 1.15 m (l)
# of sills	12 (u) \ 11 (l)
Head per sill	19.5 cm (u) \ 10 cm (l)
Min. and mean net width and length of the pool-type structure (dimension of the pool)	Upper ramp: ca. 6 m Lower ramp: ca. 5.5 m
Alignment of the ramp	
Location in relation with nearby structures and discharge division	A spinnery weir, which located at resting pools, was removed. The water intake canal next to the weir is out of service.
Location in relation with nearby barriers	
Location of main current	The bottom ramps cross the whole river width and replace the weir, natural river flow is the main current and attraction flow.
Distance between entrance / exit and barriers	
Location of attraction flow and angle	

Construction	
Boulder diameter	Min. 0.7 m for ground boulders and min. 1 m for boulders of sill
Scour measure	Stilling basin below ramps, steel sheet pile at the end of the stilling basin
Safety of the ramp beginning	Steel sheet pile
Bank design	Embankment with boulder of diameter min. 0.7 m, slope = 1:2 till level of HQ_{100}
Costs	1.2 Mio. Euro
Construction period	Autumn 2004 – June 2005

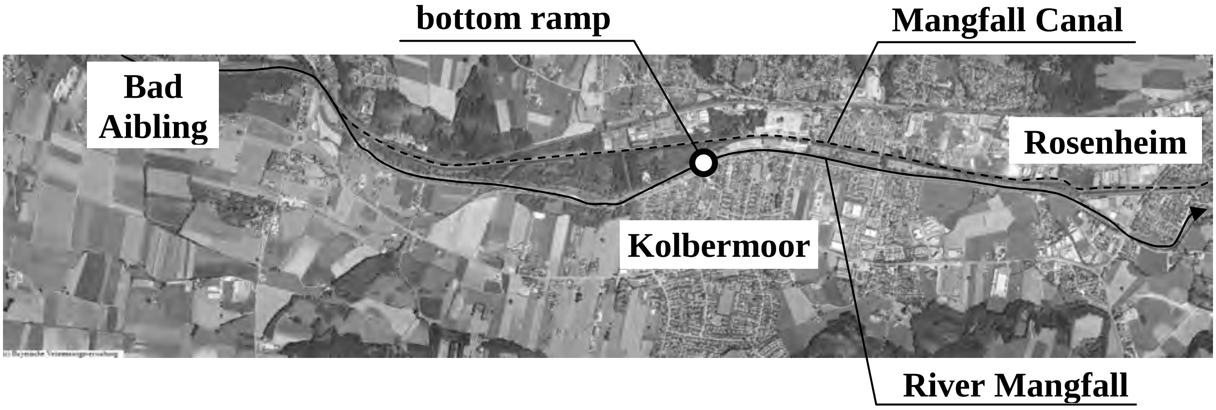


Fig 4.4.2: Location of the bottom ramp Kolbermoor in the river Mangfall

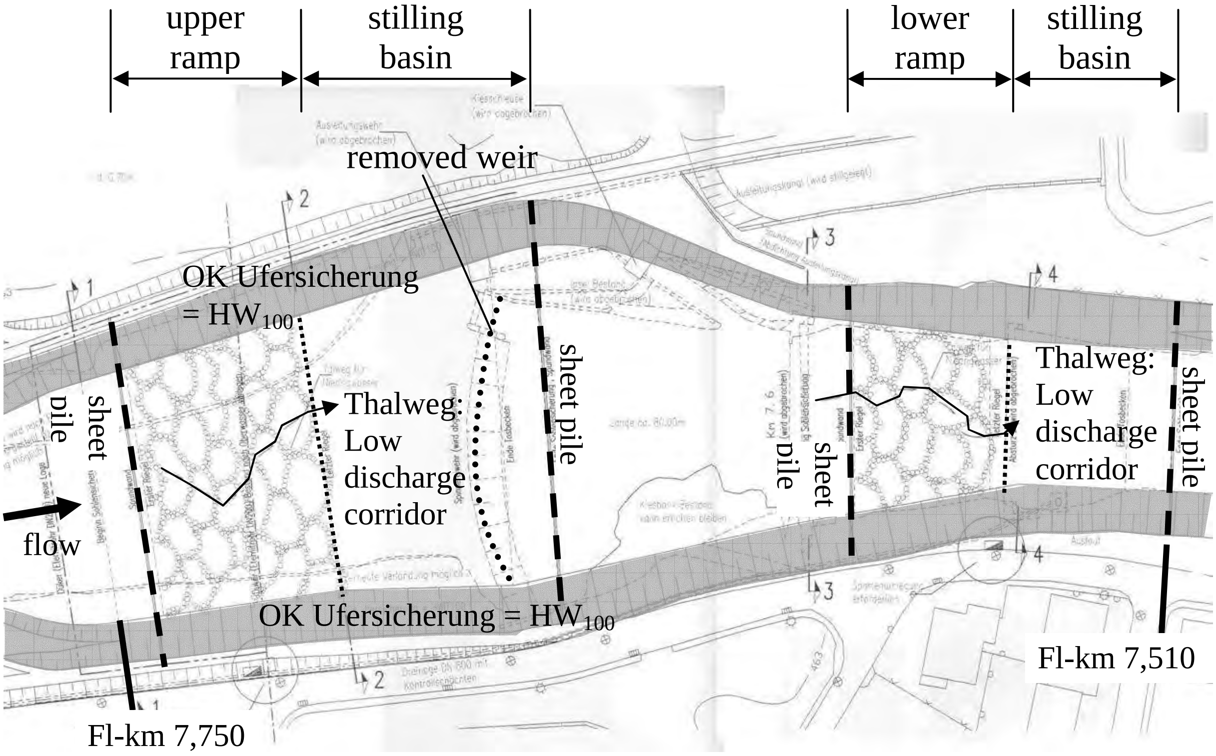


Fig 4.4.3: Sketch of the bottom ramp Kolbermoor in the river Mangfall, plan view

Fig 4.4.4: Bird's eye view of the bottom ramp Kolbermoor

(Source: Bayern Viewer)

Fig. 4.4.5: Bottom ramp Kolbermoor in the river Mangfall, photo made on Aug.09.2005, Q = 39 m³/s (≈Q_{330})

Fig. 4.4.6: Bottom ramp Kolbermoor in the river Mangfall, photo made on Oct.25.2006, Q = 4.84 m³/s (Q_{30})

The fish species in the river Mangfall nearby the bottom ramp Kolbermoor are listed in Table 4.4.2. This list is based on the data of the captured fish from the investigation of electric-fishing conducted by Bavarian Fishing Association.

Table 4.4.2: Fish species in the river Mangfall nearby the bottom ramp Kolbermoor

Fish species[1]		in German[2]	Max. size[3] [cm]
European Chub	(*Leuciscus cephalus*)	Aitel	60
Grayling	(*Thymallus thymallus*)	Äsche	60
Barbel	(*Barbus barbus*)	Barbe	120
Brown trout	(*Salmo trutta fario*)	Bachforelle	100
Nase	(*Chondrostoma nasus*)	Nase	50
Minnow	(*Phoxinus phoxinus*)	Elritze	14
Rainbow trout	(*Onchorhynchus mykiss*)	Regenbogenforelle	120
Gudgeon	(*Gobio gobio gobio*)	Gründling	20
Stone loach	(*Barbatula barbatula*)	Schmerle	21
Roach	(*Rutilus rutilus*)	Rotauge	46
Bullhead	(*Cottus gobio*)	Koppe	18
Perch	(*Perca fluviatilis*)	Flussbarsch	51
Dace	(*Leuciscus leuciscus*)	Hasel	40
Huchen	(*Hucho hucho*)	Huchen	150

[1] Scientific names from FishBase
[2] Data: Bavarian Fishing Association (Landesfischereiverband Bayern)
[3] Reported max. size from FishBase

Brown trout, grayling and barbel are selected as representatives of species for different requirements on geometric and hydraulic conditions in fish migration facilities.

Table 4.4.3: Assessment of the minimum water depth in fish migration facilities: level of assessment = B (good)

Species	Brown trout	Grayling, Dace	Barbel, pike
Body length up to [cm]	40	60	120
Min. water depth [m]	0.4	0.45	0.5
Width of notches and narrow slots [m]	0.2 ~ 0.4	0.4 ~ 0.6	0.6
Max. water level difference [m]	0.2	0.15	0.13
Max. flow velocity in notches and narrow slots [m/s]	2.0	1.7	1.6

4.4.1. First fieldwork: May.16-17.2006, Q: 20.0 m³/s, corresponding to about MQ

The first field investigation at the bottom ramp Kolbermoor was carried out on May.16-17.2006. The discharge in the river Mangfall was 20.0 m³/s, which corresponded to about the annual mean flow, MQ. Opening slots which are taken as potential free passage for fish movement must be with the dimension of the width to be at least 15 cm and the depth to be at least 10 cm. However whether these slots are adequate for fish to ascend, the measured velocity, water depths and slot widths must be examined with different migration conditions for different species, e.g. in Table 4.4.3.

From the histogram of the results in Table 4.4.4 and Fig. 4.4.9, it shows the statistics of measured velocity at the slots between the armourstones of the boulder sills. Approximate 19% of the measured velocities exceed 1.5 m/s at the upper ramp, while as approximate 11% of those at the lower ramp. Apparently most of the measured velocities are under the upper limits of flow velocity at narrow slots for brown trout, grayling and barbell; they are 100%, 92.3% and 86.4%, respectively at the upper ramp, as well as 100%, 96.8% and 94.2%, respectively at the lower ramp.

During the first fieldwork at the bottom ramp Kolbermoor, the two ramps were detailed investigated to pick out the potential barrier sills. The maximum, mean and minimum flow velocities at each sill are shown in Fig. 4.4.14. At the upper bottom ramp, some boulder sills show the high velocity flow at the slots, e.g. sills No.1, 4, 5 and 7. Both of the boulder sills No.1 and 3 at the upper ramp represent the minimum velocity exceeding 1.0 m/s. In regard to the lower ramp, more than 87% of the measured velocities fall in the range of 0.5 to 1.5 m/s. The potential barrier sills are supposed to be the No. 5, 7 and 9. The measured velocities at sills No.1 and 3 are not adopted for analysis owing to their very low values and are considered to be no good data; however the dimension of the slots at these two sills still can be used for analysis.

The flow in the resting zone was concentrated in the center of the river width by two boulder sills (shown in Fig. 4.4.4 and Figs. 4.4.12-13). From the results of the measurements (Figs. 4.4.12-13) it shows good potential on providing fish free passage through the resting pools. The velocity near the streambed distributed between 0.55 to 1.00 m/s and the velocity at 30 cm above the streambed distributed between 1.10 to 1.40 m/s.

In regard to the width and the water depth at each potential free passage slot, in Figs. 4.4.10~13, it shows a great many slots, which are recognized as potential free passage for fish by their dimensions in widths and depths, uniformly distributed at the whole ramp. From the histogram of the measured widths of the slots (Fig. 4.4.10) it shows that in general the widths at the slots are adequate for brown trout to pass through (88.1% and 99.5% of the widths equal or exceed 20 cm, upper and lower ramps, respectively), but most of the measured widths are critical for grayling (29.2% and 48.8% of the widths equal or exceed 40 cm, upper and lower ramps, respectively) and for barbel to pass (11.3% and 15.6% of the widths equal or exceed 60 cm, upper and lower ramps, respectively). As for the measured depths of water (Fig. 4.4.11), most of them are not deep enough for all the three representative species, i.e. at the upper ramp, only 15.0%, 7.2% and 5.4% of the investigated slots provided adequate water depth for brown trout, grayling and barbel, respectively; whileas at the lower ramp, the adequate ratios are only 23.8%, 15.5% and 8.9%, respectively. The result shows that the water depth is the governing factor in the assessment to evaluate whether a ramp provides good conditions for fish movement.

In Fig. 4.4.12 illustrates the possible passage for brown trout. Due to too shallow water depth no continuous migration corridor can be traced.

In Fig. 4.4.13 the same data were examined again with migration criteria for small fish species, i.e. velocity ≦ 0.5m/s and water depth ≧ 10 cm (see Table 2.4.5). The dimensions of all the investigated slots are adequate for small fish to move, because a measurement at a slot will be conducted only when the water depth there equals or exceeds 10 cm. The dominant factor for a good passage to small species is the flow velocity. From the result of the measurements, it shows that at only few slots, i.e. only two and three slots at the whole upper and lower ramps, respectively, the velocity is lower than 0.5 m/s. The result of the velocity investigations seems to indicate a bad condition to fish for a continuous corridor, but it leads, however, to a misunderstanding: because in the field investigations, measurements of velocity were conducted at slots where the maximum velocity occurs (see Fig. 4.2.2). In reality, the flow condition is more proper for small species to ascend, i.e. the flow velocity at the whole cross section of a slot is lower than the measured maximum value.

A “passage ratio” is introduced to describe the ratio of the whole width of possible passage to the width of a boulder sill, as shown in Eq. 4.1. The averaged potential passage ratios according to the criteria on measurements (dimension of a slot: $B \geq 15$cm and $H \geq 10$ cm) at the upper and the lower ramp are 13.0% and 23.1%, respectively (detail see App. E), which means that the boulder sills at the lower ramp are less “barrier” than those at the upper ramp. A specific passage ratio for each fish species can also be calculated according to its migration criteria.

$$\textit{Passage ratio} = \frac{\textit{sum of slot width } B}{\textit{length of sill at MQ}} \times 100\% \qquad [\%] \quad (\text{Eq. 4.1})$$

$$= \frac{B_1 + B_2 + ... + B_n}{L_s} \times 100\% = \frac{\sum_{i=1}^{n} B_i}{L_s} \times 100\%$$

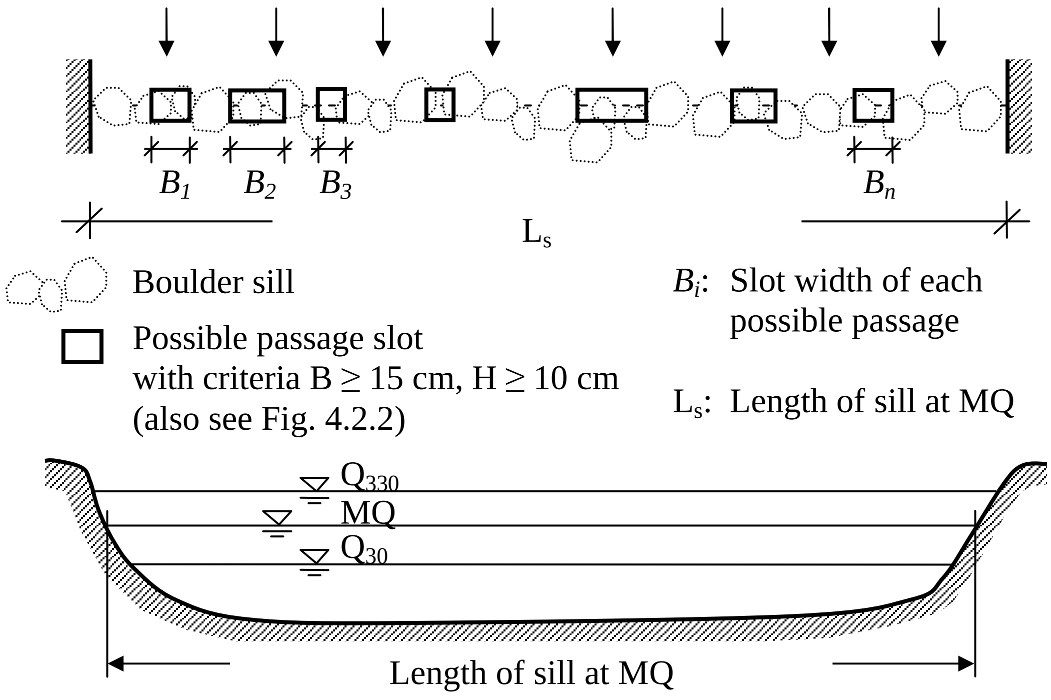


Fig. 4.4.7: Sketch of the passage ratio

Table 4.4.4: 1st field investigation on May.16-17.2006

Min. and mean water depth	ca. 50 ~ 100 cm during mean flow
Water level difference between adjacent pools	upper ramp: 18.5 cm lower ramp: 11 cm
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit) V: velocity B: slot width H: water depth	Statistics of 1st field investigation (average ± standard deviation) #. of slots V[m/s] B[cm] H[cm] upper: 169 1.22 44 29 ±0.31 ±55.8 ±12.5 lower: 205 0.93 42 30 ±0.47 ±16 ±12
Number and location of resting pool	Two resting pools between upper and lower ramps, ca. 40 ~ 50 m long
Discharge: Gauge Rosenheim Mangfall	on May.16-17: 20 m^3/s (≈ MQ)
Flow in the ramp and attraction flow	Same as river flow
Max. velocity at the slots [m/s]	Upper ramp: 1.99; Lower ramp: 1.79
Velocity in pools/migration corridor	Resting pool: V = 0.55 ~ 1.40 m/s
Velocity of the attraction flow	No entrance/exit → no attraction flow

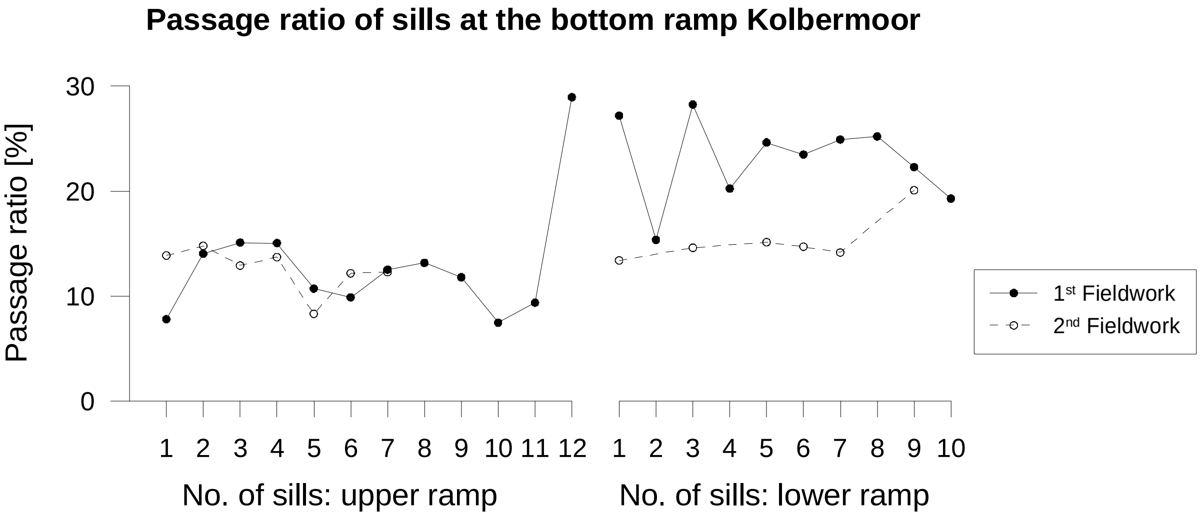


Fig. 4.4.8: Passage ratio of sills at the bottom ramp Kolbermoor (detailed data please see Appendix E)

Date: 1st field work, May.16~17.2006; Discharge: Q = 20.0 m³/s (MQ)

Date: 2nd field work, Oct.25.2006; Discharge: Q = 4.84 m³/s (Q_{30})

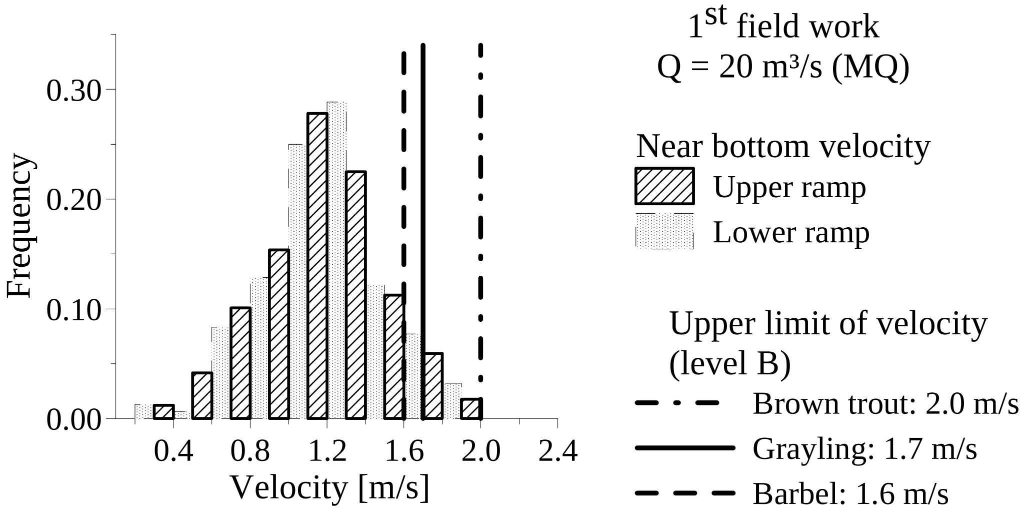


Fig. 4.4.9: Near bottom velocity (v at z = 2.8 cm) distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 1st field work, May.16~17.2006; Discharge: Q = 20 m³/s (MQ)

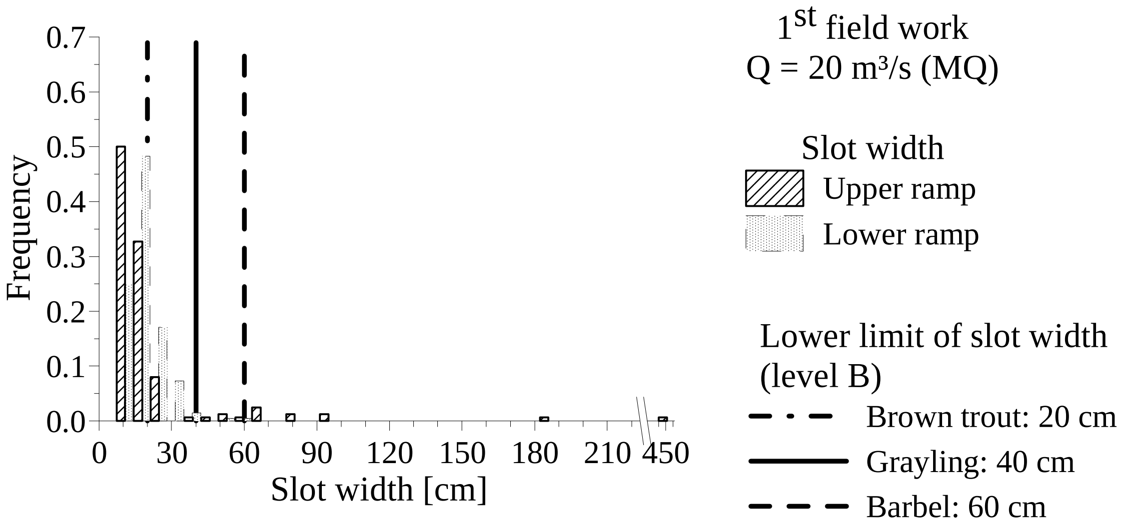


Fig. 4.4.10: Slot width distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 1st field work, May.16~17.2006; Discharge: Q = 20 m³/s (MQ)
Note: slots were not measured if the width was less than 15 cm; some slots with width > 225 cm are not shown in histogram.

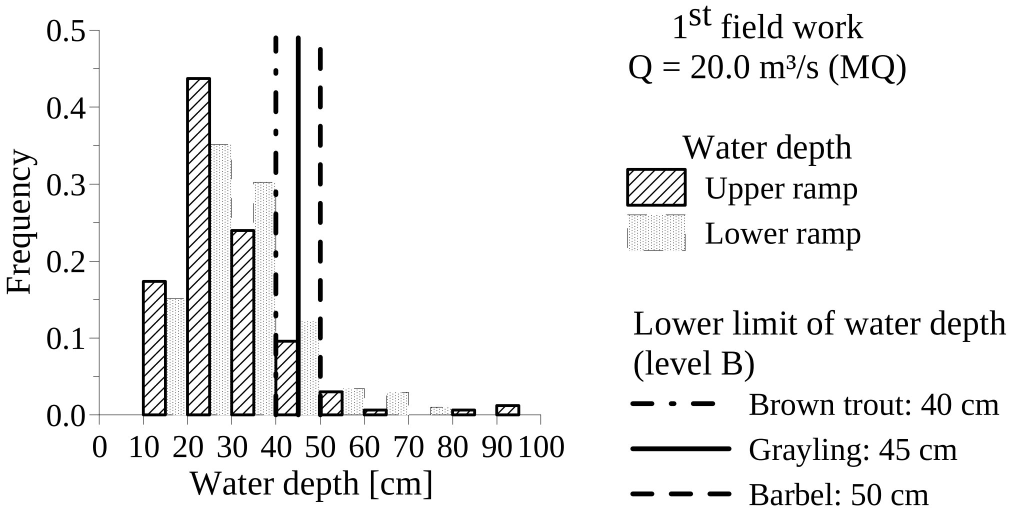
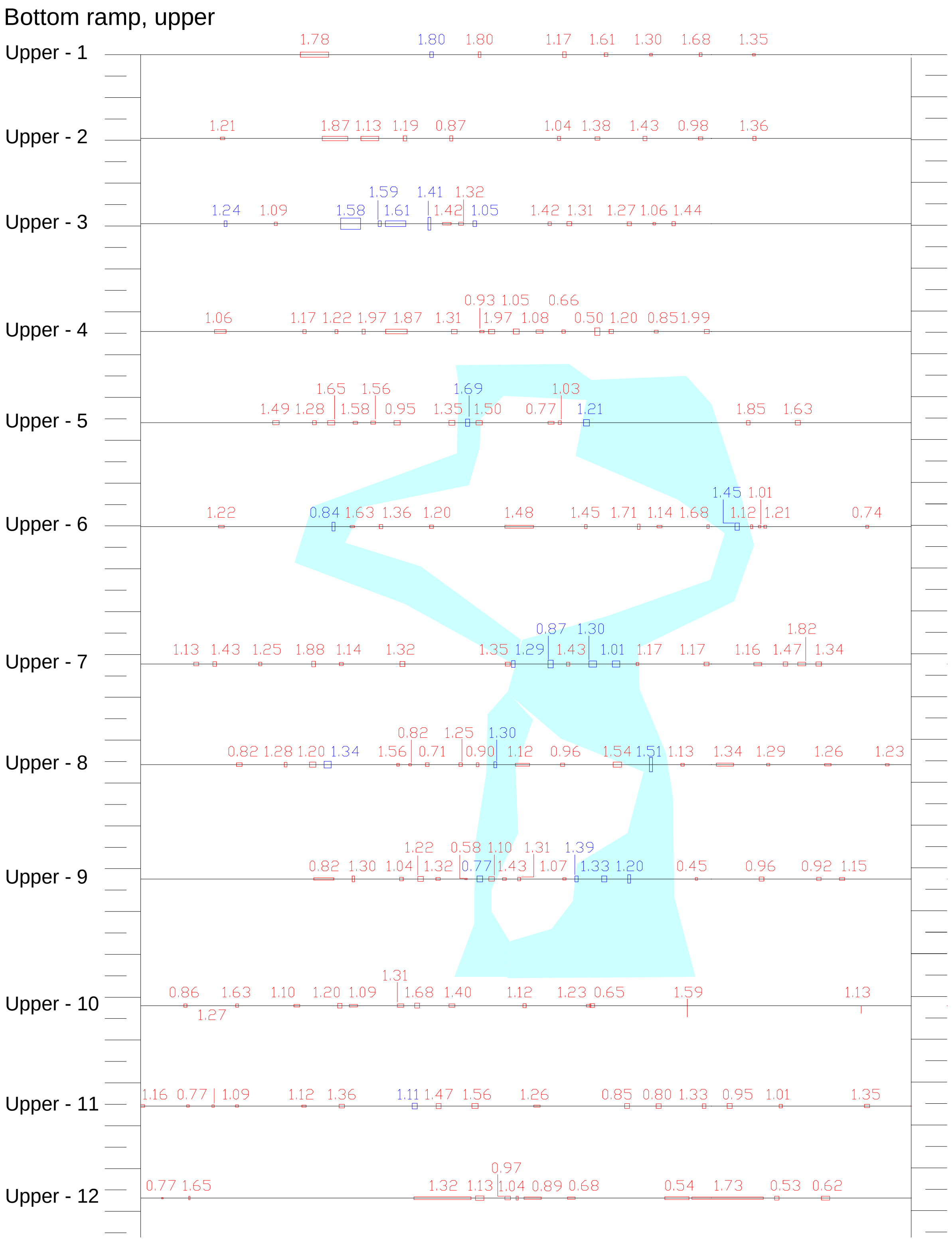


Fig. 4.4.11: Water depth distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 1st field work, May.16~17.2006; Discharge: Q = 20 m³/s (MQ)
Note: slots were not measured if the water depth was less than 10 cm.



1.25— flow velocity [m/s]
☐— water depth (to scale) [m]
└— slot width (to scale) [m]

Values and squares in blue indicate possible passage under condition for brown trout to ascend:
Velocity < 2.0 m/s, Water depth > 0.4 m,
Notch/slot width > 0.2 m

Fig. 4.4.12: Distribution of possible passage for brown trout at the bottom ramp Kolbermoor during mean annual flow (MQ), fieldwork on May.16-17.2006

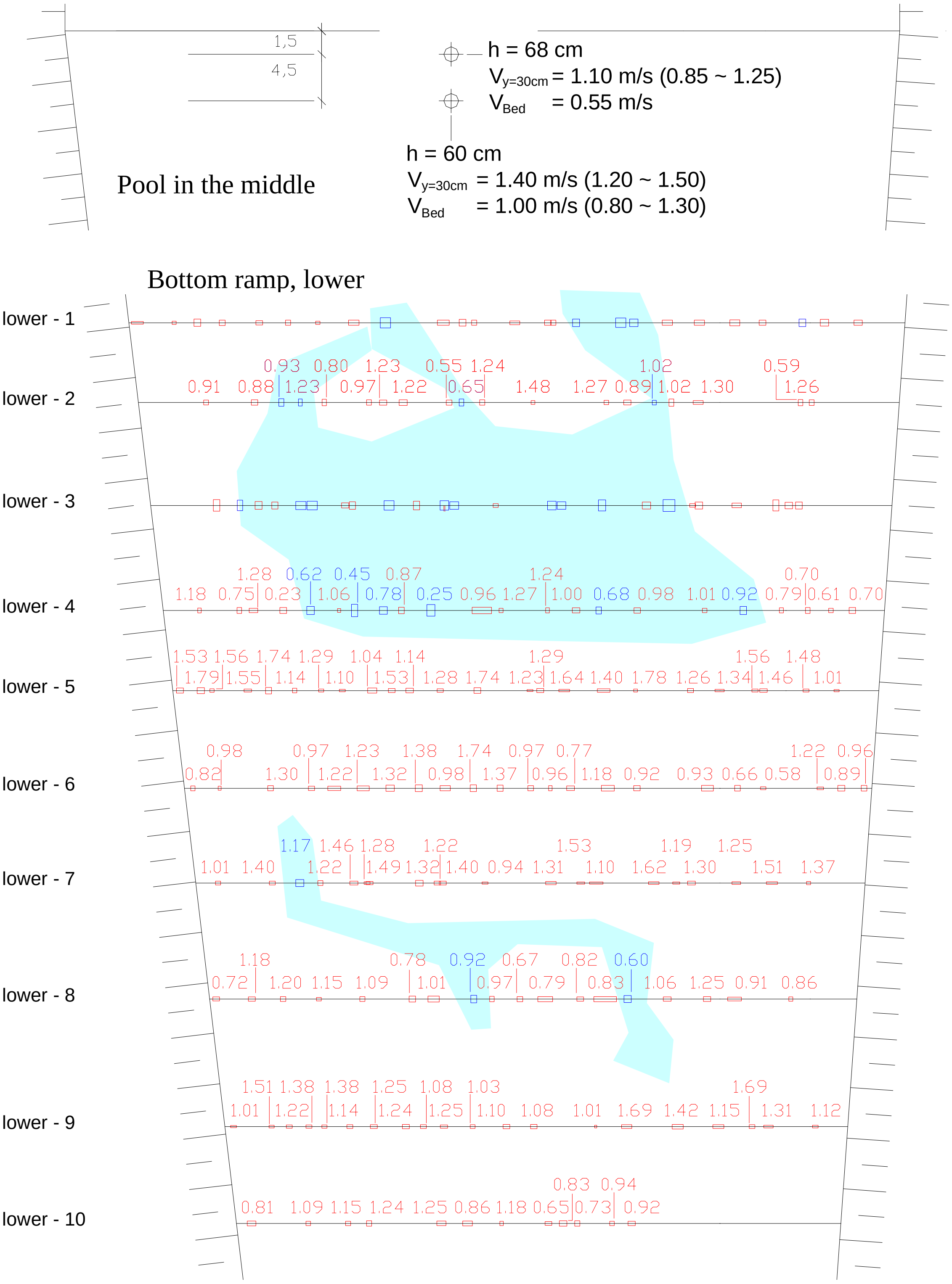
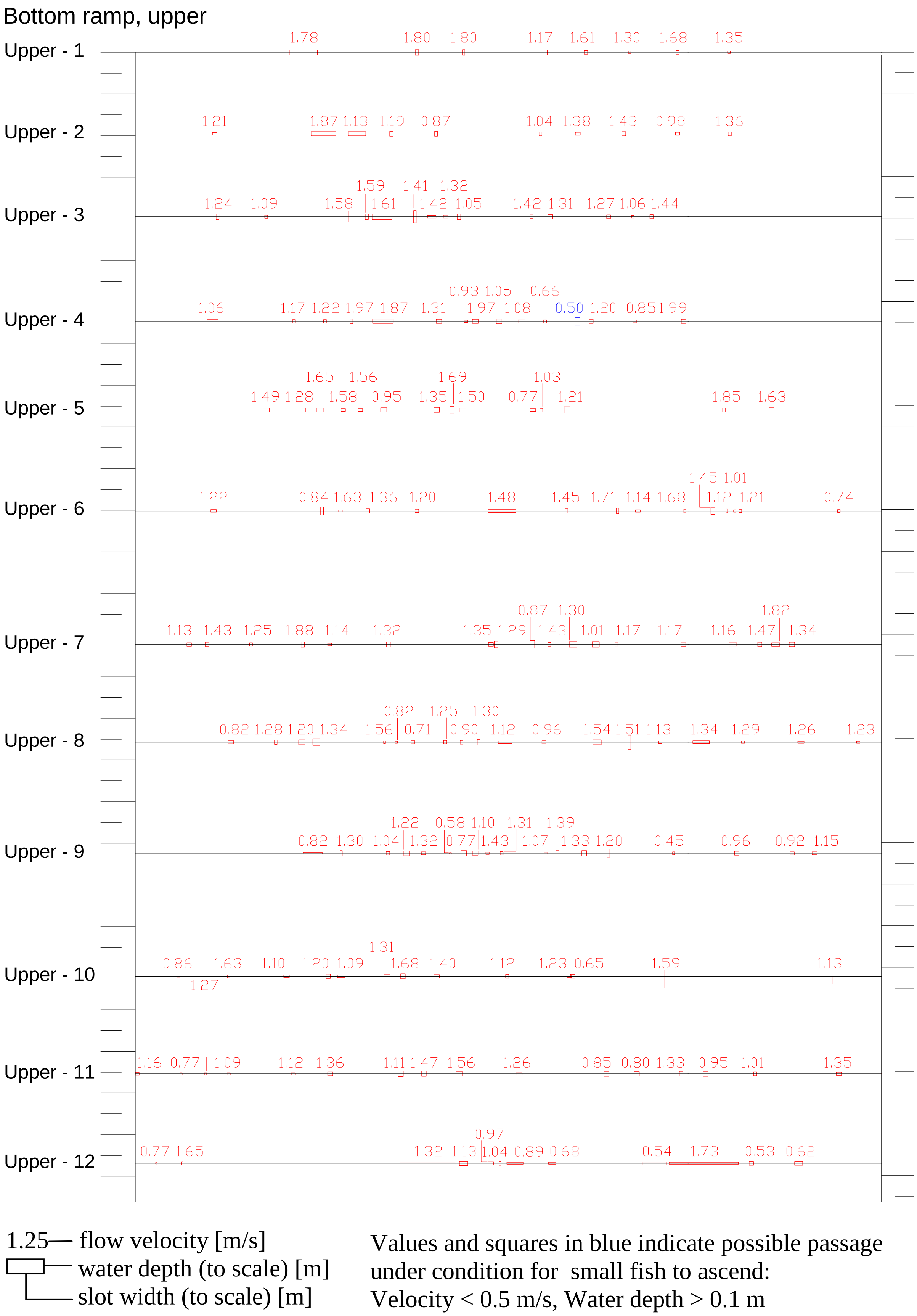


Fig. 4.4.12(conti.): Distribution of possible passage for brown trout at the bottom ramp Kolbermoor during mean annual flow (MQ), fieldwork on May.16-17.2006



Values and squares in blue indicate possible passage under condition for small fish to ascend: Velocity < 0.5 m/s, Water depth > 0.1 m

Fig. 4.4.13: Distribution of possible passage for small fish species at the bottom ramp Kolbermoor during mean annual flow (MQ), fieldwork on May.16-17.2006

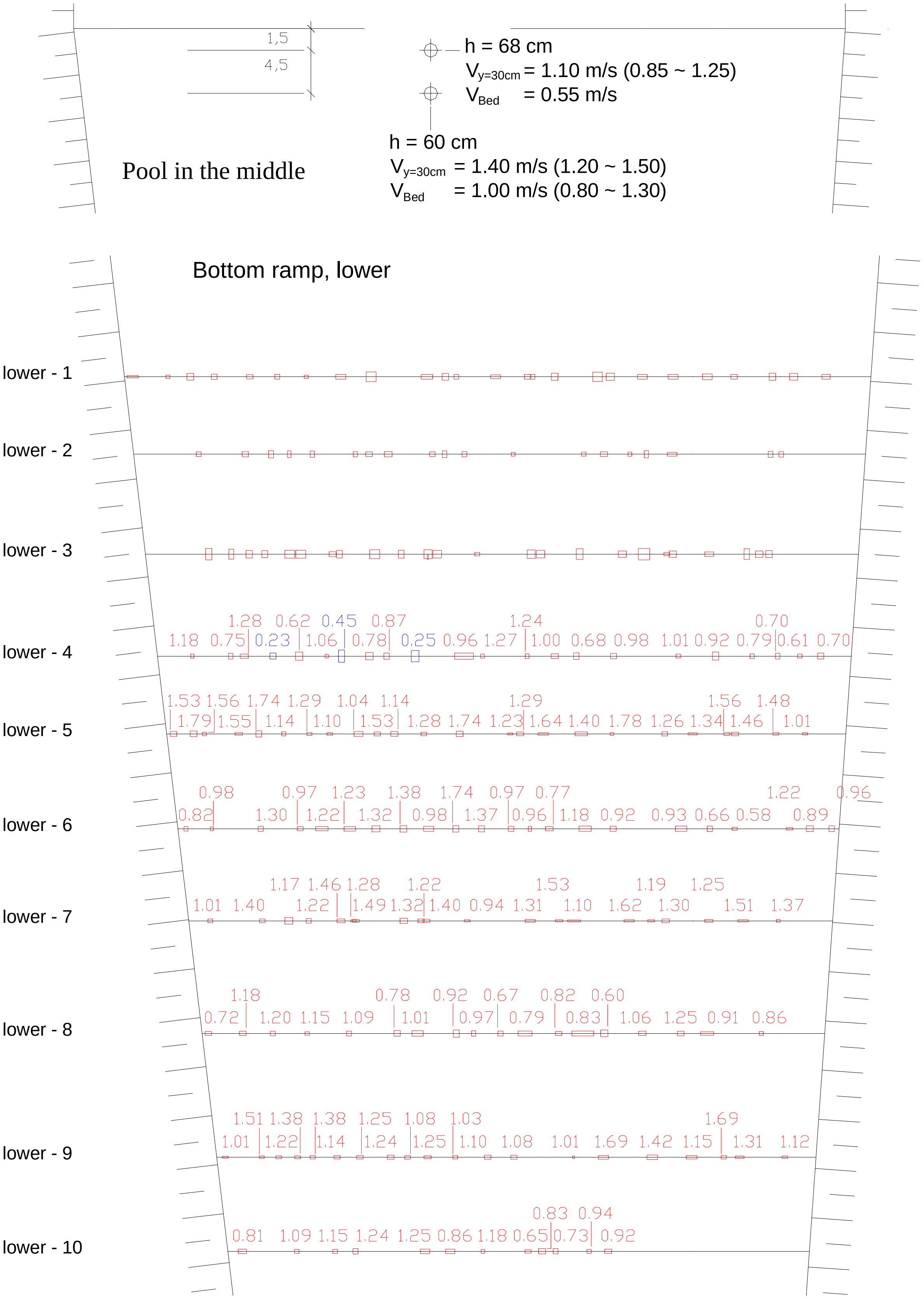


Fig. 4.4.13(conti.): Distribution of possible passage for small fish species at the bottom ramp Kolbermoor during mean annual flow (MQ), fieldwork on May.16-17.2006

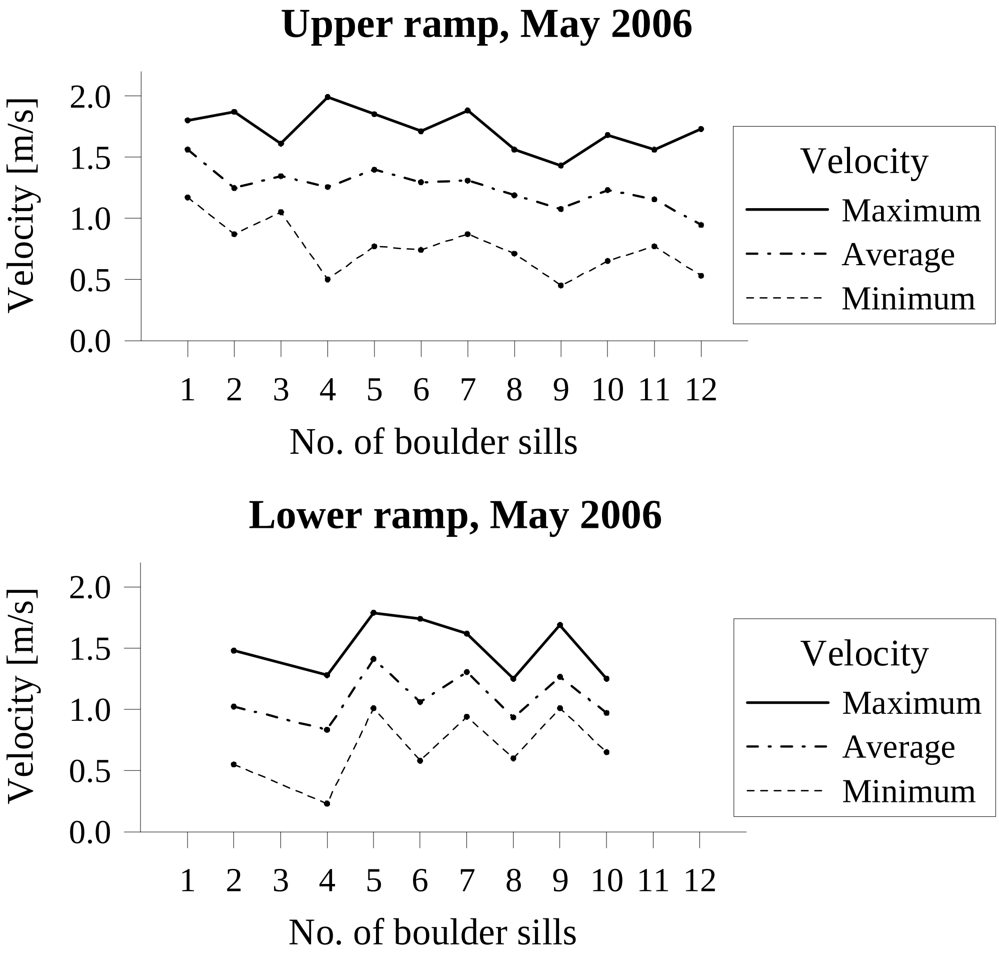


Fig. 4.4.14: Statistics of the measured velocities at the bottom ramp Kolbermoor

Fig. 4.4.15(a): Using midi-current-meter and ruler to measure the near bottom velocity and geometry of openings at boulder sills.

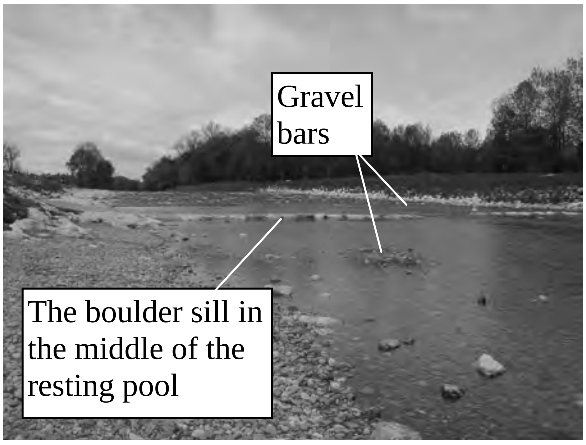


Fig. 4.4.15(b): The resting pool between the upper and lower ramps. The local fishermen association suggested that to use the boulder sill in the middle and gravel bars to create the concentrated flow and a suitable habitat.

4.4.2. Second field work: Oct. 25. 2006, Q: 4.84 m³/s, corresponding to about Q_{30}

The second fieldwork at the bottom ramp Kolbermoor was carried out when the discharge in the river Mangfall came to approximate the 30-day-nonexceedence-discharge, Q_{30}, for the investigation under the condition of lower discharge. To reduce the load of fieldwork, around one half of all the boulder sills were selected for the next investigation in field. The boulder sills which consist of opening slots with very high or very low velocities measured in the first fieldwork were selected. The first sill of a ramp at the upstream side usually has critical conditions in hydraulics for fish to move and therefore must be included in the following investigations as well. Table 4.4.5 and Figs. 4.4.19~20 show the result of the measurement at boulder sills under the low flow condition. As shown in Figs. 4.4.21 (a), (c) and (d), it seems that at many of the sills there are no adequate opening slots as free passage for fish.

Velocities at each possible passage slot were obtained at two water depths: near bottom (2.8 cm from bottom) and 10 cm above the bottom. In Fig. 4.4.16 the histograms show that 89% and 96% of the near bottom velocities at the upper and the lower ramp, respectively, distributed between 0.5 to 1.5 m/s. The ratios of the measured velocities below 1.5 m/s at both upper and lower ramp are approximate 10% higher than those in the first fieldwork with mean flow condition. In addition, the distribution of the velocities measured at positions of 10 cm above the bottom is similar to that near the bottom. Apparently most of the measured velocities are under the upper limits of flow velocity at narrow slots for brown trout, grayling and barbel; the percentages are between 90.4% and 100% for both of velocities at the two depths as well as at the upper and the lower ramps.

In regard to the width and the water depth at each potential free passage slot, as shown in Figs. 4.4.17~19, it shows a great many slots, which are recognized as potential free passage for fish by their dimensions in widths and depths, uniformly distributed at the whole ramp. From the histogram of the measured widths of the slots (Fig. 4.4.17) it shows that in general the widths at the slots are adequate for brown trout to pass through (77.1% and 89.1% of the widths equal or exceed 20 cm, upper and lower ramps, respectively), but most of the measured widths are critical for grayling (15.6% and 17.7% of the widths equal or exceed 40 cm, upper and lower ramps, respectively); there are only few slots with wide enough widths for barbel to pass (4.2% and 3.0% of the widths equal or exceed 60 cm, upper and lower ramps, respectively). As for the measured depths of water (Fig. 4.4.18) at possible passage slots, most of them are not deep enough for all the three representative species, i.e. at the upper ramp, only 3.5%, 3.5% and 1.7% of the investigated slots provided adequate water depth for brown trout, grayling and barbel, respectively; whileas at the lower ramp, the adequate ratios are only 2.5% for brown trout; there are even no slots with adequate water depths for grayling and barbel. The result shows again that the water depth is the governing factor in the assessment to evaluate whether a ramp provides good conditions for fish movement.

In Fig. 4.4.19 illustrates the possible passage for brown trout. Due to too shallow water depth only a couple of boulder sills are possible to be passed through for brown trout.

In Fig. 4.4.20 the same data were examined again with migration criteria for small fish species, i.e. velocity ≦ 0.5m/s and water depth ≧ 10 cm (see Table 2.4.5). The dominant factor for a good passage to small species is the flow velocity. From the result of the measurements it shows that at only few slots, i.e. only 9.6% and 7.6% of the slots, of the upper and the lower ramps, respectively, the velocities are below 0.5 m/s. However, as explained previously in Ch. 4.4.1, the flow condition is in fact more proper for small species to ascend, i.e. the flow velocity at the whole cross section of a slot is lower than the measured maximum value.

The averaged potential passage ratios according to the criteria on measurements (dimension of a slot: $B \geq 15$cm and $H \geq 10$ cm) at the upper and the lower ramp are 11.9% and 15.5%, respectively (shown in Fig. 4.4.8, detail see Appendix E), of which the difference between the upper and the lower ramps is much smaller in the second field investigation than that in the first fieldwork.

Comparing with the result of the measurements between different flow conditions, at the upper ramp, the averaged passage ratios of sills No. 1~7 is 12.2% and 11.9% for mean flow and low flow conditions, respectively, without significant difference between different flow conditions. However, the passage ratio of sills No. 1, 3, 5~7 and 9 at the lower ramp are 25.1% and 15.5% in the first and the second field work, respectively, which indicates that during low flow season, the possible passage slots at the lower ramp are reduced approximate 40% in the slot width.

One should take notice that during the first and the second investigations, the first sill (the last sill for upstream migration) at the upstream side of the upper ramp was modified. The main opening passage in the middle of the sill was enlarged and the sum of the width of slots at the boulder sill No.1 is greater in the second fieldwork than that in the first one. Besides, lengths of boulders sills (submerged part) are generally longer in the first investigation than that in the second one due to different discharges in the river. However, only the length of a sill under mean flow condition is used for the calculation of the passage ratio.

Table 4.4.5: 2nd field investigation on Oct.25.2006

Water level difference between adjacent pools	upper ramp: 18.5 cm lower ramp: 11 cm
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit) V: velocity B: slot width H: water depth	Statistics of 2nd field investigation (average ± standard deviation) #. of slots — V_{10}[m/s] — V_{bed} upper: 115 — 1.15 ± 0.33 — 1.10 ± 0.38 B[cm] — H[cm] 33.8 ± 38.8 — 23.7 ± 8.5 #. of slots — V_{10}[m/s] — V_{bed} lower: 119 — 1.03 ± 0.24 — 1.01 ± 0.30 B[cm] — H[cm] 29.8 ± 12.1 — 22.7 ± 7.0
discharge	Gauging station Rosenheim Mangfall on Oct.25: 4.84 m^3/s (≈ Q_{30})
Flow in the ramp and attraction flow	Same as river flow
Max. velocity at the slots	Upper ramp: 2.14 m/s (V_{10}), 1.93 (V_{bed}) Lower ramp: 1.63 m/s (V_{10}), 1.79 (V_{bed})
Mean velocity in pools and migration corridor	Resting pool V_{30cm} = 0.57 ~ 0.96 m/s V_{10cm} = 0.41 ~ 0.80 m/s V_{bed} = 0.19 ~ 0.52 m/s
Water depth	50 ~ 80 cm in resting pool
Velocity of the attraction flow	No entrance / exit → no attraction flow

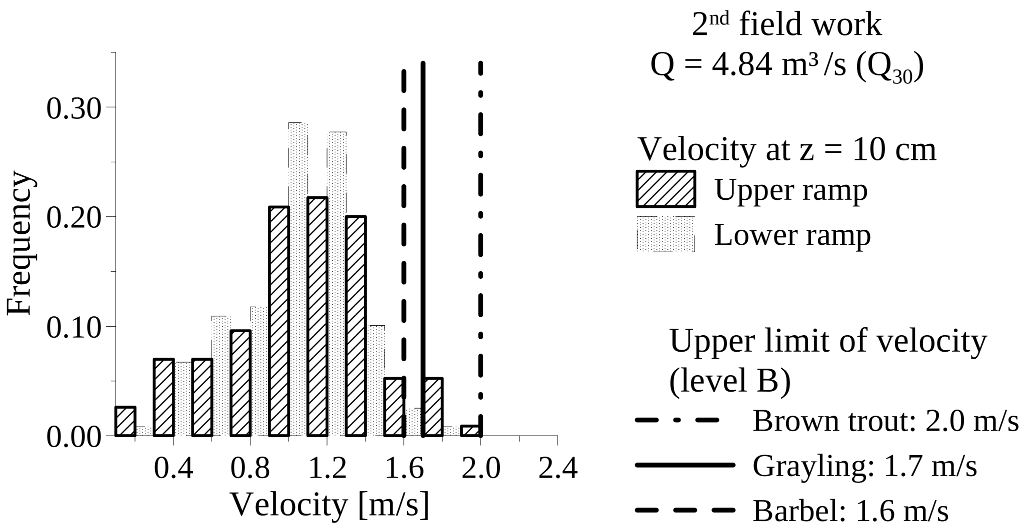


Fig. 4.4.16(a): Velocity (at z = 10 cm) distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 2nd fieldwork, Oct.25.2006; Discharge: Q = 4.84 m^3/s (Q_{30})

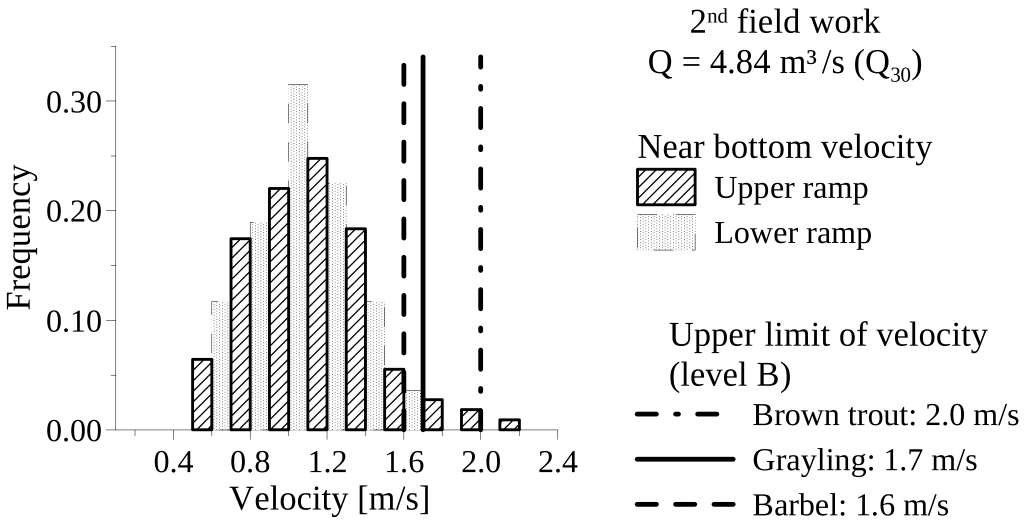


Fig. 4.4.16(b): Near bottom velocity (at z = 2.8 cm) distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 2nd fieldwork, Oct.25.2006; Discharge: Q = 4.84 m³/s (Q_{30})

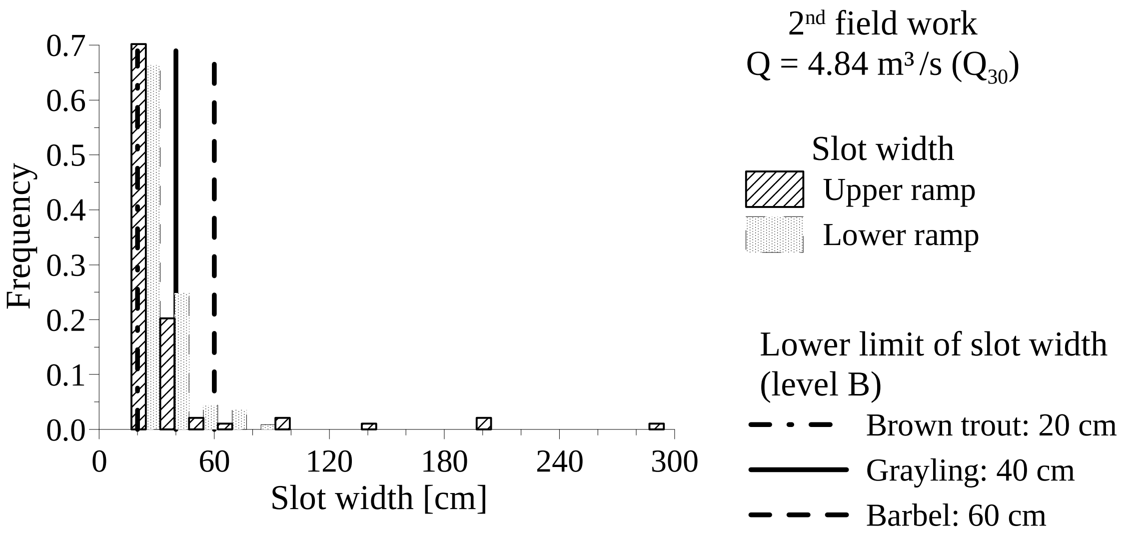


Fig. 4.4.17: Slot width distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 2nd fieldwork, Oct.25.2006; Discharge: Q = 4.84 m³/s (Q_{30})
Note: slots were not measured if the slot width was less than 15 cm.

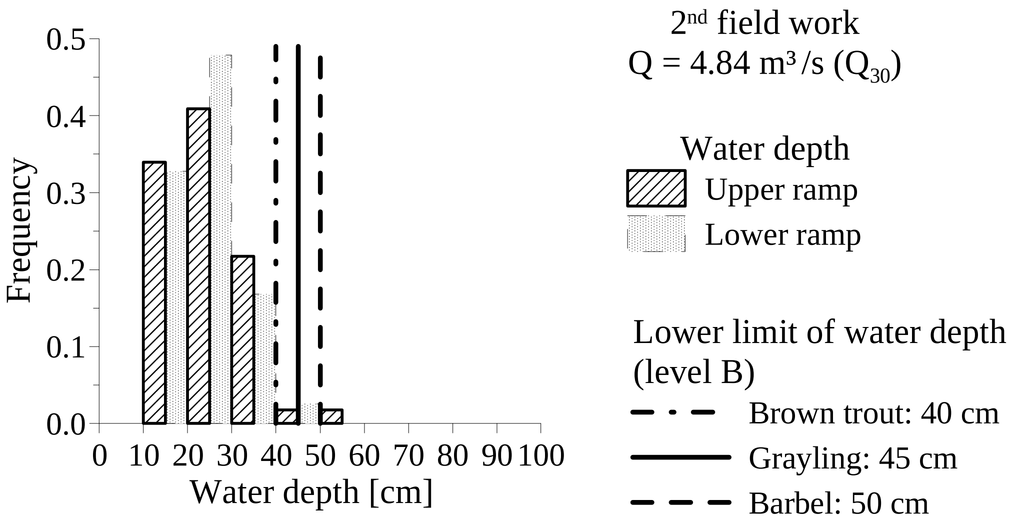
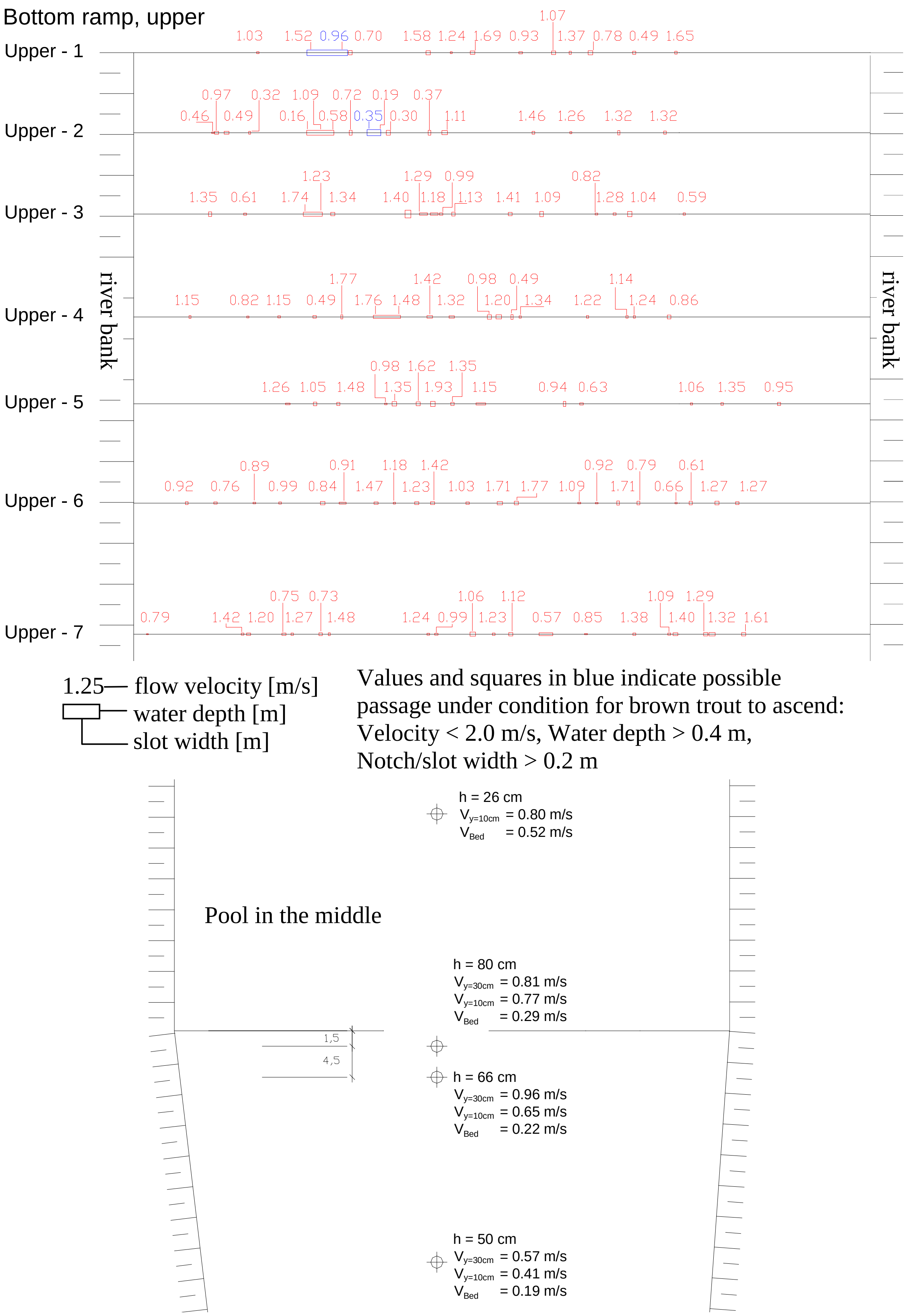


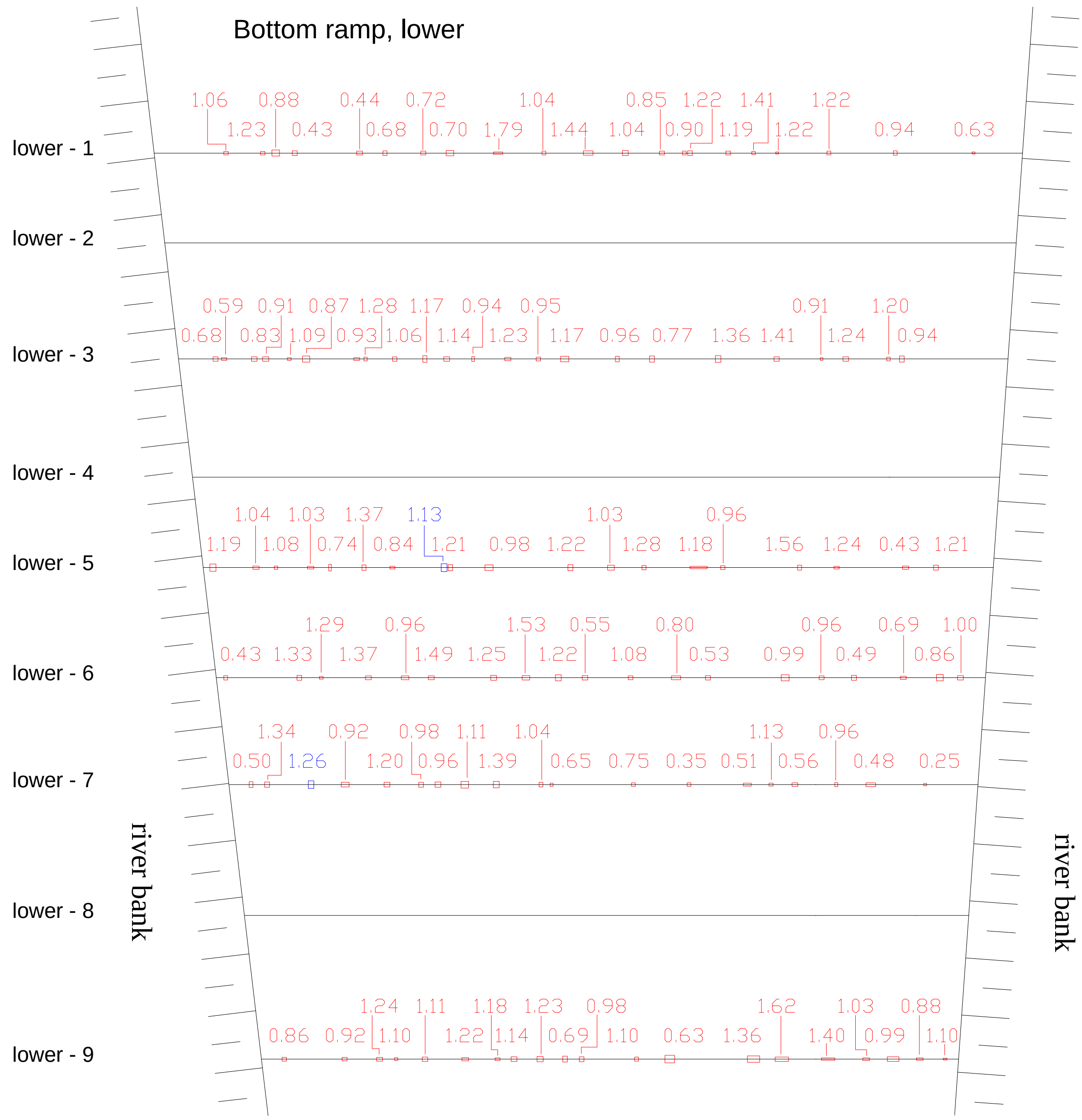
Fig. 4.4.18: Water depth distribution of the measured possible passage for fish at the bottom ramp Kolbermoor

Date: 2nd fieldwork, Oct.25.2006; Discharge: Q = 4.84 m³/s (Q_{30})
Note: slots were not measured if the water depth was less than 10 cm.



Values and squares in blue indicate possible passage under condition for brown trout to ascend: Velocity < 2.0 m/s, Water depth > 0.4 m, Notch/slot width > 0.2 m

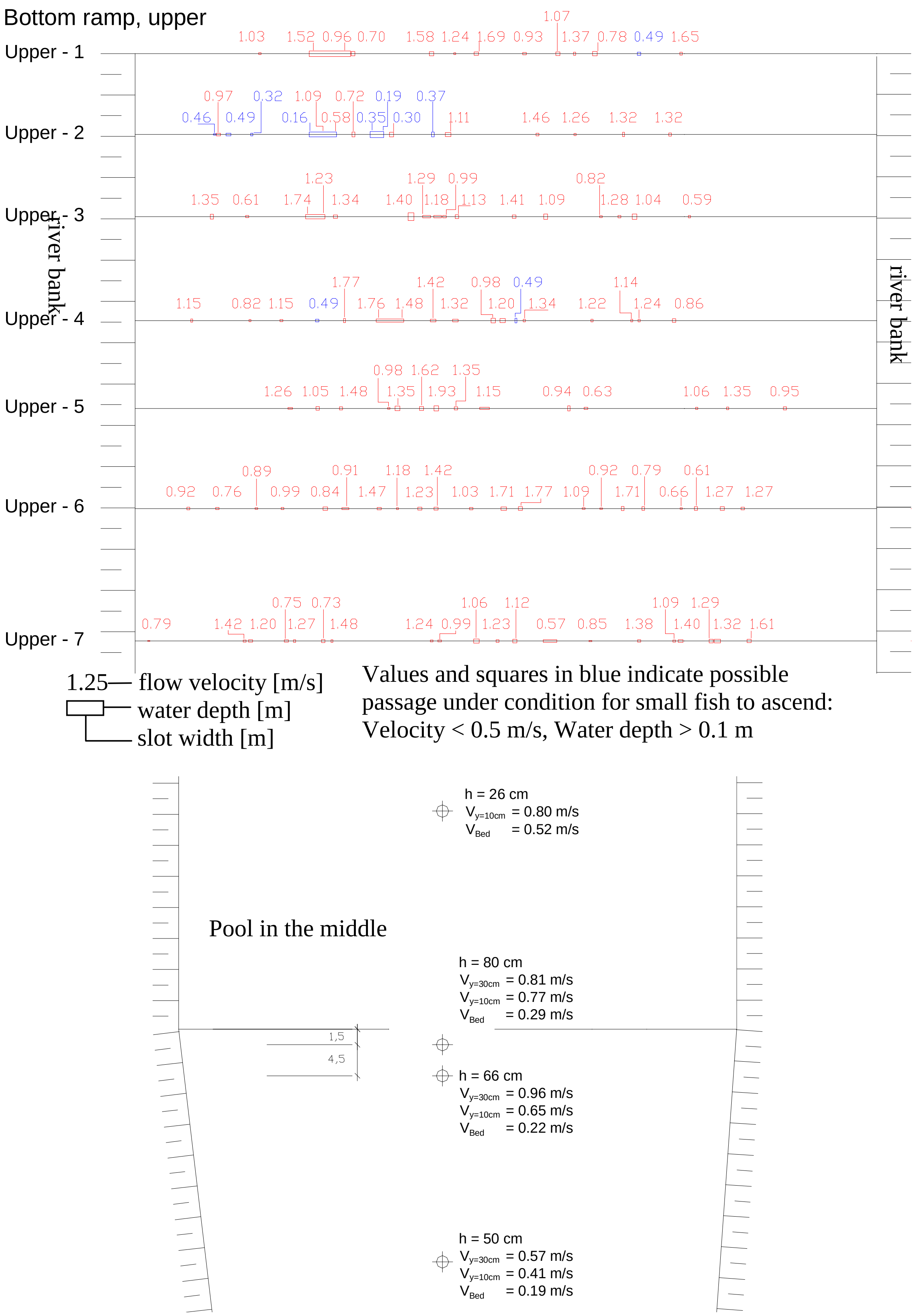
Fig. 4.4.19: Distribution of possible passage for brown trout at the bottom ramp Kolbermoor during low flow (Q_{30}), fieldwork on Oct.25.2006



1.25— flow velocity [m/s]
▭— water depth [m]
└— slot width [m]

Values and squares in blue indicate possible passage under condition for brown trout to ascend:
Velocity < 2.0 m/s, Water depth > 0.4 m,
Notch/slot width > 0.2 m

Fig. 4.4.19(conti.): Distribution of possible passage for brown trout at the bottom ramp Kolbermoor during low flow (Q_{30}), fieldwork on Oct.25.2006



Values and squares in blue indicate possible passage under condition for small fish to ascend: Velocity < 0.5 m/s, Water depth > 0.1 m

Fig. 4.4.20: Distribution of possible passage for small fish species at the bottom ramp Kolbermoor during low flow (Q_{30}), fieldwork on Oct.25.2006

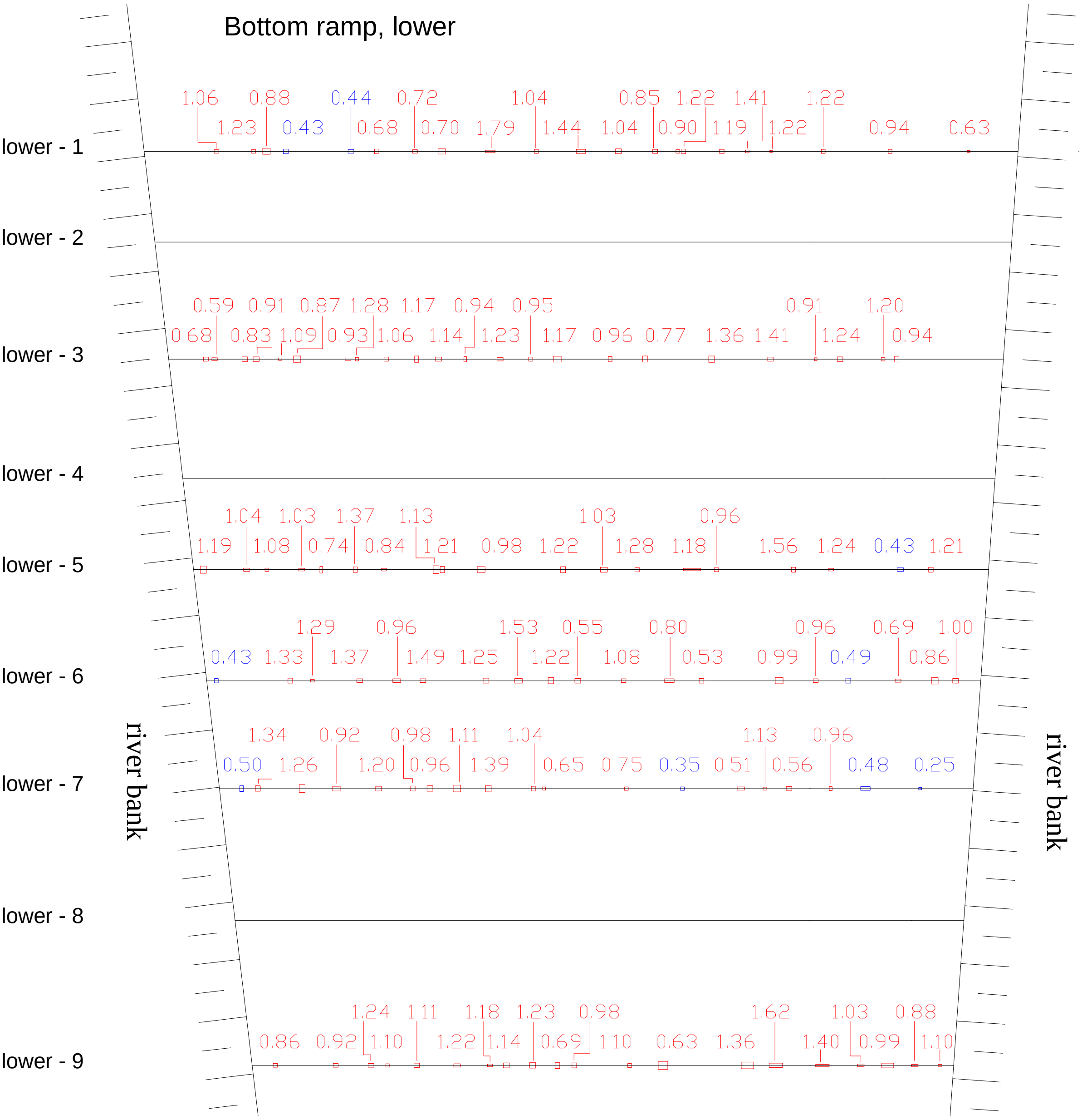


Fig. 4.4.20(conti.): Distribution of possible passage for small fish species at the bottom ramp Kolbermoor during low flow (Q_{30}), fieldwork on Oct.25.2006

Fig. 4.4.21(a): During low flow condition, no overflow at some parts of the ramp

Fig. 4.4.21(b): In the middle at the first boulder sill of upper ramp, flow concentrated well during low flow.

Fig. 4.4.21(c): View of the upper ramp from upstream

Fig. 4.4.21(d): Close view of the upper ramp from downstream. Seems to be lack of suitable passage

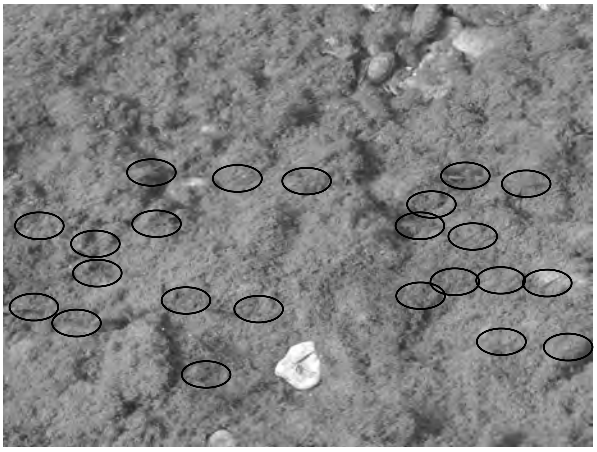


Fig. 4.4.21(e): Many small fish were observed.

Fig. 4.4.21(f): View of the resting pool and the boulder sill.

4.4.3. Third field work: Sep. 06. 2007, Q: 56.4 m³/s, corresponding to 1.5 × Q_{330}

The third fieldwork at the bottom ramp Kolbermoor was carried out when the discharge in the river Mangfall came to approximate 330-day-nonexceedence-discharge, Q_{330}, for the investigation under a high flow condition. The discharge on the investigated day was 56.4 m³/s, which was equivalent to around 1.5 times of Q_{330}. The water in the river Mangfall on the day of fieldwork was very rapid and turbid; only the river bank of the upper ramp was available to reach for conducting the measurements. The measurements were performed at one point next to the right bank at each boulder sill (see Fig. 4.4.22). It is commonly believed that fish can use near bank regions to migrate during high flow period, because they provide relative lower flow velocity due to their rough boundaries. From the result it shows that the velocities were in the range between 0.8 and 1.3 m/s (Fig. 4.4.22); the river was impounded by the ramp (Fig. 4.4.23), and the water body seemed to be continuous without any possible barrier owing to the structure of boulder sills themselves. The flow velocity was appropriate for all the three representative fish species to migrate since all the measured values are below 1.6 m/s, which is the upper limit for barbell. The flow was, however, very turbulent to provide stilling zone for fish to take rest in such long distance migration route.

4.4.4. Monitoring of fish migration

The fish capture and mark were conducted in May and September of 2006 for two to three days by electric-fishing upstream and downstream of the ramp. The captured fish were marked by dye injection to indicate the locations where they were captured. Fish stocking released during investigation period was marked as well. The monitoring were conducted several months (September 2006 and April 2007) later to detect the distribution of marked fish. Anglers were informed to report back if they angled marked fish. The biological investigation was not conducted at the fish ramp Schwaig, which locates 2 km downstream from the bottom ramp Kolbermoor, due to restricted funding and personnel resources.

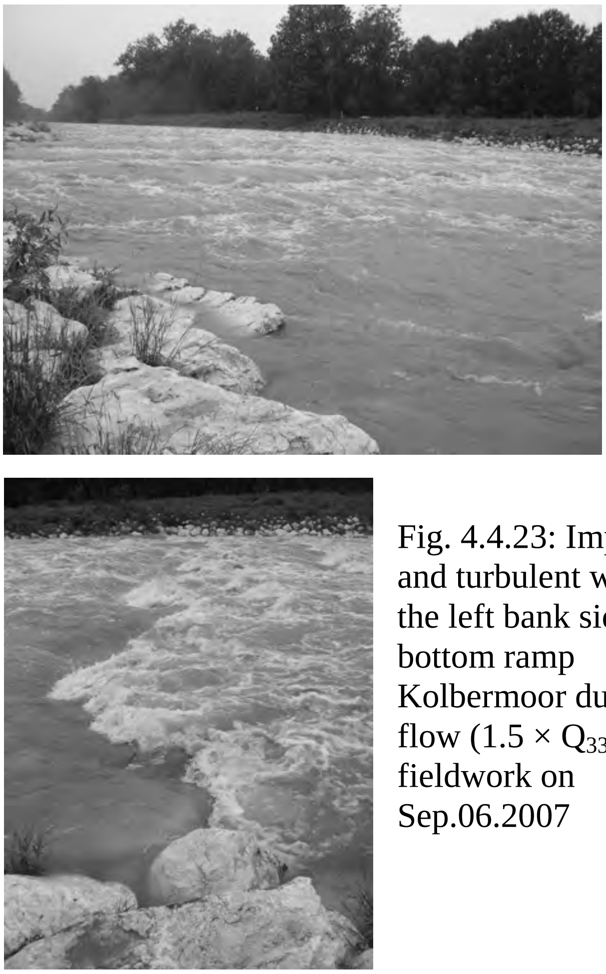


Fig. 4.4.23: Impounded and turbulent water at the left bank side of the bottom ramp Kolbermoor during high flow (1.5 × Q_{330}), fieldwork on Sep.06.2007

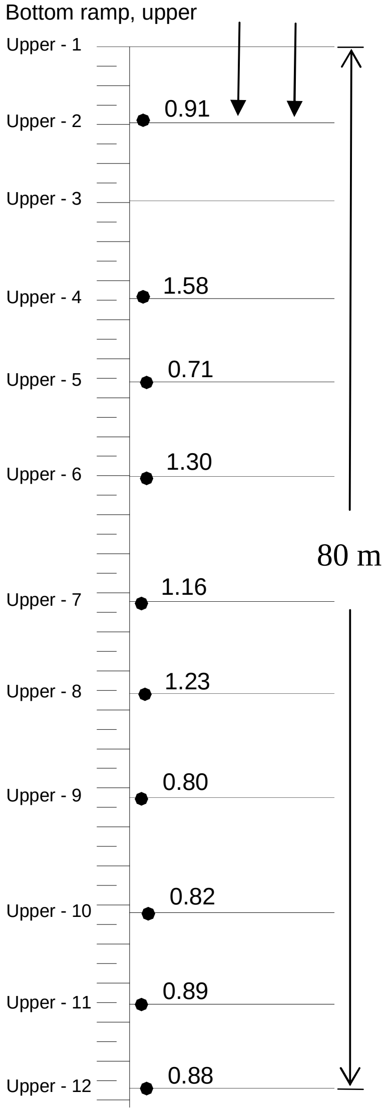


Fig. 4.4.22: Velocity distribution at the left bank side of the bottom ramp Kolbermoor during high flow (1.5 × Q_{330}), fieldwork on Sep.06.2007

Table 4.4.6: The schedule of monitoring work at the bottom ramp Kolbermoor

Period	Subject	Working hour	Note
May 2006	E-fisching + mark	2 – 3 days	Begin of 1st round
September 2006	E-fisching + monitoring + mark	2 – 3 days	End of 1st round Begin of 2nd round
	Mark of fish stocking	1 day	
April 2007	E-fishing + monitoring	2 – 3 days	End of 2nd round
	Count from anglers	1 day	

Note: schedule by Bavarian Fishing Accociation

The numbers of the total electric-fishing samples were 396 and 213 individuals upstream and downstream of the bottom ramp, respectively. Only those captured fish with body length exceeding 10 cm were marked. In the 2nd investigation, the numbers of the captured fish with mark of the 1st investigation were 11 and 4 individuals upstream and downstream of the bottom ramp respectively. Only 1 of the 11 fish migrated from downstream to upstream and 3 of the 4 migrated in the other direction. The result seems to show a bad performance of the ramp as a fish migration facility. However, the time interval between the capture and the recapture investigations was approximate two months, which is too long for a valid investigation. The result provides in fact little information and can even hardly give a qualitative evaluation.

Table 4.4.7: Fish count of E-fishing in the two investigations (Bavarian Fishing Asso.)

Fish species	1st : upstream	1st : down-	2nd : upstream	2nd : down-
European Chub	177	107	110	121
Grayling	13	–	6	20
Barbel	157	86	34	28
Brown trout	1	–	3	112
Nase	13	–	16	–
Rainbow trout	8	–	23	82
Gudgeon	4	–	–	–
Roach	1	–	–	–
Perch	1	–	–	–
Dace	–	19	1	–
Huchen	–	–	–	5
Sum	396	213	203	372
	609		575	

4.4.5. Conclusion

The bottom ramp Kolbermoor is the largest ramp in dimension in the river system of Mangfall. It is taken as an indicator to know whether there is an upper limit of dimensions when applying such ramps in river engineering.

To examine the free passage for fish migration at the bottom ramp Kolbermoor, two field investigations were done in 2006 and one was in 2007. From the results of the first field investigation (mean flow condition) it shows that there were 169 and 205 opening slots observed at the upper and the lower ramps according to the criteria on dimensions of openings, in which there were 8 to 19 and 12 to 25 opening slots per each sill, respectively. These opening slots showed a high potential on providing free passage for fish to migrate; however, to examine the results of the measurements with the criteria of the representative fish species, it indicates that the main problem for brown trout is the water depth and that for small fish species is the velocity.

In the first fieldwork, every boulder sill at the ramp was detailed investigated to study whether some of them would be barriers. If one of the sills can not provide a proper condition as possible free passage, the whole structure would be failed to be a construction for fish to successfully migrate through. In the second fieldwork, seven of the sills at the upper ramp and six of the sills at the lower ramp were selected for measurements to reduce the load of the fieldwork.

In the second fieldwork (low flow condition) it seemed that visually the ramp didn't provide many potential passage slots but the investigation results show that there were 116 and 119 opening slots observed at the upper and the lower ramps according to the criteria on dimensions of openings, in which there were 12 to 22 and 19 to 21 opening slots per each sill, respectively. However, to examine the results of the measurements with the criteria of the representative fish species, most of the opening slots are not assessed to be good for the selected representative species, brown trout and small species.

The last boulder sills at the upstream side of a ramp usually form a critical cross section which should be paid more attention on the structure. A reduced head per sill and a larger opening slot in the middle of a cross section at the last sills are suggested to improve this critical condition.

The assessed possible passage corridors for small fish species in the result of the fieldwork were done under more strict criteria when comparing with conditions *in situ*. Because some openings had dimensions less than 15 cm in width or less than 10 cm in depth and they were ignored to be measured. They may however probably provide passages for small species.

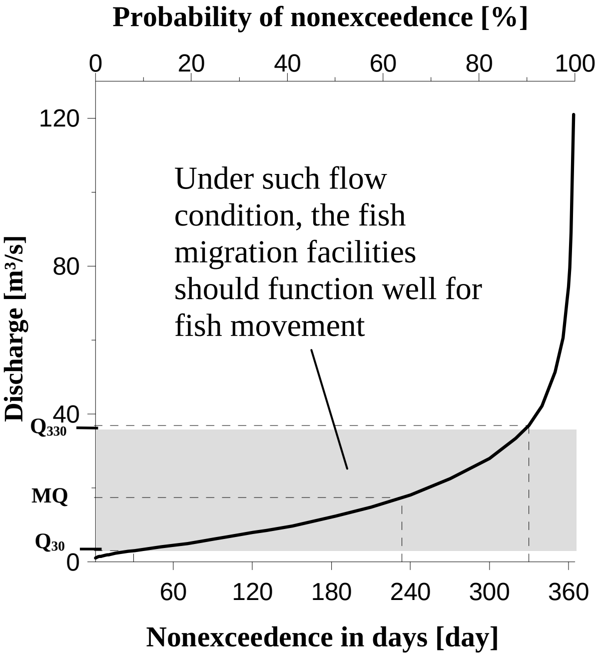
4.5. Case 2: Fish ramp “Schwaig”

The fish ramp Schwaig was built at an existing weir to replace part of the structure and to reestablish a free passage for fish and other aquatic fauna in the river Mangfall. Disregarding of several individual boulder sills in the reach between Schwaig and the convergence of the river Mangfall and the river Inn in Rosenheim, the fish ramp in Schwaig is the first ramp construction that fish will encounter during upstream migration in the river Mangfall.

The weir was originally 47 m in width while the fish ramp is approximate 35 m in length and 20 m in width. The fish ramp Schwaig consists of perturbation boulders to maintain an adequate water depth. The fish ramp is constructed as compounded cross sections, including a deep water zone adjacent to the weir and a shallow water zone at the left bank, which provide higher hydraulic diversity during seasonal flow variation.

The problems at this fish ramp were supposed to be too shallow flow depths owing to the structure of the perturbation boulders and the direction of a secondary attraction flow under the weir.

Two field investigations were conducted in May and October 2006 to study the flow conditions of mean flow (MQ) and low flow (30-days-nonexceedence discharge, Q_{30}). The flow condition corresponding to high flow was observed in September 06. 2007 on the day before a flood event. Due to the unavailable and dangerous conditions for personnel, measurements were canceled.



Under such flow condition, the fish migration facilities should function well for fish movement

Probability of nonexceedence, P_r
$P_r[Q \leq Q_{p\%}] = P\ \%$

Nonexceedence in days, D_r
$D_r[Q \leq Q_{days}] = \text{Days}$

$Q_{30} = 3.06\ m^3/s$
$MQ = 17.40\ m^3/s$
$Q_{330} = 36.90\ m^3/s$

Fig. 4.5.1. Nonexceedence discharge curve at gauge station Rosenheim Mangfall

Table 4.5.1: General Information of the bottom ramp Schwaig

General information of the catchment	
Gauging station	Rosenheim / Mangfall (1966-2003)
River system	Mangfall
Catchment area	1,099.27 km^2
River order (Gewässerordnung)	I
Local authority	WWA Rosenheim
River width	40 ~ 45 m
Hydrological statistics [m^3/s]	NQ: 1.02; Q_{30}: 3.06 MQ: 17.40; Q_{330}: 36.90 HQ : 389.00
Geometry of barrier at the site	
Construction type: Weir type, other structures nearby	Weir for intake canal
Water use general information, e.g. off-line hydropower station, in-line (run-of-river) hydropower station, navigation lock	
The operation regime of the operational constructions (weir, sluices, hydropower plant)	Intake canal
Powerhouse hydraulic capacity, spillway hydraulic capacity	There is extract water need at this section in Mangfall
Instream flow need	1.3 m^3/s

Characteristics of the ramp:

Construction type of the ramp	Fish ramp with perturbation boulders
Geometry of the ramp	
Length and width of the ramp	Length: 35 m, Width: 20 m
bottom slope	1:25
Water head	1.70 m
Alignment of the ramp	
Location in relation with nearby structures and discharge division	The fish ramp replaces part of the existing weir which is used for water intake of Mangfall Canal at the left bank
Location in relation with nearby barriers	
Location of main current	The fish ramp is a compounded structure with deep water zone in the middle of cross section next to the weir and shallow water zone at the left bank side. Main current locates in the deep water region and there is overflow through weir and shallow water zone
Location of attraction flow and angle	There are two attraction flow: main flow in the deep water zone and a secondary attraction below the weir with angle 45°
Number of possible wrong attractions	1
Safety of the ramp beginning	Steel sheet pile

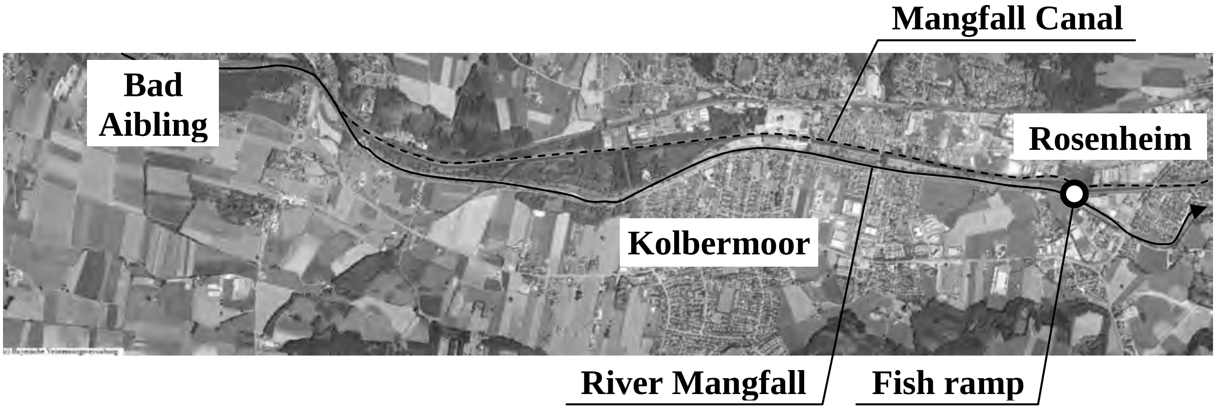


Fig 4.5.2: Location of the fish ramp Schwaig in the river Mangfall

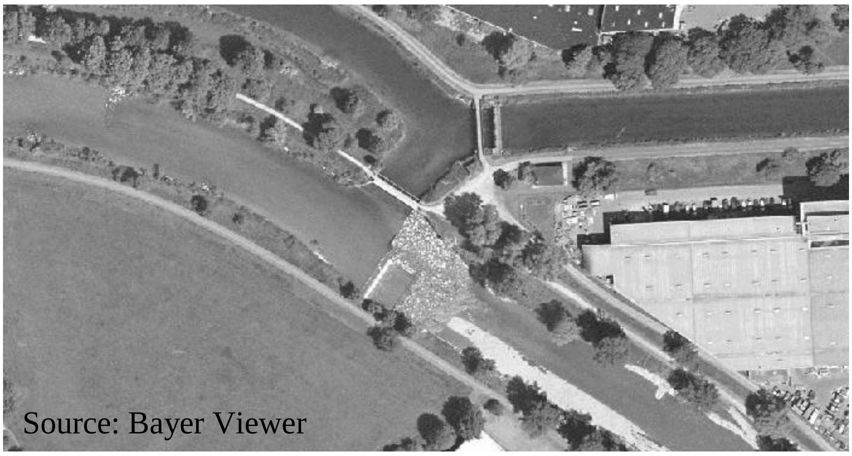


Fig 4.5.3: Bird’s eye view of the bottom ramp Schwaig

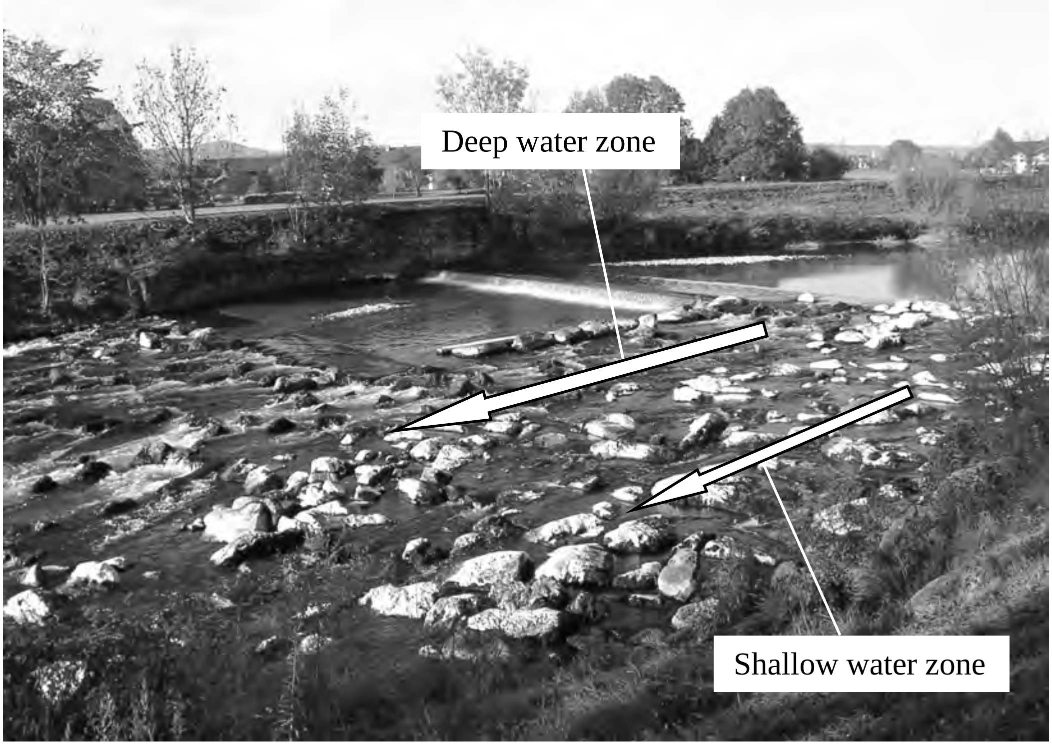


Fig. 4.5.4(a): Fish ramp Schwaig in the river Mangfall, photo made on Oct.26.2006, Q = 4.84 m³/s (correspond to Q_{30})

Fig. 4.5.4(b): Fish ramp Schwaig in the river Mangfall, photo made on Sep.03.2007, Q = 56.4 m³/s (correspond to 1.5 × Q_{330})

Due to personnel and financial restrictions, no biological tests were conducted at the fish ramp Schwaig. Since the fish ramp Schwaig is just 2.5 km downstream from the bottom ramp Kolbermoor, the captured fish species nearby Kolbermoor are used to be index species for the fish ramp Schwaig.

Table 4.5.2: Fish species in the river Mangfall nearby the bottom ramp Kolbermoor

Fish species[1]		in German[2]	Max. size[3] [cm]
European Chub	(*Leuciscus cephalus*)	Aitel	60
Grayling	(*Thymallus thymallus*)	Äsche	60
Barbel	(*Barbus barbus*)	Barbe	120
Brown trout	(*Salmo trutta fario*)	Bachforelle	100
Nase	(*Chondrostoma nasus*)	Nase	50
Minnow	(*Phoxinus phoxinus*)	Elritze	14
Rainbow trout	(*Onchorhynchus mykiss*)	Regenbogenforelle	120
Gudgeon	(*Gobio gobio gobio*)	Gründling	20
Stone loach	(*Barbatula barbatula*)	Schmerle	21
Roach	(*Rutilus rutilus*)	Rotauge	46
Bullhead	(*Cottus gobio*)	Koppe	18
Perch	(*Perca fluviatilis*)	Flussbarsch	51
Dace	(*Leuciscus leuciscus*)	Hasel	40
Huchen	(*Hucho hucho*)	Huchen	150

[1] Scientific names from FishBase

[2] Data: Bavarian Fishing Association (Landesfischereiverband Bayern)

[3] Reported max. size from FishBase

Brown trout, grayling and barbel are selected as representatives of species for different requirements on geometrical and hydraulic conditions in fish migration facilities.

Table 4.5.3: Assessment of the minimum water depth in fish migration facilities: level of assessment = B (good)

Species	Brown trout	Grayling, Dace	Barbel, pike
Body length up to [cm]	40	60	120
Min. water depth [m]	0.4	0.45	0.5
Width of notches and narrow slots [m]	0.2 ~ 0.4	0.4 ~ 0.6	0.6
Max. water level difference [m]	0.2	0.15	0.13
Max. flow velocity in notches and narrow slots [m/s]	2.0	1.7	1.6

4.5.1. First field work: May. 23. 2006, Q: 11.0 m³/s, corresponding to about MQ

The first field investigation at the fish ramp Schwaig was carried out on May.23.2006. The discharge at the nearest gauge station on that day in the river Mangfall was 11.0 m³/s, which corresponded to approximate mean flow, MQ.

From the histograms of the results in Fig. 4.5.5 and Fig. 4.5.6, it shows that at most opening slots, 89% of the measured velocities are less than 1.5 m/s at the deep water zone, while all of the measured velocities at the shallow water zone are less than 1.5 m/s. In addition, at the shallow water zone, approximate 27% of the measured velocities are less than 0.5 m/s. When comparing to the criteria for the representative species, apparently most of the measured velocities are below the upper limits for brown trout, grayling and barbel.

In Fig. 4.5.9 it shows clearly that the deep water zone locates just next to the exiting weir with a width of around 7.5 m. The attracting flow at the deep water zone is distinct with adequate water depths, which range from 10 to 100 cm and in which approximate 65% of the measured water depths ranges between 40 and 70 cm, as shown in Fig. 4.5.6 and Fig. 4.5.7. At the shallow water zone, around half of the measured water depths range from 10 to 30 cm. To examine the water depth for various species (Fig.4.5.6), the deep water zone can provide good conditions of water depths for brown trout, grayling and barbel.

In Fig. 4.5.7 illustrates the possible passage for brown trout. At the deep water zone a continuous migration corridor can be traced. There is a critical section in the middle of the deep water zone along the flow direction, where three of the four measured velocities were less than 30 cm and the other one was 50 cm, as shown in Fig. 4.5.7(b).

The boulders along this cross section can be considered to be modified for improvement of the migration corridor.

In Fig. 4.5.8 shows the same data examined again with migration criteria for small fish species, i.e. velocity ≦ 0.5m/s and water depth ≧ 10 cm. Most of the measured water depths are adequate for small fish; the dominant factor to assess the effectiveness of this ramp as a fish migration facility seems to be the flow velocity (Fig. 4.5.8(a)). However, measurements were conducted at slots where flow was plunging with local high velocities. The results show an underestimated assessment on the effectiveness of the ramp for small species.

The main problem at this fish ramp was supposed to be too shallow water depths due to the non-pool-weir (or non-cascaded) structure. However, from the results of the first fieldwork it shows that the water depth at the deep water zone provided appropriate flow for fish movement during the mean flow condition. It would be then important to examine the water depths at this ramp during the low flow period.

Table 4.5.4: 1st field investigation on May.23.2006

Min. and mean water depth	
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit)	Statistics of 1st field investigation (average ± standard deviation) V[m/s] H[cm] deep region 0.95 ± 0.43 50.4 ± 18.4 shallow region 0.64 ± 0.25 15.6 ± 7.0 V: velocity H: water depth
Hydraulic measurements	
discharge	Gauging station Rosenheim Mangfall on May.23: 11.0 m^3/s (≈ MQ)
Flow in the ramp and attraction flow	flow distributed uniformly over weir and ramp but more concentrate in the deep water region
Max. velocity at the slots	Deep water region: 2.00 m/s Shallow water region: 1.14 m/s

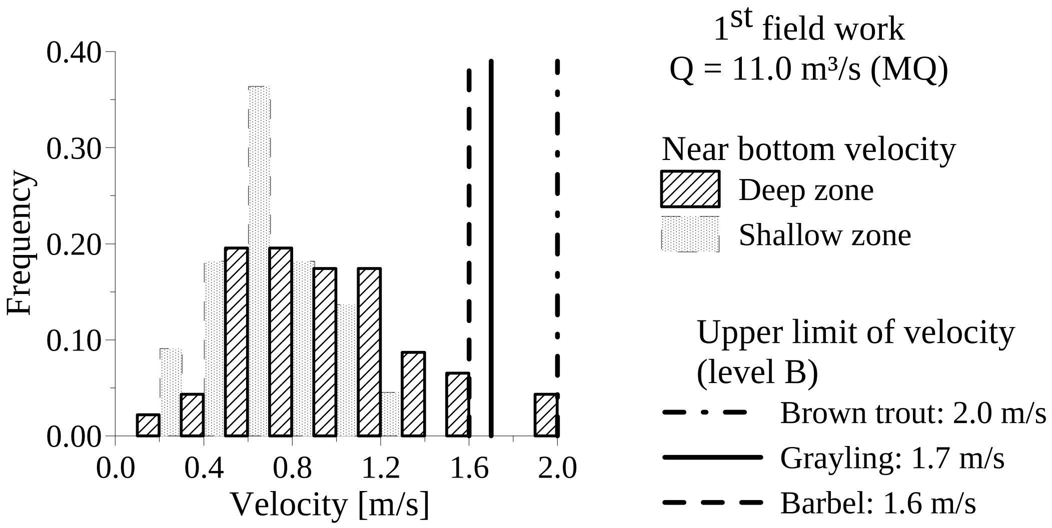


Fig. 4.5.5: Near bottom velocity (v at z = 2.8 cm) distribution of the measured possible passage for fish at the fish ramp Schwaig

Date: 1st field work, May.23.2006; Discharge: Q = 11.0 m³/s (MQ)

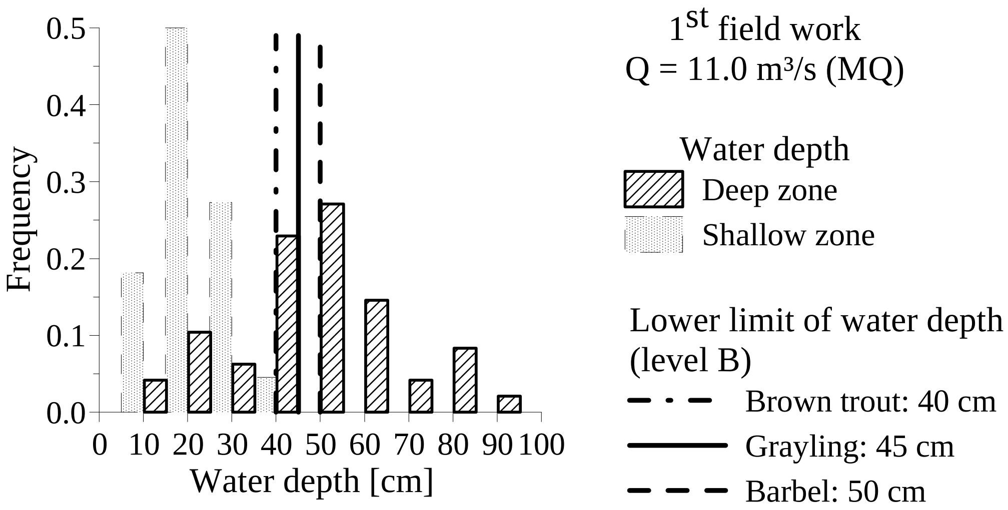
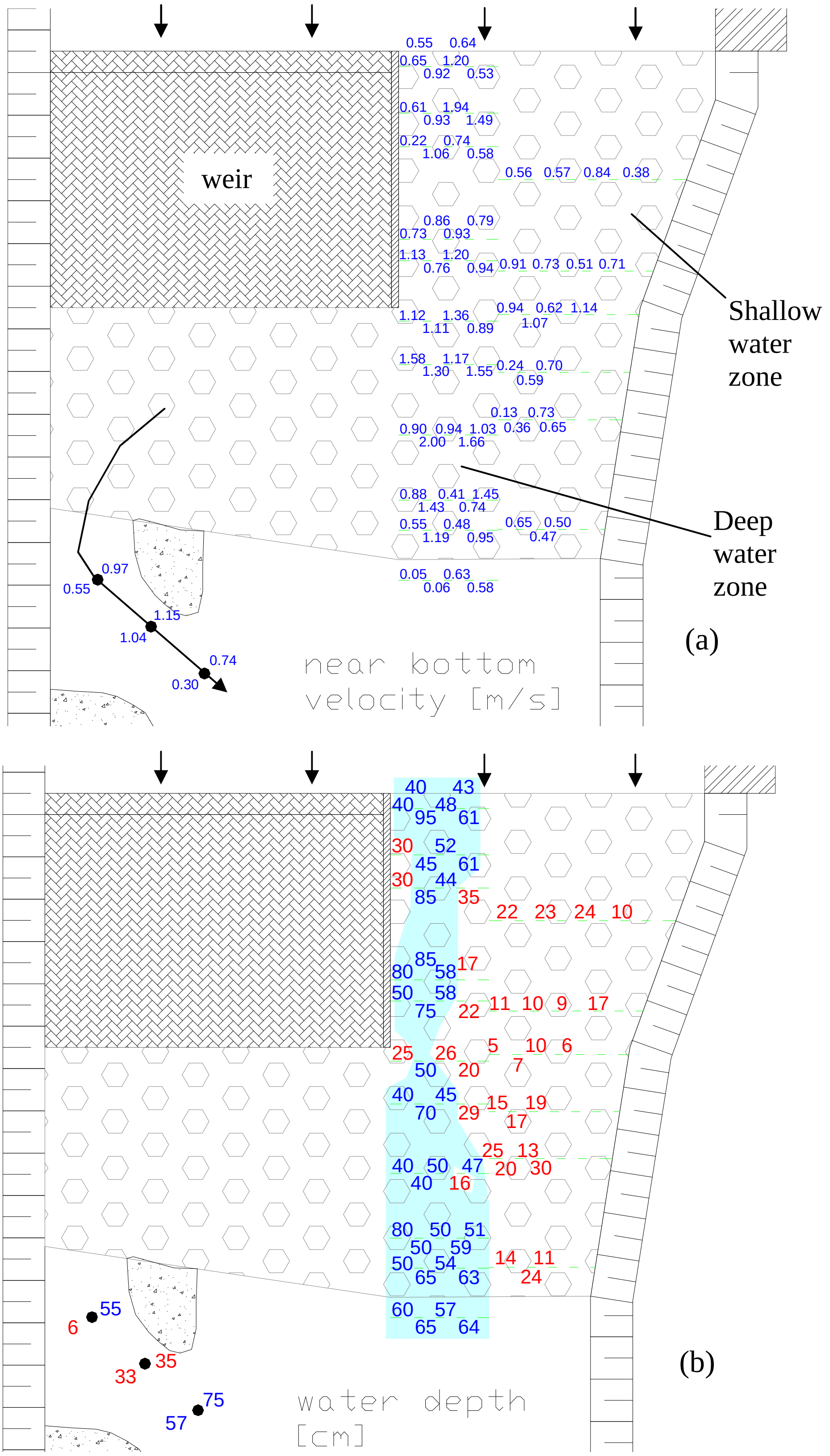


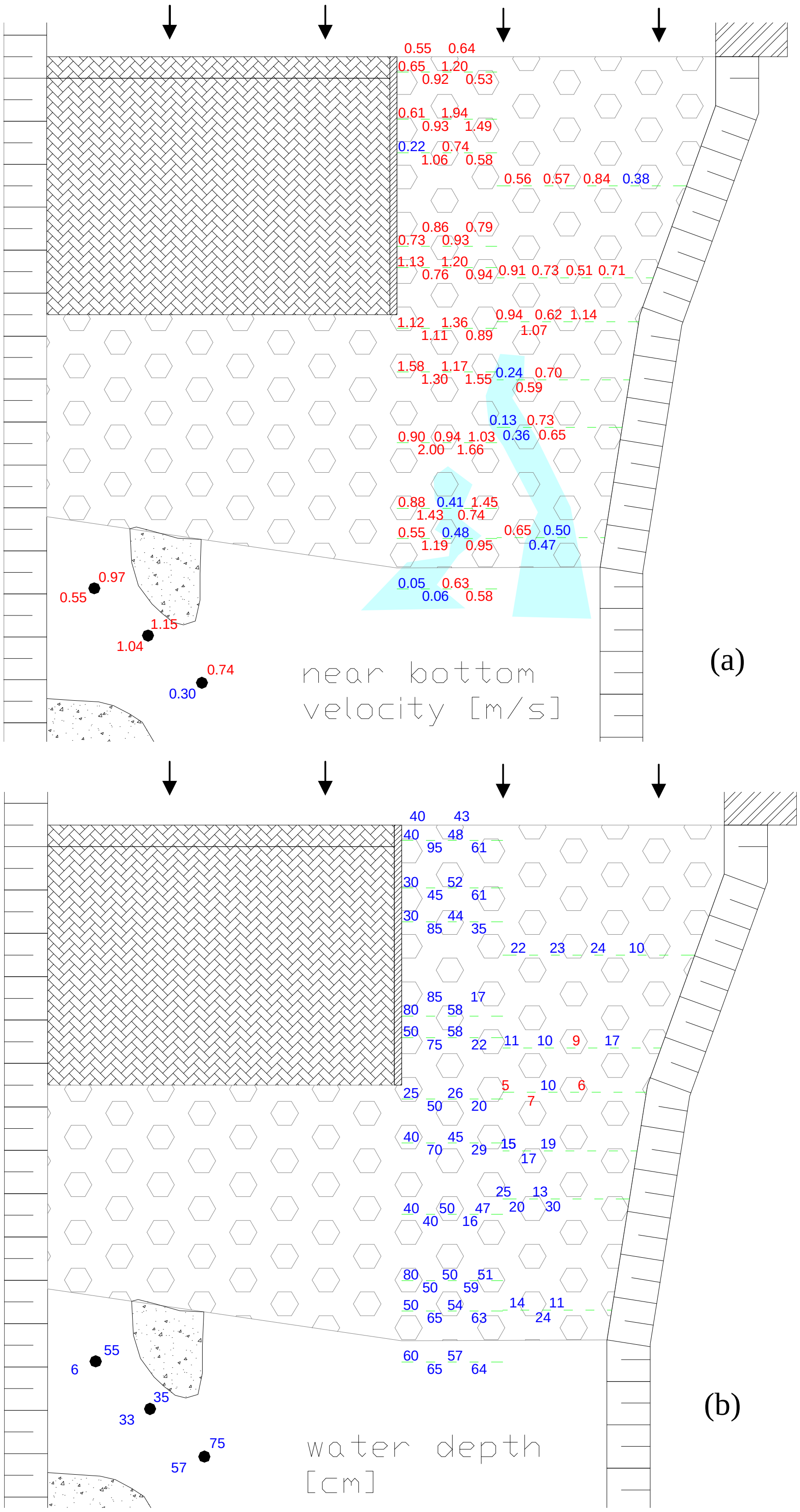
Fig. 4.5.6: Water depth distribution of the measured possible passage for fish at the fish ramp Schwaig

Date: 1st field work, May.23.2006; Discharge: Q = 11.0 m³/s (MQ)
Note: slots were not measured if the water depth was less than 10 cm.



Values and hatch in blue indicate possible passage under condition for brown trout to ascend: Velocity < 2.0 m/s, Water depth > 0.4 m,
Notch/slot widths were not examined in this case.

Fig. 4.5.7: Distribution of possible passage for brown trout at the fish ramp Schwaig during mean annual flow (MQ), fieldwork on May.23.2006



Values and hatch in blue indicate possible passage under condition for small fish species to ascend: Velocity < 0.5 m/s, Water depth > 0.1 m,
Notch/slot widths were not examined in this case.

Fig. 4.5.8: Distribution of possible passage for small fish species at the fish ramp Schwaig during mean annual flow (MQ), fieldwork on May.23.2006

(a)

(b)

(c)

Fig. 4.5.9: (a) Fish ramp Schwaig, downstream part; (b) Fish ramp Schwaig, upstream part; (c) Velocity measuring.

4.5.2. Second field work: Oct. 26. 2006, Q: 4.84 m³/s, corresponding to about Q_{30}

The second fieldwork at the fish ramp Schwaig was carried out on Oct.26.2006. The discharge at the nearest gauge station on that day in the river Mangfall was 4.84 m³/s, which corresponded to approximate low flow – 30-days-nonexceedence-discharge, MQ.

From the histogram of the velocity measurements shown in Figs. 4.5.10 and 4.5.12, it shows that the distribution of the near bottom velocity in the second fieldwork (Q_{30}) was quite similar to that in the first fieldwork (MQ, Figs. 4.5.5 and 4.5.7). The distribution of the near bottom velocity is slightly lower than the velocity at the position 10 cm above the bottom but there is no significant difference. All of the measured velocities were lower than the upper limits for brown trout, grayling and barbel.

Regarding to the water depth during this low flow condition, at every cross section, there were water depth exceeding 20 cm at the deep water zone; at the shallow water zone, 89% of the measured water depths were between 10 and 30 cm (Fig. 4.5.11).

Both deep and shallow water zones show adequate water depths for fish movement during low flow period for brown trout and small fish species (Fig 4.5.12~13).

Table 4.5.5: 2nd field investigation on Oct.26.2006

Min. and mean water depth	
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit) V: velocity H: water depth	Statistics of 2nd field investigation (average ± standard deviation) V_{10}[m/s] V_{bed}[m/s] H[cm] deep region 0.72 ± 0.45 0.95 ± 0.39 48.9 ± 17.1 V_{10}[m/s] V_{bed}[m/s] H[cm] shallow region 0.62 ± 0.27 0.74 ± 0.25 19.0 ± 6.7
Hydraulic measurements	
discharge	Gauging station Rosenheim Mangfall on Oct.26: 4.84 m^3/s (≈ Q_{30})
Flow in the ramp and attraction flow	flow distributed uniformly over weir and ramp but more concentrate in the deep water region
Max. velocity at the slots	Deep water region: 1.61 m/s (V_{10}), 1.70 m/s (V_{bed}) Shallow water region: 1.13 m/s (V_{10}), 1.38 m/s (V_{bed})

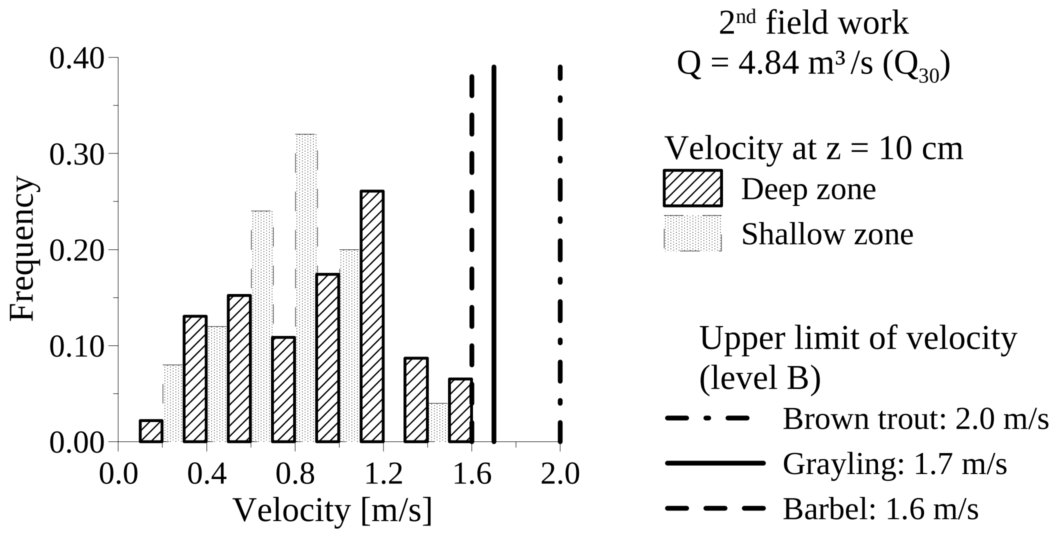


Fig. 4.5.10(a): Velocity at z = 10 cm distribution of the measured possible passage for fish at the fish ramp Schwaig

Date: 2nd fieldwork, Oct.26.2006; Discharge: Q = 4.84 m^3/s (Q_{30})

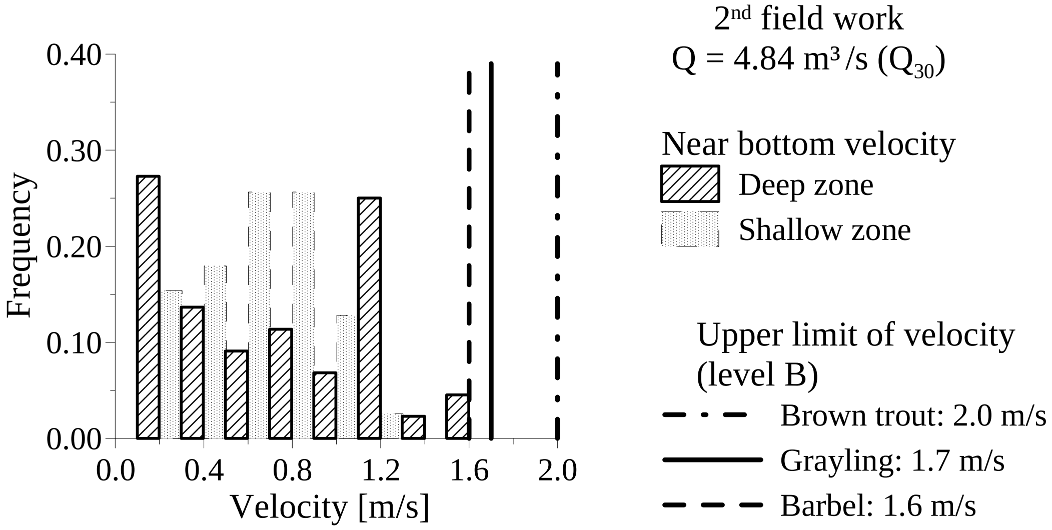


Fig. 4.5.10(b): Near bottom velocity (z = 2.8 cm) distribution of the measured possible passage for fish at the fish ramp Schwaig

Date: 2nd fieldwork, Oct.26.2006; Discharge: Q = 4.84 m³/s (Q_{30})

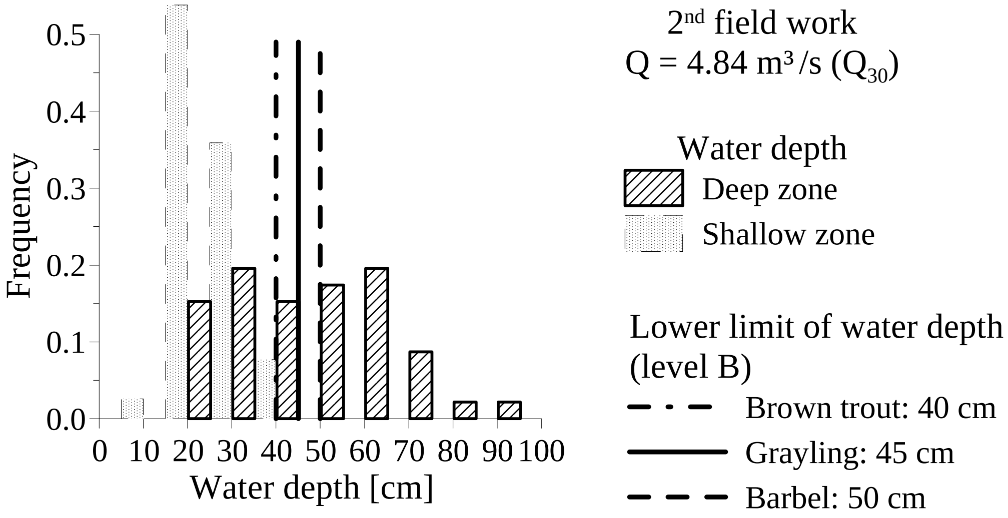
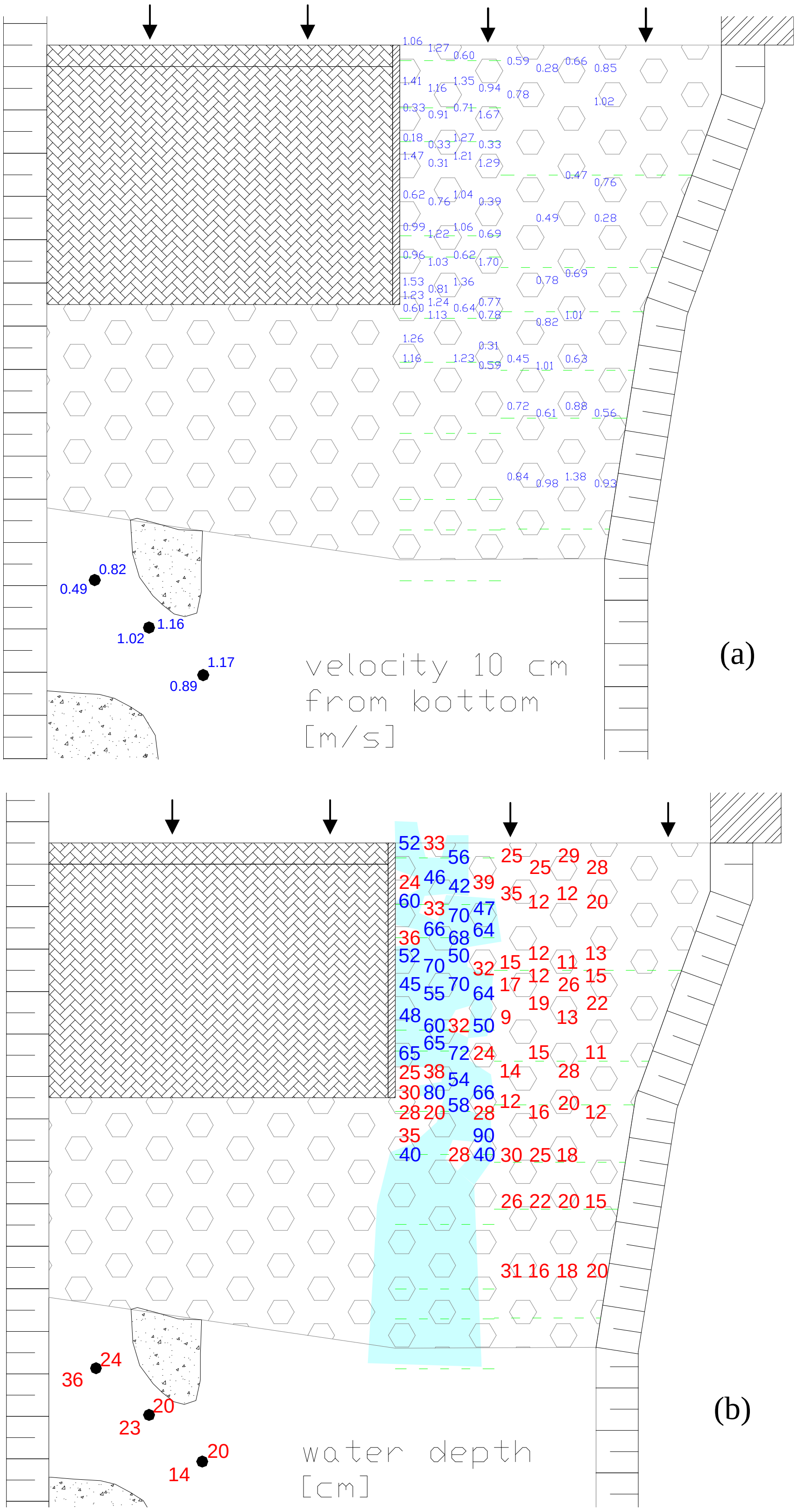


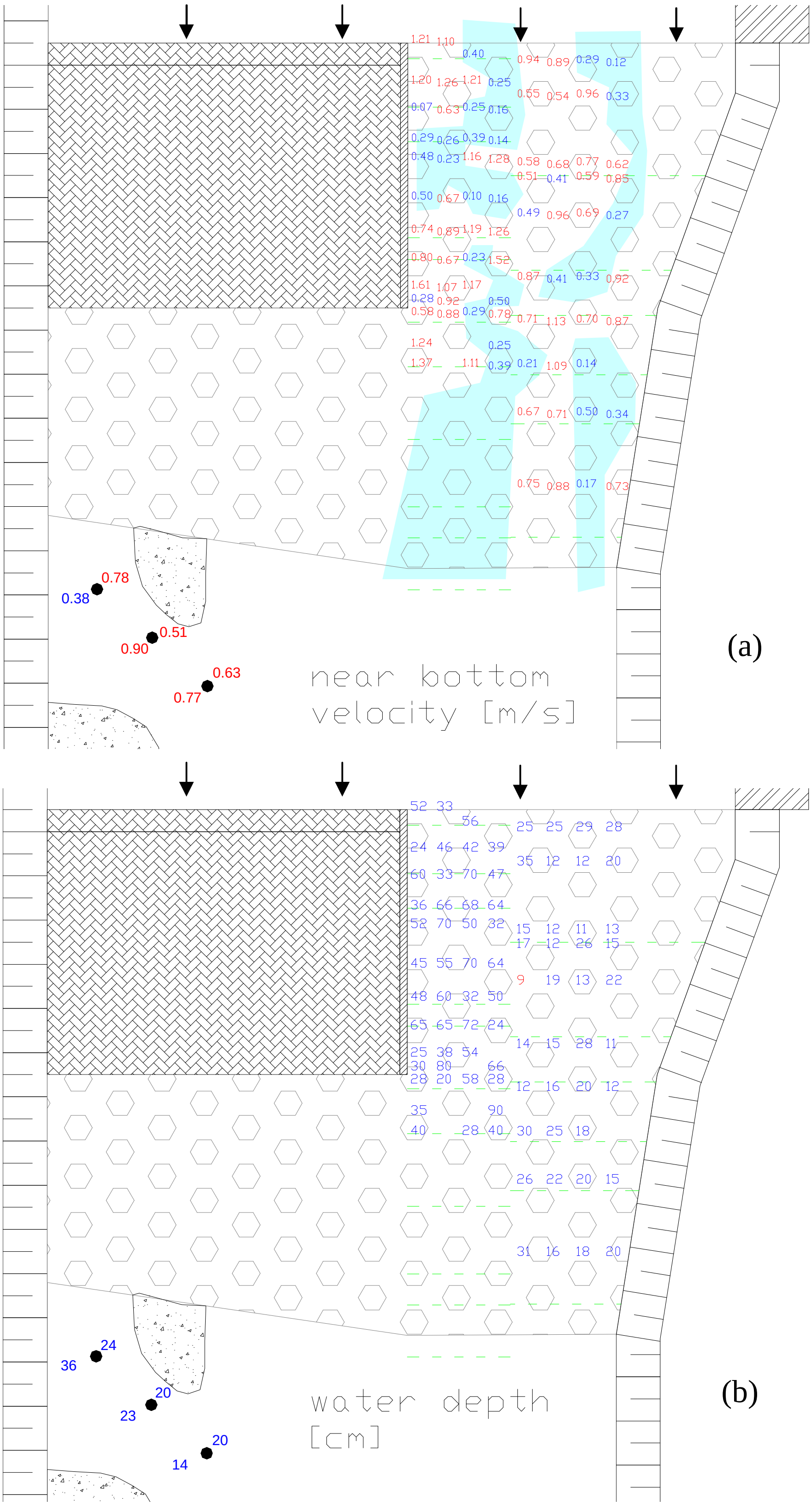
Fig. 4.5.11: Water depth distribution of the measured possible passage for fish at the fish ramp Schwaig

Date: 2nd fieldwork, Oct.26.2006; Discharge: Q = 4.84 m³/s (Q_{30})
Note: slots were not measured if the water depth was less than 10 cm.



Values and hatch in blue indicate possible passage under condition for brown trout to ascend: Velocity < 2.0 m/s, Water depth > 0.4 m,
Notch/slot widths were not examined in this case.

Fig. 4.5.12: Distribution of possible passage for brown trout at the fish ramp Schwaig during low flow (Q_{30}), fieldwork on Oct.26.2006



Values and hatch in blue indicate possible passage under condition for small fish species to ascend: Velocity < 0.5 m/s, Water depth > 0.1 m,
Notch/slot widths were not examined in this case.

Fig. 4.5.13: Distribution of possible passage for small fish species at the fish ramp Schwaig during low flow (Q_{30}) fieldwork on Oct.26.2006

4.5.3. Conclusion

Disregarding of several individual boulder sills in river section between Schwaig and the convergence of Mangfall and Inn in Rosenheim, the fish ramp in Schwaig is the first ramp construction that fish will encounter during upstream migration in the river Mangfall. The fish ramp in Schwaig is a non-pool-weir (or non-cascaded) structure but with perturbation boulders. A compounded cross section provide deep water region at the near weir side and shallow water region at the river bank side. The investigation of water depth during different flow conditions, especially during low flow, is the main course in this study.

From the result of the first fieldwork (mean flow) it shows that most measured water depth are between 40 an 70 cm in the deep water region and between 10 and 30 cm in the shallow water region, which provide good condition for fish migration.

From the result of the second fieldwork (low flow) it shows that most measured water depth are between 20 an 70 cm in the deep water region and between 10 and 30 cm in the shallow water region, which also provide good condition for fish migration. The result is similar as in the first fieldwork.

According to the results of the two field investigations, it indicates that there is no obvious difference of hydraulic parameters during mean flow and low flow conditions at this fish ramp with perturbation boulders. That figures out the principle of a well-designed prototype on fish-friendly bottom ramps / fish ramps: an effective bottom / fish ramp should provide suitable fish free passage with least influence of flow seasonal variation.

At one position of the deep water region, a drop height over 30 cm was observed. The fish ramp could be adjusted and be improved at some points. Since there is no obvious single barrier at a whole cross section, improvement of hydraulic condition at individual points is not necessary.

4.6. Case 3: Bottom ramp “Plackermühle”

The brook Kalten remains meandering. The bottom ramp Plackermühle replaced an old mill weir and was constructed under a few restricted conditions. Several meters upstream of the ramp is a small wooden bridge, at the one third length of the whole structure, there is a mini woody island in water, the foot of the ramp locates below the old mill factory and the left bank side is just next to a road (shown in Fig. 4.6.2).

The bottom ramp Plackermühle is about 50 m in length and 18 m in width. The designed bottom slope is 1:15 (6.7%), cascaded type, and constructed by armourstones, which are also used to protect the mini island and the river bank. The problems at this bottom ramp were supposed to be too high drop heights and too turbulent. Two field investigations were conducted in May and August 2006 to study the flow conditions during Q_{30} and Q_{330}.

Table 4.6.1: General Information of the fish ramp Leitner Mühle

General information of the catchment	
Gauging station	Hohenofen (1999 -2002) (no sufficient data to draw the nonexceedence discharge curve)
River system	Kalten
Catchment area	106.34 km^2
Local authority	WWA Rosenheim
River width	15 m
Hydrological statistics [m³/s]	NQ: 0.04 Q_{30}: 1.40 MQ: 2.81 Q_{330}: 4.24 ~ 5.3* HQ : 39.80
Geometry of barrier at the site	
Construction type: Weir type, other structures nearby	mill weir (removed)
Water use general information	
Powerhouse hydraulic capacity, spillway hydraulic capacity	Old mill factory (out of service)

* see Ch. 2.4.1

Characteristics of the ramp:

Construction type of the ramp	Cascaded bottom ramps
Geometry of the ramp	
Length and width of the ramp	Length: 50 m Width: 18 m
bottom slope	1:17
# of sills	ca. 8
Head per sill	ca. 15 ~ 32 cm during low flow (Q_{30})
Min. and mean net width and length of the pool-type structure (dimension of the pool)	Not measured since no problem observed
Alignment of the ramp	
Location in relation with nearby structures and discharge division	The bottom ramp replaces the old mill weir
Location in relation with nearby barriers	
Location of main current	The bottom ramps cross the whole river width and replace the weir; flow in river is the main current and attraction flow.
Distance between entrance / exit and barriers	

The fish species in the brook Kalten nearby the bottom ramp Plackermühle are listed in Table 4.6.2. The list is based on data of captured fish on the electric-fishing result during the investigation by the Bavarian Fishing Association.

Table 4.6.2: Fish species in the brook Kalten nearby the bottom ramp Plackermühle

Fish species[1]		in German[2]	Max. size[3] [cm]
European chub	(*Leuciscus cephalus*)	Aitel	60
Grayling	(*Thymallus thymallus*)	Äsche	60
Brown trout	(*Salmo trutta*)	Bachforelle	100
Barbel	(*Barbus barbus*)	Barbe	120
Carp bream	(*Abramis brama*)	Brachse	82
Perch	(*Perca fluviatilis*)	Flussbarsch	51
Gudgeon	(*Gobio gobio gobio*)	Gründling	20
Northern pike	(*Esox lucius*)	Hecht	137
Nase	(*Chondrostoma nasus*)	Nase	50
Common carp	(*Cyprinus carpio carpio*)	Karpfen	120
Burbot	(*Lota lota*)	Rutte	180
Roach	(*Rutilus rutilus*)	Rotauge	46
Rudd	(*Scardinius erythrophthalmus*)	Rotfeder	51
Bleak	(*Alburnus alburnus*)	Laube	25
Riffle minnow	(*Phenacobius catostomus*)	Schneider	12
Dace	(*Leuciscus leuciscus*)	Hasel	40

[1] Scientific names from FishBase

[2] Data: Bavarian Fishing Association (Landesfischereiverband Bayern)

[3] Reported max. size from FishBase

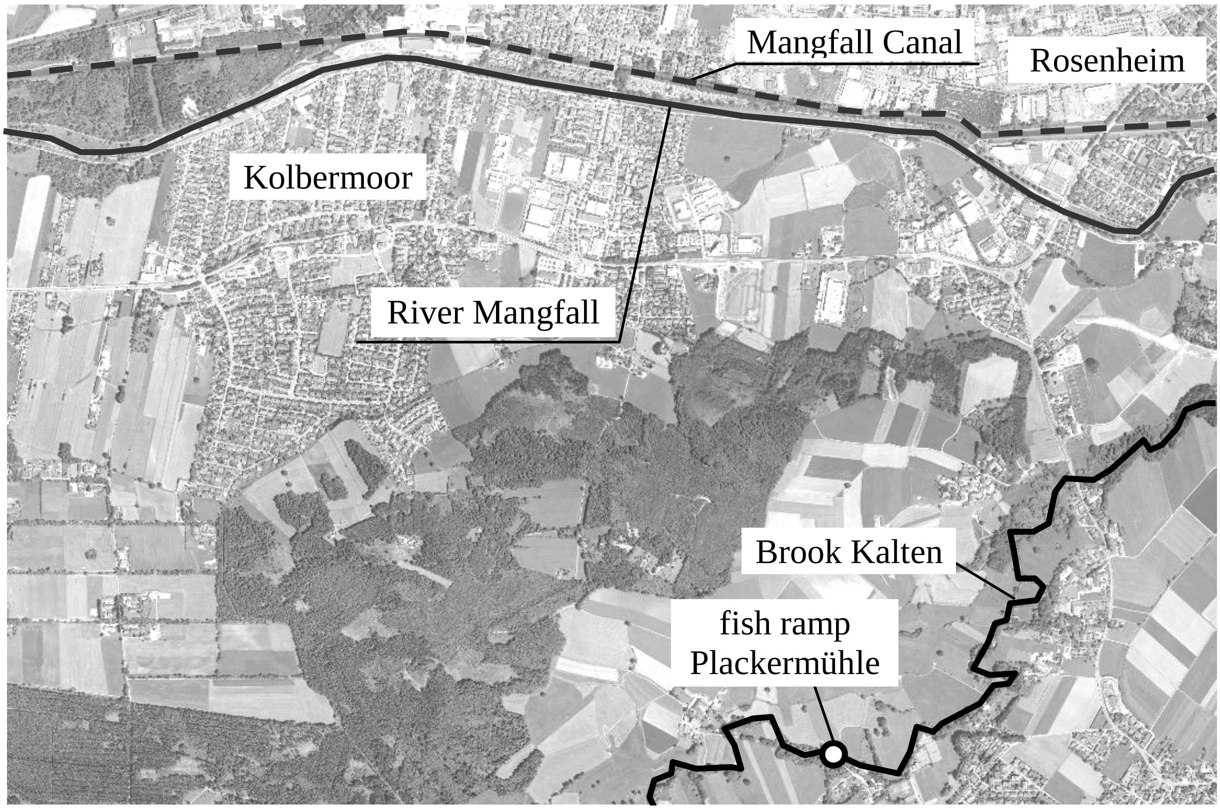


Fig 4.6.1: Location of the bottom ramp Plackermühle in the brook Kalten

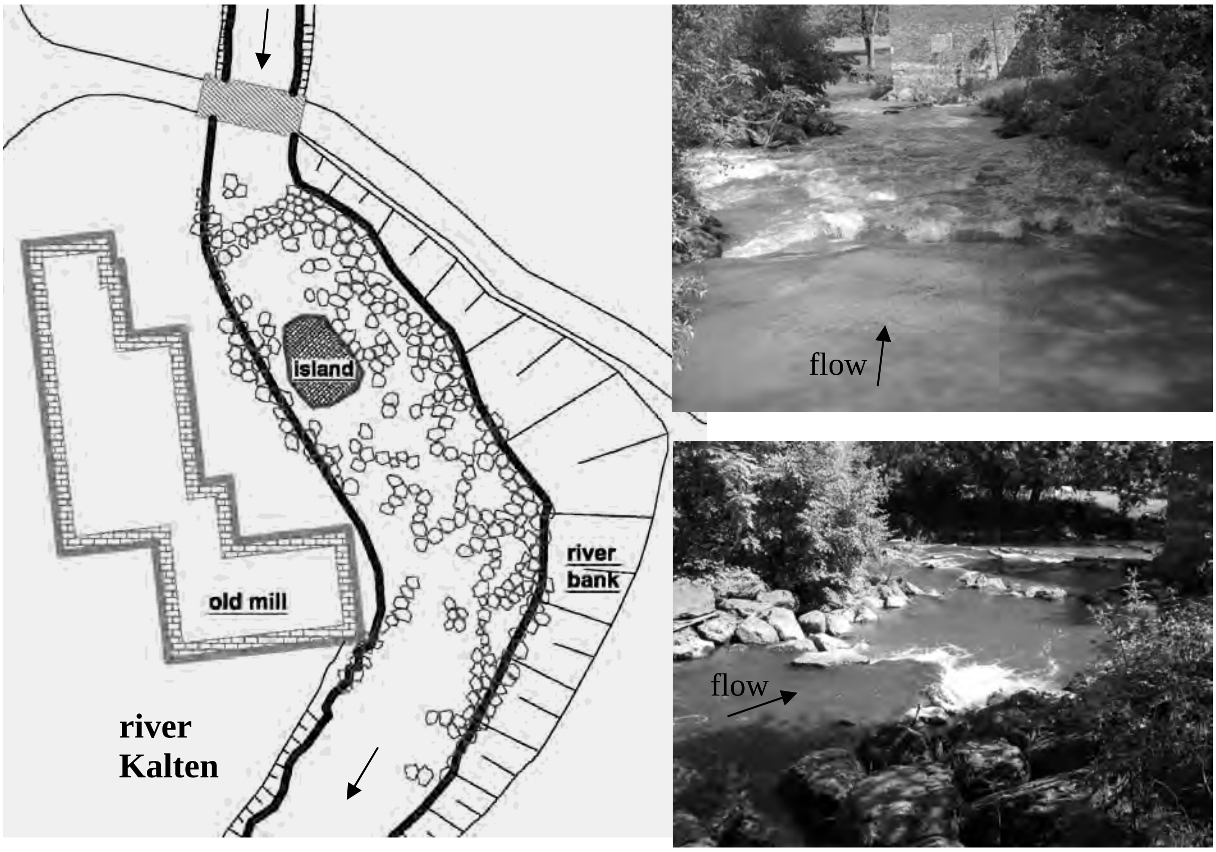


Fig. 4.6.2: Bottom ramp Plackermühle in the brook Kalten, photo made on May.17 (top, Q = 4.2 m³/s ≈ Q_{330}) and Aug.17 (bottom, Q = 1.07 m³/s ≈ Q_{30}) in 2006

Brown trout, grayling and barbel are selected as representative of species for different requirements on geometrical and hydraulic conditions in fish migration facilities.

Table 4.6.3: Assessment of the minimum water depth in fish migration facilities: level of assessment = B (good)

Species	Brown trout	Grayling, Dace	Barbel, pike
Body length up to [cm]	40	60	120
Min. water depth [m]	0.4	0.45	0.5
Width of notches and narrow slots [m]	0.2 ~ 0.4	0.4 ~ 0.6	0.6
Max. water level difference [m]	0.2	0.15	0.13
Max. flow velocity in notches and narrow slots [m/s]	2.0	1.7	1.6

4.6.1. First field work: May. 17. 2006, Q: 4.2 m³/s, corresponding to about Q_{330}

The first field investigation at the bottom ramp Plackermühle was carried out on May.17.2006. The discharge in the brook Kalten was 4.2 m³/s, which corresponds to about Q_{330}. From the histogram of the results in Fig. 4.6.3, it shows that 78% of the measured velocities at the slot openings are over 1.5 m/s, especially at the upper part of the ramp between the bridge and the island, it usually plays a critical roll on the effectiveness of such a structure. The first boulder sill is suggested to be modified to decrease the effect of critical control section.

The measured water depths show that about a half of slots are deep enough for brown trout to ascend but for barbel difficult (Fig. 4.6.4).

In Fig. 4.6.5 examine the possible passage for brown trout. There are either problems on too high flow velocity or too shallow water depth at most measured positions. No continuous corridor can be traced.

In Fig. 4.6.6 data were examined again with migration criteria for small fish species. All of the measured velocities are too high for small fish and is impossible for them to ascend.

The water depth of the measured points, which due to the safety consideration were measured only next to the river bank, distributed between 10 to 60 cm and sometimes even over 1 meter. The flow in this bottom ramp is particularly turbulent during Q_{330}. To mitigate this problem, we can consider two factors: the water level difference, which represents the dissipated potential energy, and the water depth, which affects the net pool volume for dissipation of energy. At the downstream side, several boulder sills could be added additionally to arise the water level downstream and results in decrease of water level differences at the upstream part of the ramp.

Table 4.6.4: 1st field investigation on May.17.2006

Water head	ca. 1.9 m
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit)	Statistics of 1st field investigation (average ± standard deviation) V[m/s] H[cm] 1.74 ± 0.23 41.9 ± 39.2
Hydraulic measurements	
discharge	Gauging station Hohenofen on May.17: 4.2 m^3/s ($\approx Q_{330}$)
Flow in the ramp and attraction flow	Same as river flow
Max. velocity at the slots	2.17 m/s
Water depth	See statistics
Velocity of the attraction flow	No entrance / exit therefore no attraction flow

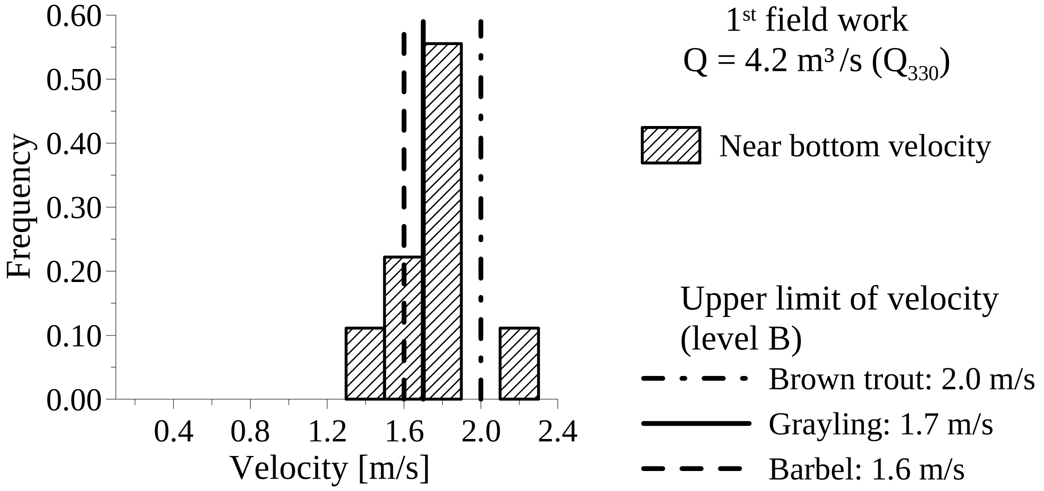


Fig. 4.6.3: Near bottom velocity (v at z = 2.8 cm) distribution of the measured possible passage for fish at the bottom ramp Plackermühle

Date: 1st fieldwork, May.17.2006; Discharge: Q = 4.2 m^3/s (Q_{330})

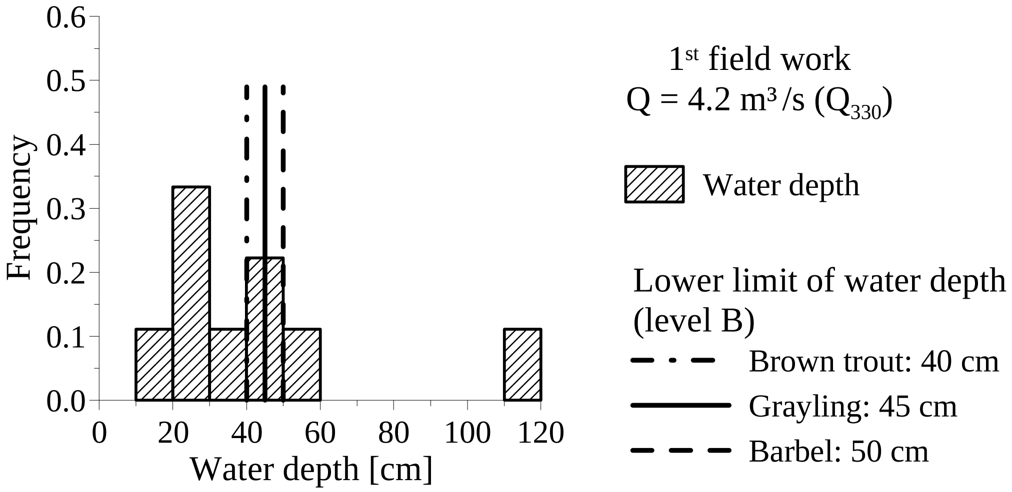
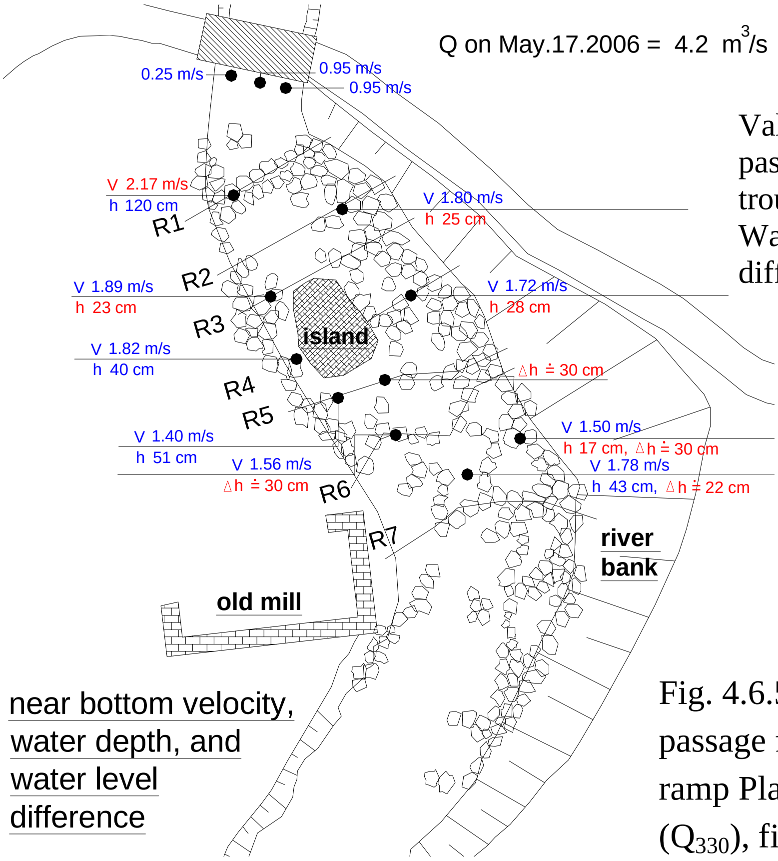


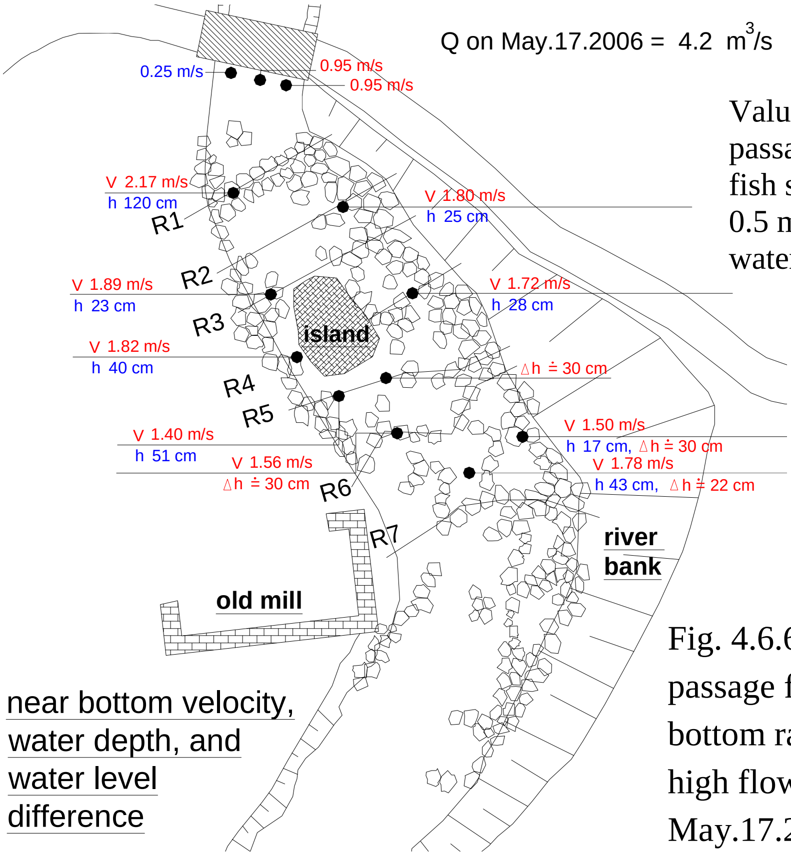
Fig. 4.6.4: Water depth distribution of the measured possible passage for fish at the bottom ramp Plackermühle

Date: 1st fieldwork, May.17.2006; Discharge: Q = 4.2 m³/s (Q_{330})
Note: slots were not measured if the water depth was less than 10 cm.



Values in blue indicate possible passage under condition for brown trout to ascend: Velocity < 2.0 m/s, Water depth > 0.4 m, water level difference < 0.2 m.

Fig. 4.6.5: Distribution of possible passage for brown trout at the bottom ramp Plackermühle during high flow (Q_{330}), fieldwork on May.17.2006



Values in blue indicate possible passage under condition for small fish species to ascend: Velocity < 0.5 m/s, Water depth > 0.1 m, water level difference < 0.1 m.

Fig. 4.6.6: Distribution of possible passage for small fish speciest at the bottom ramp Plackermühle during high flow (Q_{330}), fieldwork on May.17.2006

4.6.2. Second field work: Aug. 17. 2006, Q: 1.07 m^3/s, corresponding to about Q_{30}

The second field work at the bottom ramp Plackermühle was carried out when the discharge in the brook Kalten came to be in the range of about Q_{30} for the investigation under condition of lower discharge. Because of the low flow, much more measurements were allowed to be conducted under safety condition. But the left bank was partly difficult to reach because of the woody area.

The velocity was obtained at each gap at two water depths: near bottom and 10 cm above the bottom. From the histograms of the results in Fig. 4.6.7, it shows that at most positions along the passage, 86% and 91% of measured velocity at near bottom and 10 cm above the bottom respectively, the velocities are below 1.5 m/s, which is just on the contrary while comparing with the first field work at MQ. That means under such condition of low discharge in autumn, the flow velocity is generally adequate for fish to ascent.

In Fig. 4.6.8~9 show the histograms of the measured water depth and water level difference. Water depths were most between 20 and 40 cm and most water level differences are over upper limit.

In Fig. 4.6.10 examine the possible passage for brown trout. There are either problems on too shallow water depth and high water level difference. A continuous corridor may be constrainedly recognized between the island and the left bank side.

In Fig. 4.6.11 data were examined again with migration criteria for small fish species. Apparently only the water depths are adequate for small fish and it is impossible for them to ascend.

During the planning phase, the little island in the middle of the brook reach was requested to be conserved. The bottom ramp is therefore separated into right and left part. A mitigation solution is suggested to modify the left bank side ramp. By creating more obvious orifices with lower water level differences, the bottom ramp could be adjusted as a compounded bottom ramp.

Table 4.6.5: 2nd field investigation on Aug.17.2006

Min. and mean water depth	
Hydraulic measurements	
discharge	Gauging station Hohenofen on Aug.17: 1.07 m³/s (≈ Q_{30})
Flow in the ramp and attraction flow	Same as river flow
Max. velocity at the slots	1.67 m/s (V_{10}) 1.88 m/s (V_{bed})
Water depth	See statistics
Velocity of the attraction flow	No entrance / exit therefore no attraction flow

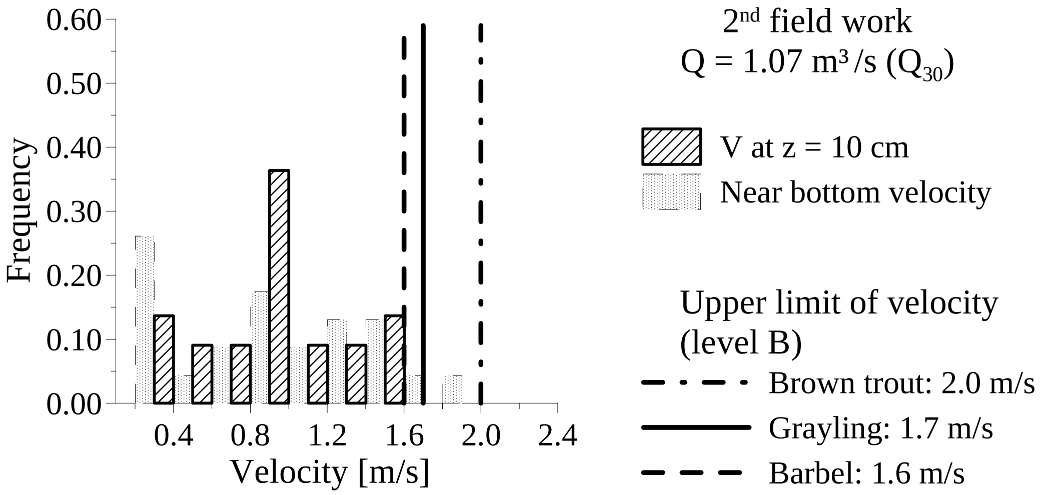


Fig. 4.6.7: Velocity distribution of the measured possible passage for fish at the bottom ramp Plackermühle

Date: 2nd field work, Aug.17.2006; Discharge: Q = 1.07 m³/s (Q_{30})

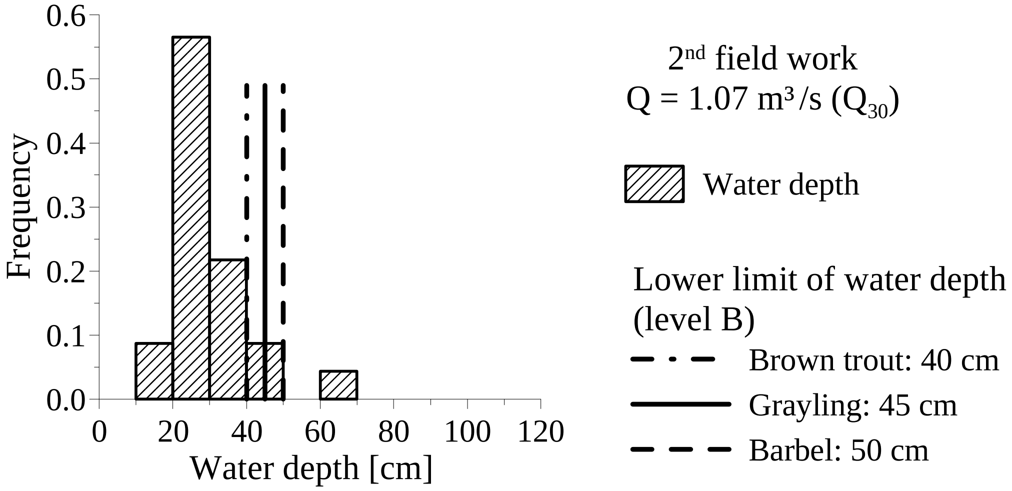


Fig. 4.6.8: Water depth distribution of the measured possible passage for fish at the bottom ramp Plackermühle

Date: 2nd field work, Aug.17.2006; Discharge: Q = 1.07 m³/s (Q_{30})
Note: slots were not measured if the water depth was less than 10 cm.

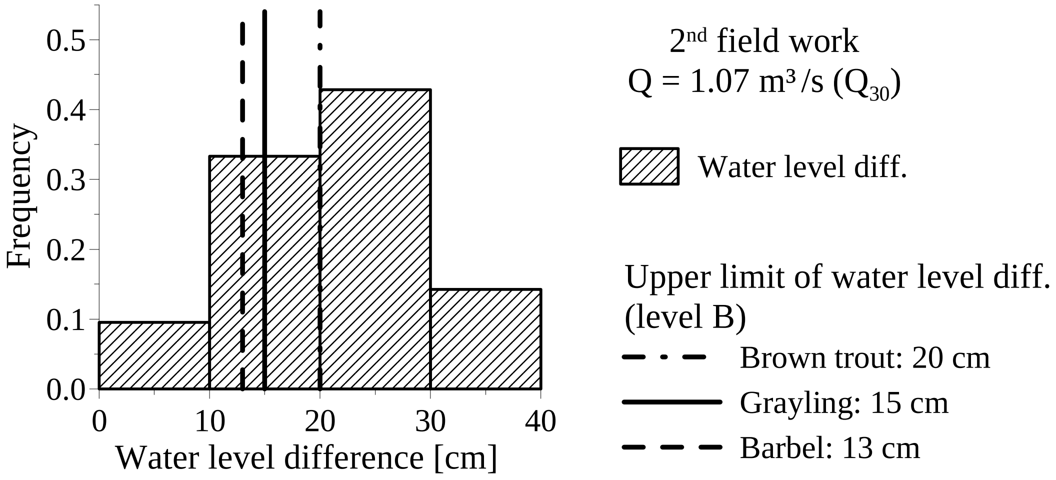
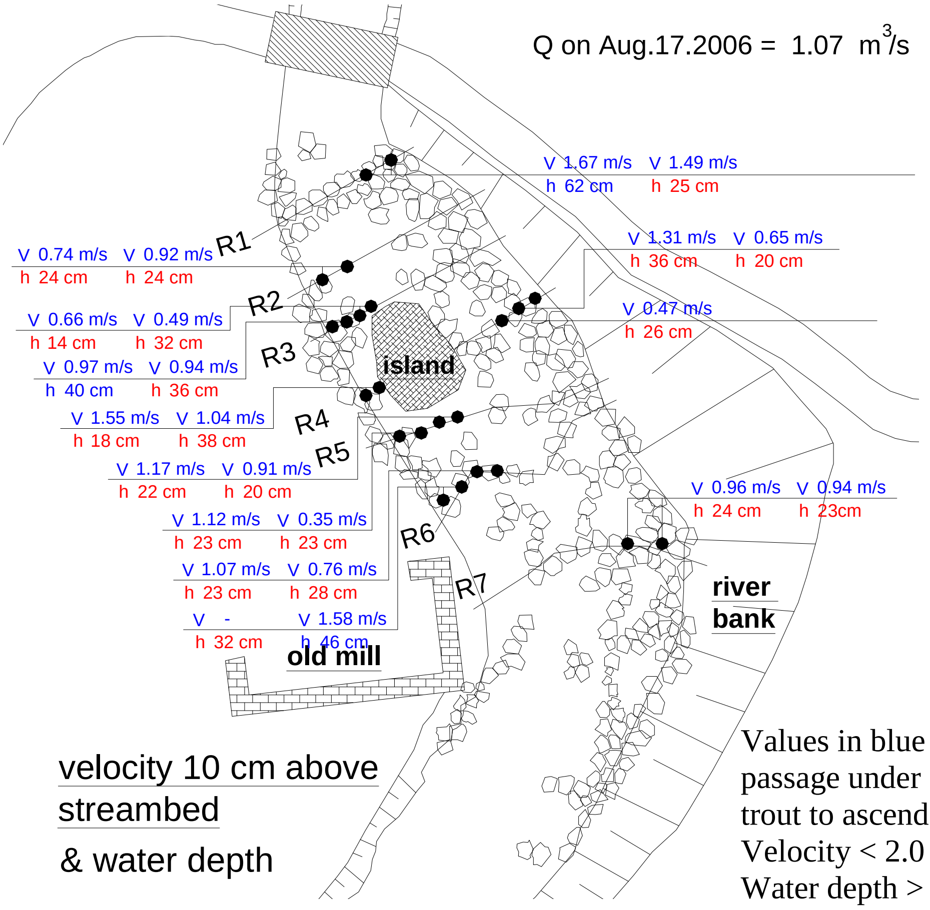


Fig. 4.6.9: Water level difference distribution of the measured possible passage for fish at the bottom ramp Plackermühle

Date: 2nd field work, Aug.17.2006; Discharge: Q = 1.07 m³/s (Q_{30})



Values in blue indicate possible passage under condition for brown trout to ascend:
Velocity < 2.0 m/s,
Water depth > 0.4 m,
Water level difference < 0.2 m.

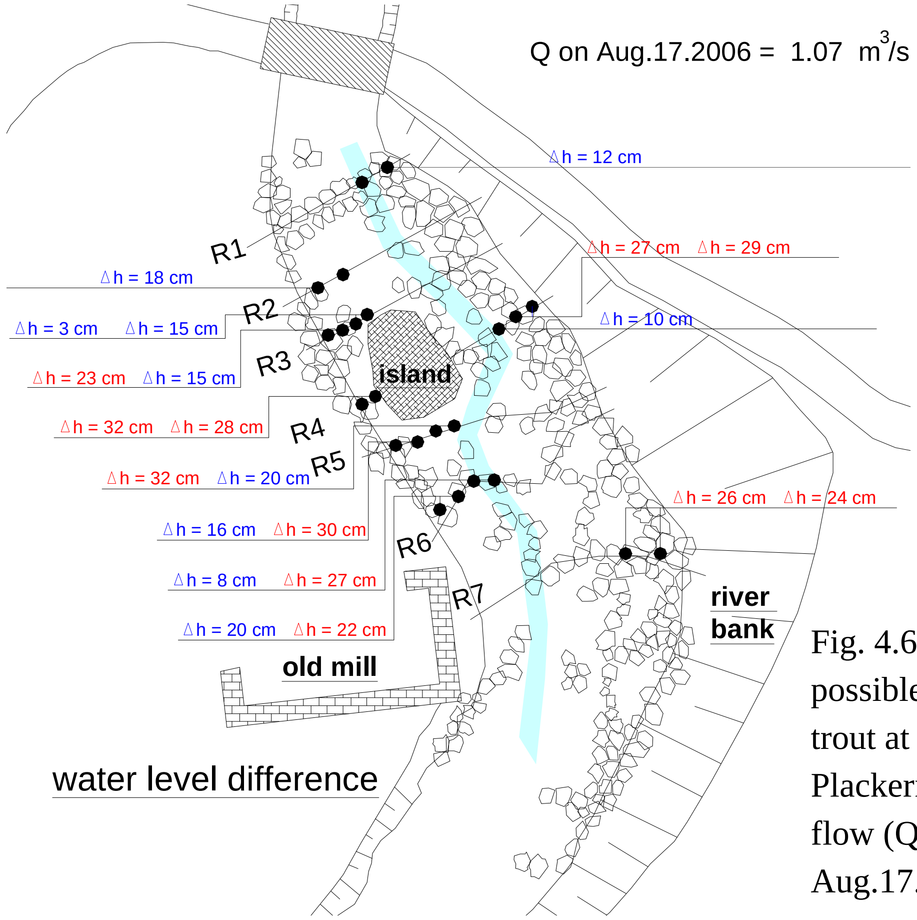
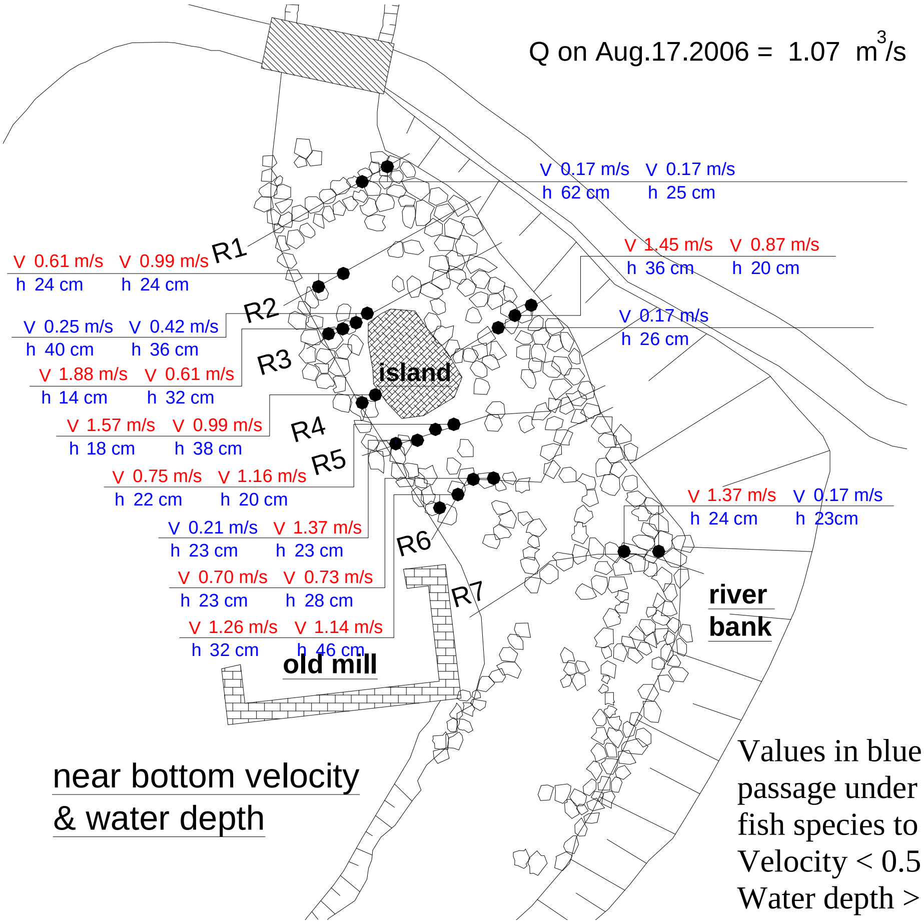


Fig. 4.6.10: Distribution of possible passage for brown trout at the bottom ramp Plackermühle during high flow (Q_{30}), fieldwork on Aug.17.2006



Values in blue indicate possible passage under condition for small fish species to ascend:
Velocity < 0.5 m/s,
Water depth > 0.1 m,
Water level difference < 0.1 m.

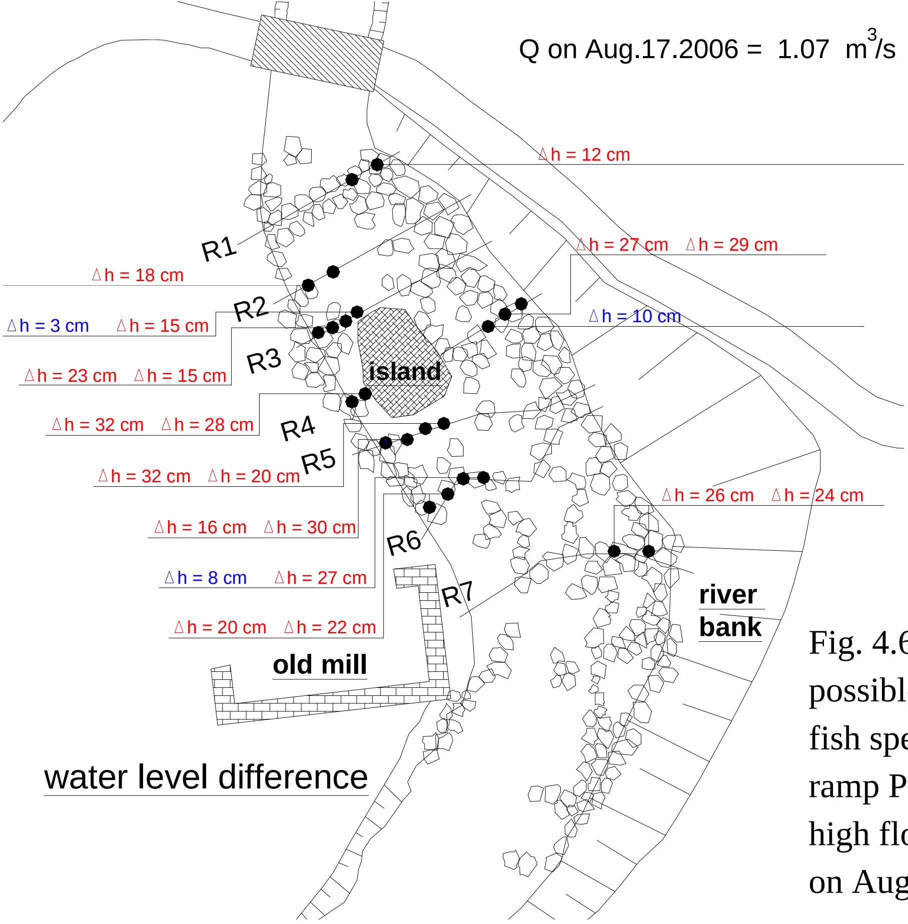


Fig. 4.6.11: Distribution of possible passage for small fish speciest at the bottom ramp Plackermühle during high flow (Q_{30}), fieldwork on Aug.17.2006

4.6.3. Monitoring of fish migration

The fish capture and mark would be conducted in May and September of 2006 for one day upstream and downstream of the ramp by electric-fishing with different inject mark to allocate the origin of captured fish. Fish stocking which was released during investigation period would be marked as well. Each monitoring lasted for three weeks by installed trap net at the upstream side of the ramp to examine fish migration. Anglers would be informed to report back if they angled marked fish.

Table 4.6.6: The schedule of monitoring work at the bottom ramp Plackermühle

Period	Subject	Working hour	Note
May 2006	E-fisching + mark	1 day	Begin of 1st round
	Mark of fish stocking	1 day	
June 2006	Trapping	3 weeks	
September 2006	E-fisching + monitoring + mark	1 day	End of 1st round Begin of 2nd round
	Mark of fish stocking	1 day	
September 2006	Trapping	3 weeks	End of 2nd round
March 2007	Trapping	3 weeks	Begin of 3rd round
April 2007	E-fisching + monitoring	1 day	End of 3rd round
	Count from anglers	1 day	

Note: schedule from Bavarian Fishing Accociation

The number of total electric-fishing samples was 375 and 211 individuals respectively upstream and downstream of the bottom ramp with body length over 10 cm (Table 4.6.4). The species show a very different spectrum from that in the river Mangfall. The monitoring was planned to conducted for three weeks per season with trap net installed at the upstream side of the ramp. However due to difficulties of maintenance of the trap and the damage of trap by high flow events, the monitoring work was not conducted as planned.

Table 4.6.7: Fish count of electric-fishing in the 1st investigation

Fish species	upstream	down-	Fish species	upstream	down-
European Chub	53	25	Roach	3	11
Grayling	–	1	Perch	2	1
Barbel	–	2	Burbot	1	2
Brown trout	5	2	Rudd	12	–
Carp bream	–	2	Dace	49	11
Nase	1	–	Northern pike	1	5
Common carp	2	4	Bleak	123	14
Gudgeon	–	17	Riffle minnow	123	114
Sum of fish captured upstream / downstream: 375 / 211					

Note: Data of fish count provided by Bavarian Fishing Association

4.6.4. Conclusion

The flow condition in the bottom ramp Plackermühle seems to be highly problematic due to very turbulent flow, shallow water depth and high water level difference between most cascaded sills.

The first field investigation (high flow) shows that flow above sills is apparently rapid and most are over 1.5 m/s. Particularly at the last three sills in upstream part of the ramp, velocities are around 2 m/s, which indicates that these upstream sills result in critical cross sections. Otherwise velocity, water depth and slot width are not problematic in this case.

The second field work (low flow) shows that the velocities at about 90% of all the 23 measured points are below 1.5 m/s, 78% measured water depth are between 20 and 40 cm. Over 50% of measured water level differences are over 20 cm and even 14% of measurements are over 30 cm. Particularly the boulder sills R4 and R5 are recognized as critical cross sections.

Based on hydraulic investigation this bottom ramp Plackermühle is assessed to be difficult for fish migration. The cross sections near the preserved island must be modified and there are three suggestions for the modification.

Alternative 1: One can add more boulder sills downstream from the Plackermühle ramp to rise the downstream water level and reduce the water level differences upstreams. However only the first several sills (downstream part) are supposed to be able to be improved.

Alternative 2: Another alternative is to use the island which separates the cross section into right hand part and left hand part. Since the right hand part locates at the outer bend and particular concern should be taken on the bank protection. One can modify the left part ramp near the island by creating more obvious opening slots with lower drop height, the bottom ramp could be adjusted as a compounded structure.

Alternative 3: In case it is acceptable under objective of natural conservation, the small island in the middle of river reach can be removed to reduce the specific discharge and also provide higher passage potential at each cross section.

4.7. Case 4: Fish ramp “Leitner Mühle”

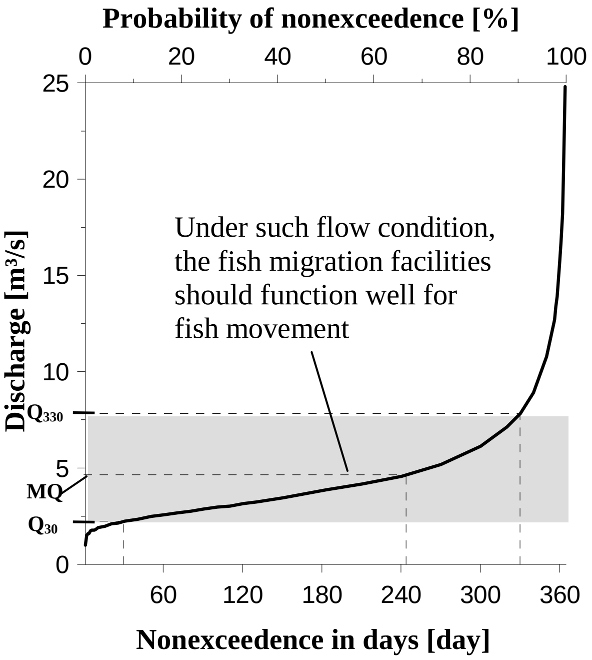
The brook Leitzach diverges in Achau for about 350 m and then converges again. In Fig 4.7.1 it shows that the weir was built to raise the water level in the right branch for use of the mill in the left branch.

The weir at the Leitner Mühle is about 2 meter high and 50 meter long and. The brook Leitzach in this section is about 14 meter wide. The fish ramp was constructed at the left bank to provide fish migration passage and to preserve the weir partly. The structure of the fish ramp is cascaded pool type. The width is about 10 ~ 20 meters and the length is about 45 meters. The fish ramp was constructed by armourstones which were concreted at the weir side and were inserted without concrete at the bank side. The slope of the fish ramp is about 1:25 (4%) and the slope of the brook Leitner at this section is about 1:65 (1.5%).

There is another small weir between the two divergent brooks and a nature-like bypass was built to enhance the free passage possibility for fish.

The problems at this fish ramp were supposed to be too high drop heights between pools and too few openings for fish to find the passage route.

Two field investigations were conducted in May and October 2006 to study the flow conditions during MQ and Q_{30}.



Probability of nonexceedence, P_r
$P_r[Q \le Q_{p\%}] = P$ %

Nonexceedence in days, D_r
$D_r[Q \le Q_{days}] =$ Days

Q_{30} = 2.25 m^3/s
MQ = 4.66 m^3/s
Q_{330} = 7.83 m^3/s

Fig. 4.7.1. Nonexceedence discharge curve at gauge station Stauden / Leitzach

Table 4.7.1: General Information of the fish ramp Leitner Mühle

General information of the catchment	
Gauging station	Stauden (1941-2002)
River system	Leitzach
Catchment area	111.70 km^2
Local authority	WWA Rosenheim
River width	15 m
Hydrological statistics	NQ: 1.00, Q_{30}: 2.25 MQ: 4.66, Q_{330}: 7.83 HQ : 105.00
Geometry of barrier at the site	
Construction type: Weir type, other structures nearby	A fixed weir for water wheel
Water use general information, e.g. off-line hydropower station, in-line (run-of-river) hydropower station, navigation lock	
The operation regime of the operational constructions (weir, sluices, hydropower plant)	No operation on the fixed weir
Powerhouse hydraulic capacity, spillway hydraulic capacity	More water derived via another branch for the water wheel use

Characteristics of the ramp:

Construction type of the ramp	Fish ramp with boulder sills
Geometry of the ramp	
Length and width of the ramp	Length: 45 m Width: 15 ~ 20 m
bottom slope	1:25
Water head	2.2 m
# of sills	ca. 7 (8 pools)
Head per sill	14 ~ 31 cm during mean flow (MQ) 19 ~ 39 cm during low flow (Q30) 43 cm at the last sill
Min. and mean net width and length of the pool-type structure (dimension of the pool)	Not measured since no problem observed
Alignment of the ramp	
Location in relation with nearby structures and discharge division	The fish ramp replace part of the existing fixed weir.
Location in relation with nearby barriers	
Location of main current	Uniformly distributed on the fish ramp and the weir during mean flow condition, no overflow on the weir during low flow.
Distance between entrance / exit and barriers	
Location of attraction flow and angle	No problem observed near fish ramp
Number of possible wrong attractions	At the convergence of natural and artifical channels.

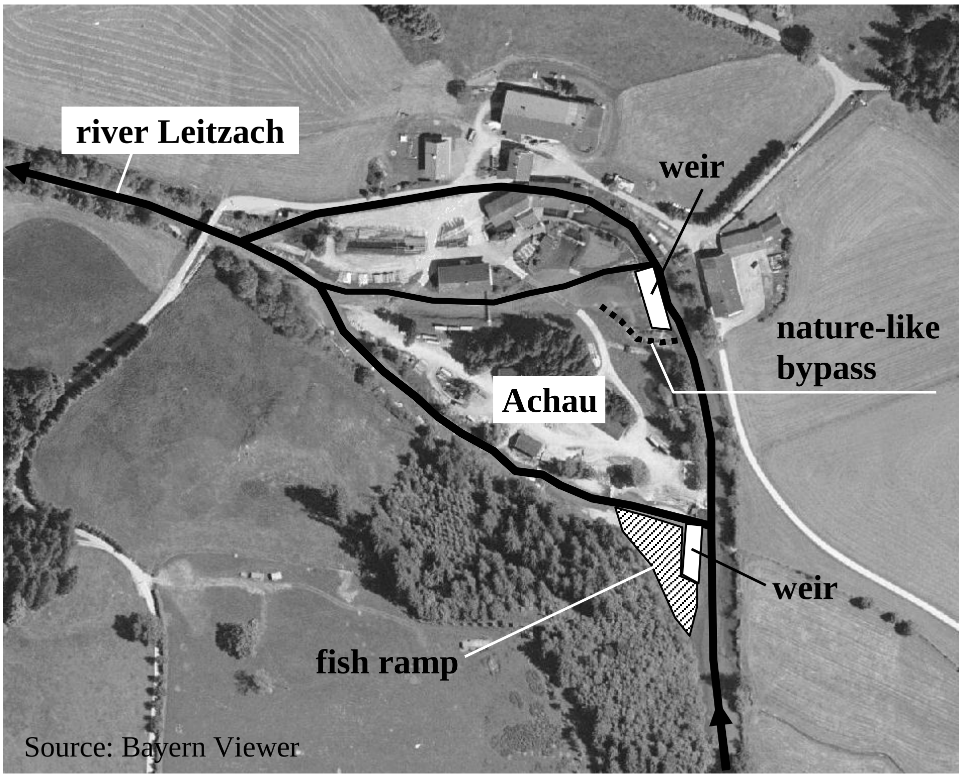


Fig 4.7.2: Location of the fish ramp Leitner Mühle in the brook Leitzach

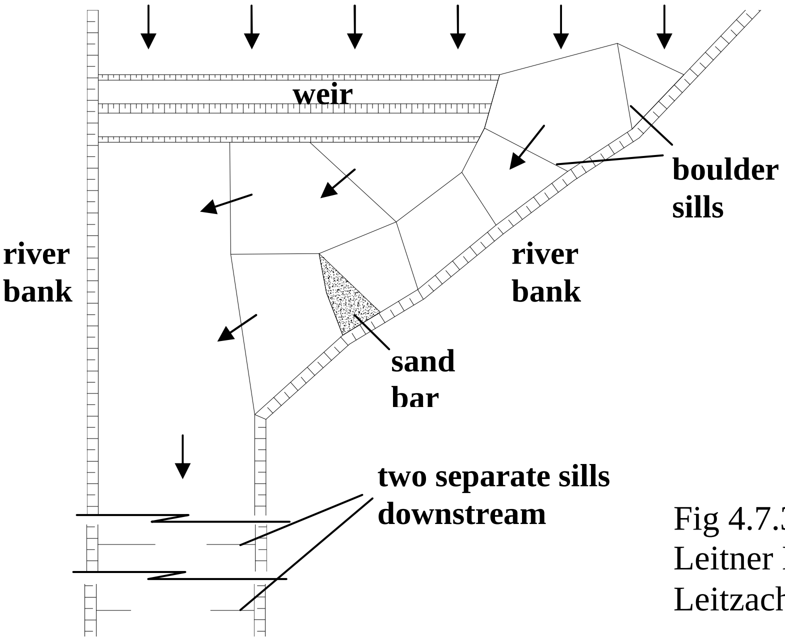


Fig 4.7.3 Sketch of the fish ramp Leitner Mühle in the brook Leitzach, plan view

Fig. 4.7.4: Fish ramp Leitner Mühle, photo made on May.23.2006, Q = 6.10 m³/s (≈ MQ)

Fig. 4.7.5: Fish ramp Leitner Mühle, photo made on Oct.12.2006, Q = 3.09 m³/s (≈ Q_{30})

The fish species in the brook Leitzach nearby the fish ramp Leitner are listed in Table 4.7.2. The list is based on data of captured fish on the electric-fishing result during the investigation by the Bavarian Fishing Association.

Table 4.7.2: Fish species in the brook Leitzach nearby the fish ramp Leitner

Fish species[1]	in German[2]	Max. size[3] [cm]
Rainbow trout (*Onchorhynchus mykiss*)	Regenbogenforelle	120
Brown trout (*Salmo trutta*)	Bachforelle	100
Grayling (*Thymallus thymallus*)	Äsche	60
Bullhead (Cottus gobio)	Koppe	18
Brook trout (*Salvelinus fontinalis*)	Bachsaibling	86

[1] Scientific names from FishBase
[2] Data: Bavarian Fishing Association (Landesfischereiverband Bayern)
[3] Reported max. size from FishBase

Brown trout and grayling are selected as representative of species for different requirements on geometrical and hydraulic conditions in fish migration facilities.

Table 4.7.3: Assessment of the minimum water depth in fish migration facilities: level of assessment = B (good)

Species	Brown trout	Grayling, Dace	Barbel, pike
Body length up to [cm]	40	60	120
Min. water depth [m]	0.4	0.45	0.5
Width of notches and narrow slots [m]	0.2 ~ 0.4	0.4 ~ 0.6	0.6
Max. water level difference [m]	0.2	0.15	0.13
Max. flow velocity in notches and narrow slots [m/s]	2.0	1.7	1.6

4.7.1. First field work: May. 23. 2006, Q: 6.10 m³/s, corresponding to about MQ

The first field investigation at the fish ramp Leitner Mühle was carried out on May.23.2006. The discharge in the brook Leitner was 6.10 m³/s, which corresponds to about MQ.

From the histogram of the results in Fig. 4.7.6 and Fig. 4.7.11, it shows that at most clear areas between armourstones at a boulder sill, the velocities are below 1.5 m/s. In Fig. 4.7.7 and Fig. 4.7.14, the measured widths of gaps are most wide enough and would not be measured in the next field works. In Fig. 4.7.8 and Fig. 4.7.13 shows that most water depths are under the lower limit. In Fig. 4.7.9 and Fig. 4.7.12 the water level differences indicate the main problem.

In Fig. 4.7.15 illustrates the possible passage for brown trout. They will be trapped between boulder sill Nr. 15 and Nr.11, 12. The water level difference at the first sill downstream (Nr. 15) is 43 cm and cannot be passed through for trout and most fish species in river. The upstream part of the fish ramp has problems on inadequate water depths and high water level difference.

In Fig. 4.5.16 data were examined again with migration criteria for small fish species. All of the measured water depths and slot widths are adequate for small fish and the dominant factors are flow velocity and water level difference.

The main problem at this fish ramp are the problematic water level differences located at the upper boulder sills, which are almost all over 30 cm. Another problematic boulder sill No. 15 locates separately downstream with water level difference of 43 cm.

Table 4.7.4: 1st field investigation on May.23.2006

Min. and mean water depth	
number of pools	8
Water level difference between adjacent pools	10 ~ 45 cm
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit) V: velocity B: slot width H: water depth ΔH: head at sill	Statistics of 1st field investigation (average ± standard deviation) V[m/s] B[cm] 1.22 ± 0.37 80.4 ± 63.6 H [m/s] ΔH [cm] 28.8 ± 16.3 27.2 ± 8.1
Hydraulic measurements	
discharge	Gauging station Stauden on May.23: 6.10 m^3/s (≈ MQ)
Flow in the ramp and attraction flow	flow distributed uniformly over weir and ramp
Max. velocity at the slots	2.06 m/s

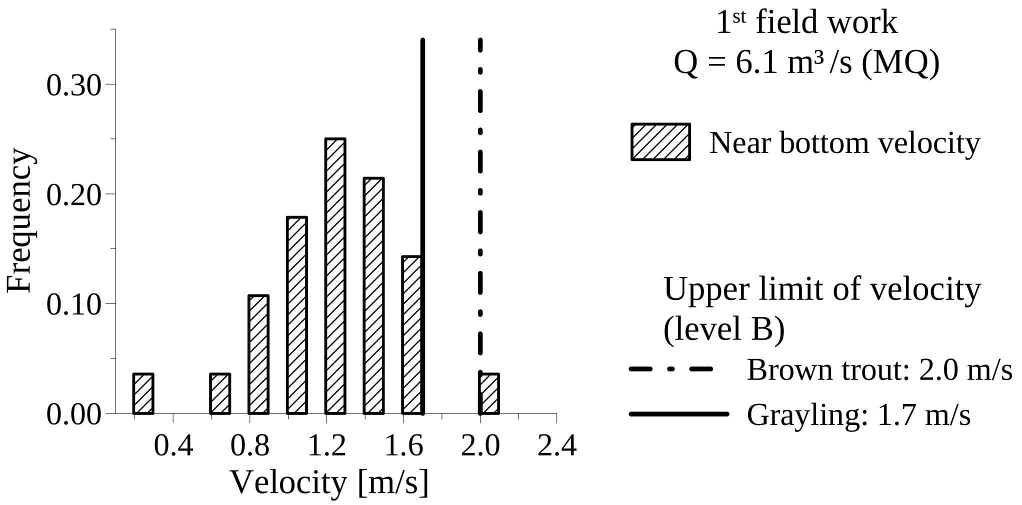


Fig. 4.7.6: Near bottom velocity (v at z = 2.8 cm) distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 1st fieldwork, May.23.2006; Discharge: Q = 6.1 m^3/s (MQ)

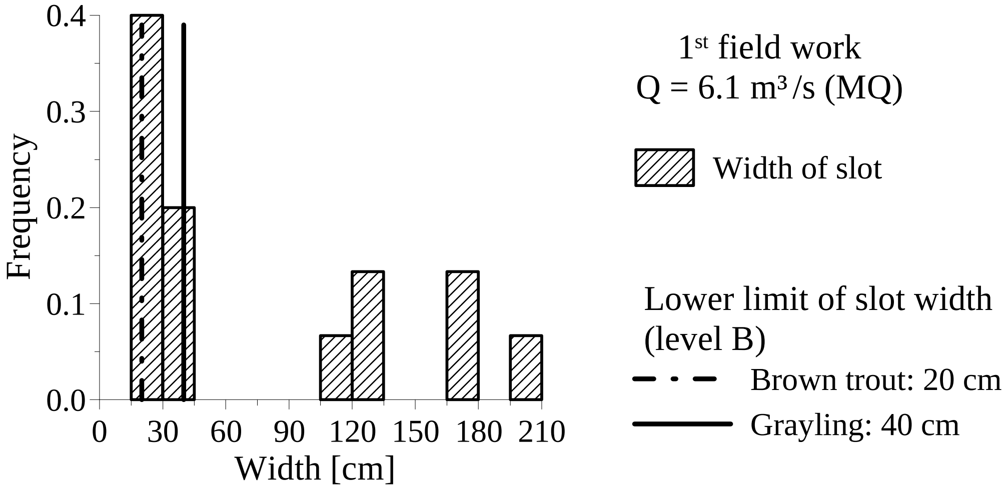


Fig. 4.7.7: Slot width distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 1st field work, May.23.2006; Discharge: Q = 6.1 m³/s (MQ)
Note: slots were not measured if the width was less than 15 cm.

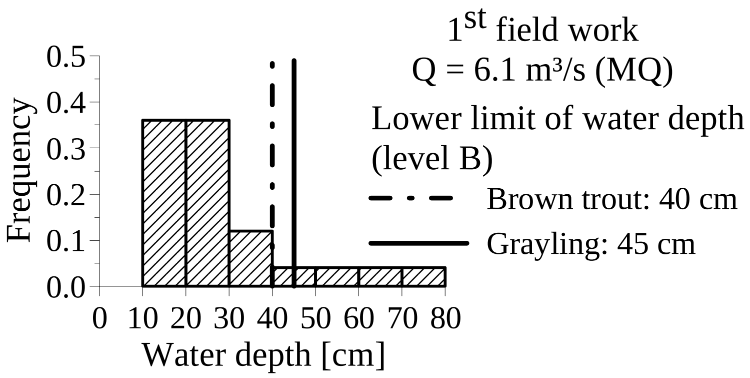


Fig. 4.7.8: Water depth distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 1st field work, May.23.2006; Discharge: Q = 6.1 m³/s (MQ)
Note: slots were not measured if the water depth was less than 10 cm.

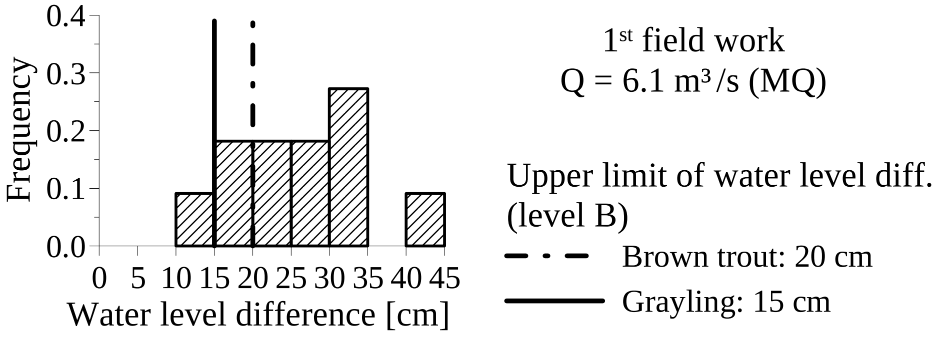


Fig. 4.7.9: Water level difference distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 1st field work, May.23.2006; Discharge: Q = 6.1 m³/s (MQ)

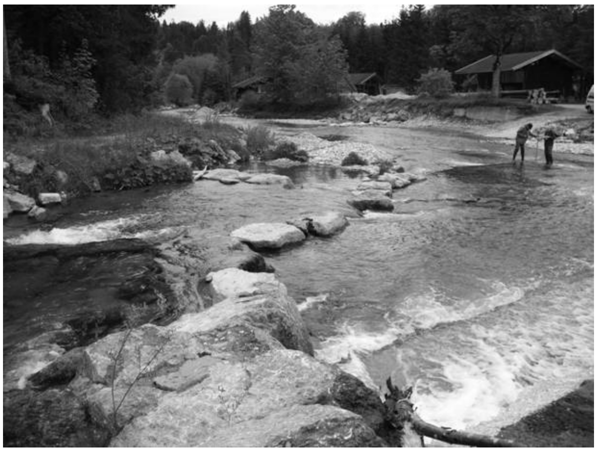


Fig. 4.7.10(a): Overview of the fish ramp Leitner

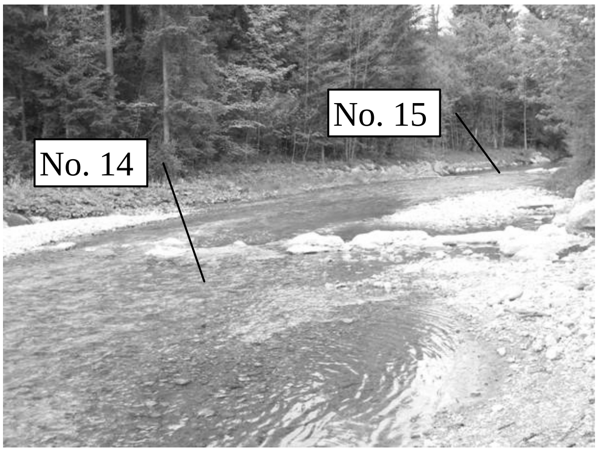


Fig. 4.7.10(b): The two separated boulder sill No. 14 and 15 downstream of the fish ramp Leitner

Fig. 4.7.10(c): Boulder sill No. 4, the drop height here is about 30 cm

Fig. 4.7.10(d): Boulder sill No. 5, the drop height here is about 34 cm.

Fig. 4.7.10(e): Boulder sill No. 11

Fig. 4.7.10(f): Boulder sill No. 13

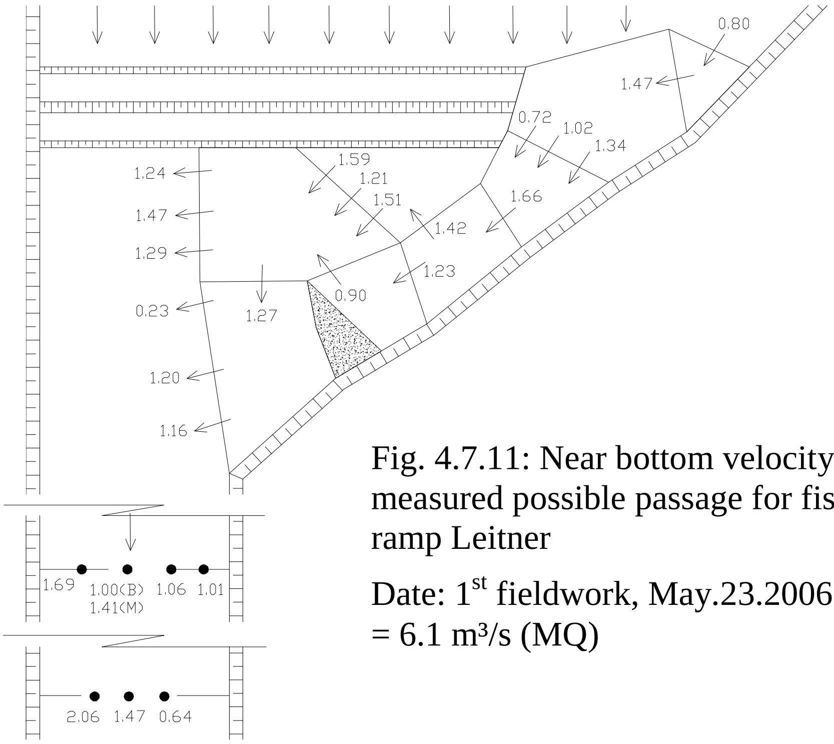


Fig. 4.7.11: Near bottom velocity of the measured possible passage for fish at the fish ramp Leitner

Date: 1st fieldwork, May.23.2006, Discharge: Q = 6.1 m³/s (MQ)

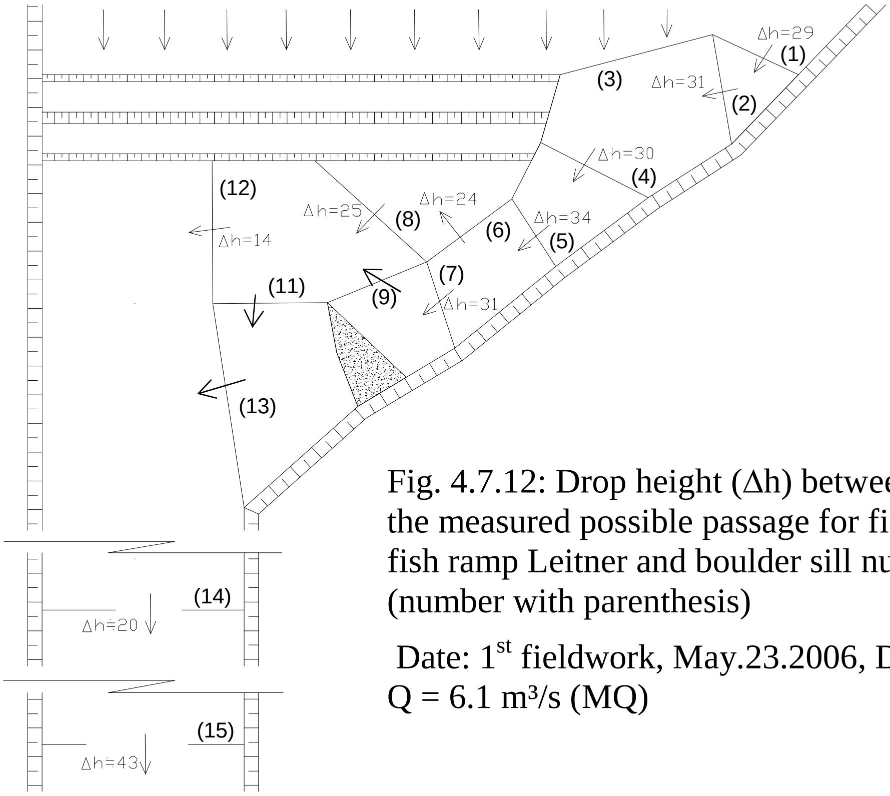


Fig. 4.7.12: Drop height (Δh) between pools of the measured possible passage for fish at the fish ramp Leitner and boulder sill numbering (number with parenthesis)

Date: 1st fieldwork, May.23.2006, Discharge: Q = 6.1 m³/s (MQ)

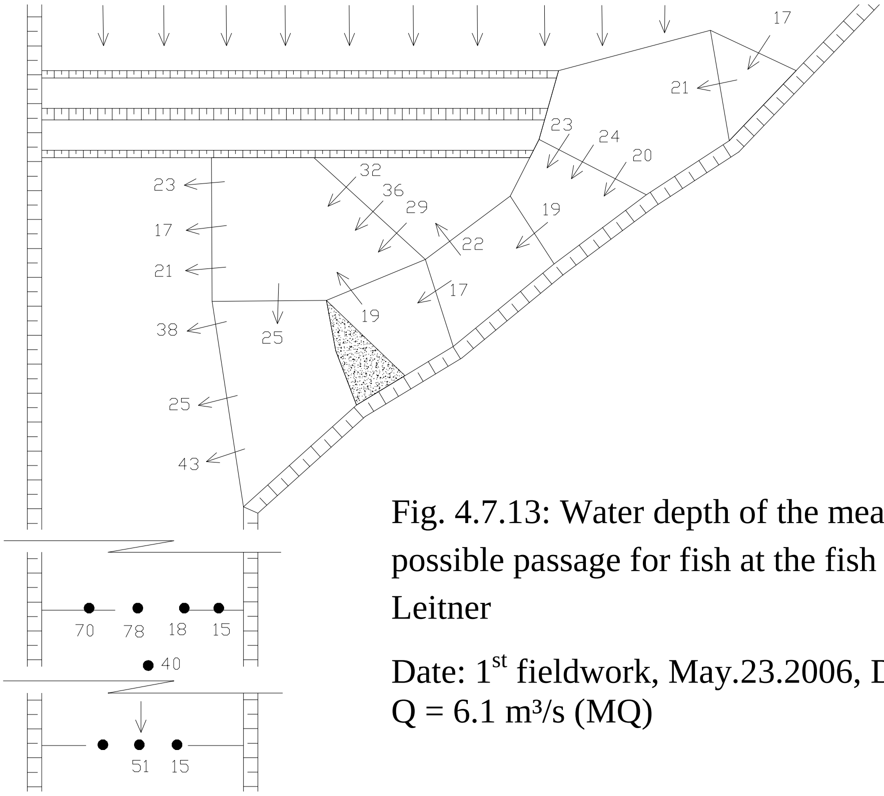


Fig. 4.7.13: Water depth of the measured possible passage for fish at the fish ramp Leitner

Date: 1st fieldwork, May.23.2006, Discharge: Q = 6.1 m³/s (MQ)

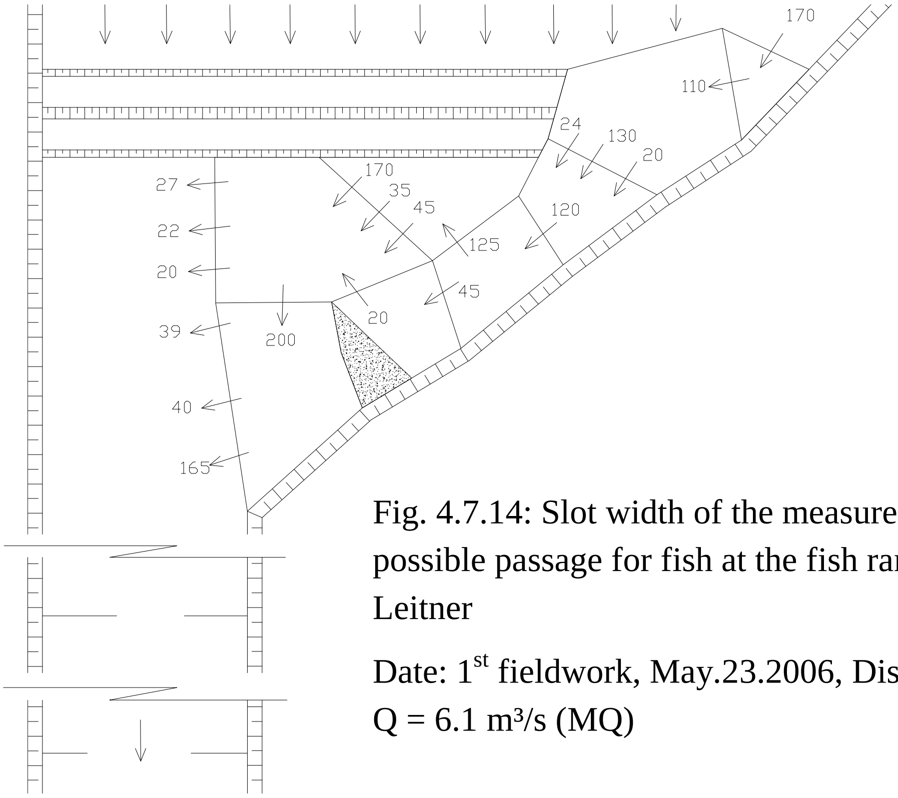
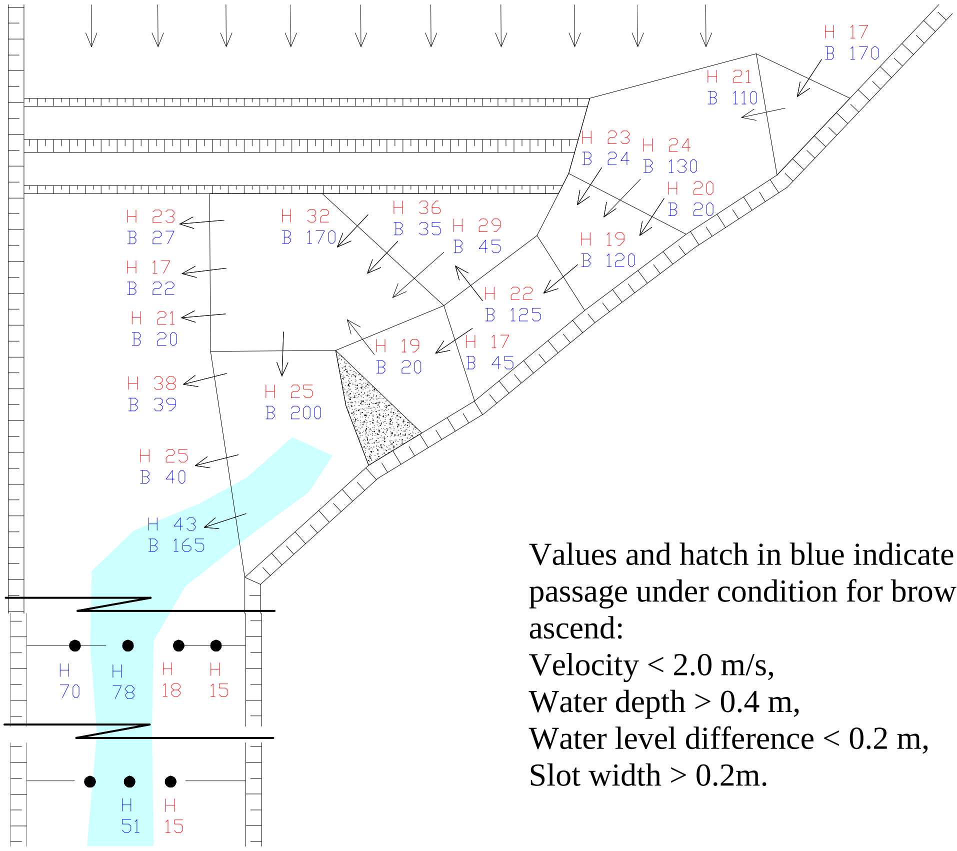


Fig. 4.7.14: Slot width of the measured possible passage for fish at the fish ramp Leitner

Date: 1st fieldwork, May.23.2006, Discharge: Q = 6.1 m³/s (MQ)



Values and hatch in blue indicate possible passage under condition for brown trout to ascend:
Velocity < 2.0 m/s,
Water depth > 0.4 m,
Water level difference < 0.2 m,
Slot width > 0.2m.

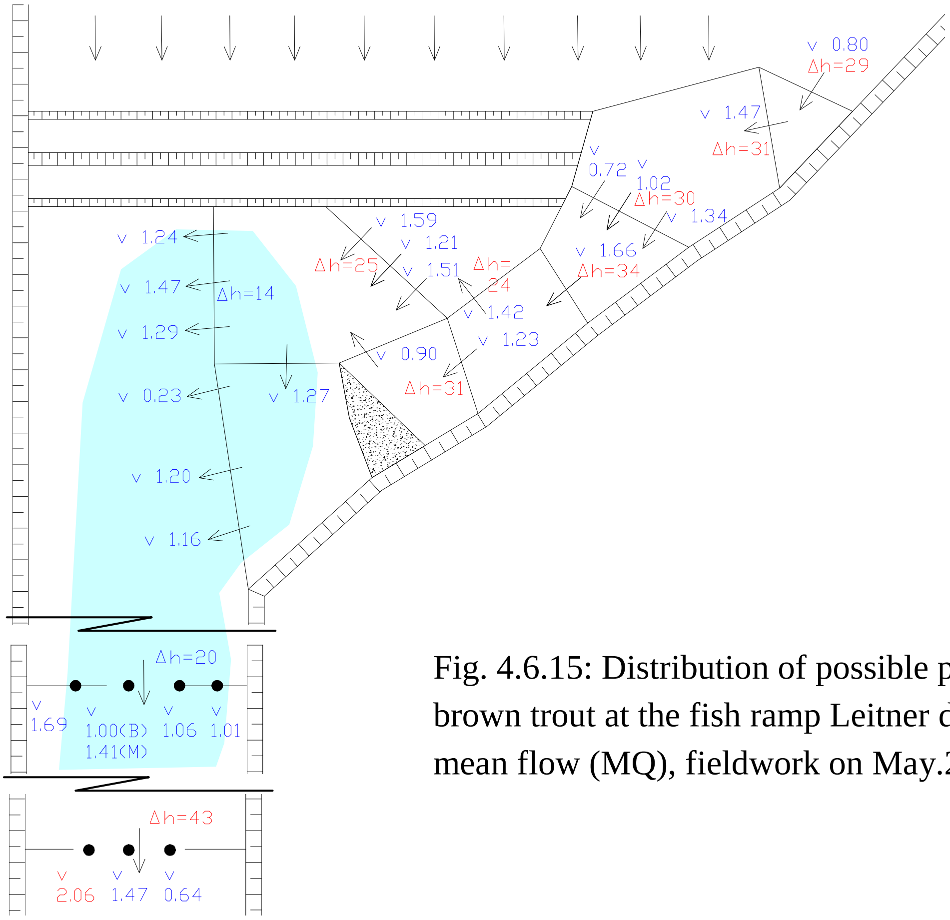
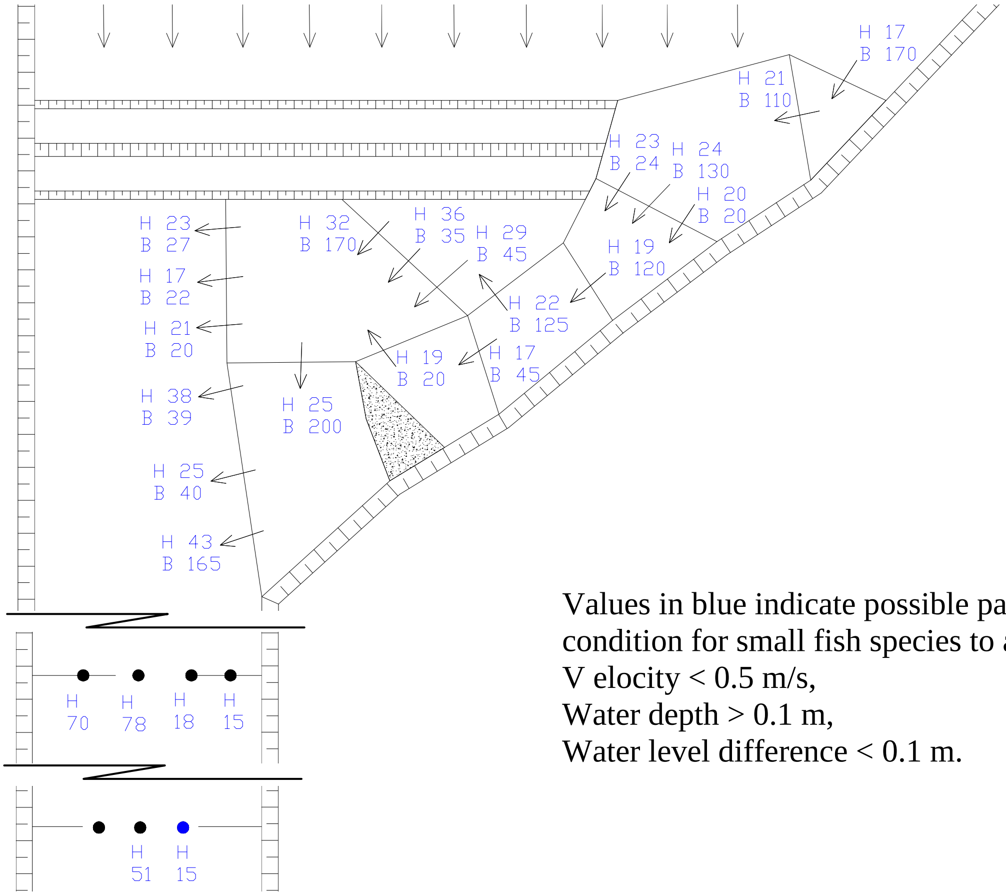


Fig. 4.6.15: Distribution of possible passage for brown trout at the fish ramp Leitner during annual mean flow (MQ), fieldwork on May.23.2006



Values in blue indicate possible passage under condition for small fish species to ascend:
V elocity < 0.5 m/s,
Water depth > 0.1 m,
Water level difference < 0.1 m.

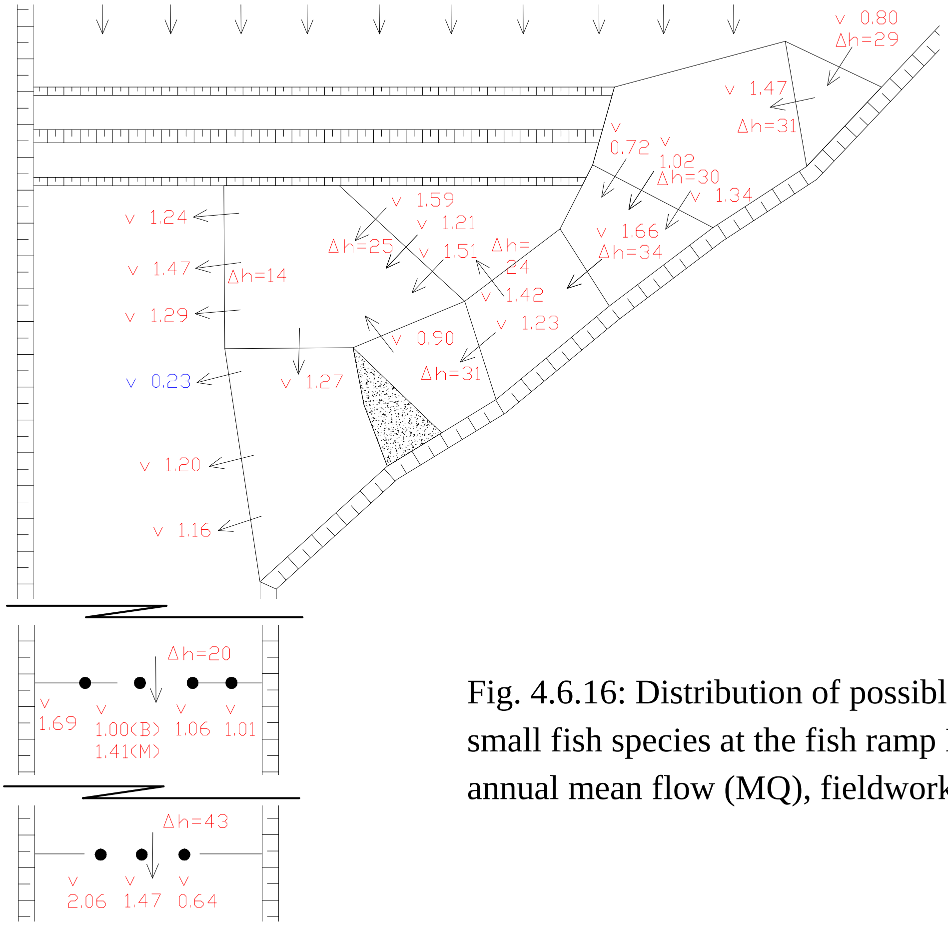


Fig. 4.6.16: Distribution of possible passage for small fish species at the fish ramp Leitner during annual mean flow (MQ), fieldwork on May.23.2006

4.7.2. Second field work: Oct.12.2006, Q: 3.09 m^3/s, corresponding to about Q_{30}

The second field work at fish ramp Leitner Mühle was carried out when the discharge in the brook Leitner came to be in the range of about Q_{30} for the investigation under condition of lower discharge.

The velocity was measured at each slot at two water depths: near bottom and 10 cm above the bottom. From the histogram of the results in Fig. 4.7.17 and Fig. 4.7.21, it shows that at almost all positions along the passage, the velocities are below 1.5 m/s, which means the flow velocity is generally adequate for fish to ascend.

In Fig. 4.7.18 and Fig. 4.7.23 it shows that the water depths are much shallower than the flow with MQ on first fieldwork and are all under the lower limit. Similar as water depths, the water level differences are almost all over the upper limit (Fig. 4.7.19 and Fig. 4.7.22). Both water depth and water level difference indicate the main problem.

In Fig. 4.7.24 and Fig. 4.7.25 illustrate the possible passage for brown trout and small fish. There is apparently no chance for them to ascend.

The problematic locations are at the upper side sills which are almost all over 30 cm, as the result from the first fieldwork on May.23.2006. The last boulder sill which locates quite separately downstream was still with water level differences of 42 cm, which was almost the same as the measurement from the first field work. The problem comes from the structure and would not be mitigated during lower discharge in flow.

Table 4.7.5: 2nd field investigation on Oct.12.2006

Min. and mean water depth	
number of pools	8
Water level difference between adjacent pools	5 ~ 45 cm
Dimension of the openings (submerged orifices, notches, slots, clear cross sections, cross section at entrance and exit) V: velocity, H: water depth ΔH: head at sill	Statistics of 1st field investigation (average ± standard deviation) V_{10}[m/s] V_{bed}[m/s] 1.06 ± 0.40 1.18 ± 0.39 H [m/s] ΔH [cm] 15.8 ± 5.9 27.4 ± 11.2
Hydraulic measurements	
discharge	Gauging station Stauden on Oct.12: 3.09 m^3/s (≈ Q_{30})
Flow in the ramp and attraction flow	flow only at fish ramp and no flow over weir
Max. velocity at the slots	1.67 m/s (V_{10}), 1.70 m/s (V_{bed})

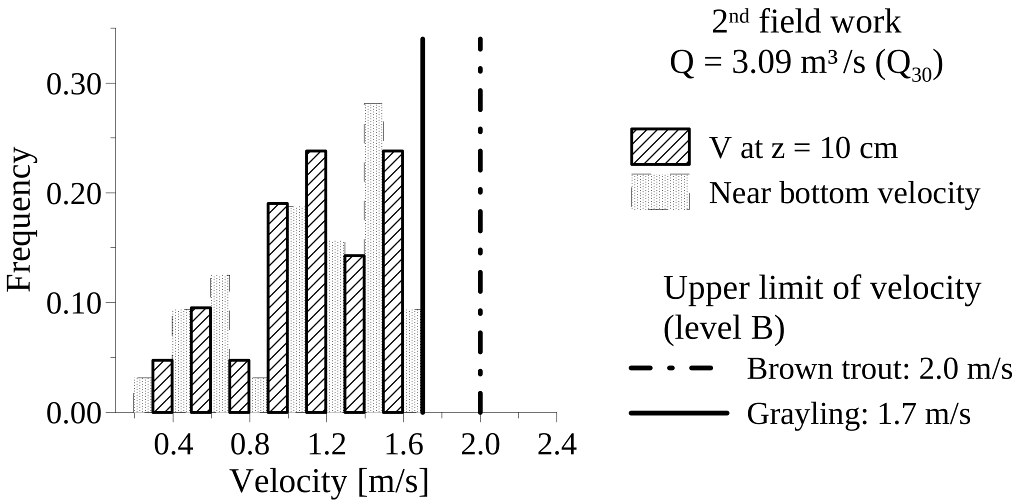


Fig. 4.7.17: Velocity distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006; Discharge: Q = 3.09 m³/s (Q_{30})

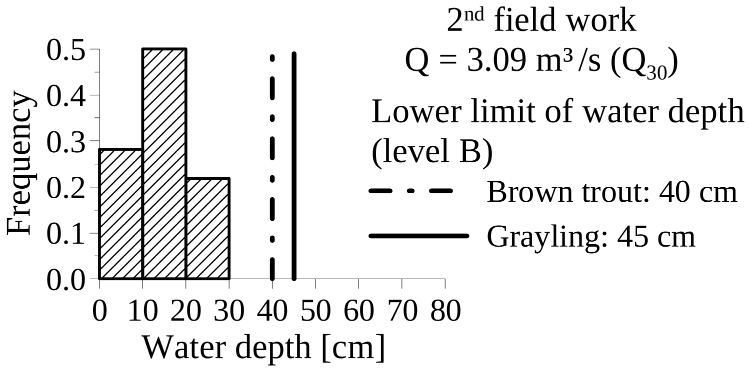


Fig. 4.7.18: Water depth distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006; Discharge: Q = 3.09 m³/s (Q_{30})
Note: slots were not measured if the water depth was less than 10 cm.

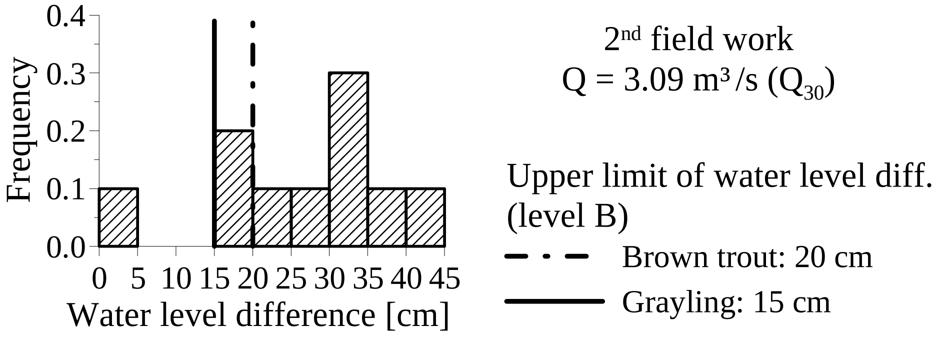


Fig. 4.7.19: Water level difference distribution of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006; Discharge: Q = 3.09 m³/s (Q_{30})

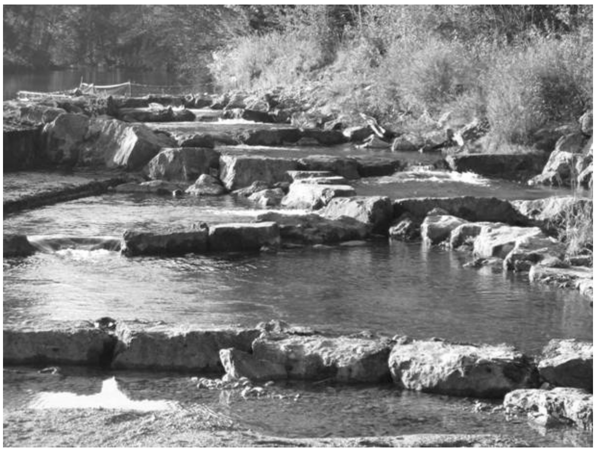


Fig. 4.7.20(a): Overview of the fish ramp Leitner at low flow condition

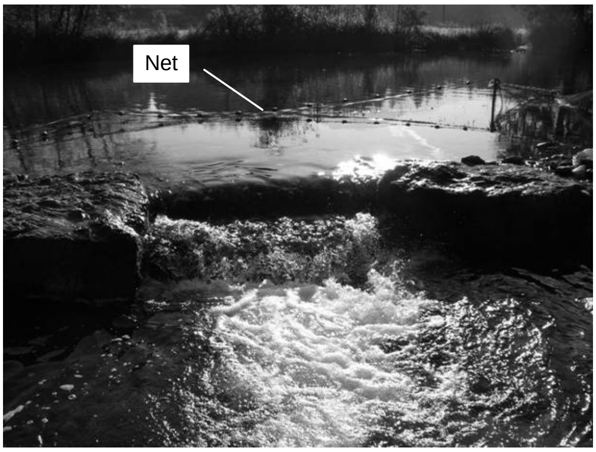


Fig. 4.7.20(b): The upstream exit and the net for fishing and monitoring

Fig. 4.7.20(c): Boulder sill No. 5, drop height was about 39 cm

Fig. 4.7.20(d): Boulder sill No. 8, drop height was about 19 cm

Fig. 4.7.20(e): Inserted amourstones

Fig. 4.7.20(f): Boulder sill No. 15, drop height was about 43 cm

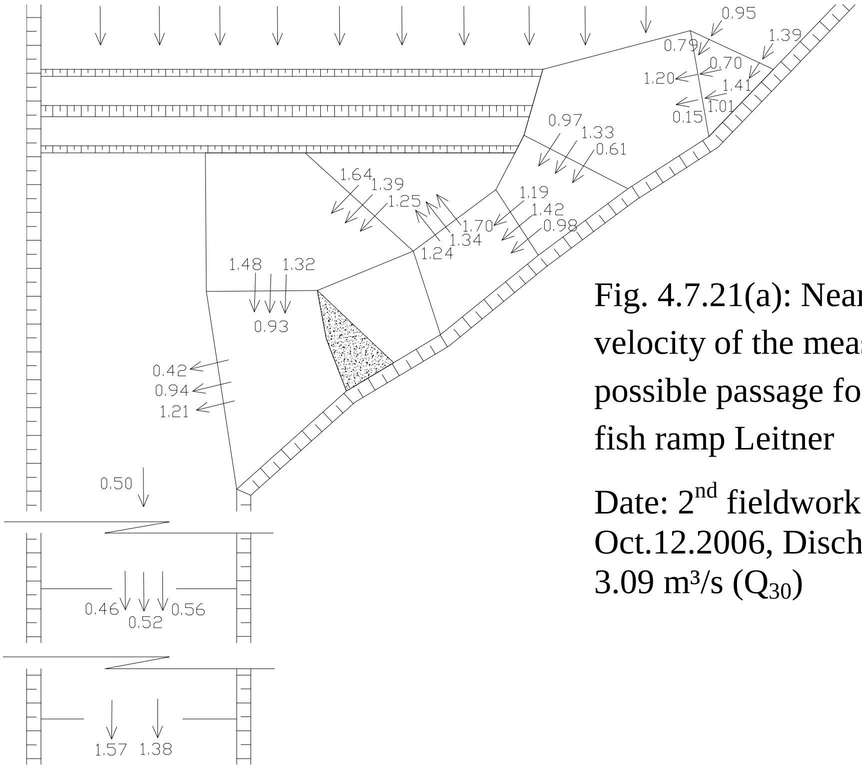


Fig. 4.7.21(a): Near bottom velocity of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006, Discharge: Q = 3.09 m³/s (Q_{30})

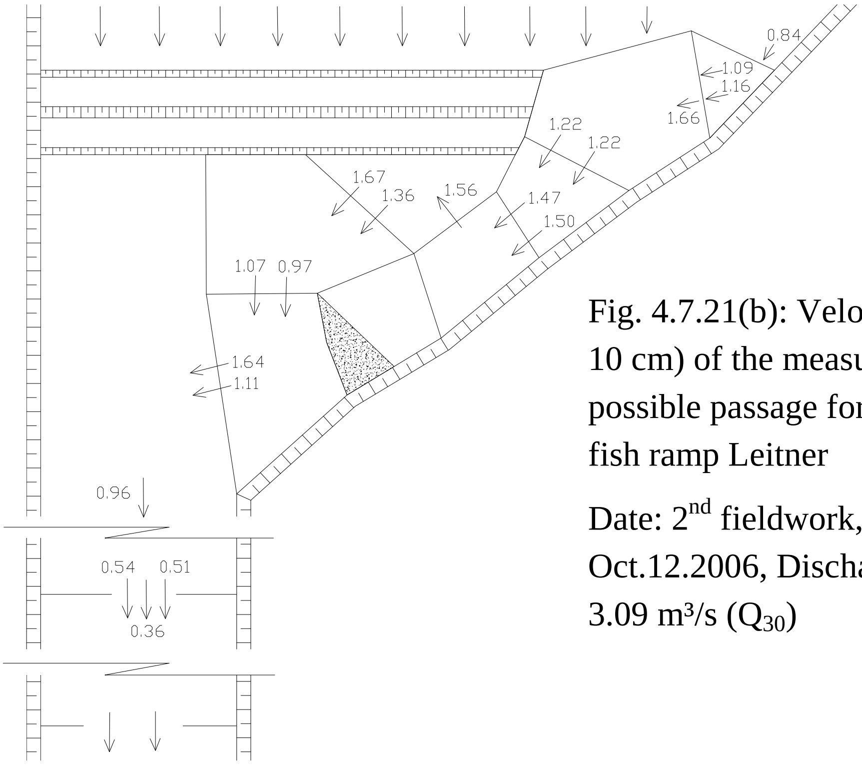


Fig. 4.7.21(b): Velocity (at z = 10 cm) of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006, Discharge: Q = 3.09 m³/s (Q_{30})

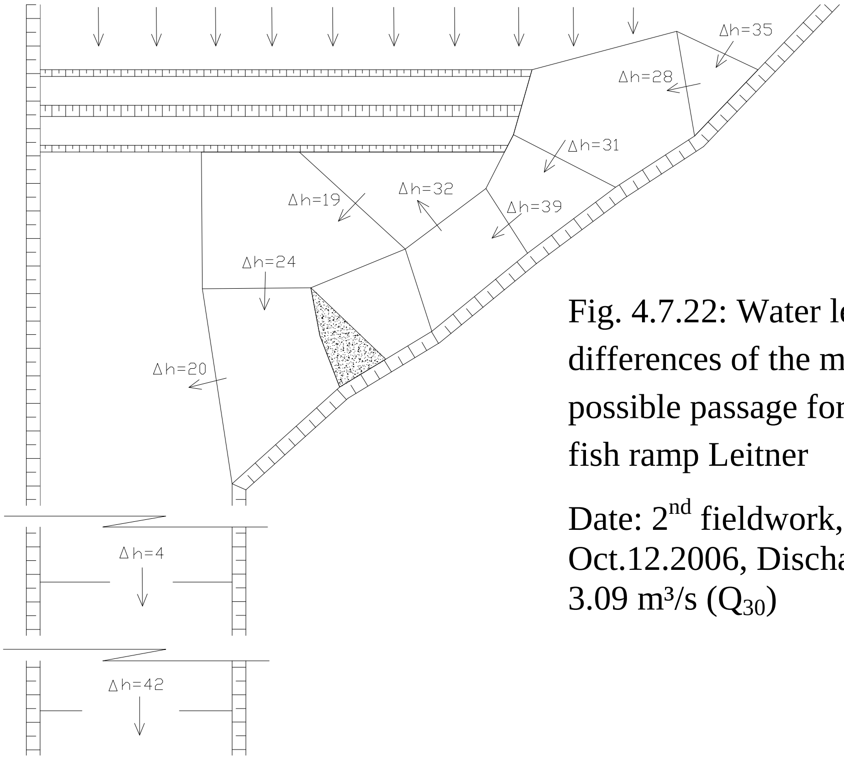


Fig. 4.7.22: Water level differences of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006, Discharge: Q = 3.09 m³/s (Q_{30})

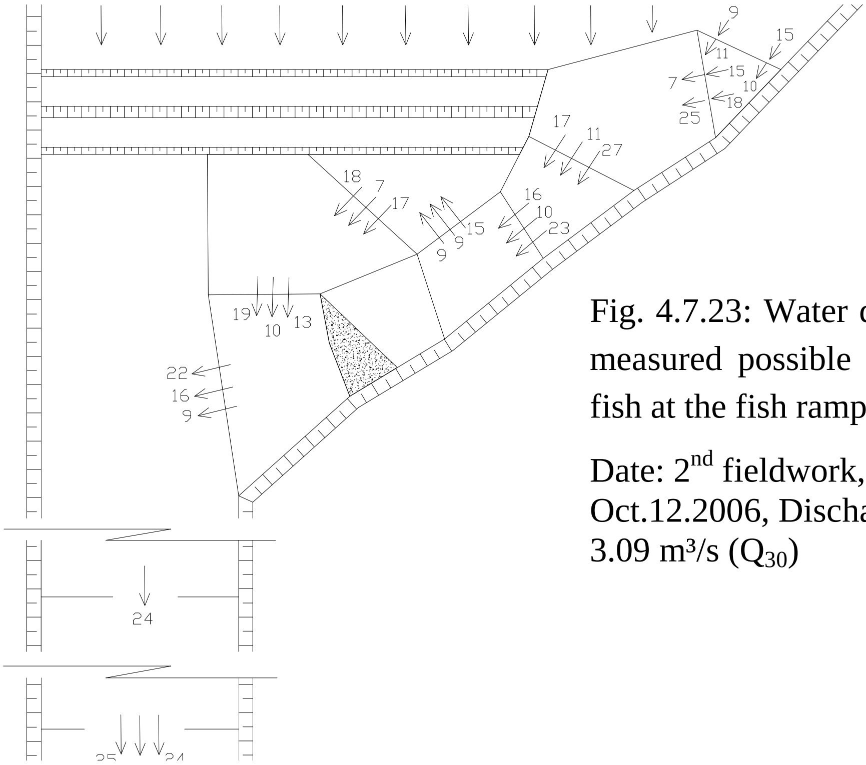
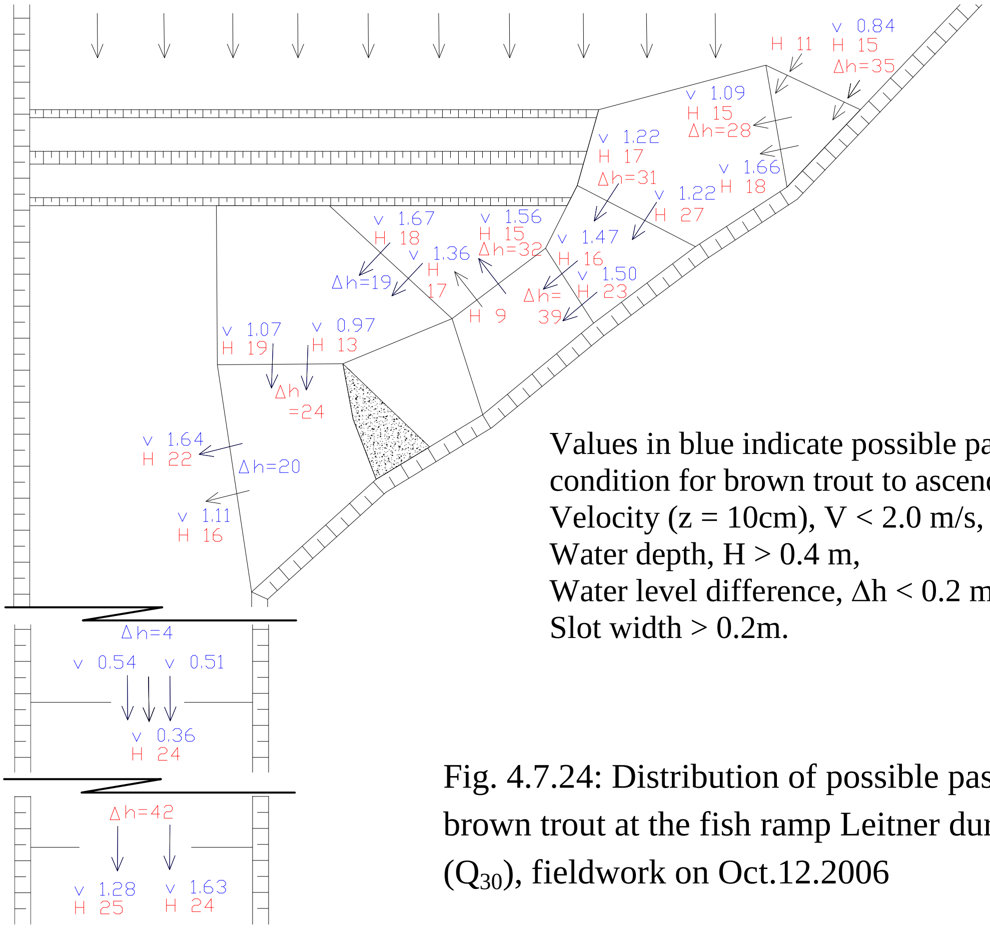


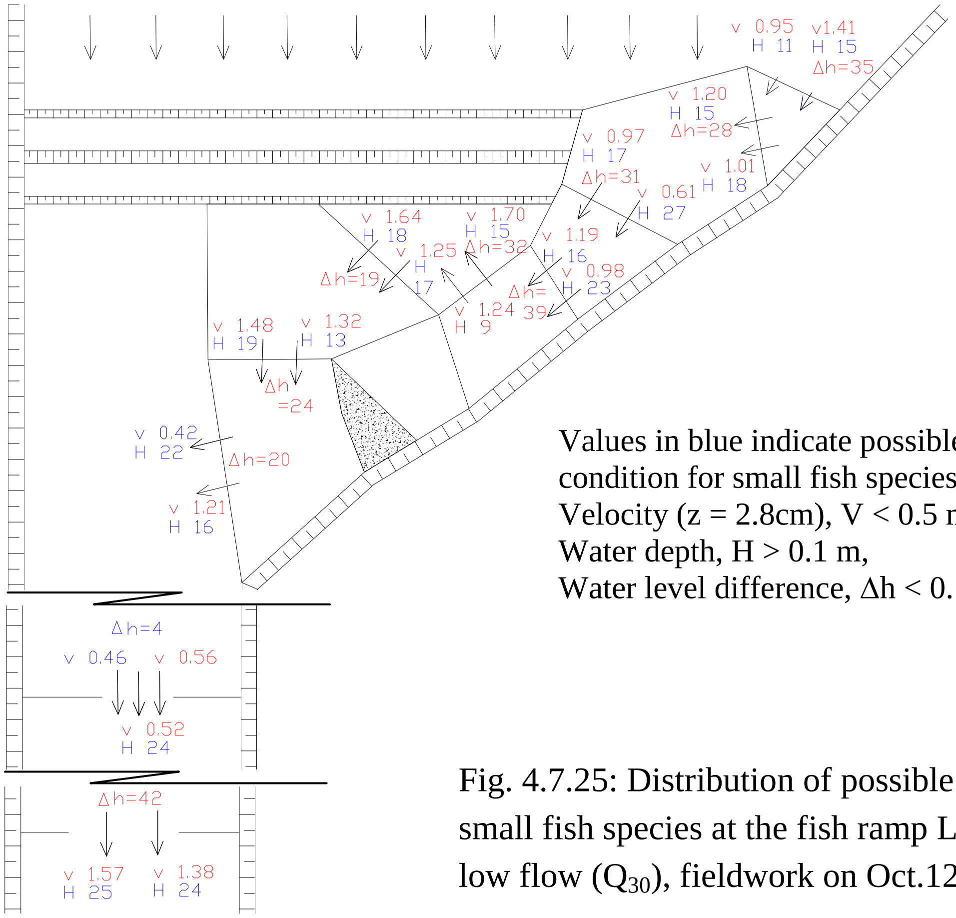
Fig. 4.7.23: Water depth of the measured possible passage for fish at the fish ramp Leitner

Date: 2nd fieldwork, Oct.12.2006, Discharge: Q = 3.09 m³/s (Q_{30})



Values in blue indicate possible passage under condition for brown trout to ascend:
Velocity (z = 10cm), V < 2.0 m/s,
Water depth, H > 0.4 m,
Water level difference, Δh < 0.2 m,
Slot width > 0.2m.

Fig. 4.7.24: Distribution of possible passage for brown trout at the fish ramp Leitner during low flow (Q_{30}), fieldwork on Oct.12.2006



Values in blue indicate possible passage under condition for small fish species to ascend:
Velocity (z = 2.8cm), V < 0.5 m/s,
Water depth, H > 0.1 m,
Water level difference, Δh < 0.1 m.

Fig. 4.7.25: Distribution of possible passage for small fish species at the fish ramp Leitner during low flow (Q_{30}), fieldwork on Oct.12.2006

4.7.3. Monitoring of fish migration behaviour at the fish ramp Leitner and the neighbourhood

Electric-fishing, fish-mark and trapping were used and the investigation was conducted three times in summer, autumn and spring respectively. Each monitoring period lasted for three weeks and the trapping nets were installed at the exits of the fish ramps at the upstream side. There are two trapping nets (see Fig. 4.7.21), trap net 1 is for the investigation at the fish ramp and trap net 2 is for monitoring the migration at the nature-like bypass. Both mesh sizes are 1 cm. The personnel checked the net twice or once a day, noted whether and how trapped fish were marked. The schedule of monitoring is listed in Table 4.2.9.

Table 4.7.6: The conducted monitoring work at the fish ramp Leitner

	1st field work summer	2nd field work autumn	3rd field work spring
Electric-fishing and fish mark	June.14.2006	Sep.28.2006	14.Apr.2006
Trapping	June.15. – Jul.05.2006	Sep.29. – Oct.19.2006	15.Apr.2006 – 05.May.2006
Correspond discharge, Q [m³/s]	ca. 5 m³/s (about MQ)	ca. 3 m³/s (about Q_{30})	ca. 3.5 m³/s (between MQ & Q_{30})

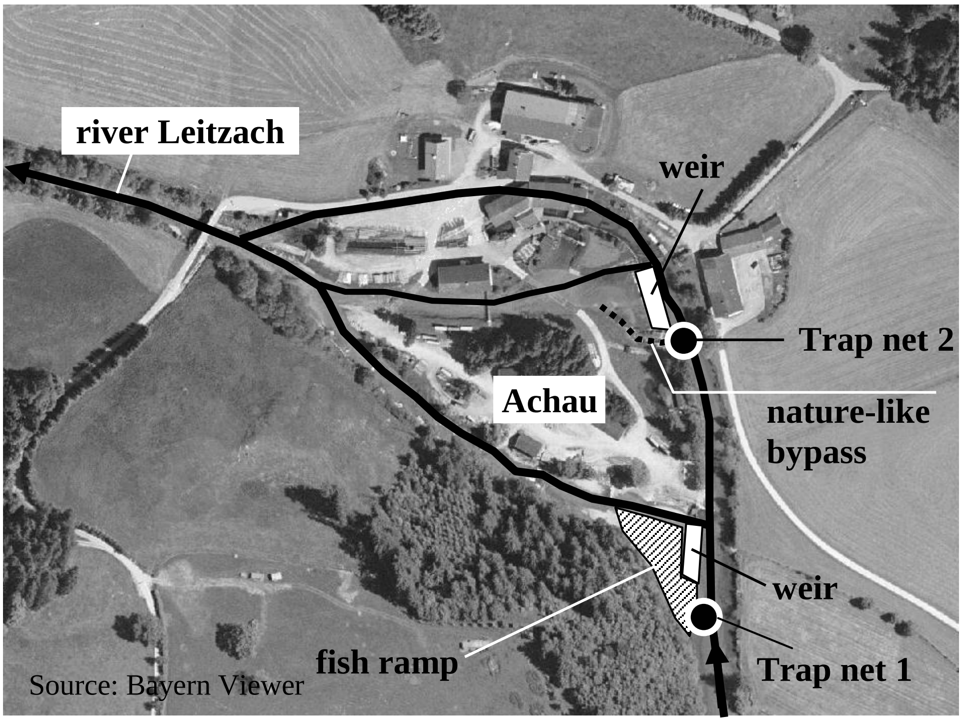
Note: schedule from Bavarian Fishing Accociation

The fish count and investigation of capture-recapture at the fish ramp Leitner and its neighbourhood were conducted by Bavarian Fishing Association. The fish species were captured by electric-fishing in the upstream and downstream sections of the fish ramp Leitner for 1 km long respectively. They were marked by injected dye and released right away where they were captured. The captured fish species include rainbow trout, brown trout, grayling, bullhead and brook trout, in which rainbow trout and brown trout are the majorities, where as grayling is categorized as “critically endangered” and brown trout and bullhead are categorized as “early warning list” in the Bavarian Red List of Threatened Fish and Cyclostomata Species (Bohl et al. 2003). As for the method of fish trapping for evaluating the effectiveness of fish migration facilities should be taken as qualitative assessment instead of quantitative assessment, it’s not appropriate to calculate the efficiency as the ratio of recaptured fish number divided by electric-captured fish number.

During the first field monitoring work, it corresponds to discharge of about annual mean flow (MQ), which provides relatively adequate hydraulic conditions for fish to migrate, as the results shown in chapters 4.7.1 and 4.7.2. Although the recaptured fish number doesn’t refer to a strong migration success, 18 fish were captured in the trap net 1, corresponding to an “efficiency” of 4.4 %, at the upstream side of the fish ramp (see chap. 4.4.2) during summer investigation period.

During the second and the third field work, the discharges corresponded to about Q_{30} and between MQ and Q_{30}. From the results of hydraulic investigation it shows that the Leitner fish ramp functions like a series of steps and is difficult for fish to swim through. In most case fish have to jump over the drops. The fish monitoring results correspond to the hydraulic investigation and only five and three fish were recaptured, corresponding to an “efficiency” of 1.8 % and 1.0 %, in the second and third fish monitoring period, respectively. Even not many fish were recaptured during the first investigation, the result of the first investigation is still different from the second and the third ones.

However besides the obstacles caused by too high drop heights in the fish ramp Leitner and the downstream separate sill No. 15, there are still two other possible barriers for fish to track back to the upstream side. One is the wrong attraction flow at the downstream part of the place Achau, which attract fish to move into the canal by stronger flow and without any fish migration facilities. The other possible barrier is the too shallow water depth in the left side reach which leads fish later upwards into the fish ramp.



Source: Bayern Viewer

Fig. 4.7.26: Locations of the installed trap net 1 and 2 at Leitner Mill: Trap net 1 installed at the upstream side of the fish ramp Leitner, whereas trap net 2 installed at the other bypass.

Table 4.7.7: Total number of electric-captured fish and fish count in the trapping nets in the three field investigations

	1st: summer								
Date	Jun.14.2006			Jun.15-Jul.5.2006					
Event Species	Electric-captured			Net 1			Net 2 (hydraulics were not investigated)		
	up-stream	down-stream	sum	number of captured fish	mark	recaptured rate [%]	number of captured fish	mark	recaptured rate [%]
Rainbow trout	122	81	203	6 (4)	down-stream	3.0(all) 4.9(down)	0	-	0
Brown trout	102	63	165	11 (9)	down-stream	6.7(all) 14.3(down)	7 (4)	(2)up-/(2)down-stream	4.2(all) 6.3(down)
Grayling	6	9	15	0	-	0	0	-	0
Bullhead	13	13	26	1	-	3.8(all)	2	-	7.7(all)
Brook trout	3	1	4	0	-	0	0	-	0
sum	**246**	**167**	**413**	**18**	**-**	**4.4**	**9**	**-**	**2.2**

	2nd: autumn								
Date	Sep.28.2006			Sep.29-Oct.19.2006					
Event Species	Electric-captured			Net 1			Net 2 (hydraulics were not investigated)		
	up-stream	down-stream	sum	number of captured fish	mark	recaptured rate [%]	number of captured fish	mark	recaptured rate [%]
Rainbow trout	44	32	76	0	-	0	0	-	0
Brown trout	27	37	64	3 (0)	-	4.7(all)	2 (0)	-	3.1(all)
Grayling	9	10	19	0	-	0	0	-	0
Bullhead	*	*	6	0	-	0	0	-	0
Brook trout	-	-	0	0	-	0	0	-	0
sum	**-**	**-**	**165**	**3**	**-**	**1.8(all)**	**2**	**-**	**1.2(all)**

	3rd: spring								
Date	Apr.14.2007			Apr.15-May.05-2006					
Event Species	Electric-captured			Net 1			Net 2 (hydraulics were not investigated)		
	up-stream	down-stream	sum	number of captured fish	mark	recaptured rate [%]	number of captured fish	mark	recaptured rate [%]
Rainbow trout	46	72	118	1 (0)	-	0.8(all)	0	-	0
Brown trout	75	63	138	2 (0)	-	1.4(all)	0	-	0
Grayling	2	19	21	0	-	0	0	-	0
Bullhead	*	*	25	0	-	0	0	-	0
Brook trout	*	*	3	0	-	0	0	-	0
sum	**-**	**-**	**305**	**3**	**-**	**1.0(all)**	**0**	**-**	**0**

Note 1: mark * are data unknown

Note 2: number in parentheses ( ) are number of marked fish

Note 3: Data of fish count provided by the Bavarian Fishing Association

The biological investigation was conducted by the Bavarian Fishing Association with support of the fish research group in Weihenstephan of the Technische Universität München. The objective of the biological investigation was however different from those of the hydraulic / geometrical investigation conducted by us. In the hydraulic / geometrical fieldwork, investigations were focused on the structure and the hydrological variation at the ramp itself to assess the effectiveness of the construction on the aspect of being a fish migration facility (since for bottom ramps, reopen the fish migration passage is an additional function for the construction). From the biological fieldwork it shows that the assessment was conducted at an extended region, including not only the fish ramp Leitner, but also the other small fish bypass and the neighbourhood. However for a broader study area, the methodology of biological investigation must be considered in different way. For example, fish which were electric-captured upstream did not provide any information for the assessment of the effectiveness level. Besides, fish which were electric-captured downstream distributed from below the fish ramp for 1 km long. There are however many other difficulties for a free passage for fish. That means, a very low recaptured rate could not refer to an inappropriate design of the fish ramp Leitner but indicated that the passage near by the Leitner Mill is problematic and the possible obstacles are as above mentioned, the fish ramp / fish bypass themselves, too shallow water depth at part of the water system and the attraction flow. But these possible barrages can be detected qualitatively by observation. The biological investigation should be conducted either focus on some of the obvious problems under restrictions for financial budget, or conducted at whole region covered all potential obstacles by a comprehensive survey.

4.7.4. Conclusion

From the two field investigations they show the problems at this fish ramp indicating clearly toward the water depths and water level differences of boulder sills, especially at boulder sills of No. 1, 2, 4, 5, 7 and 15. No. 15 locates separately downstream from the fish ramp and the measured water level differences at No. 15 during two field investigations were both over 40 cm, which indicate it an apparent barrier for fish to migrate. It should be improved by reducing the drop gap at the boulder sill or to create other openings at this boulder sill. Particularly at the last sill upstream of the fish ramp (boulder sill No. 1), appropriate slots must be created to improve the effectiveness at this critical section. Furthermore, besides the investigated ramp, one should observe if there are separate sills or other hydraulic constructions at the nearby upstream or downstream river section. In this case the sill No. 15 locates about 60m downstream from the fish ramp and is assessed to be a barrier, which will affect the effectiveness of the ramp.

The velocity was acceptable for good swimmers like brown trout (v ≤ 2.0m/s) but it was obviously too rapid for small fish species. To improve the problem about drop height, which is mentioned above, will probably improve the problem about flow velocity as well. Besides, within the safety consideration of construction, to create more openings at each boulder sills can be taken into consideration.

During low discharge, a continuous passage could be observed but it provides only a potential unique route but the hydraulic conditions were bad for trout or small fish species.

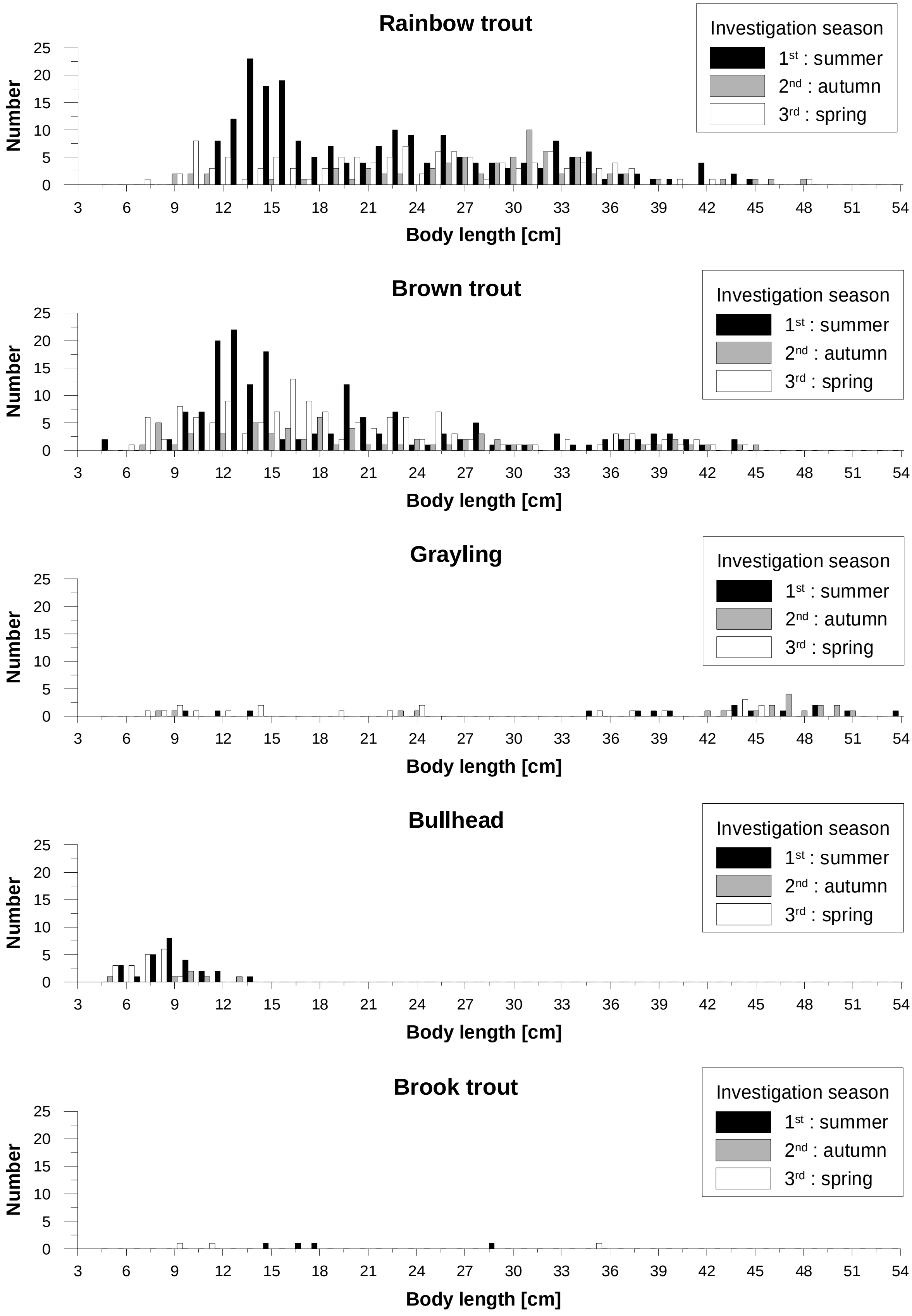


Fig. 4.7.27: Body length distribution of electric-captured fish for the three field investigations (Data provided by Bavarian Fishing Association)

4.8. Volumetric dissipated power

Applying the equation of energy dissipated rate to calculate the intensity of turbulent flow in the case studies, the results are shown in the table 4.8.1.

Table 4.8.1: Volumetric dissipated power at the four bottom ramps / fish ramps

	Kolbermoor	Schwaig	Plackermühle	Leitner
Date of data	16/17.May.2006	23.May.2006	17.May.2006	23.May.2006
River width [m] Length of river reach [m]	48 80	7 35.7	14 26	Area (second pool) = 98 m²
Discharge [m³/s] Spec. discharge [m³/s/m]	20 0.42	11 0.79	4.2 0.3	6.1 -
Water depth [m]	0.5	0.5 (deep zone)	0.6	0.7
Δh [m]	2.34 (upper ramp) 1.15 (lower ramp)	1.46	0.84	0.31
$E = \frac{\rho g \Delta h Q}{\bar{V}_{net}}$ [W/m³]	277 (upper ramp) 136 (lower ramp)	788	257	135
Note	Net volume = water volume – boulder volume	Assume ½ flow through deep water zone. Net volume = water volume – boulder volume	Net volume = water volume – (island + boulder volume)	Assume ½ flow through the ramp

As observed in situ, the bottom ramp Plackermühle may have severe problem on its flow pattern since the water during the Q_{330} investigation was very turbulent, besides the observation at the fish ramp Schwaig did not show significant problem on turbulent flow. However checking the energy dissipated rate, E = 788 for fish ramp Schwaig and E = 257 for bottom ramp Plackermühle show a contradiction to the observation. Basically the equation of energy dissipated rate is applied to pool-type fish passes. When applying to bottom ramps or fish ramps, it is not appropriate in most cases otherwise the bottom/fish ramps are also kind of pool-type, such as the fish ramp Schwaig. Whether the flow behaves turbulent or not is more depend on the structure. For rough ramp with perturbation boulders (fish ramp Schwaig), water flows through channel between boulders without drop or overflow, which are however typical flow patter for boulder sill type and cause significant turbulent flow below sills.

Furthermore as the discussions in Chapter 3, a better quantitative term to calculate the magnitude of turbulence is recommended to be TKE and energy dissipated rate should be used as an estimation of pool size.

4.9. Discussions

- Using macro-propeller-current-meter the velocity was measured at positions 2.8 cm for the 1st field work above the bottom at the 1st fieldwork and 2.8 cm as well as 10 cm above the bottom at the 2nd fieldwork, which represent near bottom position for small fish and swimming position for big fish. According to the result of the 2nd investigation, the difference of velocity at vertical position 2.8 and 10 cm apart from bottom was not significant. The velocity measurements of 10 cm above the bottom for a detailed survey can be dropped in similar field investigations.

  However even measurements 2.8 cm above the bottom do not represent all the “near bottom” velocity which should be defined according to the body height for different species. For small fish, the “near bottom” may be defined at about 1 cm above the bottom. Due to restrictions of instruments and various conditions *in situ*, it’s difficult to obtain the optimal near bottom velocity for assessment of the migration condition for small fish. A feasible alternative can be conducted in laboratory to simulate the near bottom environment in scale of prototype by selecting similar combination of substrate and to measure vertical velocity profile at the boundary layer. By developing the relationship of velocity at near bottom in laboratory and in situ, the near bottom condition in situ can therefore be more exactly evaluated.
- At the bottom ramp Kolbermoor the local fishing club asked the Bavarian Fishing Association not to use grayling (Äsche) for investigation, which is however listed in the Red List as critical endangered species and is one of the most important fish species to be studied in Bavaria. The conflict between different associations could result in lack of biological monitoring data.

- One of the biological monitoring methods, “Capture-mark-recapture”, doesn’t mean that it provides more information from result of field investigations than trapping. If the procedures of recapture can not be conducted intensively and for a valid long period to gather the seasonal variation of hydrological and biological conditions, the recaptured marked fish can not tell us more about how and where do fish migration. Otherwise what is quantitative analysis on biological monitoring and does it make sense? Or it is just mission impossible?

In middle Europe, the biological monitoring is not that necessary anymore to be conducted in every fish migration facility. Since the behaviour of many fish species are studied and the corresponded criteria are reported. It is practical in reality to ask for hydraulic monitoring instead. Only in cases of new type of fish migration facilities, newly listed fish species, for which the hydraulic requirements are not well known, demand on quantitative biological investigation data or in regions which haven’t be studied so detailed on the fish biological information, the biological monitoring will therefore be important and necessary to be made.

However one should notice that there are many factors influencing the biological monitoring results, e.g. temperature, light, nutrients and human activities, which is difficult to be analyzed in the result of capture-recapture work.

- The field investigation during high flow (Q_{330}) can be considered to be investigation of the near river bank region. Because during high flow, the current in the middle of the river flushes probably rapidly and is difficult for fish to ascend upstream, therefore fish might migrate along shore of river. The field work should be conducted along shoreline to assure that the investigation is executed under significant conditions and is also safe for the personnel.

- The obstacles due to inappropriate construction work should be examined during the check-and-accept phase to make sure that the ramp must work as in plan. The inappropriate construction work can include too high drops or too few openings due to some improper boulder sills, incorrect slope or spacing between sills, etc, which are resulted from the difficulty of constructing irregular cross sections by using irregular materials. The hydraulic monitoring, including three different flows: Q_{30}, MQ and Q_{330}, should therefore be conducted as an assessment of the effectiveness. Later a regular monitoring on the structure, e.g. the stability of the structure, should be done under a regular process. If the construction alters because of flood or other events, improvements should be executed for recovery of its ecological function.

- The bottom ramp Kolbermoor provides many potential possible passage slots for fish to migrate. However water depths dominate the quality of the ramp and seem to provide no continuous corridor for both brown trout and small fish species. The thalweg should be modified to build up a real passage with adequate water depths. Because of its structure the water is impounded during high flow. The hydraulic condition between mean flow and high flow periods may be adequate as a fish pass.

- A “Guideline” of geometrical / hydraulic monitoring is established according to the processes and results in these investigations, to suggest the engineers and authorities how to conduct an appropriate hydraulic monitoring on such ramps, which carry functions on mitigation of riverbed erosion and rebuild of free passages in river.

- Biological monitoring should concentrate on the ramp itself to match both data from biological and hydraulic investigations. Or at least part of the marked fish should be distinguished that they are released from the neighbouring area downstream of the ramp. Otherwise there is no foundation in common of biological and hydraulic investigations to give convinced conclusion.
- The slope of bottom ramps / fish ramps should be milder as 1:25 to prevent from too high flow velocity at narrow notches or openings as passage and too turbulent flow. Drop height at each sill must be exactly controlled not over 30 cm, otherwise slots must be created at both sides of the single boulder which creates water level difference over 20 cm.
- To examine the effectiveness of a fish migration facility, the necessary fieldwork include investigations of flow velocity, water depth, slot widths (if passage exists at narrow slots), water level difference (if the free surface line alone flow direction is not smooth but cascaded) and turbulent scale (quantified by TKE). The following equations can be developed:

$$\textit{Effectiveness} = \int_{Q_{30}}^{Q_{330}} (\textit{to trace}) \times (\textit{to pass})$$ (DWA-Themen 2006)

$$\textit{Level of effectiveness} = f(v, H, B, \Delta h, TKE)$$

where Q_{330}: 330-days-nonexceedence-discharge [m³/s]
Q_{30}: 30-days-nonexceedence-discharge [m³/s]
v: flow velocity [m/s]
H: water depth [m]
B: slot width [m]
Δh: water level difference [m]
TKE: turbulent kinetic energy [cm²/s²]
Level of effectiveness: A (very good), B (good), C (moderate), D (poor), E (bad)

Criteria (assessment of level of effectiveness) depend on fish species.

5. Conclusions

A. Mean Flow and Turbulence Distribution in Nature-Like Pool-Type Fishways

From the experimental results of such nature-like pool-type fish passes, the mean flow and turbulence structures are better known, hence to support a quantitative analysis in particular when comparing with technical type fish passes. Results are shown to give a systematic study of nature-like pool-type fish passes and to provide a better understanding for designing. Using statistical analysis we can have an overview of the flow pattern in both nature-like and technical type fish passes.

For conventional type of fish passes such as pool-type or vertical slot type, discharge, Q, is used for calculation of hydraulic condition in design. As for nature-like fish passes, specific discharge, q, should be used instead of discharge, Q, to refer flow at high or low flow condition, since water distributed at the whole width of constructions instead of only at slots or orifices with designed width.

B. Some ambiguity suppositions about the flow pattern and critical flow rate in nature-like design could be clarified according to the results of hydraulic model test.

Nature-like types provide better diversity in construction geometry. As for flow field, at some section in particular just at the sill and in the middle between two sills, technical type provide larger range of streamwise velocity distribution. At cross section just below the sill, flow has higher diversity by nature-like type. The mean velocity at narrow openings of sill by boulder sills is about 25 % lower than technical type sill T1, which is consistent with the conventional expectation. However at some positions in the middle of the pool, because the T1 sill functions as a separate wall and provides better impoundment, which is more stilling than impoundment upstream of the boulder sill.

C. Clarification on quantitative representations of turbulence

Due to the development of 3-D velocimeters, fluctuations of velocity can be measured and turbulence can be therefore precisely described. Volumetric dissipated power, turbulence intensity and turbulent kinetic energy were discussed and calculated by using the data from the experiments. Energy dissipated rate (dissipated power) used in pool-type fish passes is an averaged value, which can not represent the spatial variances and distribution of turbulence in a pool and should be used only for evaluation of pool size. Turbulence intensity is the proportion of turbulencet fluctuations to mean flow. In low mean flow zones, a very small perturbation of velocity can result in very high turbulence intensity, which does not refer to a significant influence on fish swimming performance. Turbulent kinetic energy is a non-dimensionless quantity and can be used to describe the scale of turbulence in space. It is recommended to use turbulent kinetic energy to study and to develop the relationship and the influences of turbulent flow and fish migration performance for both engineers and biologists on expressions in common.

Attempts to study turbulence problems in fish passes using power spectrums of turbulent fluctuations, Kolmogorov -5/3 law of local isotropic turbulence to estimate the dissipation rate or Reynolds number should be avoid. Simpler terms should be developed and to connect the relation with fish swimming performance. Here in this study turbulent kinetic energy (TKE) is recommended for application.

The design criterion of TKE is based on the existence of a resting zone for fish in a pool, i.e., a space where the flow velocity is lower than the upper limit, with dimensions at least three times the length, width, and height of the fish body. By selecting the grayling species with a resting velocity of 0.3 m/s as an example, a TKE of value up to 300~400 cm^2/s^2 for q_p = 150 l/s/m and up to 400~500 cm^2/s^2 for q_p = 200 l/s/m or higher in nature-like fish passes with slope = 1:30, as well as a TKE value of up to 500 cm^2/s^2 for passes with slope = 1:15, are recommended.

D. Hydrologic criteria for monitoring

From the statistics of historical hydrological data it shows that the Q_{30} is similar to mean low flow (MNQ) and Q_{330} is about double of mean annual flow (MQ), which can be taken as replacements if the nonexceedence discharges of Q_{30} and Q_{330} are difficult to obtain. To examine the hydraulic parameter, velocity and water depth, Q_{30} and Q_{330} should be selected as Q_{min} and Q_{max}.

E. Importance of hydraulic monitoring

The ideal approach of assessing the effectiveness of fish migration facilities is to conduct the quantitative biological monitoring. However, to reach the goal of at least 300 days/year suitable fish passage potential, the biological monitoring should be made exceeding one year (DWA 2006). In practice, the biological monitoring should be made at least for three seasons and each time lasts at least four weeks. The implemented facilities for biological monitoring should be checked out at least once a day.

Under the current water regulations about fish migration facilities in Germany, the hydraulic calculation and investigation must be conducted during planning, designing, constructing and check-and-accept phases. However, there is no requests on biological monitoring.

Since high expenses of biological monitoring are not often affordable and the fish migration facility owners have no jural obligations to do it. Therefore to establish systematic assessment procedures of geometrical / hydraulic parameters on effectiveness of fish passage facilities is the key of a successful design.

F. High spatial hydraulic diversity and low temporal variation

From the result of the first and second field works, it shows that an effective bottom / fish ramp should provide suitable fish free passage “so long as possible” during “flow seasonal variation”. The ramps that satisfy the above principle should have the following properties: dependent flow conditions, in terms of flow velocity, water depth and drop height, should have least influences from seasonal changing discharges.

Whether it forms a proper flow pattern for fish migration in a nature-like bypass channel, the point is on the structure of the construction, which means the arrangement of boulders, instead of calculation. Because the assessment of submerged overflow reduction factor or the weir coefficient can be hardly applied in practice for various types of bottom ramps.

The slope of bottom ramps / fish ramps should be milder as 1:25 to prevent from too high flow velocity at narrow notches or openings as passage and too turbulent flow. Drop height at each sill must be exactly controlled not over 30 cm, otherwise slots must be created at both sides of the single boulder which creates water level difference over 20 cm.

To examine the effectiveness of a fish migration facility, the necessary fieldwork include investigations of flow velocity, water depth, slot widths (if passage exists at narrow slots), water level difference (if the free surface line alone flow direction is not smooth but cascaded) and turbulent scale (quantified by TKE). The following relation can be developed:

$$\boldsymbol{Effectiveness = \int_{Q_{30}}^{Q_{330}} (to\ trace) \times (to\ pass)}$$ (DWA-Themen 2006)

$$\boldsymbol{Level\ of\ effectiveness = f(v, H, B, \Delta h, TKE)}$$

where Q_{330}: 330-days-nonexceedence-discharge [m³/s]
Q_{30}: 30-days-nonexceedence-discharge [m³/s]
v: flow velocity [m/s]
H: water depth [m]
B: slot width [m]
Δh: water level difference [m]
TKE: turbulent kinetic energy [cm²/s²]
Level of effectiveness: A (very good), B (good), C (moderate), D (poor), E (bad)

Criteria (assessment of level of effectiveness) depend on fish species.

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Notation

The following symbols are used in this book:

b_0	[m]	bottom width of river upstream from constructions;
b_0’	[m]	crest width of bottom ramp;
r	[m]	radius of curvature;
b_u	[m]	bottom width of river downstream from constructions;
a_x	[m]	clear distance between boulders, x- direction (streamwise);
a_y	[m]	clear distance between boulders, y- direction (lateral);
d_s	[m]	equivalent spherical diameter;
b, B	[m]	width of fish ramp, river, slot, pool in a fish pass, etc.;
L	[m]	interval of boulder sill or separate wall;
$h_{ü}$	[m]	head over weir;
S	[-]	slope;
$V_{tolerable}$	[m/s]	tolerable velocity;
V_{crit}	[m/s]	critical flow velocity for fish to pass through;
V_{max}	[m/s]	maximum velocity (appearing in the pool-type fish pass);
μ	[-]	weir coefficient;
σ	[-]	submerged overflow reduction factor;
h	[m]	water depth, height of slot;
h_m	[m]	mean water depth;
A	[m^2]	area, cross section area;
I_w	[m]	length of pool in a fish pass;
ρ	[kg/m^3]	density of water;
W	[watt]	SI derived unit of power, watt;
$\boldsymbol{q_{crit}}$	[m^3/s/m]	critical specific discharge;
ρ_s	[kg/m^3]	density of stone;
$\boldsymbol{S}$	[-]	slope of ramp;
d_{65}	[m]	diameter through which 65% of soil passes;
d_s	[m]	equivalent spherical diameter;
$\vec{\zeta}$	[1/s]	vorticity;
$\boldsymbol{\nu}$	[m^2/s]	viscosity of water;
$\vec{\omega}$	[1/s]	rotation;
$\omega_x, \omega_y, \omega_z$	[1/s]	rotation components in x-, y- and z-directions;
Γ	[m^2/s]	circulation;
$d\vec{s}$	[m]	vector of length d_s tangent to a curve in the flow;
q	[m^3/s/m]	specific discharge;
g	[m/s^2]	gravitational acceleration;
Δh	[m]	water level difference, drop height;
k_1	[-]	ratio of measured V_{max} to theoretical V_{max};
k_2	[-]	ratio of measured water level difference to designed water level difference;
TKE	[cm^2/s^2]	turbulent kinetic energy;
TI	[-]	turbulence intensity;

E	[W/m³]	volumetric dissipated power;
u	[m/s]	instantaneous velocity;
u', v', w'	[m/s]	fluctuating velocity components in x-, y- and z-directions;
e	[cm²/s²]	a value of turbulent kinetic energy at time t;
$\bar{\boldsymbol{e}}$	[cm²/s²]	a mean value of turbulent kinetic energy;
$\overline{\boldsymbol{U}}$, $\bar{\boldsymbol{u}}$	[m/s]	time averaged velocity;
P_r	[%]	probability of nonexceedence;
P	[%]	probability, in percentage is P %;
$Q_{p\%}$	[m³/s]	nonexceedence discharge at P %, at the probability of P % in a year, flow in river is under $Q_{p\%}$;
D_r	[day]	nonexceedence in days;
Q_{days}	[m³/s]	nonexceedence discharge at D_r, at D_r days in a year, flow in river is under Q_{days};
Q_{30}	[m³/s]	30-days-nonexceedence-discharge;
Q_{330}	[m³/s]	330-days-nonexceedence-discharge;
Q_{min}	[m³/s]	minimum discharge;
Q_{max}	[m³/s]	maximum discharge;
h_s	[m]	height of sills;
v_s	[m/s]	flow velocity over sills;
v_a	[m/s]	flow velocity upstream;
t_a	[m]	water depth upstream;
t_s	[m]	water depth over the sills.

Appendix A: ADV experiments and settings

Table A.1: List of ADV experiments

Slope [%]	Measured volume	Specific discharge, q [l/s/m]	Position of measurements, z [cm]	Water depth, h [cm]	Measure planes
3.33 (1:30)	S4 – S5	150	12.5	44.0	Measurements were made at planes where x = 440, 445, 450, 455, 460 cm and y = 6, 12.5, 18, 25, 31, 37 and 43 cm. Measuring grid is shown in Fig. A.1. Magnitudes are in prototype scale.
		200	12.5	50.5	
		200	17.5		
		250	15	56.3	
		250	20		
	S6 – S7	150	12.5	47.5	
		200	12.5	51.0	
		200	17.5		
		250	15	55.8	
		250	20		
	T2 – T2	150	15	52.3	
		200	15	56.7	
		200	22.5		
		250	15	-	
		250	22.5		
6.67 (1:15)	S4 – S5	200	12.5	39.8	
		250	15	43.4	
	S6 – S7	200	15	43.2	
		250	15	43.7	
	T2 – T2	200	15	49.4	
		250	15	53.5	

From the result in Fig. A.1, the average streamwise velocities in case q = 250 l/s/m, z = 4 cm and in the pool between sills S4 – S5 under different filters show that they are very consistent comparing with different criteria of filters, which gives the evidence of the adequate measuring time span. But the sensitivity of turbulence interpretation under different criteria should be examined to decide a proper filter for the ADV measured data.

From the comparison of filtered raw data using “50% correlation filter” and a filter combination “50% correlation filter plus Phase-space Despiking Method”, it shows that when using only the correlation coefficient as the filter criterion, there are still a few outliers left in the filtered data set. These outliers, also called “spikes”, can, however, be filtered effectively by using Phase-space Despiking Method.

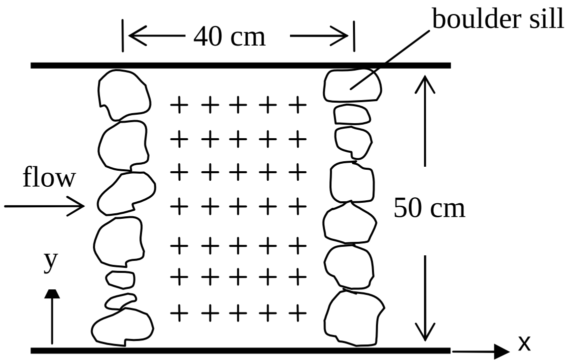


Fig. A.1: ADV measure grid

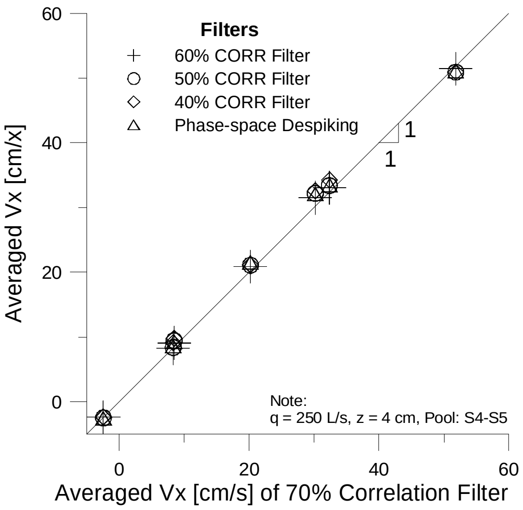
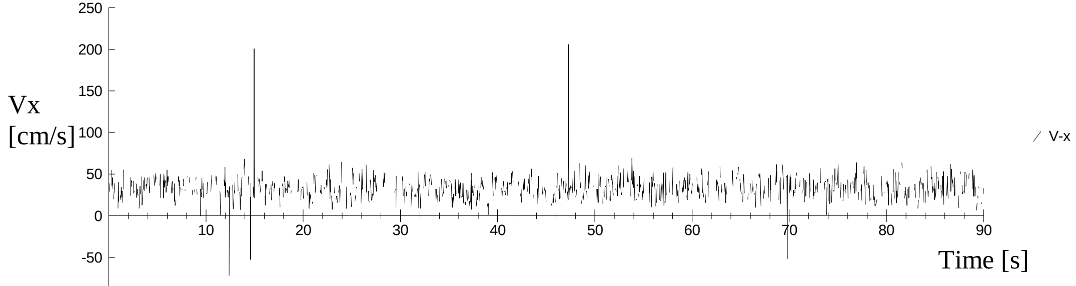


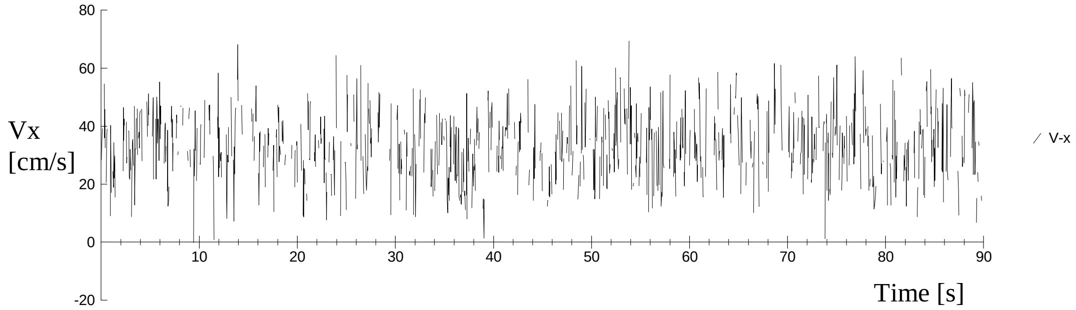
Fig. A.2: Comparison of $\overline{\boldsymbol{V}}_x$ with different filters

Case: q = 250 l/s/m, x = 450 cm, y = 31 cm, z = 4 cm, pool: S4 – S5



(a) Time series of V_x after using CORR < 50% filter

Case: q = 250 l/s/m, x = 450 cm, y = 31 cm, z = 4 cm, pool: S4 – S5



(b) Time series of V_x after using “CORR < 50%” plus “Phase-space Despiking” filter

Fig. A.3: Comparison of filtered time series of V_x with / without Phase-space Despiking filter

In Fig. A4 it shows, when only using Phase-space Despiking Method, the root-mean-square of Vx distributes widely and apparently higher than combining correlation coefficient filters. Such that in this model test, the Phase-space Filter should not be used singly to prevent from over-estimate the flow fluctuation. As for selection of the proper percentage of correlation coefficient filter, in Fig. A3 shows CORR 40% results in similar problem of root-mean-square distribution as using Phase-space Despiking Method alone. CORR 50% and 60% are consistent with 70%. Since using CORR 50% will retain more effective data points, the CORR 50% plus Phase-space Despiking Method is chosen as the filter criterion in this model test.

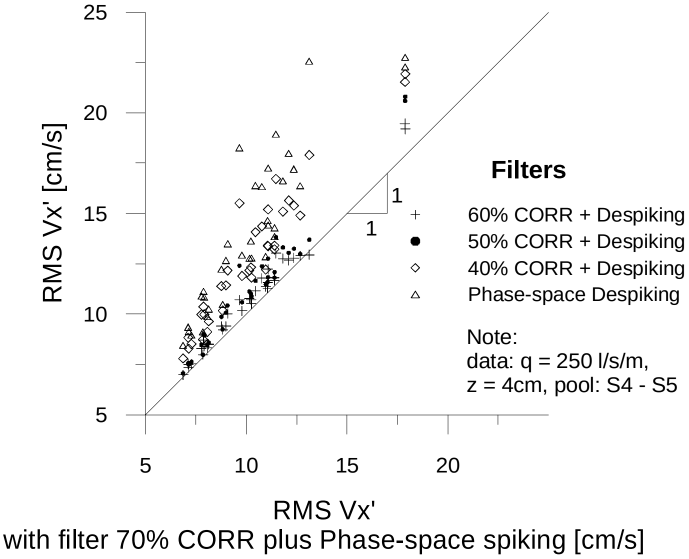


Fig. A.4: Comparison of different percentage of correlation coefficient filters

The values of correlation coefficient (CORR) are shown in the following table A.2:

Table A.2: Ranges of the correlation coefficient (CORR) in the ADV measurements

Slope	Sill pair	Spec. discharge, q [l/s/m]	CORR [%]	Slope	Sill pair	Spec. discharge, q [l/s/m]	CORR [%]
1:30	S4 – S5	150	70 ~ 85	1:15	S4 – S5	150	–
		200	70 ~ 85			200	60 ~ 70
		250	70 ~ 80			250	50 ~ 80
	S6 – S7	150	80 ~ 90		S6 – S7	150	–
		200	70 ~ 80			200	60 ~ 75
		250	80 ~ 85			250	–
	T2 – T2	150	55 ~ 80		T2 – T2	150	–
		200	70 ~ 85			200	60 ~ 70
		250	65 ~ 75			250	40 ~70

The values of CORR in the table indicate its averaged value in a test. If CORR of a test is about 70%, then there will be about 50% data retained after simply using filter of CORR ≥ 70%. The values of CORR in the tests using technical sills or with higher slope S = 1:15 are much lower comparing with the tests using boulder sills with slope S = 1:30.

In our laboratory, the water is stored in the basement and is pumped circularly. Seeds feeding was tried to increase CORR values. However the CORR values increased in the impoundment reach upstream of the boulder sills but not in the pools between sills where the water was more turbulent. The bad CORR values were supposed to be due to turbulent flow condition, in particular resulted from the rough gravel bottom and overflow through sills.

Appendix B: PIV experiments and settings

Table B.1: List of PIV experiments

Longitudinal sections:

Sill pair		q	Position, y	Sill pair		q	Position, y
Up-stream	Down-stream	[l/s/m]	-	Up-stream	Down-stream	[l/s/m]	-
T1	T1	150	Front, section (a)	T1	T1	150	Rear, section (c)
S4	S5			S4	S5		
S6	S7			S6	S7		
T1	T1	200		T1	T1	200	
S4	S5			S4	S5		
S6	S7			S6	S7		
T1	T1	250		T1	T1	250	
S4	S5			S4	S5		
S6	S7			S6	S7		
T1	T1	150	Middle, section (b)	Note: Burst length = 50 Hz, Laser power: 140 ~ 147, Pulse separation: 1000 μs, Interrogation size = 32 pixel			
S4	S5						
S6	S7						
T1	T1	200					
S4	S5						
S6	S7						
T1	T1	250					
S4	S5						
S6	S7						

Water surface:

Sill pair		q
Up-stream	Down-stream	[l/s/m]
T1	T1	150
S4	S5	150
S6	S7	150
T1	T1	200
S4	S5	200
S6	S7	200
T1	T1	250
S4	S5	250
S6	S7	250

Note:

Number of captures = 100,
Frequency = 9.07 Hz,
$\Delta t_{exposure}$ = 0.01 s,
Δt_{delay} = 0 s

Appendix C: Nomenclature

Chapter 2: Principles of fish passes and nature-like fish migration facilities

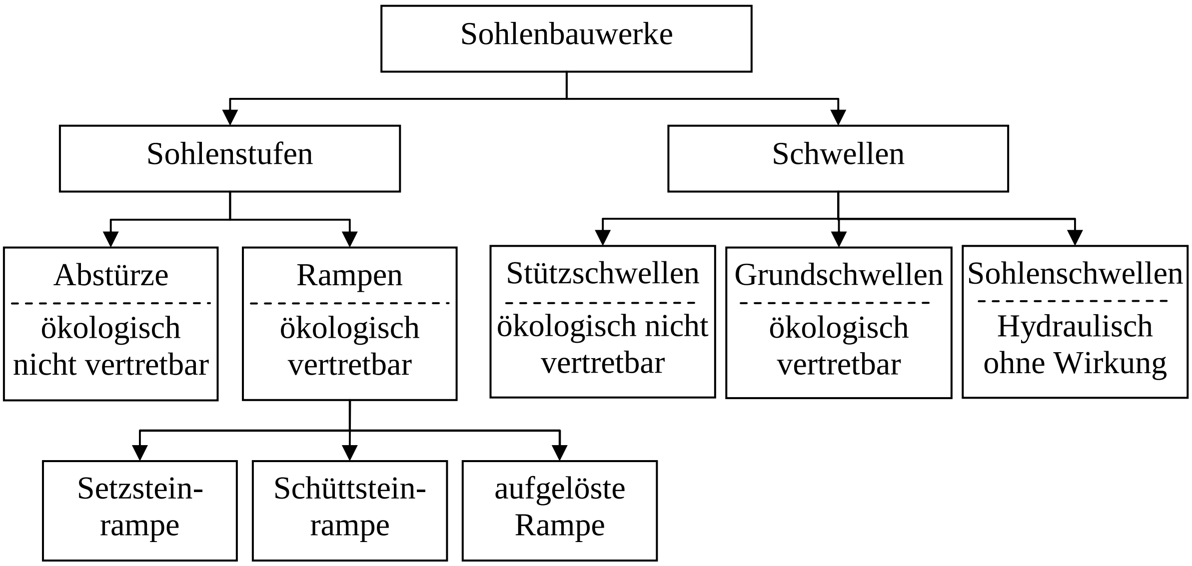


Fig. C.1: Classification of bottom protection structures according to DIN 19661-2/1991 and DVWK 232/1996 in German

Table C.1: Terms of bottom protection structures in DIN 19661-2 and DVWK 232

German	English	Source of German terms
Sohlenbauwerke	Bottom protection structure[1]	DIN 19661-2
Rampen - Sohlrampen - Sohlgleiten	Ramp - Bottom ramp - Bottom slope	DIN 19661-2, DVWK 232
Schüttsteinrampe		DVWK 118
Lockere Bauweise	Loose construction[2]	DVWK 118, DVWK 232
Geschüttete Bauweise	Rockfill construction[2], ramp with perturbation boulders[3]	DVWK 232
Setzsteinrampe		DVWK 118
Geschlichtete Bauweise	Dressed construction[2]	DVWK 118, DVWK 232
Blocksteinbauweise	Embedded-boulder construction[2]	DVWK 232
Aufgelöste Rampe	Dispersed[2]/cascaded construction[2], embedded rocky sills construction[2]	DVWK 118, DVWK 232
Riegelbauweise	Boulder bar construction[2]/ ramp with boulder sills[3]	DVWK 118, DVWK 232
Stützschwellen Stützwehre	Firm sill[3]	DIN 19661-2, DVWK 118 DIN 19661-2
Grundschwellen	Gound sill[3]	DIN 19661-2, DVWK 118
Sohlenschwellen	Bottom sill[3]	DIN 19661-2, DVWK 118

[1] DIN 19661-2, [2] DVWK 232 English version, [3] by author

Chapter 3: Mean Flow and Turbulence Structures in Nature-Like Pool-Type Fish Passes

Abminderungsbeiwert	Submerged overflow reduction factor
Überfallbeiwert	weir coefficient μ, spillway coefficient (DVWK 232)

Chapter 4: Field investigation in the river system of Mangfall

Reusen	Trapping (English references), Fish traps (DVWK 232)
Fang/Markierung/Wiederfang	mark-recapture (Travade 2006)
Steinschwelle	boulder sill
Wasserbaustein	armourstone
Restwasser/ Restwassermindestmenge	Instream flow (needs), Minimum flow, Minimum ecological flow
Obere Forellenregion	Upper trout zone (DVWK 232)
Untere Forellenregion	Lower trout zone (DVWK 232)
Äschenregion	Grayling zone (DVWK 232)
Barbenregion	Barbel zone (DVWK 232)

Hydrological statistics:

NQ	lowest flow of the uniform time segments in the considered observed period
MNQ	annual low flow
Q_{30}	30-days-nonexceedence-discharge
MQ	annual mean flow
Q_{330}	330-days-nonexceedence-discharge
MHQ	annual high flow
HQ_1	flood with a return period of 1 year
HQ	highest flow of the uniform time segments in the considered observed period

Appendix D: Estimation of Q_{30} and Q_{330} for rivers in the region of Alpine foothills

To conduct the monitoring field work at ramps / fish ramps the mean value and upper / lower limits of the concerned discharges are Q_{30}, MQ and Q_{330}, some of which are however difficult to obtain. Yet little possible is it to manage a field work for discharges exact by the concerned values, an estimations of Q_{30} and Q_{330}, will be proper enough for planning a monitoring work.

In the Table D.1 are the statistics of discharge at the three gauge stations in the region where the field work was conducted. From the data it seems that the statistics MNQ and MQ are of similar orders to values of Q_{30} and Q_{330} and NQ and HQ are extreme values which are not proper for estimations of Q_{30} and Q_{330}, while the reasons for MHQ and HQ_1 are similar. Therefore following combination ratios of MNQ, MQ, Q_{30} and Q_{330} are used to do the analysis.

Table D.1: Statistics of discharge at the corresponding gauging stations [unit: m³/s]

Ramp	Kolbermoor	Schwaig	Plackermühle	Leitner Mühle
River	Mangfall		Kalten	Leitzach
Gauging station	Rosenheim Mangfall		Hohenofen	Stauden
Data year	1966 – 2000		1999 – 2004	1941 – 2002
NQ	1.02		0.18	1.00
MNQ	2.43		0.39	1.96
Q_{30}	3.06		-	2.25
MQ	17.40		2.65	4.66
Q_{330}	36.90		-	7.83
MHQ	169		35.1	40.5
HQ_1	139		-	31.3
HQ	389		40.7	105

From the historic statistics of discharges at gauge stations in river system of Mangfall and Inn till Rosenheim as well as river system of Isar till Freising in Fig. D.1 it shows that to estimate values of Q_{30} in cases at which stations there are no statistics available, the ratio of MQ and Q_{30} from adjacent stations diverse a lot and could result in huge error of estimations. However adopting MNQ to approach Q_{30} can obtain much better estimations. The ratios of MNQ/Q_{30} exclusive at gauge station Rißbachdüker are between 1.0 and 0.7 so that a scale of 0.85 or simply of 1.0 is suggested to estimate Q_{30}. Similarly, to estimate values of Q_{330} in cases of no statistics available, the ratio of Q_{330} and MQ from adjacent stations could be adopted. From the figure it shows that the ratios of the mentioned stations are between 1.5 and 2.2 so that a scale of 1.85 or simply of 2.0 is then suggested to estimate Q_{330}. The peak values shown in the figure are data from stations with very low MNQ or Q_{30} ranging around 0.1 to 1 m³/s therefore a slight increment will result in high ratios and will be ignored for estimations of Q_{30} and Q_{330}.

From the data it is evidently that the foothills of the Alps have similar characteristics of the above mentioned statistics and the suggested ratios can be applied at rivers in this region.

$$\boldsymbol{Q_{30} = MNQ \div (0.7 \sim 1.0) \approx MNQ \div 0.85}$$
$$\boldsymbol{\textit{or simply} \approx MNQ}$$

$$\boldsymbol{Q_{330} = (1.5 \sim 2.2) \times MQ \approx 1.85 \times MQ}$$
$$\boldsymbol{\textit{or simply} \approx 2 \times MQ}$$

for rivers at the foothills of the Alps.

However for new gauge stations with historic records for merely a few years, to adopt the ratio of MQ/Q_{30} from adjacent stations instead of MNQ/Q_{30} will be suggested since MNQ still varies significantly.

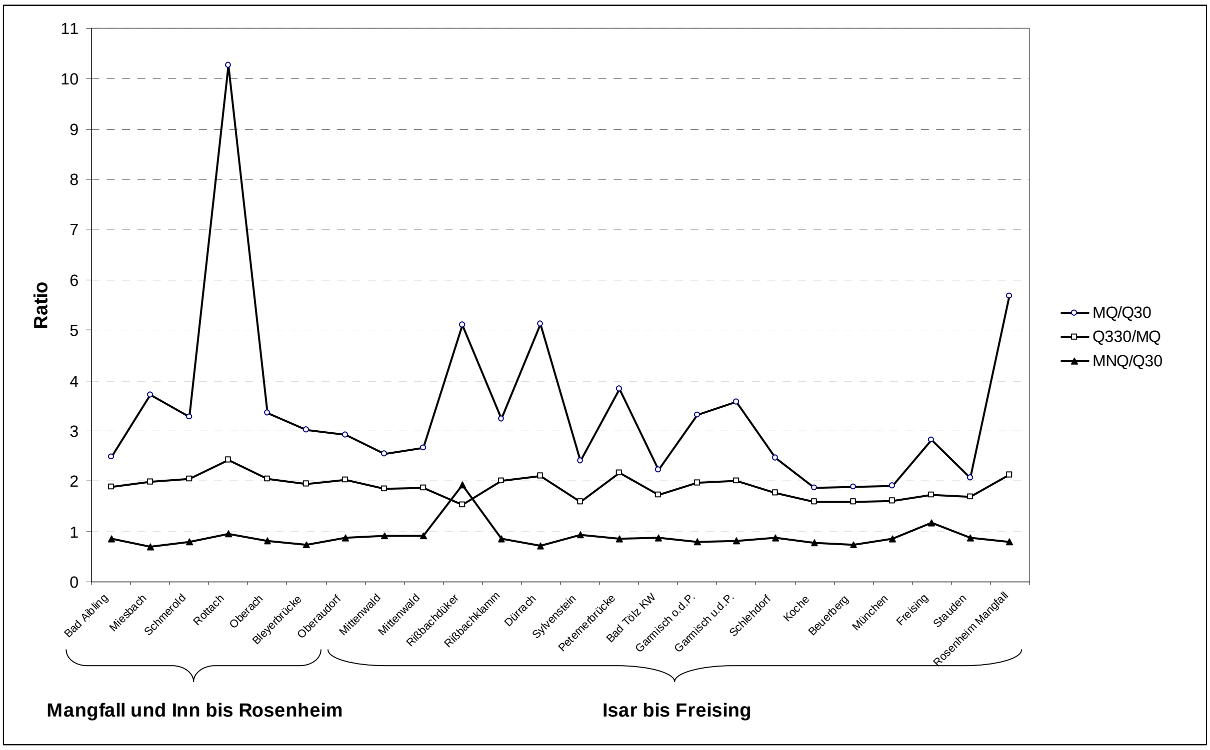


Fig. D.1: Statistics of discharges at gauge stations in river system of Mangfall and Inn till Rosenheim as well as river system of Isar till Freising

Appendix E: Data of field investigations in the river system of Mangfall

E.1. Bottom ramp Kolbermoor

Table E.1: Statistics of results of 1st field investigation at the bottom ramp Kolbermoor on May.16-17.2006, Q = 20.0 m³/s (MQ)

Boulder sill No.	Length of sill [m]	Possible passage corridor[1]		
		Number of possible passage slots	Sum of slot width [m]	Passage ratio [%]
Upper – 1	44.6	8	3.5	7.8
Upper – 2	37.0	10	5.2	14.0
Upper – 3	40.5	14	6.1	15.1
Upper – 4	42.9	15	6.5	15.1
Upper – 5	47.2	14	5.1	10.7
Upper – 6	52.1	14	5.2	9.9
Upper – 7	49.7	18	6.2	12.5
Upper – 8	54.5	19	7.2	13.2
Upper – 9	51.4	18	6.1	11.8
Upper – 10	52.7	13	3.9	7.5
Upper – 11	53.0	16	5.0	9.4
Upper – 12	50.1	10	14.5	28.9
Average (all sills)	48.0	14.1	6.2	13.0
Average [2] (sills No. 1 ~ 7)	**44.9**	**13.3**	**5.4**	**12.2**
Lower – 1	42.9	25	11.7	27.2
Lower – 2	39.6	19	6.1	15.4
Lower – 3	38.2	24	10.8	28.2
Lower – 4	40.6	22	8.2	20.2
Lower – 5	39.1	24	9.6	24.6
Lower – 6	40.0	22	9.4	23.5
Lower – 7	36.1	20	9.0	24.9
Lower – 8	34.3	18	8.6	25.2
Lower – 9	34.8	19	7.8	22.3
Lower – 10	23.4	12	4.5	19.3
Average	**36.9**	**20.5**	**8.6**	**23.1**
Average [2] (sills No. 1,3,5~7,9)	**38.5**	**22.3**	**9.7**	**25.1**

[1] The possible passage corridor varies from species to species with different migration criteria

[2] For comparison with the result of 2nd field investigation.

Table E.2: Statistics of measurements of 2nd field investigation at the bottom ramp Kolbermoor on Oct.25.2006, Q = 4.84 m³/s (Q_{30})

		Possible passage corridor		
Boulder sill No.	Length of sill [m]	Number of possible passage slots	Sum of slot width [m]	Passage ratio* [%]
Upper – 1	39.9	12	5.5	12.4
Upper – 2	39.1	15	5.8	15.6
Upper – 3	40.6	16	5.2	12.9
Upper – 4	39.5	17	5.4	12.6
Upper – 5	47.5	15	4.0	8.4
Upper – 6	44.4	22	5.4	10.4
Upper – 7	45.0	19	5.5	11.1
Average	**42.3**	**16.6**	**5.3**	**11.9**
Lower – 1	43.0	21	5.8	13.4
Lower – 3	38.8	21	5.7	14.8
Lower – 5	38.2	19	5.8	14.8
Lower – 6	39.5	19	5.8	14.5
Lower – 7	36.4	19	5.2	14.3
Lower – 9	36.2	20	7.3	20.9
Average	**38.7**	**19.8**	**5.3**	**15.5**

* Based on same criteria for comparison, here the passage ratio is the sum of slots width measured at the 2nd field work divided by length of sills from the 1st field work.

Appendix F: Assessment of monitoring results on fish migration facilities by DWA – Themen 2006

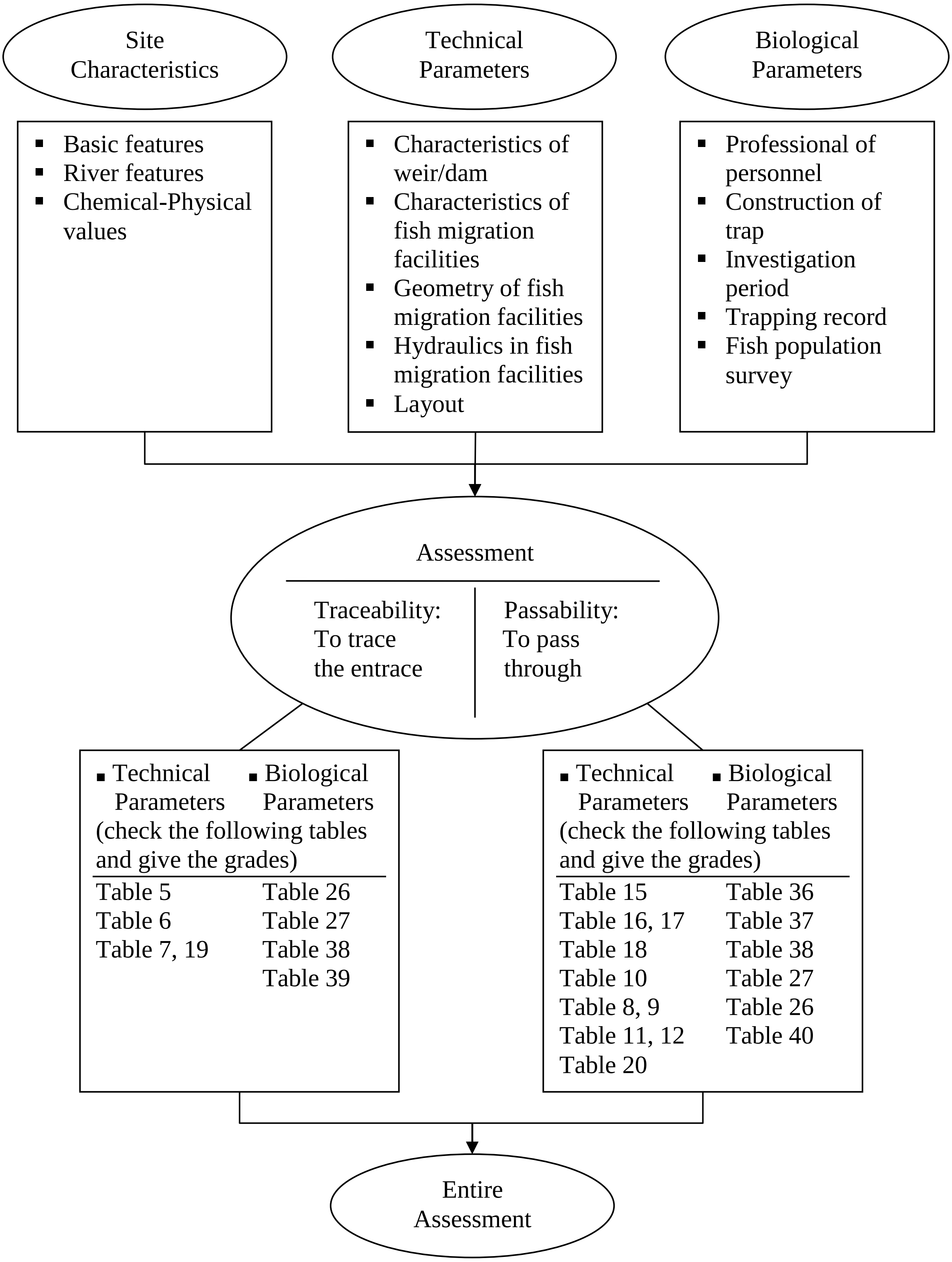


Fig. F.1 Procedures of monitoring investigations and assessments on upstream fish migration facilities (edited from DWA-Themen 2006).

Table F.1: Site Characteristics

Basic Characteristics	
Name of facility	
River Name of the river where the facility is	
Catchment Name of the catchment	
State/Province Name of the state/provice where the facility is	
Employer Name of the employer	
Consultant Name and the profession of the reporter	
Executor Name and the profession of the executor on field investigation	
River Information	
MNQ [m³/s] Mean low flow	
MQ [m³/s] Mean annual flow	
Area of catchment Area of catchment where the facility is	
Potential of natural fish fauna Spectrum of domestic fish species, foreign fish species which exist for long should be included as well	
Target species In some rivers there are target fish species for design of migration facilities, in particular salmon and trout, e.g. in "Handbuch Querbauwerke NRW". With regard to dimension of the migration facility, the largest domestic fish species can be assigned as target species.	
Chemical-Physical values During the investigation period, the following parameters, which influence the effectiveness of migration facilities straight, should be measured daily.	
Water temperature	
pH-value	
DO	
Water level upstream/downstream	
Discharge, Q [m³/s]	

Note: edited from DWA-Themen 2006

Table F.2: Technical Parameters

The technical parameters should be obtained in detail for assessment of the monitoring. Data should be collected from design data and measurements in situ.

Characteristics of weir/dam	
Type of weir/dam, operation	
Maximum/minimum of water head Name of the river where the facility is	
Existence of hydropower unit Type (run-of-river, offline), rated discharge, instream flow need	
Characteristics of fish migration facilities	
Type of construction	
Construction year	
Geometry of fish migration facilities	
Length	
Number of pools (if it’s pool type)	
Number and position of resting pools	
Maximum/mean of drop heights	
Minimum/mean length of pools	
Minimum/mean width of pools	
Minimum/mean water depths	
Dimension of orifices at the separating walls/sills, width and height	
Dimension of notches at the separating walls/sills, width and height	
Minimum width of vertical slot	
Hydraulics in fish migration facilities	
Designed discharge: Q_{30} ~ Q_{330} or other criteria To ensure well performance of migration facility for at least 300 days a year, it is necessary for design/measurement of Q_{30} and Q_{330}.	
Rated discharge	
Maximum flow velocity at narrow openings	
Mean flow velocity in pools or pool type structure	
Energy dissipation rate in pools	
Maximum velocity of attraction flow at the entrance	
Auxiliary discharge for attraction flow	
Layout and arrangement The following parameters should be described in detail and presented with graphs and pictures.	
Spatial layout of the migration facility at the site	
Description of the location, including connection to the lower reach, distance to obstacle, etc.	
Description of entrance structure, e.g. angle of junction, connection to streambed downstream	
Description of exit	
Design of bottom regarding to roughness and gaps between substrate gravels	
Description of maintenance and current status of the structure	

Note: edited from DWA-Themen 2006

Table F.3: Biological Parameters

Professional of personnel The planning, supervision and evaluation of monitoring should be committed to personnel who are qualified in field of fish biology. The daily routine could be conducted by non-professional personnel, who, however, should take training in advance.	
Construction of trap Fish recapture is usually conducted by setting box-net to trap fish. In practice the mesh size is recommended to be 8-10 mm to prevent from fish escape and getting stuck by drift. Traps should be set cross the whole section without crack at sides or bottom and do not influence the hydraulic conditions.	
Type of trapping net	
Size of mesh	
Maintenance	
Description of defect where necessary	
Investigation period Based on the criteria of at least 300 days/year good performance of fish migration facilities, the field investigation should be conducted over a complete season cycle in a year, to gather migration behaviour of all fish species under relevant hydrological conditions. A Break during flood or ice drift is acceptable. Reduction of monitoring period will cause lower credibility of the result, which is also difficult to be compared with other monitoring work.	
Period of investigation	
Number of investigation days	
Number of investigation breaks	
Trapping record It is necessary to prepare a daily report of the investigation result for common assessment related to environmental parameters.	
Identification of fish species	
Measurement of fish body length To evaluate the effect of fish size selectivity. Accuracy of measurement: 1cm	
Fish stock survey It is necessary to survey the fish stock downstream of fish migration facilities for assessment on fish species and size selectivity of migration structures. It should be conducted at least once a month for interpretation of seasonal fluctuation during monitoring. While analysing the electric fishing result, it should be taken into account that there is limit due to methodology of e-fishing and the environment such as river scale as well as conditions of e-fishing. It’s unnecessary to estimate the total fish population in waters and the stock survey upstream of facilities can be neglected. The stock survey inside migration facilities doesn’t provide further information for assessment of effectiveness and will be conducted only for inspection of structural deficiencies. Data should include species and size with accuracy of 1cm.	

Note: edited from DWA-Themen 2006

Table F.4: Assessment of traceability: to trace the entrance of a fish migration facility

Assessment of traceability includes technical and biological parameters. However technical parameters should be taken as primary factors and biological parameters as evidence to support the evaluation by technical parameters.

Technical Parameters If one of the following parameters are marked as “C” or worse, the whole level of “Traceability” will not be better as “C”. However due to complexity of conditions in situ, weights of each parameter should be decided in individual cases by consultants.	
Assessment of layout Table 5.	
Assessment of entrance Table 6: Position of entrance and the connection to water downstream of obstacle	
Assessment of attraction flow Table 7: Angle between attraction flow and river Table 19: Minimum/maximum velocity of attraction flow	
Biological Parameters The only way to assess the performance of a fish migration facility quantitatively and straight is to calculate the efficiency for anadromous species (Table 33 and 34), which is however difficult to obtain. Therefore the following parameters can be evaluated as references to approach the assessment of traceability via biological parameters.	
Particular high/low discharges/water levels Table 26.	
Comparison with nearby fish migration facility Table 27.	
Assessment of species selectivity Table 38.	
Observation of fish downstream nearby migration facilities Table 39.	

Note: edited from DWA-Themen 2006

Table F.5: Assessment of passability: to pass through a fish migration facility

To assess the passability of fish **migration** facilities it must combine both technical and biological parameters. If one of the following parameters are marked as "C" or worse, the whole level of "Passability" will not be better as "C".

Technical Parameters	
Maximum drop height in migration facility Table 15.	
Maximum velocity at narrow openings Table 16. Mean velocity in pools Table 17.	
Energy dissipated rate Table 18.	
Minimum water depth Table 10.	
Length of pools Table 8. Width of pools Table 9.	
Dimension of openings Table 11: nature-like design Table 12: technical type design	
Substrate Table 20.	
Biological Parameters	
Selectivity of fish size (body length) Table 36: small fish or bad swimmers	
Selectivity of fish size (body length) Table 37: big fish	
Selectivity of fish species Table 38.	
Observation of fish downstream nearby migration facilities Table 39.	
Comparison with nearby fish migration facility Table 27.	
Particular high/low discharges/water levels Table 26.	
Fish stock inside migration facilities Table 40.	

Note: edited from DWA-Themen 2006

Entire Assessment of effectiveness of a fish migration facility

Both of traceability and passability are of same weight while assessing the effectiveness of a fish migration facility. The entire level of assessment should be marked by the worse level of traceability and passability.

Dimension of adequate nature-like fish migration facilities

Table F.6: Assessment of the minimum water depth in fish migration facilities

Unit: [m]

Level of assessment	Brown trout	Grayling, Dace	Barbel, pike
A (very good)	> 0.4	> 0.45	> 0.5
B (good)	0.4	0.45	0.5
C (moderate)	0.3 ~ 0.4	0.34 ~ 0.45	0.38 ~ 0.5
D (poor)	0.2 ~ 0.3	0.23 ~ 0.34	0.25 ~ 0.38
E (bad)	< 0.2	< 0.23	< 0.25

Note: The category sturgeon is not included

Table F.7: Assessment of the width of notches and narrow slots in nature-like fish migration facilities

Unit: [m]

Level of assessment	Brown trout	Grayling, Dace	Barbel, pike
A (very good)	> 0.4	> 0.6	> 0.6
B (good)	0.2 ~ 0.4	0.4 ~ 0.6	0.6
C (moderate)	0.15 ~ 0.2	0.3 ~ 0.4	0.45 ~ 0.6
D (poor)	0.1 ~ 0.15	0.2 ~ 0.3	0.3 ~ 0.45
E (bad)	< 0.1	< 0.2	< 0.3

Note: The category sturgeon is not included

Table F.8: Assessment of the maximum water level difference between pools Unit: [m]

Level of assessment	Brown trout	Grayling, Dace	Barbel, pike
A (very good)	< 0.2	< 0.15	< 0.13
B (good)	0.2	0.15	0.13
C (moderate)	up to 0.25	up to 0.19	up to 0.16
D (poor)	up to 0.30	up to 0.25	up to 0.20
E (bad)	> 0.30	> 0.25	> 0.20

Note: The categories and levels are modified from species zones to representative species for a consistent classification

Table F.9: Assessment of the maximum flow velocity in notches and narrow slots

Unit: [m/s]

Level of assessment	Brown trout	Grayling, Dace	Barbel, pike
A (very good)	< 2.0	< 1.7	< 1.6
B (good)	2.0	1.7	1.6
C (moderate)	up to 2.2	up to 1.9	up to 1.8
D (poor)	up to 2.4	up to 2.2	up to 2.0
E (bad)	> 2.4	> 2.2	> 2.0

Note: The categories and levels are modified from species zones to representative species for a consistent classification

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