Test Case Presentation

Altusried

Iller, Germany

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Table of contents

List of figures

List of tables

1. Description of the Test-Case

1.1. Description of the water bodies related to the HPP

The hydropower plan (HHP) of Altusried is situated in the water body F008 between the water bodies F009 (downstream) and F006 (upstream).

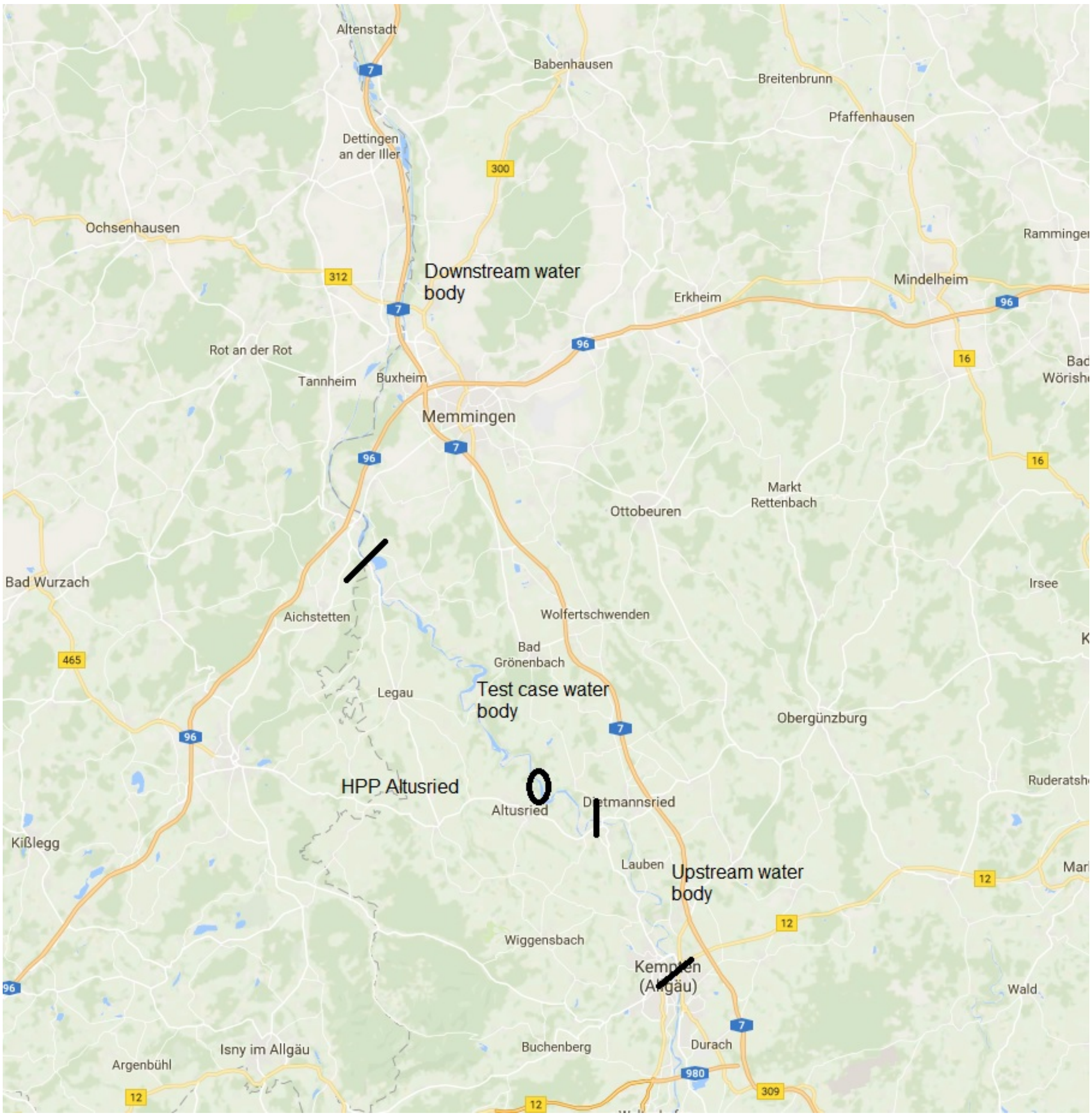


Figure 1: Water bodies related to the HPP of Altusried

1.1.1. Hydrology of the Iller at Altusried

The hydrology is characterized by sustained flows in winter, high water levels in spring due to snow melting and low water period from August to October.

At Altusried the mean inter-annual discharge is estimated at 46.6 m^3/s.

1.1.2. Main pressures

Several pressures are listed for the Saison near Altusried:

Table 1: Main pressures on the Saison

Water treatment plant effluents	medium
Spillover of Stormwater overflows	minimal
Nitrogen derived from agriculture	no significant
Pesticides	no significant
Water supply	no significant
Continuity	Former times high, since 2014 the continuity is built through fish bypass channels
Hydrology	high
Morphology	minimal

Table 2: Measures to be implemented at the river basin scale of the Iller

Flow change	Minimum HPP outflow by LEW: 9,0 m^3/s
Fish migration measures	Nature like fish ladder at every LEW power plant of the river Iller, except Fluhmühle: technical vertical slot pass
Pollution control	Done by “Gewässerkundlicher Dienst Bayern”/“Wasserwirtschaftsamt Kempten“

1.2. Presentation of the HPP

1.2.1. Location of the HPP

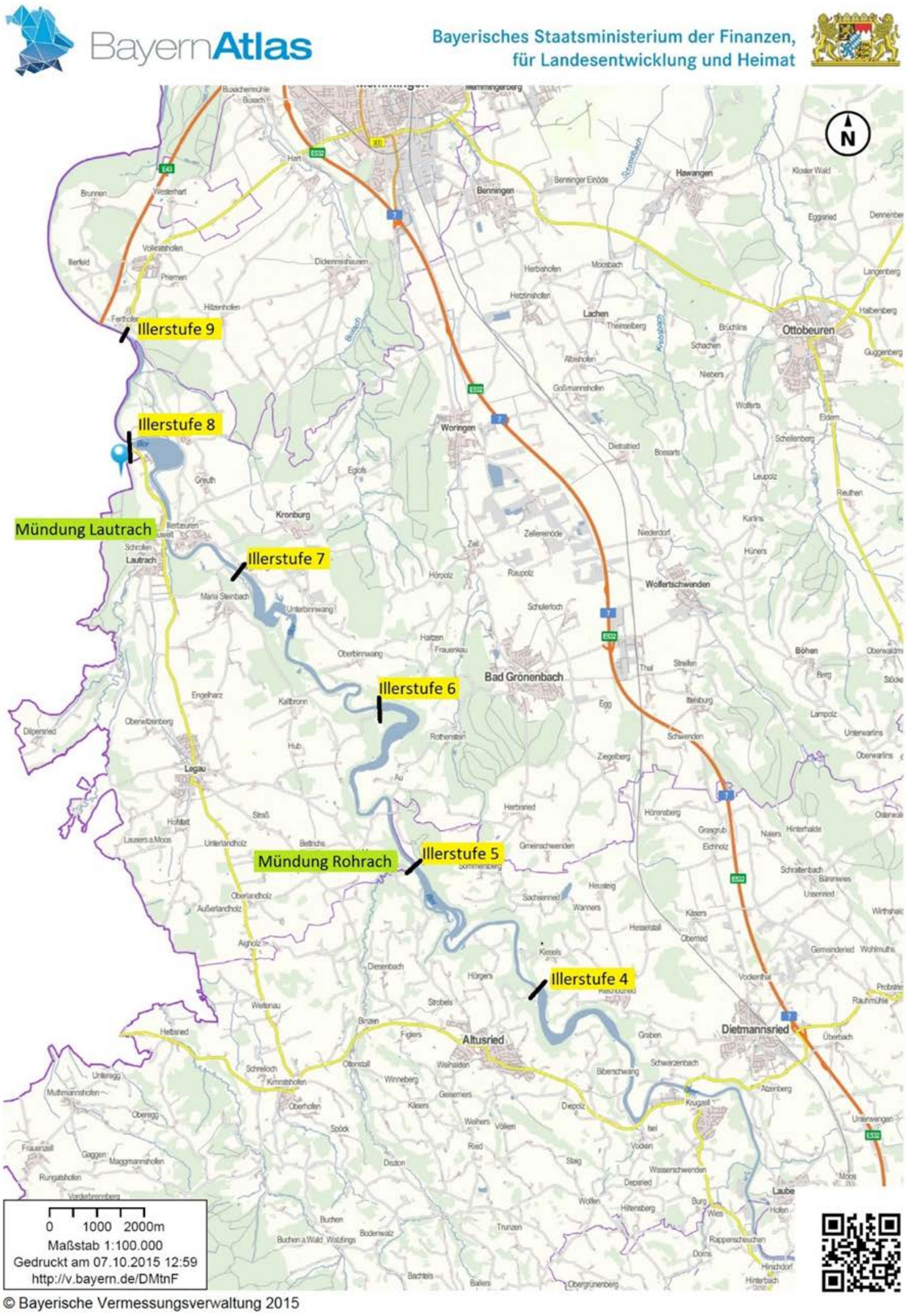


Figure 2: Location of HPP Altusried (=Illerstufe 4) at the river Iller

Table 3: Main characteristics of the HPP of Altusried

Watercourse	Iller
Situation :	Altusried
Inter-annual discharge	46.5 m^3/s
Low-water flow :	9.0 m^3/s
Function of the dam :	Hydropower
Length of bypassed reach :	900 m
Species concerned :	Danube Salmon, Brown Trout, Nase, Barbel, Grayling
Capacity of HPP	4 MW

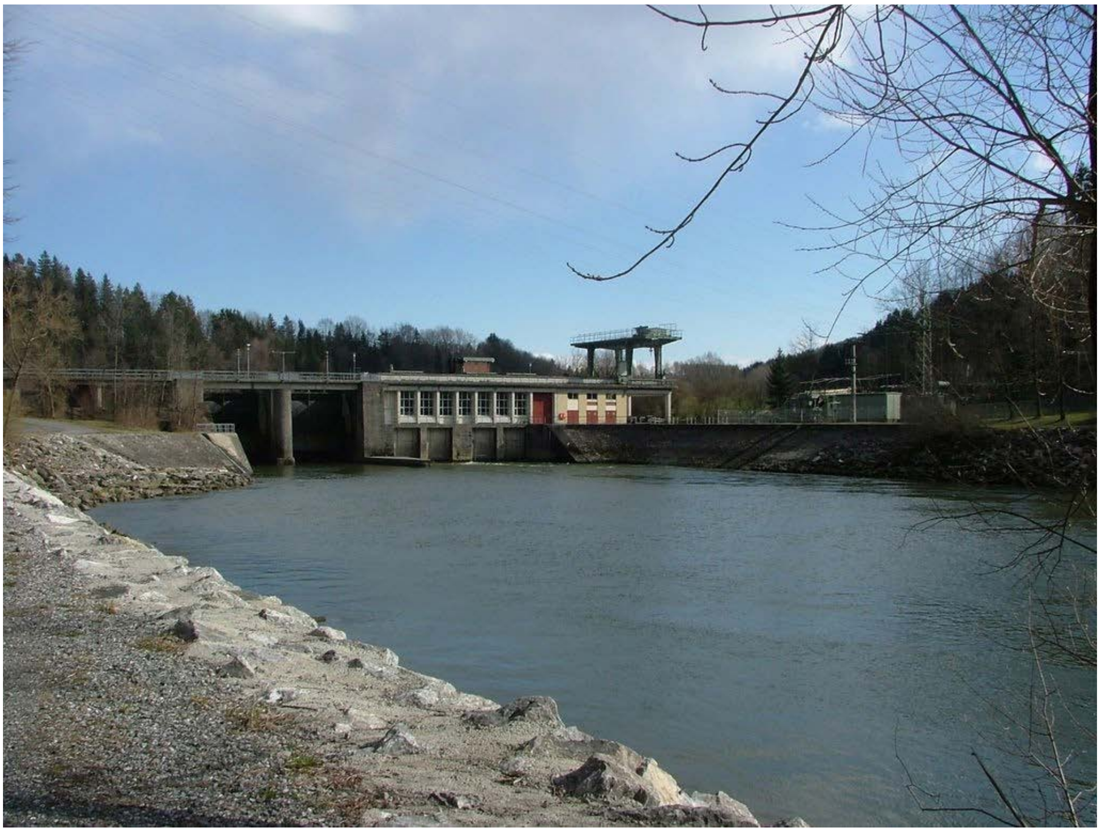


Figure 3: HPP Altusried. Source: static.panoramio.com

Equipment:

- 2 Kaplan turbines
- Each has a flow rate of 50 m³/s
- 4 MW power output
- Diameter of the Kaplan turbines: 3.0 m
- 9 m drop height

1.2.2. E-flow

Natural minimum flow: 9.0 m³/s

Minimum outflow of the LEW HPP: 9.0 m³/s

The minimum outflow of the turbines is 9.0 m³/s, during the whole year. This regulation is part of the “Illerstrategie 2020” of the LEW. It is based on the natural minimum flow of the river Iller.

1.2.3. Downstream migration devices

Downstream migration is possible during weir overflow or while the bottom outlets are opened. Thrash racks in front of the turbines, with a spacing of 20 mm between the racks, prevent fish from swimming into the turbines.

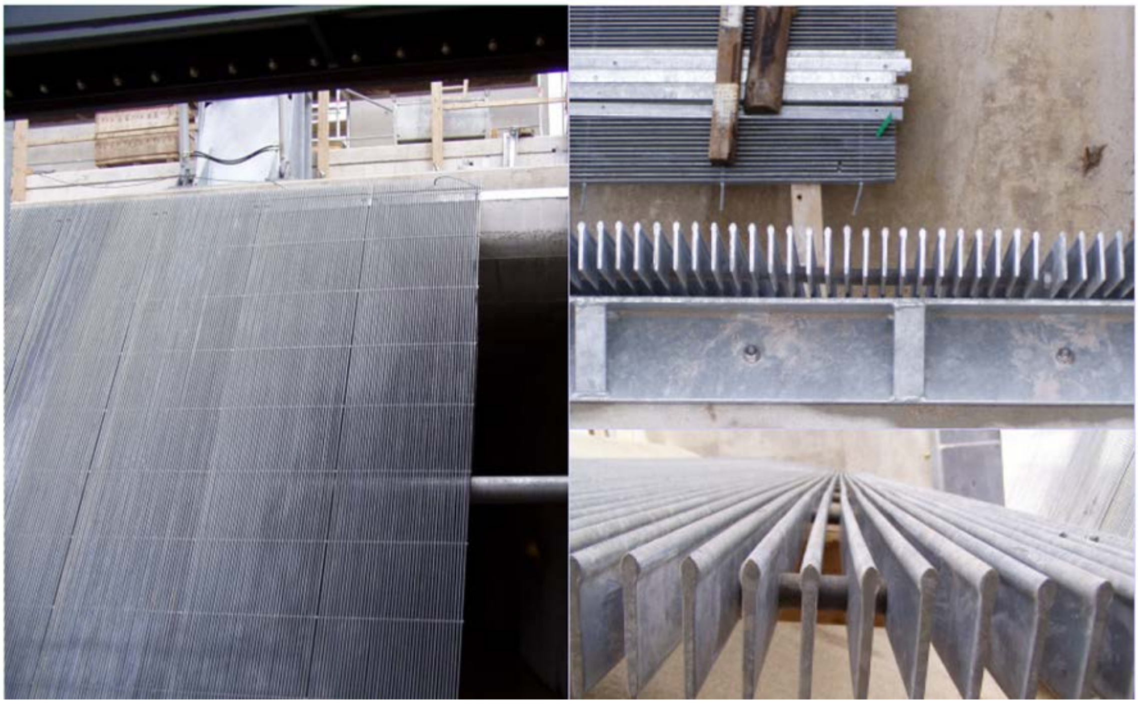


Figure 4: Thrash rack of the HPP Altusried. Source: LEW

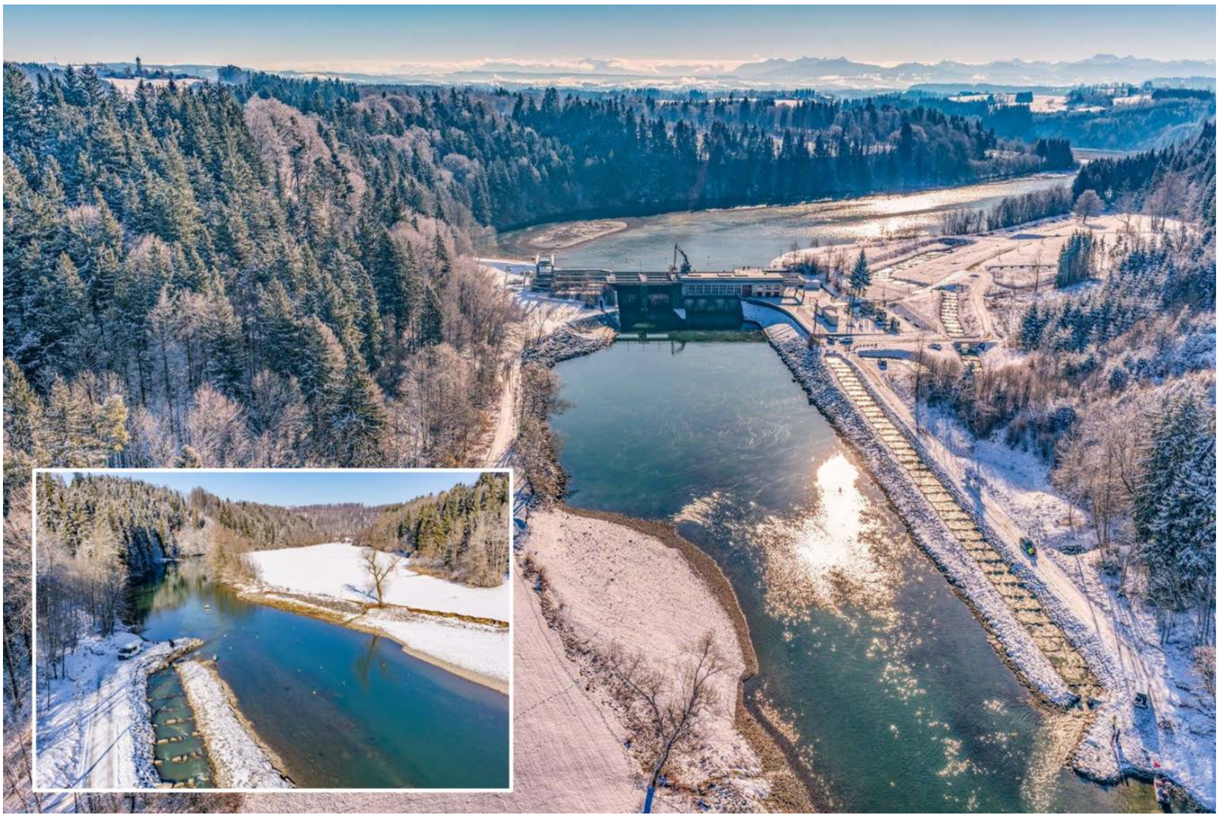
1.2.4. Upstream migration devices

At the dam, the fishes can use a fish bypass channel to go upstream.

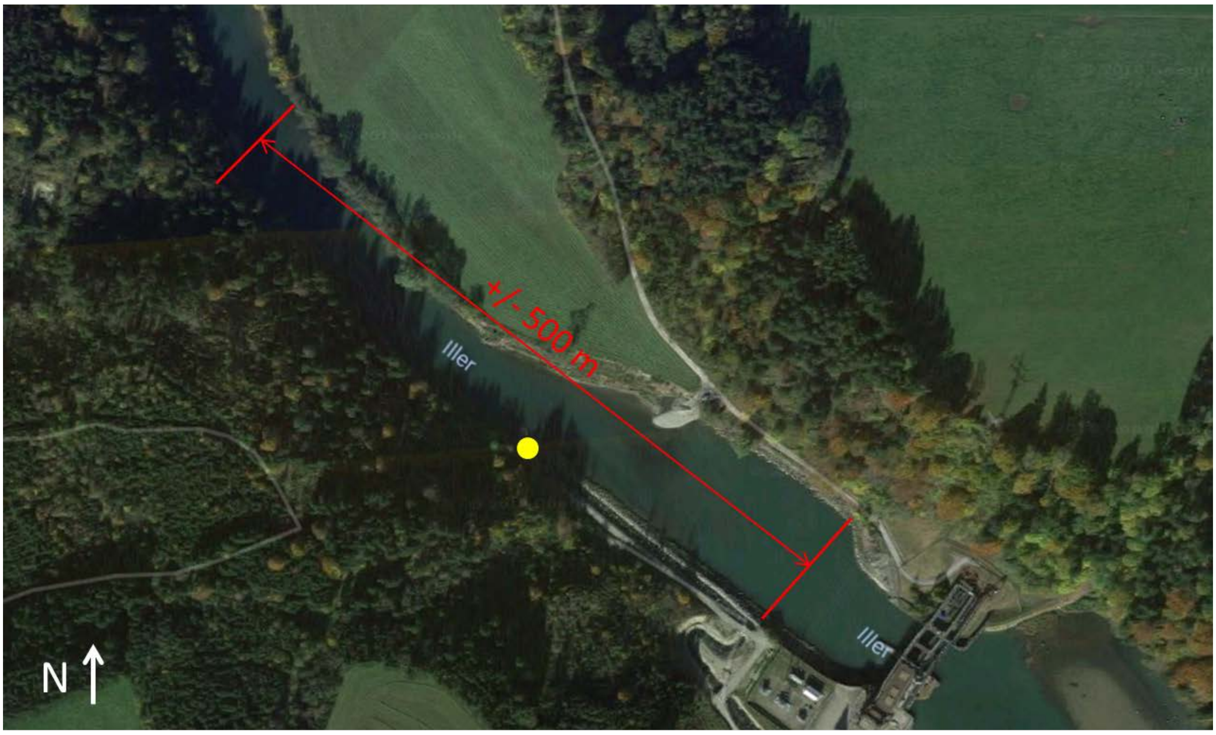
- Flow in the fish pass: 1 m^3/s;
- Length of the fish pass 700 m.
- Fish bypass channel should also fulfil a compensation habitat function. Therefore, juvenile and spawning habitats have been built into the fish-bypass channel.

1.3. Specific river area studied

The joint task of INBO and SJE (see next section on the objectives), concentrates on the area downstream of the HPP around the outflow of the fish pass. Not only the area directly surrounding the outflow, but also the area upstream of the outflow towards the dam and the area downstream are focus of the study (Figure 5).



(a)



(b)

Figure 5: Picture (a) and Indication (b) of the study area, being a river stretch of 500 m around the fish pass outflow (yellow dot) downstream of the hydropower plant of Altusried (Bavaria, Germany). This area is the focus of the joint task of INBO and SJE, see below.

2. Objectives of this Test Case

What we are planning?

The aim of the study in Altusried is manifold.

- To **analyse and assess the attraction flow** downstream of the fish pass and to evaluate if and **how fish find the fish pass entrance** and under what circumstances.
- **Evaluate the individual fishes' behaviour** downstream of the fish pass, to gain basic knowledge on their behaviour on ecohydraulic thresholds for flow velocities and flow signatures as well as searching behaviour of individual fish for the entrance of the fish pass to migrate upstream.
- **Customize** this info into **a modelling tool** that allows to analyse and assess attraction flow of fish bypass installations in general.
- Use this info to **develop an agent-based fish movement model** incorporated in the fish habitat simulation model CASiMiR.

To reach these aims the following tasks are planned, of which some have been finalized already in the past months. The responsible of each task is indicated between brackets (SJE = SJE Ecohydraulic Engineering GmbH; INBO = Research Institute for Nature and Forest; TUT = Technical University of Tallin; IC = iC flussbau).

- Setting up a 2D **hydrodynamic model** of the stretch down- and upstream of the fish pass entrance area. (IC and SJE, Task A)
- Setting up an acoustic **telemetric installation** to track fish approaching the fish pass entrance. (INBO, Task B)
- **Measuring** velocity fluctuations in the **jet stream using the LLP.** (SJE & TUT, Task C)
- **Tagging** grayling and barbell in spawning period (INBO; Task D)
- Reading and evaluating receiver data to gain info on the **fish tracks** (INBO; Task E)
- Finding **correlations** between fish tracks and **hydraulic, bathymetrical and morphological features** (SJE & INBO; Task F)
- Setting up **fish migration model** and investigating **scenarios** (SJE & INBO; Task G)

Why are we planning this on this Test case?

The following aspects make this site/test case interesting as a study site to perform the tasks and obtain the objectives listed above. Firstly, the hydropower plant and river are a representative site for many rivers and barriers in Europe. Secondly, LEW and the University of Augsburg are evaluating fish migration in the river Iller already since August 2016. In their study they investigate what fish pass the fish passes that are constructed by LEW on the 5 hydropower plants of (from downstream to upstream) Lautrach, Maria Steinbach, Legau, Fluhmühle and Altusried. No fish can pass the fish pass without being caught in a catch construction upstream in the fish pass. The catch construction (called counting pool) is evaluated nearly daily and fish that are caught are measured (length) and marked. The mark is a blue dot on their belly near the left or right pectoral, pelvic or caudal fin, depending on the fish ladder they were passing. Hence, the migratory route of marked fish can be evaluated. Next, the positioning of the fish pass outflow is interesting to test. It has an unusual location as it is not positioned near the barrier but around 150 m downstream. Lastly, interesting species to tag and track are present in the river Iller. Furthermore, we know from the on-going study of LEW and the University of Augsburg that individuals are present that are large enough to tag. The fish that is tagged and tracked should not be too sensitive and small, so that its behaviour is not influenced by the tagging procedure.

What are we expecting?

We expect to be able to evaluate fish pass efficiency at different flow scenarios, based on the link between the collected fish tracks and the ecohydraulic modelling of the fish pass outflow at this study site in Altusried. We expect to learn how flow conditions (velocities and signatures) enable or prevent fish to find the fish pass entrance.

Nevertheless, we expect as well a high individual variability in the behaviour of the fish in and around the fish pass outflow. Therefore, as much as fish as is logistically (availability of wild fish and of budget to buy tags) possible are caught, tagged and tracked of each species (grayling and barbell only). We also expect to find a good method to filter out error on the collected fish tracks. Such error is inherent to acoustic telemetry and good methods to finetune the technique need to be globally investigated further.

Relevance in FIThydro?

The research will give insight into the efficiency of the fish pass in Altusried for attracting upstream migrating fish under different flow scenario's. This info will be interesting for fish pass applications elsewhere in Europe or the world where hydropower operators cope with mitigating negative effects of barriers on fish migration and survival. Furthermore, the tool and CASiMiR model-extension that are envisaged to develop in this study are meant for application elsewhere in similar settings.

3. Presentation of results and activities in FIThydro

LEW, SJE, INBO and TUT cooperate to reach the objectives and tasks mentioned in section 2. In general, INBO is responsible to collect 2D fish tracks in high resolution, and SJE is responsible to develop a hydraulic model on the flow situation around the fish pass outflow, downstream of the HPP of Altusried. Together SJE and INBO evaluate the relation between the fish tracks and the ecohydraulic modelling as mentioned above in section 2.

Below, the methodology and first results are given in separate sections, according to the content of the task (corresponding to the different sub-task managers: INBO for the fishtracks, SJE for the ecohydraulic model).

3.1. Population and habitat analysis (LEW)

3.1.1. Data

The fish fauna of the river Iller is mainly composed of reophelic species. The main target species are: danube salmon (*Hucho hucho*), grayling (*Thymallus thymallus*), brown trout (*Salmo trutta fario*), nase (*Chondrostoma nasus*), barbel (*Barbus barbus*), chub (*Squalius cephalus*). Futhermore there are pike (*Esox lucius*), perch (*Perca fluviatilis*), tench (*Tinca tinca*), burbot (*Lota lota*), bullhead (*Cottus gobio*), loach (*Barbatula barbatula*), bitterling (*Rhodeus amarus*), stickleback (*Gasterosteus aculeatus*), gudgeon (*Gobio gobio*), bleak (*Alburnus alburnus*), rainbow trout (*Oncorhynchus mykiss*), char (*Salvelinus sp.*) and spirlin (*Alburnoidus bipunctatus*) in the river Iller.

3.1.2. Methodology

The fish ecological data are collected with electrical fishing. Therefore, the area downstream of the HPP of Altusried is fished electrically on a length of 1500 m at both shorelines against the flow and in the middle of the river with the flow. The fishing is done from a boat. An electrical fishing unit with a power of 13 kW is used. All caught fishes are collected in a tub. The tub is evaluated every 500 m of fishing. All fishes in the tub are measured (total length) and determined on species level. The electrical fishing is done twice a year, once in spring and once in autumn.

3.1.3. Results

The fish community of the river Iller has been quite poor in the last view decades. The main reason of this is suggested in the anthropogenic changes of the river Iller. The main influences have been the construction of HPPs and straightening of the shoreline. This led to a decline of spawning and juvenile habitats. As a result, the fish populations have been decreasing. To change this state, the LEW started two restoration projects, the Illerstrategie 2020 and the EU-project ISOBEL. Within these projects, the main goals are to create fish-bypass channels and a nature-like bed load situation in the downstream parts of the HPPs. Thus, spawning and juvenile habitats have been constructed. During the last few years, the populations of the main species present in the river Iller, are increasing again. This was indicated by electrical fishing campaigns in 2016, 2017 and 2018, which indicated presence of all characteristic fish species of the river Iller (Table 4 and Table 5). Most of them, such as barbell, Danube salmon, grayling, chub and brown trout were caught in gratifying numbers, both the juvenile and adult stages. Only the population of nase is still in rather poor condition. There have been documented only a few individuals.

Table 4: Results of the electrical fishing session at 12.04.2017 in the downstream area of HPP Altusried.

Species	Species	Number of individuals
Bachschmerle	*Barbatula barbatula*	5178
Barbe	*Barbus barbus*	18
Mühlkoppe	*Cottus gobio*	111
Hecht	*Esox lucius*	1
Dreistachliger Stichling	*Gasterosteus aculeatus*	203
Gründling	*Gobio gobio*	94
Huchen	*Hucho hucho*	2
Regenbogenforelle	*Oncorhynchus mykiss*	2
Flussbarsch	*Perca fluviatilis*	5
Bachforelle	*Salmo trutta fario*	9
Rotfeder	*Scardinius erythrophthalmus*	1
Döbel	*Squalius cephalus*	105
Äsche	*Thymallus thymallus*	24
Schleie	*Tinca tinca*	1
Sum		**5754**

Table 5: Results of the electrical fishing session at 10.07.2018 in the downstream area of HPP Altusried.

Spring electrical fishing 2018 downstream area HPP Altusried			Date: 10.07.2018
Species	**Species**	**Individual with a total lenght under 20 cm**	**Individuals with a total lenght above 20 cm**
Äsche	*Thymallus thymallus*	1386	97
Bachforelle	*Salmo trutta fario*	7	2
Bachschmerle	*Barbatula barbatula*	1388	0
Barbe	*Barbus barbus*	728	22
Bitterling	*Rhodeus amarus*	7	0
Döbel	*Squalius cephalus*	70	0
Dreistachliger Stichling	*Gasterosteus aculeatus*	490	0
Flussbarsch	*Perca fluviatilis*	38	4
Gründling	*Gobio gobio*	191	0
Hecht	*Esox lucius*	2	0

Huchen	*Hucho hucho*	6	0
Laube	*Alburnus alburnus*	8	0
Mühlkoppe	*Cottus gobio*	87	0
Nase	*Chondrostoma nasus*	12	0
Regenbogenforelle	*Oncorhynchus mykiss*	20	1
Saibling	*Salvelinus sp.*	0	1
Schleie	*Tinca tinca*	6	0
Schneider	*Alburnoidus bipunctatus*	2	0
Cyprinide, unbestimmt	*Cyprinidae*	0	1
Sum		**4448**	**215**

3.1.4. Conclusion

All typical species of a river of the lower alpine region can be found in the downstream water area of the HPP Altusried. Especially the high number of young grayling (*Thymallus thymallus*) in spring 2018 is very gratifying, as well as the 6 young Danube Salmon (*Hucho hucho*).

3.2. Hydrodynamic modelling (SJE)

3.2.1. Setup of model

It is assumed that hydrodynamics are among the main factors for the behaviour of migrating fish. “Attraction flow” is one of the most commonly used terms when talking about fish finding the entrance of bypass installations at migration barriers. For that reason an hydrodynamic model has been setup in the Altusried test case to deliver flow velocities and water depth as input parameter for the migration model to be developed. The model does not only cover the fish pass entrance area but also the river stretch downstream of the entrance and the area upstream of the entrance up to the area close to the weir (Figure 5). This wide coverage was chosen in order to analyse how fish approach the fish pass from downstream and how they behave when having passed by the fish ladder entrance.

In order to provide a sufficient resolution of the river bathymetry, cross sections have been measured with an approximate distance of 10 to 15 meters by flussbau IC. Deeper areas have been surveyed using a boat equipped with echosounder, reflector and total station, shallower areas close to the river banks have been surveyed wading. In addition to this terrestric an aerial survey by flights with a camera equipped drone has been performed after having surveyed the position of ground control points (GCPs; Figure 6). This has been done for two reasons: 1) the orthophoto derived from the pictures support the setting up of the hydrodynamic model, 2) the evaluation of the pictures using the SfM (Structure from Motion) methodology provides a higher resolution of the river bathymetry than the cross sections alone (Figure 7). SJE has used a self-developed approach to derive bathymetrical information not only in the areas above the water surface but also for the underwater areas.

Figure 6: Drone used for the aerial survey (left), Ground control point (GCP, right)

The hydrodynamic calculations have been done using the software Hydro-As_2D that is based on the Saint Venant shallow water equations. The model has been calibrated using the water elevation measurements performed during the field survey.

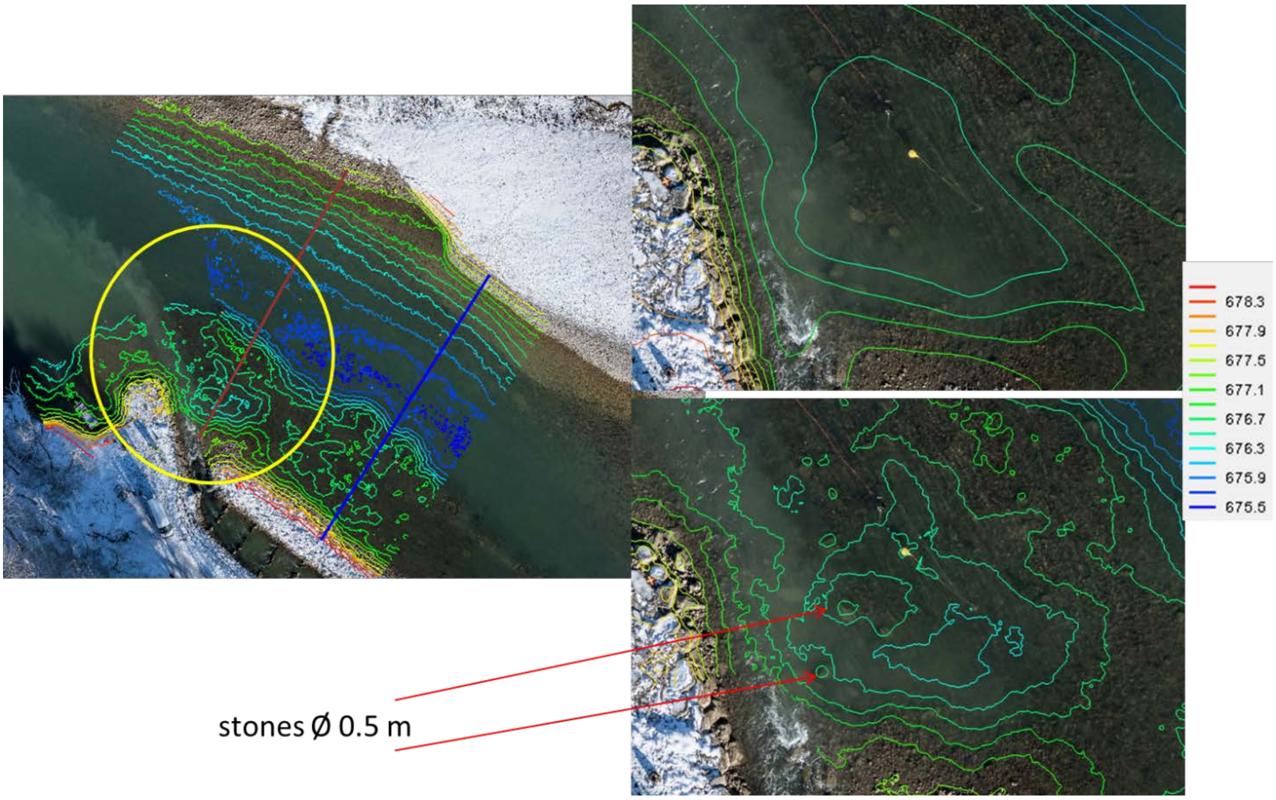


Figure 7: river bathymetry, derived by cross section interpolation (top), higher resolution derived by underwater SfM evaluation

3.2.2. Flow scenarios and results

The hydrological regime of the considered river stretch is pluvio-nival with low base flows in late summer, fall and winter and a high base flow in late spring and early summer during snow melt. However, the base flow is overlaid by regular mean and major flood events caused by rainfall events. In warm and rainy winter periods base flow can also be high, as can be seen in the following figure of the flow time series for the year 2018 (Figure 8).

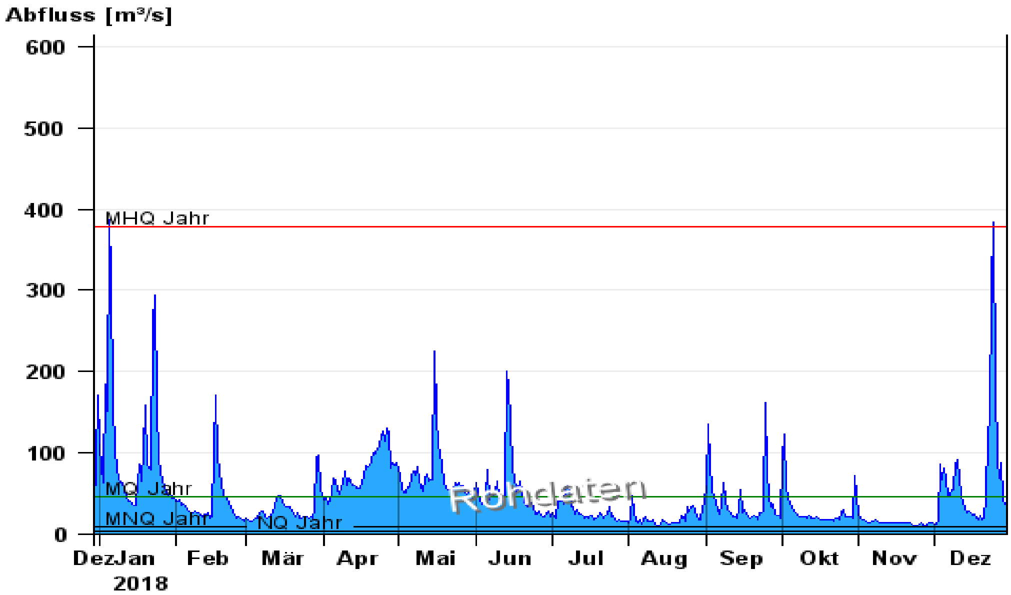


Figure 8 : Flow registered at gage Kempten, approx. 8 km upstream of the test case site (source: hnd.bayern.de)

The flow scenarios to be modelled with the hydrodynamic model have been selected in order to cover a wide flow range with a certain probability to occur during the migration period of the considered fish species (grayling: March/April, barbell: May/June). However, since the HPP in the upper Iller are operated in a sort of storage mode during low flow situations, the probability of having a flow around 10 m³/s in the low flow season is increased. The following flows are considered:

Table 6: flows covered with model and hydrological characteristic

Flow	Hydrological characteristic
10 m³/s	Approx. MALF*, close to minimum flow (9 m³/s)
20 m³/s	Approx. 2 MALF
40 m³/s	Approx. MAF** winter
60 m³/s	Approx. MAF Summer
80 m³/s	Slightly increased summer flow

*MALF: Mean annual low flow

**MAF: Mean annual flow

Results from the hydrodynamic model are shown in Figure 9. It can be seen that for the low flow situation with 10 m³/s the flow velocities are increased in the area close to the fish ladder outlet. Usually this zone of increased flow velocities is considered to have a guiding function for fish searching the fish ladder entrance. But even for the low flow situation the increased flow velocities can only be detected in the direct vicinity of the fish ladder entrance (see figure top right). For higher flows the extension of the higher flow velocity area is much less distinct (see figure bottom left).

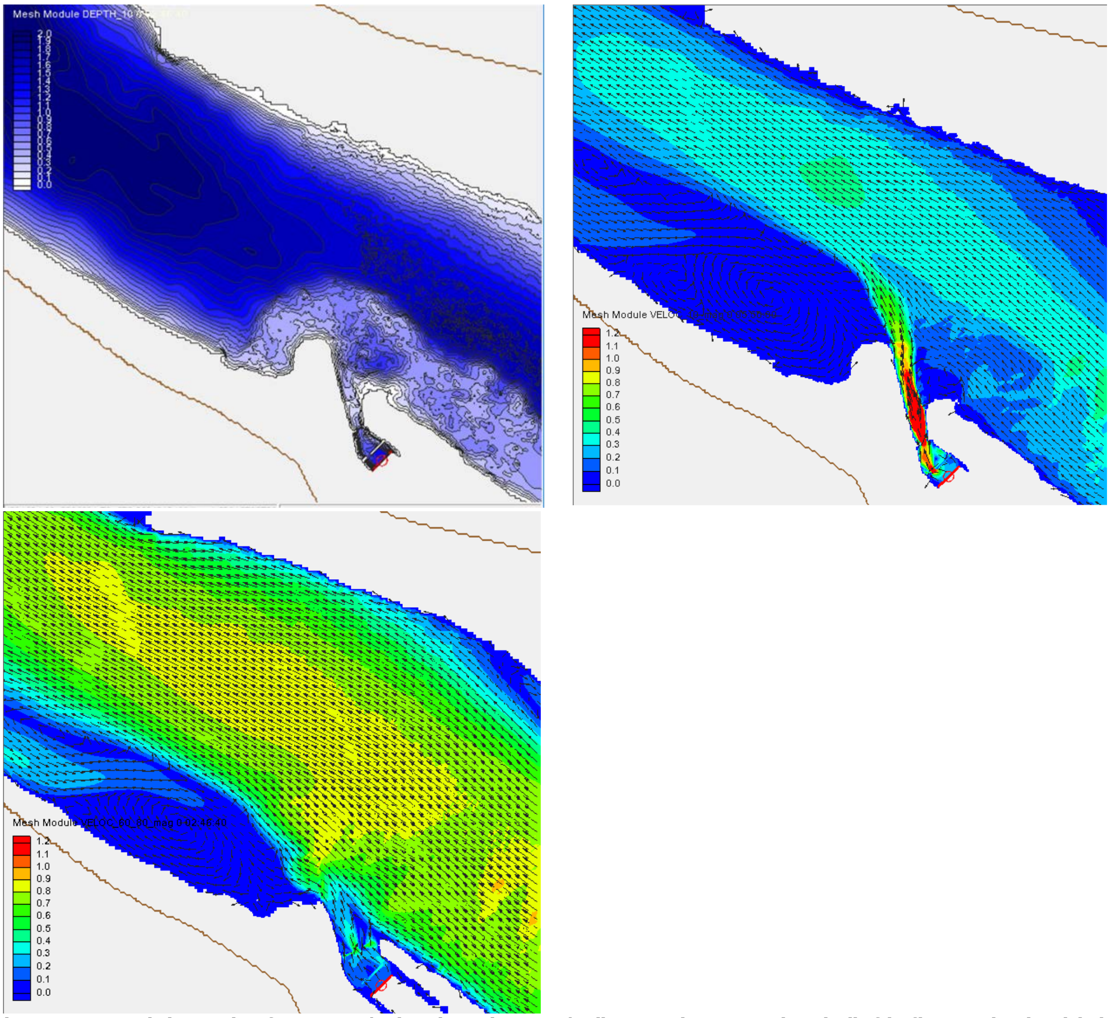


Figure 9 : Model results for 10 m³/s (top) and 60 m³/s (bottom), water depth (left), flow velocity (right)

3.3. Telemetry system (INBO)

Acoustic telemetry was chosen to analyse how upstream swimming fish approach the fish pass from downstream and how they behave when having passed by the fish ladder entrance. More precisely, the Vemco Positioning System (VPS) was applied to track the behaviour of the fish in 2 dimensions (2D telemetry). The area of interest is the same as for which the hydraulic model is developed, and includes the fish pass entrance area but also the river stretch downstream of the entrance and the area upstream of the entrance up to the area close to the weir.

3.3.1. Acoustic telemetry and the Vemco Positioning System (VPS)

Telemetry is used to monitor objects, such as animals, remotely. It involves placing electronic devices ("transmitters" or "tags") on animals that autonomously transmit data to data logging or relay-receiving stations ("receivers" or "hydrophones"). Because radio waves do not propagate in salt water, most aquatic telemetry is rooted in two principal approaches: acoustic and satellite telemetry. Acoustically tagged animals are detected and logged by receivers moored at fixed locations that are retrieved periodically, or by mobile receivers (e.g., on a pursuit vessel), whereas satellite observations are sent to land-based receivers via orbiting satellites. Electronic tags may be secured externally, inserted into the stomach, or surgically implanted in animals and programmed to record and/or transmit various data types, ranging from simple presence and location to extensive time series records of the animal's movements and environment (e.g., depth, temperature).

With rapid technological advancements over the past several decades more telemetry techniques, such as acoustic telemetry, became available to observe animal behaviour and movement in challenging environments (Hussey et al. 2015). Each technique has its opportunities and drawbacks and these greatly depend on the research question and characteristics of the environment where the studied animals behave and move. For instance tracking aquatic animals under water requires techniques that allow propagation of info through water. As air is needed to transmit and receive satellite telemetric signals, satellite telemetry does not support tracking animals that exclusively behave and move below the water surface. Instead, radio telemetry, Passive Integrated Transponder (PIT) telemetry and acoustic telemetry are techniques that enable the monitoring of aquatic animal behaviour and movement under water. To study fish behaviour and movement in two dimensional space in the area of interest in the river Iller, acoustic telemetry was selected and assumed to be the most (cost-) efficient technique.

Acoustic telemetry is a technique that makes use of the propagation of sound through water. It is much like speaking and listening under water. An acoustic tag emits a sound with regular or irregular time intervals. The sound is propagated through water as sound-waves and can be received by an underwater antenna or hydrophone. The hydrophone is part of what is called a receiver or acoustic listening station (ALS ; also simply named hydrophone). The sound that is emitted/transmitted by the acoustic tag is unique and encodes a unique series of numbers, called the ID code of the tag. When the tag is in the detection range of an hydrophone, the hydrophone hears and decodes the sound and logs the resulting ID code and precise timing of the detection.

In one dimensional acoustic telemetry an autonomous hydrophone is placed under water to evaluate the potential presence of an acoustic tag within its detection range. The detection range is a spherical area around (but not below) the antenna of the hydrophone (Figure 10).

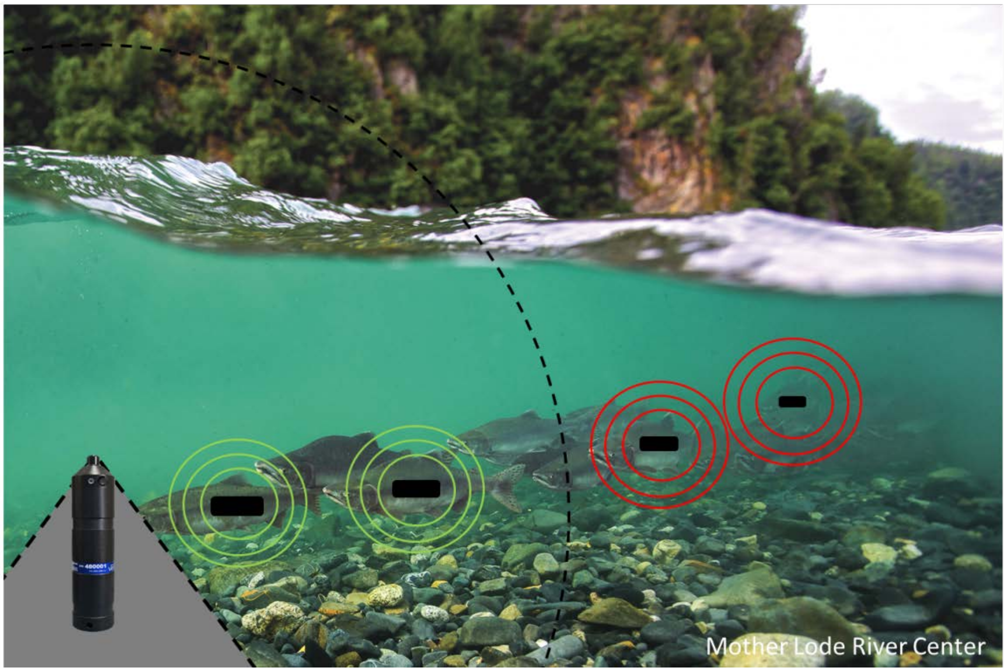


Figure 10: Schematic view of the detection range (the not grey area within the dashed circle) of one autonomous hydrophone fixed at the bottom of a river. Tagged fish that are within the detection range (green encircled tags) are logged (ID code) as being present at each time stamp that their emitted signal is heard by the hydrophone. ID codes of tagged fish outside of the detection range of the hydrophone are not logged at those time stamps because they are not heard by the hydrophone and are thus assumed absent from the detection range of the hydrophone. One hydrophone can only define presence/absence and not the exact position of the tag within its detection range (1 dimensional acoustic telemetry).

The dimensions of the detection range are not static and depend on a variety of environmental cues, ranging from background noise over hydro morphology and bathymetry of the lake or river, type of substrate, and the stream velocities and signatures potentially causing turbulence and air bubbles. The exact relation between environment and dimensions of the detection range is different for each study area and difficult to disentangle. Therefore, in each newly installed acoustic telemetry network, range tests need to be performed to get a good idea of the detection coverage and detection probability before any conclusions can be drawn on the presences of fish in a certain area (1 dimensional telemetry) or its exact position in the area (2 dimensional telemetry; Kessel et al. 2013).

In 2 and 3 dimensional acoustic telemetry, autonomous receivers are installed in a configuration so that every location in the area of interest is covered by the detection range of at least three receivers. Based on the theory of the propagation speed of sound through water and info on the exact timings of emission and detection of the acoustic signal of a tag, its position relative to the hydrophones that detected it, can be defined. More precisely, this method is called hyperbolic triangulation and is based on the time difference of arrival of the signals on the hydrophones detecting the signal. More info on hyperbolic triangulation can be found in the manual of the Vemco company (Smith 2013). The subsequent calculated positions of one tag give an idea of the track that the tagged fish has swum (Figure 11).

When Vemco hydrophones are used to set up a 2D/3D acoustic telemetry network, it is called VPS telemetry (Vemco Positioning System; https://vemco.com/products/vps/). Sometimes VPS telemetry is used as a synonym for 2D/3D acoustic telemetry, regardless of the company providing the acoustic devices. In this study we used Vemco hydrophones and tags (see section 3.3.2).

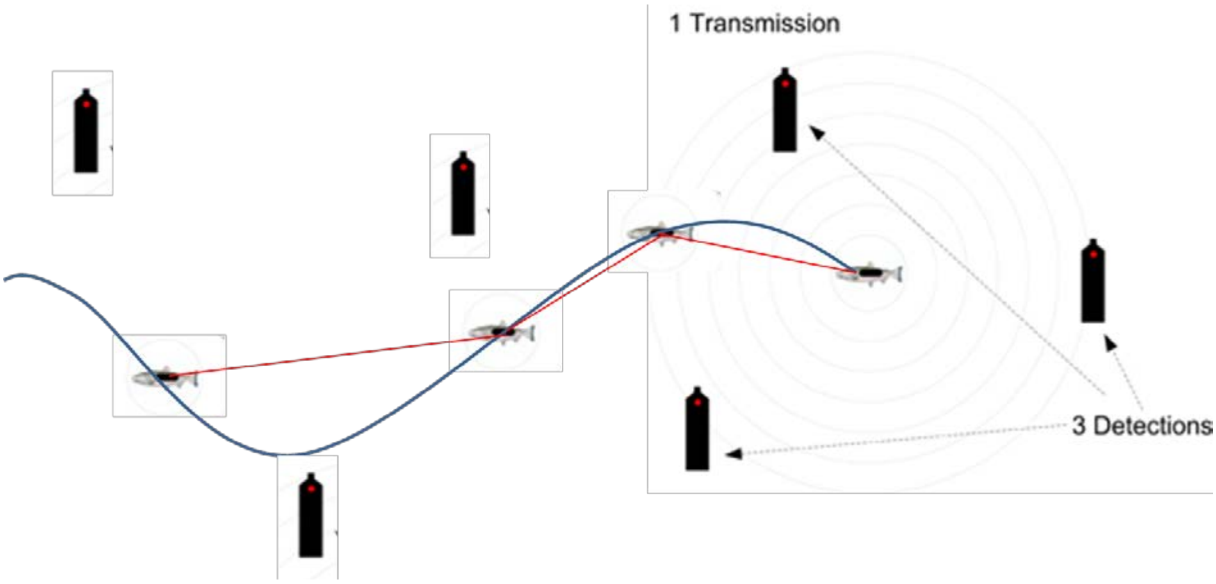


Figure 11: Schematic view of 2 dimensional acoustic telemetry. The relative position of a tagged fish towards the hydrophones (black bottles) is calculated based on the theory of the propagation speed of sound through water and info on the timing of emission of the tag signal and its detection on minimally three hydrophones. Subsequent positions give an idea (red line) of the track that the fish has swum (blue line).

Each calculated position has a certain error involved. This is due to a propagation of errors in each step of the detection and calculation process and the causes of these errors at each level are multiple and different. For instance environmental cues that affect the arrival time of a detection can cause errors on the calculated position, but also errors on the defined positions of the hydrophones detecting the tag will cause an error on the calculated positions of the fish in its environment. Next, a certain error on each position also follows from the configuration of the hydrophone network and is inherent to the method of hyperbolic triangulation (see also Smith 2013). Specifically, tags that are within a triangle of hydrophones are far less sensitive to error than tags that are at the boundaries of the triangle or outside.

Error caused by static phenomenon's such as the configuration of the receiver network or an error on the positioning of the hydrophones are easier to define and deal with than errors that are caused by environmental cues, which are mostly spatially and temporally dynamic. For instance the error following from the configuration of the network is calculated and reported by Vemco and defined in an HPE (Horizontal Positioning Error) value that comes along with each calculated position (see also Smith 2013). The relation between environmental cues and the error following from this is far more difficult to define and more difficult to assess. To date, no standard method is available to filter out all error present on calculated positions. Research on this topic is on-going (Baktoft et al. 2017, Meckley et al., 2014) and available methods will be tested in this study as well. Although detailed knowledge on the error on the calculated fish positions is necessary, it is not always needed to filter out all present error to solve a research question in a correct way, but it depends on the research question.

Regardless of any method to filter out error on calculated positions, it is necessary to get a clear view on the error present in each study before you can decide how this affects the correctness of your research result. To get a view on the present error, reference situations are created in the VPS network. For instance test tracks can be created at the setup of the hydrophone network or during the study. A test track is a track of a test tag, which is not implanted in a fish but for instance attached to a small floating vehicle and of which the exact position is permanently known (measured with a GPS). So, the observed (real) positions can be compared to the calculated positions. Another way to test for error during the continuation of the entire study is to install reference tags in the study area. These tags are fixed at a known (measured with a precise GPS), fixed position. The tags are detected throughout the entire study so that the fixed, known position can be compared with the calculated positions and error can be defined on the calculated positions as the difference between the observed and calculated positions. The latter may also clarify potential temporal patterns in error.

Acoustic telemetry devices
Different types of telemetric systems and devices exist that can be used for acoustic telemetry. First of all, different companies exist that each have their own specific products. In this study we chose to work with Vemco (www.vemco.com). Generally, Vemco provides two different ways of ID code/signal emission from the tags. The signal can be either emitted as a pulse train of sounds, each encoding a small part of the ID code (called PPM way of transmitting the ID code), or it can be emitted as one sound that encodes the entire ID code at once (called HR way of transmitting the ID code). PPM and HR transmission each have their advantages and disadvantages and one or the other might be better suited depending on the study objectives and environment. Differences between PPM and HR that might affect the choice for one or the other are the duration of ID code emission, which is higher (up to 3 sec) in PPM than HR (less than 1 sec), their sensitivity to reflections of the signals, which is lower for PPM than HR, and their detection range. Only the first difference is not affected by the environment that is investigated.

Depending on the system that is selected for the study (PPM or HR) different hydrophone types are available. Hydrophones differ in the frequency that they can hear and decode. Vemco produces hydrophones that work either for emitted signals on 69 kHz or 180 kHz. No hydrophones exist that can hear and decode both frequencies. Hydrophones that hear and decode 69 kHz only work for PPM emitted signals, whereas the more recently developed 180 kHz hydrophones can hear and decode both PPM and HR emitted signals. Some types of hydrophones have a built-in tag, which is called the sync-tag and which enables the synchronisation of different hydrophones in the same (VPS) network and which can be used as reference tags at the same time, and others don’t have this ability built in. Next, some hydrophones contain sensors, measuring temperature, background noise and the vertical position of the hydrophone (the tilt), whereas others do not have these sensors built in.

3.3.2. Setup of the VPS network

To collect accurate and precise fish tracks in the study area of 500 m around the fish pass outflow (Figure 5), a VPS network of hydrophones had to be installed in the area. Previous to installation, the most efficient telemetric system (devices) had to be defined for this study and the study environment. Multiple tests were performed with different types of devices.

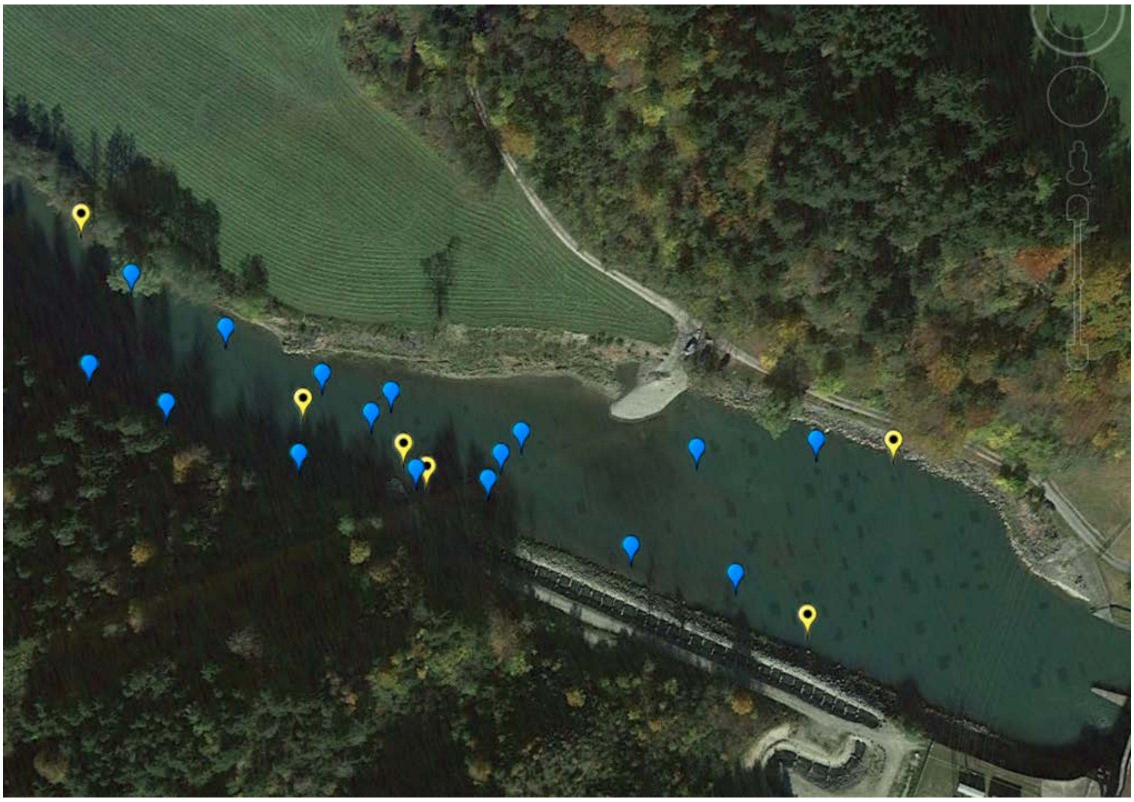
In May 2017 the 69 kHz PPM system of Vemco was tested with hydrophones having built-in sensors and a tag. In August 2017, range tests with the 180 kHz PPM and HR system were performed. The results of the tests indicated that the 180 kHz system performed better than 69 kHz in this study area, which is characterised by high flow velocities and a rough bathymetry causing turbulence (air bubbles and noise) and reflections of the tag signals, and background noise from the HPP turbines. Next, it was found that HR performed well and since it can have very short emission delays (the time between two emissions is called the delay of the tag) of only 1 sec, in contrast to PPM tags that already need up to 3 sec for one emission, it was selected above PPM. Very frequent emissions (delays of only 1,1 sec) are needed to get accurate tracks that are based on positions of the tagged fish every 1 to 3 m. Such 'high resolution' tracks are needed to make the link with flow velocity and bathymetry info in high detail resulting from the hydrodynamic model (section 3.2). Further, the tests indicated an optimal spacing of hydrophones of around 40 m (direct line of sight).

In February 2018 further profound tests were performed with the 180 kHz HR and PPM systems to clarify the number of hydrophones needed and their best positions so that the entire study area is covered with the detection ranges of minimally three receivers in the best possible way. Next, the mooring system needed to fix the hydrophones at their best position was tested. It is important that this mooring system holds the hydrophone near the bottom of the river, in a perfect vertical position (tilt of 0 to maximally 10°) for the entire study and thus also in harsh conditions with high discharges and flow velocities. At the same time, the mooring system should allow an easy recovery of the hydrophones at the end of the study to download the logged data. Figure 12 shows the mooring system used for the hydrophones and reference tags in this study.

The resulting VPS network existed of 16 180 kHz HR2 (High Residency) receivers with built-in sync-tags and temperature, noise and tilt sensors, and 6 reference tags (Figure 13). The hydrophones were moored on steel pyramid constructions that were fixed on the river bottom by means of steel chains running from one river bank to the other over the river bottom.

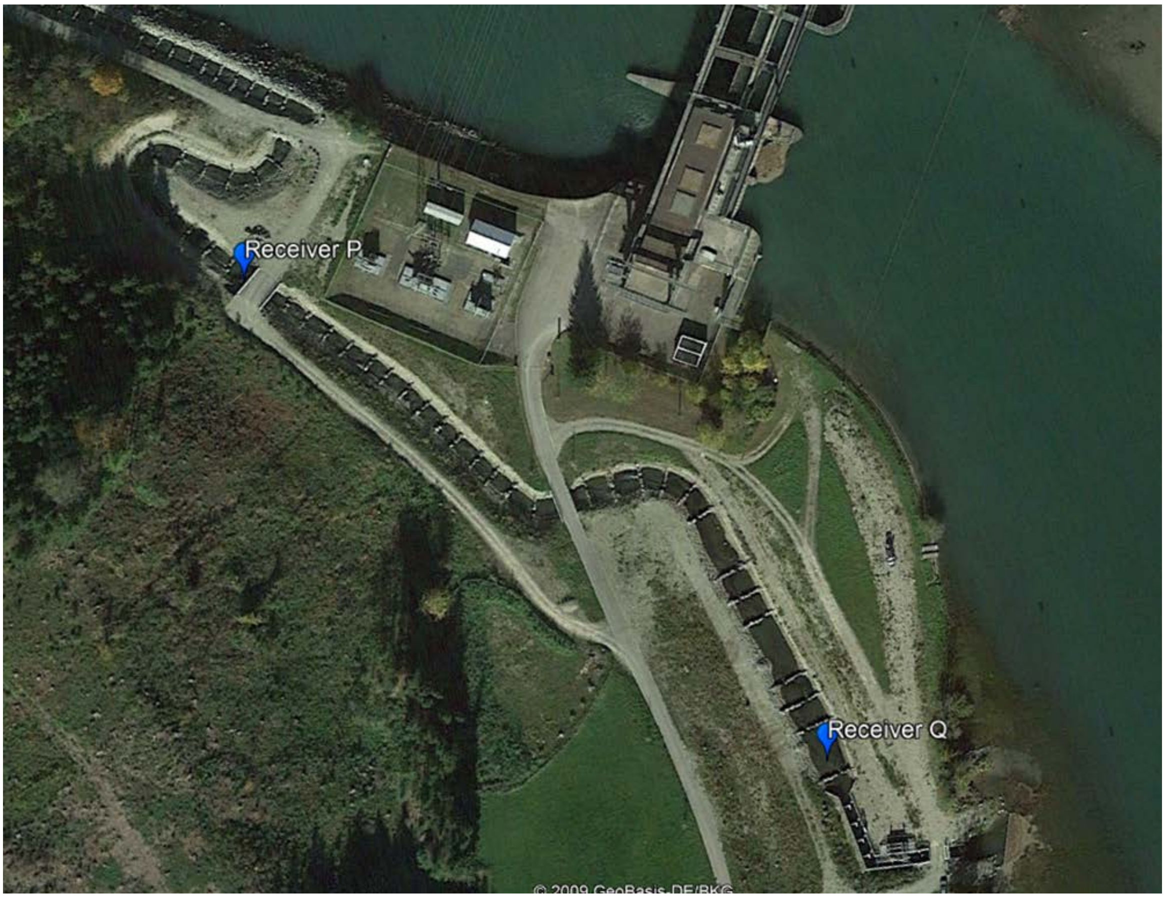
(a) (b) (c)

Figure 12: Pictures of the mooring of the reference tags (a) and the hydrophones with steel pyramid constructions (c) attached to a steel chain that is anchored at both sides of the river and runs over the river bottom (b). In total 16 pyramid constructions where attached to 7 chains spread over the study area. The hydrophone is held vertically by attachment to the top of the pyramid in picture c.



(a)

(b)



(c)

Figure 13: (a) Locations of the 16 hydrophones (blue marks) and 6 refefence tags (yellow marks) as positioned with a Trimble GPS at (installation) and recovery. (b) Location of all 19 hydrophones in the study, and 6 reference tags of the VPS network. (c) Zoom on the locations of the two hydrophones in the fish pass.

The fish tags were chosen to emit an HR signal with a variable delay between 1.1 and 1.3 sec and an additional PPM signal with a variable delay between 50 and 70 sec. Table 7 lists all specific receiver and tag characteristics used in this study.

Table 7: Overview of the type of devices (hydrophones and tags) used in this study and their specifications. The sensors in the hydrophones log temperature, tilt of the hydrophone and background noise.

Device (#)	Delay of the (built-in) tag (sec)	Output power of the (built-in) tag	Sensor logging frequency	Estimated battery life	Weight (g)
180 kHz HR2 hydrophones (19)	HR: 4-6 PPM: 25-35	Very High		6 months	-
V9-2x 180 kHz reference tags (6)	HR: 25-35 PPM: 270-330	High	-	min. 6 months	-
V9-2x 180 kHz fish tags (47)	HR: 1.1-1.3 PPM: 50-70	High	-	143 days	In air: 3.7 In water: 2

Apart from the 16 hydrophones installed in the area surrounding the fish pass outflow, three hydrophones (same type and characteristics) were placed around the study area to evaluate presence of tagged fish. One hydrophone was placed at app. 2 km downstream of the VPS network in the river Iller, covering the width of the river with its detection range to evaluate if studied fish left the study area in downstream direction. Two other hydrophones were placed half way and upstream in the fish ladder, respectively (Figure 13). These hydrophones were used to evaluate if fish used the fish ladder to migrate upstream. Next, the upstream hydrophone helped to evaluate the efficiency of the counting pool (Figure 13). Not all fish that swim upstream to the counting pool are trapped in it and thus caught and marked by the LEW investigator.

3.3.3. Fish tagging and tracking

In the week of March 19th 2018, the VPS network was installed in its final position for the study. In the weeks following on the hydrophone installation 47 wild fishes were caught, tagged and released in the VPS array at the most downstream hydrophone near the left bank (Table 8). The hydrophones were recovered again on the 22nd of August 2018 to download the logged data and were not re-installed in the water because the battery life of hydrophones and tags was ending. Furthermore, the aim was to monitor upstream fish migration and the spawning season (and so upstream spawning migration) is believed to last no longer than the beginning of July. None of the batteries of tags, neither hydrophones had run out before the end of the study. Some of the fish had left the VPS array before the end of the study (Table 8), but the reason is not known. They might have died and drifted downstream, might have been caught by anglers or might have swum downstream actively. Active escapement upstream was not possible as the dam is not passable unless the fish takes the fish pass. However, fish could not leave the fish pass upstream without being caught in the counting pool.

The aim was to tag and track as much individuals as possible of one species with a special focus on grayling and barbell as these species are known to be dominant in the river Iller and are known to swim upstream during the spawning period to find suitable spawning habitat. Grayling mainly spawn in March-April in this area, whereas barbell is known to spawn later in spring (late April, beginning of May). Therefore first grayling were caught until the spawning was believed to have started. To define the timing of spawning of grayling and barbell in the river Iller in spring 2018, the presence of eggs or sperm in the bellies of caught fish was evaluated during tagging surgery. 25 grayling were caught, tagged and released in the VPS array successfully (Table 8). Next, 22 barbell were successfully caught, tagged and released. Table 8 indicates the catch method and location of each of the tagged grayling and barbell as well as the dates of catch, tagging and release. Next, this table indicates the day at which the fish was detected by the VPS array the last time. Figure 14 shows the catch and release locations of the studied fish.

Table 8: Info on the 47 individual wild fish of two species (barbell and grayling) that were tagged and tracked in this study.

ID code	Species	Total length (mm)	Weight (g)	Catch method	Catch location	Release date	Last VPS detection
46838	Barbus barbus	570	2160	Counting pool Altusried	Fish pass	29/05/2018	22/08/2018
46839	Barbus barbus	594	2161,7	Counting pool Altusried	Fish pass	29/05/2018	22/08/2018
46840	Barbus barbus	456	932,6	Counting pool Altusried	Fish pass	29/05/2018	22/08/2018
46844	Barbus barbus	504	1285,8	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46845	Barbus barbus	496	1106,8	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46846	Barbus barbus	460	911,2	Counting pool Altusried	Fish pass	24/05/2018	5/06/2018
46847	Barbus barbus	619	2343,3	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46848	Barbus barbus	545	1567,6	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46849	Barbus barbus	480	1180,5	Counting pool Altusried	Fish pass	29/05/2018	22/08/2018
46850	Barbus barbus	526	1465,7	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46851	Barbus barbus	330	327,2	Counting pool Altusried	Fish pass	24/05/2018	1/06/2018
46852	Barbus barbus	460	1053,2	E-fishing	Fish pass	24/05/2018	22/08/2018
46853	Barbus barbus	461	1010,6	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46854	Barbus barbus	585	2105,1	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46855	Barbus barbus	594	2212,7	Counting pool Altusried	Fish pass	24/05/2018	22/08/2018
46856	Barbus barbus	513	1544,1	Counting pool Altusried	Fish pass	24/05/2018	26/06/2018
46857	Barbus barbus	457	822,9	E-fishing	Fish pass	24/05/2018	22/08/2018
46858	Barbus barbus	516	1306,5	Counting pool Altusried	Fish pass	17/05/2018	22/08/2018
46859	Barbus barbus	387	648,4	Counting pool Altusried	Fish pass	17/05/2018	22/08/2018
46860	Barbus barbus	545	2074,4	Counting pool Altusried	Fish pass	17/05/2018	22/08/2018
46861	Barbus barbus	466	1009,6	Counting pool Altusried	Fish pass	17/05/2018	22/08/2018
46862	Barbus barbus	400	621,2	Counting pool Altusried	Fish pass	17/05/2018	18/05/2018
46863	thymallus thymallus	403	673,3	E-fishing	Iller	11/04/2018	19/04/2018
46864	thymallus thymallus	409	623,2	Counting pool Altusried	Fish pass	11/04/2018	18/04/2018

46865	thymallus thymallus	350	315	NA	NA	11/04/2018	7/06/2018
46866	thymallus thymallus	326	262,1	Counting pool Altusried	Fish pass	11/04/2018	24/04/2018
46867	thymallus thymallus	439	755,4	Counting pool Altusried	Fish pass	11/04/2018	20/04/2018
46868	thymallus thymallus	420	791,3	E-fishing	Iller	4/04/2018	15/04/2018
46869	thymallus thymallus	508	1250,8	Counting pool Altusried	Fish pass	11/04/2018	11/04/2018
46870	thymallus thymallus	426	756,8	Counting pool Altusried	Fish pass	11/04/2018	17/04/2018
46871	thymallus thymallus	416	843,9	E-fishing	Iller	11/04/2018	19/04/2018
46872	thymallus thymallus	411	640,1	Counting pool Altusried	Fish pass	11/04/2018	20/04/2018
46874	thymallus thymallus	348	402,1	E-fishing	Iller	4/04/2018	23/05/2018
46901	thymallus thymallus	383	657,7	E-fishing	Iller	4/04/2018	20/04/2018
46902	thymallus thymallus	431	712,3	E-fishing	Iller	4/04/2018	4/04/2018
46903	thymallus thymallus	371	444,6	Counting pool Altusried	Fish pass	4/04/2018	9/04/2018
46904	thymallus thymallus	494	1048,5	E-fishing	Iller	4/04/2018	24/04/2018
46905	thymallus thymallus	425	642,4	Counting pool Altusried	Fish pass	4/04/2018	15/04/2018
46906	thymallus thymallus	498	1152,9	E-fishing	Iller	4/04/2018	15/06/2018
46907	thymallus thymallus	331	317,3	Counting pool Altusried	Fish pass	4/04/2018	11/04/2018
46908	thymallus thymallus	400	683	E-fishing	Iller	4/04/2018	15/04/2018
46909	thymallus thymallus	389	634,2	E-fishing	Iller	4/04/2018	14/04/2018
46910	thymallus thymallus	406	707,3	E-fishing	Iller	4/04/2018	18/04/2018
46911	thymallus thymallus	309	233,4	E-fishing	Iller	4/04/2018	12/04/2018
46912	thymallus thymallus	407	606,4	Counting pool Altusried	Fish pass	4/04/2018	13/04/2018
46913	thymallus thymallus	318	312	E-fishing	Iller	28/03/2018	5/04/2018
46914	thymallus thymallus	304	286	E-fishing	Iller	28/03/2018	10/04/2018

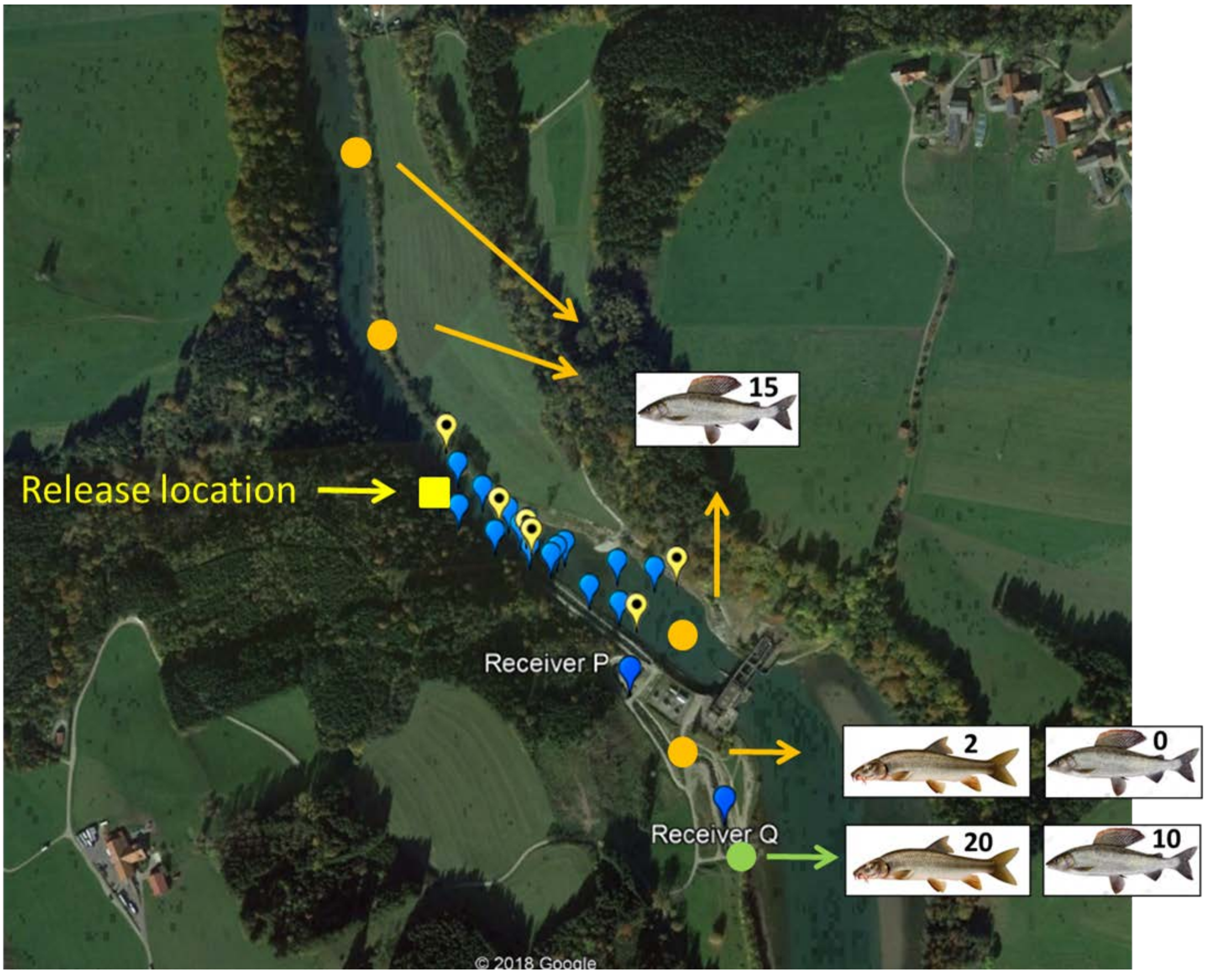


Figure 14: Indication of the number of grayling (top and right fish pictures) and barbell (left fish pictures) and their catch and release location in the study area. Yellow dots indicate locations where fish were caught electrically, whereas the green dot indicates the location of the counting pool, which was also used to catch studied fish. Further biometric info and info on the catch method is listed in Table 8.

Fish were caught electrically or in the counting pool. Once a fish was caught it was held in an aerated tank with water and brought to the hydropower plant, where the fish were operated on. Before surgery fish were put in an aerated tank with phenoxy-ethanol to sedate the fish (around 10 ml phenoxy-ethanol for 50 l of water). Once the fish was sedated (this took on average 6 +/- 1:46 min), it was laid on his back in a V-shaped tray placed in a water tank filled with a diluted solution of the anaesthetic so that the gills were constantly under water. The tag (Vemco V9-2X-180k, cylindrical shape 26x9 mm, weight 2·0 g in water, 180 kHz frequency, 143 days battery life, high power output and small HR delay of 1.1-1.3 sec) were implanted surgically by a 1·0–1·5 cm incision made behind the pelvic girdle, at the level of the upper edge of the pelvic fin, according to Nykänen et al. (2001). The weight of the tag in water was always < 0.85 % of the grayling weight and < 0.61 % of the barbell weight, remaining well below the recommended maximum of 2% (Winter, 1983). The surgery lasted for 7 min, on average. The tagged fish were transferred into another aerated tank with water to recover, and released into the river as soon as they could swim. Recovery generally took minimally 3 to maximally 12 min.

3.4. Fish tracks and evaluation – preliminary results (INBO)

Throughout the study, over 15 million fish positions of 47 fish were collected. Tagged fish stayed in the VPS network between 2 and 96 days (Table 9). Barbell resided on average far longer in the VPS network than grayling. Three of 25 tagged grayling were recovered at the hydropower plant of Fluhmhüle, downstream of Altusried. These fish were dead and infected with a fungus. The fish itself was infected and not/not only the stitched incision of the tagging surgery. Also not-tagged grayling were caught that were alive but infected with the parasite. The grayling positions and tracks collected do not indicate that grayling was highly affected by the tagging procedure. Nonetheless it appeared that grayling was more sensitive to the handling and tagging than barbell, since no dead tagged barbell were found and most moved in the VPS network from the day of release till the end of the study.

3.4.1. Performance of the VPS network

As a broad, preliminary, measure, the median error of sync/ref positions was 0.32 m, and the 90% percentile error was 2.08 m. These numbers vary both spatially throughout the array, and temporally, as environmental conditions change. The primary source of error in the system was that of multipath signals, which are transmissions that reflect and are received later than they should if they were transmitted to the hydrophone in a straight line.

The mooring system withstood the highest discharges of 200 – 220 m³/s encountered during the studied period (Figure 15). Although some hydrophone movements were detected by Vemco during analyses of the detections of sync-tags, all calculated (based on the detections) hydrophone positions were within 1 m of the positions as measured with the Trimble GPS, after adjustments for hydrophone movement and time synchronisation of the hydrophone clocks. The trimble GPS measurements had a maximal error of 20 cm, but with hydrophone movement included finally each hydrophone position had a potential error of up to 1 m. Beside the hydrophone positions, the tilt was measured at the start and end of the study. The largest difference in tilt of a hydrophone observed between start and end of the study was 2°, which is minimal.

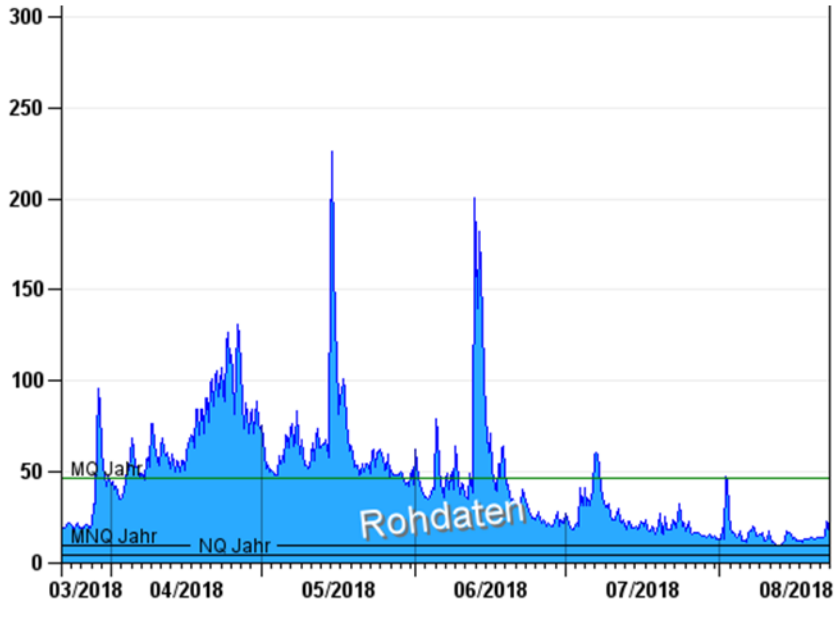


Figure 15: Discharge (in m³/s) of the river Iller in Kempten during the studied period (see also Figure 8).

3.4.2. Fish behaviour

So far, no fish tracks were evaluated although they are collected already. This is due to the fact that present errors on the fish positions still need to be evaluated and positions with low precision and accuracy need to be removed from the dataset before any further analysis can be performed.

The detections on the hydrophones in the fish pass give already info on which fish have found the fish pass entrance and have swum up the fish pass. These detections indicated that of all 25 tagged grayling, 12 found the entrance of the fish ladder at least once and swum up the fish ladder till halfway. Of these 12 grayling, 10 proceeded their way up until the counting pool (hydrophone upstream) of which two did this repeatedly (Table 9). Those two grayling were caught in the counting pool on 9th and 12th of April 2018, which is 5 and 8 days after their release in the VPS network, respectively. Of the 22 tagged barbell, eight found the entrance of the fish pass and swum upstream to the hydrophone halfway. Six of them proceeded their way up till the hydrophone upstream. Three of them moved upstream repeatedly and were finally caught in the counting pool respectively on the 2nd , 2nd and 12th of June 2018, which is 10, 10 and 19 days after their release in the VPS network. Hence, these data give a catch efficiency of the counting pool of 2 out of 10 (20%) for grayling, and 3 out of 6 (50%) for barbell.

Table 9: Indication of the number of days that a tagged fish was detected in the VPS network and if the fish swum up the fish ladder or not, till where and only once or multiple times, and the date that a fish was caught in the counting pool if any catch occurred.

ID code	Species	Days detected (#)	Detection half way fish ladder	Detection upstream fish ladder	Repeated detections upstream fish ladder	Counting pool catch
46838	Barbus barbus	79	yes	yes	no	-
46839	Barbus barbus	83	yes	no	no	-
46840	Barbus barbus	71	no	n/a	no	-
46844	Barbus barbus	69	yes	yes	no	-
46845	Barbus barbus	72	no	n/a	no	-
46846	Barbus barbus	6	no	n/a	no	-
46847	Barbus barbus	70	yes	yes	yes	2/06/2018
46848	Barbus barbus	81	no	n/a	no	-
46849	Barbus barbus	81	no	n/a	no	-
46850	Barbus barbus	86	yes	yes	no	-
46851	Barbus barbus	9	no	n/a	no	-
46852	Barbus barbus	73	yes	yes	yes	2/06/2018
46853	Barbus barbus	84	no	n/a	no	-
46853	Barbus barbus	82	no	n/a	no	-
46854	Barbus barbus	90	no	n/a	no	-
46855	Barbus barbus	81	yes	yes	yes	12/06/2018
46856	Barbus barbus	32	no	n/a	no	-
46857	Barbus barbus	83	no	n/a	no	-
46858	Barbus barbus	96	yes	no	no	-
46859	Barbus barbus	90	no	n/a	no	-
46860	Barbus barbus	83	no	n/a	no	-
46861	Barbus barbus	89	no	n/a	no	-
46862	Barbus barbus	2	no	n/a	no	-

46863	thymallus thymallus	6	no	no	no	-
46864	thymallus thymallus	8	no	n/a	no	-
46865	thymallus thymallus	14	no	n/a	no	-
46866	thymallus thymallus	14	no	n/a	no	-
46867	thymallus thymallus	7	no	n/a	no	-
46868	thymallus thymallus	10	yes	yes	no	-
46869	thymallus thymallus	1	no	n/a	no	-
46870	thymallus thymallus	6	yes	yes	no	-
46871	thymallus thymallus	8	yes	yes	no	-
46872	thymallus thymallus	10	yes	yes	no	-
46874	thymallus thymallus	7	no	n/a	no	-
46901	thymallus thymallus	16	yes	no	no	-
46902	thymallus thymallus	1	yes	yes	no	-
46903	thymallus thymallus	6	no	n/a	no	-
46903	thymallus thymallus	5	no	n/a	no	-
46904	thymallus thymallus	21	no	no	no	-
46905	thymallus thymallus	13	yes	yes	no	-
46905	thymallus thymallus	12	yes	yes	no	-
46906	thymallus thymallus	59	yes	no	no	-
46907	thymallus thymallus	3	no	n/a	no	-
46908	thymallus thymallus	12	yes	yes	no	-
46909	thymallus thymallus	9	no	n/a	no	-
46910	thymallus thymallus	14	yes	yes	yes	9/04/2018
46911	thymallus thymallus	2	no	n/a	no	-
46912	thymallus thymallus	9	yes	yes	yes	12/04/2018
46913	thymallus thymallus	3	no	n/a	no	-
46914	thymallus thymallus	9	no	n/a	no	-

3.4.3. Future work

The positions of sync- and reference tags should be analysed further to clarify how errors were induced spatially and temporally, and how these errors can be corrected for.

Next, three different methods will be applied on the data and their results compared, to filter out calculated fish positions of which the error is known to be too large to correctly aim for the study objective. The three methods that will be applied are (A) the YAPS method based on Time of Arrival (TOA) as developed by Baktoft et al. (2017), (B) a filtering based on HPE and RMSE values provided by Vemco, and (C) a filtering method developed by Vergeynst (not published) that is based on the receiver clusters that define fish positions with large errors.

Lastly the resulting accurate and precise fish tracks will be linked to the results of the hydrodynamic model and tracks will be evaluated in the light of the migration model that needs further fine-tuning (see objectives section).

3.5. Migration model (SJE)

3.5.1. Model development

The aim behind an agent-based model (ABM) for the prediction of fish upstream movement close to downstream fish pass entrances, is the assessment of attraction flows. Using the model for different local positioning of the entrance and different dotations provides the basis for mitigation of the attraction flow. This is a crucial aspect of the functionality of bypass installations. The mitigation of these installations is one of the main goals in FIThydro.

As described in deliverable 3.2, a migration habitat model serves as basis for the Agent based model (ABM). The migration habitat model is a habitat suitability model that reflects that hydraulic conditions preferably used by fish before entering the fish pass, i.e. in the migration phase. These hydraulic conditions in terms of flow velocity and water depth are assumed to be one of the factors leading fish their way when looking for an opportunity to migrate upstream.

In the evaluation of the fish tracks recorded with an acoustic telemetry system in the test case Altusried at river Iller (see. deliverable 3.2) it turned out, that spatial gradients and flow direction seem to be additional factors with an impact on fish movements.

The concept of the migration model integrated in the simulation system Casimir [2] allows to combine the basis suitability maps for migrating fish with an additional information on the swimming behavior of the observed fish in the flow field. This information expressed mainly in terms of histogram of probability to move in certain direction in respect to the velocity direction is recorded in the "property box" of **fish agents** (virtual model fish) moving in the habitat suitability space defined by the model. In every step of a simulation, the migration algorithm checks the local conditions in a particular model-cell (like basis migration suitability, flow velocity direction and value) and applies the rules for the selection of the next direction of an agent. Derived agent tracks can be compared with observed ones and can also be used further to assess the overall effectiveness of bypass installation.

3.5.2. Rule-based system and model implementation

As mentioned in deliverable 3.2 hydraulic parameters are believed to be, among others, main drivers for the migratory behaviour of fish. Thus, it seems adequate to select hydrodynamic modelling as a basis for the migratory model.

The present model operates on the results of a 2D hydrodynamic model. Original results, obtained with the model HydroAs-2D [3] on the unstructured mesh, are converted for the simplicity to a grid representation. Hydrodynamic parameters like flow velocity components in x and y directions and flow depth are interpolated from the mesh nodes into grid cell centres of the migration model (see Figure 1). Every cell (i, j) with the dimensions of Δ (0,5 m in our case) in x- and y-directions has 8 neighbours numbered counter-clockwise with indexes ranging from 0 to 7. Correspondingly, the movement of the fish agent from the centre cell towards the neighbour cell 1 is named movement in “Direction 1”. As an example, assuming the river flow in the current cell has a “Direction 3”, the fish which moves strictly against the flow will possess movement into the “Direction 7”.

3	2	1
4	Cell i, j	0
5	6	7

112.5° to 157.5°	67.5° to 112.5°	22.5° to 67.5°
157.5° to 202.5°		337.5° to 22.5°
202.5° to 247.5°	247.5° to 292.5°	292.5° to 337.5°

Figure 16. Migration model cell with neighbour ids (left) and corresponding angles (right).

The model evaluates at every movement step the parameters in the current cell i,j and compares them with the parameters in the 8 neighbour cells. After applying the migration model algorithm as described below, a virtual fish moves into the new cell and the calculation is started over. The total number of fish movement steps (NMoveTotal) can be set flexibly.

Basis for the Agent-based model are “migration habitat corridors”. Fish agents in their search for the upstream path swim in general within these corridors. For the demarcation the corridors, a fuzzy rule-based approach as standard approach in the habitat suitability module of CASiMiR [2] is applied. Parameters defining these corridors and corresponding fuzzy rules and sets are detected through the analysis of the observed fish position prior entering the fish migration facility. A map of the output parameter “Migration habitat suitability” shows which parts of the river are highly suitable for migration and which are not. These maps are generated for every flow situation of interest (see example of the migration corridor suitability for the grayling at hydropower plant discharge of 80 m^3/s in Figure 17). The threshold of “Migration corridor suitability” – “Minimum SImigr” (SI = suitability index between 0 and 1), e.g. the value above which a mode element is considered to be a good migration habitat can be adjusted (calibration parameter). The migration suitability is calculated via the hydraulic preferences of fish during the last period before entering the fish pass.

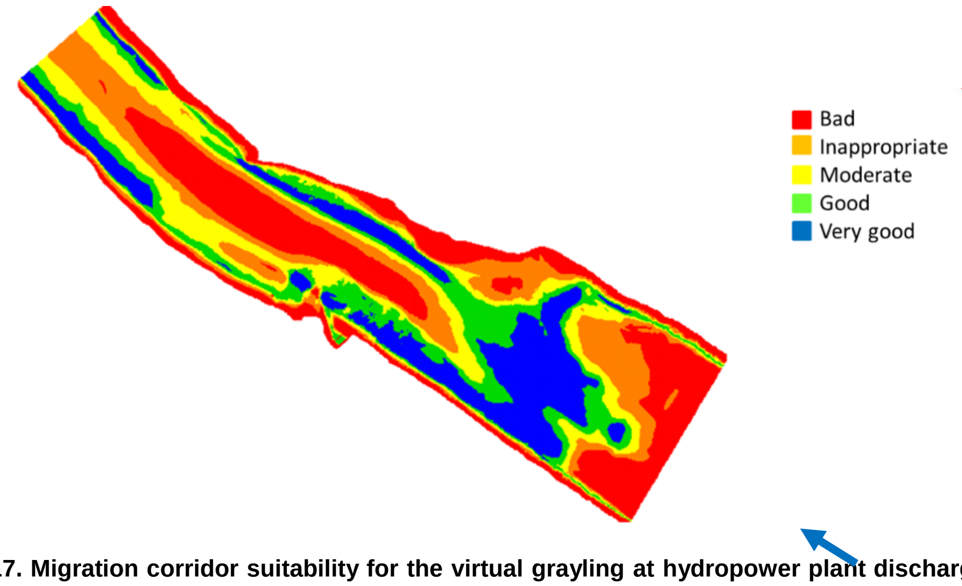


Figure 17. Migration corridor suitability for the virtual grayling at hydropower plant discharge of 80 m³/s, fuzzy system with two parameters: water depth and flow velocity

3.5.3. Validation and first model results

Comparison with observed fish tracks

Some simulation results are presented in the following figures. They are overlayed with the ortho images of the situation downstream of the weir Altusried with integrated HPP. The comparison of observed tracks with modelled tracks shows that the concept of flow probability histogram combined with the random method for the final selection of movement direction allows to mimic up to a certain degree the searching (random lateral, zig-zag) movement behaviour of observed fish in some cases (example for grayling in Figure 18 and for barbel in Figure 19).

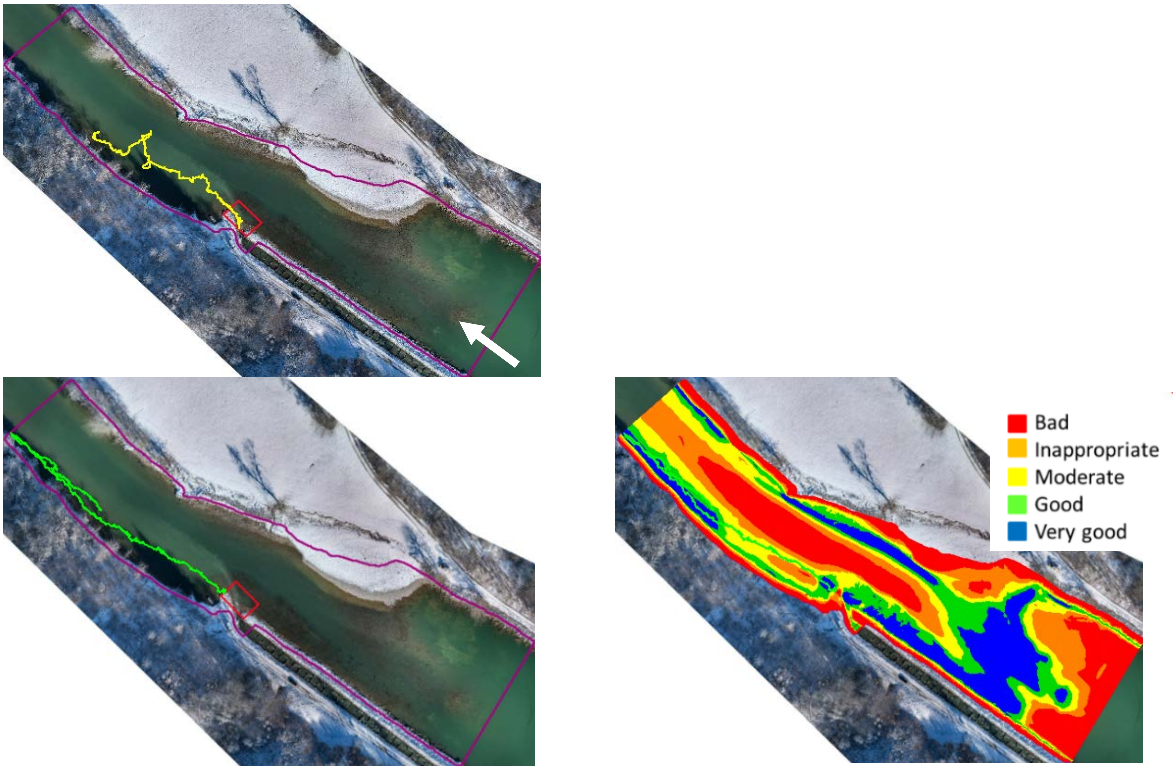


Figure 18. Observations and model results for grayling at 80 m³/s, Fish 46908. observation (left top), migration habitat suitability (left bottom), Fish 46908 with 2 parameters migration SI overlaid with SI map (right bottom)

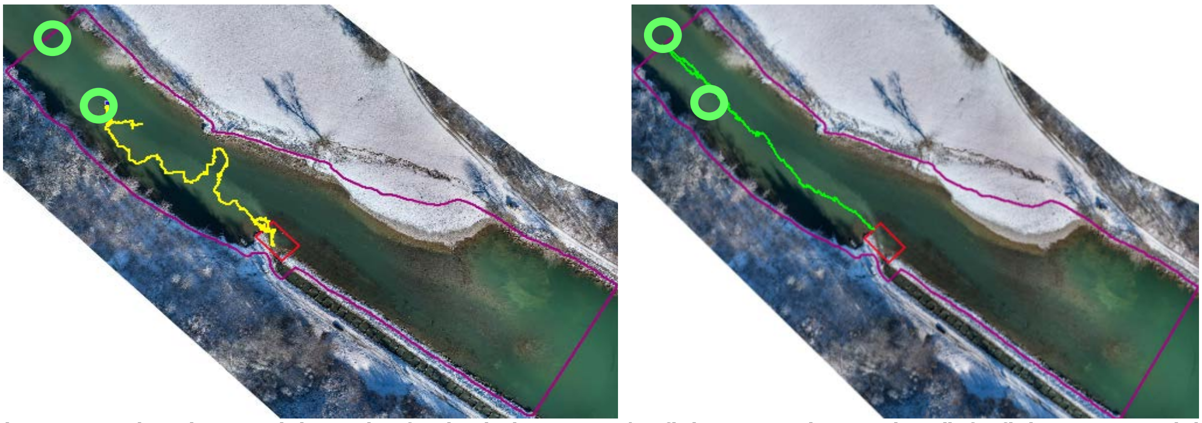


Figure 19. Migration model results for barbel at 40 m³/s: fish 46850 observation (left, fish 46850 model (right). The model fish starts moving in flow direction (first movements are chosen randomly by the model) but then changes swim direction against the flow and finds the fish pass entrance upstream

Different flow rates

The proposed model shows relatively consistent predictions also for the grayling and barbel under conditions of different hydropower discharges as shown in Figure 20. Still, results are highly dependent on the starting point of the virtual fish and on the first direction (with flow or against) it will choose.

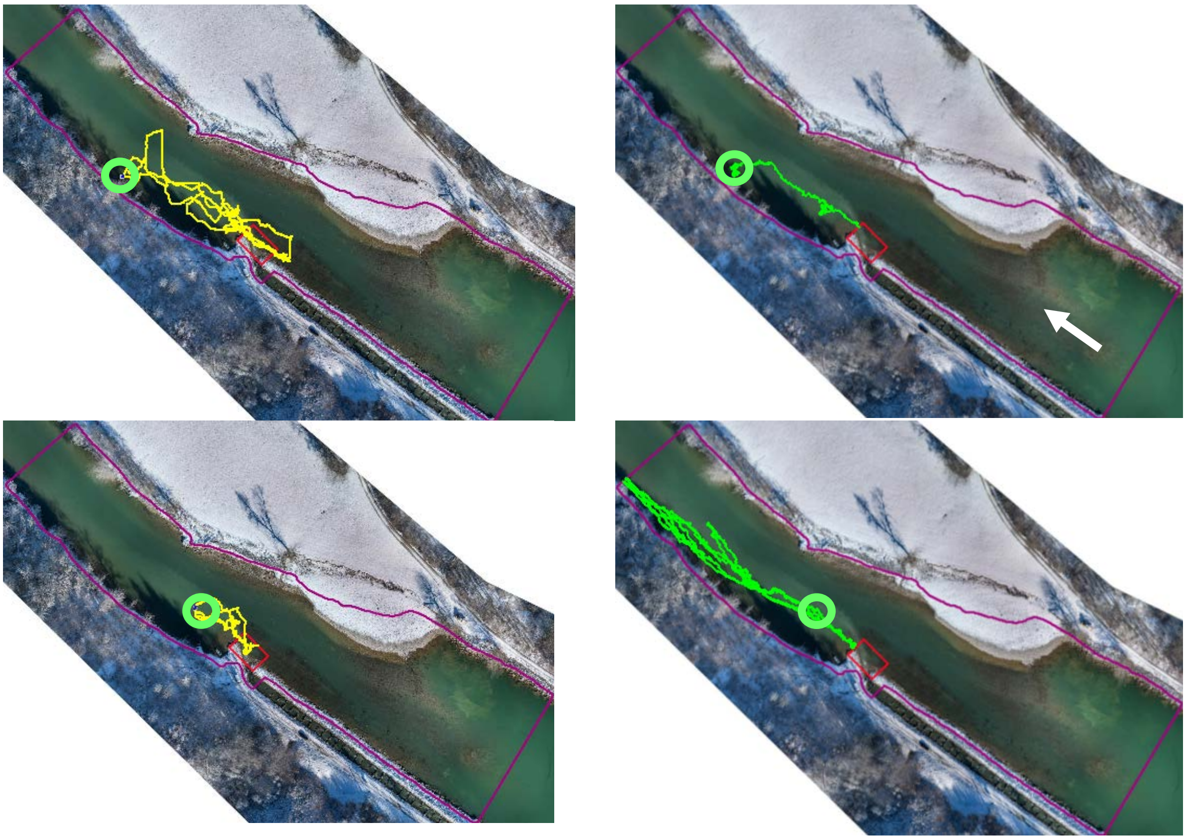


Figure 20. Observations and migration model results ($N_{MoveTotal}$ = 1500) at different flow situations with indicated starting points (red circle): 30 m³/s - observation grayling 46902 (left top), 30 m³/s - model grayling 46902 (right top), 50 m³/s - observation barbel 46852 (left bottom), 50 m³/s - model barbel 46852 (right bottom).

3.5.4. Mitigations scenarios

Adapted river flow

One option to mitigate the attraction flow is the seasonal adaptation of the flow rate in the river which is feasible in the test case Altusried via several reservoirs upstream. The simulation scenarios show that migration corridors for barbel are getting narrower with discharge. This can be interpreted that way, that the chance that fish will stay near one bank and find finally the entrance is bigger, as long as fish approach the fish ladder in the migration corridor located at the same river side as the fish pass. (see Figure 21). Since corridors are more distinct for flow rates higher than 50 m³/s attraction of the fish ladder could be supported by increasing the flow in the migration season of barbel.

In contrast, increasing the flow too much to values of 80 m³/s and higher leads to an interruption of the migration corridor on the left river side which could impair the attraction to the fish pass entrance (Figure 21 bottom right).

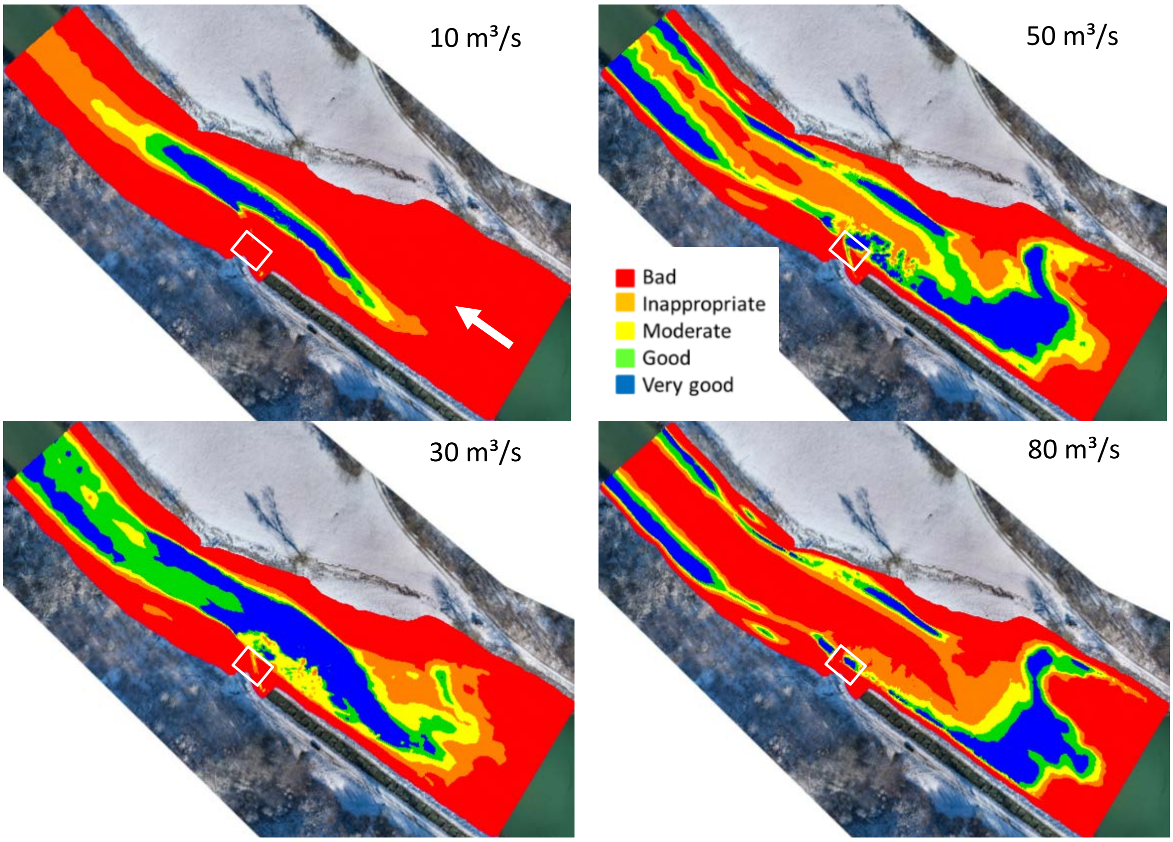


Figure 21. Migration corridor for barbel based on fuzzy system with 2 parameters (vel, depth) and its change with hydro power station discharge: 10 m³/s (top left), 30 m³/s (bottom left), 50 m³/s (top right) and 80 m³/s (bottom right), entrance area marked by a white rectangle

Additional dotation at fish pass entrance

Another option to increase the attraction flow which is often used in practise is the release of additional water into the river in direct neighbourhood to the fish pass entrance. This option has been studied for the test case Altusried with the model for two scenarios: an additional release (dotation) of 1 m³/s and a release of 3 m³/s. Both scenarios were combined with river flows.

Figure 17 shows the dotation scenarios with a flow rate of 20 m³/s in the river. While for the 20 + 1 m³/s situation the model barbel passes the fish pass entrance and moves further upstream, in the case of the 20 +3 m³/s situation it finds the entrance area but moves back again since the migration habitat suitability is too low in the direct entrance area (Figure 22, row 2).

For the model grayling the swim paths between the two dations are not very different either. However, the migration habitat corridor for the 40 + 1 scenario is more continuous in the direct entrance area. This might be due to flow velocities that are exceeding the swim capacity of grayling in some locations for the high dotation of 3 m³/s (Figure 22 row 3 left and right).

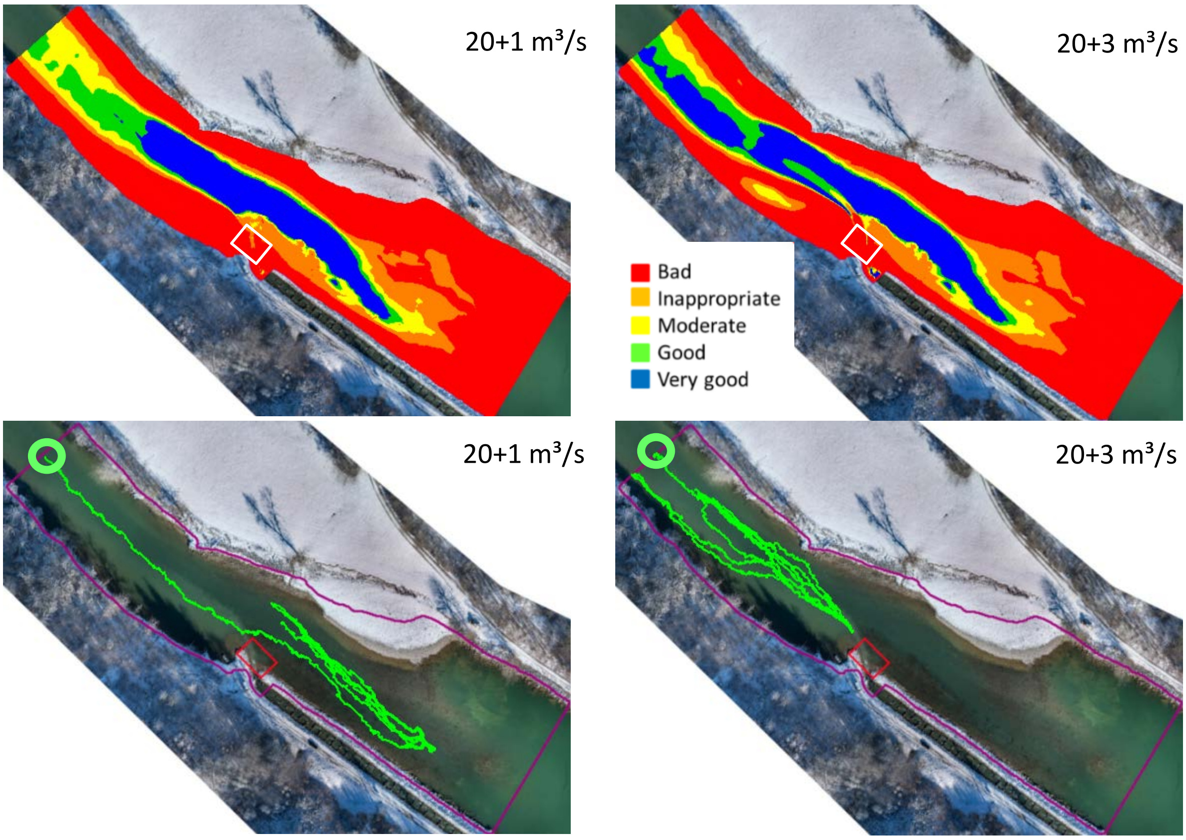


Figure 22. Migration model results for barbel at 20 m³/s with additional dotation of 1 and 3 m³/s from the fish pass entrance: SI barbel at dotation 1 m³/s (left top), SI barbel at dotation 3 m³/s (right top), path barbel at dotation 1 m³/s (left top) (left bottom), path barbel at dotation 3 m³/s (right bottom), fish pass entrance area marked with red and white rectangles

3.5.5. First findings and Outlook

The telemetry study in Altusried has delivered a very large amount of fish positioning data. The first information processing part consisted mainly of data filtering with the purpose to eliminate unreliable recordings caused by system related errors (e.g. noise, reflection). After filtering the data sets were still large due to the comparatively long period that most of the tagged fish spent in the system. Additionally, the sets had to be split into different subsets because the river flow and respectively hydraulic conditions changed considerably during the study period.

From the authors' point of view the most crucial aspect for the model development is the further data processing aiming to distinguish between different behaviour types (feeding, resting, searching…). For the migration model the periods that fish are searching for the fish pass entrance are the most relevant. In the current approach the period 30 min prior to the first entrance into the fish pass has been considered as phase of migration movement, which is probably a severe simplification. Further work to identify different behaviour types is ongoing.

The current model tries to mimic the movement of a single fish by a combination of a habitat suitability maps with the rule system for the behaviour of virtual fish (fish agents). Thus, the model makes the virtual fish approach a fish pass entrance on similar paths as the ones of real fish. The basis for the habitat suitability model are flow velocity, water depth and hydraulic gradients. Further research is needed on the relevance of different hydraulic or other environmental parameters. Also, the temporal aspect has to be analysed, which might be decisive for the identification of searching behaviour.

Many fish that found the entrance area of the fish pass did finally not enter it or entered it with a considerable delay. This indicates that there is a clear distinction between two types of attraction flows. The first, at a larger scale, allows the fish to find the entrance area and a second, at a smaller scale, motivates the fish to enter the first basin of the fish pass. This is also one of the topics for further studies.

Finally, 3D effects could play a role for the behaviour of fish willing to migrate upstream. In case of a large vertical heterogeneity of the flow field or vertical gradients in hydraulic parameters, the attractiveness of the fish pass entrance area or pathways leading to this area might be affected largely. This is an aspect to be investigated using 3D hydrodynamic models and telemetry systems.

All in all, the first results of the agent-based model are promising. The model succeeded in generation of fish agents tracks that are close to the ones of real fish. However, the aspects listed above make clear, that the prediction of fish movements in the environment of fish pass entrances is an extremely complex problem. The data base generated by the evaluation of telemetry observations in Altusried is most helpful for finding relations between hydraulics, morphology and fish behavior. But it has to be extended substantially by data from future studies to allow reliable estimates of fish movements and to enable an assessment of the findability of fish passes.

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