Freudenau

Vienna - Austria

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1 Description of the Test-Case

1.1 Description of the water bodies related to the HPP

The Danube River is the second longest river in Europe with a total length of 2,850 km and a total catchment area of 817,000 km2. The project area is located on the upper reach of the Danube River (distance from the mouth: 1,921 km) within the city of Vienna/Republic of Austria.

1.1.1 Waterbody upstream: 409040013

HMWB ; moderate or worse ecological potential

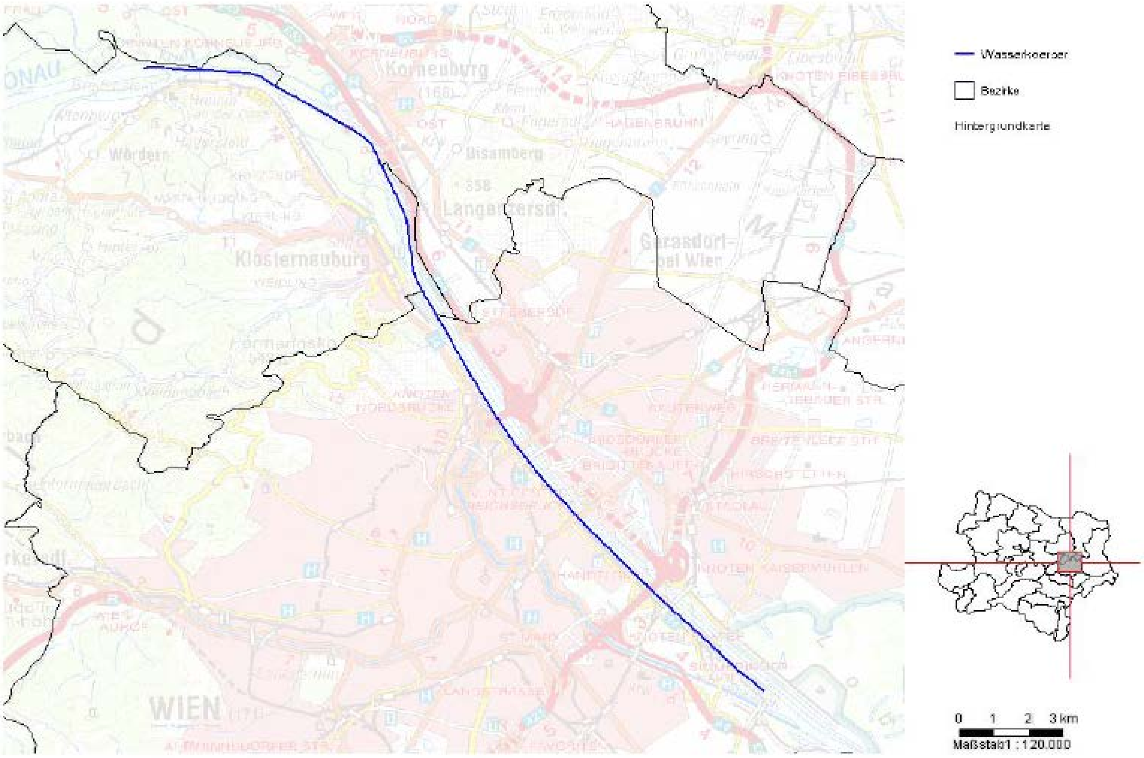

Figure 1: Water body upstream of HPP Freudenau

1.1.2 Waterbody downstream: 409040008

natural water body ; good ecological status

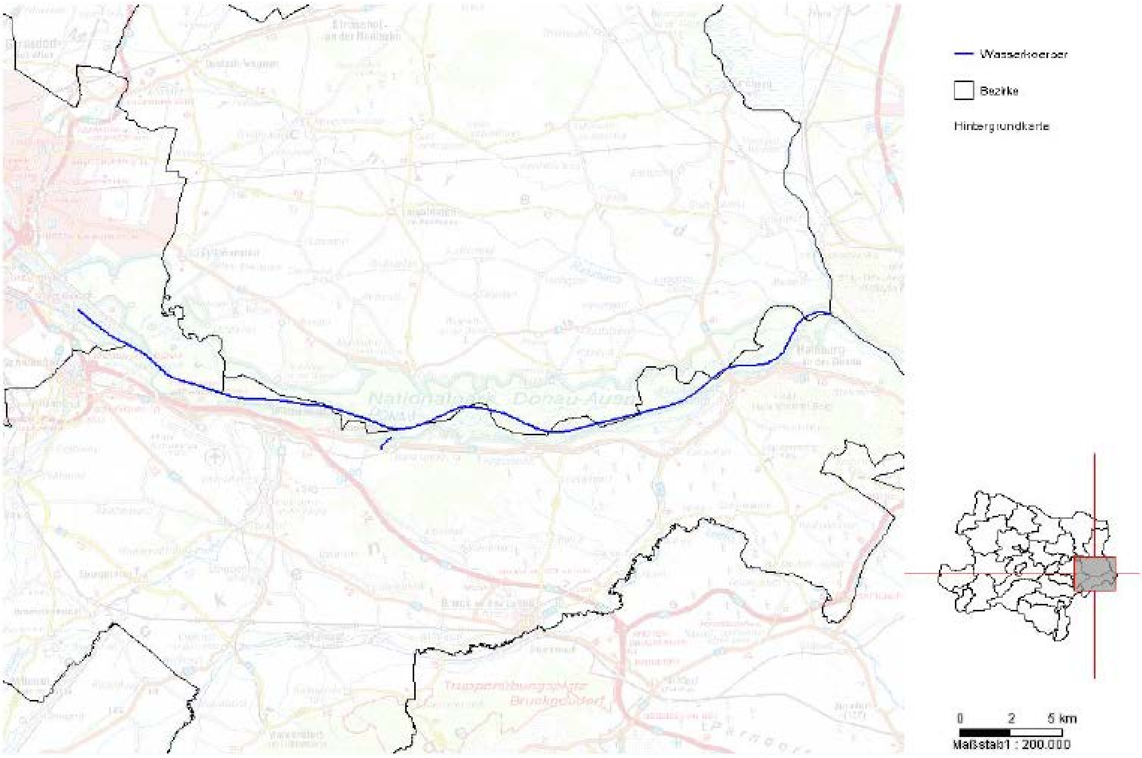

Figure 2: Water body downstream of HPP Freudenau

1.1.3 Flow and Temperature of the Danube at Vienna

The hydrology of the Danube is characterized by high water levels in spring due to snow melting and low water levels from September to the beginning of March. Floods due to heavy rainfall may occur the whole year but more often in summer.

Maximum summer temperatures are >20°C.

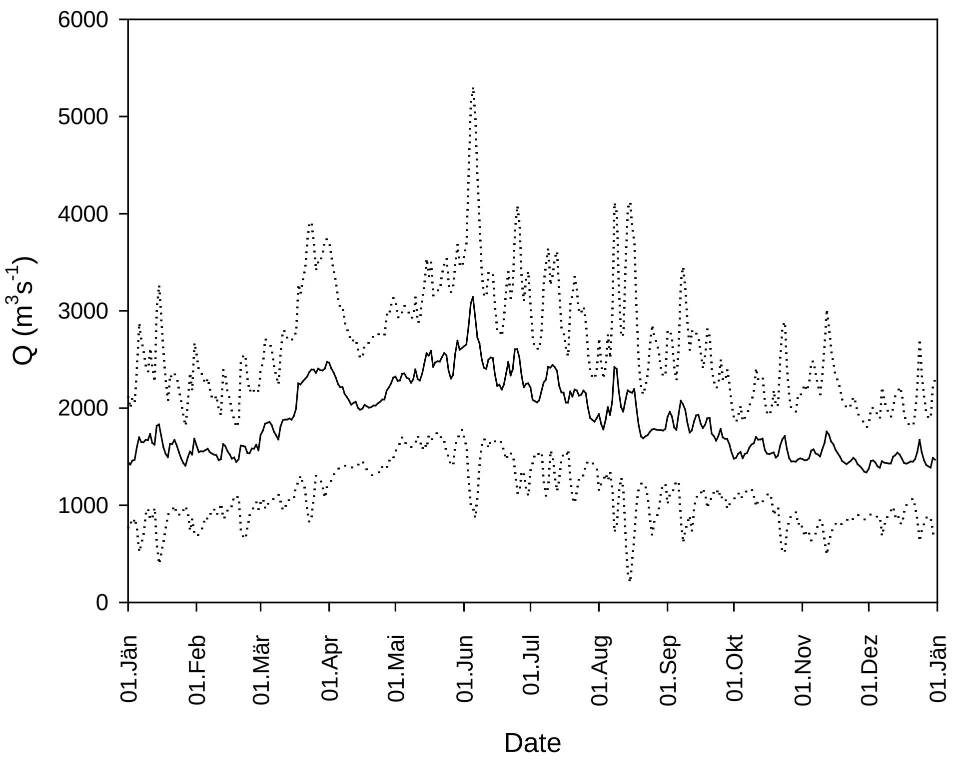

Figure 3: Mean monthly discharge (±SD) of the Danube at the gauge Wildungsmauer (source: www.ehyd.at)

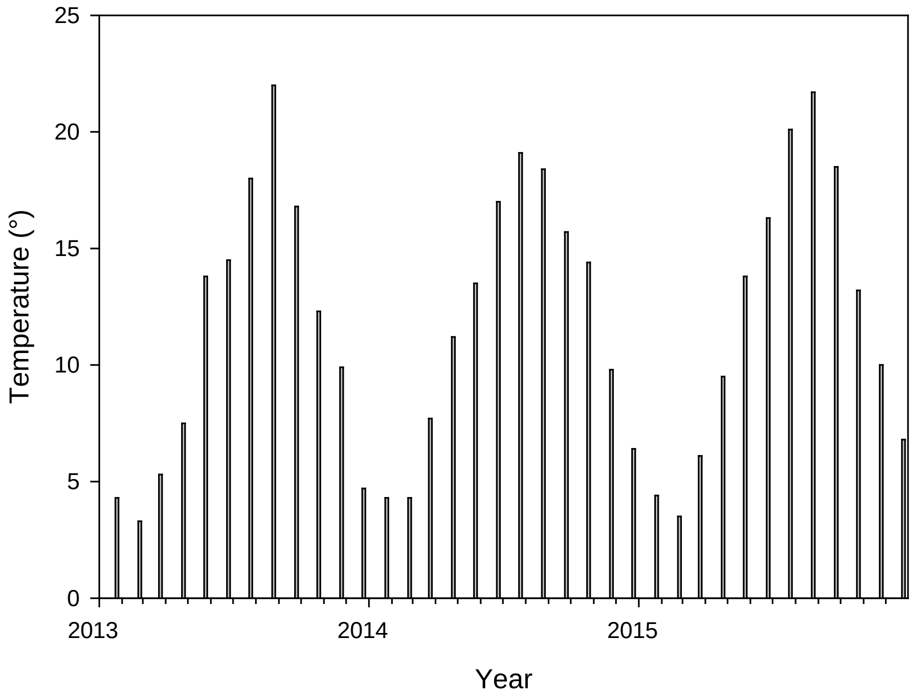

Figure 4: Mean monthly temperature of the Danube at the gauge Orth (source: www.ehyd.at)

1.1.4 Main pressures

The Upstream water body (409040013) is a heavily modified water body with the main pressures hydropower, navigation and flood control. The ecological potential based on the WFD is “moderate or worse”.

The Downstream water body (409040008) is a natural water body with the main pressures navigation and flood control. The ecological status is defined as “good”.

All pressures are directly anthropogenic and highly connected to the need to save life and goods as well as economical use. The reasons for designation as HMWB ((heavily modified waterbody) are manifold and any measures to reach the good ecological status have significant adverse effects on hydropower, navigation & flood control.

According to the River Basin Management Plan “Habitat measures in-channel” and “Fish migration measures” have been implemented to mitigate pressures. Details on the effects of these measures can be found in Reckendorfer et al. 2006, Schiemer and Reckendorfer 2000, 2004, Meulenbroek et al. 2015, 2018a, 2018b.

1.2 Presentation of the HPP Freudenau

1.2.1 Location of the HPP

The HPP is located in Austria at Vienna at r-km 1921.

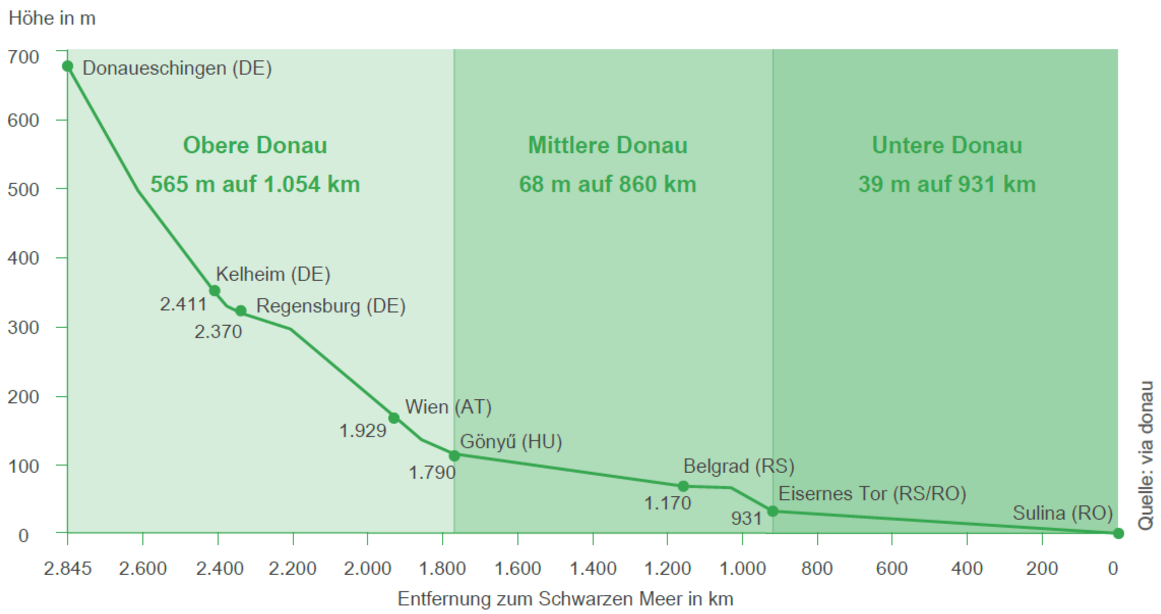

Figure 5: Longitudinal section of the Danube River with the location of HPP Freudenau at Vienna (r-km 1921)

1.2.2 Main characteristics of the HPP

VERBUND's Freudenau power plant was constructed from 1992 to 1998 using the wet construction method. It was designed as a multi-purpose hydro-power scheme located in the southern region of the Vienna metropolitan area. Six Kaplan bulb turbines are installed in the power house which is located in the middle of the river between the lock and weir systems. With a runner diameter of 7.5 m the turbines rank among the biggest in Europe. Each one of them propels a DC coupled three-phase generator. The HPP has an installed capacity of 172 MW and a mean annual output of 1,052 GWh. The power plant is equipped with two navigation locks.

Ecological measures include the water supply to the New and Old Danube, new biotopes, gravel management, and an ecologically designed bypass stream as a fishway on the Danube island.

Table 1: Main characteristics of the HPP Freudenau

Watercourse :	Danube
Situation :	r-km 1921, Vienna
Annual discharge :	Mean : 2.000 m^3/s ; low flow : 900 m^3/s ; HQ1 : 5.000 m^3/s
Function of the dam :	Hydropower, Navigation, Flood control
Length of the impoundment :	27 km

Design discharge :	3.000 m^3/s
Fish species ::	50 species, including several rheophilic species such as nase, barbel, and Danube salmon
Capacity of HPP :	172 MW
No turbines :	6 Kaplan turbines a 500 m^3/s ; D = 7.5 m, 65 rpm
Head :	8.6 m

Figure 6: Aerial view of the HPP Freudenau

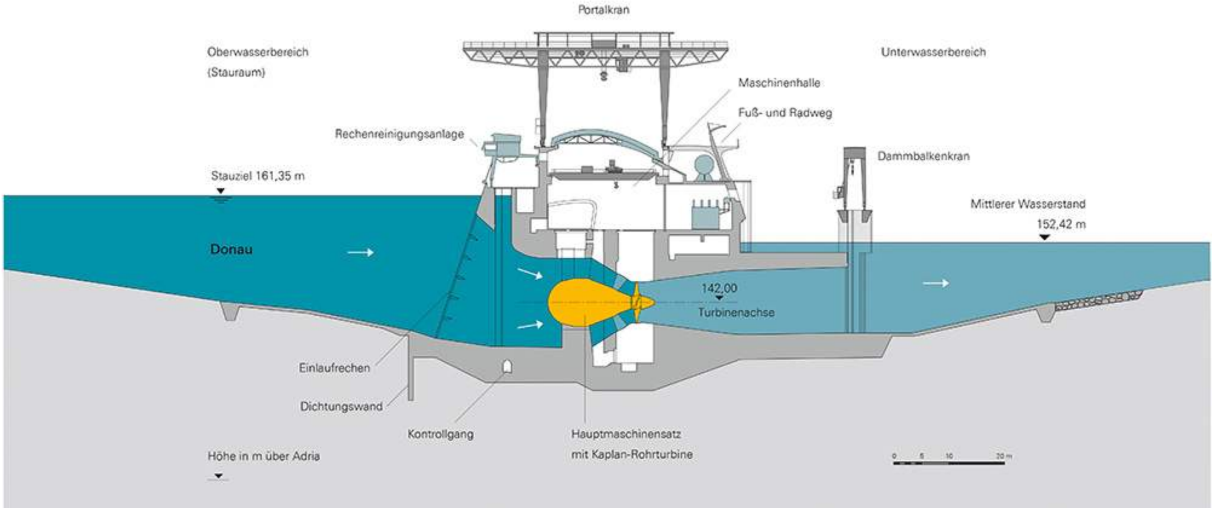

Figure 7: Longitudinal section through the HPP Freudenau © VERBUND

1.2.3 Habitat measures

The construction of the run-of-river power station Kraftwerk Wien/Freudenau included several environmental compensatory measures. The previously straight shoreline was reconstructed by creating backwaters, coves, gravel banks, and pools. Subsequently, further attempts have been made to restore the shorelines and provide ecologically functional habitats. These restored sections provide habitats for a wide range of fish species and different life stages (Straif et al. 2003, Meulenbroek et al. 2018a).

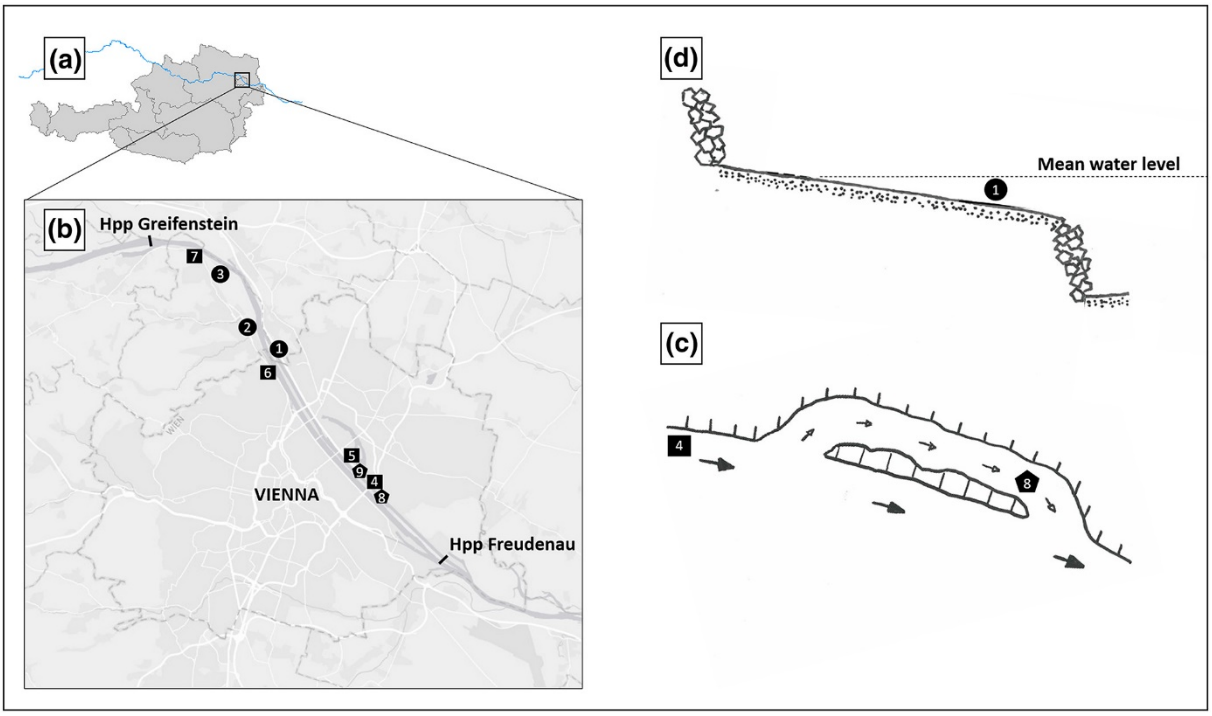

Figure 8: (a) Location, (b) different habitat measures, (c) illustration of one of the artificial side arms, and (d) illustration of the man-made gravel bar Donauinsel; circle: gravel bar (1: Donauinsel; 2: Hügelland; 3: Kritzendorf); square: riprap (4 and 5: central impoundment; 6: Kuchelau; 7: free flow); pentagon: side arms (8: Habitat C; 9: Habitat D); HPP: hydropower plant; © wileyonlinelibrary.com, Meulenbroek et al. 2018a

1.2.4 Downstream migration

Downstream migration is possible through the turbines (one of the largest turbines in Europe with a diameter of 7.5m), through the navigation locks, and through the nature-like fishway.

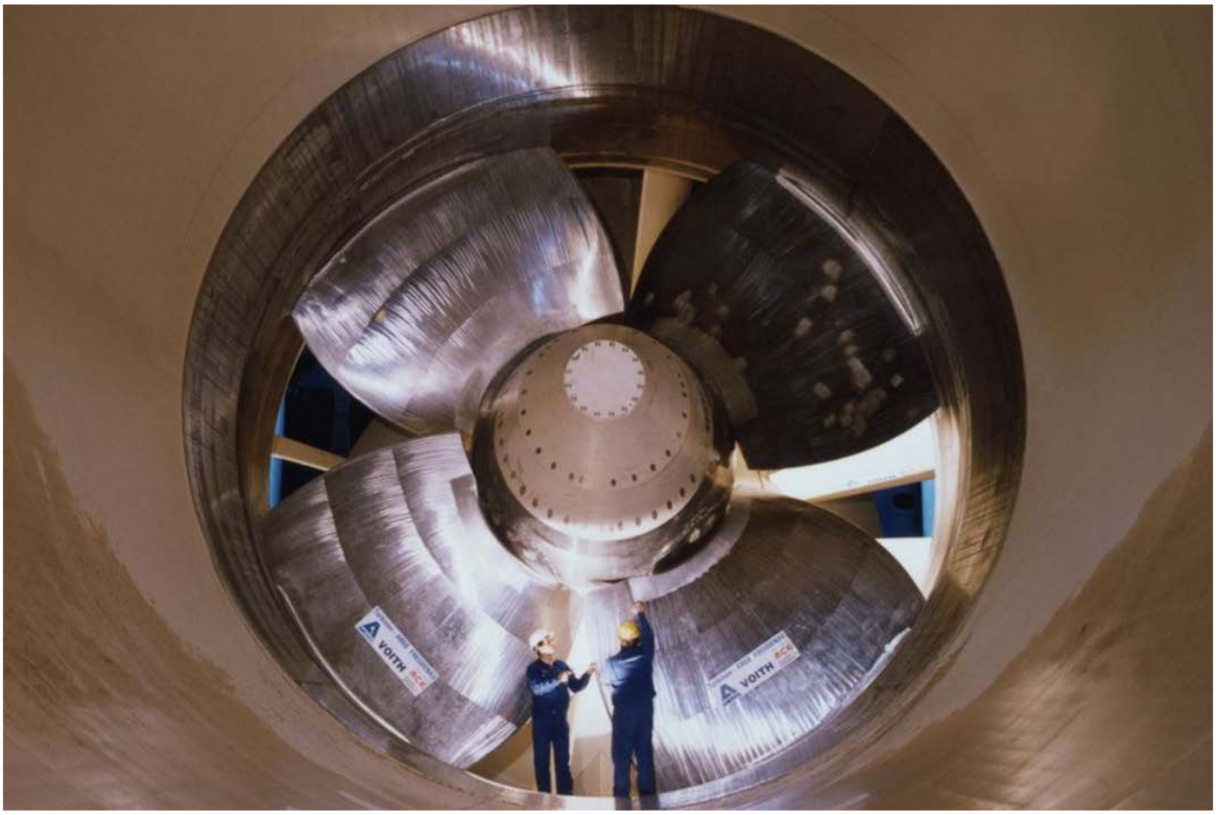

Figure 9: The turbine of the HPP Freudenau © VERBUND

1.2.5 Upstream migration

During the course of construction of Freudenau power plant (commissioned in 1999), a fish pass was erected on the orographic left bank between the Danube and the flood discharge channel of the New Danube. This comprises an approx. 1 km long bypass stream and an upstream connecting pool pass. In the process, the bypass stream negotiates an average difference in height of 6.7 m and the pool pass that of 2 m. The entrance to the bypass stream is situated approx. 500 m downstream from the power plant‘s weir system. Two estuaries with a permanent flow of water ensure the attracting currents for detection of the fish passes. In the event of increased mean flows, a third branch forms as an additional residual flow.

Apart from the stable bank at the island between the Danube and the right estuary, as well as in the lowest section of the left estuary, the banks are unfortified. As a result, currents can lead to small-scale redistribution and continue to develop dynamically. In addition, parts of trees and rootstocks have been installed, which - as deadwood - represent important structures for fish habitats. The 19 pools of the pool passes comprise a total length of 420 m.

The average difference in water level between the individual pools amounts to 11 cm. The rough, asymmetric shape of the sills made from rough blocks increases the flow diversity and therewith the connectivity. The pools are characterised by flow rates of less than 1 m/s and scours of up to 1.5 m deep. As a result of the very slow flow velocity, fine sediment is increasingly covering the original sand-gravel mixture as integrated bottom substrate. The residual flow of the pool pass amounts to 900 l/s. The pool pass can receive additional residual water by means of an electronically controlled spillway gate or via an emergency pump. The bypass stream will be fed via the outflow from the pool stream and via two flood gates depending upon the season and water flowing from the Danube. The rewith with dynamic total residual flow fluctuates between 1,500 l/s and 3,600 l/s.

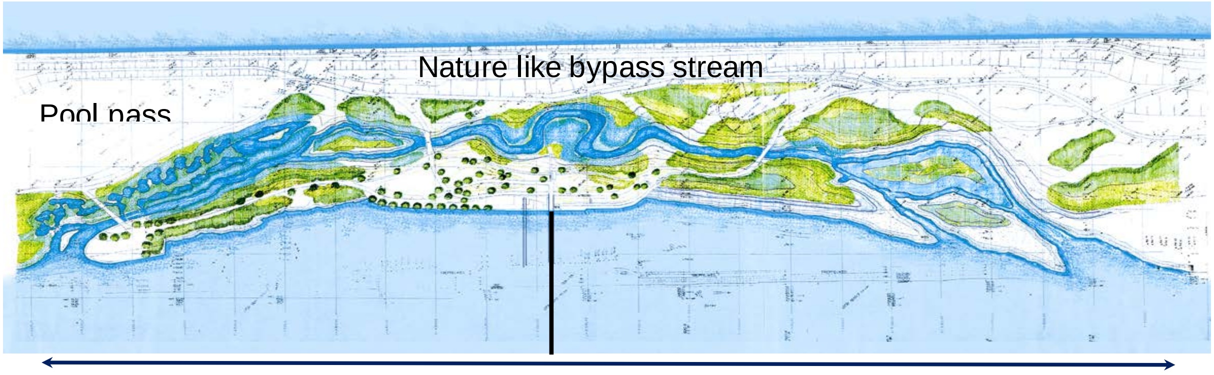

Figure 10: The fish pass

1.2.6 Sediment management

Gravel is artificially added downstream of the HPP (bed-load addition) to prevent further erosion. Without gravel feeding this erosion would be about 2-3.5 cm per year. The amount of added gravel is about 190.000 m3 per year to prevent this erosion.

Figure 11: Artificial bed load addition

2 Objectives on this Test case

One paradigm with regard to fish migration is, that the orientation of migrating fish is predominately based on hydraulic cues; that led to recommendations concerning the positioning of the fishway entrance and minimal flow requirements at the entrance. We postulate that different species use different cues for orientation, e.g. cyprinids have excellent hearing abilities due to the Weberian apparatus and they are also known to use chemical signals and cues for their social behaviour especially kin recognition and sexual behaviour. We assume that these cues together with learning help fish to find the entrance of fishways. If this is the case, it has a considerable bearing on fishway design and operation with regard to entrance location and flow recommendations.

The Test Case Freudenau, situated on a large river, gives the opportunity to study this question. Orientation of potamodromous fish and implications for the positioning of the fishway entrance and flow recommendations will be investigated using the method of numerical modelling of coupled hydro-thermo-chemical-mechanical cues. These results will be combined with the results and interpretations of fish swimming paths, obtained with 2D Telemetry.

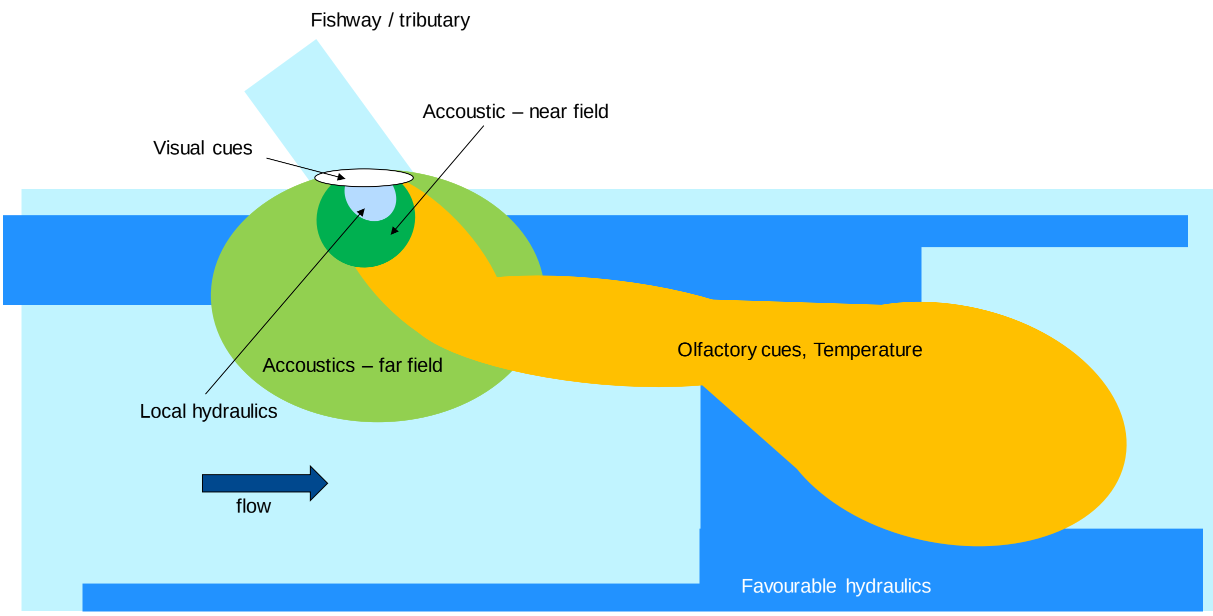

Figure 12: Multiple reliable cues for fish orientation

The research tasks and field studies conducted at Freudenau are:

- Feasibility study
  to investigate the feasibility of 2D hydroaccoustic telemetry below a large HPP in a river with heavy navigation
- 2D and 3D Hydraulic modelling of (attraction) flow below the fishway
- Coupled hydro-thermo-chemical-mechanical modelling
  to model pheromone diffusion, temperature distribution and acoustics below the fishway entrance
- Telemetry study of fish swimming paths, Investigation and interpretation of fish swimming paths

FIThydro

3 Presentation and results of activities in FIThydro

3.1 Fish species

The Leitbild for the Danube at Vienna comprises 58 species including 8 key species.

Table 2: Fish ecological "Leitbild" (Leitbild according to BAW / IGF 2017)

Species	german name	type of species
Lota lota	Aalrutte	b
Squalius cephalus	Aitel	b
Thymallus thymallus	Äsche	s
Salmo trutta fario	Bachforelle	s
Barbatula barbatula	Bachschmerle	s
Barbus barbus	Barbe	l
Rhodeus amarus	Bitterling	b
Abramis brama	Brachse	l
Gymnocephalus baloni	Donaukaulbarsch	s
Phoxinus phoxinus	Elritze	s
Perca fluviatilis	Flussbarsch	b
Rutilus pigus	Frauennerfling	s
Carassius gibelio	Giebel	b
Acipenser nudiventris	Glattdick	s
Sabanejewia balcanica	Goldsteinbeißer	s
Gobio gobio	Gründling	s
Blicca bjoerkna	Güster	b
Leuciscus leuciscus	Hasel	l
Huso huso	Hausen	s
Esox lucius	Hecht	l
Hucho hucho	Huchen	l
Umbra krameri	Hundsfisch	s
Carassius carassius	Karausche	b
Gymnocephalus cernuus	Kaulbarsch	s
Romanogobio kesslerii	Kessler Gründling	s
Cottus gobio	Koppe	s
Alburnus alburnus	Laube	l
Leucaspius delineatus	Moderlieschen	s
Chondrostoma nasus	Nase	l
Leuciscus idus	Nerfling	l
Eudontomyzon mariae	Neunauge	s
Rutilus meidingeri	Perlfisch	s
Rutilus rutilus	Rotauge	b
Scardinius erythrophthalmus	Rotfeder	s
Vimba vimba	Rußnase	b
Aspius aspius	Schied	b
Misgurnus fossilis	Schlammpeitzger	s

Species	german name	type of species
Tinca tinca	Schleie	s
Alburnoides bipunctatus	Schneider	s
Gymnocephalus schraetser	Schrätzer	b
Alburnus mento	Seelaube	s
Barbus balcanicus	Semling	s
Pelecus cultratus	Sichling	s
Cobitis elongatoides	Steinbeißer	s
Romanogobio uranoscopus	Steingreßling	s
Acipenser ruthenus	Sterlet	s
Acipenser stellatus	Sternhausen	s
Zingel streber	Streber	b
Telestes souffia	Strömer	s
Acipenser gueldenstaedtii	Waxdick	s
Romanogobio vladykovi	Weißflossen Gründling	b
Silurus glanis	Wels	b
Cyprinus carpio	Wildkarpfen	s
Sander volgensis	Wolgazander	s
Sander lucioperca	Zander	b
Zingel zingel	Zingel	b
Ballerus sapa	Zobel	b
Ballerus ballerus	Zope	b
Number	key species (l)	8
	typical companion species (b)	18
	rare companion species (s)	32
	total	58
		58

Recent investigations (2010) of the fish fauna below the HPP (r-km 1880 - 1894) showed a good fish-ecological status according to WFD compliant assessment. A total of 31 species of the Leitbild and seven species not included in the Leitbild were found. The fish biomass was about 184 kg /ha and was dominated by pike, bream, pike prech, catfish, and Giebel. The abundance was about 7.500 Individuals per hectare and was dominated by bitterling, perch, roach, and rudd.

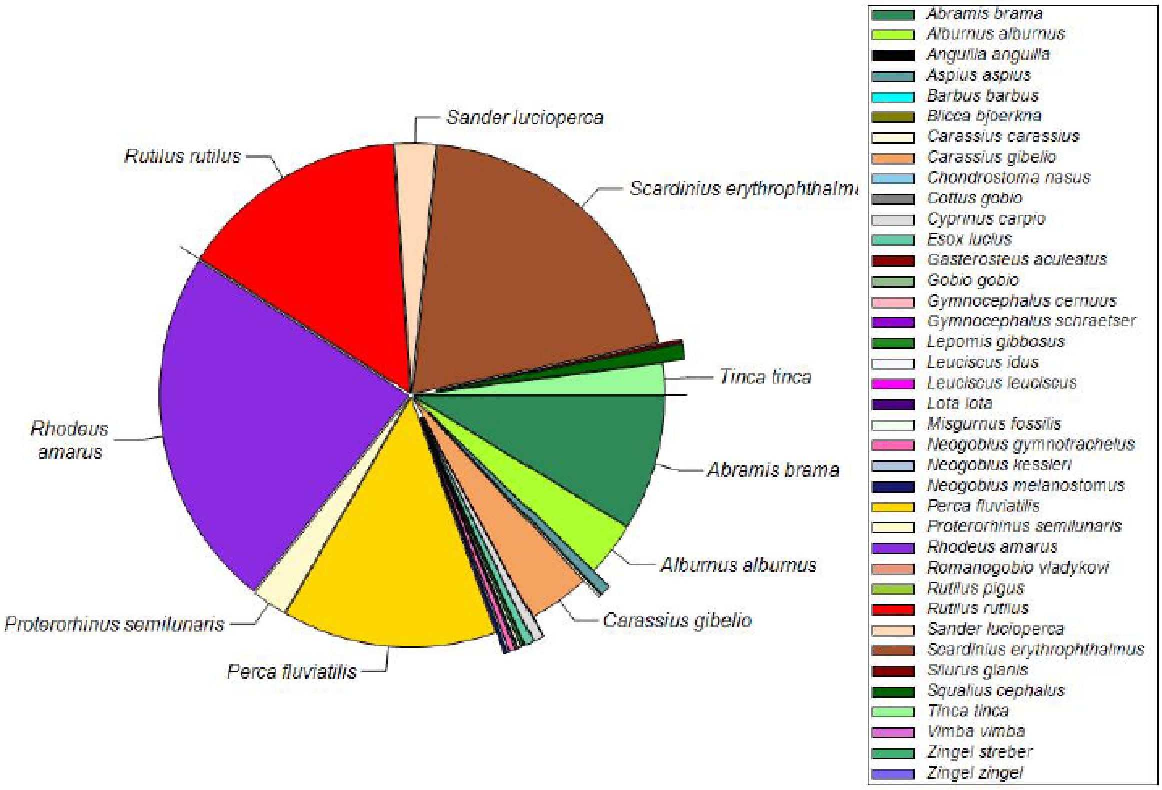

Figure 13: Relative abundance

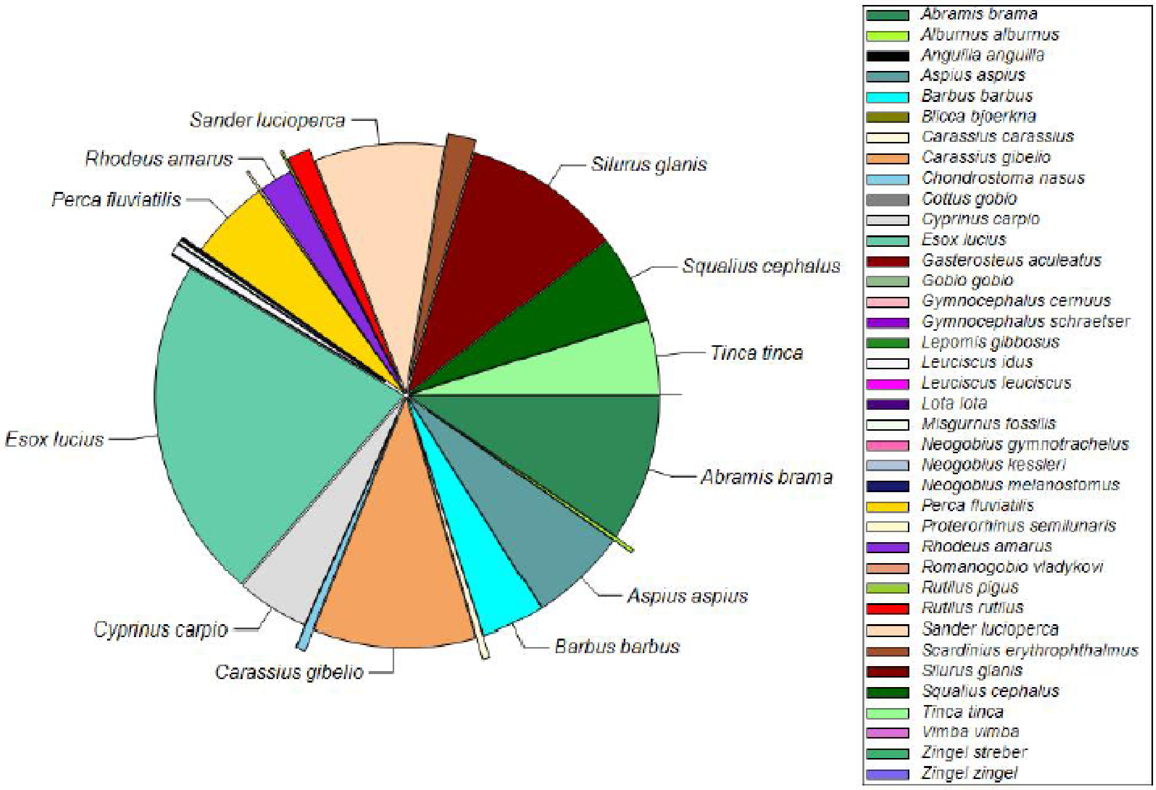

Figure 14: Relative biomass

3.2 Direct impacts on fish

The direct impact (turbine related impacts on survival and fitness) on fish populations depend on characteristics of the turbine with size and rotational speed beeing most imortant and on the species and size of fish under consideration, their behaviour with regard to migration, and their life history.

The turbine at Freudenau is one of the largest in Europe with a diameter of 7.5 m and a rotational speed of 65 rpm. Blade strike models predict turbine related injuries for small size classes (10-15 cm) in a range of <1-2 % and for spawning large sized fish (30-40 cm) in the range of 5 – 10 %.

At the test case Freudenau no diadromous species are present. Most (> 90 %) of the down-migrating potamodromus fishes in rivers are larvae and juvenile with a total length < 15 cm (e.g. Pavlov 2002, Schmalz & Schmalz 2006, 2007, Schmalz 2010, Holzner 1999, Gubbels 2010, 20111012, 2013, Edler et al. 2011). These have a great chance of passing turbines without injuries due to blade strike which is by far the most important factor with regard to turbine related injuries.

Only a small proportion of adults ever pass turbines and passage over several turbines is extremely unlikely. When considering published homes range sizes and the size of the impoundments on the Austrian Danube the proportion of adult fish passing a turbine per year can be estimated at <5 %. Although some potamodromous fish species are able to migrate over large distances (see the literature survey on migration, D2.1), the average migration distances and home ranges of adult fish are relatively small. For the barbel the documented median home range size is between two (2) and eleven (11) km, for the European grayling between one (1) and four (4) km, and for the nase between three (3) and nine (9) km. The home range sizes are largely species specific but also differ between rivers. It seems that migration distances are smaller in natural and nature-like rivers providing high habitat heterogeneity and larger in channelized rivers. Although the investigated rivers differed in fragmentation, these parameter was only of minor importance for the median home range but had an effect on so called « strayers », i.e. the fish in the population which showed the largest home ranges and migration distances respectively.

Putting information on turbine encounter probability and turbine related injuries together, injuries on the population level caused by turbines are presumably <<1 % for larvae and juveniles and <<0.5 % for adults of the long distance migrating potamodromous guild.

The relationship between habitat heterogeneity and migration distances is also a possibility to reduce the probability of turbine encounter for potamodromous fish. A reduction of the home range leads to a reduction in turbine encounter probability. This reduction is in the range of the efficiency of guidance structures. Contrary to guidance structures its effects are not limited to size classes physically excluded by the bar spacing but also effects larval and juvenile fish.

At Freudenau several habitat measures have been implemented upstream and downstream of the power plant. Additionally the nature-like bypass channel provides valuable habitat. All these measures mitigate turbine related impacts on survival and fitness by reducing the probability of turbine encounter significantly.

3.3 Habitats

During the construction of the HPP Freudenau the previously straight shoreline was reconstructed by creating backwaters, coves, gravel banks, and pools and thereby provide ecologically functional habitats for a wide range of species including fish and also different life stages.

Figure 15: Constructed shallow water areas (r-km 1936) out of gravel have a high ecological value specially for rheophilic fish species (Massinger & Michlmayr 2003).

Figure 16: Side arm during construction (r-km 1926). After rising the water level in the reservoir, the dam turns into an island difficult to reach and develops to a refuge for animals (Massinger & Michlmayr 2003).

Figure 17: Artificial side arm during construction (r-km 1925.5). The side arm is connected to the Danube through pipes, covered by stones (Massinger & Michlmayr 2003).

Monitoring results show their value for amphibians (Cabela et al. 2003), fish (Straif et al. 2003, Meulenbroek et al. 2018a), benthic invertebrates (Straif et al. 2003), odonates (Raab 2003a), reptiles (Cabela & Teufl 2003), and water fowl (Raab 2003b).

For instance 44 species of waterbirds,six gulls, twelve amphibian species including the Danube Crested Newt (Triturus dobrogicus), 29 species of dragonflies including Leucorrhinia pectoralis one of Europeans most threatened dragonfly species and listed in the Annex II of the Habitats Directive were observed. N. natrix uses the newly created structures at the Danube's bank for foraging, and L. agilis has established several small populations there.

The fish population structure and abundances showed a astonishing diversity (Straif et al. 2003). The central part of the impoundment and the transition area were characterised by an euryoecious and a stagnooecious fish species composition. The head of the impoundment was dominated by the two Danube fish species Chondrostoma nasus and Barbus barbus. Particularly a high abundance of juvenile fishes and larval stages were caught in the new structured habitats at the left Danube shoreline.

During a recent investigation of larval and juvenile fish (Meulenbroek et al. 2018a) about 15,000 fish larvae were trapped, and a subsample was determined to species level by DNA barcoding. In total, 26 different species were detected, including 10 species that are endangered or in danger of extinction. When species composition was considered, cyprinids become dominant at sites downstream of gravel bars, whereas in riprap sections, the majority of the larvae consist of invasive Gobiidae. Side arm habitats provide spawning and nursery grounds for additional species. Furthermore, clear species-related seasonal patterns were observed with peak densities and multiple spawning periods of some species being recorded. The largest peak of Percidae occurred in the first half of May, followed by Cyprinidae at the end of May and Gobiidae in mid-June.

3.4 Bypass channel

(Excerpt from Meulenbroek et al 2013b)

The by-pass system consists of two major components, namely, a near-natural by-pass channel and a near-natural pool pass. The entrance is about 500 m downstream of the weir, with a delta system in the tailwater that has calm, shallow waters over some 200 m with two permanent wetted channels. The subsequent semi-natural by-pass channel has an average slope of 0.7% and is situated in a 7 m wide riverbed with and an average current speed of 0.6 $m.s^{-1}$. The first 160 m are straight, followed by a 300 m-long meandering section and a 140 m long branched section. One of the branches is blocked by a beaver dam and has calm to stagnant water. The remaining section of 170 m up to the weir is straight again. The total length of this free-flowing section is 1000 m. The channel bottom consists of gravel and sand; some rifle-pool sequences are developed and very dense riparian vegetation has been well established, consisting mainly of willows and alders. The uppermost part of the system is a pool pass of 19 pools (20–40 m in length and 3–16 m in width), a water-level difference of 11 cm from pool to pool, and a total length of 420 m. It is characterised by a pool depth of 1.5 m, different flow conditions, and a high abundance of reeds and macrophytes.

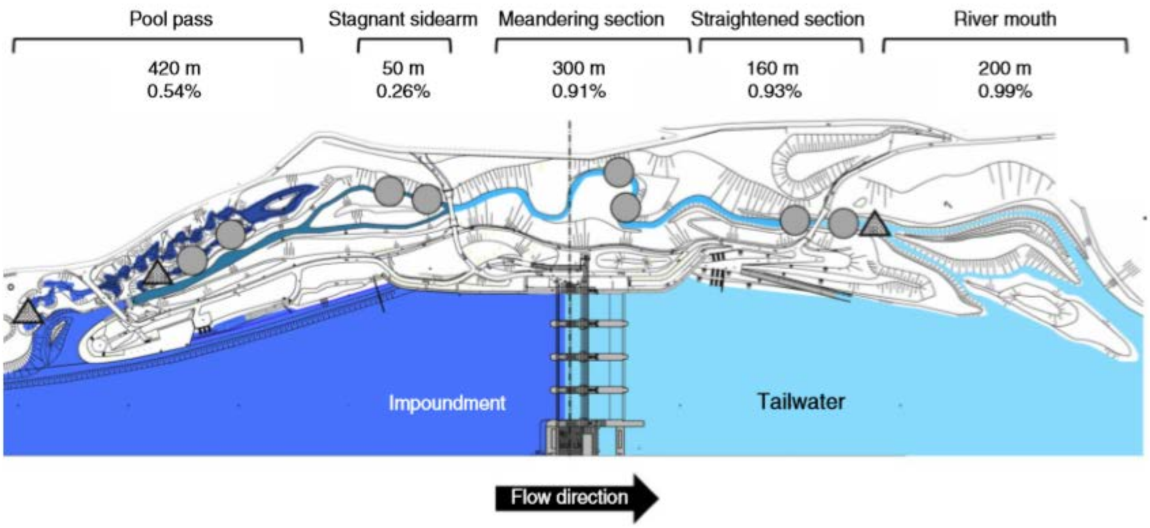

Figure 18: Fish by-pass system Freudenau. Triangles indicate fish larvae sampling points, circles indicate electrofishing points; length of the sections (m) and slope (%) are given beneath each section name (from Meulenbroek et al. 2018b, adapted after Eberstaller et al. 2001).

The chosen nature-like construction of the by-pass system functions like natural tributaries. More than 17 000 fish and 43 species, including several protected and endangered species, in all life stages, including eggs, larvae, juveniles and adults, were captured. Furthermore, the indicator species of the free-flowing Danube, nase (Chondrostoma nasus) and barbel (Barbus barbus), migrated into the fishby-pass and successfully spawned before returning. Therefore, our results suggest that by-pass systems can function as an important habitat for the conservation of native fish fauna. The heterogenic habitat configuration provides conditions for all ecological guilds and, consequently, increases biodiversity.

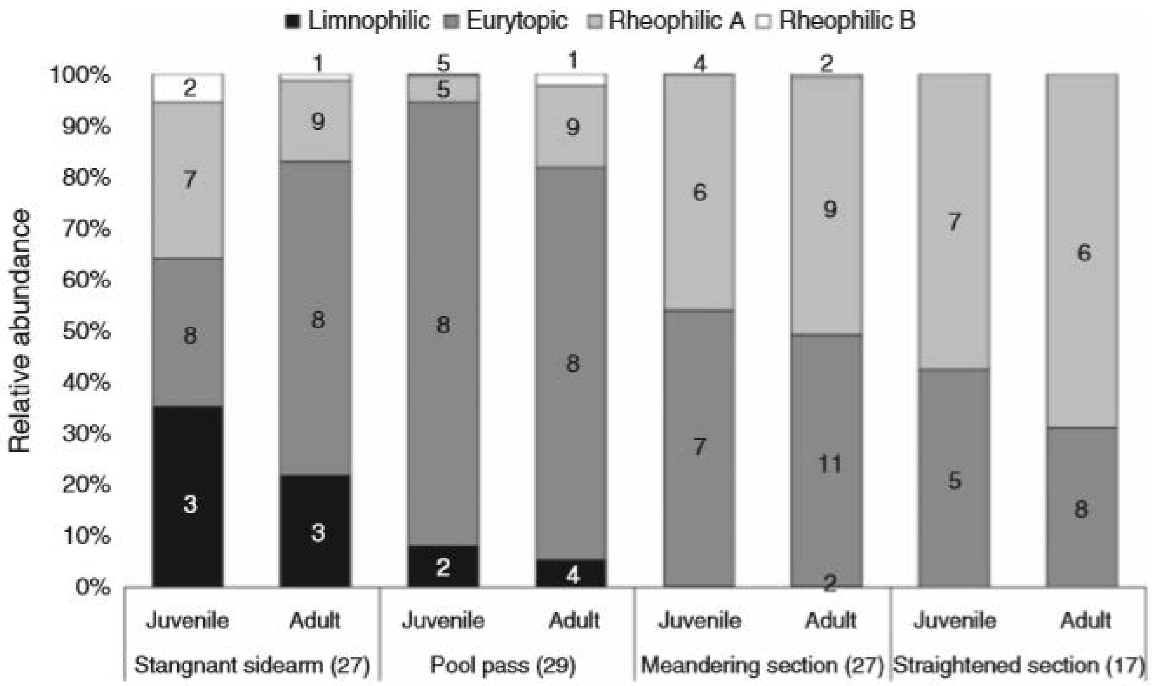

Figure 19: Relative abundances of flow guilds and number of species for the given sections. Bars indicate relative abundance of flow guilds for juvenile and adult of all caught fish; numbers within each category show the number of species per guild; numbers in parentheses indicate total number of species per section (from Meulenbroek et al. 2018b).

3.5 Feasibility study

The feasibility study started in 2018 and was finished in 2019. The test series upstream of the power station Freudenau have been completed in December. Several hydrophone arrays were tested close to the influx building Langenzersdorf (see Figure 20). The applicability of the acoustic system in the Danube River could positively be tested. Satisfying positioning results could be obtained using up to six hydrophones and test tags (Figure 20).

Figure 20: Test array using six hydrophones close to the influx building Langentzersdorf. Yellow dots indicate the positive positioning of a test tag. The dots describe the path of the test tag. Hydrophones are indicated by blue squares.

Since December 2018 preparations were undertaken to start with the test series at the power station Freudenau. In a first step a hydrophone array was conceived (Figure 21). Mounting devices were developed for hydrophones in the free water column as well as for hydrophones attached to the power plant (Figure 23). The test series started on January 30th 2019 with the installation of the devices. The first tests were finished by the end of February 2019. Within that week test tags are dragged in the investigation area to generate positioning data.

Figure 21: Test array power station Freudenau. Eight hydrophones are tested in the proximity of the power station to test the positioning success with test tags.

A metal construction was developed which should be used for the longer deployment of hydrophones. The design allows that the hydrophones sit in perfect operating position and are protected from suspended load (Figure 22). Throughout February/March 2019 the deployment of the construction were tested in the Danube. Negotiations with the responsible authorities were carried out in February/March to retain necessary permissions for the deployment.

Figure 22: Mounting construction for open water hydrophones.

Figure 23: Mounting construction for the deployment at the power station

3.6 Hydraulic modelling with coupled diffusion models for temperature and chemicals

A digital elevation model of the Danube and the fishway has been compiled as a basis for the hydraulic model.

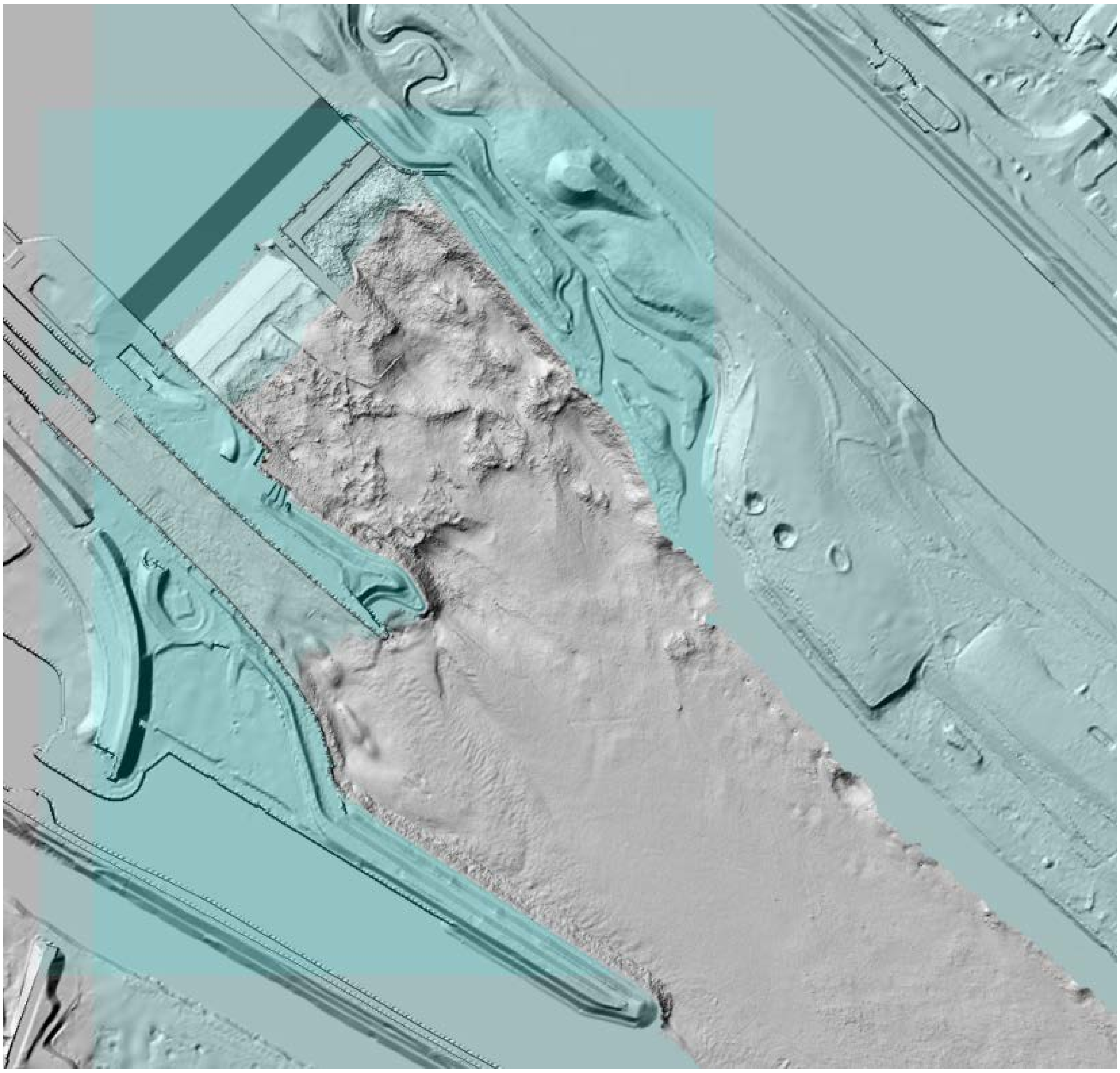

Figure 24: Digital elevation model of the Danube below the HPP Freudenau and the fishway

The bathymetry and topographical measurements were merged to set up a terrain model of the fish pass and downstream reach at Freudenau. This will be used as a basis for a numerical model. A 2D-TELEMAC model of the fish pass was set up and combined with a simple habitat modelling approach. Using Flow3D, a more sophisticated hybrid 2D and 3D combined numerical model was created, coupling hydro-thermo-chemical-mechanical modelling.

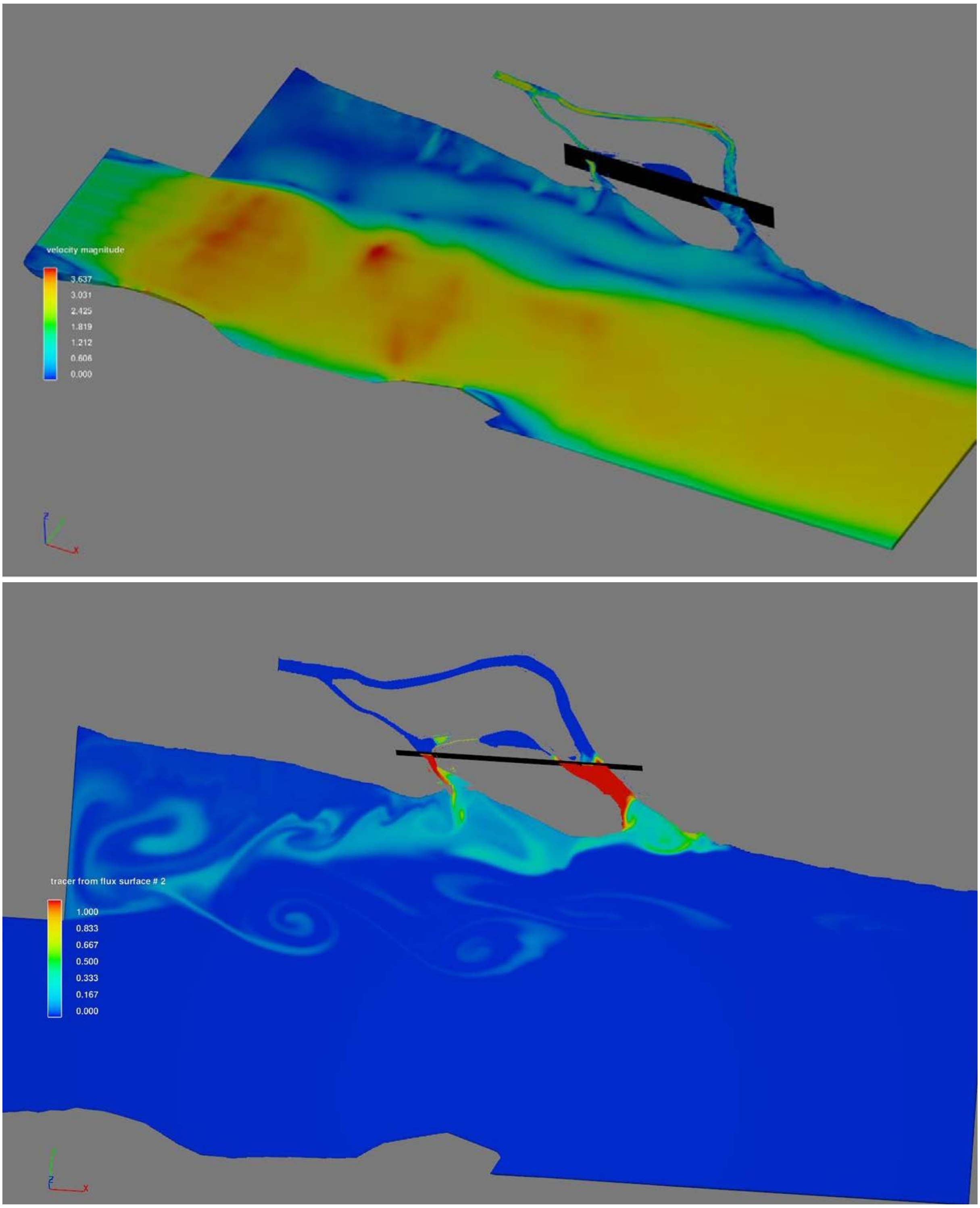

Figure 25: Numerical simulationof the fish passage and downstream reach using FLOW3D. Top: surface water velocity; bottom: Visualisation of circulation and mixing of water from the fishway and the Danube.

3.7 Investigation and interpretation of fish swimming paths

Following the feasibility study, a study of fish swimming paths is planned for spring 2020.

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