NEAR-NATURE WATER COURSES AT HYDROPOWER PLANTS AS FISHWAYS AND RUNNING WATER HABITATS

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Since several years near-nature water courses are installed at large hydropower stations in Germany and Switzerland. They serve as fishways and but as well as habitats, especially for rheophilic species. So far 3 of them are in use at the rivers Rhine and Aare. With a length of about 1000 m, a width of 15-20 m and a discharge of 2.0-5.0 m³/s, these water courses have the dimension of little rivers. Another much bigger river course with a discharge of 10-30 m³/s has been commissioned recently and others are in the planning stage. These near-natural running waters are arranged with a natural river bed, including riffles and gravel banks. The function of these structures is to establish the habitat connectivity between the upstream and the downstream section of the power station but also to offer running water habitats for rheophilic species. The author is the chief executive of the engineering consultants responsible for design and construction of these river-courses.

1 INTRODUCTION – OBJECTIVES

The facilities pictured in the following are located in the centre of Europe in the borderland of Switzerland and Germany. The stretch of the Rhine in between Lake Constance and Basel, known as High-Rhine, represents the frontier of these two countries. Coming from Switzerland the Aare with its mean discharge of 560 m³/s is the major tributary to the High-Rhine (mean discharge: 1040 m³/s). Due to the high slope of the river a lot of running-water power stations are in function along these river sections. Some of these big hydroelectric power stations are running since more than 100 years. The upcoming granting of concessions is attended with comprehensive analysis regarding the environmental impact.

Because interventions like impounding and depression have predominantly negative impacts on river-biocenosis, the generation of characteristic fluvial living space are prior compensating measures. For this purpose near-nature water courses were developed, which in addition to the function as fishway provide running water habitats and reproduction space as well.

2 ARRANGEMENT OF BYPASS CHANNELS

Bypass channels are fishways that circle an ascent obstacle widely via a standalone water course. For the arrangement and the design it has to be considered, that for an efficient function as fishway the downstream outlet (fishway entrance) has to be located as close as possible to the weir or the turbine outlet (Figure 1). Achieving this requirement is often difficult, particularly in case of big bypass channels.

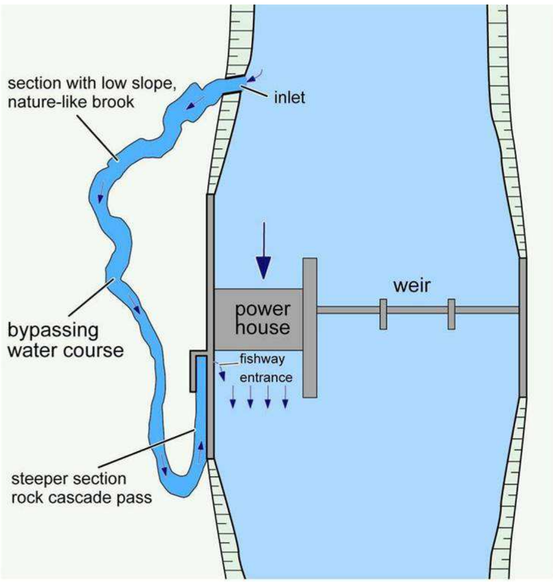

Figure 1. Arrangement of a nature-like bypass channel.

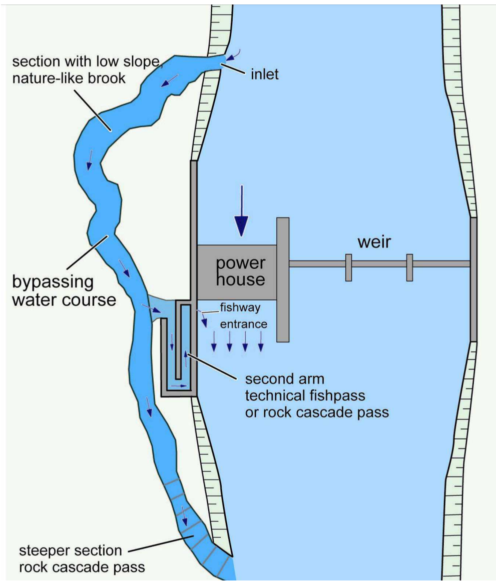

Figure 2. Nature-like bypass channel with two entrances.

Leading back the water course is often possible for smaller bypass channels, whereby the lower section consists of a technical fish pass in many cases. An example is the bypass channel at the weir Wettingen on the Limmat downstream from Zurich (Figure 3-6) which surmounts the very big height of 18.30 m.

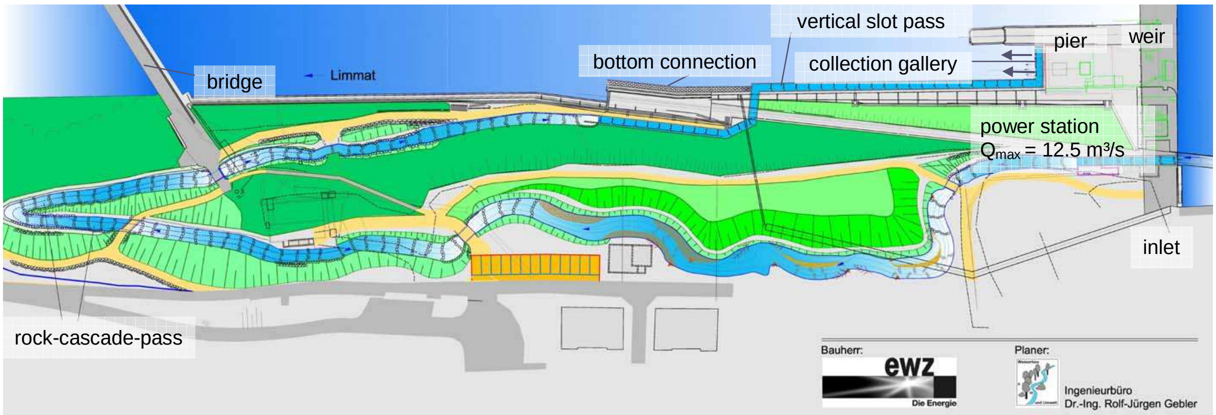

Figure 3. Nature-like bypass channel: River Limmat, Wettingen (CH): Total length 620 m, discharge 0.4 m³/s, additional attraction water 0.6 m³/s, total difference in water level 18.30 m, mean slope 3 %.

Figure 4. River Limmat, Wettingen (CH) (CH): Upper section: nature-like brook course.

Figure 5. River Limmat, Wettingen (CH): Middle section: rock-cascade-pass.

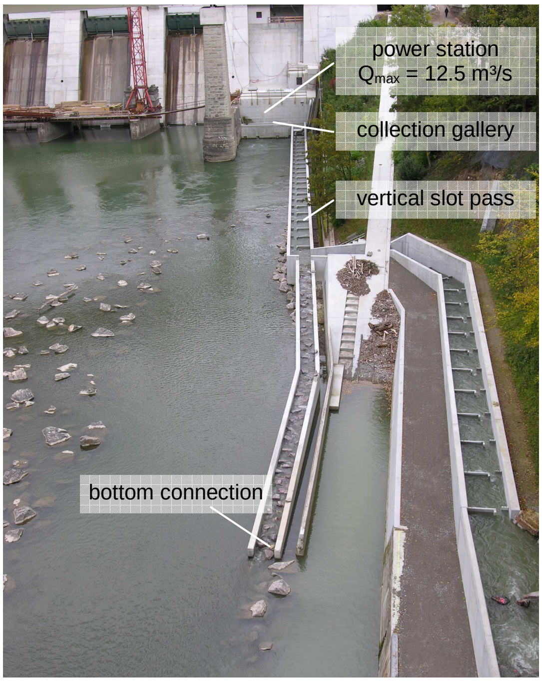

Figure 6. River Limmat, Wettingen (CH): Downstream section.

Whereas a near-nature water course was formed in the upper section (Figure 4), a rocky-cascade fishway (Figure 5) with a height of 10 meters surmounts the biggest part of the altitude. Due to the limited space the lower section consists of a vertical-slot-pass which is converted into a collection-gallery at the power house (Figure 6).

When it comes to bigger bypass channels leading back the water course to the power house is not possible. Splitting the water into two branches offers a good solution for these cases (Figure 2). The main branch continues towards the tailwater as a near-nature water course and ends further downstream, where a connection to the natural river bed is possible. The smaller second branch diverts from the main branch towards the power house and can also be formed as a rock-cascade-pass or a vertical-slot-pass.

3 GENERAL SHAPING

Bypass channels circumvent weirs or other obstructions outside of the main water course. As the construction is outside the main flow cross-section of the river, heavy armouring of the stream bed is not necessary. According to the available space the watercourse can be divided into different sections with a different shaping. In upland or mountain regions a near-nature bypass channel attains its necessary drop with a series of riffles or cascades as in natural watercourses. Sections designed as a rocky cascade pass are often necessary to overcome large heights. A combination of conventional and biological armouring of the channel bed can be applied, depending on the design discharge. In lowland regions, the preferred construction material are dead and living wood whereas in mountain regions grit, cobbles or boulders are more common.

4 Examples

The first investigations of the author to create a near-nature water course as a running water habitat were made in the beginning of the 90th for the project “New Power Plant Rheinfelden at the Rhine”. The main intention of this water course was to provide suitable habitat for rheophilic species, especially spawning grounds for gravel dependent fish species, for example barbel (Barbus barbus) and nase (Chondrostoma nasus).

For designing this water course comprehensive investigations of natural structures in rivers as samples were made. Also several structures and sections were tested by hydraulic modelling at the University of Karlsruhe

(IWK 1994). Because of a large delay of the implementation of the project “New Power Plant Rheinfelden” meanwhile these existing investigations were used in the designing and constructing of similar projects.

4.1 Power plant Ruppoldingen, Aare (CH)

The first water course of this design was commissioned in the year 2001 at the river Aare, the main tributary of the Rhine with a discharge of 130 m³/s up to 900 m³/s. The old hydroelectric power plant (Figure 7) designed as a diversion-channel type was replaced by a new power-station designed as run-of-river type. The old headrace channel was filled up and a near-nature artifical river was installed (Figure 8). With a width of 10-20 m, a length of 1.2 km, a mean gradient of 0.5 % and a discharge of 2-5 m³/s the water course has the character of a small mountain river. A diverting rock cascade fishpass connects the river course with the tailwater of the powerhouse (Figure 9, 10). The river section offers a high variety of structures, like riffles, pool, gravel islands etc. (Figure 11). The main intention is the habitat enrichment for rheophilic species. The pool and riffle sections are divided in a deeper course for fish passage and a riffle made of gravel with potential spawning grounds (Figure 12). At the downstream end a rocky ramp with a steeper gradient of 3 % is placed, thus downstream water-level fluctuations are limited to this ramp (Figure 13).

Figure 7. River Aare, Ruppoldingen (CH): Old hydroelectric power-station.

Figure 8. River Aare, Ruppoldingen (CH): New hydroelectric power-station. The headrace channel was filled up and a nature-like river was installed.

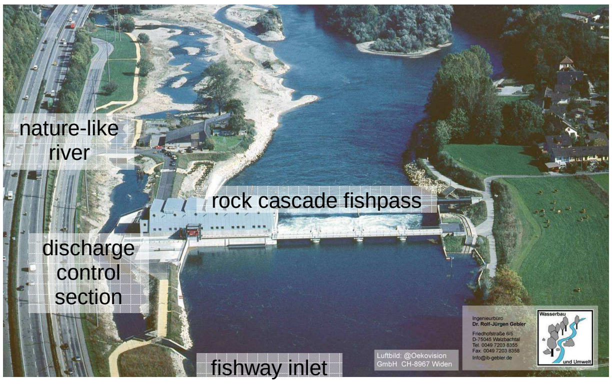

Figure 9. River Aare, Ruppoldingen (CH).

Figure 10. River Aare, Ruppoldingen (CH): Rock cascade pass at the powerhouse.

Figure 11. River Aare, Ruppoldingen (CH): Nature-like river section with a high variety of structures.

Figure 12. River Aare, Ruppoldingen (CH): Pool and riffle section.

Figure 13. River Aare, Ruppoldingen (CH): Rock ramp at the river mouth.

4.2 Power plant Abbruck / Dogern, Rhine (CH / D)

The hydroelectric power plant (Figure 7) at the High Rhine is designed as a diversion-channel type (Figure 14). In addition to the main power station (Q = 1000 m^3/s) a new second power station (Q = 300 m^3/s) was installed at the diversion weir to feed the natural river bed with a sufficient discharge. In the course of this project a permanent near-natural running water, with a length of about 900 m and a discharge of 2-5 m^3/s has been installed at the left embankment (Figure 15). The total height of 10.4 m is established by a near-nature water course with a slope of 0.8% and a steeper downstream end. The design of the running water (Figure 16) is similar to the design at the power station Ruppoldingen. At the upper end the water course is divided into two arms (Figure 17). The rock-cascade-pass (Q = 0.8-3.0 m^3/s) leads straight onto the river bed at the left bank. The second arm, designed as a vertical-clot-pass connects the water course with the tailwater of the turbine outlet. Above the turbine outlet a collection gallery with different fish entrances is installed. The total discharge at the outlet varies between 0.6 m^3/s and 4.0 m^3/s.

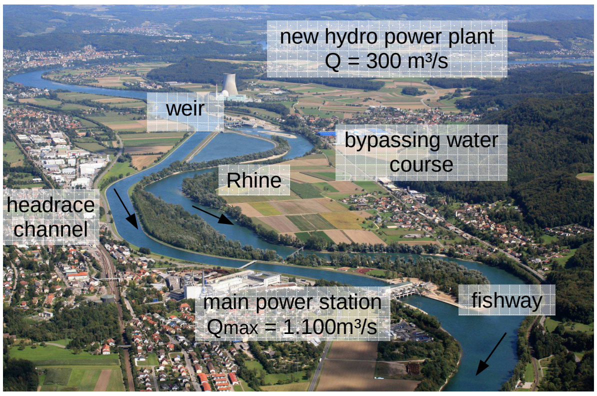

Figure 14. River Rhein, Albruck / Dogern (D): Overview.

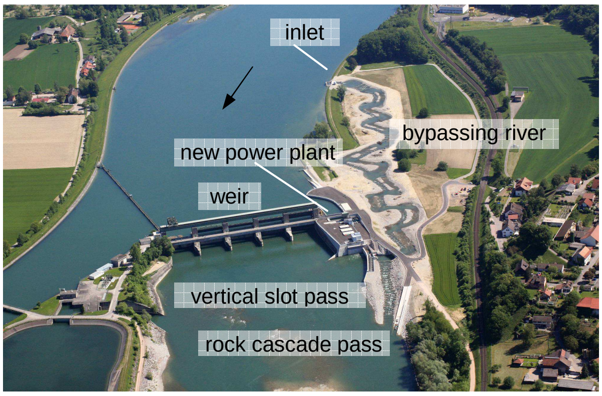

Figure 15. River Rhine, Albruck / Dogern (D): Weir, new power plant, bypassing river.

Figure 16. River Rhine, Albruck / Dogern (D): Bypassing running waters.

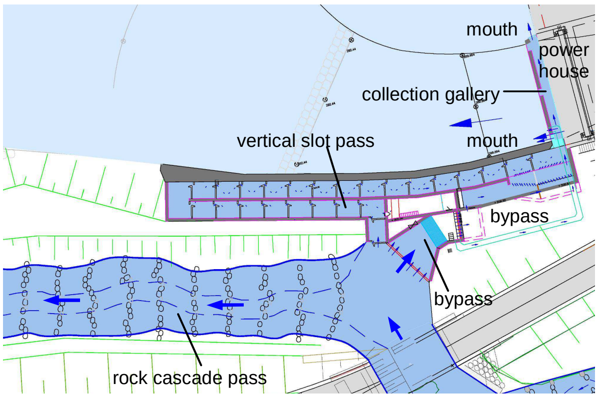

Figure 17. River Rhine, Albruck / Dogern (D): Diversion of the discharge into two courses: rock cascade pass, vertical slot pass with collection gallery.

4.3 Power plant Rheinfelden, Rhine (CH / D)

The bypassing water course at the hydropower plant Rheinfelden, on the High Rhine, is the largest fish pass facilitiy of this type in Central Europe. The old hydropower station was a diversion-channel type plant (Figure 18). The new station is a run-of-river power plant. Three fishways are installed (Figure 19), a vertical slot pass at the power house (left bank), the new bypassing river course installed in the old headrace channel (right bank) and a rock cascade pass which connect the tailwater of the weir with the river course.

The main intention of this new river course is to provide suitable habitat for rheophilic species, especially spawning grounds for gravel dependent fish species, for example barbel (Barbus barbus) and nase (Chondrostoma nasus).

With a width of 40-50 m, a mean gradient of 0.9 % and a discharge of up to 35 m^3s^{-1} the bypass channel has the character of a mountain river. The aim is to provide a high variety of bottom and flow structures induced by sequences of riffles, bars, pools and single gravel islands (Figure 20-22). The bed material consists of continuous gravel. In riffles and fast flowing reaches coarser material is provided. A deeper flow path ensures fish passage even at minor discharges. The river banks are characterized by bars, shallow regions, small bays, undercut banks and riparian vegetation. The bypass channel is connected to the weir impoundment with a gentle transition involving several braided channels. The intake structure itself is divided into two sections. One section will be controlled by two gates, the other will be unregulated. The unregulated section will guarantee a constant discharge of 10 m^3s^{-1} in the bypass channel. Additional discharge up to 25 m^3s^{-1} can be provided via the regulated gates in order to provide a dynamic flow regime.

The downstream entrance is designed as a rock ramp (Figure 19) with a steeper gradient (3 %), thus downstream water-level fluctuations are limited to this ramp; i.e. flow characteristics in potential spawning grounds in the bypass channel will not change. The cross-section at the mouth of the channel is narrowed to provide more efficient attraction flow into the tailrace.

Figure 18. River Rhine, Rheinfelden (D): Old hydrolic power plant designed as diversion type.

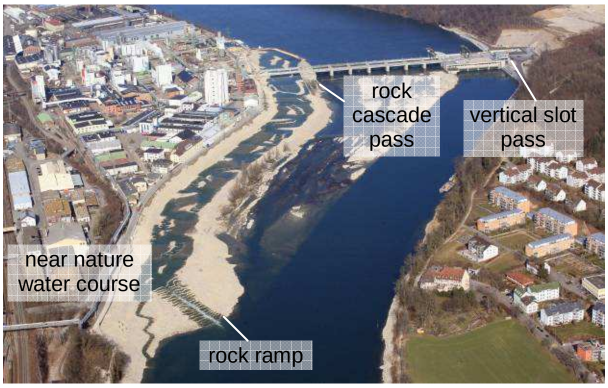

Figure 19. River Rhine, Rheinfelden (D): New power plant designed as run-of-river type. Near-nature water course installed in the old headrace channel.

Figure 20. River Rhine, Rheinfelden (D): Downstream section of the water course at the end of construction.

Figure 21. River Rhine, Rheinfelden (D): Downstream section of the water course in operation, Q = 10 m³/s.

Figure 22. River Rhine, Rheinfelden (D): Typical elements: riffle made of gravel and stone, deeper flow path (blocks) and structures of deadwood.

Figure 23. River Rhine, Rheinfelden (D): Typical riffle structure, Q = 10 m³/s.

5 Experiences and Conclusions

The operating experience with near-nature water courses are very positive. The results of the associated monitoring programs demonstrate that these water courses are used as habitat by many species, not only by fish but also by birds, amphibians and invertebrates. Especially rheophilic fish use these running waters as permanent or temporary habitat. The big water courses with riffles made of gravel are used as spawning area by barbel (Barbus barbus) and grayling (Thymallus thymallus). Particularly a lot of juvenile grayling could be observed in these structures. Also the general public´s acceptance of near-nature water courses is very high. Special arrangements of visitor direction are necessary to protect the created habitats.

In summary near-nature water courses offer many advantages:

- suitability for a wide spectrum of fauna
- habitat enrichment for rheophilic species
- flexible instead of static construction
- toleration of limited erosion an aggradation
- good integration into the landscape
- aesthetic value

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[4] Rheinkraftwerk Albbruck-Dogern AG (RADAG): Figure 14, 15.