Introduction

The hydropower potential in Europe – and especially in South-Eastern Europe - is still considerable. However, a number of technical and ecological challenges have to be mastered since this potential often lies at locations, which have very unfavourable framework conditions (e.g. very low water heads, strongly variable discharges, high bed load volumes, particular flood protection measures). Furthermore, most river reaches are ecologically highly sensitive and have to be protected and occasionally show a great need for river restoration measures, like river bed stabilisation, renaturation and flood protection. The potential at such ecologically sensitive locations cannot be used for power generated by applying conventional methods. Therefore, a research and development project was initiated and subsidised by the Austrian Government’s Climate and Energy Fund. The project aims at examining specific river locations where conventional technologies cannot be applied and at developing innovative hydropower plant solutions.

The focal point of the project is the development of new solutions for hydropower use in connection with river restoration measures. A great number of rivers have been massively regulated in the past, creating narrow, straightened channels, which eventually resulted in an extensive erosion of the river bed. Restoration measures can aim at widening the river wherever possible and integrating so-called block ramps (rock layers) to stabilise the river bed. In spite of their unsatisfactory morphological status, the affected river reaches and the wetlands along their banks can represent ecologically sensitive and valuable ecosystems. Due to this aspect, restoration measures aim at upgrading and safeguarding such areas in the long run. Therefore, conventional power plant technologies with impoundments and dams cannot be applied. The concept of a “river flow power plant” aims at adding a new type of power plant to the block ramp used for river restoration. Only heads of up to a few meters can be used for power generation, which means that a classical hydropower plant with dams cannot be used. The output of renewable energy is lower. Both the power plant part and the block ramp are constantly overflowed and a system of side arms is created, ensuring fish passability upstream and downstream. Flexible openings in the block ramp allow for the water level to constantly change in accordance with the discharge, which leads to a natural dynamic, crucial for the side arms and the wetlands, and facilitates secure flood water removal.

The biggest challenges for the turbine technology are posed by the very low water heads, the high and variable discharges and the high bed load volumes. Within the framework of the research and development project feasible solutions could be found by using compact
turbines. In a next step, the handling of the high bed load transport rates was examined. On the one hand, the “river flow power plant” should help restore the river bed and allow bed load to pass through the structure; on the other hand, the turbine inflow and outflow have to be kept free of it. For this purpose, a complex bed load management system was developed which is currently being examined in hydraulic model tests at the University of Innsbruck. A number of examinations have already showed that hydropower solutions can be environmentally sustainable even at the most difficult locations.

The innovative concept of the “river flow power plant” is planned to be implemented as a pilot plant at the Lower Salzach river at the Austrian-Bavarian border which is in great need of restoration. A hydropower plant under given circumstances at this location would generate around 30 GWh/a. A successful implementation of this pilot project would represent a milestone in the implementation of innovative hydropower projects and serve globally as an example for a sustainable use of the remaining hydropower potential for reaching the ambitious energy and climate targets.

1. Situation and Background

A great number of rivers have been massively regulated in the last 200 years – especially for territorial gain, navigability and flood protection – creating narrow, straightened channels, which eventually resulted in an extensive erosion of the river bed. This erosion has had a number of negative consequences such as undercutting of technical constructions, aggravated bank stability, lower ground water level and drying-up of side arms and wetlands. To stop this development river restoration measures are considered as essential in many cases.

In spite of the unsatisfactory morphological status, the affected river reaches and, above all, often the adjacent wetlands can still be considered as ecologically highly sensitive and valuable. For this reason river restoration measures often aim at safeguarding and upgrading such areas in the long run.

Just a few decades ago, river bed stabilisation was achieved through the construction of conventional hydroelectric power plants with dams. Through increased importance of ecological aspects transverse structures became smaller and flatter over the years, whereas generation of hydroelectric power in this context was not further developed.

The need to increase the share of renewable energy is undisputable today. It seems now obvious that hydro power needs to be used wherever possible, even at ecologically sensitive locations. In many of these river reaches the main target, however, is the preservation of the river flow characteristics.

2. River Flow Power Plant – the Concept

The river flow power plant as such is nothing new. The term describes the arrangement and the operation of known hydraulic elements taking into account ecological considerations. The characteristics of a river power plant are

• low heads, sufficiently high flow velocities and
• dynamics of water levels (Fig 1).
The difference in water levels in case of river restoration with block ramps is rather low, resulting in very low heads available for a possible power generation at such locations. Flow velocities upstream of the structure remain relatively high, as the river bed rises and the water depth decreases. The high elevation of the river bed makes hydro power use quite challenging due to unfavourable bed load transport processes. During operation of the river flow power plant, the upstream water level can be adjusted according to discharge rates. A near-natural variability of water levels can be guaranteed (see Fig. 1 and Fig. 2). Also, remaining reaches between river flow power plants are very long, with a higher gradient being achieved than in the headwater of the plant. Dynamics in water levels as well as relatively high flow velocities are a main requirement for ecologically healthy river reaches. Compared to a conventional hydropower plant the available head is very low. Due to project-specific reasons it might be necessary to adjust the stage-discharge relation (e.g. increase in hydro electric output, flood protection, bed stabilisation).
The concept poses high demands on the features of the structure. The block ramp needs to provide a migration corridor for aquatic animals during a wide range of discharges and water levels. A flat ramp (e.g. with an inclination of 1:50) and an adequate design can safeguard passability during various conditions. In case of very low discharges, a universal opening within the block ramp, which might be shut with a rubber dam, can be opened, allowing more water to enter the block ramp (Fig. 3 and 4).

Fig. 3. Layout of the concept [1]

Fig. 4. The concept of the passability of the structure [1]

The structure provides the necessary variability of water levels and preserves the ecological passability by means of a coordinated regulation of its openings. This is the main prerequisite for the river flow power plant. The number and dimensions of the openings can vary due to project-specific conditions.

The high elevation of the river bed upstream of the structure and accompanying high flow velocities lead to bed load related problems, if the intake of the power house is located very low. To mitigate this effect, compact turbines, which can be placed in a row, should be used. Structural measures such as bed load barriers and sluices need to be put into place in order to keep turbine inlets free of bed load. The power plant can be designed completely overflowed.
3. River Flow Power Plants at the Lower Salzach

The Lower Salzach River, located at the border between Austria and Germany, is characterised by massive erosion. Following a very intense planning process a range of restoration measures has already been realised in the upper part of the river reach since 2007. The first block ramp to stabilise the river bed was only finished in 2009 (width of 140 m, slope 1:50, see Fig. 5).

More restoration measures are planned to be installed further downstream in the Tittmoning basin. Considerations regarding the combination of restoration measures and generation of hydro-electric power were dealt with in the framework of a feasibility study subsidised by the Austrian Climate and Energy Fund. The concept of the river flow power plant was investigated taking project-specific constraints into account.

The river flow power plant has to cope with a range of requirements whilst ensuring a sensible way of power generation. The requirements include the stabilisation of the river bed, the damage-free flood discharge and ecological aspects like fish migration and protection of site-specific flow characteristics.

![Existing block ramp at the Lower Salzach River](image.png)

Based on a block ramp as shown in Fig. 4, a power house is added to the structure. The power house is situated at the outer bend of the river reach.

A detailed assessment of possible machine types including conventional tube turbines with vertical and horizontal axis and compact turbines showed that compact turbines are most suitable for the given circumstances. The main advantage of compact turbines is their small dimension, which enables a relatively low installation depth. The basic idea of compact turbines consists in the use of several small unregulated turbine-generator-units, with the discharge of the power house being regulated through turning the single units on and off. A cross section through the power house is shown in Fig. 6.

The high amount of bed load transport at this river reach and the large width of the structure necessitate the implementation of bed load sluices within the power house. The turbines are arranged in blocks of five each. The bed load sluices are situated between...
these blocks, allowing the flushing of sediments deposited in the inlet area. To avoid bed load input into the immediate power plant area, a bed load barrier is situated across the intake area leading towards the universal opening, where bed load is passed on to the downstream reach.

At this site, the available head amounts to 2.5 m to 3.5 m. Assuming a discharge of 200 m³/s and using 20 compact turbines, an installed power of 5.5 MW and a yearly generation of 30 GWh/a can be reached at this location.

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**Fig. 6.** Cross section of the power house [2]

The block ramp plays an integral role in the concept of the river flow power plant, having to fulfill a variety of requirements (Fig. 7). The main requirements include the damage-free flood discharge considering bed load transport and ecological aspects like fish migration and protection of site-specific flow characteristics.

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**Fig. 7.** River Flow Power Plant at the Lower Salzach (digital visualization)

Two openings equipped with rubber dams are embedded in the block ramp, which has a slope of 1:50. The larger opening is used for bed load transport and is hence situated right next to the power house in the middle of the river. The second opening allows for fish migration in case of low headwater levels and forms – together with a second rubber dam – a navigation canal for boats. During normal operation the passability for fish is given through the block ramp. In case of low headwater levels, when the water depth at the crest of the block ramp is not sufficient for migration, passability can be ensured by opening the rubber gate of the universal opening.
A physical model of the river flow power plant in a scale of 1:30 was built at the hydraulic lab of the University of Innsbruck (Fig. 8). It mainly aims at investigating bed load transport processes through and around the power plant. Extensive tests and optimisations show that the turbine inlet area can be kept free of bed load whilst bed load transport is ensured in the block ramp. An optimisation regarding turbine in- and outflow has to be undertaken and the block ramp has to be checked regarding its hydraulics and effectiveness.

The ecological functionality of the structure can be assessed using ecological passability and preservation of the river character as parameters. The existing concept of the river power plant provides three ecological corridors for migration: the block ramp, a bypass system and the immediate power house area. All corridors serve both the upstream and the downstream directed migration.

The passability of the block ramp is given by a pool-ripple sequence. Height differences between pools and the maximum energy dissipation within the pools are adjusted to the main fish species occurring in the reach. The bypass system provides not only a migration corridor but also offers additional reaches and areas with dynamic and functional banks. The outlet of the bypass system is located right next to the outlet of the power house to guarantee optimal migration. The third corridor is located in the immediate power house area, where a technical fish pass located next to the turbine outlet will provide for upstream and downstream migration.

Achieving a site-specific river character represents the essential goal of the project. The character of the river can be evaluated in particular by the parameter of flow velocity. Due to dynamic water levels in the headwater of the power plant only a very small reduction in average flow velocities occur. The result is, thus, an only minimal change in the river character.

Fig. 8. River Flow Power Plant (Lower Salzach) in the physical model
4. Conclusions and Outlook

The concept of the river flow power plant aims at combining necessary river restoration measures with the generation of renewable energy. On the basis of the positive results of the research and development project, there are plans to implement the innovative concept of the river flow power plant in the form of a pilot plant at the Lower Salzach, a river in great need of restoration. A hydro power plant under given circumstances at a location on the Lower Salzach river would generate around 30 GWh/a.

A successful outcome of this pilot project would represent a milestone in the implementation of innovative hydro power projects and serve as an example for a sustainable use of the remaining hydro power potential for reaching the ambitious energy and climate targets.

References


