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INNOVATIVE SOLUTIONS AND NEW TOOLS FOR FISH-FRIENDLY HYDROPOWER

BY ATLE HARBY, LEA BERG & PETER RUTSCHMANN

Hydropower is an important renewable energy source, but often with adverse impacts on hydro-morphology and aquatic ecosystems. Under legislations, such as the Water Framework Directive, many hydropower plants in Europe will need to be refurbished or upgraded in the coming years to mitigate these impacts. The FIThydro project aims to find innovative methods, tools and solutions to safeguard fish populations and maintain electricity production in hydropower affected rivers.

Introduction

Hydropower is the largest source of renewable energy in Europe and worldwide. In 2018, hydropower provided 63 % of renewable generation globally, and 47 % of renewable generation in Europe [3]. With its adaptability, predictability and grid stabilisation possibilities, hydropower will continue to play a key role for the EU to meet energy needs and climate mitigation targets beyond 2020.

However, hydropower also can have a large impact on hydro-morphology, aquatic ecosystems, and fish fauna. This includes river fragmentation and impoundments, changes in habitat, flow, and sediment conditions, as well as blocking or delaying of fish migration and potential injury or mortality of fish from turbine or spillway passage.

To meet the goals and requirements of the EU Water Framework Directive (WFD) and other legislation, and to ensure an environmentally friendly, socially acceptable, and economically viable hydropower production, measures need to be taken to mitigate these impacts.

A large number of hydropower plants in Europe have been in operation for decades, and they are in need of refurbishment, redesign and upgrading. This requires technical improvements, adapted operational and management strategies as well as the implementation of mitigation measures to avoid any impact on aquatic ecosystems and individual fish as well as fish populations.

While the impacts of hydropower on fish, ecology and ecosystems are well known, there is still limited knowledge on how to quantify and reduce these impacts effectively. Furthermore, decisions on mitigation measures are often made on assumptions rather than on objective and scientifically-based knowledge, quantification, and models.

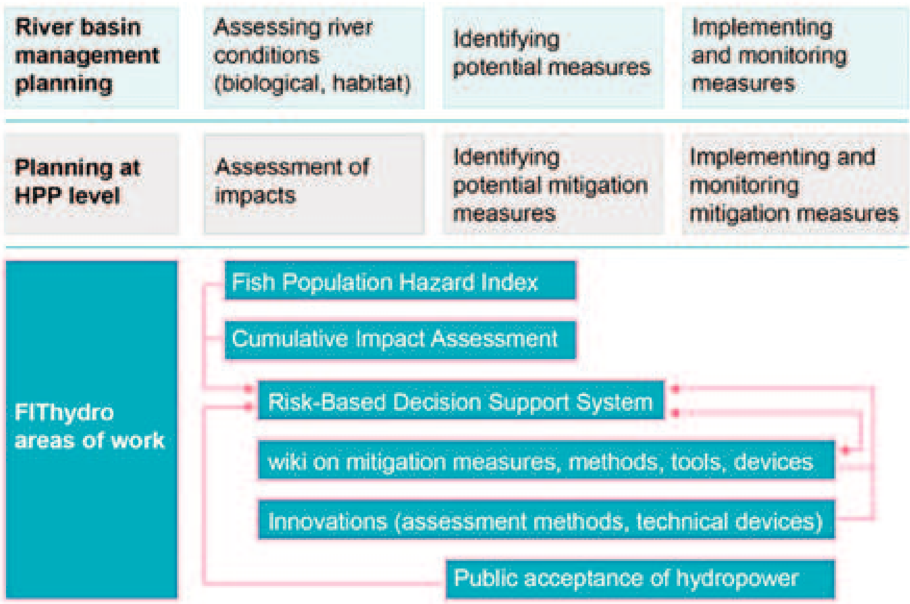


Figure 1. Key outputs from the FIThydro project in relation to planning of mitigation measures at hydropower plant level and to key relevant phases of river basin management planning. © FIThydro.

The FIThydro project began in 2016 to bridge this gap and improve the knowledge of and availability of innovative technologies and decision-making tools. The project consortium includes researchers, private companies, hydropower operators and engineering/ environmental consultants.

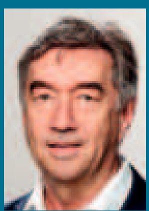
Fish-friendly Innovative Technologies for Hydropower (FIThydro)

FIThydro is a 4-year Horizon2020 research and innovation action with 26 partners (13 research, 13 industry) from 10 European countries, involving several of the leading companies in the renewable and hydropower energy sector in Europe. The aim is to test and develop cost-effective environmental solutions, strategies, devices, and measures to ensure self-sustained fish populations and increase the ecological compatibility of existing and new hydropower schemes.

Special emphasis was placed on the application and enhancement of technologies, methods, tools, and devices at 17 sites across Europe. These test cases were chosen to represent some of the main challenges facing hydropower development in four regions across Europe, namely Scandinavia, the Alpine region, France and Belgium for north-west Europe and the Iberian Peninsula. Scenario modelling in different geographic, climatic, and topographic test case regions will allow the quantification of effects and resulting costs for different mitigation options in Europe.

Atle Harby is a senior research scientist at SINTEF Energy Research in Norway. He has 25 years of experience in research and development with emphasis on ecohydraulics, environmental impacts of hydropower, water resources problems, climate change impacts and energy storage technologies. He was the Director of the research centre CEDREN (Centre for Environmental Design of Renewable Energy), an interdisciplinary research centre for the technical and environmental development of hydropower, wind power, transmission lines and the implementation of environmental and energy policy. He is work package leader in FIThydro and leading its Case Study Management Board.

Lea Berg works at the Chair of Hydraulic and Water Resources Engineering of the Technical University of Munich. She is responsible for the communication, dissemination, and exploitation of the FIThydro project. Her background is in natural resources management, sustainable development and education with a Master of Science in Sustainable Resources Management from the Technical University of Munich and a Bachelor of Arts from Maastricht University.



Peter Rutschmann is a full professor at Technical University of Munich. He has 40 years of experience in hydraulic engineering and expertise in physical and numerical as well as hybrid modelling. He has managed some 50 hydropower projects, 35 sediment and flood management projects, and also a few eco-hydraulic projects. He is one of the inventors of the innovative TUM hydroshaft powerplant and owns 8 patent families. Peter Rutschmann is a member of IAHR and the coordinator of the FIThydro project.

The key outputs from the project, illustrated in Figure 1, are two-fold: 1) A set of novel risk assessment and decision making tools to help practitioners evaluate, plan and find solutions for fish-friendly hydropower, and 2) a number of innovative and improved methods, tools and devices to address key challenges related to the assessment of self-sustained fish populations and fish-friendly hydropower production. A selection of the key outputs is highlighted in this article.

Novel risk assessment and decision-making tools

The scientific knowledge on the assessment of hydropower plants is largely limited by fragmented regional information on specific aspects, such as damage of single fish species or size classes, or a regionally occurring species pool. To address this challenge, FIThydro developed the first European-wide guidance and assessment tool for fish hazards in hydropower environments, the Fish Population Hazard Index [8]. This tool includes a population-biological sensitivity index and a conservation value index of European lampreys and fishes, as well as a mortality risk for fish and lampreys [7]. Information on the characteristics of the hydropower infrastructure is needed to run this tool. The Fish Population Hazard Index supports the implementation of mitigation measures for sustaining and improving local fish populations and thereby for meeting the requirements and targets under European environmental policy, especially the WFD.

Furthermore, FIThydro developed a more comprehensive Decision Support System (DSS) to support the decision-making by assessing risks to fish populations in hydropower affected rivers. The DSS considers the specific hydropower plant characteristics, national environmental status assessments as well as environmental and conservation policies and mitigation requirements. It guides the user through questions and decision-trees to identify risks and hazards to fish populations and enable the screening of potential mitigation measures. The different DSS measures are described in the FIThydro wiki.

The FIThydro wiki (https://www.fithydro.wiki/index.php/Main_Page) is an open access online platform that provides an overview of and information on different mitigation measures for fish-friendly hydropower. The mitigation measures are classified according to hydropower and river characteristics, climate regions, fish species and physical conditions. For each measure, a set of methods, tools and devices for planning, implementation and maintenance are given. It provides users with the possibility to look up problems and solutions concerning hydropower and fish at a superficial, as well as a detailed level. The wiki enables deepening the knowledge of hydropower impacts and mitigation measures and can help users implement the appropriate mitigation measures for environmental problems caused by hydropower production.

Innovative methods, tools, and devices

During the project, several innovative methods, tools, and devices for fish-friendly hydropower have been developed or enhanced. This includes devices to improve the assessment of fish behaviour at hydropower plants, fish

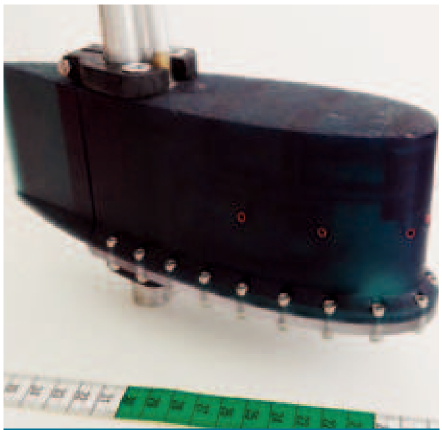


Figure 2. The "iRon" device, developed by the Centre for Biorobotics at the Tallinn University of Technology (TUT), that mimics the lateral line sensory system used by fish, is equipped with six differential pressure sensors that measure the pressure gradients simultaneously © Jeffrey Tuhtan, TUT.

guidance and protection systems, assessment methods for upstream and downstream migration facilities as well as tools for the assessment of impacts from hydropeaking.

The major obstruction to migrating fish is barriers such as dams and weirs. Fishways are the most common way to bypass the barrier and enable upstream migration of fish. However, the actual effectiveness of these structures is often unknown. Getting fish into fishways requires that fish can differentiate between the flow in the river and the flow entering from a fishway. Even though fish tracking in FIThydro indicates the need for additional stimuli, we usually assume that fish are mainly driven by sufficient "attraction flow". Knowing exactly how the fish experience this flow and thus making it effective poses a difficulty. The "iRon" (Figure 2) is a device that mimics the lateral line sensory system used by fish in nature (artificial lateral line), and is the world's first lab and field-ready instrument to capture flow "from a fish's perspective". It consists of a 0,22 m long streamlined body, which measures the pressure gradients simultaneously using six differential pressure sensors. In addition, the water depth is measured by the probe using an absolute pressure sensor. The "iRon" can be used not only to study flow velocity and turbulence, but also to sense the flow left-to-right and front-to-back, providing a sense of how fish detect obstacles and react to large-scale turbulences in real-world conditions.

The entrance to the fishway, the path to it and the consequent downstream swimming behaviour of fish during upstream migration was studied in several test cases during the project. The fish habitat simulation software

CASiMiR-Migration was used to model the fish swimming path during upstream migration by mimicking fish behaviour (Figure 3), as well as model migration corridors for different flow rates. The CASiMiR software enables investigation of the dynamic relationships between flow and biota in rivers, substrata, as well as in the connected bank and floodplain zones. Available habitats can be assessed for their migration suitability and be optimized.

Hydropeaking is becoming more important to balance the electricity grid with increasing shares of variable generation from wind and solar energy. FIThydro has developed a Hydropeaking Tool to assess the impacts on fish populations, considering different hydromorphological impacts as well as the vulnerability of fish populations. The tool can help to document impacts and guide the user towards which factors to mitigate. The hydromorphological impacts such as frequency, duration and magnitude of peaking, dewatered areas and ramp rates can be described from measurements or from hydraulic modelling.

There has been a lot of research and solutions for upstream migration of fish past dams and hydropower structures in the last few decades [5]. However, there is a lack of design standards and solutions for downstream migration. In the scope of FIThydro, fish guidance hydraulics and efficiencies are studied in laboratories and at test cases. Fish monitoring, velocity measurements and numerical modelling are conducted to investigate possible downstream fish migration measures and impacts.

Installations of fish guidance and protection structures in the headwater can reduce fish injury and mortality during downstream migration. Combining both, effective fish guidance and high hydraulic performance to avoid power losses is often a challenge. The newly developed Curved-Bar Racks (CBR) are mechanical behavioural fish protection and guidance structures that consist of vertical curved bars with an adjacent open channel bypass (Figure 4). CBRs present a technical solution for both effectively guiding fish and maintaining hydropower production and operation. The results from extensive laboratory tests show that the CBRs provide high fish protection and guidance efficiency for most of the tested fish species endemic in Central Europe. They also show significantly improved hydraulic performance, i.e. reduced head losses and uniform turbine admission flow [1], [2] CBRs have great potential for prototype hydropower plant application. They are suitable for medium-to-large hydropower plants with high design discharges ($Q > 100$ m^3/s) and high approach flow velocities and could be an alternative to fine-screened horizontal bar racks for small hydropower plants.

In many small and medium-sized run-of-river hydropower plants, the only way for downstream migration of fish is through turbine passage. Fish may experience adverse impacts as they pass through the turbines, ranging from potential injury to mortality[6]. To quantify the hydraulic conditions, which can lead to pressure induced mortality, and gain accurate measurements, the Barotrauma Detection System (BDS) was developed and applied in several test cases. The BDS is an advanced waterproof

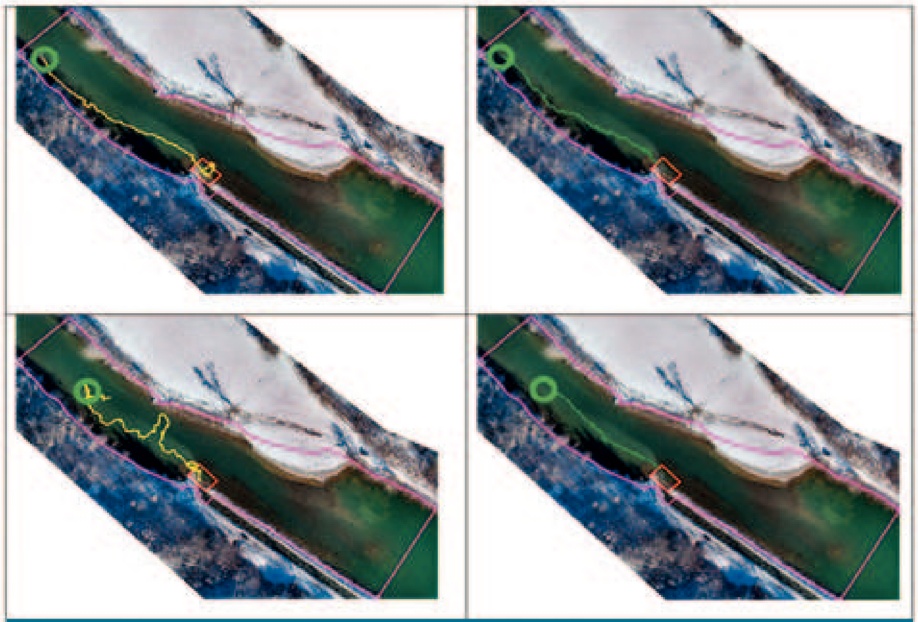


Figure 3. Comparison of the observed fish tracks (left, yellow) and the modelled fish agent tracks (right, green) created with the CASiMiR-Migration software, developed by SJE Ecohydraulic Engineering, to model migration pathways at the test case Altusried at the river Iller in Germany © SJE.

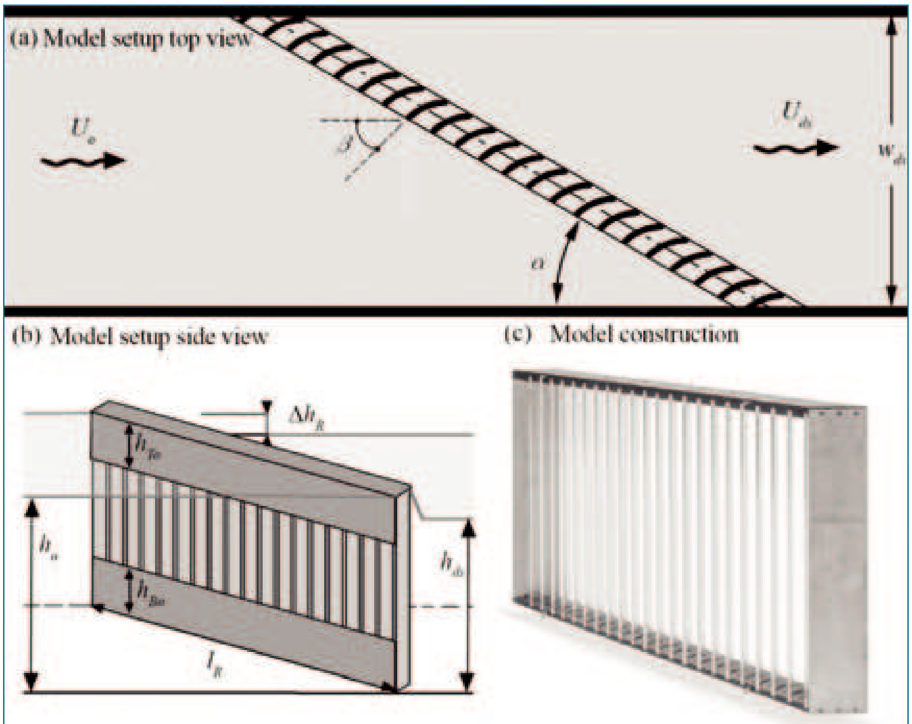


Figure 4. Illustration of the Curved Bar Rack fish protection and guidance system, developed at the VAW lab of the ETH Zurich, in top (a) and side (b) view, as well as (c) the model construction. © ETH Zurich, VAW.

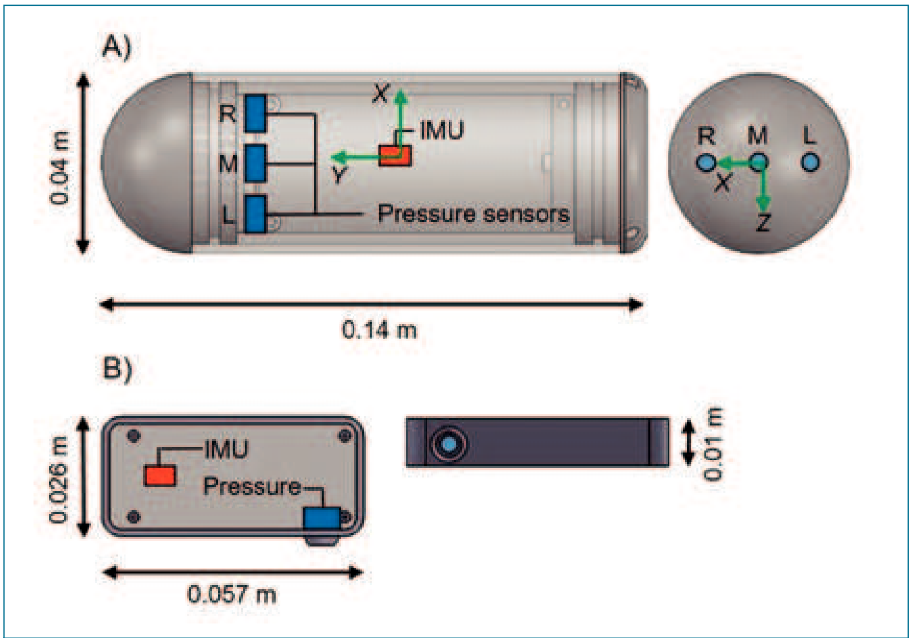


Figure 5. Illustration of the Barotrauma Detection System (BDS) and sensor tags, developed by the Centre of Biorobotics at the Tallinn University of Technology. © Jeffrey Tuhtan, TUT.

Figure 6. Calibration of the BDS sensors in the laboratory © Jeffrey Tuhtan, TUT.

autonomous sensing array (Figures 5 and 6) that can be inserted into the hydropower plant to collect information on the pressure and inertial changes that fish experience. Its three pressure sensors are auto-calibrating and provide fault-tolerant data collection and data quality control for each measurement while also recording its absolute orientation. They have been deployed at the test sites of Ham (Belgium), Bannwil (Switzerland), and Guma and Vadocondes (Spain). The BDS will help hydropower owners to assess the impacts on fish passing through turbines, and it can be used to identify where turbine passage is acceptable.

Conclusions

Hydropower plays an important role in producing renewable energy as well as enabling better integration of variable renewable generation from wind and solar power. At the same time, there is a strong need to improve the ecological status of rivers and catchments, and it is vital that negative impacts of hydropower on fish and the aquatic ecosystem are mitigated.

FIThydro has drawn together scientists, consultants, and hydropower operators from across Europe to test, develop and demonstrate innovative methods, tools, and devices that support managers, engineers, ecologists, and hydropower operators on the way towards sustainable hydropower generation.

This article introduced selected key outputs of the FIThydro project that support the assessment, planning, commissioning, and operation of ecological compatible and fish-friendly hydropower schemes. The tools, devices and technologies presented here are available for use and will also be further implemented, tested, and potentially adapted by project partners.

In addition to these main outcomes, the project deliverables include extensive information, data, analysis, and results of relevance to researchers in the field of ecohydraulics. The deliverables include an extensive list of existing solutions, models, tools, and devices to attain self-sustained fish populations and their application range, a metadata overview on fish response to hydropower and guidelines for mortality modelling. These publications and results are freely accessible and can be used as a basis for further research and development towards improved fish protection and hydropower impact mitigation.

Most of the results, deliverables, tools and scientific articles of FIThydro are accessible via the project website https://www.fithydro.eu

Acknowledgements

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