White Paper

Hydropower & Biodiversity

Environmental Flows/Hydropeaking (E-Flows)

ETIP HYDROPOWER

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Intended Purpose: The present White Paper is intended to provide European decision-makers with background information on key issues that are and will be discussed in pending and upcoming EU and national legislation processes relevant to hydropower development. These are, among others, the methodology for the establishment of free-flowing rivers and updates on ecological flows under the process of the Common Implementation Strategy (CIS) under the Water Framework Directive (WFD), as well as the implementation of the revised Renewable Energy Directive (RED III) and the Nature Restoration Regulation (NRR).

Hydropower plays a key role for the EU goal to decarbonize Europe's energy systems providing renewable electricity and increasingly important flexibility services. This paper shows ways how hydropower can contribute to the achievement of European environmental goals and policies. It is part of a series of three papers on environmental topics; the other topics are Fish Mobility and Sediment Dynamics.

Executive Summary

Environmental flows (E-flows) describe the flow of water that has to be released at the weir or dam to remain in the riverbed instead of being diverted and used for hydropower generation or other uses. E-Flows support not only fish populations, but the entire river ecosystem, including connectivity in longitudinal direction. Since the water cannot be used for power generation, E-flows reduce the capacity for hydropower to contribute to climate change mitigation through low-carbon generation and reduce economic profitability of the hydropower plant. Therefore this requires a balanced approach.

Various methodologies exist to determine E-flow regulations ranging from simple hydrological methods to complex numerical modelling methods leading to scenario-based decision support information. Across Europe and even within countries different methodologies are implemented and there is a lack of monitoring and adaptation to clearly demonstrate which methodologies should be implemented in specific situations. Research is therefore still needed to find generally accepted robust methodologies to determine E-flows in different types of settings and catchments.

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Introduction

Certain types of hydropower plants (HPPs) divert water from the catchments and the river into a system of canals, tunnels and penstocks which leads to so-called residual flow reaches or dewatered reaches. Other types of HPPs can drastically alter the hydrological regime downstream of the dam or powerhouse like hydropeaking due to electricity production on demand and sometimes combinations of both occur. Environmental flows (E-flows), also referred to residual, minimum, ecological or instream flows (although these terms are not exactly equivalent) must be released in such riverbeds to sustain aquatic ecosystems. Originally, the concept of E-flows was restricted to environmental flows focused on river ecology only, but the social and economic dimensions of flows are increasingly emphasized. The CIS Guidance Document No. 31 therefore refers to ecological flows, forming a major and often most relevant component of E-flows. Water used to ensure E-flows is no more available for power generation. The determination of its quantity requires a balanced approach between renewable energy generation and environmental protection goals.

What are environmental flows?

A commonly used definition is this:

> *Environmental flows describe the quantity, timing and quality of freshwater flows and levels necessary to sustain aquatic ecosystems, which, in turn, support human cultures, economies, sustainable livelihoods, and well-being […] The goal of environmental flow management is to protect and restore the socially valued benefits of healthy, resilient, biodiverse aquatic ecosystems and the vital ecological services, economies, sustainable livelihoods and well-being they provide for people of all cultures* (Arthington et al. 2018)

Unlike a fixed value (resulting from the definition of a minimum flow), E-flows can encompass a spectrum of flow patterns—both constant and variable—that are strategically released at specific times, corresponding to seasonal demands, with certain return intervals or during natural occurrences. They depend on the hydrological regime of the rivers and their biological communities.

In the context of CIS Guidance Document No. 31 [2], the term of “ecological flows” was adopted with the following working definition: Ecological flows are considered within the context of the WFD as “a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)”.

Why are E-flows important?

Biodiversity, especially related to fish species, in freshwater ecosystems is significantly reduced in Europe. Reduced flows and flow alteration like hydropeaking are part of the pressures leading to this reduction, along with pollution, land-use change, climate change, morphological alterations, and others. Given the wide variation in existing regulations in Europe, further research is needed for identifying appropriate methods to determine E-flow regulations, which take into account the variability found in the natural hydrological regime to meet the demands of the ecosystem functions.

Figure 1. A river is diverted at the weir into a pipeline running under the riverbank on the left side of the picture. The dewatered river reach downstream of the dam is very dry because of low E-flow releases. Such a situation can be avoided by a state-of-the-art E-flow management. Photo: K. Jorde

E-flows are relevant for the following reasons:

- E-flows maintain freshwater habitats (their composition, characteristics and dynamics) and vital functions of freshwater ecosystems, for their biological communities.
- Many aquatic organisms, particularly fish, rely on seasonal flow variation to support important life history processes such as breeding and migration as well as seasonal activities (spawning, winter habitats, recovering, etc.)
- E-flows are important for longitudinal and lateral connectivity (e.g. into tributaries or into the floodplain)
- E-flows are important for riparian vegetation, which depends on specific flow conditions for nutrients, seed dispersal, germination and growth. The riparian vegetation itself is an important part of the habitat and refuge for many aquatic species.
- E-flows are also relevant to the temperature regime and may contribute to climate change resilience of the stream, particularly in residual flow reaches.

Where are E-flows relevant?

E-flows are relevant wherever the hydrological regime of the river reach is altered. Most typically, E- Flows are relevant in the case of:

1) River reaches downstream of dams and reservoirs built to store water, which alter the flow regime.
2) Diversion type hydropower plants where most or all of the natural flow in the river is diverted into canals or conduits towards the turbines for the purpose of power generation.
3) River reaches below the tailrace outlet of intermittently operating hydropower plants (so-called hydropeaking).
4) Water abstraction for irrigation or any other type of anthropogenic uses.

E- Flows are not relevant in the case of run-of-river HPPs built directly into the riverbed without diversion.

Why are E-flows important for hydropower?

E-flow releases reduce hydropower generation, generally resulting in economic losses for hydropower operators and in systemic losses for the power system. Furthermore, a reduction of electricity from hydropower is counterproductive in relation to volatile renewable energy and climate change mitigations targets. Therefore, hydropower operators are often advocating a reduction of E-flows. Some old hydropower plants still operate on a license without E-flow releases, a common practice in the past. Sound compromises between the volumes of E-flow releases and the water to be used for electricity generation must be found.

How are E-flows determined?

There are a range of methods for assessing and managing environmental flows which span different levels of complexity and data requirements. An overview is given in CIS Guidance document No. 31. Methods can be classified as shown in Figure 2 and described as follows:

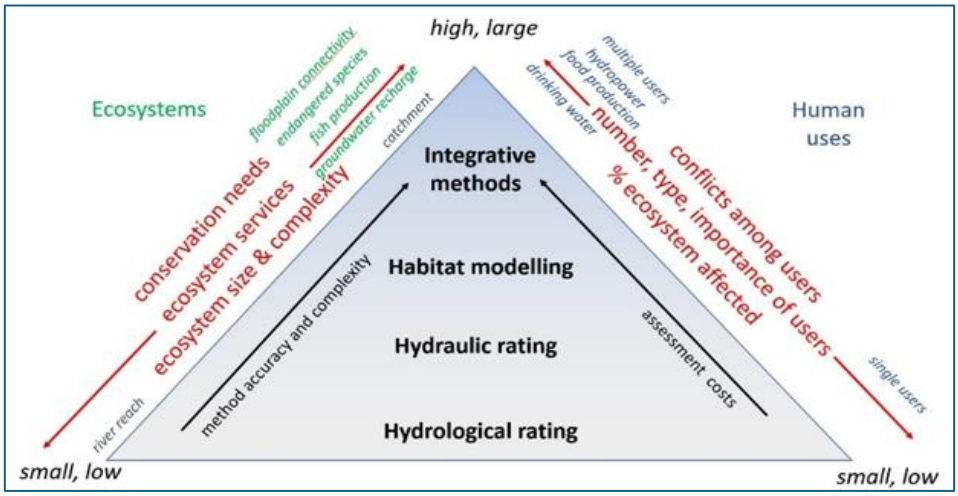

Figure 2. E-flow methodologies, modified from Nale et al. 2020.

The most basic approaches (**hydrological rating**) are based solely on statistical analyses of the hydrological characteristics of the river. E-flows are then determined by some percentage fraction of the natural flow. These methods are quick and easy to apply but often lack ecological relevance; **hydraulic rating** methods seek to guarantee a minimum wetted area and/or to optimize the diversity of hydraulic habitats. Field measurements are necessary and some ecological relevance can be included; **habitat modelling** methods based on the habitat preferences of species are more complex, but also more context-specific, since they model changes in hydraulic characteristics with flow and how well these characteristics then match with species' preferences. These methods require field data collection and complex modelling and are also subject to uncertainties (as not all species' preference parameters are included in the models). Finally, **integrative approaches** consider the whole river socio-ecosystems, including ecological, physical (like sediment transport and river morphodynamics) and social/recreational aspects as well as power generation to define E-flows that best meet the needs of all components. Similarly, **holistic approaches** can be used in conjunction with integrative approaches, or via expert opinion workshops, in which specific stakeholders are engaged, designed to reach a consensus on E-flows.

All approaches mentioned could be implemented in an adaptive management strategy but that is rarely the case. There is a general lack of data and scientific evidence on how well certain methods lead to achieving the desired ecological situation.

What is today's common practice in Europe?

In the EU, the Water Framework Directive (WFD) requires Member states to achieve good ecological status in natural water bodies (NWB) and good ecological potential in heavily modified water bodies (HMWB) and Artificial Water Bodies (AWB). This generally requires ecological flows (defined as flows that ensure good ecological status).

Most Member States have established abstraction permit systems that respect E-flows, however there are differences in legal frameworks, river management priorities, ecological conditions, stakeholders' involvement, and water resource use. Hydropower abstractions are the most relevant case in the northern part of Europe, but abstractions for agricultural irrigation become more and more relevant in the southern part.

Consequently, the state of the art in determining E-flows is significantly different in EU-countries and sometimes even differing between provinces (Figure 3).

Some countries rely on very simple purely hydrological desktop methods whereas others require ecologically meaningful but more elaborated methods.

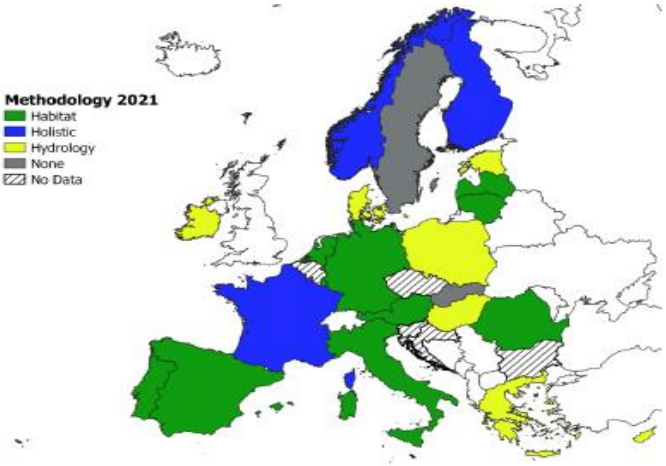

Figure 3. E-flow methodological approaches applied in EU (In Vezza et al, 2023, based on Ecostat 2021 questionnaire)-where 2 or more methods are used, the map reports the most "advanced"

Today's common practice differs across Europe and even more throughout the world. The following problems and research needs have been identified. They should be addressed in multilateral and interdisciplinary research projects.

Key Takeaways

- E-flows are critically important for both, river ecosystems and hydropower operators as well as for renewable energy generation in general.
- Across Europe a variety of methods to determine E-flows are used, some have little ecological relevance, others have more.
- A common goal should be to release only as much water as needed to protect the ecosystem to a certain degree but to make as much water as possible available for hydropower generation. This balance can only be achieved with advanced methods.
- Holistic approaches should be supported – with a focus on the establishment and preservation of functional habitats on all trophic levels.
- Biological databases based on long-term monitoring programs should be developed and shared across Europe to advance E-flow management strategies based on science-based facts, optimized impact mitigation measures and reduced uncertainties.

References

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[2] Ecological flows in the implementation of the Water Framework Directive, Guidance Document No. 31 Environment, doi: 10.2779/775712, © European Union, 2015

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