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Ecological flows in the implementation of the Water Framework Directive

Guidance Document No. 31

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Policy summary

Why this guidance

Building on an assessment of progress in Water Framework Directive (WFD) implementation in its 1st cycle, the Blueprint[1] to safeguard Europe's water resources stressed the urgent need to better address over-abstraction of water, the second most common pressure on EU ecological status, and to recognize that water quality and quantity are intimately related within the concept of 'good status '. This would require an EU-wide acknowledgement of the ecological flows, i.e. the "*amount of water required for the aquatic ecosystem to continue to thrive and provide the services we rely upon*". To achieve this, the Blueprint proposed the development of a guidance document in the framework of the WFD common implementation strategy (CIS) that would provide an EU definition of ecological flows and a common understanding of how it should be calculated, so that ecological flows may be applied in the next cycle of river basin management plans (RBMPs) due for adoption by the end of 2015.

What this document covers (and does not)

This document is intended to support a shared understanding of ecological flows (Eflows) and ways to use them in the RBMPs. To that end, it covers a working definition in the context of the WFD. Secondly, it provides an overview of the steps in the WFD cycle where Eflows play a role. Thirdly, this document draws upon lessons learned from practices that Member States already carry out in this field and provides information on methodologies, monitoring, measures and evaluation concerning Eflows.

This document does not offer a full protocol for the implementation of Eflows in water bodies, nor is it intended to lead to uniform implementation of Eflows. Member States are encouraged to make best use of the shared understanding of Eflows in all steps of the WFD process. The site-specific Eflows implementation might also take into account other aspects like national or regional legislation, specific environmental values or ecosystem services, while at the same time respecting the obligations under the WFD, Habitats Directive and other EU Directives and international commitments (World Heritage, Ramsar Convention…).

Alternative flows consistent with good ecological potential or with the exemptions in article 4 of the WFD could take into account considerations of disproportionate costs and sustainable human development activities.

Flow requirements of aquatic ecosystems

WFD provisions acknowledge the critical role of water quantity and dynamics in supporting the quality of aquatic ecosystems and the achievement of environmental objectives.

This link has received quite a lot of attention in the scientific literature developed over the 3 last decades. The recognition that the hydrological regime plays a primary role in determining physical habitats, which in turn determines the biotic composition and support production and sustainability of aquatic ecosystems, is well documented. Beyond the sole consideration of minimum flows in dry periods, this knowledge base

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[1] COM(2012) 673

stresses the need for all flow components to be included as operational targets for water quantitative management from base flows (including low flows) to flood regime (magnitude, frequency, duration, timing and rate of change).

A working definition of ecological flows for WFD implementation

In the context of this Guidance, the Working Group adopted the term of "ecological flows" with the following working definition:

Ecological flows are considered within the context of the WFD as "an hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)".

Considering Article 4(1) of the WFD, the environmental objectives refer to:

- non deterioration of the existing status
- achievement of good ecological status in natural surface water body,
- compliance with standards and objectives for protected areas, including the ones designated for the protection of habitats and species where the maintenance or improvement of the status of water is an important factor for their protection, including relevant Natura 2000 sites designated under the Birds and Habitats Directives (BHD)[2].

Where water bodies can be designated as heavily modified water bodies and/or qualify for an exemption, related requirements in terms of flow regime are to be derived taking into account technical feasibility and socio-economic impacts on the use that would be affected by the implementation of ecological flows. The flow to be implemented in these water bodies is not covered by the working definition of ecological flow and it will be referred distinctively. These latter flows are to some extent addressed in the guidance document.

Recommendations for implementing ecological flows in the WFD process

These recommendations consist in the collection of all "key messages" of the guidance document which are listed at the start of chapters 3 to 8.

A gradual and incremental consideration of the recommendations in this guidance is expected from Member States in their implementation of WFD. This document was developed with Member States in the year before the finalisation of their draft RBMPs for the 2nd cycle. Member States are expected to consider the extent to which the recommendations in this guidance can be included in these RBMPs before their adoption in December 2015, and in subsequent planning steps such as the review of the monitoring programmes, in making operational their programmes of measures by December 2018 and in the implementation of measures all along the 2nd cycle. Obviously full consideration of some recommendations (e.g. about the Pressures and Impact analysis addressed in chapter 4) will be only possible when preparing the third cycle.

[2] Directives 92/43/EC and 79/409/EEC

Setting the scene

- The Water Framework Directive, as well as the Birds and Habitats Directives, set binding objectives on protection and conservation of water-dependent ecosystems. These objectives can only be reached if supporting flow regimes are guaranteed. The establishment and maintenance of ecological flows, in the sense used in this document, is therefore an essential element in meeting those objectives. Therefore consideration of ecological flows should be included in national frameworks, including binding ones as appropriate, referring clearly to the different components of the natural flow regime (and not only to minimum flow) and the necessity to link their definition to biological requirements according to the objectives of WFD and BHD; exemptions should be justified in accordance with the ones of the WFD.

- It is recommended that these frameworks include means to ensure effective implementation of ecological flows, e.g. binding the strategic planning for development of impacting uses (e.g. irrigation, hydropower, navigation, flood control…) and the permitting process.

Eflows in status assessment and environmental objectives

- Assessment of the hydrological regime is explicitly required by the WFD when assigning high ecological status.

- For other status classes, classification of ecological status must rely on biological methods sensitive to all existing pressures, in particular to hydrological ones. Classification of a water body subject to significant hydrological pressures using only biological methods that are not appropriately sensitive to hydrological alteration may result in an overestimation of the ecological status that would not be in line with the WFD. In case such methods are not available yet, Member States should urgently develop them, providing metrics more specifically sensitive to hydrological pressures taking into account the relationship between hydrology, morphology and the biological impacts. Evidence of severe hydrological alteration should trigger appropriate monitoring (operational or investigative) and action to significantly mitigate the impact.

- The definition of ecological flow should encompass all environmental objectives in article 4(1) (non-deterioration, achievement of GES, meeting specific requirements of protected areas where relevant).

- The maintenance of the conservation status of water-dependent habitats and species protected under the Birds and Habitats Directives may require flow conditions which are different or go beyond the one required for the achievement of GES or maintenance of HES. These specific requirements should be identified and considered in the implementation of the different steps of WFD.

Assessment of hydrological pressures and impacts

- Article 5 analysis should carefully assess the significant pressures altering the flow regime which result in an impact on biology likely to contribute to the failing of environmental objectives.

- Ecological impacts of hydrological alterations and their significance should be ultimately assessed with biological indicators built on monitoring data that are specifically sensitive to hydrological alterations.

- In case the available biological metrics do not detect hydrological pressures or are not specific enough to isolate their contribution to the overall impact on the status, and because hydrological regime is well acknowledged as a key driver for river ecosystem quality, the evaluation of the significant impact of hydrological pressure can rely to a large extent on an assessment of hydrological alterations of the river flow.

- Most severe hydrological alterations can in many cases already be detected with some simple tools considering the extent of the pressures or the spatiotemporal alteration of habitats.

Establishment of monitoring programmes

- Proper definition and efficient implementation of ecological flows require a significant amount of hydrological data derived from monitoring the hydrological regime; modelling approaches may to some extent supplement insufficient monitoring data.

- Monitoring programmes should be adapted to provide an improved picture of hydrological alterations and their impact on habitat/morphology and biology and to effectively support the achievement of ecological flows.

- Sufficient hydrological information should be collected to enable estimation of the current flow regime and how it deviates from the natural flow regime.

- The development of operational hydrological monitoring should relate to the surface and groundwater hydrological pressures and be prioritised where action is likely to be needed.

- The integrated monitoring of hydrological, morphological and biological quality elements will enable the estimation of the effectiveness of flow restoration action as part of the programme of measures.

- The first step to address climate change is to know how hydrology is affected and evolves in the long-term; hydrology included in the surveillance monitoring will inform about the long-term evolution of natural flow regime.

Defining ecological flows and analysing the gap with the current situation

- To be consistent with the environmental objectives in article 4(1), the definition of Eflows should be the result of a technical/scientific process with no consideration of the associated socio-economic impacts. These latter impacts should only be considered when deriving the flow regime to be implemented in HMWB or water bodies subject to an exemption, consistent with the conditions set by the WFD.

- Many methods have been developed and may be used to inform the definition of Eflows, mostly differing in terms of integration of biological aspects, scale, complexity and volume of required data.

- The selection of the most appropriate method depends on resource availability (incl. monitoring data) and on the severity in the pressures. Purely hydrological methods may be a reasonable approach to cover the whole river basin; a more detailed approach will be needed to take specific actions, potentially affecting the socio-economic uses, to ensure their effectiveness.

- In cases where hydrological alterations are likely to prevent the achievement of environmental objectives, the assessment of the gap between the current flow regime and the ecological flow is a critical step to inform the design of the programme of measures.

Measures for the achievement of ecological flows

- In order to achieve WFD environmental objectives in natural rivers, the programmes of measures (PoM) should ensure the protection of ecological flows and their restoration.

- Being part of the basic measures, controls on surface and groundwater abstractions, impoundments and other activities impacting hydromorphology form a strong basis to protect and restore ecological flows, through the authorization process and regular review of permits.

- Many supplementary measures may be needed to support the achievement of WFD environmental objectives. In many cases, the combination of hydrological measures (ensuring the maintenance of ecological flows by all abstractions and regulation) and morphological measures (improving the aquatic habitats in order to make them less vulnerable to flow impairments) may be the most cost-effective approach.

- The PoM should support the development of knowledge on river ecosystem flow requirements both at large scale and at site level where appropriate.

- A careful assessment of costs associated with the implementation should be carried out to inform the selection of the most cost-effective measures or combinations of measures.

- These latter considerations shouldn't be used to revise the values associated with ecological flows which are to be derived from a technical / scientific process; they can however usefully inform the possible designation of the water body as HMWB or to apply for an exemption.

Heavily modified water bodies and exemptions

- Hydrological alterations without substantial change in morphology can in very specific circumstances justify the provisional designation of heavily modified water bodies (HMWB), which should generally only be based on the identification of a substantial change in morphology.

- Definition of ecological flow and identification of the necessary measures to deliver it and achieve GES should, where hydrology is significantly altered, be considered as part of the designation test for HMWB and justify that these measures cannot be taken.

- A careful assessment of the hydrological regime to be delivered should be carried out in the definition of good ecological potential together with the mitigation measures to improve the flow conditions; depending on the nature and severity of morphological alteration, the hydrological regime consistent with GEP may be very close to the ecological flows.

- Similarly an exemption under Article 4(5) can be justified with a significant hydrological pressure; this justification will require the definition of ecological flow and identification of the necessary measures to deliver it. The flow regime to be implemented in the water body should be the closest possible to ecological flow. When hydrology is not the cause for exemption, the hydrological regime should be as a default the ecological flow identified to support GES unless evidence can be used to set a different hydrological regime which supports the alternative objective.

Public participation

- Given their importance for the achievement of environmental objectives and the potential impacts of their related measures on users, participation schemes are particularly crucial for the achievement of ecological flows.

- Success will ultimately depend upon effective interaction with stakeholders, from politicians to local users, and the ability to communicate the need for ecological flows among those whose interests are affected.

- Public participation on Eflows should be developed in all the phases of the WFD planning process, from its design, implementation plan and effective implementation follow-up, ensuring the participation continues in subsequent planning cycles.

Table of Contents

Part I: Introduction

1.1. Mandate

Building on an assessment of progress in Water Framework Directive (WFD) implementation in its 1st cycle, the Blueprint[3] to safeguard Europe's water resources stressed the urgent need to better address over-abstraction of water, the second most common pressure on EU ecological status, and to recognize "*that water quality and quantity are intimately related within the concept of 'good status '*". This would require an EU-wide acknowledgement of the ecological flow, i.e. "*the amount of water required for the aquatic ecosystem to continue to thrive and provide the services we rely upon*".

To achieve this, the Blueprint proposed the development of a guidance document in the framework of the WFD common implementation strategy (CIS) that would provide an EU definition of ecological flow and a common understanding of how it should be calculated, so that ecological flow should be implemented in the next cycle of river basin management plans (RBMPs) due for adoption by the end of 2015. The elaboration of such a guidance document on ecological flows by 2014 was included in the CIS work programme and entrusted to a new dedicated working group that could build on previous CIS activities.

1.2. Scope

This document aims to be guidance to stimulate a common uptake of ecological flows in order to support the achievement of the Water Framework Directive's (WFD) environmental objectives addressing pressures affecting the hydrological regime (e.g. surface and groundwater abstractions and impoundments). Covering the whole WFD implementation process, it develops the steps where consideration for ecological flows is critically needed.

A gradual and incremental consideration of the recommendations in this guidance is expected from Member States in their implementation of WFD. This document was developed with Member States in the year before the finalisation of their draft RBMPs for the 2nd cycle. Member States are expected to consider the extent to which the recommendations in this guidance can be included in these RBMPs before their adoption in December 2015, and in subsequent planning steps such as the review of the monitoring programmes, in making operational their programmes of measures by December 2018 and in the implementation of measures all along the 2nd cycle. Obviously full consideration of some recommendations (e.g. about the Pressures and Impact analysis addressed in chapter 4) will be only possible when preparing the third cycle.

The target audience for this document consists of the policy makers responsible for drafting the RBMPs, in combination with implementers/practitioners, specialists and scientists supporting the distinctive contributions. This includes policy-makers and experts responsible for habitat conservation (Natura 2000 network and protected areas) and for international coordination (on the river basin level).

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[3] COM(2012) 673

Although its working definition for Eflows and some of its recommendations may apply to other surface water categories (such as lake and transitional waters), the guidance document addresses the situation of rivers and mainly focuses on natural water bodies. This reflects:

- the need to initially focus on these water bodies as a starter, and examine what further guidance may be appropriate on other water categories to aid the river basin management plan (RBMP) process;

- the lack of information and examples that could be collected about other water categories within the drafting process linked to the composition of the group and the relatively short time dedicated to the elaboration of this document;

- the need to coordinate the delivery of this guidance with on-going CIS activity on the intercalibration of good ecological potential for heavily modified water bodies.

The consideration for climate change in dealing with ecological flows, although very relevant, is very limitedly addressed in this document, reflecting the lack of experience about this issue in the working group.

1.3. Structure of the document and drafting process

The guidance document includes a policy summary targeted at policy makers which notably collects all key messages further elaborated in the main body of the document. This main body contains an explanatory part explaining why ecological flows are essential for the achievement of environmental objectives of the WFD and leading to a working definition of ecological flows for the purpose of WFD implementation. The third part of the document screens the different steps of the WFD planning process and develops guiding message to help Member States in considering ecological flows whenever and wherever relevant. This part is illustrated with references to existing practices and experiences in Member States that were collected throughout the drafting process in the format of case studies. These case studies are collated in a separate document as they have not been subject to an evaluation and remain under the responsibility of their individual authors. Lessons learned from these case studies are included in the guidance in the relevant sections.

This document is the outcome of the CIS working group on ecological flows that met 3 times in plenary meetings between October 2013 and October 2014. It has been endorsed by EU Water Directors on 24 November 2014.

The drafting was coordinated by Thomas Petitguyot (European Commission, DG ENV) and Victor Arqued (Magrama, Spain) as co-leads, with Max Linsen (RWS, The Netherlands), Nataša Smolar-Žvanut (Institute for Water of the Republic of Slovenia), Maria Helena Alves (Portuguese Environmental Agency), Nikos Skoulikidis & Christos Theodoropoulos (HCMR, Greece), Martina Bussetini (ISPRA, Italy), Kathryn Tanner (Environment Agency, UK), Jorge Ureta (Magrama, Spain) and Eva Hernández-Herrero (WWF) as main coordinating drafters of different chapters. Guido Schmidt (Fresh-Thoughts Consulting GmbH) and Rafael Sánchez Navarro have provided support as consultants (Contract 07.0307/2013/664902/ENV C.l).

Part II: Concepts

This Chapter provides the technical and scientific basis of ecological flows (foundations, key concepts, utilities). Given that this chapter is instrumental for a good understanding of the importance of ecological flows, the targeted audience is all stakeholder groups involved in or affected by water management, specifically river basin authorities, policy makers, industry, business, agriculture, managers of protected areas, researchers, academics and students and finally the general public.

Throughout this Guidance the term "ecological flows" refers to a flow specifically supporting the implementation of the WFD and the achievement of its objectives (cf. working definition in section 2.3., whereas the "environmental flows" covers concepts developed in other contexts (e.g. scientific and international literature)).

2. The aim of establishing ecological flows

This section analyses the role that the hydrological regime plays and could play in the aquatic ecosystems, the need for ecological flows and their influence on the achievement of the WFD objectives.

2.1. The relevance of the hydrological regime for the status of water bodies

2.1.1. The hydrological regime and the ecological status of water bodies

The Water Framework Directive is aimed at maintaining and improving the quality of aquatic ecosystems in the EU. The WFD requires surface water classification through the assessment of ecological status or ecological potential, and surface water chemical status. WFD Annex V explicitly defines the quality elements that must be used for the assessment of ecological status/potential. The lists of quality elements for each surface water category are subdivided into 3 groups of 'elements': (1) biological elements; (2) hydromorphological elements supporting the biological elements; and (3) chemical and physical-chemical elements supporting the biological elements. The hydrological regime is part of the hydromorphological quality elements.

All categories of surface water bodies (rivers, lakes, transitional waters or coastal waters) include the hydrological regime as a relevant variable that affects the ecological status (Table 2.1).

Table 2.1: The hydrological regime in the the definition of ecological status (WFD Annex V 1.2)

Water Category	Hydro-morphological quality element	Normative definition of high status	Normative definition of good status	Normative definition of moderate status
Rivers	Hydrological Regime	The quantity and dynamics of flow, and the resultant connection to groundwater, reflect totally, or nearly totally, undisturbed conditions.	Conditions consistent with the achievement of the values specified for the biological quality elements in order to be classified as good status	Conditions consistent with the achievement of the values specified for the biological quality elements in order to be classified as moderate status
Lakes		The quantity and dynamics of flow, level, residence time, and the resultant connection to groundwater, reflect totally or nearly totally undisturbed conditions.		

Transitional Waters	Tidal Regime	The freshwater flow regime corresponds totally or nearly totally to undisturbed conditions.		
Coastal Waters		The freshwater flow regime and the direction and speed of dominant currents correspond totally or nearly totally to undisturbed conditions.		

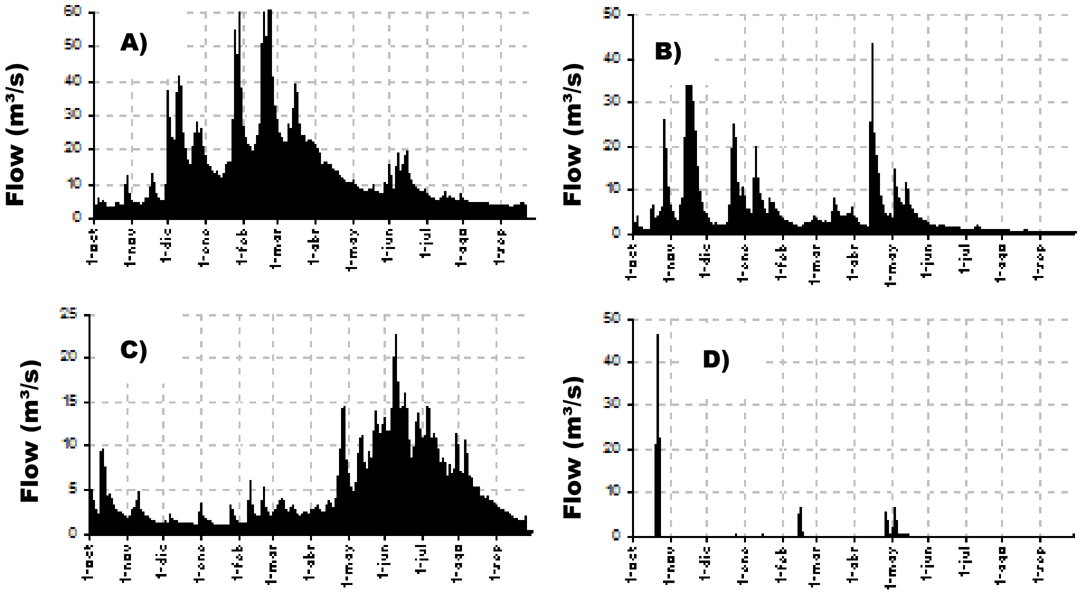
The first river basin management plans included an assessment of significant pressures affecting water bodies. Hydromorphological pressures and altered habitats were reported for a large proportion of classified water bodies, particularly in rivers (more than 40 %) and transitional waters (40 %) and one third of the lake water bodies. Several of the RBMPs reported water abstractions as a significant pressure affecting the hydrology and flow regime in the RBD. Overall, 8 % of European river water bodies are affected by water abstraction pressures. Four Member States identified pressure from water abstraction that affected more than 20 % of their river water bodies. About 4 % of lake water bodies are affected by water abstraction pressures (EEA, 2012).

2.1.2. Why is flow regime so important for aquatic ecosystems?

A large body of evidence has shown that the flow regime plays a primary role for structure and functioning of aquatic ecosystems (Junk *et al.*, 1989; Poff *et al.*, 1997; Bunn and Arthington, 2002; Arthington *et al.*, 2006, Poff and Zimmerman 2010). Virtually all rivers, lakes, wetlands and groundwater dependent ecosystems are largely controlled by the hydrological regime. The changing origin and quantity of water flowing in a river provides habitat and significantly influences water quality, temperature, nutrient cycling, oxygen availability, and the geomorphic processes that shape river channels and floodplains (Poff *et al.*, 1997; Richter *et al.*, 1997; Ward *et al.*, 1999). Similarly, zonation of vegetation in lakes and riparian wetlands is controlled by the flooding regime (Mitsch and Gosselink, 2000; Keddy, 2002; Keddy and Fraser, 2000; van der Valk, 1981; Acreman, 2003). Freshwater flows from the upper catchment are a major determinant of the environmental conditions in estuaries and coastal waters due to their impact on salinity gradients, estuarine circulation patterns, water quality, flushing, productivity and the distribution and abundance of many plant and animal species (Batzer and Sharitz, 2006).

Natural flow regimes display variability at a range of time scales, including seasonal, and inter-annual (cf. figure 2.1), and native aquatic and riparian biota are adapted to this variability. For this reason, the magnitude, frequency, duration, timing and rate of change of the natural flow regime are generally agreed to be the key elements central to sustaining and conserving native species and ecological integrity (Poff *et al.*, 1997; Bunn and Arthington, 2002; Lytle and Poff, 2004).

Figure 2.1: Natural flow variability measured in four Spanish rivers.
A) Cabriel river. B) Eo river. C) Esera river. D) Algeciras river
(Source: ROEA (Spanish official network of gauging stations) flow data)

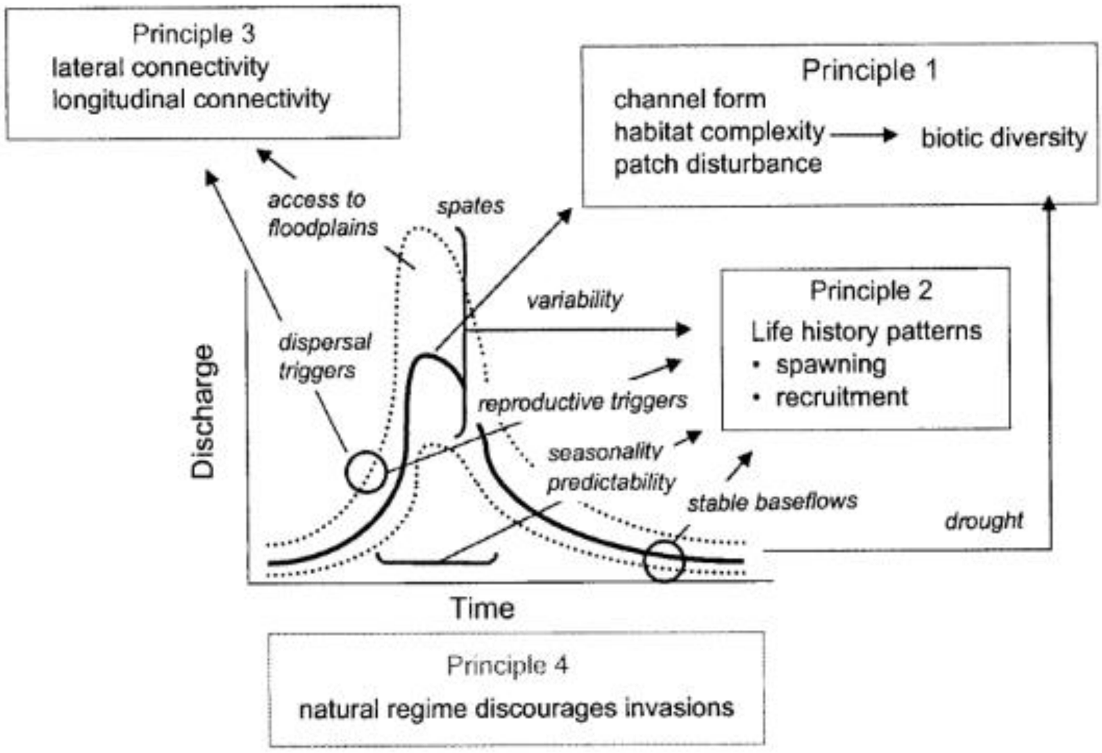


Results of numerous studies led Bunn and Arthington (2002) to formulate four key principles to illustrate how altering flow regime affects aquatic biodiversity in streams and rivers (Figure 2.2):

i. The hydrological regime is an important determinant of physical habitat, which in turn determines the biotic composition and life history strategies.
ii. Aquatic species have evolved in direct response to the natural hydrological regime and morphological conditions.
iii. Maintaining natural patterns of longitudinal and lateral connectivity is essential for the viability of populations of species.
iv. The success of the invasion of exotic and introduced species is facilitated by the alteration of hydrological regimes.

It can therefore be said that the natural hydrological regime plays a primary role for biodiversity conservation, production and sustainability of aquatic ecosystems, a general principle that is known as "the natural flow paradigm" (Poff *et al.*, 1997).

Figure 2.2: Key principles to highlight the importance of the natural flow regime
Source: Bunn and Arthington, 2002)



The link between surface and groundwater is essential for a proper analysis of hydrological conditions. Flow regime in aquatic ecosystems is in many cases heavily dependent on natural groundwater outflow (WFD CIS 2011a) which is:

- a stable flow component, especially important in maintaining flows during low-flow and drought situations
- chemically different from surface derived flows and thus essential for meeting specific biological requirements.

This input is critical for many temporal rivers and lakes that are especially prevalent in southern Member States. It also plays a major role for biodiversity protection and many Natura 2000 sites whose habitats and species depend on groundwater outflow, both in terms of quantity (e.g. providing long term stable refuge on the flood plains essential for survival during extreme low flows) and quality (e.g. stable temperature, oxygenated habitats in river sediments, essential chemical habitat aspects for adapted species such as in alkaline rivers).

2.1.3. Why a flow regime for aquatic ecosystems?

Structure and functioning of aquatic ecosystems is largely caused by different kinds of flow (low flows, high flow pulses, etc.) which vary throughout of hours, days, seasons, years, and longer (Poff *et al.*, 1997). Attempts to better understand the role of the flow regime in ecosystem dynamics have led to distinguish two broad environmental situations. Extreme situations imposed by extreme events (i.e. floods and droughts[4]) regulate ecosystem process rates, and exert selective pressure on populations to dictate the relative success of different species (Resh *et al.*, 1988; Hart and Finelli, 1999). Normal conditions imposed by regular flows allow habitat fidelity that may constrain (adapt) the species or life stage to a habitat with quite specific spatial or functional attributes (Stanford *et al.*, 2005).

From this basic and functional perspective flow types are known as "*environmental flow components*" or simply EFCs (Richter *et al.*, 2006; Richter *et al.*, 1997; King *et al.*, 2003; Poff *et al.*, 1997, The Nature Conservancy, 2011a). EFCs can be identified and characterized at several different scales. They are generally broadly distinguished between base flows (including low flows) and the flood regime (magnitude, frequency, duration and timing of high flow pulses).

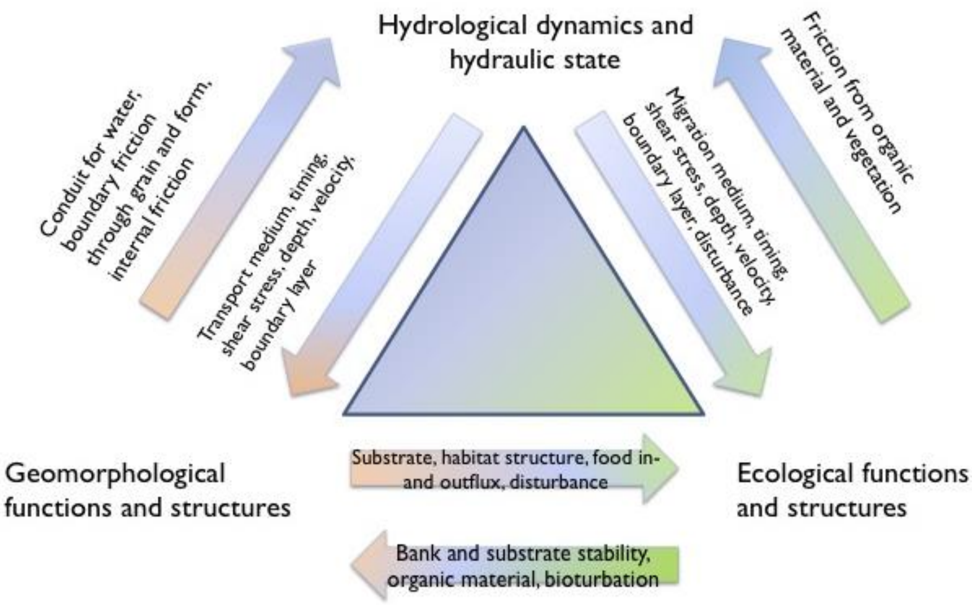
Low flows control the water chemistry, concentrate prey species, dry out low-lying areas in the floodplain, and are often associated with higher water temperature and lower dissolved oxygen conditions (TNC, 2011a). These low flows also control connectivity, thereby restricting movement of some aquatic organisms. Because native species may be adapted to the extreme low flow events that occur naturally, these periodic events may allow native species to outcompete generalist invasive species that are not adapted to extreme low flows.

On the other hand, the flood regime plays a critical role in the structure and functioning of the aquatic ecosystem (TNC, 2011a). Short-term changes in flow caused by freshets may provide necessary respite from stressful low-flow conditions. Small floods allow fish and other mobile organisms to access floodplains and habitats such as secondary channels, backwaters, sloughs, and wetlands. These areas can provide significant food resources allowing for fast growth, offer refuge from high-velocity, lower-temperature water in the main channel, or be used for spawning and rearing. Large floods can move significant amounts of sediment, wood and other, organic matter, form new habitats, and refresh water quality conditions in both the main channel and floodplain water bodies. The role played by the sediments is quite relevant due to their interaction with the biological “elements” and the hydromorphological ones.

Through mobilization of fine and coarse sediment, the hydrological regime induces geomorphological processes and therefore habitat formation. Some specific discharges are particularly effective in bed load mobilization and in shaping the stream channel; these channel-forming discharges are generally related to the most frequent floods (peak discharges with return periods from 1.5 to 3 years or even more frequent floods in large alluvial rivers). Methods to derive channel-forming discharges can be found in literature (e.g. Biedenharn *et al.*, 2001). Hydrology and morphology are therefore closely intertwined (figure 2.3): variations on hydrological regime will be reflected in hydromorphological parameters, such as water depth, flow velocity, substrate composition, and channel geometry which form the ecological habitat. In particular, alteration of channel-forming discharges and/or interruption of bed load will significantly change the channel geometry and therefore its conveyance capacity.

[4] Drought is a natural phenomenon. It is a temporary, negative and severe deviation along a significant time period and over a large region from average precipitation values (a rainfall deficit), which might lead to meteorological, agricultural, hydrological and socioeconomic drought, depending on its severity and duration (WFD CIS, 2012).

Figure 2.3: Links between geomorphology, hydrology and ecology
(J. Kling, personal communication)



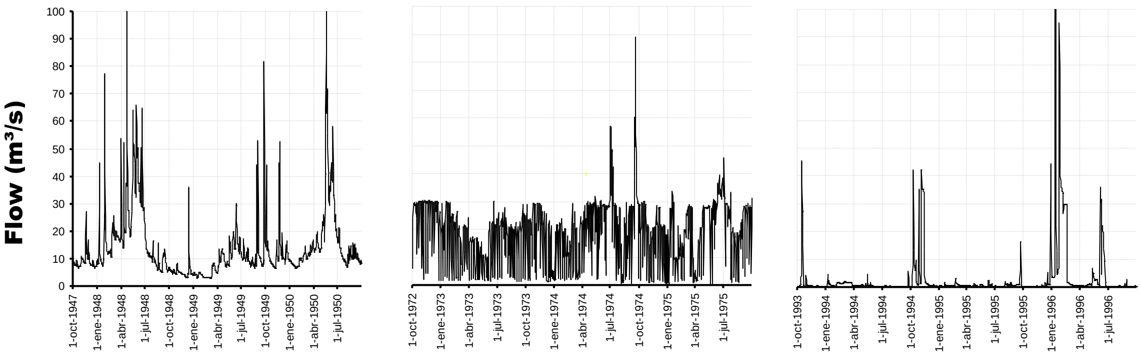
2.1.4. Ecosystem deterioration due to changes in flow regimes

Natural ecosystems have some level of disturbances that characteristically occur within a range of natural variability (Landres *et al.*, 1999; Gayton, 2001; Richter *et al.*, 1997; Smith and Maltby, 2003). Disturbances beyond this range, however, can exert pressure upon the system by altering fundamental environmental processes and ultimately generating stressors (USEPA, 2005; Davies and Jackson, 2006)).

As shown in Figure 2.4, human activities, such as the direct removal of water from rivers and groundwater bodies (abstraction), and impoundment (construction of dams or weirs for various purposes) have greatly modified the natural flow regimes of many rivers (Ward and Stanford, 1983; Poff *et al.*, 1997; Nilsson *et al.*, 2005). Assuming that flow regime is of central importance in sustaining the ecological integrity of freshwater systems, the modification of the flow regime shall lead to environmental degradation (Poff and Zimmerman, 2010; Lloyd *et al.*, 2003; Naiman *et al.*, 1995, Wright and Berrie, 1987; Giles *et al.*, 1991; Wood and Petts, 1994: McKay and King, 2006).

Figure 2.4 Measured flow characteristics of the Noguera Ribagorzana river (Spain) in three different periods. (Source: ROEA (Spanish official network of gauging stations) flow data)

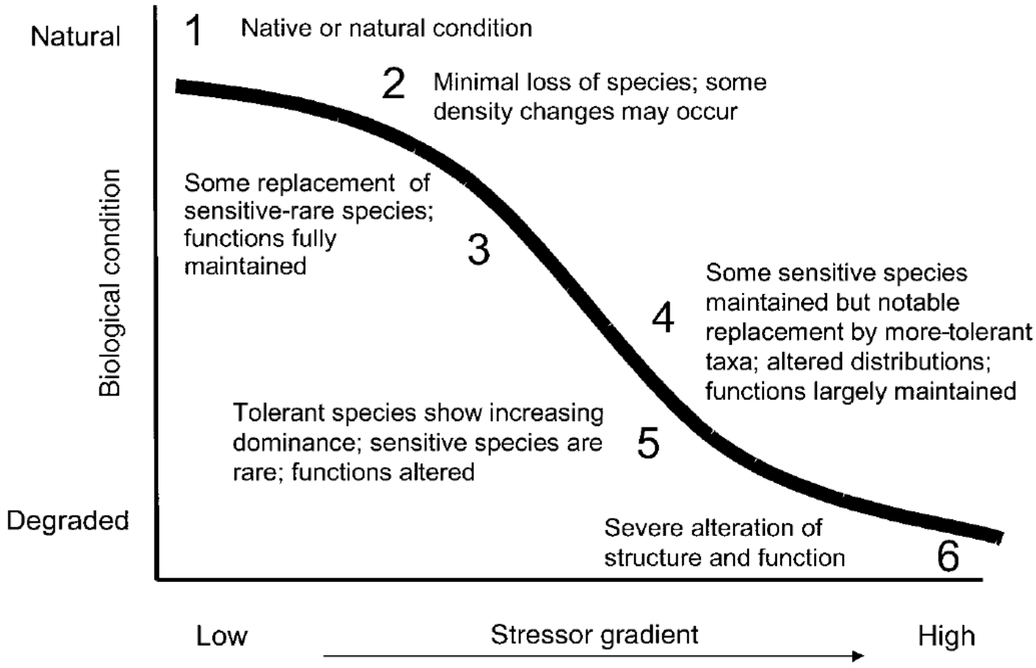
Left hydrograph shows the natural flow regime. The middle and right ones show a modified flow regime caused by hydropower and flow diversion respectively



Numerous studies have shown the effects of modifying the natural hydrological regime on ecosystems (Poff and Zimmerman, 2010). A reduction in flow alters the width, depths, velocity patterns and shear stresses within the system (Statzner and Higler, 1986; Armitage and Petts, 1992). This can modify the distribution and availability of in-stream habitat, which can have detrimental effects on invertebrates and fish populations (Wood *et al.*, 1999). Altered flow regimes have also been linked to invasion of non-native species (Baltz and Moyle, 1993; Brown and Moyle, 1997: Brown and Ford, 2002). Velocity is a significant factor affecting the distribution and assemblage of running water invertebrates (Statzner *et al.*, 1988), by influencing their respiration, feeding biology and behavioural characteristics (Petts, 2008). Low flows can impede the migration of salmonids and limit the distribution of spawning fish (Strevens, 1999; Old and Acreman 2006).

These mechanisms of impact are reasonably well known, however it can still be very difficult to diagnose the ecological impacts of low flows in any particular situation (Acreman and Dunbar, 2004). The Biological Condition Gradient (Davies and Jackson, 2006; USEPA, 2005) is a conceptual model that explains the degradation of aquatic ecosystems to the pressure gradient (figure 2.5). When there is no flow modification, natural or near-natural conditions of the aquatic ecosystem prevail. However, as increasing magnitude of flow alteration, structure and functioning of aquatic systems deviate from "natural" conditions to those classified as "severely altered".

Figure 2.5: The Biological Condition Gradient to show the degradation of ecosystems to stressors
Source: USEPA, 2005
(NB: the six classes on the schema cannot be directly related to the classes for WFD ecological status.)



2.2. Environmental flows concepts

2.2.1. An evolving concept

The concept of environmental flows was historically developed as a response to the degradation of aquatic ecosystems caused by the overuse of water. The recognition of the need for a minimum amount of water to remain in a river for the benefit of emblematic fish species (e.g. salmon) gave rise to terms such as minimum flows, in-stream flows and fish flows.

A second conceptual shift resulted in referring the concept to multiple river ecosystem aspects (Hirji and Panella 2003), recognising the vital role of the entire natural flow regime in ecosystem structure and functioning. Environmental flow, ecological reserve, environmental water allocation or requirement, environmental demand and compensation flow are terms used across different regions and by different groups to broadly define the water that is set aside or released to meet the environmental flow needs of water (eco) systems.

The holistic approach to environmental flow assessment in the 1990s was not just restricted to in-stream processes, but encompassed all aspects of a flowing water system, including floodplains, groundwater bodies, and downstream receiving waters such as wetlands, terminal lakes and estuaries. This approach also considered all facets of the flow regime (quantity, frequency, duration, timing, and rate of change), the dynamic nature of rivers and water quality aspects (Moore, 2004).

In the 2000s the link between river flows and livelihoods (Arthington and Pusey 2003; Brown and King 2003) was considered by integrating the human dimension as part of the holistic approach to environmental flow assessment, covering issues such as aesthetics, social dependence on riverine ecosystems, economic costs and benefits, protection of important cultural features and recreation, links to morphological processes (King, Tharme, *et al.*, Brown 1999; Meitzen *et al.*, 2013).

The concept continues to evolve and is shifting from the traditional view of minimum water amounts to a more comprehensive and holistic understanding. As this field of research continues to evolve and spread into new areas, it is expected that different interpretations will appear and new aspects will be integrated (Moore, 2004). In order to focus on the role in ecological status of water bodies and to reduce potential confusion with some of the broader definitions captured by the term "environmental flows" we refer to "ecological flows" or "Eflows" (instead of "environmental flows") for the purpose of this guidance and WFD implementation.

2.2.2. Key definitions of environmental flows

Despite the fact that the concept of environmental flows has existed for over 40 years (including terms such as instream flows), there is still no unified definition for it (Moore, 2004). This lack of uniform agreement for a definition of environmental flows can be illustrated by looking at a sample of literature over the last 15 years. The concept of environmental flows underlying these definitions is a certain amount of water that is left in an aquatic ecosystem, or released into it, for the specific purpose of managing the condition of that ecosystem (Arthington *et al.*, 2006; Brown and King, 2003).

Some of the most relevant definitions used internationally are the following:

i. In 2007 the Brisbane Declaration described environmental flows as "*the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems*".
ii. Dyson *et al.* (2003) in the IUCN guide on environmental flows define the concept as the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated.
iii. The 4th International Ecohydraulics Symposium (2002) defined environmental flows as the water that is left in a river system, or released into it, to manage the health of the channel, banks, wetland, floodplains or estuary.
iv. Hirji and Davis (2009) describe environmental flows as "*the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people*".
v. Arthington and Pusey (2003) define the objective of environmental flows as maintaining or partially restoring important characteristics of the natural flow regime (i.e. the quantity, frequency, timing and duration of flow events, rates of change and predictability/variability) required to maintain or restore the biophysical components and ecological processes of in-stream and groundwater systems, floodplains and downstream receiving waters.
vi. Tharme (2003) defines an environmental flow assessment (EFA) as an assessment of how much of the original flow regime of a river should continue to flow down it and onto its floodplains in order to maintain specified, valued features of the ecosystem.
vii. IWMI (2004) defines environmental flows as the provision of water for freshwater dependent ecosystems to maintain their integrity, productivity, services and benefits in cases when such ecosystems are subject to flow regulation and competition from multiple water users.
viii. Brown and King (2003) state that environmental flows is a comprehensive term that encompasses all components of the river, is dynamic over time,

takes cognizance of the need for natural flow variability, and addresses social and economic issues as well as biophysical ones.

ix. Meitzen *et al.* (2013) define environmental flows as the ecological-based stream flow guidelines designed to inform sustainable water resource management that supports healthy riverine habitats and provide sufficient water supply for society.

2.3. Working definition for ecological flows in the context of the WFD

As seen in the previous section, there is a variety of definitions around the concept of environmental flows. In the context of this Guidance, the Working Group adopted the term of "ecological flows" with the following working definition:

Ecological flows are considered within the context of the WFD as "an hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)".

Considering Article 4(1) WFD, the environmental objectives refer to:

- non deterioration of the existing status
- achievement of good ecological status in a natural surface water body,
- compliance with standards and objectives for protected areas, including the ones designated for the protection of habitats and species where the maintenance or improvement of the status of water is an important factor for their protection, including relevant Natura 2000 sites designated under the Birds and Habitats Directives (BHD)[5].

Where water bodies can be designated as heavily modified water bodies and/or qualify for an exemption, related requirements in terms of flow regime are to be derived taking into account technical feasibility and socio-economic impacts on the use that would be impacted by the implementation of ecological flows. The flow to be implemented in these water bodies is not covered by the working definition of ecological flows and it will be named distinctively.

[5] Directives 92/43/EC and 79/409/EEC

Part III: Understanding and recommendations for considering ecological flows in the WFD implementation

Acknowledging the need for a greater integration of qualitative and quantitative aspects of both surface waters and groundwaters, this part is intended to provide guidance on how to improve surface and groundwater quantitative management with consideration of flow requirements from the river ecosystems in order to achieve environmental objectives. It follows closely the WFD planning process as described in CIS Guidance N°11 (WFD CIS 2003a) and expected consideration for Eflows in the different steps are as far as possible illustrated with practical tools/methods developed by Member States and references to case studies. In water bodies affected by hydrological alterations Eflows should be considered in many steps, notably i) identify significant pressures; ii) assess the risk of failing environmental objectives; iii) design of the monitoring programme; iv) construct a cost-effective programme of measures to achieve environmental objectives, etc. Consideration of Eflows should be embedded in the planning process and not considered as a separated one.

> *A Case Study (1, AT, Art.5) describes the Austrian approach to connecting the different elements of the WFD process to Eflows. A thorough analysis of the main typical pressures, allowed designing the monitoring programme in a most efficient and cost-effective way. In preparing the first river basin management plan the biological monitoring results were compared to the environmental objective GES (GAP Analysis). In the meantime, biological assessment methods had been developed with specific metrics sensitive to hydrological and morphological alterations in addition to metric sensitive to physico-chemical impacts. Guide values for the Eflows parameters were set for GES for all water body types, limit values for high status. For the 2nd pressure and impact analysis the values for the hydrological pressure/impact parameters were refined.*

The present guidance document is not intended to provide binding standards on Eflows but to promote their consideration in the WFD planning process with a common understanding about their definition and illustration of their practical implementation.

Although chapters 3 to 8 focus on natural water bodies, most of their recommendations also apply to heavily modified water bodies and water bodies subject to an exemption, as the conditions they must fulfil will mostly require the consideration of ecological flows and the measures that would be needed for its achievement. Specific considerations for these water bodies are included in chapter 9.

3. Setting the scene

This chapter elaborates on the legal framework supporting the implementation of ecological flows in EU Member States. It includes the review of EU countries legislation, regulations, and guidelines on ecological flows and proposes some recommendations for improving existing legislations in Member States.

Key messages for this chapter

- The Water Framework Directive, as well as the Birds and Habitats Directives, set binding objectives on protection and conservation of water-dependent ecosystems. These objectives can only be reached if supporting flow regimes are guaranteed. The establishment and maintenance of ecological flows, in the sense used in this document, is therefore an essential element in meeting those objectives. Therefore consideration of ecological flows should be included in national frameworks, including binding ones as appropriate, referring clearly to the different components of the natural flow regime (and not only to minimum flow) and the necessity to link their definition to biological requirements according to the objectives of WFD and BHD; exemptions should be justified in accordance with the ones of the WFD.

- It is recommended that these frameworks include means to ensure effective implementation of ecological flows, e.g. binding the strategic planning for development of impacting uses (e.g. irrigation, hydropower, navigation, flood control…) and the permitting process.

3.1. The EU legal framework for Eflows

The legal framework for implementation of Eflows in EU Member States is set out in the WFD and in the Birds and the Habitats Directives. WFD’s main objectives are for Member States to prevent deterioration of the status of all water bodies and to protect, enhance and restore all water bodies, with the aim of achieving good ecological status by 2015 at the latest. Hydrological regime is explicitly identified in the Directive as an element of ecological status.

The Birds and Habitats Directives aim is to conserve important habitats and species. Although there is no explicit reference to ecological flows in these Directives, flow regime is for most of the aquatic ecosystems a critical element controlling the conservation status of the related protected habitats and species. Sites which are designated under the Birds and Habitats Directives and where the maintenance or improvement of the water status is an important factor in their protection are ‘protected areas’ under WFD (Sánchez and Schmidt, 2012).

Ecological flows are linked to the legal provisions of these Directives and the environmental objectives Member States are required to achieve. Therefore, implementation of these EU Directives through the national legislation should include where relevant the protection and the restoration of hydrological regime consistent with their environment objectives (e.g. basic measures listed in article 11(3) (e) and (i), cf. section 8.1) and consequently the determination of these ecological flows.

In addition to these EU Directives, other international commitments (e.g. World Heritage, Ramsar Convention…) may require Member States to appropriately protect, maintain and/or restore certain aquatic ecosystems. These form an additional legal basis for the maintenance and restoration of ecological flows in these areas (Sánchez and Schmidt, 2012).

3.2. Legislation and guidelines on Eflows in Member States

Information on Eflows legislations in EU member States has been compiled when elaboration this guidance document and is presented in Appendix 1.

Most EU Member States have developed provisions in their legislation referring to flow requirements in rivers to account for ecosystems needs, either at national or regional level. In 2012, the European Commission assessed the implementation of Eflows in RBMPs (Benítez Sanz and Schmidt, 2012). 88 River Basin Districts (47%) either have already implemented Eflows or plan to implement it in the framework of the programme of measures, while other 69 (34%) show no explicit intention in this regard. In 29 River Basin Districts (16%), there is not sufficient information available to evaluate the implementation of Eflows in RBMPs. The existence of national and/or regional guidelines or regulations on the definition of Eflows has been established in 50 RMBPs out of 123 (41%). Specific measures have been taken to achieve Eflows in 61 RBMPs (50%) and it must be pointed out that there is no coincidence with those basins where general guidelines or regulations are available, meaning that some River Basin Authorities should have established their own standards. EU Member States legislation use different terms to name these required flows, the most commonly used being "environmental flow"; other terms frequently found are "ecological flow" or "ecological minimum flow"; or in some cases "minimum acceptable flow", "ecologically acceptable flow", "common low flow", "minimum allowable flow", "minimal residual flow", "minimum (balance) discharge", etc.

These differences in terms reflect differences in concepts and definitions, and subsequent methodologies used to define these flows. Information on Eflows methodologies developed by EU Member States has also been compiled to supplement this guidance document and is presented in Appendix 2. In many Member States, these methodologies are included or referred to in the water legislation itself. Even when not binding, technical guidelines have been developed by public authorities and are publicly available.

However, in most of the cases the review of legislation and related methodologies didn't find evidence that these concepts have been developed with direct consideration of WFD requirements in terms of environmental objectives and definition of ecological status. Consequently the methodologies generally lack consideration for all the relevant flow components (beyond minimum flow which is the most commonly covered) to be considered in a flow regime consistent with the environmental objectives of EU Directives; most of them refer to statistical hydrological values with unclear relation to biological impacts; very few elaborate on river-type specific natural hydrological, morphological and biological characteristics.

> *A Case study (2, ES, legal) explains how the regulatory framework on ecological flows in Spain was developed Derived from the Water Act and reflecting concepts and criteria of the EU Directives and the relevant steps of the water planning process, the Hydrological Planning Instruction sets technical specifications for the following elements: objectives and components of the ecological flow regime, hydrologically heavily modified water bodies, flow regime during prolonged droughts, water requirements in lakes and wetlands, repercussion of the ecological flow regime on water uses, public participation process of the flow regime and flow regime follow-up.*
>
> *A Case Study (3, AT, Legal) explains how hydrological limit and guide values related to Eflows included in national legislation (Ordinance on Ecological Status Assessment, 2010) were defined in Austria. Guide values for the Eflows*

parameters were defined for the quantity of flow - consisting of a base flow and a dynamic share, flow velocity, water depth, daily water depth/flow fluctuations and wetted area (habitat extent and natural type characteristic) - for ensuring the ecological and biological objectives of the WFD (GES) and therefore combined for an Eflows definition taking into account river typology and site specific natural flow characteristics. These values have been proven by the evaluation of a significant number of biological and hydrological monitoring data, so that GES is ensured.

A Case Study (4, SI, Legal) describes the legislation developed for the implementation of ecologically acceptable flows in Slovenia. The "Decree on the criteria for determination and on the mode of monitoring and reporting on ecologically acceptable flow" was prepared in 2009 based on Article 71 of the Water Act in Slovenia (2002). The Decree consists of six chapters including general provisions, criteria, the mode of monitoring, supervision, penal provisions and transitional provisions. The Decree prescribes the use of either one of two approaches for the determination of an "Ecologically Acceptable Flow" (EAF), i.e., the hydrological approach and the "holistic" approach which also considers biological, chemical and hydromorphological aspects, upon request of the applicants for the water right.

There are large variations in Member States legislation and methodological approaches to ecological flows; this is likely to lead to different decisions in different parts of Europe, and potentially inequitable implementation of EU environmental requirements.

This state-of-play may reflect the current eco-hydrological knowledge, and also other factors such as data availability, modelling capacity, experience and skills and financial resources. However it is recommended that Member States legislation evolve to better acknowledge the common understanding of European Directives objectives in terms of flow regimes to be protected and, where necessary, restored.

It is recommended that Member States develop effective national frameworks on Eflows that could be practically implemented with the relevant skills. These national frameworks should provide a clear basis for issuing and regulating water use, allocations, water rights and permits: in all cases, Eflows should be included in RBMPs. The development of scientifically credible Eflows national frameworks, taking into account their regional and local specificities, will be a major contribution to the resolution of conflicts on over water uses and to ensure of achieving EU ecological objectives. Such a common understanding of ecological flows and its effective implementation is particularly critical to embed in the management of transboundary river basins.

To this extent, it is recommended that national frameworks include:

- a conceptual definition of ecological flows with a clear reference to both flow quantity and dynamics and to their consistency with the environmental objectives required under the WFD
- ecological flows as a binding requirement where relevant:
    - to all water uses (in particular abstraction, impoundment, flow regulation) in their different characteristics (surface and groundwater, reversible and irreversible, periodic and permanent…);
    - in the strategic planning for development of impacting uses
    - in the delivery of new permits
    - in the review of existing water rights
- conditions for exemptions to this requirement should be consistent with related exemptions in the WFD (article 4 (4) to (7)).

- clear responsibility for validating the definition of ecological flows and the inspection of their achievement
- deterrent penal provisions when regulatory requirements are breached.

It is also recommended that national methodologies or guidelines include:

- the methodological approach and methods for determination of Eflows that include relevant elements of river ecosystem, at least quality elements of WFD;
- a range of procedures which can be selected according to the kind of use, the river type and the linkage between surface and groundwater where relevant;
- the data required for Eflows determination;
- the requirements for monitoring and reporting to the competent authorities;
- the requirements to ensure the transparency of methodologies and results to all interested parties, including water users.

This set-up should enable the adaptation of legal requirements to the local specific conditions (in terms of use and environment). Eflows methods should be integrated into RBMPs and encompass legal issues and governance aspects.

4. Eflows in status assessment and environmental objectives

When setting environmental objectives for natural surface waters, Article 4 of the WFD requires that Members take the necessary measures in order to i) prevent deterioration in status and ii) achieve good ecological status by 2015. It also requires the achievement of the specific objectives for protected areas established under Community legislation. Objectives (i) and (ii) are expressed in terms of ecological status where hydrological regime is a key component to be considered in the classification itself (HES) or to check the confidence of the assessment (GES).

NB: although this guidance document focuses on environmental objectives for rivers, it is reminded that Eflows are also relevant to groundwater quantitative status. In order to achieve good groundwater quantitative status the level of groundwater should not be subject to anthropogenic alterations which would result in failure to achieve the environmental objectives for associated surface waters or any diminution in the status of such waters. Flow requirement of water bodies are captured via 2 tests described in CIS Guidance No.18 (WFD CIS 2009a):

- Test Water Balance: for a GWB to be of good status for this test, long-term32 annual average abstraction from the GWB must not exceed long-term average recharge minus the long-term ecological flow needs. This test considers the cumulative effects across the body and is a body-wide test.

- Test surface water flow: For a GWB to be of good status for this test, there should be no significant diminution of surface water ecology that would lead to a failure of Article 4 surface water objectives (relating to surface water bodies at local scale). This test requires that the flow requirement of surface water bodies (associated with GWBs) needed to support achievement (and maintenance) of good ecological status is determined. For rivers impacts of groundwater abstraction may be seen as a reduction in flow.

Key messages for this chapter

- Assessment of the hydrological regime is explicitly required by the WFD when assigning high ecological status.

- For other status classes, classification of ecological status must rely on biological methods sensitive to all existing pressures, in particular to hydrological ones. Classification of a water body subject to significant hydrological pressures using only biological methods that are not appropriately sensitive to hydrological alteration may result in an overestimation of the ecological status that would not be in line with the WFD. In case such methods are not available yet, Member States should urgently develop them, providing metrics more specifically sensitive to hydrological pressures taking into account the relationship between hydrology, morphology and the biological impacts. Evidence of severe hydrological alteration should trigger appropriate monitoring (operational or investigative) and action to significantly mitigate the impact.

- The definition of ecological flow should encompass all environmental objectives in article 4(1) (non-deterioration, achievement of GES, meeting specific requirements of protected areas where relevant).

- The maintenance of the conservation status of water-dependent habitats and species protected under the Birds and Habitats Directives may require flow conditions which are different or go beyond the one required for the achievement of GES or maintenance of HES. These specific requirements should be identified and considered in the implementation of the different steps of WFD.

4.1. Hydrological regime in ecological status assessment

As seen in Chapter 2, the hydrological regime is a variable of aquatic ecosystems strongly correlated with many physico-chemical characteristics such as water temperature, channel geomorphology, and habitat diversity, which are critical to preserving the ecological integrity of aquatic ecosystems (Poff *et al.*, 1997).

More precisely, hydrological regime is one of the hydromorphological quality elements supporting the biological elements and should therefore be taken into account for the classification of ecological status. As indicated in the CIS Guidance N°13 on classification of ecological status, the values of the hydromorphological quality elements must be explicitly taken into account when assigning water bodies to the high ecological status class. For the other status classes, the hydromorphological elements are required to have "conditions consistent with the achievement of the values specified for the biological quality elements." and the WFD does not require to explicitly take them into consideration when assigning water bodies to the good, moderate, poor or bad ecological status which may be made on the sole basis of the monitoring results for the biological quality elements (and also, in the case of the good ecological status the physico-chemical quality elements). This is particularly valid when the set of monitoring results for the biological quality elements accurately covers and reflects all pressures for anthropogenic activities on the status of the water body.

However several reviews have demonstrated that, although biology in general is strongly affected by hydrology, most of the methods developed so far for the assessment of biological quality elements either:

- are largely insensitive to main hydrological alterations (see e.g., Poff and Zimmerman 2010, Friberg *et al.*, 2011, Demars *et al.*, 2012, Friberg 2014).

- respond to many different pressures whose respective contribution may be difficult to apportion. As an example, alteration of fish community composition can be linked to a hydromorphological alteration but also to massive restocking, angling or introduction of alien species.

These limitations have been reported in detail in the FP7 REFORM Project (Rinaldi *et al*., 2013): only 24% of the methods developed for macrophytes, 21% for benthic invertebrates, and 40% for fish are sensitive to flow modifications. Available metrics for phytobenthos do not detect hydromorphological alterations. This reflects the fact that most of these assessment methods were historically designed to assess the overall water quality impairment, mostly in terms of organic pollution (Friberg, 2014, Bradley *et al.*, 2012).

There is presently a strong need for further developments of biological methods to provide metrics more specifically sensitive to hydrological pressures and alteration of flow components (magnitude, frequency, duration, timing and rate of change). About 69% of the studied European freshwater fish species show a significant response to hydromorphological pressures (Friberg *et al.*, 2013). Metrics using size and age structure of populations are particularly responsive to flow alterations. Similarly, benthic macroinvertebrates indices have been developed (e.g. LIFE index, Extence *et al.*, 1999) and specific taxa show significant response to flow alteration. These kinds of methods have a clear potential for being further developed.

Where biological assessment methods sensitive to hydrological pressures have not been developed and implemented yet, monitoring results of biological quality elements alone are not sufficient to guarantee that hydrological pressures have no significant impact of water body status as normatively defined by Annex V 1.2 of the WFD. This potential flaw is particularly important to be considered in situations where all biological quality elements indicate a good status whereas data on hydrological pressures, and/or data from hydrological monitoring indicate that the water body is subject to a significant alteration of the flow regime. Classifying such a water body as good status may result in an overestimation of the ecological status that would not be in line with the WFD. In case such methods are not available yet, Member States should urgently develop them, providing metrics more specifically sensitive to hydrological pressures taking into account the relationship between hydrology, morphology and the biological impacts. Evidence of severe hydrological alteration should trigger appropriate monitoring (operational or investigative) and action to significantly mitigate the impact.

> *A case study (5, UK, Tummel) compares classification results of ecological potential using hydrological and biological criteria in the River Tummel (Perthshire, Scotland) subject to hydromorphological alteration due to hydropower generation facilities and which is as such designated as a series of HMWB. Using new e-flow standards produced in the UK it would be classified as poor or bad ecological potential because it does not meet the hydrological criteria. Application of existing WFD biological classification techniques for ecological status demonstrated that the River Tummel site would probably be of good ecological status or higher if classified using biological evidence rather than hydrology. This case study highlights the conflicting results which are a consequence of the lack of fully defined ecological metrics which are sensitive to flow pressure. The use of real data from local reference sites is appropriate to important site-specific investigations to overcome the shortcomings of standard classification tools.*
>
> *See also CS 6 (IT) referenced in section 6.3.*

4.2. Non deterioration in status

As a general principle, ensuring non-deterioration in the status of water bodies requires that any new significant alterations in hydrological regime should be actively prevented.

This consideration is particularly important for water bodies initially classified in high ecological status where according to Annex V 1.2.1 of the WFD "*there are no, or only very minor, anthropogenic alterations to the values of the hydromorphological quality elements from those associated with undisturbed conditions*". For rivers, this is translated into the definition of hydrological regime under high status: "*The quantity and dynamics of flow, and the resultant connection to groundwaters, reflect totally, or nearly totally, undisturbed conditions.*"

Consideration for Eflows is particularly appropriate to ensure non deterioration in case of a new project proposal which would alter the hydrological condition in a water body. In these cases, the definition of Eflows is needed to be able to assess *ex ante* the impact on biology and whether GES would be maintained or deteriorated, in a scientific based, transparent and reproducible way.

The RBMP could include operational methods to define 'nearly totally undisturbed' quantity and dynamics of flow which should reflect the most up-to-date scientific knowledge. As an illustration UK TAG Guidance on Environmental Standards (UK TAG, 2008) set the flow targets for river in HES as no more than 5% deviation from natural flows when they are lower than Q95 (flow expected to be exceeded 95% of the time within a long-term record), and no more than 10% deviation from natural flows otherwise.

In England and Wales this was interpreted into the following guidance for assessment of the hydrological regime component of river surface water bodies.

Four categories of anthropogenic influence are tested independently, with the final outcome determined by the worst case result (one out all out). These four tests are:

- Actual abstraction within 5% of Q95
- Actual discharge within 5% of Q95
- Total surface area of reservoir must be less than 1% of upstream catchment area
- Urban and sub-urban area less than 20% of upstream catchment area and urban area must be less than 10% of upstream catchment area.

4.3. Eflows to achieve good ecological status (GES)

The WFD does not specify the flow regime required to achieve the good status but requires that the flow regime should provide conditions '*consistent with the achievement of the values specified for the biological quality elements*'. The hydrological regime deviates from the nearly natural range but is sufficiently close to it not to impact biological quality elements beyond the values specified for GES.

Eflows as an hydrological regime consistent with GES shall ensure the good functioning of the ecosystem according to river type-specific biological conditions. This means that hydrological regime values identified should be appropriate for the water body type to which they apply.

Possible methods to define such a regime are described in section 7.1.

4.4. Eflows and conservation objectives in BHD protected areas

The standards required to achieve the objective for a protected area are the biological, physico-chemical and hydromorphological standards in surface water and groundwater that are necessary to support the achievement of the conservation objectives that have been established for those areas. Article 4(2) of the WFD states that where more than one objective applies to a water body, the most stringent objective shall apply. It is therefore necessary to check whether the flow which is consistent with the achievement of GES (or the non-deterioration of HES) in the water body is sufficiently close to undisturbed conditions in order to support the achievement of the specific objective of the protected area.

The register of protected areas in the river basin management plans (WFD Art. 6) covers any Natura 2000 site ('special areas of conservation' and 'special protection areas' as respectively designated under the Habitats and Birds Directives) when one or more habitats and species[6] directly dependent on the status of water and the presence of these species or habitats has been the reason for the designation of that protected area. There is wide range of types of water dependency amongst Natura 2000 habitats and species. Frequently asked questions on the relationship between the WFD and the Nature directives have been addressed in a document prepared by DG Environment[7].

Table 6 sets out ecological criteria used to identify those habitats and species likely to be directly dependent on the status of water.

Table 4.1: Ecological criteria used in UK for identifying Natura 2000 Habitats and Species that are directly dependent on status of water - Source: WFD CIS (2003b)

	Natura 2000 SPECIES		Natura 2000 HABITATS
1.a	Aquatic species living in surface waters as defined in Article 2 of the Water Framework Directive (e.g. bottle-nose dolphin, freshwater pearl mussel)	2.a	Habitats which consist of surface water or occur entirely within surface water, as defined in Article 2 of the Water Framework Directive (e.g. oligotrophic waters; estuaries; eelgrass beds)
1.b	Species with at least one aquatic life stage dependent on surface water (i.e. species that use surface water for breeding; incubation, juvenile development; sexual maturation, feeding or roosting - including many Natura bird and invertebrate species)	2.b	Habitats which depend on frequent inundation by surface water, or on the level of groundwater (e.g. alluvial alder wood, blanket bog, fens)
1.c	Species that rely on the non-aquatic but water-dependent habitats relevant under 2.b and 2.c in the habitats column of this Table (e.g. Killarney fern).	2.c	Non-aquatic habitats which depend on the influence of surface water - e.g. habitats reliant on the spray or humidity caused by a surface water body (bryophyte-rich gorges)

Article 2(2) of the Habitats Directive (HD) specifies that measures taken in Natura 2000 sites '*shall be designed to maintain or to restore, at a favourable conservation status, natural habitats and species of wild fauna and flora of Community interest*'. The conservation status will be taken as '*favourable*' for habitat and species when criteria set out in Article 1 (e) and 1 (i) are met (table 4.1).

Article 6(1) of the HD specifies that the necessary conservation measures have to correspond '*to the ecological requirements of the natural habitat types of Annex I and the species in Annex II present on the sites*'. Although the Habitat Directive does not contain any definition of the '*ecological requirements*', the purpose and context of Article 6(1) indicate that these involve all the ecological needs of biotic and non-biotic factors required to ensure the favourable conservation status of the habitat types and species, including their relations with the environment (air, water, soil, vegetation, etc.)(CEC, 2000).

Flow regimes are most generally significant for the conservation of water-dependent species, and therefore the definition of ecological flows for water bodies included in such a protected area have to be consistent with the achievement of the favourable conservation status for the relevant species and habitats.

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[6] This provision refers to Annex I aquatic habitat types or Annex II aquatic species under the Habitats Directive (HD) or with water-dependent bird species of Annex I of the Birds Directive

[7] http://ec.europa.eu/environment/nature/natura2000/management/docs/FAQ-WFD%20final.pdf

A Case Study (7, Scottish Natural Heritage, Pearl Mussel) explains Eflows requirements of the freshwater pearl mussel (Margaritifera margaritifera L.), an endangered species, with only a few sustainable populations. The best examples in EU countries are now protected as 'special areas of conservation' under the EC Habitats Directive. Pearl mussels have demanding environmental requirements, including the presence of salmonid hosts for the larval stage, low nutrient concentrations and relatively stable, well-sorted substrates. Flow regimes are also known to be critically important, directly and indirectly, yet there is little information on what constitutes 'ecological flows' for pearl mussels.

A case study (8, IT, crayfish) describes a definition of ecological flows based on the requirements of the White-clawed Crayfish (Austropotamobius pallipes) an endangered species included in Annexes II and V of the Habitat Directive (92/43/EEC). Local Italian populations have significantly decreased over the last decades, and are currently located in streams with high ecological status. Using a meso-scale habitat simulation model (MesoHABSIM) and time series analysis, detailed schemes of flow management were defined to represent habitat changes over time and to identify stress conditions for A. pallipes created by persistent limitation in habitat availability. Such small streams may not have available ecological and flow data, and the presented methodology provides a tool for establishing flow recommendations where few are currently available

See also CS9(EL) referenced in section 7.1.2.

5. Assessment of hydrological pressures and impacts

This chapter is intended to deliver guidance for the assessment of the hydrological pressures and impacts performed as part of the analysis required under Article 5 of the WFD and it periodical review.

It builds on the review of several methods and approaches to assess hydrological pressures, assessing their advantages and limitations and proposes criteria to assess the significance of the changes in the hydrological regime and their impact on ecological status.

Key messages for this chapter

- Article 5 analysis should carefully assess the significant pressures altering the flow regime which result in an impact on biology likely to contribute to the failing of environmental objectives.

- Ecological impacts of hydrological alterations and their significance should be ultimately assessed with biological indicators built on monitoring data that are specifically sensitive to hydrological alterations.

- In case the available biological metrics do not detect hydrological pressures or are not specific enough to isolate their contribution to the overall impact on the status, and because hydrological regime is well acknowledged as a key driver for river ecosystems quality, the evaluation of the significant impact of hydrological pressure can rely to a large extent on an assessment of hydrological alterations of the river flow.

- Most severe hydrological alterations can in many cases already be detected with tools considering the extent of the pressures or the spatiotemporal alteration of habitats.

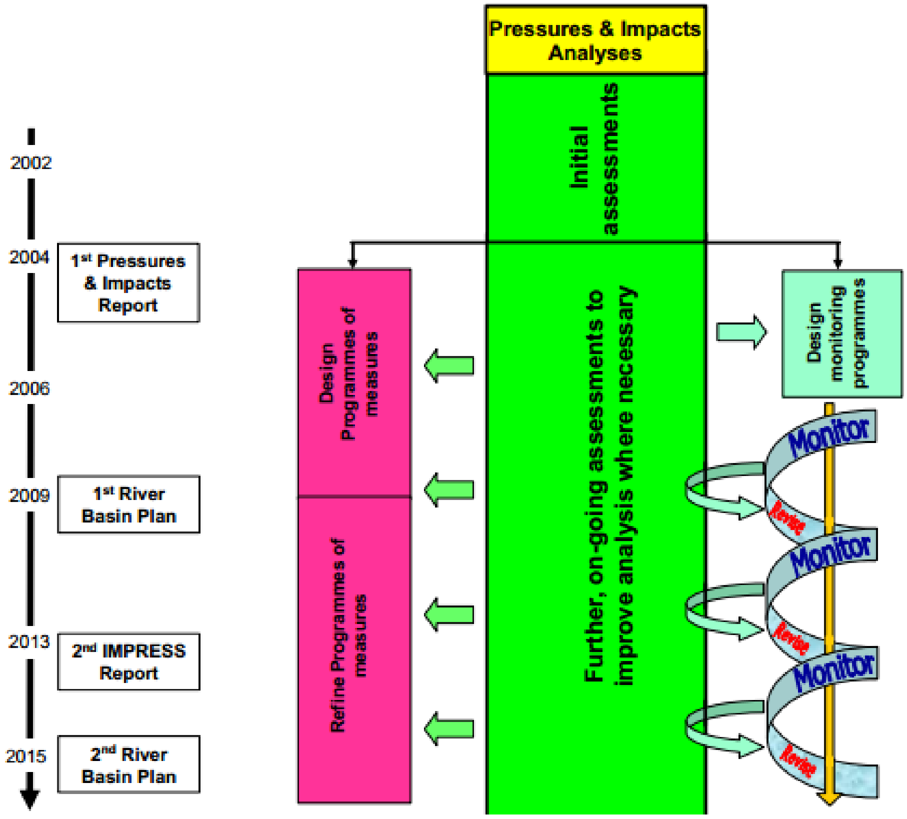
5.1. Assessment of hydrological pressures and impacts in the planning cycle

WFD introduces on its Article 13 a 6-yearly cycle of river basin planning, requiring that the river basin management plan (RBMP), started in 2009, should be revised and updated in 2015, 2021 and so on (Figure 5.1).

In each planning cycle, previously to each RBMP, and as established in Article 5 of the WFD, a revision of the analysis of pressures and impacts and a risk assessment should be performed in order to determine "if" and "which" significant pressures are likely to compromise the achievement of the environmental objectives, defined under the Article 4 of the WFD.

The review of pressures and impacts analysis is a key element of the planning process, being required to the design of monitoring programmes (Article 8 of the WFD), for the definition of the environmental objectives (Article 4 of the WFD and for the development of the programmes of measures (Article 11 of the WFD).

Figure 5.1: Pressures and impacts analyses are a key element of the planning cycle. SOURCE: WFD CIS, 2003c.



According to Annex II 1.4 of the WFD, this Article 5 analysis should explicitly include hydrological pressures through:

- the *"Estimation and identification of significant water abstraction for urban, industrial, agricultural and other uses, including seasonal variations and total annual demand, and of loss of water in distribution systems"*;

- the "*Estimation and identification of the impact of significant water flow regulation, including water transfer and diversion, on overall flow characteristics and water balances*".

This analysis should use the monitoring data collected from surveillance and operational monitoring programmes, benefiting from the better current knowledge on the relationship between pressures and impacts and ecological status. Key recommendations for this analysis are included in the CIS Guidance No.3 (WFD CIS, 2003a) and notably about the Driver, Pressure, State, Impact, Response (DPSIR) analytical framework to be used. Applied to hydrological pressure, the DPSIR includes the following steps:

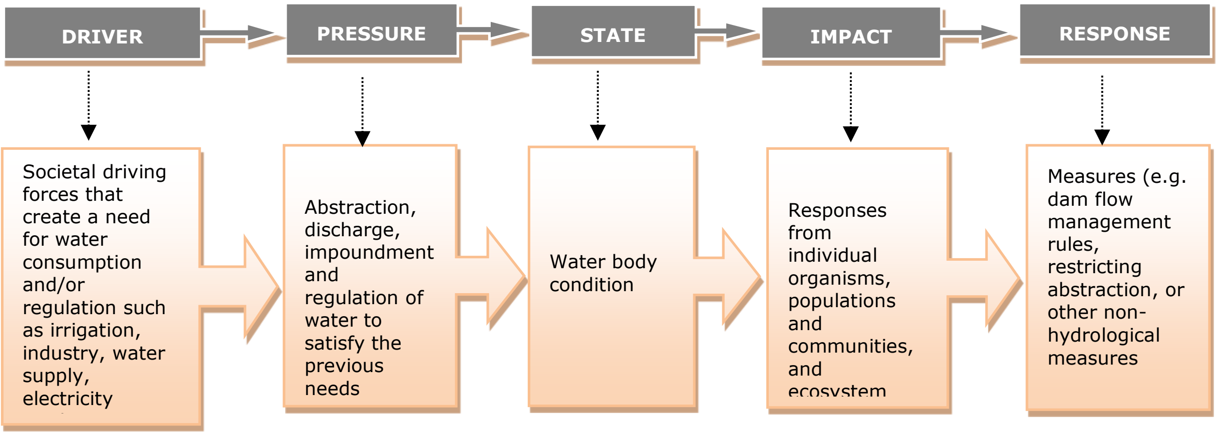
a) Description of the "driving forces" on hydrology;
b) Identification of the hydrological pressures with possible impacts on the water body status, by considering their magnitude and the water body susceptibility to those pressures;
c) Assessment of the impacts resulting from the hydrological pressures;
d) Evaluation of the failure risk to meet the water body environmental objectives.

The assessment of hydrological pressures on a water body should take place when at least one of the ”driving forces” potentially responsible for alterations on the hydrological regime is present in this water body or in a groundwater bodies whose outflows contribute to the river flow, or in water bodies upstream in the catchment, as described in Table 5.1 and ilustrated in Figure 5.2. In particular, this assessement should be done downstream of major surface abstractions or flow regulation structures, or by default at, or near, the downstream end of a water body or group of water bodies, preferably at gauging stations. This assessment should preferably be carried out by comparing the hydrological regime before and after major abstractions, construction of flow regulation structures or land use changes through a statistical analysis of daily flow time series.

Table 5.1: Driver, Pressure, State, Impact, Response (DPSIR) analytical framework applied to the hydrological pressures and impacts - Based on: WFD CIS, 2003c, Bradley *et al*., 2012.

Term	Definition
Driver	An anthropogenic activity creating a water demand that may affect the hydrology such as agriculture (irrigation), industry, water supply, electricity production, etc.
Pressure	The direct effect of the driver such as abstraction and impoundment of water to satisfy the water demand: • direct abstraction (e.g. groundwater and surface water abstraction, and run-of-river hydropower dam); • seasonally varying abstractions (e.g. spray irrigation); • reservoirs for water supply, hydroelectric power generation, other water uses of flood mitigation; • water transfers to other water bodies, subcatchments, river basins or river basin districts; • pumped storage reservoirs.
State	Effects of the pressures on the physical environment: • direct hydrological effects that result from the pressures; • hydraulic effects that result from hydrological changes; • direct or indirect geomorphological effects (incl. erosion-sedimentation); • changes in water quality (e.g. temperature, nutrient and sediment loads); • combination of these (alongside other physical-chemical properties), creating the habitat state in which aquatic organisms live which is the principal link between the pressures exerted by human water use and aquatic organisms.
Impact	Responses of individual organisms, populations and communities and ecosystem functions.
Response	The measures taken to improve the state of the water body, such as Eflows, overall water allocation and specific abstractions rules, dam flow/sediment management rules, or other non-hydrological measures, such as habitat improvement)

Figure 5.2: Application of the DPSIR framework to hydrological pressures and impacts
Adapted from Bradley et al., 2012.



5.2. Methodologies to assess hydrological pressures and impacts

The inventory of pressures is likely to contain many that have no, or little, impact on the water body status. The WFD only requires "significant" pressures to be identified, where significant, according to CIS Guidance No.3 (WFD CIS 2003c), means that the pressure contributes to an impact that may result in the failing of an environmental objective.

As stated in Chapter 2, structure and functioning of aquatic ecosystems is largely dependent of the flow regime. Significant changes in flow characteristics such as magnitude, seasonality, duration, frequency, rate of change, and in intra-annual and inter-annual variability of the flow regime are likely to cause significant impacts on water bodies ecology (Richter *et al*., 1996; Poff *et al*., 1997; Junk *et al*., 1989; Arthington, 2012). The analysis of hydrological pressures should identify significant changes in the key flow components that may involve a risk of failing environmental objectives.

5.2.1. Identiying and assessing the pressures

The first step of the analysis consists of identifying pressures on the hydrological regime which are the most likely to lead to an alteration of the ecological status.

As indicated in Annex II 1.4 of the WFD, this assessment should start with an inventory over the entire river basin of:

- all *significant water abstractions for all uses, with detailed data on their seasonal distribution and inter-annual variations*;

- all *significant water flow regulation, including water transfer and diversion;*

- all changes in *land use pattern*s which could have a significant effect on the hydrological regime.

This information should be collected with the exact location in the water body, also considering water bodies upstream.

Assessment of significance of these pressures will require this information to be combined with monitoring data which will inform about the extent of impacts in terms of altered hydrological regime and biological communities. However in some cases, a basic assessment can help in identifying the areas where major and severe impacts are likely to occur, such as:

- Water scarcity indicators
- Inventory of abstractions and regulation structures

In France, the first step is founded on the risk with a relational multi-scale system for auditing the hydromorphology of rivers: the SYRAH-CE audit system (Chandesris *et al.*, 2008 and Valette *et al.*, 2012) has been used to first assess at large scale the risk of hydrological alteration using available data such as inventory of dams, weirs and irrigation abstractions. This tools helps focus the analysis at a smaller scale onto areas where high probabilities of impacts are identified (Figures 5.3 and 5.4).

Figure 5.3: Pressure and physical damage risk variables as risk of hydrological alteration
Source: Chandesris *et al.*, 2008; Valette *et al.*, 2012.

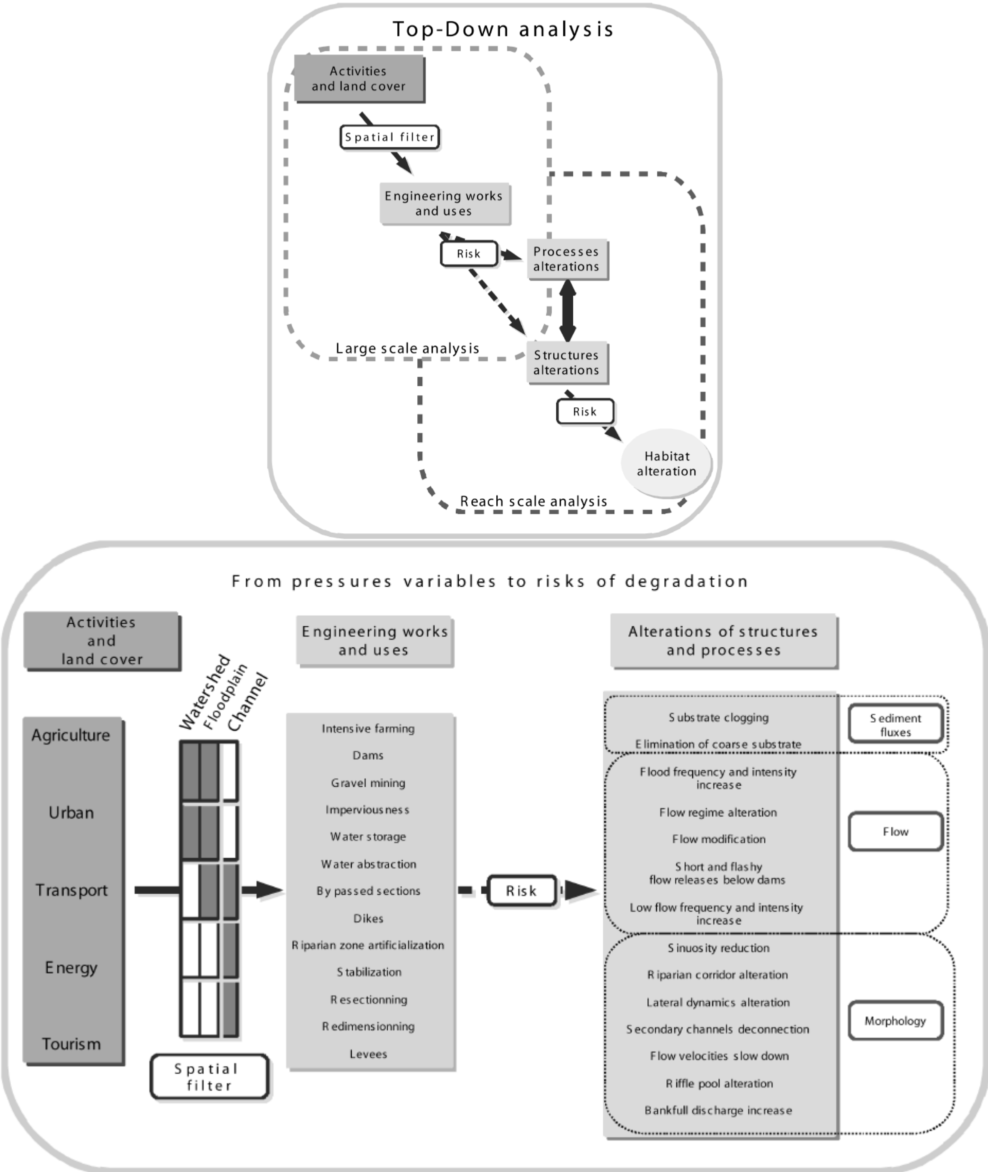
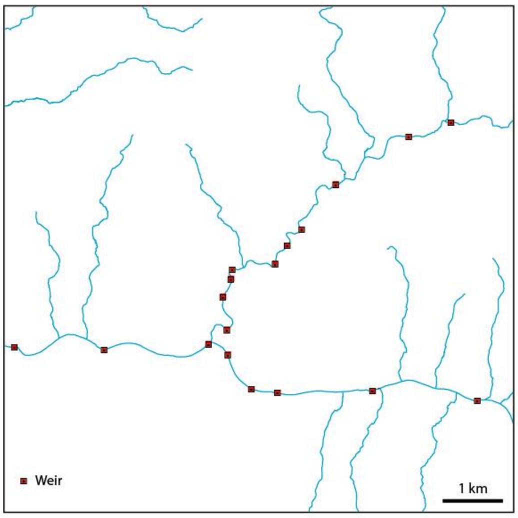
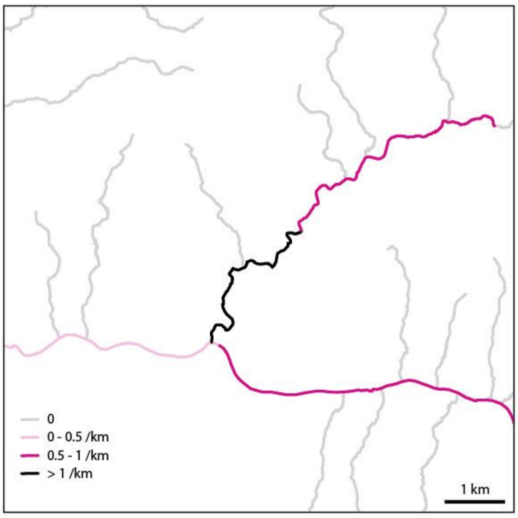


Figure 5.4: Example of mapped results using SYRAH-CE system for the hydrological alteration by the analysis of engineering works and uses. (Source: based on Chandesris *et al.*, 2008).





Generally, a first evaluation of pressures can be derived from some basic criteria (LAWA, 2002, in WFD CIS, 2003a) such as:

- volume of water abstracted (without recirculation),
- height of the dam/weir, as a surrogate of the regulation capacity,
- length of the diversion stretches

A Case Study (10, UK, HES) describes the four tests developed in the UK to assess 'high hydrological regime' (consistent with high ecological status) which is part of identifying WBs at high ecological status. These tests consist of GIS-based modelling and consider standards for abstraction, discharges, reservoir land use in the upstream catchment area and urban land use in the upstream catchment area. The use of the four tests to determine high hydrological regime can be replicated in other areas. A substantial amount of operational work is required to form a useable baseline of flow, artificial influence and land use data. Once this data is in place, tests can be automated and run quickly. In the UK, maintaining consistent databases since 2009 has allowed the reprocessing and direct comparison with interim classifications.

Although these approaches cannot inform precisely about the impact on the status, they allow for a general overview that can inform about e.g. the most critical places where to take urgent actions, and the areas where developments of hydrological monitoring are to be prioritised.

5.2.2. Assessing the alteration of the flow regime

The WFD explicitly acknowledges the importance of the flow regime for the status of aquatic ecosystems and include it as one of the key elements supporting biological elements in the classification of the ecological status. As seen in chapter 2, the hydrological regime (both in terms of quantity and dynamics of water flow) is a control over biota via habitat formation (Poff *et al.*, 1997; Richter *et al.*, 1997; Bunn and Arthington 2002; Petts, 2009). The analysis of relevant flow components and their alteration can therefore be used to derive reliable indicators/metrics of hydrological impact on the aquatic ecology and biotic communities (Bradley *et al.*, 2012). Therefore analysis of the impact of hydrological alterations can be reliably supported by a statistical analysis of the available hydrological data in actual and undisturbed conditions with the appropriate indicators/metrics.

Although the scientific community agrees on the basic components of the hydrological regime to be assessed (Bussettini *et al.,* 2011), relatively few methods exist for the identification and quantification of hydrological regime alteration at both European and international level. In fact, most of the available methods analyse five main components of the hydrological regime (magnitude, seasonality, duration, frequency, rate of change) related to the understanding of the ecological response to hydrological changes, and consider the intra-annual and inter-annual variability of the flow regime (Richter *et al*., 1996; Poff *et al*., 1997; Junk *et al*., 1989; Arthington, 2012; Rinaldi *et al*., 2013).

A comparative analysis of the assessment methods for hydrological regime alteration was done on the REFORM Project[8], considering the characteristics of the methods (source of information/data collection, spatial and temporal scale, river typology, type of assessment, reference condition, predictive ability, strengths/gaps, connection to ecology) and the recorded features (hydrological conditions, flow regime metrics, assessed pressures). Most of these methods combine the assessment into a final (or multiple) index and define boundaries above which the hydrological alterations constitute a significant pressure (Table 5.2).

Table 5.2: Hydrological assessment methods.
Based on: Rinaldi *et al.*, 2013.

Method	Code	Country	Reference
The Indicators of Hydrologic Alteration/ Range of Variability Approach	IHA	USA	Richter *et al*. (1996; 1998)
Hydrological Condition Assessment	HCA	USA	OWEB (2000)
Hydrology Driver Assessment Index	HAI	South Africa	Kleynhans *et al*. (2005)
Dundee Hydrological Regime Alteration Method	DHRAM	Scotland	Black *et al*. (2005)
Hydrologic Index Tool)	HIT	USA	Henriksen *et al*. (2006)
HIDRI - Protocolo 3: Cumplimiento de caudales de mantenimiento	QM - HIDRI	Spain	Munné *et al*. (2006)
Histogram Matching Approach	HAI	Taiwan	Shiau and Wu (2008)
Indices de Alteracion Hidrologica en Rios -	IAHRIS	Spain	Fernandez Yuste *et al*. (2008)
Indice di Alterazione del Regime Idrologico	IARI	Italy	Ispra (2011)

One of these methods, the Indicators of Hydrologic Alteration (IHA) was proposed by Richter *et al*. (1996, 1997, 1998; Poff *et al*., 1997) to assess the degree of hydrologic alteration attributable to anthropogenic changes on rivers and lakes (Table C.1 in

[8] http://www.reformrivers.eu/

annex C). This approach has been applied worldwide and most of the European methods are based on all, or on some, of the IHA (Rinaldi *et al*., 2013). The number of parameters can be reduced by identifying a set of adequate and non-redundant indices (Olden and Poff, 2003); as an example, see selected IHA for UK proposed by UK TAG (2008) and Acreman *et al.*, (2009) on table C.3 in annex C). The IHA includes 32 hydrologic parameters to characterize statistical attributes of the flow regime relevant to the ecosystem functioning (Annex C.1).

The method includes a "Range of Variability Analysis", using the Hydrologic Alteration Factor (HFC), perfomed for each one of the parameters. This analysis allows an effective comparison between "pre-impact data" and "post-impact data" and the assessment of the degree of alteration of the natural flow regime attributable to anthropogenic changes on rivers and lakes (Richter *et al*., 1996, 1997, 1998; Mathews and Richter, 2007). Although most of the literature relating to this method do not propose limit values, some authors propose thresholds for a set of selected IHA (e.g. Holmes *et al.,* 2007; UK TAG, 2008).

More recently, another set of selected indicators of hydrologic alteration were proposed for Spain: Indicators of Hydrologic Alteration in RIverS (IHARIS) (Martínez Santa-María and Fernández Yuste, 2010a,b) (Annex C.2). Each IHA varies between 0 and 1, considering 5 classes, as defined in the WFD. These indicators are aggregated in the Global Alteration Indicator (IAG), also varying between 0 and 1 and with 5 classes. The hydrologic alteration is assessed against criteria established on the Spanish Hydrologic Planning Instruction.

Both methods allows a quite accurate evaluation of the changes in the hydrological regime, although IHARIS does not consider flow change rates. The main limitations to their application are:

- requirement of long flow time series before and after water abstractions/construction of the flow regulation structures, with at least 15 years;
- small-scale hydrological alterations (e.g. hydropeaking) are not assessed, and
- groundwater/surface interactions are only indirectly considered, via the evaluation of baseflow.

In a broad sense, these methods use indicators derived by quantitative, statistical or physically based models. This implies the use of existing large data sets and long-time series, which represent the main limitation; in particular, the application of such methods to ungauged streams is problematic. If models are applied when data are not available or to infill incomplete data series, the problem of uncertainties that can affect the estimation should be carefully considered. Moreover, these methods often do not take into account small-scale hydrological alterations (e.g. hydropeaking) as well as groundwater/surface interactions, apart from an indirect assessment through low-flow analysis (Rinaldi *et al*., 2013). The calculation of a large number of hydrological parameters is sometimes also considered a limitation, however the existence of specific software, to either IHA[9] or to IHARIS[10] and online training, namely for IHA[11], facilitates the application of these methods.

[9] Can be downloaded at:
https://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofhydrologicAlteration/Pages/indicators-hydrologic-alt.aspx

With a different approach, the **European Standard on determining the degree of modification of river hydromorphology** (CEN, 2010 - Table 5.3) provides a guidance on appraising the quality of rivers based on the set of hydromorphological features, including the hydrological regime. It sets out scoring systems to assess hydrological changes, considering five classes and using quantitative data; it also suggests suitable sources of information which may contribute to characterize the modification of hydromorphological features. Focusing especially on human pressures that affect rivers, it may provide a first useful framework for assessing the extent of hydrological alteration.

Although relevant to the WFD, this standard is not principally designed for WFD assessments and its five classes cannot be directecly related to the ones of ecological status. As with some of the previous methods, it does not include the flow change rate.

Table 5.3: Quantitative criteria to assess the departure from naturalness of the flow regime (1 – discharge near natural to 5 – Discharge greatly altered) - Source: CEN, 2010.

% days flow different from natural in spring, summer, autumn or winter (worst)	<20	20-<40	40-<60	60-<80	≥80
<5% decrease or <10% increase in flow	1	1	1	2	2
5-<15% decrease in flow or 10-<50% increase in flow	1	2	2	3	3
15-<30% decrease in flow or 50-<100% increase in flow	1	2	3	3	4
30-<50% decrease in flow or 100-<500% increase in flow	1	2	3	4	5
≥50% decrease in flow' or ≥500% increase in flow	2	3	4	5	5

Methods to assess the impacts of hydropeaking are fewer and mainly based on the amplitude of inter-hourly – intra-hourly oscillations in discharges (e.g. Zolezzi *et al*., 2009). In France, a recent study focused on the role of hydropeaking (Couret *et al.*, 2014) collected and analysed 490 years of hydrological data influenced by hydropeaking in order to determine an aggregate indicator of hydrological disturbance at water body.

A Case Study (11, IT, Arno) aims at producing useful outputs and testing the feasibility of hydrological indicators (extracted from the approved Water Balance Plan) by comparing them with "Minimum Vital Flow" data and a first approximation of Eflows in order to assess pressures and the gap from GES conditions. Some of the parameters proved to be useful for such a first screening, though further analysis is needed for the definition of Eflows.

5.2.3. Deriving significant threshold from biological impacts

The assessment of significance of hydrological alterations should ultimately consider the extent to which the pressure impacts biological communities and is likely to prevent the achievement of good ecological status, and specific requirements of protected areas where relevant. Where biological monitoring data are available and indicate that some biological quality elements are below good status, then results for the different metrics should be checked to find out whether this can be linked to a

[10] Can be downloaded at: http://www.ecogesfor.org/IAHRIS_es.html

[11] Available at: https://www.conservationtraining.org

hydrological alteration, i.e. if the metrics which are sensitive to hydrological pressures are altered.

Ideally, as biological assessment methodologies should allow the detection of all significant pressures, a water body where all biological indicators are in good or high status could be considered as not impacted by any significant pressure including hydrological ones. However, as explained in section 4.1, several reviews have demonstrated the limitations of currently available methods for the assessment of biological quality elements under the WFD as regards hydrological alterations. Therefore in the current development stage of biological methods, monitoring results of biological quality elements alone are not sufficient to guarantee that hydrological pressures have no significant impact of water body status or that the failure in good ecological status is due to hydrological pressures.

As a result, the biological impact of the alteration of flow regime should also rely on other ecological parameters of habitat quantity, quality as well as spatial and temporal distribution (Bradley *et al.*, 2012; Parasiewicz *et al.*, 2012) sensitive to flow alterations and enabling source apportionment between different pressures, as already developed and used by some Member States. In addition, hydromorphological conditions in a water body or river reach can strongly be influenced by upstream interventions and processes, and usually responds in a delayed way to processes and interventions within the catchment. As a result, understanding hydromorphology at the reach scale requires an understanding of current and past processes and interventions at larger spatial scales, such as the river basin (Gurnell *et al.*, 2014).

In **UK**, a **set of standards for river flows** were developed (table 5.4) with the following objectives: i) assess the risk of deterioration in ecological status that is posed by recommended changes to river flows; ii) estimate the status of rivers already subject to flow alterations in cases where no suitable biological methods are available to assess directly the impact on ecological quality; and iii) inform investigations into the potential causes of biological damage, by comparing the degree of alteration to river flows with the results of assessments of ecological quality.

The standards are expressed as the percentage of the natural flow that may be abstracted without a significant risk of damage to the ecology of rivers. Different percentages apply depending on the flow, with higher percentages used for higher flows.

Table 5.4: Water Resource standards for good ecological status in Rivers. Source: UK TAG 2008.

Natural Flows	Above QN60	Above QN 70 and less than QN60	Above QN95 and less than QN70	Less than QN95
Acceptable abstraction (%percentage of the natural flow)	20% - 35%	15% - 30%	10% – 25%	7.5% - 15%
	(depending on river type and season)			

A Case Study (12, UK, EFI; see also Case Study 13, UK, RBMPs) describes the Environment Flow indicator (EFI) that is used in England and Wales to indicate where flows in surface water bodies support or don't support good ecological status (GES). There are a number of learned lessons from the development and application of the EFI and previous flow objectives in Abstraction management in England and Wales: (1) The use of a generic high-level flow target is simple and allows for an effective management of licensed abstraction. However, comparing its application at the local level with local data and an evidence base can lead to it being considered as inaccurate or incorrect.

> *Ideally, a system needs to encompass both a simple methodology which can be used for permitting, but which has a better link to evidence and data, which may be available locally. (2) Application of any ecological target is strongly influenced on the hydrological methodologies to which it is applied. Hydrological tools often have error margins that are greater than 'allowable' deviations in an environmental target. Agreement of things such as a 'standard' period for flow naturalisation can make the difference between whether a particular flow is considered to be 'ok' or not. (3) The use of ecological flow targets as strict standards can also be a challenging area. Applying set 'standards' can make the process very simple and transparent. However, this does not recognise the uncertainties in application of standards at a local level and making them locally relevant. Where water is in abundant supply these uncertainties are less likely to be challenged. Where there is greater competition between water users and the environment there is usually a greater pressure for any control placed to be more precise. The use of local data and analysis to inform this becomes of higher significance.*

Austria defined a set of criteria to assess the pressures and impacts of water abstraction, hydropeaking and impoundment (Mühlmann, 2010). Water abstraction is considered as a significant pressure compromising GES achievement as soon as one of the following criteria is fulfilled:

- *"MQ_{RW} < $MJNQ_t$ or NQ_{RW} < NQt nat [12];*
- *no eflow requirement in the permit or no eflow requirement for the whole year;*
- *abstraction in a reach where flow is already reduced due to an abstraction upstream;*
- *stretches that dry up over the whole year/temporarily due to the low return flow"*

As well, criteria for Hydropeaking to be considered as a significant pressure are:

- *"Downsurge/surge ratio is >1:5 in small and medium-sized bodies of water.*
- *In large rivers, any surge pressure is generally considered significant."*

> *A Case Study (1, AT, Art.5) describes the Austrian approach to the pressure and impact analysis. Austria first defined the main typical pressures affecting the hydrological regime: water abstraction, impounding/damming, water storage/hydropeaking, (river regulation/channelization). Their relevant "impact" components (most important for the biological elements) are alterations of quantity of flow, seasonal flow dynamics, daily flow fluctuations, flow velocity, water depth /wetted area. In a first rough estimation a panel of experts sets values for the parameters mentioned indicating 3 levels of impacts: 1. Values by which the achievement of GES would be ensured with very high confidence; 2. values which might lead to a failure of GES and 3) values which would mean a*

[12] MQ_{RW} (average residual flow at water intake): average flow in an abstraction stretch directly downstream of the water intake consisting of the averaged totals of average minimum monthly surplus water at the water intake – over the entire year.

$MJNQ_t$ (average annual minimum flow): the arithmetic mean in annual minimum flow of a contiguous series of years. The respective series of years must be specified.

NQ_{RW} Lowest residual flow during the period of observation

$NQ_{t\ nat}$ Lowest daily flow: the lowest daily average flow during a time period to be specified *failure of GES in any case. In the first pressure and impact analysis (2004), information was collected on the main pressures and pressure parameters mentioned above in order to define water bodies “not at risk” (values level 1), “possibly at risk” (values level 2) and “at risk” (values level 3). Biological monitoring for water bodies at risk, and possibly at risk was performed to clarify the exact water status class. If the failing of GES was proved by biological monitoring (the biological QE/metric sensitive to hydrological alterations in particular) the information of the hydrological pressures/alterations collected in the P&I analysis was used to define the reason for failing GES and to carve out the appropriate measures (and responsible "Causer") to restore GES.*

6. Establishment of monitoring programmes

Key messages for this chapter
- Proper definition and efficient implementation of ecological flows require a significant amount of hydrological data derived from monitoring the hydrological regime; modelling approaches may to some extent supplement insufficient monitoring data.
- Monitoring programmes should be adapted to provide an improved picture of hydrological alterations and their impact on habitat/morphology and biology, and to effectively support the achievement of ecological flows.
- Sufficient hydrological information should be collected to enable estimation of the current flow regime and how it deviates from the natural flow regime.
- The development of operational hydrological monitoring should relate to the surface and groundwater hydrological pressures and be prioritised where action is likely to be needed.
- The integrated monitoring of hydrological, morphological and biological quality elements will enable the estimation of the effectiveness of flow restoration action as part of the programme of measures.
- The first step to address climate change is to know how hydrology is affected and evolves in the long-term; hydrology included in the surveillance monitoring will inform about the long-term evolution of natural flow regime.

6.1. Combining biological, morphological and hydrological monitoring

The objective of monitoring is to establish a coherent and comprehensive overview of water status within each river basin district. Following the results of the risk analysis carried out under Article 5 WFD, Member States shall ensure the establishment of monitoring networks to provide information about specific, WFD defined, biological, hydromorphological and physico-chemical quality elements enabling the classification of all water bodies. According to Article 8 WFD hydrological monitoring shall cover *"the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential for surface water bodies".*

<u>NB:</u> Groundwater monitoring, detailed in CIS guidance documents No.7 (WFD CIS, 2003e) and No.15 (WFD CIS, 2007), has an already established quantitative hydrological procedure, requiring no further adaptation to be incorporated in the concept of ecological flows. Moreover, the CIS Guidance No.18 (WFD CIS, 2009a) and Groundwater Technical Report No.6 (WFD CIS, 2011a) include specific tests to address the interactions between surface water bodies, groundwater bodies and groundwater dependent terrestrial ecosystems. This quantitative monitoring of groundwater bodies, integrated with the hydrological monitoring will provide an effective assessment framework to facilitate the assessment and application of ecological flows.

To support the application of ecological flows, monitoring should be appropriately designed/adapted to include a hydrological, together with the ecological, component (including biology and morphology). This combination will enable the derivation of more reliable and quantified relationships between biology and hydrology and strengthen the definition of ecological flows as related to environmental objectives.
Regarding flow regime, the overall purpose of a hydrological monitoring network designed according to the WFD requirements is to:

- Support the assessment of pressures (cf. chapter 5) and the gap analysis (cf. chapter 7) by providing initial information on the current hydrological situation, and reference hydrological data to enable the estimation of the deviation between conditions currently observed and the reference conditions;

- Facilitate the assessment of the effectiveness of the programme of measures; monitoring results should provide the necessary information to estimate whether the applied Eflows contribute to improve ecological status, or additional measures are required to reach GES, enabling the selection of the optimum combination of measures to achieve the WFD environmental objectives.

Small water bodies (small parts of creeks, headwaters, little rivers…) may not be specifically included in the monitoring programmes required under WFD. As Eflows are particularly important for them because of their sensitivity, specific studies for improving knowledge of their requirements may be very useful.

In the long term, the accumulative collection of hydrological data from an effectively established monitoring network, in combination with monitoring the response of the ecosystem through specific habitat/hydromorphological and biological quality elements will enable more accurate Eflows estimations, providing a sufficient level of confidence on the values of the hydrological reference conditions and changes of ecological status over time.

Monitoring programmes should incorporate biological, hydrological and morphological components with specific objectives (DPSIR approach):

Hydrological component

- To facilitate the assessment of the cause of hydrological alteration, natural or anthropogenic, based on the risk analysis carried out under article 5 WFD (DRIVERS and PRESSURES);
- To evaluate the current hydrological regime, including magnitude, timing and rate of change (STATE);
- To quantify hydrological alteration, describing the degree of divergence from historical and/or predicted (modelled) reference conditions regarding the flow regime (IMPACTS);
- To support the recommendation of a flow regime consistent with the rehabilitation of hydromorphological processing, especially achieving river connectivity, in terms of water, sediment and biota (RESPONSE).

Biological and morphological components

- To evaluate the current ecological conditions, in particular to evaluate the status of those water bodies at risk of failing good status because of hydrological pressures (STATE)
- To quantify the degree of divergence from type-specific biological reference conditions caused by hydrological alteration (IMPACTS).
- To support the recommendation of a flow regime consistent with the biological values associated with environmental objectives (HES, GES…) (RESPONSE).
- To assess the effectiveness of the applied ecological flows according to the programme of measures (STATE)

6.2. Hydrological monitoring

6.2.1. Incorporating hydrology in the WFD monitoring programmes

Hydrology, incorporated in the surveillance network, shall be monitored to provide information on long-term natural and anthropogenic changes in the flow regime, including climate change, placing them in a historical context for future reference, identifying trends and predicting impacts. This will enable a safe comparison between hydrologically altered and unimpacted sites according to risk analysis, providing the basis for the operational network, preventing possible misclassification and increasing the confidence in the identification of water bodies at risk of failing GES/GEP or good GW status due to flow-regime alteration. Natural and climate-change induced alterations are more detectable in sites with HES and to some extent also GES of the surveillance network, which do not receive additional influence from anthropogenic pressures.

For operational monitoring, the parameters used should be those indicative of the biological and hydromorphological quality elements most sensitive to the pressures to which the water body is subject. A risk-based approach should be followed in order to assess the ecological and chemical status or ecological potential of those water bodies that have been identified as being at risk of failing to meet the environmental objectives. In cases where the risk of a water body's failure to meet GES is attributed to hydrological alteration (e.g. pressures from water or groundwater abstraction, water storage and hydropower production - see also chapter 5), hydrological information from the operational network is essential to evaluate the deviation between the current hydrological regime and the estimated Eflows, as well as the effectiveness of the application of ecological flows according to the programme of measures (see chapters 7 and 8).

> *A Case Study (1, AT, Art.5) shows how a harmonised Eflows definition can streamline the risk assessment as part of the pressure and impact analysis (acc. to WFD Art. 5) and thus ensure a cost-efficient, effective and biological-impact driven monitoring programme.*

6.2.2. Site selection

Based on the recommendations of WMO (2008) and CIS Guidance No.7 (WFD CIS, 2003d), the following concepts should be considered in the design of a hydrological network to serve the purpose of the surveillance monitoring schemes according to the WFD requirements:

1. A sufficient number of monitoring sites (gauging stations) should be established along the main stems of large rivers and covering catchments of different dimensions and characteristics to permit interpolation between the sites. The exact location of each site should be governed by the specific topographic (soil, hydrogeology, physiography) and climatic diversity (mainly precipitation, temperature and evapotranspiration) with a view to being able to reconstruct the natural flow regime at any section in the river basin district. A cost-effective approach should include at least one permanent monitoring site (station) at each homogenous climatologic and physiographic region at national level.
2. Sites should be established where the water leaves the mountainous reach and above the points of water storage or abstraction to provide for a general knowledge of the evolution of the natural hydrological conditions and climate changes. Sites should also be located on the lower reaches of major rivers, above river mouths to provide information on water losses from the channel by evaporation and infiltration and on the accumulating anthropogenic hydrological impacts across the floodplain. Sites should be included at various strategic points, upstream and downstream of structures interrupting river

continuity (dams, weirs etc.) or important abstractions. Additional sites should be defined at areas where flow exhibits critical changes.

3. Particularly for temporary streams/ stream sections, sites should be placed in order to allow for a better assessment of intermittency cause, i.e. if it is due to natural reasons (e.g. downwelling, evaporation) or to water abstractions.
4. Water bodies in protected areas should be equipped with stations to monitor the achievement of the favourable conservation status for the relevant species and habitats.
5. Time series of flow quantity should be as long as possible, preferably longer than 20 years (Kennard *et al.*, 2010), in order to reflect the intra-annual and annual variability of the hydrological regime and to get the long-term tendency of the variation of hydrological regime due to natural variability and climate changes.

Reconnaissance surveys using discharge measurements, satellite and precipitation maps, aerial photographs, remote sensing and other methods to define hydrologic boundaries and to characterize streams with respect to their runoff productivity would be helpful to design a cost-effective hydrological monitoring network.

Advanced hydrological modelling may be used to extrapolate hydrological information between monitored and unmonitored river stretches, reducing the density of the hydrological network towards cost-effectiveness.

Allocation of hydrological monitoring sites at the operational network could conform to the BACI design (Before-After / Control-Intervention) (Cottinghan *et al.*, 2005; Bradley *et al.*, 2012) collecting information before and after a hydrological pressure, at control and/or reference sites and at the location of the intervention. Adaptations can be applied when a full BACI design is not economically viable, but ideally, sites should be allocated in a spatiotemporal concept, upstream and downstream of pressures in order to efficiently describe flow-regime alterations.

Member States should therefore consider already established gauging stations as candidates for the hydrological monitoring network, but if necessary, new sites should be added in water bodies affected by hydrological alteration, independently from the initial network, forming an additional hydrological monitoring scheme. The establishment of a hydrological monitoring network is not a static process, but a process of continuous evaluation and adjustment. Sites may be moved or removed and new sites may be allocated as hydrological information is accumulated, whilst keeping sufficient long-term observing stations, important to get the annual and intra-annual flow variability, and changes and trends over time.

6.2.3. Selecting key hydrological components

The hydrological components to be included in the design of hydrological monitoring programmes should address the characteristics of the flow regime defined in chapter 2.2.3 - magnitude, duration, timing, frequency and rate of change. Following WFD Annex V and CIS Guidance No. 7 (WFD CIS, 2003d); these specific hydrological components are for rivers:

- *Quantity and dynamics of water flow:* flow (magnitude, duration, timing, frequency and rate of change; Poff *et al.*, 1997), current velocity, water level

- *Connection to groundwater bodies:* surface - groundwater interactions - water table height and fluctuation

6.2.4. Monitoring frequency

According to Annex V of WFD, quantity and dynamics of water flow for rivers shall be measured continuously. Connection to groundwater bodies should be monitored at least every six months (winter - summer), adapted according to climate and geology (WFD CIS 2003d, table 3.2).

6.2.5. Monitoring equipment

River flow is measured indirectly, by establishing permanent gauging stations measuring water level (stage), which is converted to flow (discharge) using a stage-discharge relationship, often referred to as rating or calibration curve. The water level is generally measured and recorded against time using stage measuring gauges or other recording devices. The mean velocity is combined with the cross-sectional area of the river to provide a measurement of flow at points throughout the flow range at a site characterised by its ability to maintain a reasonably stable relationship (WMO 2008 and 2010; ISO, 2008).

For water bodies where a gauging station may not exist, a general overview of the characteristics of the flow regime can be obtained by installing a recording device on a stable and well defined section of the river, with minor changes on the structure of river banks and riverbed, allowing for a continuous registration of the water level during a pre-determined period. Hydropower dams might provide records of the amount of water discharged by the turbines, considering their technical characteristics and the number of hours that the power plant is working. For flood flows frequently discharged by spillways, the discharged volume can be measured by considering the spillway section and the registration of time and duration of discharge.

Connection to groundwater bodies can be measured by boreholes/wells/piezometers measuring groundwater level. For measuring groundwater levels (see further detail in WFD CIS, 2007 and 2009a) two wells should be selected downstream of the pressure. Alternatively, at least two short piezometers could be constructed and measurements acquired using a level sensor.

6.3. Assessing the effectiveness of Eflows measures

The implementation of ecological flows according to the programme of measures requires the supporting existence of an integrated monitoring programme (including biological, hydrological and morphological components) to assess its effectiveness on river ecosystem recovery and to inform whether the WFD environmental objectives are being achieved or flow adaptations and new measures are required. Although the overall target of the WFD in natural rivers is GES, this may require a long period to be achieved, considering time lags before ecosystem recovery and that the system may not respond as expected or progress to some alternative state or even may be unstable (Bradshaw 1996; Lake 2001). Possible slow ecosystem adaptation to any changes in flow is also indicated by Dyson *et al.* (2003), suggesting that monitoring, although often focused on key indicator species, should cover as many elements of the ecosystem as possible to capture any unforeseen changes, using methods/metrics sensitive to hydrological pressures.

All the above suggest that an effective monitoring programme adapted to assess the effectiveness of ecological flows on ecosystem recovery should utilize specific quality elements/indicators to capture not only the long-term ecological status upgrade but also any short-term changes indicative of a future positive ecosystem response to ecological flows.

This can be consolidated as:

1. Short-term monitoring of specific morphological quality elements. According to Annex V WFD, river depth and width variation, structure and substrate of the river bed and river continuity are accounted as morphological elements to be monitored in support to the biological quality elements. These morphological elements are indicative of the habitat availability, the unique combination of flow velocity, depth, substrate type and cover, integrated at the micro- or meso-habitat scale, which is expected to increase after the application of ecological flows.
2. Long-term monitoring of ecological status based on the biological quality elements of the WFD that show the most significant response to hydrological regime alteration and restoration. Higgins *et al.* (2011) have consolidated a large set of long-term, flow-related biological indicators.

The two monitoring strategies should be applied simultaneously. However, results may not be expected immediately after the application of ecological flows for the long-term component, although in some cases there may be response. A negative or no response of the morphological/habitat and specific biological indicators in the short term will suggest reconsideration of the programme of measures and possible adaptations of ecological flow application. Positive response will indicate that the applied programme of measures is becoming effective. The combination of the short-term positive response with the positive long-term biological response should indicate effectiveness, and a final upgrade of ecological status should be expected to ensure that the application of the ecological flows is achieving the WFD environmental objectives.

A case study (6, IT, indicators) discuss the appropriateness of different indices to monitor environmental impacts of different flow regime releases in a river based on an experimental programme carried out in 2008-2013 in alpine streams (Valle d'Aosta Region) increasingly exploited for hydropower production. Incremental Eflows releases were annually implemented and compared to assess resulting ecological improvements. A pool of indices was applied at an annual scale. Results suggested that in this context biological and physico-chemical quality elements currently used for the classification of the ecological status under WFD do not appropriately reflect the hydrological alterations and cannot support the design of suitable mitigation measures; to the contrary, approaches based hydrological and habitat availability analysis were found much more suitable to monitor effectiveness of different flow regime releases.

A Case Study (14, FR, Rhone) describes the monitoring of physical restoration of the French Rhône River that started in 1999. Due to the original characteristics of the Rhône restoration at the international level (strong physical changes in multiple sites; data-rich situation before and after restoration; collaborating stakeholders) the project was a unique occasion to test quantitative ecological predictions and monitor the effectiveness of measures. This case study provides evidence of the effects of flow restoration on habitats, fish and invertebrates in multiple sites. Observed changes confirmed quantitative predictions. The case study also provides general lessons in terms of monitoring strategies. Typically more than 4 surveys distributed over several years before and after restoration were needed to have *a chance of detecting population-level changes. These results support the idea of sustained monitoring in selected flow experiments across Europe.*

6.4. Cost-effectiveness of hydrological monitoring

Establishing an effective hydrological monitoring network often requires conciliation between the ideal solution and the requirement for cost-effectiveness. The high costs required to establish and maintain an extended number of permanently operating gauging stations at each water body could be counterbalanced by considering basic and extended networks (including principal and secondary stations) and a combination of monitoring sites with data extrapolation through hydrological/hydraulic modelling, allowing the transferability of hydrological information from monitored to unmonitored areas. For Mediterranean basins, monitoring requirements, and thus costs, are expected to be higher compared to central and northern European basins, due to high spatial and temporal variability of the hydrological regime (as a result of geological, hydrogeological and climatic factors) that causes modelling uncertainties.

The design of an effective hydrological monitoring network is generally an evolutionary process, starting with a minimum number of gauging stations and increasing gradually until an optimum network is attained. This optimum network is achieved when the amount and quality of hydrological information collected serves the objectives of each type of monitoring programme described above. Several designs for a cost-effective hydrological monitoring network have been proposed (Langbein and Hoyt, 1959) but recent approaches favour the establishment of principal gauging stations (operating permanently), secondary stations operating only long enough to establish the flow characteristics of their river basin district and special stations to measure specific inflows and outflows for particular time periods (WMO, 2010).

Many water users (e.g. water companies, hydropower operators etc.) may detain hydrological records needed for their operations or required as conditions in their permit. Developing common monitoring standards with these users and ensuring access to these data by the water authorities and possibly the general public may be a cost-effective way to increase the amount of available hydrological data.

6.5. Hydrological and hydraulic modelling

Hydrological and hydraulic models are useful and cost-effective complements to the hydrological monitoring network. Unmonitored river reaches (where no stream gauge exists) may be simulated and discharge can be extrapolated based either on the hydraulic similarities between gauged and ungauged areas (hydraulic models) or on knowledge about the hydrological behaviour of a comparable monitored river reach, in combination with meteorological data from the unmonitored areas (rainfall-runoff models).

Hydraulic models use cross-sections to simulate a specific gauged reach in terms of length, depth profile, bank width, bank height etc. and develop a stage-discharge rating curve, which can be extrapolated to ungauged reaches with similar typological and hydraulic properties.

Rainfall-runoff models are initially calibrated using meteorological and hydrological data from a gauged reach (mean daily flow, daily precipitation data, evapotranspiration, snow water equivalent and temperature). Usually, 20-years series of flow, precipitation and temperature are required to provide for statistical significance (Kennard *et al.*, 2009; Martinez Santa-Maria and Fernandez Yuste, 2010a,b). More sophisticated models also utilize cartographic information from GIS maps (Digital Terrain Models, land use, soil properties etc.). Water flow is simulated through various flow processes such as, overland flow, infiltration into soils, evapotranspiration from vegetation and groundwater flow and extrapolated according to the meteorological and cartographic properties of the ungauged reach. Velez *et al.* (2009) provide an interesting case study where flow is extrapolated for 41 basins, with only 17 of them having at least one flow gauge station.

Regarding ungauged Mediterranean river basins with high intra-annual and inter-annual hydrological variability, hydrological modelling may prove to be insufficient to simulate the hydrological regime and a denser hydrological monitoring network may be required.

7. Defining ecological flows and analysing the gap with the current situation

In water bodies affected by significant hydrological pressures, the gap between the current flow regime and the one consistent with the achievement of the environmental objectives should be assessed in order to set appropriate measures. This gap analysis consists in the estimation of the "distance" or "deviation" between the water body conditions assessed on the basis of monitoring and/or modelling results, and those consistent with the achievement of good ecological status. It requires an estimation of the ecological flow as the flow consistent with the given environmental objective for the water body taking into consideration the natural flow regime and morphology.

Key messages for this chapter

- To be consistent with the environmental objectives in article 4(1), the definition of Eflows should be the result of a technical/scientific process with no consideration of the associated socio-economic impacts. These latter impacts should only be considered when deriving the flow regime to be implemented in HMWB or water bodies subject to an exemption, consistent with the conditions set by the WFD.

- Many methods have been developed and may be used to inform the definition of Eflows, mostly differing in terms of integration of biological aspects, scale, complexity and volume of required data.

- The selection of the most appropriate method depends on resource availability (incl. monitoring data) and on the severity in the pressures. Purely hydrological methods may be a reasonable approach to cover the whole river basin; a more detailed approach will be needed to take specific actions, potentially affecting the uses, to ensure their effectiveness.

- In cases where hydrological alterations are likely to prevent the achievement of environmental objectives, the assessment of the gap between the current flow regime and the ecological flow is a critical step to inform the design of the programme of measures.

7.1. Available methodologies for estimating Eflows

Several methodologies have been developed in the scientific field to estimate environmental flows, in which three general categories are recognised; (1) Hydrological, (2) Hydraulic-Habitat, and (3) Holistic methodologies (Tharme, 2003; Petts, 2009; Linnansaari *et al.*, 2012). Commonly used methodologies within each category are reported below along with their primary reference. To contrast the pros and cons of each of the three categories, their specific attributes (i.e. purpose, scale, scope, duration of assessment, relative cost and use) are mentioned and compared in Table 7.1.

7.1.1. Hydrological methodologies

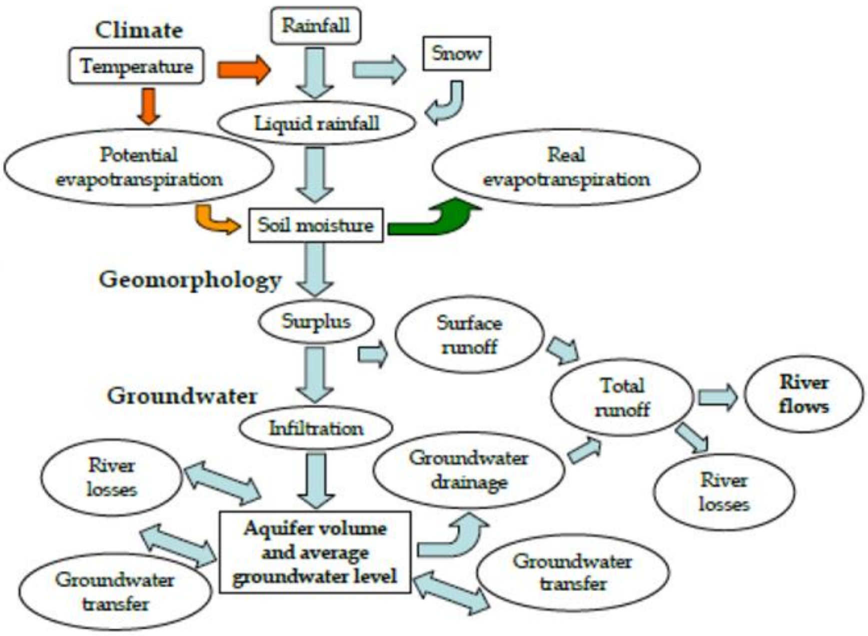
Hydrological methodologies are based on the analysis of historic (existing or simulated) streamflow data. Not operating at a species- or community-specific level, these methodologies provide an overall range and variation of flows for contemporary ecological processes and native biodiversity maintenance (Bunn and Arthington, 2002; Lytle and Poff, 2004; Doyle *et al.*, 2005).

The basic assumption is that the full range of natural variability in the hydrological regime is necessary to conserve river ecosystems. Therefore, depending on the desired level of environmental conservation, Eflows recommendations should reflect, to a greater or lesser extent, the natural flow regime (Poff *et al.* 1997).

The current application trend is getting away from methodologies that just set one minimum flow (e.g. Tennant, 1976), towards more comprehensive methodologies that consider the hydrological regime that is needed to maintain the whole system's morphological and ecological processes, e.g., the Sustainability Boundary Approach (SBA, Richter 2011).

Hydrologically-based methodologies currently represent the most widely used approaches internationally, most probably because of their ease of use and low cost (based on real or simulated stream flow data series not requiring field visits, Linnansaari *et al.*, 2012). For example, Patrical is a conceptual and distributed hydrological model for medium and large catchments. It is broadly used in Spain by water authorities (i.e. River Basin Authorities), responsible for the planning and management of both surface water resources and groundwater. Thus, the model has a conceptual formulation (figure 7.1), operates on a monthly time scale, and calculate the water flows and storages (groundwater levels) in discrete sub-units of the basin. Hydrological data from modelling have been used extensively in Spain to estimate ecological flows in the river basin districts.

Figure 7.1. Conceptual basis of the Patrical hydrological model.
Source: Pérez, 2005



Provided that a suitable streamflow record for Eflows estimation can be obtained, the hydrological methods are the simplest, quickest and most inexpensive way to provide information on Eflows, but by themselves these methodologies do not directly include any ecological and morphological characteristics and processes of rivers.

In some settings, hydrological methodologies have been suggested to be used at the planning level or to set up preliminary flow targets in low risk, low controversy situations but are not recommended for studies requiring a high level of detail (Tharme 2003; Acreman and Dunbar 2004).

Simple hydrological analyses can however be hindered by three main issues. First, hydrological metrics need to be derived from an appropriate record length with at least 15 years, being required for statistical integrity (Kennard *et al.*, 2010). Second is the problem of ''naturalizing'' the gauged flow records in catchment characterized by long-term human interference, determining flow regime in the absence of existing dams, reservoirs, diversions, and abstractions and in the current morphological conditions. Third is the issue of spatial distribution of gauging stations, which have to be located in both low- and high-order streams, capturing the hydrograph characteristics of both headwaters and main water courses.

In the context of climate change, the case study CS 15 on Arno River Basin, Italy, aims at producing useful outputs and testing the feasibility of quantitative indicators (extracted from the approved Water Balance Plan) by comparing them with Minimum Vital Flow data and a first approximation of ecological flow.

The case study CS 4 describes the legislation developed for the implementation of ecologically acceptable flows in Slovenia. The Decree prescribes the use of either one of two approaches for the determination of an Ecologically Acceptable Flow (EAF), i.e., the hydrological approach and the holistic approach. The main terms used in the determination of an EAF are: 'Mean low flow (MLF)' at the abstraction site, which is defined as the arithmetic average of the lowest annual values of mean daily flow at that site over an extended monitoring period, usually the last 30 years. The other important term is 'Mean flow (MF)' at the abstraction site which is defined as the arithmetic average of the mean annual flow values at that site over an extended monitoring period, usually the last 30 years. The hydrological approach is based on the reversibility, quantity, length and duration of water abstraction, the ecological type of watercourse, and the ratio between the mean flow and mean low flow.

7.1.2. Hydraulic-habitat methodologies

Hydraulic–habitat methodologies are based on the fact that the variability of flows acts on biota through a hydromorphological template, determining when and for how long habitats are available to aquatic and riparian communities (Petts, 2009).

Hydraulic-habitat simulation consists of 1) physical or hydraulic modelling of the river channel and 2) modelling of the biological associations with the physical environment. The latter may consider different habitat parameters, such as water depth, flow velocity, substrate composition, channel geometry, cover availability, water temperature. Thus, the amount of available habitat for biota can be determined in relation to both stream flow and channel morphological characteristics.

The physical and biological models are then combined to simulate how indices of habitat quality-quantity (e.g., the wetted area suitable for a target species) vary with streamflow. While the conceptual basis of the different hydraulic-habitat models available in literature is the same, there are differences between models (both in the physical and biological models) in the detailed calculations (Linnansaari *et al.*, 2012).

A recent in-depth review of habitat-simulation methods used for setting Eflows is provided in Dunbar *et al.* (2011). Many methodologies currently address the sustainability of communities and ecosystems within the whole river corridor. Several authors incorporated the ecological importance of floodplain and riparian habitats (Merritt *et al.*, 2010) as well as the need for high flows and floods to sustain the geomorphological dynamics of rivers (Konrad *et al.*, 2011). Moreover, to represent the intra- and inter-annual habitat variability and to identify stress conditions created by persistent limitation in habitat availability, habitat time series analysis is currently considered a key component in the definition of Eflows with hydraulic-habitat methodologies (Parasiewicz *et al.*, 2013). The ability of habitat models to simulate changes in flow and morphology qualifies them for comparative analysis of different scenarios and selection of the best available options (e.g. Parasiewicz *et al.*, 2012).

Hydraulic-habitat methodologies are often considered more accurate than the hydrological ones, and hydraulic-habitat simulations are recommended in high-risk projects (Linnansaari *et al.*, 2012). Generally, hydraulic-habitat methodologies require a considerable amount of field work and expertise to collect both the hydromorphological and biological data. They can be time consuming and expensive. However, simplified "generalized" habitat models enable cheaper applications in some states, in and outside EU (Lamouroux & Jowett, 2005; Wilding *et al.*, 2014).

It is very important to recognize that the hydraulic-habitat simulation methods estimate only the amount of habitat as a function of hydromorphological conditions, not accounting for more complex ecological and biological factors (e.g., food availability, interspecific interactions and presence of alien species).

A case study (9, EL, Gadouras) explains as temporary rivers require a particular approach in defining ecological flows, gaining special relevance episodes of cessation of flow and resulting water pools. The flow regime of River Gadouras (Rhodes Island – Greece) was modified after construction of a new dam. The objectives of the study was to identify the critical water levels in pools as a refuge for the survival of Gizani (Ladigesocypris ghigii), an endemic fish species listed in Annex II of the Habitats Directive. The methodology resulted in a flow schedule, applied by the dam operator, with relative adjustments for wet/dry periods, wet/dry years and water level fluctuations in the artificial lake. After one year of application the new flow regime was assessed by physical, biological and physico-chemical monitoring. Gizani populations were well maintained during the dry season and fish survival was ensured.

A case study (16, SE, Granö) illustrates a practical process for creating favourable hydraulic conditions for given aquatic species in River Mörrumsån which has been diverted for power production since 1959. The river stretch has potential spawning grounds for salmon and sea trout, but they would require a larger flow and physical restoration in order to reach their potential. The process of evaluating different flows was based on hydraulic habitat simulations in the river section, combined with a salmonids population model. Based on the simulations, a recommendation of a base flow was established which should potentially be combined with flow peaks, especially in the migration season.

A case study (8, IT, crayfish), already mentioned in section 4.4, *describes a definition of ecological flows* to support local populations *of the* endangered *White-clawed Crayfish (Austropotamobius pallipes). A meso-scale habitat simulation model (MesoHABSIM) was used for Eflows definition, since the approach adapts well to high gradient streams, can describe complex morphology and involves a large range of habitat descriptors.* The MesoHABSIM model emphasizes the temporal scale by statistically analysing habitat time series and establishes habitat stressor thresholds (HST) which consider not only the magnitude of an impact (i.e. the amount of diverted water), but also provided a means of quantitatively measuring duration and frequency of stress events for crayfish. Specific negative impacts of persistent limitation in habitat availability could be detected, and suitable e-flows releases proposed.

A case study (17, NL, Meuse) shows the effect of various flow regimes on the quality of a target fish species affected by strong alterations in the hydrological regime, in the context of the Meuse characterized by high fluctuations in *natural run-off, combined with abrupt fluctuations due to mismanagement among navigation, hydropower operations and water managers up- and downstream in the Meuse catchment. The river habitat simulation model showed the effects of low flows on the amount of suitable habitat for the Barbel. Reliability analysis of the model was carried out resulting in overestimates of the suitable habitat for each life stage of the target species except spawning area. Some shortcomings of the habitat method were overcome by combining with on-site information.*

A case study (18, ES, tools) illustrates the combination of hydrological and habitat simulation methods used in Spain for the assessment of Eflows. Hydrological parameters were calculated for the all the Spanish water bodies according to the technical criteria of the Hydrological Planning Instruction. Habitat simulation assessment was conducted in strategic water bodies for water allocation and/or environmental significance (10% of total). Hydrological approaches required the use of modelled natural flow data for the whole country (on a monthly and daily basis), hydro-regionalization and assessment of hydrological alteration. Habitat simulation models required intensive field works, building of habitat suitability models and physical habitat simulation software (PHABSIM, RHYHABSIM, River2D).

A Case Study (19, ES, Cantabria) explains the design of a methodology for the extrapolation of the minimum flows regime to all the water bodies of the Cantabrian river basins. This methodology combines hydrologic methods and habitat modelling methods, and starts with the monitored data of a selection of water bodies (10% from the total). The resulting minimum flows have been incorporated to the 1st cycle river basin management plans (2009-2015). The designed methodology allows the simplification of the minimum flows calculation procedure, though its results have not yet been evaluated. Out of the learned lessons, the case study considers crucial to analyse whether all regions in the river basin district are hydrologically homogeneous. If this is the case, the extrapolation factor can be calculated with the average values of all the water bodies (as it was done in the Cantabrian river basin). On the contrary, it is necessary to calculate different extrapolation factors for the separated regions in terms of hydrologic functioning.

A Case Study (20, ES, Duero-Bocos) provides insight into the use of hydraulic-habitat methodologies, and the need to ensure coherence between the indicators for status classification of the water bodies and the requirements of ecosystems and/or species linked to these water bodies e.g. in protected areas. Existing gaps should be closed by more specific studies. The case study provides information about the extent of monitoring and modelling for hydrology, and for modelling of habitats. Reference is also provided to the LIFE project MedWetRivers, addressing particular requirements in protected areas.

A Case Study (3, AT, Legal) explains how guide values for the Eflows parameters were defined in Austria for the quantity of flow. Biological limit values have been set for fish, benthic invertebrates, phytobenthos, as well as macrophytes with regard to the good ecological status class. Limit values for Eflows were defined to describe the hydrological conditions for high ecological status. Within its "learned lessons", the case study explains that biological monitoring data are indispensable to define Eflows for HES and GES. It is necessary for all water body types to identify those biological quality elements (BQEs) which are most sensitive to hydrological pressures and to develop specific metrics reacting on hydrological alterations for those BQEs. Fish proved to usually be the most sensitive BQE to hydrological pressures. Furthermore, the case study discusses the advantages of a uniformed procedure/method for Eflows definition compared to a case-by-case assessment.

7.1.3. Holistic methodologies

Holistic methodologies aim to merge human and ecosystem flow requirements into a seamless assessment framework (Arthington 1998). The philosophy of these approaches is that all major biotic and abiotic components constitute the ecosystem to be managed, and secondly, that the full spectrum of flows, and their temporal and spatial variability, constitutes the flows to be managed (Arthington 1998).

Holistic frameworks are sometimes referred to as expert panel approaches, where environmental flow standards are developed in a workshop setting where river-specific data is considered by a multi-disciplinary team of experts (typical areas including hydrology, geomorphology, water quality and various disciplines of ecology).

These frameworks may also integrate social, cultural and economic values within ecosystem protection goals, and associate other stakeholders as the basis for consensus recommendations (Linnansaari *et al.*, 2012). To this extent this kind of approach may be particularly useful for the evaluation of hydrological regime to be achieved in HMWB or water bodies subject to an exemption.

NB: while these holistic approach are useful for the integration of many ecosystem traits (as opposed to methods that would focus on a limited number of species) in the definition of Eflows, only ecological consideration should be included in the methodology for this case and not socio-economic impacts on uses which are only relevant to HMWB or water bodies subject to an exemption.

Many holistic frameworks have been described in literature; the most commonly used methodologies are the Building Block Methodology (BBM, Tharme and King 1998) and the Downstream Response to Imposed Flow Transformation (King *et al.*, 2003, DRIFT). Arthington (1998a) and Tharme (2003) provide thorough reviews of various holistic methodologies.

Most recently the Ecological Limits of Hydrologic Alteration Framework (ELOHA) was specifically developed to meet the needs of managing environmental flows at state, provincial or basin scale, and at national water policy level, being used to integrate environmental water requirements into regional water resource planning and management worldwide (Poff *et al*., 2009). ELOHA is a "top down" method that defines environmental water requirements in terms of acceptable levels of change from the natural flow regime, involving the quantification of stress–response relationships and the definition of environmental water requirement guidelines for different classes of rivers with contrasting flow regime types (Arthington *et al*., 2006). This framework addresses many rivers simultaneously, including lakes and wetlands, and applies across a spectrum of flow alteration, data availability, scientific capacity, and social and political contexts (Poff *et al*., 2009, Arthington, 2012).

Depending on the depth of evaluation, data collection, and the extent of expert consultation, applications of holistic framework can be time consuming and very expensive.

Table 7.1: Comparison of the three general categories of Eflows estimation methodologies Adapted from Linnansaari et al., 2012

Methodology category	General purpose	Scale	Duration of assessment (months)	Relative costs	Relative frequency of use
Hydrological	Examination of historic flow data to find flow levels that naturally occur in a river and can be considered "safe" thresholds for flow abstraction	Whole rivers, applicable for regional assessments	1-6	€	+++
Hydraulic-Habitat	Examination of change in the amount of physical habitat for a selected set of target species or communities as a function of discharge	Applied at a study site / river segment scale, upscaling to whole river basin based on the assumption of "representative" site conditions	6-18	€€	++
Holistic	Examination of flows in an expert opinion workshop leading to recommendation of flows for all components of the river ecosystem, including societal and recreational uses	Whole rivers, applicable for regional or river specific scales	12-36	€€ - €€€	+(increasing)

A Case Study (4, SI, Legal) describes the two approaches for the determination of an "Ecologically Acceptable Flow" (EAF) prescribed in the Slovenian legislation. The holistic approach evaluates the biological, chemical and hydromorphological characteristics of the river reach where the water diversion/abstraction occurs. The final determination of the EAF should also include requirements linked to nature protection and conservation policies. Although developed in the context of Slovenia, the "holistic" approach can be used anywhere else. Replicability of this holistic approach is however limited as it is based on expert knowledge.

7.2. Selecting an appropriate method

This paragraph is intended to guide the process towards selection of a suitable methodology for Eflows estimation. Based on available knowledge and information (on hydrological and catchment's characteristics, scale and scope of the analysis and the wider environmental and economic context) a hierarchical framework for choosing the appropriate methodology is suggested.

A range of techniques, from simple to complex, can be selected to respond progressively to the scale of the analysis, range of risk, intensity of water use, budgets, capacity, and timeframes of a country (Hirji and Davis, 2009). Phased, hierarchical implementation can be undertaken in a number of different dimensions, such as: i) increasing complexity of scientific assessment, from very simple catchment-scale hydrological analysis to comprehensive site-based investigations; ii) increasing complexity of flow regime, from basic protection of low seasonal base flows to more complex flow regimes with intra/inter-annual variability; iii) geographical phasing, starting with high priority sites (Le Quesne *et al.*, 2010).

As Eflows estimation can be resource-demanding, a phased hierarchical approach is the most efficient way to address the application of methods in order to develop the ecological flow policy in a region or a country.

Hierarchical approaches mentioned above have been proposed in different countries. Two assessment levels have been extensively applied in Spain to incorporate Eflows in the RBMPs (Order ARM/2656/2008). Three assessment levels of Eflows are proposed for application to UK river water bodies, in which greater investment in the assessment yields lower uncertainty in results (UK TAG, 2007).

Based on several authors (Arthington *et al.*, 1998b; Acreman and Dunbar, 2004; King *et al.*, 2008; TNC, 2011b), Table 7.2 suggests a three-tiered hierarchy approach to accommodate Eflows applications. Some primary references of methods for each of the assessment levels are also named.

Table 7.2: A three-tiered hierarchy of Eflows methodologies
Adapted from: Arthington et al., 1998b; Acreman and Dunbar, 2004; King et al., 2008; TNC, 2011b

	Applications	Observations	Type	Primary reference of methods	Information required
Level 1	-Regional planning -Preliminary standard setting -Screening and analysing available hydrological and ecological information for a Level 2 approach	This approach could be appropriate for setting preliminary targets in any situation or as part of a screening process at basin scale. Credible initial Eflows recommendations can be provided when hydrologic desktop methods are combined with a review of available ecological information and knowledge about key riverine processes. These initial targets based on level 1 analysis should be precautionary, in line with their level of confidence	Hydro-logical	-Indicators of Hydrologic Alteration (IHA) and the Range of Variability Approach (RVA, Richter *et al.*, 1997) -Sustainability Boundary Approach (SBA, Richter 2011)	- Consistent and spatially distributed hydrological data (at least 15 years of continuous measures) - Reliable hydrological models to extrapolate streamflow time series to ungauged sites - Literature review of the linkages between flow regime and key riverine processes
Level 2	-RBMP -Organizing and pre-analysing information for Level 3 approach	It might apply where more detailed Eflows specifications are required. Basin scale planning involves the assessment of ecological flows through hydrological analysis and holistic methodologies. Eflows recommendations may be based on limited data and conflicting or subjective expert judgement.	Holistic + generalised habitat models	-Building Block Methodology (BBM, Tharme and King, 1998) -Downstream Response to Imposed Flow Transformation (DRIFT, King *et al.*, 2003) -Ecological Limits of Hydrologic Alteration Framework (ELOHA) (Poff *et al.*, 2009, Arthington, 2012) -Generalised habitat models (Snelder *et al.*, 2011)	- Collecting new data, basic ecological modelling and economic assessment methods - Synthesis of information and articulation of expert judgement into Eflows recommendations occurs within the framework of a flow workshop with diverse participants

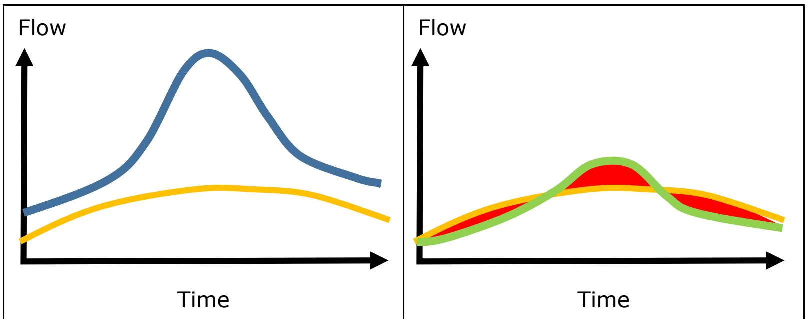
	Applications	**Observations**	**Type**	**Primary reference of methods**	**Information required**
Level 3	-Examining trade-off and predicting results of current operational changes (e.g., designation and managemen t of HMWB) -Restoration/ re-habilitation of aquatic and riparian habitats -Water Body level	A level-3 processes is appropriate for situations that require high degree of certainty. Such situations may include those where water is over-allocated and heavily contested, affected protected areas, presence of endangered species, etc. In these situations, decision makers will require a higher threshold of analysis and objectively, legally defensible assessment. Analyses of level 3 approach can incorporate hydraulic-habitat methodologies and, for HMWB and water bodies subject to an exemption, socio-economic impact analysis.	Holistic + Hydraulic -habitat	-BBM / DRIFT as recommended above supported by hydraulic-habitat methodologies -The cost action 626 "European Aquatic Modelling Network" defined and developed models and methods of assessing the interactions between biota and riverine habitats at both a reach and a catchment scale -Dunbar *et al.*, 2011 provide an in-depth review the available hydraulic-habitat modelling	- Intensive data collection and advanced modelling approaches (species /community oriented) - Wider assessment framework that identifies problems, uses the best available methods and present results to decision makers - Assessment of technical feasibility, significant adverse effects and economic assessment methods can be applied

7.3. Analysing the Eflow gap

In the general context of the WFD, "gap analysis" consists in the identification for each water body of any deviation between its existing status and the one required to achieve the environmental objective. In cases where hydrological alterations are likely to prevent the achievement of environmental objectives, an assessment of the gap between the current flow regime and the ecological flows should be carried out: the "Eflow gap analysis". This analysis requires the previous definition and calculation of ecological flows.

While the pressure analysis (chapter 5) assessment of hydrological alteration considers the deviation of current flows from natural flows, Eflow gap analysis consists in assessing the distance between current flows and ecological flows (figure 7.2).

Figure 7.2: Pressure analysis and Eflow gap analysis (R. Sanchez Navarro, personal communication)



Pressure Analysis	Definition of Eflows and analysis of Eflow gap
Natural flows (blue), current flows (yellow), ecological flows (green) and Eflow gap (red)	

Figure 7.2 gives an illustrating example only relating to quantity and dynamics of flow; but an Eflow gap can be computed over any time scale (month, season, or year) and should focus on any of the flow components (incl. flow velocity) identified as altered. Regarding low-flows, the Eflow gap may be understood as the net volume of water actually unavailable for ecological flow needs due to abstractions or regulation.

Water balances (cf. on-going elaboration of a CIS guidance document on this topic) usually consider ecological flows and can inform about the existence and the location on such a gap at large scale and on seasonal basis.

> *A case study (21, SK, water balance) describes how Eflows are included in the water balance used for the quantitative assessment of water resources in Slovakia. The water balance is based on the assessment of water demands and availability of water resources during the previous year; it expresses the status and the possibilities of water resources use and provides the binding background for the water management for the next period. Eflows are represented by the value of minimum balance discharge which is one of the inputs on the side of water demands. Deficit in the water balance is used as a signal indicating the need to review the existing measures and possibly set additional ones.*

The assessed gap will inform about the measure required to achieve ecological flows and environmental objectives. For surface water bodies that currently meet the ecological flow regime (no Eflow gap), the PoM should focus of non-deterioration, whereas for those water bodies where a gap between the current flow conditions and Eflows has been identified the PoM should be targeted at restoring Eflows and closing the gap.

8. Measures for the achievement of ecological flows

Building on the characterisation of hydrological pressures and impacts and on the gap analysis, the programme of measures should identify the measures that are to be implemented in order to achieve a hydrological regime consistent with environmental objectives in each water body.

This chapter intends to give recommendations on how to select and implement this kind of measures, based on the existing experience in Member States. It also includes considerations about the analysis of cost-effectiveness of these measures.

Key messages for this chapter

- In order to achieve WFD environmental objectives in natural rivers, the programmes of measures (PoM) should ensure the protection of ecological flows and their restoration.

- Being part of the basic measures, controls on surface and groundwater abstractions, impoundments and other activities impacting hydromorphology form a strong basis to protect and restore ecological flows, through the authorization process and regular review of permits.

- Many supplementary measures may be needed to support the achievement of WFD environmental objectives. In many cases, the combination of hydrological measures (ensuring the maintenance of ecological flows by all abstractions and regulation) and morphological measures (improving the aquatic habitats in order to make them less vulnerable to flow impairments) may be the most cost-effective approach.

- The PoM should support the development of knowledge on river ecosystems flow requirements both at large scale and at site level where appropriate.

- A careful assessment of costs associated with the implementation should be carried out to inform the selection of the most cost-effective measures or combinations of measures.

- These latter considerations shouldn't be used to revise the values associated with ecological flows which are to be derived from a technical / scientific process; they can however usefully inform the possible designation of the water body as HMWB or to apply for an exemption.

8.1. Hydrological measures for impacting uses and activities

Measures should be targeted at the drivers and pressures that have been identified as causing the flow alteration in the Article 5 analysis described in chapter 4.

As part of the basic measures, article 11(3) imposes setting controls over the abstraction of fresh surface water and groundwater and impoundments of fresh surface waters (e) and other uses likely to cause a significant adverse impacts on hydromorphological conditions (i). According to this article, these uses shall be subject to prior authorisation and this authorisation shall be periodically reviewed and if necessary revised. These controls on abstractions and impoundments and other uses impacting the flow regime should be implemented in order to ensure the achievement of environmental objectives, and regarding this kind of uses especially checked against ecological flows considerations.

8.1.1. New and increased uses

Non-deterioration of status should be considered for new uses impacting hydrological regime or change in these uses corresponding to an increase in the hydrological impact. Through the authorisation process, it shall be checked that the additional alteration of the flow regime is not significant and not likely to have an impact on the ecological status of the water body, also taking into account cumulative effects.

This requirement is particularly stringent in water bodies at high ecological status where classification explicitly takes into account hydromorphological conditions. In addition to the non-deterioration of biological indicators, the impact of the new/increased use shall not result in any alteration of the hydrological regime from nearly undisturbed conditions. Practically, this means e.g. that no or only very minor new abstractions or flow regulation shall be permitted in water bodies at high ecological status (except when this is part of a new modifications to the physical characteristics of the water body fulfilling all conditions of article 4(7)).

> *As one of the measures to ensure non-deterioration of water ecosystems, a thorough screening of all rivers was carried out in each river basin district in France in order to identify the ones with major ecological interest including those in high ecological status. These lists of rivers were completed in 2013. In these rivers no new permit can be delivered to any activity or infrastructure that would alter river continuity (including alteration of hydrological regime and obstruction to sediment transport).*

These new uses shouldn't prevent the achievement of the good ecological status. In water bodies where the ecological status is impaired because of hydrological alterations, and/or where a gap has been identified between the current flow regime and the ecological flow, no additional flow alteration should be allowed: no, or only very minor, abstractions or flow regulation shall be permitted in these water bodies. Exception to this principle is the case where action is included in the PoM and implemented so that ecological flow will be restored within the same timeframe. In this case, the flow gap to be filled as a consequence of these measures should take into account the additional deterioration due to the newly permitted uses.

8.1.2. Existing uses

In water bodies where the ecological status is impaired because of hydrological alterations, and/or where a gap has been identified between the current flow regime and the ecological flow, the review of permitting conditions imposed by Article 11(3) shall be used to especially adapt these conditions and impose limitations and/or actions in order to make the existing use compatible with the ecological flows and environmental objectives.

8.1.3. Examples of measures

Numerous kinds of measures for the mitigation of hydrological impact of existing uses have been developed and illustrated in many reports (e.g. WFD CIS, 2006) and case studies in Member States; the present document do not intend to list them exhaustively. The following measures are illustrated by case studies collected in the preparation of this document:

- **Changes in the facilities** in order to establish a flow regime consistent with the objectives of the WFD.

  A Case study (22, SE, Edeforsen) shows how to improve ecological conditions restoring a more natural flow regime. Edeforsen river is one of the large hydropower rivers in Sweden, with 23 large hydropower plants. Spawning grounds and winter habitat are very limited for brown trout (Salmo trutta) and *grayling (Thymallus thymallus) caused by high discharge in the regulated river and by the fact that the river is narrow at the site. Diversion of water towards an old hydro power plant can reduce flow and velocity at the main natural channel. Expertise on fish ecology has studied and modelled habitats for different flow scenarios (current versus diverted) as well as seasons and life stages of the fish species. The model results suggest the modified spill scheme and physical habitat rehabilitation measures in the channel proposed would mitigate the effects of strong flows and would offer improved habitats for reproduction of the local fish species. This project would result in enhanced ecological conditions and increased hydro production.*

- **Changes in the water exploitation regimes and in the water rights**.

  A Case Study (23, ES, Ter) presents a large process with water users, in order to adapt existing uses and make them consistent with ecological flows with different actions such as:
  - *Modifying the timing in which water is taken*
  - *Renew the user rights in exchange of the progressive adoption of the ecological flow requirements*
  - *With holders managing small and larger hydroelectric dams, reduced energy production in one facility can be offset by an increase in production in another.*

- ***Optimized combined competing tasks of reservoir management.***

  A Case Study (15, DE, Aabach Reservoir) explains the trial approach for implementing Eflows in the management of drinking water reservoirs, and developing a combination of measures for achieving WFD objectives. Following the approval of the WFD, a combination of measures has been implemented, e.g. reducing water consumption per capita and losses in the drinking water networks, which was done throughout Germany during the last decades. Furthermore, a variety of field tests were conducted to define Eflows, targeting trout and macrozoobenthos. The trials showed that the impact of flow pattern was strongly influenced by complementary morphological measures. Especially the placement of woody debris supported the effectiveness of Eflows. The final design of Eflows and hydromorphological measures was completed in 2004. As a result, the population of trout could be doubled within one decade. In this case study, coupling of the discharge of Eflows (seasonal variable and near to natural floods) from the reservoir and morphological measures helped to limit the water release to the downstream river section by only 10 % of the available mean annual water resources in the Aabach catchment, thus keeping 90 % for drinking water purposes and minimising the impact on drinking water supply.

Other examples can be found in national libraries of mitigation measures for rivers affected by water storage used for defining good ecological potential, such as:

- Mitigation related to low flow: additional provision of flow to the river
- Mitigation related to flow variability: passive (e.g. using natural variability via V-notch weir) or active (e.g. timed release from dam) restoration of flow variability
- Mitigation related to hydropeaking: installation of a (series of) balancing reservoir(s) in the river channel, relocation of the tailrace (e.g. to the sea, a lake, a larger river or a separate channel alongside the original or a recreated

river channel), reduction of rate at which flow (and hence tailrace recharge) ramps down (including using a bypass valve).

(Source: WG ECOSTAT, ad hoc group on GEP and water storage, October 2014)

8.2. Improving knowledge and prioritisation

Depending on the existing knowledge of ecological flows in the river basin, and in addition to the development of hydrological monitoring as seen in a previous chapter, it may be needed to develop knowledge and understanding of ecosystems' flow requirements in order to be able to set consistent and effective ecological flows. These further studies may be useful to compare different kind of measures, and their cost effectiveness. Making them transparent and associating water users, other stakeholders and the public may greatly help to develop and share understanding about ecological flows and required actions and to get support to their implementation.

A Case Study (24, NO, Alta) explains the Norwegian system of trial regulations based on temporary rules of operation that has been applied in more than 30 rivers nationwide and with particular success in River Alta. Trial regulations are mainly recommended in rivers of particular importance and when it is considered necessary to test out the effects of various flow regimes in practice, before the ecological flow requirements are finally decided. In The River Alta the main focus has been on safeguarding the wild Atlantic salmon stocks. In large rivers such as the River Alta, the salmon has a generation time of 5-7 years, which means that the long-term effects of hydropower might not be detectable for a long time, often 10 years or more. The biological response time must therefore be taken into consideration when the trial regulations are planned. Sufficient time and resources must be allocated, and the purpose and objectives of the trial regulations should be clearly defined and consented.

A master plan was recently produced for all hydropower in Sweden based on a multicriteria analysis using information from each hydropower plant and considering the national environmental goals regarding rivers and lakes (incl. WFD and BHD objectives). Most of the information was collected at water body level and aggregated to catchment level. At the end, all catchments were compared in relation to value for energy system and the national environmental goal. The result shows that rather few catchments produce the majority of the hydropower production and almost all regulating power. GES could be targeted in the majority of the catchments and the total production loss according to the strategy would be 2.3% of total hydropower production and very limited impact on regulating power. This experience also stresses the importance of making national strategies before detailed Eflows studies and decisions on measures. Next step in SE is prioritisation within each catchment regarding hydropower which will include studies for Eflows definition or design of measures.

However, the lack of knowledge about the detailed values of ecological flow components should not prevent taking urgent mitigation action in areas where the hydrological alterations are severe and where the impacts on the ecological status is anyway certain and must be alleviated.

Building on the analysis of pressures, a strategic approach is recommended is order to prioritise the different kind of actions over the river basin. As a principle, non-deterioration should be prioritised e.g. through the identification of areas where no further hydrological pressures (with distinction of abstraction and regulations issues) should be allowed, possibly until mitigation action is implemented.

> *A case study (25, NO, strategic assessment) illustrates a screening project aiming at identifying the catchments with highest potential for flow restoration with criteria considering biological value and energy production loss. Hydromorphological alterations due to Hydropower are among the most frequent impacts on ecological status in Norwegian rivers (more than 2500 water bodies significantly impacted). 395 existing HP licenses were screened against the potential for flow restoration by setting a minimum flow and restrictions on reservoir and/or run-of river operations. For almost 40 % of the priority catchments, consequences for power generation are relatively small (production loss: 0-5 GWh for each catchment; 2.3 to 3.6 TWh / year for all the prioritised rivers i.e. 1.8-2.8 % of the mean annual production in Norway).*
>
> *A Case Study (26, ES, Tormes) describes the use of a Decision Support System (DSS) to integrate ecological flows requirements into decision making in a context of intensive use by irrigation and hydropower. Water management of the Tormes River (Duero river basin) was simulated with the DSS using three different models (water quality, water resource and ecological flow). The use of these models provides objective criteria for distributing the water resources based on the users demand in the catchment and the environmental requirements. It also enables the design of an effective programme of measures.*
>
> *A Case Study (27, AT, Hydropower) explains that hydropower water abstraction is one of the most relevant pressures in Austrian rivers, with 10% of the rivers to fail GES. The majority (>85%) of the ~2000 existing hydropower plants are abstraction plants and lacks regulatory requirements for ecological flow, as it is obligatory only since 1990. Studies were carried out to evaluate the impacts of the existing pressure (water abstractions/reduced flow, hydropeaking, dams/migration barriers) on the environment (on biological elements) as well as the impact of measures necessary to achieve good ecological status (GES) on hydropower sector. By using scenarios, possible impacts like loss of electricity production (base load as well as peak load/regulation services), investment costs, and financial losses were evaluated on different scales and for the subsectors (small HP < 10 MW, large hp > 10 MW, storage plants). Based on the results, and to minimise the negative effects on the hydropower sector, a stepwise restoration including an ecological prioritisation approach was set in the PoM. For water abstractions in the first step, flow conditions have to be improved to allow fish migration (basic flow value and regulations for minimum depth and minimum flow velocity). In the second step, flow conditions have to be further improved to achieve good ecological status for the biological elements. It was evaluated that the restoration of the ecological flow to achieve GES in water bodies affected by water abstractions due to hydropower use would lead to production losses of 3% of the total national hydropower generation.*

8.3. Combining with non-hydrological measures

In addition to basic measures developed in section 8.1, supplementary measures may be needed to achieve ecological flows and their effectiveness regarding environmental objectives. Some of such measures listed in Annex VI Part B of the WFD may be especially relevant to ecological flows, e.g. (iv) negotiated environmental agreements, (vii) recreation and restoration of wetlands areas, (ix) demand management measures, inter alia, promotion of adapted agricultural production such as low water requiring crops in areas affected by drought, (x) efficiency and reuse measures, inter alia, promotion of water-efficient technologies in industry and water-saving irrigation techniques.

> *A Case Study (28, AT, Advisory Service), illustrates the setting of an advisory service for hydropower in Austria where more than 60% of the national electricity is generated by hydropower. To achieve the objectives set for Austria in the RES Directive it is necessary to increase the hydropower production by 3.5 TWh until 2020. In Austria more than 3000 small hydropower plants exists with very old, usually unlimited abstraction permits that impact on rivers leading them to failing good status. To achieve the objective of the RES Directive as well as WFD, an advisory service in combination with specific financial support programs was developed in several provinces as an incentive to increase the hydropower production at small hydropower plants by modernisation and increasing efficiency and to restore the ecological flow at the same time.*

The selection of the appropriate restoration and mitigation measures will depend on a number of site-specific considerations about e.g. expected effectiveness regarding the environmental objectives, its technical feasibility and possible adverse effects on the wider environment. In many cases, the combination of hydrological measures (ensuring the discharge of an appropriate flow regime by all abstractions and regulation) and morphological measures (improving the aquatic habitats in order to reduce their vulnerability to flow impairments) may be the most cost-effective approach to achieve efficiently environmental objectives.

> *A Case Study (14, FR, Rhone) describes the physical restoration of the French Rhône River that started in 1999 and has combined so far minimum flow increases (by a factor up to 10) with hydromorphological measures, e.g. in four reaches bypassed by artificial channels (total length 47 km) and the dredging and/or reconnection of 24 floodplain channels.*

The Blueprint to safeguard Europe's water resources recognised the role of Green infrastructure for addressing these pressures and proposed tools to be developed under the CIS to promote the uptake of Natural Water Retention Measures (NWRM) in the next RBMP and Flood Risk Management Plans (FRMP)[13]. This is in line with the Communication on Green Infrastructure (GI) [14] which supports the EU 2020 Biodiversity Strategy. GI is based on the principle that protecting and enhancing nature and natural processes, and the many benefits human society gets from nature, should be consciously integrated into spatial planning and territorial development. NWRM are multifunctional measures that integrate GI considerations into river basin management in order to, inter alia, contribute significantly to mitigating the effects of hydromorphological pressures, reducing the impacts of floods and droughts and delivering good water quality.

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[13] A policy document on NWRM is under development by CIS PoM group

[14] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and thee Committee of the Regions: Green Infrastructure (GI) — Enhancing Europe's Natural Capital. COM(2013) 249 final

Non exhaustively, the following kinds of actions may have a positive impact by reducing the vulnerability of river ecosystems to hydrological alterations, thus making more effective the improvements made in the flow regime:

- Improving longitudinal continuity: e.g. establishing fishways, demolishing old dams, rehabilitating sediment transport.
- Improving river bed and riparian areas: remeandering, removal of hard embankments, reconnecting rivers to floodplains, restoration of habitats, etc.
- Other natural water retention measures in the floodplain and the catchment.

As an example, Forseth and Harby (2013) have assessed the appropriate combination of mitigating measures to optimize the effect of the possible flow in regulated rivers. The assessment is based on analyzing the ecological bottlenecks in regulated rivers with migrating salmon, and designing the targeted flow to mitigate the bottlenecks (the "building block" – approach). Parasiewicz at al 2012 documented that morphological restoration can partially compensate habitat losses caused by water abstraction.

As a principle, measures to restore flow quantity and dynamics should firstly address pressures causing the hydrological alteration and avoid creating new kind of impacts in the water body or simply move the impact to another area. As an example, damming a river to create a new reservoir and sustain the flow regime shouldn't be considered as a suitable option when abstraction already exceeds available resources, as the morphological (continuity disruption and alteration of morphological dynamics) and hydrological (alteration of the flow dynamics) impacts will most probably outweigh the benefits. Another example is the case of inter-basin transfer where the uptake will significantly alter the flow regime in other water body. These cases are likely to result in non-achievement of the ecological status or even a deterioration of the status in one or the other water bodies. Therefore the reduction of existing abstractions should be prioritised in this kind of situation.

8.4. Cost effectiveness of Eflows measures

The economic analysis carried out under article 5 and Annex III of the WFD should inform about the most cost-effective combination of measures in respect of water uses to be included in the programme of measures in order to achieve environmental objectives. This analysis will consider the different possible measures to achieve these objectives and estimates of the potential costs in order to inform the selection of the ones of least cost and least impacts on the uses. In some cases, different combinations of measures could deliver ecological flows in the water body consistent with the achievement of GES (and specific requirements of BHD protected areas where relevant). The analysis enables selection of the most cost-effective combination.

This discussion should be clearly distinguished from the one about the proportionate cost and the technical feasibility of the measures which are only relevant for water bodies where an exemption is applied.

Information on the cost and effectiveness of different measure options should be sufficiently detailed for making judgements about the combination of measures that will produce required improvement the most cost-effectively. It is important not to look at each measure separately, but include bundles or packages of measures and look at also the saved costs by implementing measures at the same time. Annex IV of the Hydromorphological Pressures Technical Report (WFD CIS, 2006) presents a list of potential restoration and mitigation measures and their cost-effectiveness.

The analysis of costs should include all direct and indirect costs including impacts on important human uses such as energy generation, agriculture, forestry, transport, and flood control, as well as the polluter-pays principle.

> *A Case Study (29, SE) analyses the consequence on hydropower production of regulation for ecological flows in Sweden. The study showed that a set of proposed ecological flows (aiming at restoring natural reproduction of Baltic salmon) in water channels dried by large-scale hydropower would give a production loss of 10-13 TWh per year. The loss corresponds to 15-20% of the yearly hydropower production. Reduced short-term regulation decreases the flexibility of the hydropower and thereby ability to integrate variable renewable production such as wind power. Changes in seasonal regulation would result in electricity production excess during summer and a deficit during winter.*

Cost-effectiveness of measures to restore ecological flows can in many cases be greatly improved by combining hydrological and morphological measures and by a strategic planning of impacting uses and the mitigation actions in the river basin.

Due to the specific impacts of measures on the river ecosystems and on the uses, this cost-effectiveness analysis may require a case-by-case assessment to refine the detailed aspects of the measures.

9. Heavily modified water bodies and exemptions

This chapter is intended to indicate how ecological flows should be considered in the specific cases of heavily modified rivers and rivers subject to exemptions and to give some initial recommendations. Its scope is voluntarily limited as not to overlap with the on-going CIS activity on the intercalibration of good ecological potential of HMWBs which is expected to further elaborate on flow consideration. Although this chapter does not elaborate on exemptions under Article 4(7), such exemptions may be applied as mentioned in section 8.1.1.

Key messages for this chapter

- Hydrological alterations without substantial change in morphology can in very specific circumstances justify the provisional designation of heavily modified water bodies (HMWB), which should generally only be based on the identification of a substantial change in morphology.

- Definition of ecological flow and identification of the necessary measures to deliver it and achieve GES should, where hydrology is significantly altered, be considered as part of the designation test for HMWB and justify that these measures cannot be taken.

- A careful assessment of the hydrological regime to be delivered should be carried out in the definition of good ecological potential together with the mitigation measures to improve the flow conditions; depending on the nature and severity of morphological alteration, the hydrological regime consistent with GEP may be very close to the ecological flows.

- Similarly an exemption under Article 4(5) can be justified with a significant hydrological pressure; this justification will require the definition of ecological flow and identification of the necessary measures to deliver it. The flow regime to be implemented in the water body should be the closest possible to ecological flow. When hydrology is not the cause for exemption, the hydrological regime should be as a default the ecological flow identified to support GES unless evidence can be used to set a different hydrological regime which supports the alternative objective.

9.1. Heavily modified rivers

As defined in article 2(9) of the WFD , "*a heavily modified water body means a body of surface water which as a result of physical alterations by human activity is <u>substantially changed in character</u>*".

Water bodies candidates for being designated as heavily modified can be identified during the Article 5 analysis and its regular updates; this process is described in CIS guidance No.4 (WFD CIS, 2003f; section 5).

As indicated in the latter document (section 3.1.1), a HMWB is substantially changed in character as a result of physical alterations, i.e. any significant alterations that have resulted in substantial changes to the hydromorphology of a water body such that the water body is substantially changed in character. In general these hydromorphological characteristics are long-term and alter morphological <u>and</u> hydrological characteristics.

"*The situation is more difficult for water bodies subject to substantial changes in hydrology as such changes may only be temporary or short term. The water body may look substantially changed on one occasion but it may look like a normal water body on another occasion. In cases of temporary or intermittent substantial hydrological changes, the water body is not to be considered substantially changed in character. Nevertheless, it may be that in some limited circumstances substantial hydrological alterations may result in long-term or permanent changes with additional substantial* *changes in morphology. In such specific cases, the application of the HMWB designation tests may be justified. Justification for the decision of a HMWB and AWB designation should always be provided.*

Notwithstanding the agreed general approach described in the paragraph above, it was agreed that a slightly different approach could be taken for limited stretches of rivers, e.g. downstream of dams. Under these circumstances, substantial hydrological changes that are accompanied by subsequent non-substantial morphological changes would be sufficient to consider the water body for a provisional identification as HMWB."

Once provisionally identified, the water body has to go through the designation test which considers the possible adverse effect on use of the "restoration" measures to achieve good ecological status (section 6 of the CIS guidance No.4). In order to carry out this test for water bodies subject to only a significant change in hydrology, it is thus necessary to first estimate the ecological flow for this water body to achieve GES and identify the measures that would deliver this ecological flow (step 7.1). Then the effect on use of these should be evaluated according to the following step of this test.

This designation test on hydrology is not necessary for water bodies subject to substantial change in their morphology and which would pass the designation test on this element.

Once designated as HMWB, the flow consistent with the related environmental objective (good ecological potential) should be evaluated, in accordance with the morphological conditions to be achieved. The definition of this flow requires consideration for adverse effects on the "specified uses" of the water body at the origin of the designation, for which holistic methodologies may be well adapted (cf. Level in table 7.2). Related measures to improve the flow regime accordingly should be identified as part of the practical definition of GEP. In most of the cases, achievement of this objective will require mitigation measures to improve the flow conditions to the extent this wouldn't have a significant adverse impact on the "specified uses".

As a result, depending on the nature and severity of morphological alteration, the hydrological regime consistent with GEP may be very close to the ecological flows that would have been required in the same water body before its morphological modification.

9.2. Exemptions under Article 4(4) – extended deadline

Under certain conditions, water bodies may be subject to an exemption under Article 4(4) when all necessary improvements to achieve the environmental objectives (or GEP in HMWB) cannot reasonably be achieved by 2015, for reasons of technical feasibility, disproportionate cost or natural conditions.

Technical feasibility may be relevant in cases where the achievement of ecological flows requires complex changes or refurbishment of infrastructure (e.g. changes to the dams' outlets) and where the technical and administrative procedures may take longer than one cycle.

Regarding natural conditions, as explained in CIS guidance No.20 (WFD CIS, 2009b) on exemptions, the term refers to the conditions which dictate the rate of natural recovery, recognizing that it may take time for the conditions necessary to support good ecological status to be restored and for the plants and animals to recolonise and become established.

This may be relevant in situations where, although ecological flows is achieved and the additional measures (such as morphological measures possibly necessary to ensure effective ecosystem recovery, cf. section 8.3) are implemented in due time, there is a lag period for the ecosystem to recover and achieve the environmental objective.

In any case all conditions set in Article 4(4) must be fulfilled. In particular, all intermediate measures that can be taken in the meantime to improve the status and bring progressively the water body to the required status are to be set out in the RBMP.

9.3. Exemptions under Article 4(5) - less stringent environmental objective

In some cases, water bodies may be subject to an exemption under Article 4(5) when they are so affected by human activity that the achievement of environmental objectives (or GEP in HMWB) would be technically unfeasible or disproportionately costly.

In cases where this exemption is applied for an alteration of the hydrological regime, this should be justified regarding the measures that would be required to achieve a flow regime consistent with the environmental objectives. Assessment of the ecological flow in the water body and identification of the necessary measures to deliver it will then be part of the process of justifying the exemption under article 4(5), following CIS guidance No.20 (WFD CIS, 2009b).

Article 4(5) paragraph (b) states that in the water body subject to an exemption the highest ecological status is to be achieved given impacts that could not reasonably have been avoided due to the nature of the human activity.

This involves that if the ecological flow cannot be delivered in the water body for technical impossibility or disproportionate cost then the closest possible hydrological regime to ecological flow should be defined and implemented, consistent with achievable morphological conditions.

This provision also involves that when the exemption applied in the water body is justified by pressures other than hydromorphology (e.g. pollution), then the hydrological component of the less stringent objective should actually be the ecological flow.

9.4. Exemptions under Article 4(6) – prolonged drought

Article 4(6) of the WFD allows for temporary deterioration in the status of water bodies if this is the result of circumstances of natural cause or force majeure which are exceptional or could not reasonably have been foreseen. This exemption may be in particular relevant when prolonged drought prevents the achievement or the maintenance of ecological flows. As explained in CIS guidance document No.20 (WFD CIS, 2009b), drought as a natural unpredictable phenomenon should be clearly distinguished from water scarcity which is generated by human activities. The conditions of a prolonged drought, i.e. the circumstances that are exceptional or that could not reasonably have been foreseen, should be demonstrated, as normal dry hydrological conditions should be addressed in the reference conditions.

As explained in chapter 2, drought is part of the natural hydrological variability which is a key element in the functioning and the natural dynamics of aquatic ecosystems. This has led some countries to include the particular ecological conditions of natural droughts in the definition of ecological flows:

- In Spain the design of "drought flows" considers refuge habitats and connectivity, and likely temporary deterioration in water body. These flows are activated in River

Basins according to their drought monitoring system. Drought Management Plans of these river basins include measures to minimize the frequency and intensity of water shortage conditions, and to reduce the environmental and socioeconomic effects of these extreme situations.

- In Portugal, Eflows for particularly dry years are defined considering the value of accumulated precipitation since the beginning of the hydrological year (October) in reference weather stations.

Combined hydrological and biological monitoring is particularly important in these cases to assess the impacts of drought on the river ecosystem and their recovery, as regards the achievement of environmental objectives.

In any case all conditions set in Article 4(6) must be fulfilled. In particular, the indicator used to declare that conditions can indeed be considered as a prolonged drought are to be included in the RBMP, together with the measure taken in these exceptional circumstances (e.g. temporary lowering of ecological flows requirements).

> *A Case Study (30, UK, Droughts) provides an overview of the process and necessary requirements to identify if the provisions of Article 4.6 (temporary deterioration in status caused by prolonged droughts) are being met. Standardised hydrological methodologies for developing drought indicators enable a consistent understanding of when low rainfall and low flows are considered to be a drought, and what action is required. At present although there is a requirement for environmental impact assessment of actions to be taken during a drought within Water Company and Environment Agency drought management plans, constraints and limits are determined on a case-by-case basis. This can result in widely differing levels of understanding and potentially environmental protection.*

As many anthropic alterations to river ecosystems have reduced the natural capacity of ecosystems to recover from drought (resilience), the management plan should include mitigation and prevention measures in order to maintain, and restore where altered, the resilience of river ecosystems to droughts. To this extent Natural Water Retention Measures are particularly relevant.

10. Public participation

Required by the article 14 of the WFD, public participation plays a key role in its implementation and should be integrated all along the planning process, following the recommendations of the CIS guidance No.8 (WFD CIS, 2003e).

Key messages for this chapter
- Given their importance for the achievement of environmental objectives and the potential impacts of their related measures on users, participation schemes are particularly crucial for the achievement of ecological flows.
- Success will ultimately depend upon effective interaction with stakeholders, from politicians to local users, and the ability to communicate the need for ecological flows among those whose interests are affected.
- Public participation on Eflows should be developed in all the phases of the WFD planning process, from its design, implementation plan and effective implementation follow-up, ensuring the participation continues in subsequent planning cycles.

Given their importance for the achievement of environmental objectives and the potential impacts of their related measures on users, participation schemes are particularly crucial for the achievement of ecological flows (Alcácer *et al.*, 2011). To this extent, depending on the local situation, it may be useful to design specific participation processes to ensure a successful implementation. Success will ultimately depend upon effective interaction with stakeholders, from politicians to local users, and the ability to communicate the need for environmental flows among those whose interests are affected. (Bovee *et al.*, 1998, Arthington *et al.*, 1998a, Arthington, 2012; Richter, 2011).

> *The case of Lake Koitere, in Finland (CS 31D), shows that public participation should be interactive and open for all interested people. That is one of the key factors that allowed this case, and other cases regarding water level regulation in Finland, to achieve a compromise which was more sustainable from an ecological, economical and sociological point of view than original water level regulation.*

10.1. Objectives of public participation on Eflows

The participation process on Eflows should be a way to improve the definition of the measures required for their achievement and to facilitate the implementation of these measures. Participation should in no case serve as a tool to negotiate the definition of ecological flows and the value of their different component for the satisfaction of all demands.

Apart from the basic objectives of participation of improving transparency, increasing acceptance and sharing responsibility in the implementation by involving stakeholders in the planning process, participation around Eflows should also serve to:

- Ensure stakeholders understand and assume the need for the measures targeted at delivering ecological flows;
- Identify obstacles for the implementation of such measures, including existing water rights or the presence of illegal or uncontrolled water use;
- Collect additional information on costs and benefits of measures related to Eflows;

- Consider alternative combination of measures that would allow reaching the same objectives;
- Propose mechanisms and measures to allow the achievement of Eflows, including implementation processes that would have not been included in the technical studies prior to the participation process;
- Consider a process of gradual adaptation in the implementation of Eflows, to minimize negative impacts on affected stakeholders, defining a clear calendar and deadlines.

Public participation is also particularly important to inform HMWB designation and GEP setting, and application for exemptions.

It is essential that all those involved in the participation process clearly perceive what benefits or losses they could obtain from the agreement, what trade-offs may be possible for those losses, and that they are aware of the need to participate and be actively involved in the consultation process and, by extension, in decision-making regarding water.

A Case Study (23, ES, Ter) illustrates implementation strategies for Eflows in the context of competing water uses (mainly water derivations for hydroelectric production) in Catalonia. Considering the strong impact on aquatic ecosystems (more than 940 weirs and dams along 6,265 Km of rivers and streams), the Regional Government approved in 2006 a Plan defining Eflows consistent with GES for all water bodies. The case study focuses on the upper half of the Ter river basin (85 HP facilities) where potential production loss and social benefits were estimated. Some of the negotiating strategies were to maintain the same annual energy production by modifying timing or renewal of water rights subjected to progressive adoption of Eflows. Implementation strategies were discussed in a participatory process that involved water users and multiple public agencies, environmental groups and interested parties. When comparing the expected costs with the expected social benefits, they found that costs were unlikely to exceed the range of what society is willing to pay for the recovery of river ecosystems.

A Case Study (13, UK, RBMPs) shows the UK approach to establishing Eflows. Local agreement with stakeholders was found vital in agreeing a suitable WB specific Eflows and defining, assessing and implementing measures to achieve this.

10.2. Participation on Eflows along the WFD planning process

Public participation on Eflows should start early in the river basin planning, in order to establish a good whole process and allow integration of ideas, comments and input from stakeholders along the way (Krchnak *et al.*, 2009). The present section develops how public participation on Eflows may be considered in the different planning phases, and what information the River Basin Authority should provide to stakeholders for each of those phases. A new planning cycle would mean to start over with this participation process, with much more background information and with the added task to assess the implementation of Eflows in the previous cycle.

A Case Study (24, NO, Alta) explains the Norwegian system of trial regulations based on temporary rules of operation that has been applied in more than 30 *rivers nationwide. Sufficient time and resources must be allocated, and the purpose and objectives of the trial regulations should be clearly defined and consented. In the Alta case, the trial period was organized as a stepwise and adaptive learning process with the active involvement and commitment of the key stakeholders and research institutions, which has been crucial for the success.*

10.2.1. Timetable, work programme and consultation measures

The first stages of the planning process will serve to identify stakeholders that could be affected by, or interested in, the measures related to Eflows, either due to variation in water available for consumption or due to variation in services from ecosystems. For that same purpose, it is necessary to identify existing uses and demands (holding permits, where applicable, or not) and consider the allocation system.

Apart from basic stakeholder information such as contact details, negotiation capabilities, expectations and possible conflicts; it is important to know their level of knowledge regarding Eflows, or if they would or would not understand technical concepts, and to adapt the language already in the first drafting documents for the technical studies. The publication of the public participation objectives and calendar, as well as a draft list of stakeholders at this early stage of the planning process will improve the understanding of all parts, and the possibility to later reach an agreement on the measures related to Eflows and their implementation. As this early stage, it should be explained to participants what is negotiable and what is not.

10.2.2. Significant water management issues

The information provided to stakeholders should include the scope, methodology, and components of the hydrological regimes that will later be included in the RBMP, as well as the environmental objectives established in the RBMP those Eflows intend to support. The draft implementation deadline should also be specified at this stage. The information gathered on the previous phase should serve to better define contents so that, either reading the documents of the plan or attending the presentations, all stakeholders can understand the relevance of Eflows and their relationship with the environmental objectives.

The interaction with stakeholders will allow commenting and clarifying doubts around Eflows calculation, but also identifying conflictive sites and issues. On the other hand, it will bring up opportunities for agreement and water saving potential in the basin that could ease their implementation. It is also important to gather information regarding what is water saving and good water management practices for the different stakeholders. This feedback will be crucial for the design of the PoM. The definitive text of the document on Significant Water Management Issues should reflect the results of the participation process, since it will form the basis for the RBMP.

10.2.3. Draft river basin management plans

The public consultation on draft RMBMPs is the moment to present the full calculation of ecological flows and reach an agreement on the implementation path to achieve them. Building on the previous steps, this is the most critical moment to ensure the success of the implementation.

Ecological flows should be presented at this point, both in a simple language for non-experts and in a technical language for experts, allowing the possibility to access the full basic studies that lead to the calculation for Eflows.

This data should be complemented with an analysis of the impact of their implementation. Information should be collected on environmental, economic, and social or cultural impacts of current and proposed hydrological regimes. The results should therefore be expressed in a way that enables them to be displayed through graphs, figures, tables or explanatory charts which let stakeholders understand the implications of Eflows for their interests or activity. For example, the impact on the conservation of endangered species and on the provision of ecosystem services, or the interrelationship of the proposed ecological flows with existing uses. In the event that there are still no clear answers, the degree of uncertainty should be adequately expressed.

> *A Case Study (31, FI, Koitere) explains how stakeholders and public participation helped in achieving more environmental friendly regulation practice of Lake Koitere (164 km2). Water level regulation of Lake Koitere started in 1955 and caused significant changes in ecology of the lake and erosion of shoreline. A simple water level fluctuation analysis tool (REGCEL) was used to assess the impact of different regulation practices, and was presented to the participating stakeholders. Interviews and meetings with different stakeholders allowed integrating opinions together with monetary and non-monetary data, into a multiple-criteria decision analysis tool with the help of a group of experts and specific software.*

Once this information is shared, an integrative negotiation phase can start, aimed at:

- Encouraging reflections on the benefits, needs and desires, preferences, conflicts, uncertainties and risks that stakeholders associate to changes that the achievement of ecological flows will bring over time, and in the different timeframes that are considered;
- Developing new alternatives of measures to distribute the risks and benefits (including compensation) so that they are acceptable to all stakeholders while complying with the objectives of the WFD and the RBMP.

The definitive RBMP should incorporate the results of the public participation and explain the agreements reached with the different stakeholders.

10.2.4. Follow up and intermediate evaluation of RBMP

Stakeholders should be involved also during the implementation of the RBMP, providing them with information about the implementation of measures related to Eflows and about the achievement of the environmental objectives (Dyson *et al.*, 2003). For that purpose, a set of indicators should be developed considering the specific concerns of the participants. Some of the available tools include the *Most Significant Change* (MSC) or the *outcome mapping* (Alcácer *et al.*, 2011).

At the same time, a space can be provided for interaction to occur, so they can provide the administration with their perception of how the implementation is moving forward, and what effects it is actually having on the ground, both for the river basin and their activities. This will keep them informed of the implications of the agreements reached, as well as involved and prepared for the next planning cycle.

A Case Study (32, ES, Gaià) describes how public participation led to a suitable strategy optimizing operational management rules and restoring river ecosystem with Eflows provisions. Since the construction of the Catllar dam in 1976, water flowing in the lower Gaià was totally interrupted, leaving 11 km of riverbed completely dry from the dam to the sea. The average water used is about 3.45 hm^3/year of which 80% is for industrial use and 20% for irrigation. Environmental organizations and local authorities had continually claimed for water return to the river. Through negotiations between the water authority (ACA) and Repsol Company a satisfactory agreement was found in 2010 to deliver ecological flows without significant economic impact. A technical committee (Repsol–ACA) was created to monitor the compliance of the new flow regime allowing the partial restoration of the lower Gaià River. An informative and public commission composed of local authorities, irrigators, water users, environmentalists and local residents was also set up in order to discuss proposals to improve the agreement.

It is in fact possible to keep stakeholders involved over a long period, if sufficient time and resources are allocated.

Part IV: Further steps

The present guidance document could not cover all issues relevant to ecological flows in WFD implementation. Pending issues have been identified in the elaboration process and would deserve further developments.

Some of these issues may be given specific attention when developing deliverables included in the CIS work programme 2013-2015:

- Eflows in mitigation measures and GEP setting – Intercalibration of ecological potential by WG ECOSTAT
- Combination of hydrological and biological quality elements in ecological status classification - information exchange on approaches for combining quality elements into water-body level classification and approaches for dealing with uncertainty in classification by WG ECOSTAT
- Eflows in physical water balances – Guidance on water accounts by a dedicated working group
- Eflows and groundwater - Recommendations for Groundwater dependent aquatic ecosystems by WG on Groundwater

Other issues should be considered, possibly for inclusion in a future CIS work programme

- further development of biological metrics specifically sensitive to hydrological changes
- exchange of good practices in developing and implementing methodological frameworks for Eflows definition in the 1st and 2nd cycle
- exchange of good practices in inclusion and implementation of measures for achieving Eflows in the 2nd RBMPs
- revision of CIS guidance No.4 on HMWB (WFD CIS, 2003f) to better address flow issues
- preservation and restoration of Eflows in Flood management (linking WFD and Floods Directive)
- Eflows in a changing climate
- Eflows for lakes and transitional and coastal waters
- Eflows in other wetlands and in protected areas under the Birds and Habitats Directives

Annexes

A. List of collected case studies

Nº	Proposed by	Location	Title	Referenced in chapter(s)	Providers /Contacts
CS01	Austria	Austria	Using Art. 5 information on hydrological pressures and impacts for the gap analysis	Part III, 5, 6, 8	Veronika Koller-Kreimel
CS02	Spain	Spain	Development of the national regulation on ecological flows	3	Teodoro Estrela Maria Regidor
CS03	Austria	Austria	Regulations concerning ecological flow with special regard to the National Quality Objectives Ordinance	3, 7	Gisela Ofenböck Veronika Koller-Kreimel
CS04	Slovenia	Slovenia	Criteria for determination and on the mode of monitoring and reporting on ecologically acceptable flow	3, 7	Nataša Smolar-Žvanut
CS05	Eurelectric	United Kingdom	Water Framework Directive classification study - Tummel (Scotland)	4	Dr. Alastair Stephen
CS06	Italy	Italy	Assessing the ecological effects of e-flows in Alpine streams: the role of hydromorphological and habitat indicators to overcome the limitations of biological ones	4, 6	Paolo Vezza
CS07	Scottish Natural Heritage	United Kingdom	Defining e-flows for supporting viable populations of the species of Community interest *Margaritifera margaritifera*	4	Phil Boon Rafael Sánchez
CS08	Italy	Italy	Defining e-flows for the conservation of the endangered crayfish (*Austropotamobius pallipes*) complex	4,7	Paolo Vezza
CS09	Greece	Greece	Estimating the minimum ecological flow downstream of the Gadouras reservoir (Rhodes Island) for conserving the local Gizani (*Ladigesocypris ghigii*) populations	4,7	Maria Stoumboudi Elias Dimitriou
CS10	United Kingdom	United Kingdom	Eflows to achieve high ecological status	5	Rachel Newnam Kathryn Tanner
CS11	Italy	Italy, Arno	GES-Flow estimation - the case of the Arno River Basin	5	Bernardo Mazzanti
CS12	United Kingdom	United Kingdom	Environmental Flow Indicators – Development and use in indicating compliance with good ecological status	5	Kathryn Tanner

Nº	Proposed by	Location	Title	Referenced in chapter(s)	Providers /Contacts
CS13	United Kingdom	United Kingdom	E-flows in the RBMP process	5, 10	Kathryn Tanner Rachel Newnam
CS14	France	France, Rhone	Rhone flow restoration	6, 8	Nicolas Lamouroux
CS15	CEEP	Germany, Aabach	Implementing eflows in a drinking water reservoir (example of the Aabach Reservoir)	7, 8	Rainer Gutknecht Prof. Dr. Lothar Scheuer Dr. Gerd Demny
CS16	Eurelectric	Sweden	Granö case study	7	Johan Tielman
CS17	Netherlands	Netherlands	Minimum discharge at the Common Meuse	7	Aleksandra Jaskula Max Linsen
CS18	Spain	Spain	Methodology for e-flows assessment	7	Carmen Coleto Fiaño
CS19	Spain	Spain, Cantabrian RBD	Extrapolation of the minimum e-flows regime to the Cantabrian water bodies	7	Jesús González Piedra Iñaki Arrate Jorrín
CS20	Spain	Spain, Duero	Assessment of the integrity and effectiveness of the e-flows proposed for the middle section of the Duero River	7	Angel J. González
CS21	Slovakia	Slovakia	Use of Water Resource Balance as a tool for the assessment of the quantitative relation between water requirements (including the minimum balance discharge) and water resources	7	Lotta Blaškovičová
CS22	Eurelectric	Sweden	Edeforsen case study	8	Birgitta Adell Katarina Erelöf
CS23	Spain	Spain	Implementation strategies and cost/benefit analysis for compliance with an e-flow regime in the Ter River affected by several small hydropower plants	8, 10	Antoni Munné
CS24	Norway	Norway, Alta	Trial regulations for defining ecological flow in River Alta	8, 10	Jan Sørensen
CS25	Norway	Norway	National screening for prioritization of revised Eflow requirements with highest benefit in regulated rivers	8	Jo Halvard Halleraker
CS26	Spain	Spain	The use of multidisciplinary models to optimise the e-flows regime in the Tormes river basin	8	Javier Paredes-Arquiola

Nº	Proposed by	Location	Title	Referenced in chapter(s)	Providers /Contacts
CS27	Austria	Austria	Restoration of eflows in the development of the 1st river basin management plans	8	Gisela Ofenböck Veronika Koller-Kreimel
CS28	Austria	Austria	Incentive to implement ecological flows in case of hydropower abstraction plants	8	Veronika Koller-Kreimel
CS29	Eurelectric	Sweden	Analysis of consequences on production and regulation possibilities and ecological effects of ecological flows in the large-scale hydropower sector	8	Erik Sparrevik Christian Bostorp
CS30	United Kingdom	United Kingdom	Consideration of drought impacts in assessing WFD status	9	Kathryn Tanner
CS31	Finland	Finland	Public participation and collaborative planning in water level regulation projects	10	Seppo Hellsten
CS32	Spain	Spain	Implementing e-flows in the lower Gaià River affected by a big dam built for industrial water supply	10	Antoni Munné

B. Review of legislation and methodologies in Member States for the definition of ecological and/or environmental flows

B.1. Legislation referring to ecological and/or environmental flows

An overview table has been developed by the WG members, and complemented with the information available in WFD CIS (2011b) and Benítez Sanz and Schmidt (2012). Legend: Yes (Y), No (N).

Country	National legislation	Other regulation	National guidelines	Comments and/or Reference to the key legislation, regulation or guidance
AT	Y[1]	N	N	[1]**Ordinance by the Federal Minister for Agriculture and Forestry**, Environment and Water Management on the Determination of the Ecological Status of Surface Waters (Quality Objective Ordinance – Ecological Status of Surface Waters [Qualitätszielverordnung Ökologie Oberflächengewässer] – QZV Ökologie OG includes regulations for water abstraction (base flow+dynamic flow + min. water depth + min flow velocity), water storage/hydropeaking (flow fluctuations -ratio between daily low flow and high flow and wetted area) and due to impoundments/impounding weirs (maximum extent of reduced flow velocity < 0,3 m/s) http://www.bmlfuw.gv.at/wasser/wasser-oesterreich/wasserrecht_national/planung/QZVOekologieOG.html [1]**National River Basin Management Plan** (Nationaler Gewässerbewirtschaftungsplan) prioritisation and stepwise approach for restoration of ecological minimum (Eflow) and good ecological status http://wisa.bmlfuw.gv.at/fachinformation/gewaesserbewirtschaftungsplan.html [1]**National Water Act (Wasserrechtsgesetz);** Art. 12 a, 13, 30 a and 30 b in particular https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=BundesnormenandGesetzesnummer=10010290
BE	N	N	N	No legal requirement or recommendation but defined in individual cases (WFD CIS, 2011b)
BG	Y[1]	N	N	[1]**Bulgarian Water Act** (§ 125) - until the issuance of the methodology or determining the minimum allowable flow in rivers, the minimum allowable flow (ecological flow) in rivers shall be set at 10 per cent of the mean multiannual run-off, but not less than the minimum average monthly water quantity with a 95 per cent availability at the point of each facility for regulation of the flow or for water abstraction (2010)
CY	Y[1]	Y[2]	Y[3]	[1]**Integrated Water Management Law** (N.79(I)/2010). The Law does not mention ecological flows explicitly but it provides instruments to impose them. [2]**Cyprus River Basin Management Plan,** adopted by Decision of the Council of Ministers on 9 June 2011. Annex II (Programme of Measures) includes Minimum Flow Thresholds for all major dams of Cyprus. [3]Cyprus River Basin Management Plan, adopted by Decision of the Council of Ministers on 9 June 2011. Annex VII includes a proposal for Sustainable Diversion Limits (SDL).
CZ	Y[1]	N	Y[2]	[1]The term of „ecological flow" is not currently defined in the Czech legislation. The Czech legislation uses term minimum residual flow (MRF) defined in the **§ 36 of Act Nr. 254/2001 of the Coll. (amended by the law 20/2004 of the Coll.** and the law 150/2010 of the Coll. – Water Act) MRF is defined as the flow of surface water that still allows general use of surface water and ecological functions of the watercourse. The amendment of the Water Act 2010 says that the method and criteria for determination of minimum residual flow are set by the Regulation of the Czech government. The Regulation of the Czech government is being prepared and it is expected to be completed by the end of 2014 or during 2015. [2]For determination of minimum residual flow is currently used **Guideline of Ministry of Environment** (ME Bulletin Part 5, 1998). A Methodological guideline which will serve as a base for elaborating the Regulation of the Czech government, mentioned above, is being processed. This guideline is based on the hydrological methodology; however, biological aspects of water flow for fish and benthic invertebrates are taken into account.
DE	Y	Y	N	(WFD CIS, 2011b)

Country	National legislation	Other regulation	National guidelines	Comments and/or Reference to the key legislation, regulation or guidance
DK	Y	Y	Y	**Act on Water supply**, Act No. 1199 of 30. September 2013 **Act on Watercourses**, Act No. 1208 of 19. October 2013. **River basin management plans** **National guideline** no. 38
EE				No information
EL	Y[1]	Y[2]	N	[1]**Law 3199/2003**. Protection and Management of Water. Harmonization with the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000." Government Gazette A' 280 (2003). [2]**Joint Ministerial Decision 49828/2008**. "Approval of a Special Framework for the Spatial Planning and Sustainable Development for the Renewable Energy Sources". Government Gazette B' 2464 (2008).
ES	Y[1]	Y[2]	N	[1] **Water Act**, art 42, section 1.b.c'; art. 59.7 [1] **Hydrological Planning Regulation**, art. 18 [1] **EIA Regulation Act** [1] **Biodiversity and natural heritage protection act** [2]**Hydrological Planning Instruction**
FI	N	N	Y	There is no clear reference to ecological or environmental flows in Finnish legislation, but minimum flow is taken into account in permissions. Additionally ecological flow is mentioned in national strategy of fishpassages (8.3.2012) as one measure http://www.mmm.fi/attachments/mmm/tiedotteet/660ag2jJE/kalatiestrategiasuomi.pdf
FR	Y[1,2,3,4]	Y[5]	Y[6]	Water abstraction: In all basins with water quantitative deficit, the Prefects (local State authority) determine maximum volumes for abstractions for all uses, which is the volume which can ensure the good functioning of aquatic ecosystems and in the respect of eight years out of ten for low flows objectives ("Débits Objectifs d'Etiage – DOEs"). These DOEs are set in river basin management plans. DOE is a monthly average rate above which it is considered that all uses can be in equilibrium with life, circulation and reproduction of the species in the rivers. The "harvestable volume" is the volume that can be abstracted from the environment while ensuring compliance with DOEs 8 years out of 10 and therefore guarantee a biological minimum flow in the river. [1] **L. 211-3 of French Environmental Code** [2] **R. 211-66 of French Environmental Code** [3] **Circular dated 30 june 2008 on management of water abstraction (e.g. irrigation)** [5] **Art.6 of Order dated 17 march 2006 for the river basin management plans (SDAGEs)** **Regulation of water abstraction is implemented in the river basin management plans** Ecological minimum flow: In France, the water legislation has required an ecological minimum flow downstream to dams since 1984. This legislation has been supplemented and adapted by the Law on Water and Aquatic Ecosystems dated 30 December 2006 in order to better meet the objectives of achieving good ecological or potential status of rivers. [4] **L.214-18 of French Environmental Code** [6] **Circular dated 5 july 2011 pursuant to L. 214-18 Article of French Environmental Code on instream flows**
HR	N	N	N	No legal requirement.

Country	National legislation	Other regulation	National guidelines	Comments and/or Reference to the key legislation, regulation or guidance
HU	Y[1,2]	Y[3]	Y[4]	[1] Nature Protection Law (LIII./1996. Törvény a természet védelméről) declares in Article 18 (1) and (2) points: For maintaining of natural or near natural condition of water related habitats and wetlands, protecting and maintaining of other nature systems the relevant and demanded (ecological) water flows to use for other man-made using are not allowed. The decision on ecological flows as a ratio of natural water resources is the responsibility of relevant authority. [2] Ministerial l Order on tax for water resources using (43/1999 KHVM rendelet a vízkészletjárulékról) declares that in case of ecological water flow using there is no tax payment obligatory for. [3] Governmental Decision on enforcement of River Basin Management Plan of Hungary (1127/2010.Korm. határozat). In RBMP for Hungary there are many commitments to fulfil Programme of Measures inter alia revision and application of ecological water flows at border scale. [4] In Chapter 8 on Programme of Measures (Annex 8.3.IP 12 Implementation of sustainable water using) there are technical proposals and targeted actors in applying of ecological flows for fulfilling of environmental objectives of WFD for HU water resources management.
IE	Y[1]	N	Y[2]	[1] **"Water Supplies Act 1942"** ***3.—(1)*** (*e*) where part only of the water at a place is proposed to be taken and the source of water is a lake, the estimated lowest summer level of the lake and sufficient particulars of the method by which it is proposed to take the water to enable a reasonable estimate to be made of the effect of such taking on the level of the lake; (*f*) where part only of the water at a place is proposed to be taken and the source of water is not a lake, the estimated minimum quantity of water flowing past such place in the summer during any continuous period not exceeding one day; [1] **"Shannon Fisheries Act 1935" -** Discharge of water through Parteen Villa weir: **20.**—The Board shall not, without the previous consent of the Minister, permit the rate of discharge of water through the weir at Parteen Villa to be less at any time than ten cubic metres per second [1] **"LIFFEY RESERVOIR ACT, 1936" -** stipulates the minimum residual flow to be released downstream and the minimum level to be maintained in the reservoir. [1] **"S.I. No. 600/2001 - Planning and Development Regulations, 2001, Schedules 5,6,7"** contains guidelines for abstractions where EIS required, including transfer of water resources, impoundments. These are reviewed by Planning Appeals Body on a case by case basis. [2] **"Guidelines on the Construction and Operation of Small-Scale Hydro-Electric Schemes and Fisheries 2005" –** Includes guidelines on residual flow from Small Scale Hydro-Schemes. [2] **"Guidance on Thresholds and Methodology to be Applied in Ireland's RBDs 2004" –** includes guidance on the impacts of abstractions from HMWBs. [2] **"Abstractions - National POM/Standards Study, Revised Risk Assessment Methodology for Surface Water Abstractions from Lakes 2009"**
IS	Y	N	N	**Water Governance Act, No. 36/2011.** The Act does not mention ecological flows explicitly, but it provides the instruments to impose them. **Electricity Act, No. 65/2003.** Does not mention ecological flows explicitly, but by power of the Water Governance Act, already issued hydropower licences may be altered in that regard, if necessary. **Survey and Utilisation of Ground Resources Act, No. 57/1998.** Does not mention ecological flows explicitly, but by power of the Water Governance Act, already issued groundwater utilisation licences may be altered, if necessary. **Water Act, No. 15/1923.** Does not mention ecological flow explicitly, but by power of the Water Governance Act, already issued licences for alteration or damming up of water courses may be altered, if necessary.

Country	National legislation	Other regulation	National guidelines	Comments and/or Reference to the key legislation, regulation or guidance
IT	Y	Y	N	(WFD CIS, 2011b)
LT	Y	N	N	(WFD CIS, 2011b)
LU	N	N	N	No legal requirement or recommendation but defined in individual cases (WFD CIS, 2011b)
LV	Y	N	N	Regulations of Latvian construction standard LBN 224-05 "**Amelioration systems and hydraulic structures**", No.631, 2005 http://likumi.lv/doc.php?id=115151 Includes the guarantee and ecological discharges downstream of HPPs.
MT	N	N	N	Not available.
NL	Y	N	N	(WFD CIS, 2011b)
PL				No information
PT	Y[1]	N	Y[2]	[1] Directive 85/337/EEC, transposed for Portuguese law in 1990, by the **Decree-Law 186/90**, being the Eflows considered a mitigation measure of the impacts on the aquatic and riparian ecosystems. **Water Law 58/2005** implements the Water Framework Directive in Portugal, **Decree-Law 226-A/2007 and Ordinance 1450/2007,** both regulating the uses of water. The Ordinance 1450/2007 states that the permit request for hydroelectric production must be supported by a study presented by the claimant proposing an Eflow regime and also demonstrating that the dam exploitation will not affect the maintenance of that Eflow regime **Law n.º 7/2008,** not yet implemented, establishes that the owner must discharge an Eflow regime adapted to fishes' life cycles, which would maintain the ecosystem integrity. [2] **river basin management plans (RBMP)** For international large rivers the Eflows are established in the Convention signed between Portugal and Spain for the management of these rivers"
RO	Y	N	Y	[1]**Water Law** no. 107/1996 with its subsequent amendments; [1]**Government Decision 80/2011,** which approved the first National River Basin Management Plan [2]**Instructions regarding the calculation of the salubrious discharge and servitude discharge of watercourses** (2012)
SE	N	N	N	No legal requirement or recommendation, but defined in individual cases (WFD CIS, 2011b)
SI	Y[1,2]	Y[3]	N	[1]**Water Act OG RS, No. 67/2002:** The Slovenian Water Act article 71 states that "in the case of a water abstraction that causes a decrease of water flow or a decrease in water level, an EAF should be determined" and therefore the need to determine EAF in Slovenia is readily apparent. On the basis of this article, the Decree on Criteria for Determination and on the Mode of Monitoring and Reporting of Ecologically Acceptable Flow (Decree) was adopted in 2009. [2]"**Decree on the criteria for determination and on the mode of monitoring and reporting on ecologically acceptable flow**", OG RS, No. 97, (2009). [3]"**Decree on the river basin management plan for the Danube Basin and the Adriatic Sea Basin**", OG RS, No. 61 (2011), changes OG RS, No. 49 (2012). This Decree also includes the limits for water abstraction.
SK	Y[1]	N	Y[2]	[1] **Act No 364/2004** Coll. as later amended (Water act), (§ 21) and its implementing regulations, Government Decree 279/2011 (4.3) – enunciating the mandatory part of Water Management Plan of Slovakia containing the programme of measures for achieving environmental objectives; Regulation of Ministry of Environment of Slovak Republic No 457/2005 constituting the details about Operating rules of water constructions [2] **Methodology of Water Resource Balance** in Slovak Republic for previous year

Country	National legislation	Other regulation	National guidelines	Comments and/or Reference to the key legislation, regulation or guidance
UK	Y[1,2,3]	N	Y[4,5,6]	[1]England and Wales – **The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003, Water Resources Act 1963, Water Resources Act 1991, Conservation of Habitats and Species Regulations 2010** [2]Scotland **- the Water Environment and Water Services (Scotland) Act 2003, Water Environment (Controlled Activities) (Scotland) Regulations 2011, Nature Conservation (Scotland) Act 2004 Act and Regulations 47-49, 50-52 and 83-85 of the Conservation (Natural Habitats, andc.) Regulations 1994** [3]Northern Ireland - **The Water Environment (Water Framework Directive) Regulations (Northern Ireland) 2003, The Conservation (Natural Habitats, etc.) (Amendment) Regulations (Northern Ireland) 2007, Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006** [4] England and Wales – **Draft River Basin Planning Guidance** May 2014 (currently under review), **Water Framework Directive implementation in England and Wales: new and updated standards to protect the water environment May 2014** (currently under review) [5]Scotland - **The Scotland River Basin District** (Surface Water Typology, Environmental Standards, Condition Limits and Groundwater Threshold Values) Directions 2009, **The Scotland River Basin District** (Classification of Water Bodies) Directions 2009 [6] Northern Ireland - **The Water Framework Directive (Priority Substances and Classification) Regulations** (Northern Ireland) 2011
CH	Y	N	N	(WFD CIS, 2011b)
NO	Y[1]	N	Y[2]	[1] **Water Resources Act** (Act of 24. November 2000 No. 22 relating to river systems and groundwater), Section 10: Abstraction of water and minimum permitted rate of flow. [2] **National guidelines relating to HMWB** (01:2014). The guidelines include list of criteria on functioning (aquatic) ecosystem to meet GEP, e.g. minimum water cover throughout the year.

B.2. Methodologies for assessing gaps in ecological flows

The following methodological approximations are being used by the EU Member States in order to assess gaps in ecological flows. This table has been developed by the WG members, and complemented with the information available in King *et al.* (2008) and Benítez Sanz and Schmidt (2012). Legend: Yes (Y), No (N).

Country	Hydrological	Hydraulic	Habitat simulation	Holistic	Comments
AT	Y	Y	Y	Y	A combination - General hydrological/hydraulic requirements which can be refined by habitat modelling on a voluntary (case by case) basis taking into account specific ecological functions of the flow regime which are necessary to achieve and maintain GES for the biological elements not only now but also in the long run. But no additional aspects like economics are included because this is only relevant for definition of GEP and application of exemptions.
BE	Y	N	Y	N	Static type of method and modelling, which depends on the type of the watercourses (navigable or not navigable) (Benitez Sanz and Schmidt, 2012)
BG	N	N	N	N	The foreseen project will address determination of Eflows and develop a proper Eflow linked with good ecological status and river type. The project included activities for determination of environmental minimum flow complied with the established types of the category "river" and the methods included in an European level document „Environmental flows as a tool to achieve the WFD objectives (discussion paper)"
CY	Y[1]	N	N	N	[1] All methods proposed and used in the RBMP are hydrological methods (Sustainable Diversion Limits, Minimum Flow Threshold, Maximum Extraction Rate).
CZ	Y	N	Y	N	The hydrological approach is based on ability of minimum residual flow to maintain hydrological and biological balance in watercourse. Also other water management and abstractions should be available below (downstream) the abstraction. Currently used method is based on hydrological approach mainly. The new method which is developing as a base of the Regulation of the Czech government is also mainly based on hydrology but it also uses results from habitat simulation. The research of habitat simulation was conducted on Czech watercourses focused on fish. The IFIM methodology and PHABSIM model as a modelling tool was used.
DE	Y	N	Y	N	Hydrological indices, case-specific expert opinion, and a habitat simulation methodology: CASIMIR (Computer Aided Simulation Model for Instream Flow Requirements). Mean of minimum daily flows for each year, or a fraction thereof and expert opinion have been used to assess 100 flows. CASIMIR has been applied for benthic invertebrates as a benthic shear stress model, and new models are under development for fish habitat and riparian zone plant communities (King *et al.*, 2008)
DK	Y	N	N	N	Hydrological methods: median Minimum Method (King *et al.*, 2008)
EE					No information

Country	Hydrological	Hydraulic	Habitat simulation	Holistic	Comments
EL	Y[1]	Y[2]	Y[3]	N	[1]Environmental flows are considered downstream of small hydropower plants by the use of hydrological criteria. There exists no specific legislation referring to ecological flow assessments or instream flow requirements for aquatic communities. [2,3]Hydraulic/Habitat methodologies are being applied in a scientific (research) level. Dam operators and water managers are required to conform to the hydrological standards set by the JMD 49828/2008.
ES	Y	N	Y	Y	Most of the cases in Spain combine hydraulic and habitat models, cases studies 18, 19, 20, 23, 26 and 32 illustrate some Spanish methodologies.
FI	N	N	Y	N	In some cases: fish habitat and other habitat modelling based on the relationship between flows, water depth, substrate and the quality and quantity of available habitats (Benitez Sanz and Schmidt, 2012)
FR	Y[1]	Y[2]	Y[3]	N[4]	[1] Hydrological methods are based on the analysis of hydrological data; [2] Hydraulic methods are based on the relationship between hydraulic parameters, morphology of river and value of minimum flow; [3] Habitat methods intersect evolution of hydraulic characteristics with biological preferences of species, life stages or species groups. These three methods can be combined. Two main approaches are used (http://www.irstea.fr/dynam): - EVHA method (Evaluation of Habitat), based on the hydraulic and topographic characterization of a station and use a hydraulic model for different values of the calculated velocity and water level at several speeds (Ginot *et al.*, 1998); - ESTIMHAB method. based on modelling results of EVHA method. The evolution of habitat areas depending on the flow rate is directly related to the channel geometry, hydraulic and value of median flow. This approach includes the principles of relations between hydraulic, wetted surface and geometry of streams that itself depends on hydrology (Souchon *et al.*, 2003). [4] Holistic methods set minimum flow values and assists in the determination of hydrological regimes. In France, these methods have been developed over the last 15 years. But French Water Law defines only one requirement of minimum value and not a set of characteristics of the hydrological regime. *Reference :* Circular dated 5 july 2011 pursuant to L. 214-18 Article of French Environmental Code on instream flows
HR	Y	N	N	N	In most cases this is average minimum annual flow.

Country	Hydrological	Hydraulic	Habitat simulation	Holistic	Comments
HU	Y[1]	Y[2]	N	N	[1]For ecological water flow calculation the base element is the minimal values of multi- annual monthly average flows (m3/s). Because in HU the critical month for availability of surface water volume is month of August (regularly this month has minimal values of flows), the HU practice is focusing on multi-annual average flows only in months August as the most critical flow values in years. The minimum value of minimal multi-annual average flows in months of August is the base- value of ecological flows in m3/s. In HU, the 75% of this base- value means the ecological flow currently in practice. It is only a simple number and not suitable for broad variety of living life of water and different types of water bodies. [2]For waterways in relevant river channels HU has applied a pragmatic technical solution as computing so-called obligatory to be maintained water flow for assuring the good river bed condition. The first goal has been really of transport and other water services assuring but indirectly it solved ecological aims as well in case of non-natural condition rivers, too. The rate of this water flow has been calculated as 75% of minimal water flow registered before in relevant rivers.
IE	Y	N	N	N	No comments.
IT	Y	Y	Y	N	Hydrological indices, including Flow Duration Curve Analysis (FDCA), daily and annual mean flows; Instream Flow Incremental Methodology (IFIM); Tennant Method; Wetted Perimeter Method; Singh Method, and Orth and Leonard Method for regionalisation; hybrid approach using regionalisation of Q95 on the basis of geology and catchment area. Hydrological indices and IFIM in resource-intensive applications are the most commonly applied but MesoHABSIM modelling is spreading. Relationships between fisheries standing crop and environmental variables are under development. (King *et al.*, 2008) Minimum instream flows are required by Law (D.M. 28 luglio 2004) and evaluated through a given methodology where hydromorphological and ecological aspect are taken into account.
LT	Y	N	N	N	No comments.
LU	Y	N	N	N	10% AMF or 30% MMF (Benitez Sanz *et al.*, 2012)
LV	Y	N	N	N	Methodology is based on the hydrological regime and chemical characteristics of type specific rivers (salmonid / cyprinid rivers)
MT	N	N	N	N	The concept of ecological flows is completely new to the Maltese Islands. No data exists and therefore none of the methods can be applied for now. Malta is constructing its information base as a first step in this lengthy process.
NL	Y	Y	Y	N	A lot of different methods have been used: hydrological model, PAWN; alternative approaches, including HEP, a general habitat suitability scoring model, an ecotype classification (ECLAS), a physical habitat model (MORRES), a habitat suitability model (EKOS), and a policy and alternatives analysis model (AMOEBA);HSI type model; hybrid methodologies based on habitat simulation, such as a GIS-based microhabitat model. (King *et al.*, 2008)
PL					No information

Country	Hydrological	Hydraulic	Habitat simulation	Holistic	Comments
PT	Y	N	Y	N	For small irrigation dams and small hydropower plants it is recommended the application of a national method developed for the 2003 National Water Plan (Alves and Bernardo, 2003). This method defines instantaneous flows for each month, considering the flow duration curve and the water needs of the ecosystem. This method considers different Eflows regime for normal/ wet years and for dry years, which are chosen considering the precipitation in the previous months, and a flood flow, with a return period of 2 years. The total volume of water for the maintenance of the Eflow regime is around 15 to 18% of the total annual runoff. For large dams more complex methods are suggested such as the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982), other methods scientifically based, can be used.
RO	Y	N	N	N	It defines salubrious (sanitary) discharge as the minimum discharge required in a cross-section on a watercourse, in order to ensure the natural life conditions, for the existing aquatic ecosystems. In addition, the article 64(1) of the Water Law requires ''the juridical persons with water works under their administration or exploitation are obliged [……] to assure the water demand for industry, agriculture, population and the required flow for the protection of the aquatic ecosystem”. Eflow was considered to be the minimum between Q95% (yearly minimum monthly mean discharge with 95% probability of occurrence and 10% out of the multi –annual mean discharge (standing on the available studies done by the research institutes).
SE	Y	Y	Y	N	Commonly static but in some cases defined from fish migration (Benitez Sanz and Schmidt, 2012). River System Simulator (RSS) is the most widely used but few environmental flow studies have been completed. (King *et al.*, 2008)
SI	[1]Y	N	N	[2]Y	[1] The hydrological approach is based on the reversibility, quantity, length and duration of water abstraction and the ecological type of watercourse. [2] A lower value of ecologically acceptable flows may be determined on the basis of an holistic approach at the request of the applicant for the water right. The study should evaluate the hydromorphological, biological and chemical characteristics of the river reach where the water diversion/abstraction occurs. Nevertheless, if a hydrological or holistic approach is used, the final determination of the ecologically acceptable flows should also include the protection arrangements.
SK	Y[1]	N	N	Y[2]	The design of values of Eflow (the minimum residual flow) is based on hydrological approach, with input values for calculation: 100-year minimum discharge, probability field of mean monthly discharges (value for high degree of guaranty, usually 98%), M-day discharges (Mean daily discharge equal or exceeded in M days), However, the final design value for each profile includes the holistic approach as well.
UK	Y[1]	N	Y[2]	N	**England** [1] Hydrological screening is undertaken comparing flow statistics based on flow duration curves, with standards adjusted for different types of rivers based on ecological sensitivity. [2] Investigations are then undertaken to determine if failure to comply with hydrological standards are having an adverse impact on ecology. If this is the case, measures are proposed reflecting proposed ecological flow. This can include consideration of habitat availability.
CH					No information

Country	Hydrological	Hydraulic	Habitat simulation	Holistic	Comments
NO	Y[1]	N	N	Y[2]	[1] No specific method or technical requirement, due to large variety in river basins and different purposes (ecology, landscape, recreation etc.). However, hydrological indexes are commonly used as a starting point for the assessment, e.g. Q95 summer/winter or "common low flow" (often between 6-12 % of mean annual flow). [2] Different methods applied in each case, based on a dynamic definition/comprehensive approach, including trial regulations in some cases.

C. Hydrological Assessment Methods

C.1. Indicators of Hydrologic Alteration (IHA)

The Indicators of Hydrologic Alteration (IHA) proposed by Richter *et al*. (1996, 1997, 1998; Poff *et al*., 1997) to assess the degree of hydrologic alteration attributable to human induced changes on rivers and lakes, are being applied worldwide. Most of the European methods are based on all, or some, of the IHA (Rinaldi *et al*., 2013).The number of parameters can be reduced by identifying a set of adequate and non-redundant indices (Olden and Poff, 2003); as an example, see selected IHA for UK proposed by UK TAG (2008) and Acreman *et al.* (2009) (Table C.1).

The IHA includes 32 hydrologic parameters to characterize statistical attributes of the flow regime relevant to the ecosystem functioning, such as i) magnitude of monthly flow conditions, ii) magnitude and duration of annual extremes (e.g. high and low flows), iii) timing of extreme flow events; iv) frequency and duration of high and low flow flood pulses, rate and frequency of changes in flows (Richter *et al*., 1996, 1997, 1998, Mathews and Richter, 2007). These parameters can be calculated by the IHA software[15], which performs a "Range of Variability Analysis", using the Hydrologic Alteration Factor (HFC) calculated for each one of the parameters, and allows an effective comparison between ‘pre-impact data’ and ‘post-impact data’.

[15] Can be downloaded at: https://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofhydrologicAlteration/Pages/indicators-hydrologic-alt.aspx

Table C.1 Indicators of Hydrologic Alteration (IHA) proposed by Richter *et al*. (1996) and by Acreman et al. (2009) and UK TAG (2008) for UK.

IHA full List (Richter *et al.*, 1996)	IHA short list for UK (Acreman *et al.*, 2009)	IHA short list for UK (UK TAG, 2008)
December flow (m^3/s)	Mean January flow (m^3/s)	Mean January flow (m^3/s)
January flow (m^3/s)		
February flow (m^3/s)		
March flow (m^3/s)		
April flow (m^3/s)	Mean April flow (m^3/s)	Mean April flow (m^3/s)
May flow (m^3/s)		
Jun flow (m^3/s)		
July flow (m^3/s)	Mean July flow (m^3/s)	Mean April flow (m^3/s)
August flow (m^3/s)		
September flow (m^3/s)		
October flow (m^3/s)	Mean October flow (m^3/s)	Mean October flow (m^3/s)
November flow (m^3/s)		
1 day minimum flow (m^3/s)		
3 day minimum flow (m^3/s)		
7 day minimum flow (m^3/s)	Mean of annual minimum 7 day flow (m^3/s)	Q95[16]
30 day minimum flow (m^3/s)		
90 day minimum flow (m^3/s)		
1 day maximum flow (m^3/s)		
3 day maximum flow (m^3/s)		
7 day maximum flow (m^3/s)	Mean of annual maximum 7 day flow (m^3/s)	Q5
30 day maximum flow		
90 day maximum flow		
Mean Julian day of minimum flow		
Mean Julian day of maximum flow		
Number of times flow rate rises above Q25	Mean number of times per year flow exceeds Q25 (1)	Estimates based on the ratio of Q50:Q95
Number of times flow rate drops above Q75	Mean number of times per year flow is less than Q75	
Mean fall rate		
Mean duration of high pulses	Mean number of times of flow rises	
Mean duration of low pulses		
Number of low rises		
Number of flow falls		
Mean rise rate	Mean fall rate-mean different between falling flows (m^3/s per day)	

[16] The flow exceeded for 95 per cent of the time. Hence Q5 is the flow exceeded for 5 per cent of the time, etc.

The Indicators of Hydrologic Alteration (IHA) (Richter *et al*., 1996, 1997, 1998; Poff *et al*., 1997) allows a quite accurate evaluation of the changes in the hydrological regime, although does not suggest any thresholds. Nevertheless, other authors propose thresholds for a set of selected IHA (e.g. Holmes *et al.*, 2007; UK TAG, 2008).

Holmes *et al.* (2007) suggest for UK:

- <40% in any Richter indicators of hydrological alteration - low risk of failing to meet GES;

- 40% - 80% change in any Richter indicators of hydrological alteration – medium risk of failing to meet GES; and

- >80% change in any Richter indicators of hydrological alteration – high risk of failing to meet GES.

The main limitations to the application of this method are i) the requirement of long flow time series before and after water abstractions/construction of the flow regulation structures, ii) the hydrological alterations that occur at short time scales, such as hydropeaking, are not assessed, and iii) groundwater alterations are not included.

The calculation of a large number of hydrological parameters is sometimes also considered a limitation; however the existence of specific software and online training[17] allows an easy application of this method.

C.2 Indicators of Hydrologic Alteration in RIverS (IHARIS)

More recently, Indicators of Hydrologic Alteration in RIverS (IHARIS) were developped in Spain (Martínez Santa-María and Fernández Yuste, 2010a,b - Table C.2). They also include free software[18] which calculates two set of Indicators of Hydrologic Alteration (IHA) to evaluate the degree of alteration of the flow regime, whether the data included in natural and altered series, linked to a point in the river, is referred to the same period of time (for at least 15 years) – "contemporary data", or not – "non contemporary data". A set of Eflows scenarios associated to certain flow conditions in a natural regime are obtained.

The characterization of the hydrological regime includes "normal or habitual values" (determinants of the general availability of water in ecosystem), extreme values, such as floods and droughts (determinants of the most critical conditions in the ecosystem), and the intra and inter-annual variability of the hydrological regime. However, the flow change rates are not considered in any of the two set of parameters.

[17] Available at: https://www.conservationtraining.org

[18] Available at: http://www.ecogesfor.org/IAHRIS_es.html

Table C.2: Indicators of Hydrologic Alteration proposed in IAHRIS.
Source: Martínez Santa-María and Fernández Yuste, 2010a, b.

IHA		Contemporary data (1)	Non - contemporary data
Habitual Values (Contemporary data) / Normal values (non-contemporary data	Magnitude	Magnitude of annual volumes	Magnitude of annual volumes
		Magnitude of monthly volumes	Magnitude of monthly volumes
			Magnitude of the monthly volumes: 12 values
	Variability	Habitual variability	Variability of the annual volumes
		Extreme variability	Variability of monthly volumes
			Variability of the monthly volumes: 12 values
			Extreme variability
	Seasonality	Seasonality of maximum values	Seasonality of maximum values
		Seasonality of minimum values	Seasonality of minimum values
Floods	Magnitude and Frequency	Magnitude of the maximum floods	Magnitude of the maximum floods
		Magnitude of the effective discharge	Magnitude of the effective discharge
		Magnitude of the connectivity discharge	Magnitude of the connectivity discharge
		Magnitude of the flushing floods	Magnitude of the flushing floods
	Variability	Variability of the maximum floods	Variability of the maximum floods
		Variability of the flushing floods	Variability of the flushing floods
	Duration	Floods duration	Floods duration
	Seasonality	Floods seasonality (12 values, one for each month)	Floods seasonality (12 values, one for each month)
Droughts	Magnitude and Frequency	Magnitude of the extreme droughts	Magnitude of the extreme droughts
		Magnitude of the habitual droughts	Magnitude of the habitual droughts
	Variability	Variability of the extreme droughts	Variability of the extreme droughts
		Variability of the habitual droughts	Variability of the habitual droughts
	Duration	Droughts duration	Droughts duration
		Nº of days with null flow days (12 values, one for each month)	Nº of days with null flow days (12 values, one for each month)
	Seasonality	Droughts seasonality (12 values, one for each month)	Droughts seasonality (12 values, one for each month)

(1) Depending if the data included in the natural and altered series, linked to a point in the river, is referred to the same period of time (at least for 15 years) (contemporary data), or not (no contemporary data).

Detailed indicators for each type of year, with the weighted mean used as a summary

Indicator specified per month, with the annual mean used as a summary

Hydrologic alteration is assessed with consideration to the requirements of the Spanish Hydrologic Planning Instruction (Order ARM/2656/2008). Each IHA varies between 0 and 1, considering 5 classes, as defined in the WFD (Table C.3).

Table C.3.: Criteria for the assignation of qualitative categories to the Indicators of Hydrological Alteration (IHA). SOURCE: Martínez Santa-María and Fernández Yuste, 2010 a,b.

HYDROLOGICAL STATUS **: PARTIAL INDICATORS (IAH)**				
LEVEL I	**LEVEL II**	**LEVEL III**	**LEVEL IV**	**LEVEL V**
0.8< IAH ≤1	**0.6<IAH ≤0.8**	**0.4<IAH ≤0.6**	**0.2<IAH ≤0.4**	**0≤IAH ≤0.2**

These indicators are aggregated in the Global Alteration Indicator (IAG), also varying between 0 and 1 and with 5 classes (Table C.4).

Table C.4: Criteria of assignation of qualitative categories for the Indicator of Global Alteration (IGA). SOURCE: Martínez Santa-María and Fernández Yuste (2010 a,b).

HYDROLOGICAL STATUS **: GLOBAL INDICATORS (IAG)**				
LEVEL I	**LEVEL II**	**LEVEL III**	**LEVEL IV**	**LEVEL V**
0.64< IAG ≤1	**0.36<IAG ≤0.64**	**0.16<IAG ≤0.36**	**0.04<IAG ≤0.16**	**0≤IAG ≤0.04**

This approach can only be applied if daily or monthly flow time series are availbale for at least fifteen complete years, not necessarily consecutive. This threshold was determined on the basis of the minimum amount of information considered necessary to get reasonable results in relation to variability and extreme values (Martínez Santa-María and Fernández Yuste, 2010a,b).

Simalrly to the IHA, IHARIS allows a quite accurate evaluation of the changes in the hydrological regime. But results are delivered in 5 classes consistent with WFD, and can be aggregated in a global index.

However, IHARIS is very specific to Spain and hydrologic alteration are assessed against criteria established on the Spanish Hydrologic Planning Instruction. Moreover, flow change rates are not considered.

Most of the limitations mentioned for Richter's IHA are also valid for IHARIS.

D. References

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