ENVIRONMENTAL FLOWS IN THE EU

DISCUSSION PAPER

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Contents

1. EXECUTIVE SUMMARY

As reported by EU countries under article 17 of the Habitats Directive, the conservation status of freshwater species of European Community interest is generally unfavourable (ETC/BD, 2009a). Over-abstraction is causing low river flows, lowered groundwater levels and the drying-up of wetlands (EEA, 2010 and EEA, 2012). In many locations, water demand often exceeds availability, and the need for adequate water supplies to service vulnerable ecosystems is often neglected. In many cases exploitation of water resources in Europe has led to significant degradation of freshwater biodiversity (EEA, 2010).

To meet the needs of a resource efficient future, sustain human and economic development and maintain the essential functions and services of our water-related ecosystems, an integrated approach to water resource management is needed. The Water Framework Directive (WFD) establishes a new integrated approach to the protection, improvement and sustainable use of Europe's rivers, lakes, estuaries, coastal waters and groundwater. The upcoming Blueprint to Safeguard Europe's Water will aim to ensure good quality water in sufficient quantities for all legitimate uses, including ecosystems.

The quantity, quality and timing of water flows required to sustain ecosystems and the services they provide are together called environmental flows. From this perspective environmental flows appear as an important mechanism to protect and enhance the status of aquatic ecosystems and promote a sustainable water use, thus contributing to the achievement of EU water policy goals.

While there is significant current dynamism around defining and implementing environmental flows across the EU, an understanding of its true scope and potential in the context of the WFD still holds many uncertainties. This document aims to provide technical support to initiate the debate of environmental flows as a relevant part of the EU water policy.

The document is structured in two parts. The first part (section 2) provides the technical and scientific bases of environmental flows (foundations, key concepts, utilities). This part is complemented in section 3 with a brief overview of the main types of assessment methods. We introduce a phased hierarchical approach, probably the most efficient way to address the implementation of methods in a country or region.

The second part addresses the role of environmental flows in the context of the WFD. Section 4.1. highlights the importance of the hydrological regime in different fields of application of the Directive (e.g. in the monitoring program). Section 4.2. shows how environmental flows are necessary to achieve the WFD objectives, such as the GES/GEP or the conservation objectives of protected areas. This section also shows how, when defining the quantitative status of groundwater, it is also necessary to explicitly consider environmental flows. Section 4.3. looks at the role of environmental flows in the Program of Measures.

2. WHY ENVIRONMENTAL STREAMFLOWS (EFLOWS)?

2.1. The Hydrological regime shapes freshwater ecosystems

2.1.1. Why is flow regime so important for freshwater and transitional 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 & 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 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 & Gosselink, 2000; Keddy, 2002; Keddy & 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, 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 hte key elements central to sustaining and conserving native species and ecological integrity (Poff et al, 1997; Bunn & Arthington, 2002; Lytle & Poff, 2004). Results of numerous studies led Bunn and Arthington (2002) to formulate four key principles to highlight the importance of the natural flow regime in the conservation of aquatic ecosystems (Figure 1):

1. The hydrological regime is an important determinant of physical habitat, which in turn determines the biotic composition and life history strategies.

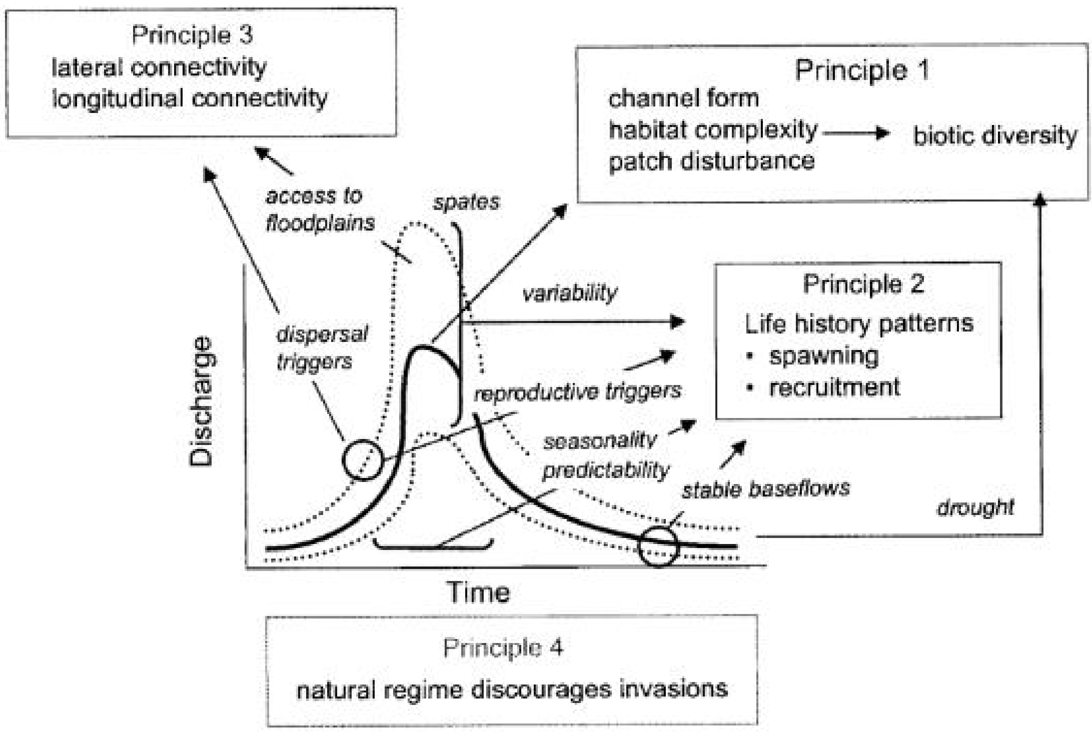
2. Aquatic species have evolved in direct response to the natural hydrological regime.

3. Maintaining natural patterns of longitudinal and lateral connectivity is essential for the viability of populations of species.

4. The success of the invasion of exotic and introduced species is facilitated by the alteration of hydrological regimes.

It can therefore say 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).

Fig. 1. Key principles to highlight the importance of the natural flow regime. SOURCE: Bunn & Arthington, 2002



2.1.2. Why a flow regime?

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 understand better 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[1]) regulate ecosystem process rates, and exert selective pressure on populations to dictate the relative success of different species (Resh et al., 1988; Hart & Finelli, 1999). Normal conditions imposed by regular flows (e.g. base 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). There are several detail scales to identifying and characterizing the EFCs. More generally EFCs can be 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

[1] 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 (CIS EG WS&D, 2012).

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 naturally occur, these periodic events may allow natives 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.

These environmental flow components (base flows and the flood regime) provide a heuristic framework for describing the ways in which an organism experiences river flow variability (TNC, 2011a). Native organisms' life histories are tied to the timing, magnitude, duration, and frequency of the flow components. The particular distribution of these hydrological events is characteristic of the ecosystem from which species interact, organize, change, vary and evolve.

2.2. Ecosystem deterioration due to changes streamflow 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, 2001). Disturbances beyond this range, however, can exert pressure upon the system by altering fundamental environmental processes and ultimately generating stressors (USEPA, 2005; Davies & Jackson, 2006)).

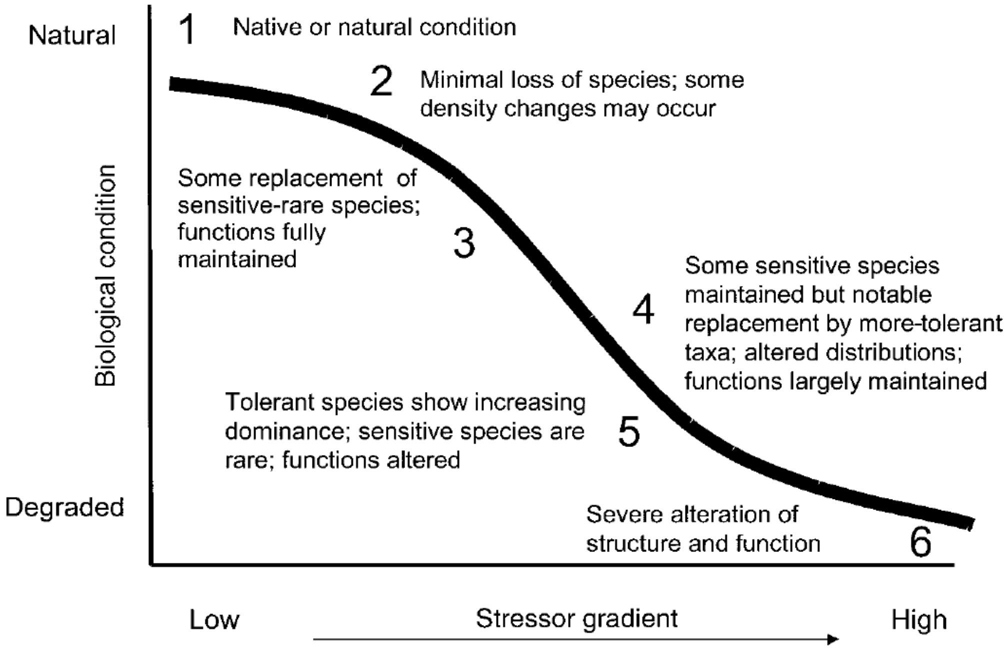
Human activities, such as the direct removal of water from rivers and aquifers (abstraction), and impoundment (construction of dams for various purposes) have greatly modified the natural flow regimes of many rivers (Ward and Stanford, 1983, 1995; Poff et al. 1997; Nilsson et al. 2005). Assuming that flow regime is of central importance in sustaining the ecological integrity of freshwater systems, the modification of the flow regime should lead to environmental degradation (Poff & 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).

Numerous studies have shown the effects of modifying the natural hydrological regime of ecosystems (Poff & Zimmerman, 2010). A reduction in discharge alters the width, depths, velocity patterns and shear stresses within the system (Statzner & 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; Environment Agency, 2004; 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 & Jackson, 2006; USEPA, 2005) is a conceptual model that explains the degradation of aquatic ecosystems to the pressure gradient (figure 2). 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”.

Fig. 2. The Biological Condition Gradient to show the degradation of ecosystems to stressors. SOURCE: USEPA 2006



2.3. Environmental flows: a society response

2.3.1. The concept and definitions of environmental flows

The concept of environmental flows (eflows) historically was developed as a response to the degradation of aquatic ecosystems caused by overuse of water. In this context environmental flows may be defined as the 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 (King & Brown, 2003; Arthington et al, 2006; Brown and King, 2003).

Despite the fact that the concept of eflows has existed for over 40 years (including by other terminology, 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 the ways in which it has been defined in the literature by researchers and organisations involved in assessing and implementing the concept all around the world over the last decades (Box 1). In these definitions of environmental flows, there are always two key aspects of the concept included; the flow regime that should be considered and the level of conservation for the ecosystem that is intended.

A combination of Arthington & Pusey and Tharme definitions (2003) might consider the most basic and relevant aspects of the concept of environmental flows. *"Maintaining or partially restoring important characteristics of the natural flow regime (ie. the quantity, frequency, timing and duration of flow events, rates of change and predictability/variability) in order to maintain specified, valued features of the ecosystem is the concept known as environmental flows".*

Box 1

Definitions of environmental flows

Some of the definitions used internationally are the following.

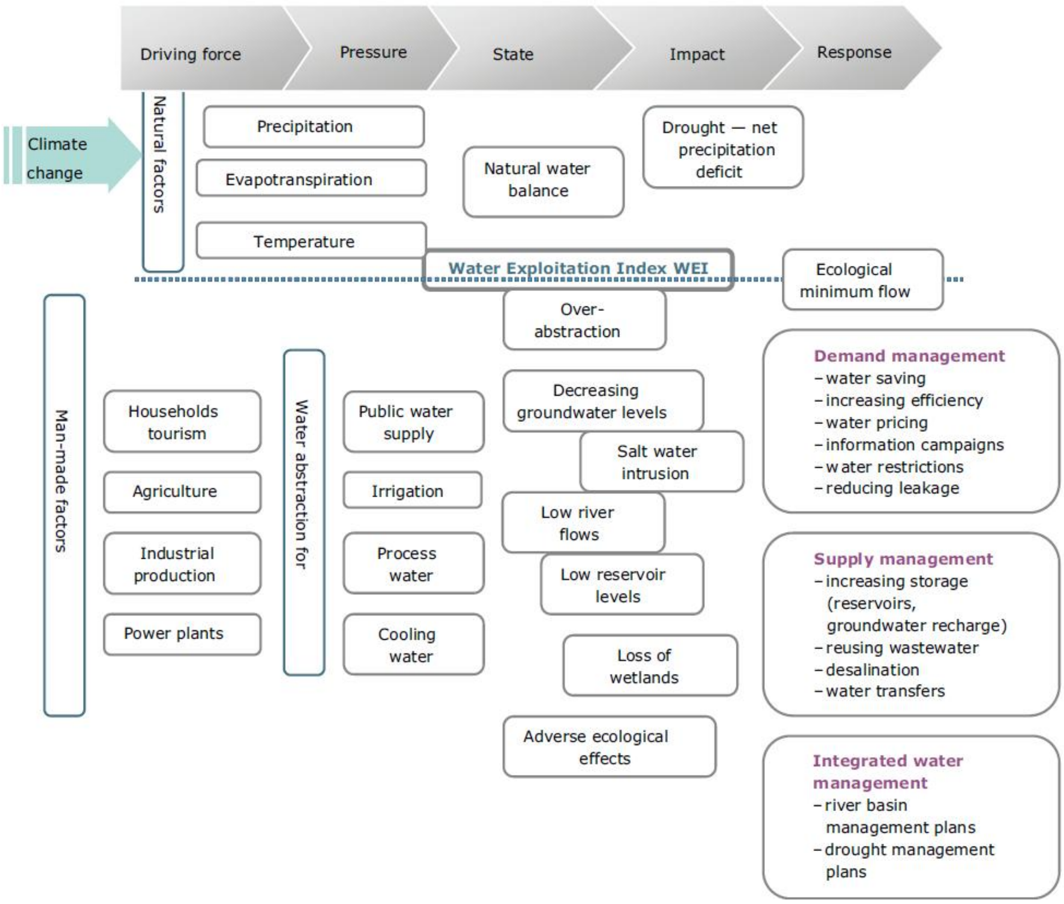
- Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems (Brisbane Declaration).
- Dyson, Bergkamp & Scanlon (2003) in the IUCN guide on environmental 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.
- The 4th International Ecohydraulics Symposium 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.
- Environmental flows can be described 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 (Hirji and Davis, 2009)
- Arthington & Pusey (2003) define the objective of environmental flows as maintaining or partially restoring important characteristics of the natural flow regime (ie. 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.
- 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.
- 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.
- 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.

2.3.2. Beyond the concept of eflows

Eflows are a management concept, and thus it should give responses in terms of management. From the DPSIR conceptual framework, the potential role of environmental flows as a management tool can be better understood.

Figure 3 illustrates some relationships between eflows and water management. Generally, certain human activities create a water demand that requires the development of infrastructure (diversion weirs, dams, etc.). The presence and operation of this infrastructure produce a modification of the natural flow regimes towards water scarcity[2] that affects the biophysical conditions of ecosystems. These changes result in negative impacts such as loss of biodiversity, degradation of natural areas, etc. Those responsible for making decisions try to minimize or mitigate impacts from different responses that may influence each of the links in the process. To this regard, environmental flows can help to restrict water use, to define the maximum limits of hydrological alteration to maintain a certain biological condition and may appear as a basic tool for the recovery of certain species affected by the modification of aquatic habitats.

Fig. 3. Eflows under the DPSIR conceptual framework. SOURCE: EEA, 2009



[2] Water scarcity is a man-made phenomenon. It is a recurrent imbalance that arises from an overuse of water resources, caused by consumption being significantly higher than the natural renewable availability. Water scarcity can be aggravated by water pollution (reducing the suitability for different water uses), and during drought episodes (CIS EG WS&D, 2012).

3. ESTIMATING EFLOWS

3.1. Methodologies and fundamentals

As described in the previous section, environmental flow assessment should determine the hydrological regime necessary for aquatic ecosystems to reach environmental goals. Tools and techniques developed in the field of science to determine the amount of water needed by ecosystems are so called "methods of calculation".

Since the 1970s, there has been a progressive evolution of methodologies for assessing the water needs of aquatic ecosystems (Dunbar et al, 1998; Acreman and Dunbar, 2004; Tharme, 2003). Although the techniques for assessing eflows can be categorized in a variety of ways, four basic groups of methodologies are widely recognised; hydrological methods, hydraulic methods, habitat simulation methods and holistic methodologies (King et al, 1999; Tharme, 2003, King et al. 2008; etc.). Each of these different methods is described briefly below.

3.1.1. Hydrological methods

These methods are based on the natural flow regime as a key variable in the structure and functioning of aquatic ecosystems (for more details see section 2.1.). The range and variation of flows over recent historical time sets a template for contemporary ecological processes, evolutionary adaptations and native biodiversity maintenance (Resh et al., 1988; Doyle et al., 2005; Lytle & Poff, 2004; Bunn & Arthington, 2002). Historical flow data in natural conditions reflect this template of aquatic ecosystems. Eflow recommendations designed from the natural flow regime[3] will result in processes and conditions that will maintain native habitats and species. Depending on the desired level of environmental conservation, eflow recommendations should reflect to a greater or lesser extent the natural flow regime (see the Biological Condition Gradient in section 2.2).

There are numerous methodologies that rely primarily or solely on hydrological data for deriving environmental flow recommendations (Tharme, 2003). The basic assumption of hydrological methods is that the full range of natural variability in the hydrological regime is necessary to conserve aquatic ecosystems. However, the first hydrological methods were used in rivers to define only a minimum flow (Gippel, 2001). Taking into account the needs of all freshwater systems, the current trend is away from methods that set one minimum flow towards more holistic methods that consider the hydrological regime and aspects that, with some degree of hydrological variability, are needed to maintain the system morphology and ecologically-based values (Beca, 2008). Those methods based on the characterization of the "natural range of variability" and the "natural disturbance regime" usually have the greatest scientific support.

[3] The long-term change in hydrological conditions may result in areas with high ecological value. In these cases, it is necessary to assess if the natural hydrologic regime is the appropriate reference for the environmental flow recommendations.

3.1.2. Hydraulic Methods

Hydraulic methods relate various parameters, from stream geometry to discharge rate. The hydraulic geometry is based on surveyed cross-sections, from which parameters such as width, depth and wetted perimeter are determined (Jowett, 1989). The hydraulic parameter is used as a surrogate for habitat factors that are limiting for riverine biota, to develop a relationship between habitat and discharge from which to derive environmental flow recommendations (Loar el al. 1986).

Tharme (1996) reviews commonly applied hydraulic rating methodologies and a number of associated hydraulic simulation models used to derive environmental flow recommendations. The third most used methodology in North America (Reiser el al. 1989) is the Wetted Perimeter Method. Minimum or optimal flows, usually for fish spawning or maximum production by benthic invertebrates, are generally identified from a discharge near the breakpoint of the wetted perimeter-discharge curve (e.g. Collings 1974, cited in Stalnaker & Amette 1976; Prewitt & Carlson 1980).

3.1.3. Habitat Modelling Methods

Habitat methods are an extension of the hydraulic methods (Jowett, 1989). The habitat methods establish flow requirements on the basis of the hydraulic conditions needed to meet specific habitat requirements for biota (Bovee et al, 1998; CRCA, 2005). Some habitat features such as depth and velocity are directly related to flow; other habitat features such as substrate and cover are indirectly related. These habitat features are sometimes referred to collectively as hydraulic habitat.

Habitat methods are based on hydraulic models that predict how water depths and velocities change with discharge (Beca, 2008). These models are based on each species' range of preferences regarding the parameters that define the physical habitat (current velocity, depth or substrate type, etc.). Based on the channel characteristics, the amount of habitat for these species can be determined in relation to different flows.

The same hydraulics models can also be used to evaluate the effects of flow regime changes on many aspects of the riverine environment, including sediment entrainment (for flushing flow and channel maintenance flow requirements), fish passage, water quality, sediment or seston deposition, and fish bioenergetics (Beca, 2008).

3.1.4. Holistic methodologies

These alternative approaches are distinguished from single purpose methods by the common feature that they aim to assess the flow requirements of the many interacting components of aquatic systems (Arthington, 1998; King et al. 2008). The philosophy of these approaches is that all major abiotic and biotic 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 (King et al, 2003). The flow components are identified and described in terms of their magnitude, duration, timing, and frequency. The output is a description of a flow regime needed to achieve and maintain a specified river condition.

The holistic approaches are essentially processes that allow aquatic scientists from many disciplines to integrate data and knowledge. Each specialist uses methods of her/his choice to develop an understanding of flow–ecosystem relationships, and then works with the other team members, within the overarching process of the holistic approach, to reach consensus on environmental flows (King et al, 2003).

In most of these methodologies is implicit that attributes of the modified flow regime must lie within the range of values characterising the historical pattern (Arthington, 1998), on the assumption that if a particular modified flow regime contains elements (eg. sequences of days of set discharge) which have never occurred in the historical record, then that modified flow regime is ecologically unacceptable (Pusey 1998).

3.2. Key features of the methods

Existing methods for the estimation of environmental flows differ in input information requirements, types of ecosystems they are designed for, time which is needed for their application, and in the level of confidence in the final estimates. As seen above, they range from purely hydrological methods, which derive environmentally acceptable flows from flow data and use limited ecological information or eco-hydrological hypotheses (e.g. Richter et al. 1997; Hughes and Münster 2000), to multidisciplinary, comprehensive methods, which involve expert panel discussions and collection of significant amounts of geo-morphological and ecological data (e.g. Arthington et al. 1998a; King and Louw 1998).

Reviews of these methods may be found in multiple sources, including Tharme 1996, Arthington et al. 1998, Dunbar et al. 1998, and King et al. 2008. The four types of “eflow methods” are broadly compared in Table 1 (next page).

3.3. Implementation of methods

3.3.1. The choice of the right assessment method

It has been estimated that some 200 different generic methods have been developed to derive ‘environmental flows’ (Tharme, 2003; Arthington et al. 2006). Different methods should be and are used for different purposes depending on the specifics of the case study and the type of issue to be addressed (water planning, monitoring, river restoration plan, etc.). However, no single environmental flow assessment technique suits all social, economic, hydrological, and ecological contexts within a country (Hirji and Davis, 2009; Annear, 2003; Dyson et al, 2008).

Multiple variables must be taken into account for the implementation of the different methods. A widely used criterion for the implementation of methods is based on a risk-based approach, meaning that for flow decisions with greater environmental, social or economic risks more sophisticated methods shall be applied (UK TAG, 2007; Beca, 2008; MARM, 2009).

It should be noted that assessments can take several years and high cost of resources. Generally speaking, high-confidence, very explanatory, easily-defensible assessments contrast with quick and easy, inexpensive, lower-confidence estimates, that may need to be monitored and revised. As a general rule, the efforts and time required increases as the spatial scale of assessments decreases, and more focused and quantitative assessments are necessary (Arthington et al, 1998b). It can therefore be stated that there is no one right way to assess environmental flows; the context is everything in this assessment.

Table 1: Main features of the calculation methods. SOURCE: Based on King et al, 1999.

		FEATURES							
		ECOSYSTEM COMPONENTS ADDRESSED	DATA NEEDS	EXPERTISE	COMPLEXITY	RESOURCE INTENSITY	RESOLUTION OF OUTPUT	FLEXIBILITY	COST
METHODS	HYDROLOGICAL	The whole ecosystem, non specific	L (mainly desktop) Historical flow records (virgin or naturalized) Historical ecological data	L Hydrological Some ecological expertise	L	L	L	L	L
	HYDRAULIC	Instream habitat for target biota.	L-M (desktop limited field) Historical flow records Hydraulic variables of representative cross-sections of the reach	L-M Hydrological Some hydraulic modelling Some ecological expertise	L-M	L-M	L	L	L-M
	HABITAT SIMULATION	Primarily instream habitat for target biota. Some consider channel form, sediment transport, water quality, riparian vegetation, etc.	M-H (desktop and field) Historical flow records Numerous cross-sections data Suitability habitat data for target species	H Hydrological Advanced level in hydraulic and habitat modelling. Specialist ecological expertise on physical habitat-flow needs of target species	M-H	H	M-H	M	H
	HOLISTIC	The whole ecosystem- all/most individual components Some consider the groundwater, wetlands, estuary, floodplain, social dependence on ecosystem, instream and riparian components.	M-H (desktop and field) Historical flow records Many hydraulic variables - multiple cross-sections. Biological data on flow and habitat-related requirements of all biota and ecological components	H Hydrological Advanced hydraulic modelling. Habitat modelling in some cases. Specialist expertise on all ecosystems components Some require social and economic expertise	M-H	M-H	H	H	H

The choice of methods on a case-by-case basis is compatible with a broader context of strategic application of methods. A range of techniques, from simple to complex, can be selected to respond progressively to the range of risk, intensity of water use, budgets, capacity, and timeframes of a country (Hirji and Davis, 2009).

3.3.2. A phased hierarchical approach in the implementation of methods

Experience suggests that eflow policy should be thought of not as a single event, but as a process with cycles of development, implementation, evaluation and review (MacKay and Roux, 2004; De Coning and Sherwell, 2004; De Coning 2006). Phased implementation of methods is a mechanism for overcoming some initial barriers (e.g. constrained resources) while allowing for the evolution of approaches to and methods of implementation.

Phased implementation can be undertaken in a number of different dimensions (Le Quesne et al, 2010), such as: i) increasing complexity of scientific assessment, from desktop rules to complex site-based investigations; ii) increasing complexity of flow regime, from basic protection of low season base flows to complex flow regimes prescribing multiple flood peaks and inter-annual variability; iii) geographical phasing, starting with high priority sites.

In ecological literature, hierarchy is usually identified with the concept of levels of organization. When speaking of implementation of methods, three key characteristics of hierarchical frameworks are included (Le Quesne et al, 2010):

i. Funds for research and modelling to support flow assessment and implementation are invested strategically to address the most important issues and reduce the most vexing uncertainties; methods are matched to the level of certainty required and the level of funding available;
ii. The framework is iterative, such that higher levels are deployed to the extent they are necessary and information generated at one level can provide the foundation for, and identify the need for, higher levels
iii. Processes for flow assessment and flow implementation are intertwined; many of the key characteristics of the assessment process are designed to lay the foundation for flow implementation. The framework not only gets environmental flows protected quickly, but also catalyses the broader process of implementation, including capacity building and institutional strengthening.

A phased hierarchical approach is probably the most efficient way to address the application of methods in order to develop the environmental flow policy in a country or region.

3.3.3. A three-level assessment framework

Hierarchical approaches mentioned above have been proposed in different countries. South Africa was one of the first to adopt a hierarchy of methods of varying complexity (King et al, 2000). Two assessment levels have been extensively applied in Spain to incorporate eflows in the RBMPs (MARM, 2009). 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).

Opperman (cited in Le Quesne et al, 2010) prescribes a consistent three-level assessment and implementation framework that builds seamlessly from simple desktop estimates of flow needs through to a highly sophisticated programme of research and modelling to refine environmental flow targets with each level building information, capacity, and support for subsequent levels of sophistication as deemed necessary. Arthington et al (1998b) also suggested a three-tiered hierarchy to accommodate the circumstances, objectives and spatial scales of eflow assessments. The three-level hierarchy ties in closely with the types of methodologies and appropriate detail levels of eflow assessments.

Based on several authors (Arthington et al. 1998; Acreman and Dunbar, 2004; King et al, 2008; TNC, 2011b), Table 2 (next page) suggests a three-tiered hierarchy approach to accommodate some common eflow applications, types of methodologies and appropriate detail levels of eflow assessments. Some promising methods for each of the assessment levels are also named.

4. EFLOWS AND THE WFD

4.1. The relevance of the hydrological regime in the WFD

4.1.1. The role of the hydrological regime in classifying the Surface Water Status

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.

4.1.1.1. The hydrological regime is used for assigning the high ecological status and the maximum ecological potential

All categories of water bodies (rivers, lakes, transitional waters or coastal waters) include the hydrological regime as a relevant variable that affects the ecological status (Table 3). However, the values of the hydromorphological quality elements just have to be necessarily used when assigning water bodies to the High Ecological Status class (WFD CIS, 2003d). For the other status/potential classes, the hydromorphological elements are required to have “conditions consistent with the achievement of the values specified for the biological quality elements”.

Table 2: A three-tiered hierarchy of eflow methodologies (modified from Arthington et al. 1998; Acreman and Dunbar, 2004; King et al, 2008; TNC, 2011b)

		APPLICATIONS	OBSERVATIONS	TYPE	EFLOW PROMISING METHODS	INFORMATION REQUIRED
LEVEL 1	Preliminary assessment	- Regional planning - Preliminary standard setting - Screening at basin scale planning, organizing and pre-analyzing 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 and comprehensive initial flow recommendations can be provided when hydrologic desktop methods are combined with a review of available information for a given river system and augmented by basic understanding of river functions. Initial targets based on Level 1 analysis should be precautionary, in line with their level of confidence. Furthermore, such standards could play a strategic monitoring role, and could provide advance warning of situations where further investigation is required.	Comprehensive hydrologic desktop methods	- Range of Variability Approach (RVA): Yet probably the most advanced hydrological methodology used at this level. A simplified version of RVA reducing the number of variables might be sufficient to address screening or preliminary eflow assessment at catchment scale (e.g. Initially consider only monthly minimum flows applying 10-25 percentiles on a monthly basis). - ELOHA. The Ecological Limits of Hydrologic Alteration (ELOHA), is a flexible, scientific framework for assessing and managing environmental flows across large regions, when limited time and resources preclude evaluating individual rivers. ELOHA combines desktop hydrologic analysis with a review of existing ecological databases and literature.	A comprehensive hydrologic desktop approach synthesizes two primary sources of information: (1) a hydrological analysis tool that is capable of assessing a range of flow levels; and (2) a literature review of the linkages between the flow regime and key riverine resources. This review should incorporate all the available relevant information for the specific river or basin augmented by broader literature on riverine processes.
LEVEL 2	Intermediate assessment	- Basin scale planning - Organizing and pre-analyzing information for a Level 3 approach	It might apply to selected sites where more detailed environmental flow specifications are required. These circumstances require a greater level of detail in the application of eflow approaches. Basin scale planning involves the assessment of environmental flows through an entire basin. In this case assessment may begin with use of comprehensive hydrological desktop models to home-in on important sites. Then a holistic methodology would be most appropiate.	Holistic methodologies	- Building Block Methodology (BBM): Perhaps the best known holistic approach. Its basic premise is that riverine species are reliant on basic elements (building blocks) of the flow regime. The BBM revolves around a team of experts. They follow a series of structured stages, assess available data and model outputs and use their combined professional experience to come to a consensus on the building blocks of the flow regime. - The Downstream Response to Imposed Flow Transformation (DRIFT), offers promising and innovative advances to interactive eflow assessment. The DRIFT Methodology is an interactive, top-down holistic approach based on the same conceptual tenets and multidisciplinary, workshop-based interaction as the BBM.	Eflow recommendations at Level 2 require new data collection or basic modelling. Synthesis of information and articulation of expert judgment into flow recommendations occurs within the framework of a flow workshop with diverse participants. At this second level of assessment, some aspects of environmental flow recommendations will be based on limited data and professional judgement, and will amount to hypotheses about flow-geomorphology and flow-ecology relationships.
LEVEL 3	Comprehensive assessment	- Examining Tradeoffs and Predicting Results of Operational Changes (e.g. designation and management of HMWB) - Impact assessment processes - Restoration/re-habilitation of aquatic ecosystems;	A Level-3 process is appropriate for situations that require a high degree of certainty before any operational changes can made. Such situations may include those where water is over-allocated and heavily contested (e.g. Heavily Modified Water Bodies), affected Protected Areas, presence of endangered species which limits operational flexibility, defined policies dictate processes, etc. In these situations, decision makers will require a higher threshold of rigorous analysis before initiating an environmental flow program. Analyses of a Level 3 approach can incorporate both typical environmental flow assessment techniques as well as diverse approaches for studying socio-economical impacts (e.g. on water users) and others.	Holistic methodologies with advanced modelling approaches	- Holistic methodologies: BBM / DRIFT as recommended above. - Advanced modelling approaches: Habitat modelling is considered by many ecologists to be the most sophisticated and scientifically and legally defensible methodology available for quantitatively assessing environmental flows for rivers. In the European context, COST Action 626 "European Aquatic Modelling Network" defined and developed integrated methods and models of assessing the interactions between aquatic flora and fauna and riverine habitats on reach scale and provide transferability to a catchments scale.	Level 3 require intensive data collection and advanced modelling approaches (species/component-oriented). The research and modelling program of a Level 3 approach can be incorporated into a wider assessment framework that identifies the problem, uses the best methods and presents results to decision-makers. Assessment of technical feasibility, significant adverse effects and economic assessment methods can be applied.

Something similar happens with the Heavily Modified Water Bodies (HMWB) and Artificial Water Bodies (AWB). The reference conditions of these water bodies mainly depend on the hydromorphological changes necessary to maintain the specified uses listed in Article 4(3)(a). Maximum Ecological Potential (MEP), as the reference conditions for HMWB and AWB, is intended to describe the best approximation to a natural aquatic ecosystem that could be achieved given the hydromorphological characteristics that cannot be changed without significant adverse effects on the specified use or the wider environment. Accordingly, the MEP values for the biological conditions should reflect, as far as possible, the biological conditions associated with the closest comparable natural water body type at reference conditions, given the MEP hydromorphological and associated physical-chemical conditions (see WFD CIS, 2003b: Section 6.2.3).

Table 3: The hydrological regime for the Ecological Status classification

Category	Variable	Definition of High Status	Definition of Good 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.
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.	

4.1.1.2. The hydrological regime may complement the use of biological indicators in assigning the ecological status

The assessment of ecological status is based on biological quality elements as well as supporting hydromorphological, chemical and physicochemical quality elements. However, in accordance with the Annex V section 1.4.2. WFD, the classification of ecological status and ecological potential for surface water categories shall be represented only by the lower of the values for the biological and physical-chemical monitoring results for the relevant quality elements.

Accepting this as a general fact, the Directive also permits Member States to make estimates of the values of the biological quality elements using monitoring data for parameters, which are indicative of the biological quality elements (such as the hydrological regime) (see WFD CIS, 2003c). It is not intended that these supporting elements can be used as surrogates for the biological elements in surveillance and operational monitoring. However, in some circumstances, achieving a reliable assessment of the condition of a particular biological quality element may require consideration of the monitoring results for several parameters as indicatives of that single element. The use of indicator parameters such as the hydrological regime should facilitate reliable and cost-effective assessments.

The possibility of using more than one indicator to estimate the value for a biological quality element also could provide an important means of avoiding unacceptable risks of misclassification. This is because the results for different indicators can be cross-checked. If the result for one is at odds with the result for another, this may suggest that more data is needed to achieve the required confidence in the estimated value of the quality element.

To this concern, the information available on the status of development of biological monitoring methods in many Member States is currently unclear and insufficient. As reflected in the 2nd implementation report (CEC, 2009), the biological assessment methods have not yet been developed in all Member States or in all river basin districts. For quite a large number of river basin districts there was either no information on the status of method development or the information was incomplete. No Member State has delivered complete information on the level of confidence and precision of the methods developed, an about half of the Member States have at least delivered some information, but this is largely insufficient for the purpose of assessing confidence and precision in the biological assessment results.

In this context of early development of biological assessment methods, the role of the Hydromorphological Quality Elements complementing the ecological classification should not be understated.

4.1.2. The hydrological regime and the monitoring of water bodies

In accordance with Article 8(1) WFD Member States need to establish monitoring programmes for the assessment of the status of surface water and of groundwater. The Directive foresees three different kinds of monitoring programmes for surface waters: surveillance monitoring, operational monitoring, and investigative monitoring.

- Surveillance monitoring is established to provide an assessment of the overall surface water status within a catchment or sub-catchment in a river basin district, thereby taking into account the results of the risk analysis carried out under Article 5 WFD in 2004 and supplementing and validating it. Surveillance monitoring should include all biological quality elements, all hydromorphological and all general physicochemical quality elements as well as the priority list pollutants which are discharged into the river basin or sub-basin, and other pollutants discharged in significant quantities.
- Operational monitoring is established to follow a targeted approach in order to assess the ecological and chemical status of those water bodies that have been identified as being at risk of failing to meet the environmental objectives. In order to assess the magnitude of the pressure to which bodies of surface water are subject Member States shall monitor for those quality elements which are indicative of the pressures to which the body or bodies are subject, including parameters indicative of the hydromorphological quality element most sensitive to the pressure identified.
- Investigative monitoring has to be carried out where the reason for failing to reach good status is unknown or in order to determine the magnitude and impacts of accidental pollution.

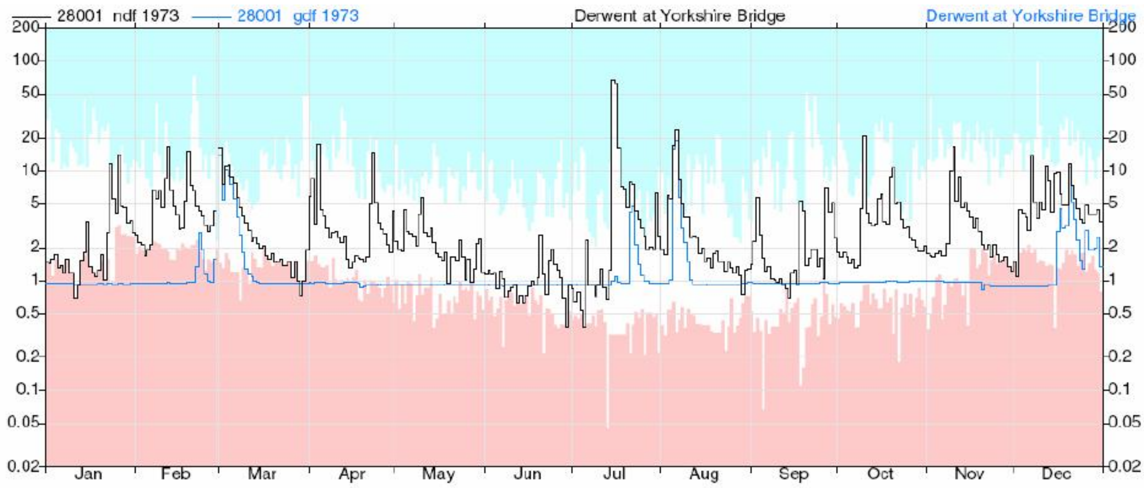
The monitoring programmes should be based on the results of the pressure and impact analysis carried out under Article 5 and Annex II WFD. The Article 5 reports show that the most significant and widespread pressures are diffuse pollution, physical degradation of water ecosystems (physical modifications) and, particularly in Southern Europe, overexploitation (EC, 2007).

The first implementation report (CEC, 2007) shown that detailed information, on the types of pressures leading to the identification of water bodies at risk, was often not provided and that a complete risk analysis per water category was, in most cases, missing. 12 Member States reported information on the relative importance of different pressures and impacts for surface waters and only 5 Member States have provided complete information on the main pressures (point source pollution, diffuse source pollution, water flow regulations/morphological alterations and water abstraction).

The monitoring programmes must provide the information necessary to assess whether the Directive’s environmental objectives are being (or will be) achieved. This means that a clear understanding of the environmental conditions required for the achievement of the objectives, and of how these could be affected by human activities, is essential to the design of effective monitoring programmes (WFD CIS, 2003c).

There is no doubt that hydromorphological pressures will play an important role in achieving or not the GES. In making effective and operational the monitoring programs, quantitative information should be necessary, as part of the hydromorphological assessment. In the case of the hydrological regime this would allow identifying flow values outside the range established, so as to ensure the functioning of the type specific ecosystem or a probably risk of not achievement the values specified for the biological quality elements (figure 4).

Fig. 4. Flow chart of Derwent River at Yorkshire Bridge (UK). Quantitative assessment of the hydrological regime allows identify flow values outside predefined relevant thresholds. Black line: pre-impoundment typical year; Pale blue and red shading: historical range; Blue line: post-impoundment typical year. SOURCE: UK TAG, 2007



4.1.2. Assessing the quality of the hydrological regime

In making the Directive operational, it would be necessary to better understand the relationships between the quality of the hydrological regime and biological components of ecosystems. This knowledge would be useful for:

- Establishing boundaries between reference conditions and other 'status' classes in developing classification schemes;

- Identifying pressures and impacts in catchment characterisation;

- Identifying appropriate (regulatory) actions to improve ecological status (in developing programmes of measures).

Assessment of hydromorphological parameters is particularly important in the operational monitoring. As seen in previous sections, the assessment system would identify those hydromorphological factors that prevent attainment of the environmental objectives if properly designed.

Following the CIS document on Monitoring (Littlejohn et al., 2002) Member States should ensure a number of general criteria in the monitoring programmes that include: i) an assessment of the deviation of observed conditions to those that would normally be found under reference conditions; ii) an assessment that provides for natural and artificial habitat variation; iii) a protocol that accounts for the range of natural variability and variability arising from anthropogenic activities of all quality elements in all water body types; and, iv) a scheme that provides for the detection of the full range of potential impacts to enable robust classification of ecological status.

The European Standard "CSN EN 15843 - Water quality - Guidance standard on determining the degree of modification of river hydromorphology" provides guidance on appraising the quality of rivers based on a suite of hydromorphological features described in EN 14614, including the hydrological regime.

This standard enables consistent, broad-based characterization across a wide spectrum of hydromorphological modification including effects of catchment-wide modifications to natural flow character (table 4) and effects of daily flow alteration (e.g. hydropeaking). Its primary aim is to assess 'departure from naturalness' as a result of human pressures on river hydromorphology. Specifically, it sets out scoring systems to assess among others the hydrological regime in five classes using quantitative data and suggests suitable sources of information which may contribute to characterizing the modification of hydromorphological features.

Table 4: Quantitative criteria to assess the departure from naturalness of the flow regime SORCE: CSN EN 15843

% 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

Although relevant to the WFD, this standard is not principally designed for WFD assessments. In fact, the names used to describe each class (e.g. 'near-natural') have been deliberately chosen to be different from terms used in the WFD (e.g. 'high', 'good') to emphasise that classifications made using this standard are unrelated to classifications of ecological status made for the WFD. However it focuses especially on human pressures that affect rivers and where characterisation may be helpful for implementing the WFD, to indicate to what extent these pressures could have caused a deviation from the reference hydromorphological conditions.

It is recalled that the Directive indicates that the monitoring of type parameters for surface waters, including hydro-morphological elements, should conform to appropriate international standards such as those developed by CEN and ISO, which should ensure the provision of data of an equivalent scientific quality and comparability.

4.2. Eflows to achieve WFD objectives

As set out in Article 174 of the Treaty, the Community policy on the environment is to contribute to pursuit of the objectives of preserving, protecting and improving the quality of the environment, in prudent and rational utilisation of natural resources, and to be based on the precautionary principle and on the principles that preventive action should be taken, environmental damage should, as a priority, be rectified at source.

The WFD introduces new, broader ecological objectives, designed to protect and, where necessary, restore the structure and function of aquatic ecosystems themselves, and thereby safeguard the sustainable use of water resources. The three principal environmental objectives for surface water bodies and bodies of groundwater are to: i) prevent deterioration in status; ii) restore to good status by 2015; and iii) protect and restore, where applicable, to achieve the objectives for Protected Areas established under Community legislation.

As seen in Section 1.2, the hydrological regime is a "master variable" of aquatic ecosystems strongly correlated with many physical-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). For the purpose of protecting the environment is necessary to consider the water needs of aquatic ecosystems, thus contributing to preserve, protect and improve environmental quality and the rational use of water resources. The Directive is explicit in this regard since the classification of ecological status should be considered a hydrological regime consistent with environmental objectives (see Section 4.1.1.).

4.2.1. Eflows to achieve the GES

4.2.1.1. Implicit eflow definition for the 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*'. GES is unlikely to be reached in a water body with significantly altered flows, as this will result in changes to the river ecosystem through modification of physical habitat and alterations in erosion and sediment supply rates (see Section 2.2.). Consequently, restoring a suitable flow regime may well be a necessary measure in an aquatic ecosystem that fails GES (Hirji and Davis, 2009).

A hydrological regime consistent with the environmental objectives that impose the Directive is very close to the eflow concept handled in Section 2.3.1. that was defined as *"Maintaining or partially restoring important characteristics of the natural flow regime in order to maintain specified, valued features of the ecosystem"*.

Accepting this parallelism it can be said therefore that the concept of environmental flows is implicit in the WFD. Accordingly, eflows for the GES can be defined as *the hydrological regime necessary to achieve the values specified for the biological quality elements in order to be classified as Good Status*.

4.2.1.2. A hydrological regime, but not anyone

In a similar way as happens with the physical-chemical quality elements, a hydrological regime consistent for the GES must ensure the functioning of the type specific ecosystem and the achievement of the values specified for the biological quality elements.

This statement raises several issues for consideration:

- A hydrological regime for the functioning of aquatic ecosystems. Proper structure and functioning[4] is a first condition for preserving aquatic ecosystems. As seen in Section 2.2 functioning of aquatic ecosystems is largely caused by different flows types which vary throughout the seasons and over the years. From a pragmatic point of view the hydrological regime should adequately consider the Environmental Flow Components[5] that should be defined for different hydrological conditions (drought and wet years) in order to capture the interannual variability
- A hydrological regime for a type specific ecosystem. The magnitude, duration, frequency and timing of the EFC are particular to each type of ecosystem. Overall species have evolved according to the ranges and typical patterns of the natural hydrological regimes. In these circumstances, the

[4] Ecological status is an expression of the quality of the structure and functioning of aquatic ecosystems
[5] Environmental Flow Components would include at least the seasonal base flows and the flood regime

hydrological regime to achieve GES should be based on the natural regime typical of that type of ecosystem.

- A hydrological regime where values of biological quality elements are classified as GES. Processes and conditions imposed by this hydrological regime will be consistent with the values of the biological quality elements for GES, that is to say, these values show low levels of distortion resulting from human activity[6]. Considering the high level of environmental protection required for the GES, a consistent hydrological regime should reflect in a great extent the natural flow regime.

To sum up, it can be said that a hydrological regime consistent with the GES must include the most relevant components of the hydrological regime to active the ecosystem dynamic (EFC), must be based on the natural hydrological regime of the water body and must reflect a large proportion of such natural regime.

4.2.1.3. Exploring some preliminary benchmarks

The BCG[7] is a good model to theoretically illustrate the required naturalness of the hydrological regime in the context of the GES. The original six levels of biological integrity defined in the BCG can be reinterpreted as the five ecological status classes of the WFD. In this case the stress-response curve moves from the High Status with no or low levels of flow modification to Bad Status due to high levels of hydrological alteration (Figure 5). This model can also be interpreted in reverse since the ecological status will fall as environmental flows are lower.

Fig. 5. Theoretical relationships between environmental flows and ecological status classes. SOURCE: Authors

Overall, the generic evidence to support the ecological need to protect the whole of the natural flow regime is strong, but there remains uncertainty to define levels of flow modification and subsequent tiers of ecological response. Expert judgement has been used also to suggest limits on deviations from naturalised flow conditions that might be considered ecologically acceptable, such as the maximum abstraction levels that would maintain GES. The WFD 48 project (Acreman et al, 2005) assembled a panel of ecologists to try and agree acceptable limits across the range of UK Rivers and for key components of the biota. The project produced lookup tables for each river type, specifying the maximum abstraction allowable at different flows (Table 5). The maximum levels of abstraction ranged from 7.5 to 35 percent of the natural flow, depending on river type and flow rate.

[6] According to the general definition of Good Status (Annex V, table 1.2.) the values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions.
[7] The Biological Condition Gradient model is described in Section 2.2.

Table 5: Recommended standards for UK river types for achieving GES as % allowable abstraction of natural flow. SOURCE: Acreman *et al*, 2005

Type	Season	flow > Qn_{60}	Flow > Qn_{70}	flow > Qn_{95}	flow < Qn_{95}
A1	Apr – Oct	30	25	20	15
	Nov – Mar	35	30	25	20
A2 (ds), B1, B2, C1, D1	Apr – Oct	25	20	15	10
	Nov – Mar	30	25	20	15
A2 (hw), C2, D2	Apr – Oct	20	15	10	7.5
	Nov – Mar	25	20	15	10
Salmonid spawning & nursery areas (not Chalk rivers)	Jun – Sep	25	20	15	10
	Oct – May	20	15	flow > Q_{80} 10	flow < Q_{80} 7.5

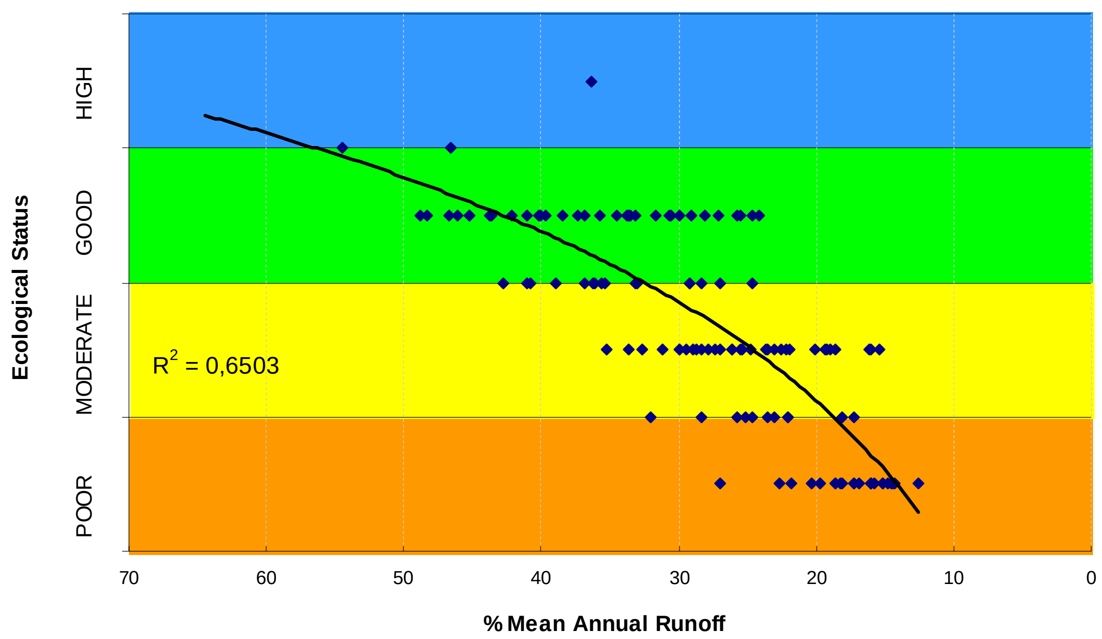
Nevertheless, one of the most promising approaches to establish benchmarks for GES is making use of the recommendations produced by comprehensive eflow assessments (e.g. the Building Block Methodology). These studies explicitly estimate eflows (including minimum and high flows) related to adopted environmental flow objectives.

King (1998) formulated the Bulk Water Estimate approach to provide very conservative and low confidence answers during the reconnaissance phase of planning for water resource developments. The BWE compared the results of a comprehensive holistic approach (Building Block Methodology) as a percentage of the Mean Annual Runoff (MAR) with the Management Class of the rivers. The results expressed as a percentage of the MAR would allow the definition of the volume of water necessary to maintain a body of water in a given ecological status.

This BWE approach can be applied to the eflows worldwide database developed by IWMI in collaboration with TNC and UNEP GEMS/Water as part of the activities of UNESCO Task Force on Eco-Hydrology. The database is a collection of actual estimates of environmental flows in 207 case studies and has been specifically designed to support further development of environmental flow assessment methodologies.

Selecting only those cases with a classification system of ecological classes similar to that proposed by the WFD (159 cases selected) it is noted that the relationship between eflows (expressed as % of MAR) and ecological classes is similar to the BCG model (figure 6). Unfortunately there is now a database at the European level to develop a study of this nature. However, notwithstanding the limitations of this preliminary analysis, the results are illustrative: based on the IWMI database environmental flows would lie roughly between 25% and 50% of the Mean Annual Runoff for the GES class.

Fig. 6. Quantitative relationships between environmental flows as % of MAR and ecological status classes. DATA SOURCES: IWMI-Worldwide database on eflow assessments



4.2.2. Eflows in Heavily Modified Water Bodies (HMWB)

The concept of HMWB was introduced into the WFD in recognition that many water bodies in Europe have been subject to major physical alterations so as to allow for a range of water uses. Important uses of surface waters include navigation, flood protection, activities for the purpose of which water is stored (drinking water supply, power generation or irrigation) and recreation as specified in Art. 4(3)(a) of the WFD.

These specified uses tend to require considerable hydromorphological changes to water bodies of such a scale that restoration to GES may not be achievable even in the long-term without preventing the continuation of the specified use. The concept of HMWB was created to allow for the continuation of these specified uses which provide valuable social and economic benefits but at the same time allow mitigation measures to achieve an appropriate ecological objective: good ecological potential (GEP).

4.2.2.1. Can be designated a HMWB due only to hydrological alteration?

According to the 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 substantially changed in character*". It is important to emphasise that changes in hydromorphology must be not only significant, but also result in a substantial change in the character of a water body.

A water body could be described as substantially changed in character if both morphology and hydrology are subject to substantial changes, especially when morphological changes are likely to be long-term. It is less clear that a water body should be considered as substantially changed in character if only hydrology is substantially changed as such changes may only be temporary or short term. As a general rule it is considered that temporary or intermittent substantial hydrological changes is not to be considered substantially changed in character (WFD CIS, 2003b).

In other cases, 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.

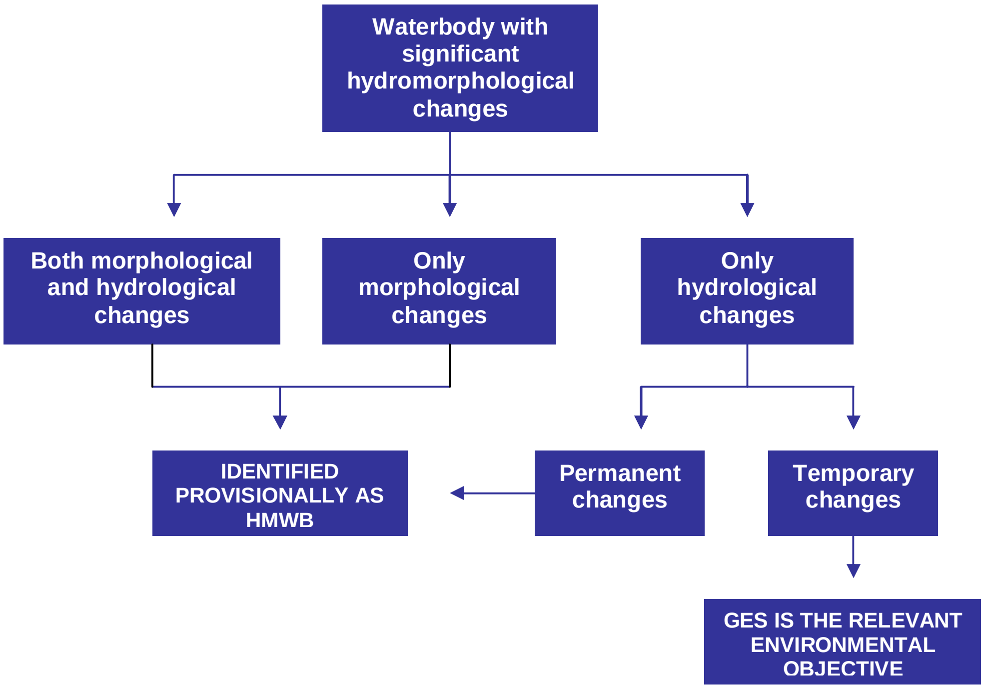
A slightly different approach could be taken for limited stretches of rivers, e.g. downstream of dams. Under these circumstances, substantial hydrological changes that are accompanied by subsequent non-substantial morphological changes would be sufficient to consider the water body for a provisional identification as HMWB (WFD CIS, 2003b).

According to the WFD CIS (2003b), all of these possible situations are shown in Figure 7. At this point, a water body affected by permanent and substantial hydrological changes[8] could be designated as HMWB if restoration measures (mainly eflows) have significant adverse effects on the wider environment or the "specified uses" and there are not "other means"[9] to achieve the beneficial objectives served by the modification of the HMWB.

[8] CIS Document concludes that a "substantial" change in hydromorphology is one that is extensive/widespread or profound, or very obvious in the sense of a major deviation from the hydromorphological characteristics that would have been there before the alterations.

[9] It has to be assessed whether the "other means" are a) technically feasible, b) a better environmental option and c) not disproportionately costly.

Fig. 7. Provisional identification of a waterbody as HMWB depending of different hydromorphological changes. SOURCE: Based in WFD CIS (2003b).



4.2.2.2. What is the role of environmental flows in the designation of HMWB?

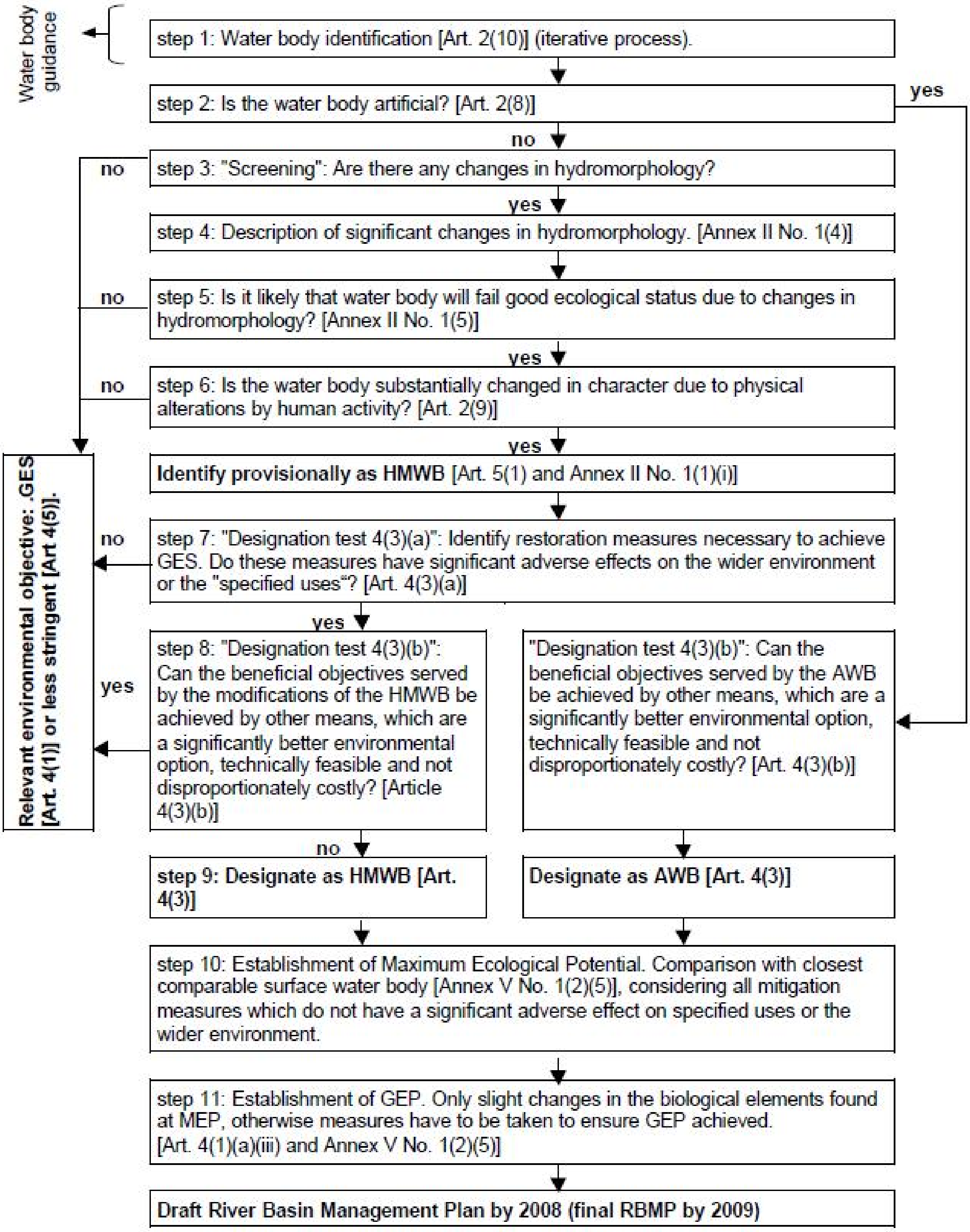
A very large number of water bodies were going to be assessed for possible designation as HMWB. It was important therefore to ensure that the approaches and methods used for the designation process were practicable and comparable in all Member States. WFD CIS (2003b) proposed a stepwise approach to the identification and designation of HMWB (figure 8).

Environmental flows are useful and necessary in the process of identifying and designating HMWB because:

- They serve to identify significant changes in hydromorphology (step 4). By definition environmental flows integrate key elements of the hydrological regime (environmental flow components) which are necessary for proper ecosystem dynamics. Eflows establish thresholds beyond which is expected to produce significant effects on aquatic ecosystems.

- They are a useful tool to assess the likelihood of failing good ecological status (step 5). It is important to determine whether hydrological changes on the water body will prevent achieving GES. By definition environmental flows are designed to ensure the functioning of the specific type of ecosystem and the achievement of values specified for the biological quality elements, in order to be classified as Good Ecological Status (see Section 4.2.1.). Flow values under thresholds should indicate the likelihood of failing GES.

Fig. 8. Steps of the HMWB identification and designation process. SOURCE: WFD CIS (2003b).



- They are the first restoration measure (step 7) to consider when there is a significant change in the hydrological regime. As defined previously eflows are specifically designed to achieve GES.

- They are indispensable to evaluate possible significant adverse effects on the specified uses (step 7.2). According to the CIS (2003b), it is not considered possible to derive a standard definition for "significant" adverse effect. Although it is possible to give an indication of the difference between “significant adverse effect” and “adverse effect”. For example, an effect should not normally be considered significant where the effect on the specified use is smaller than the normal short-term variability in performance (e.g. total kilowatt). However, the effect would clearly be significant if it compromised the long-term viability of the specified use by significantly reducing its performance. This quantitative difference can be evaluated if defined environmental flows.

4.2.3. Eflows in Protected Areas

4.2.3.1. General provisions

Under Article 4 the environmental objectives of the Water Framework Directive (WFD) are divided into those for surface waters, groundwater and protected areas. For protected areas the objectives are those noted in the Community legislation under which these areas are designated, with the additional objective that “*Member States shall achieve compliance with the existing standards and objectives*”

Article 6 of the WFD requires Member States to establish a register of protected areas. The register (or registers) is limited to areas lying within river basin districts designated *“…as requiring special protection under specific Community legislation…*” for the protection of their surface water and groundwater or “… for the conservation of habitats and species directly depending on water”.

The standards required to achieve the objective for a Protected Area are the biological, physical-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. To the extent that environmental flows can appreciably affect protected areas, eflow estimates are necessary, in order to maintain the quality levels of their surface water and groundwater, as well as the ecological requirements of communities, habitats or species. Article 4(2) of the WFD states that where more than one objective applies to a water body, the most stringent objective shall apply. Within a protected area the most stringent of the protected area and, for example, the status objective would apply.

4.2.3.2. Eflows in Natura-2000 sites

The register of protected areas in the river basin management plans (WFD Art. 6) covers any Natura-2000 site when one or more habitats and species[10] 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.

[10] 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

There is wide range of types of water dependency amongst Natura 2000 habitats and species. Table 6 sets out ecological criteria used to identify those habitats and species likely to be directly dependent on the status of water.

Table 6: Ecological criteria used in UK for identifying Natura Habitats and Species that are directly dependent on status of water. SOURCE: WFD CIS (2003e).

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 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 7).

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). Eflows are significant for the conservation of water-dependent species, and therefore the eflows has to be adequate to meet the favourable conservation status.

Table 7: Criteria to define conservation status of habitats and species under the HD. SOURCE: Authors

HABITATS	SPECIES
Its natural range and areas it covers within that range are stable or increasing, and	Population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and
The specific structure and functions which are necessary for its long term maintenance exist and are likely to continue to exist for the foreseeable future, and	The natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and

HABITATS	SPECIES
The conservation status of its typical species is favourable as defined in (i)	There is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis;

These considerations are reinforced with Article 6 (2) of the HD since establishes that Member States shall take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbances of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this directive.

Deterioration referred to the previous paragraph is a physical degradation affecting a habitat. Deterioration against the objectives of the HD refers to the definition of the favourable conservation status of a natural habitat set out in Article 1(e) (CEC, 2000), on the basis of the following factors: i) Any event which contributes to the reduction of the areas covered by a natural habitat for which this site has been designated can be regarded as deterioration; ii) Any impairment of the factors necessary for the long-term maintenance of the habitats can be regarded as deterioration; iii) The functions necessary for the long-term maintenance depend of course on the habitat concerned.

Thereby it can be said that Member States have to know eflows requirements since Article 6(1) provides that they have to take measures 'which correspond to the ecological requirements of the habitats in Annex I and species in Annex II' and Article 6 (2) establishes that Member States shall take appropriate steps to avoid the deterioration of natural habitats and the habitats of species.

4.2.4. Eflows and groundwater

4.2.4.1. Groundwater quantitative status

Article 4.1(b) (ii) states that Member States shall *"...ensure a balance between abstraction and recharge of groundwater with the aim of achieving good groundwater status... by 2015... in accordance with the provisions in Annex V..."*

The definition of good quantitative status is set out in WFD Annex V 2.1.2. For a groundwater body (GWB) to be of good quantitative status each of the criteria covered by the definition of good status must be met. These criteria are:

- available groundwater resource is not exceeded by the long term annual average rate of abstraction;
- no significant diminution of surface water chemistry and/or ecology resulting from anthropogenic water level alteration or change in flow conditions that would lead to failure of relevant Article 4 objectives for any associated surface water bodies;

- no significant damage to groundwater dependent terrestrial ecosystems resulting from an anthropogenic water level alteration;n

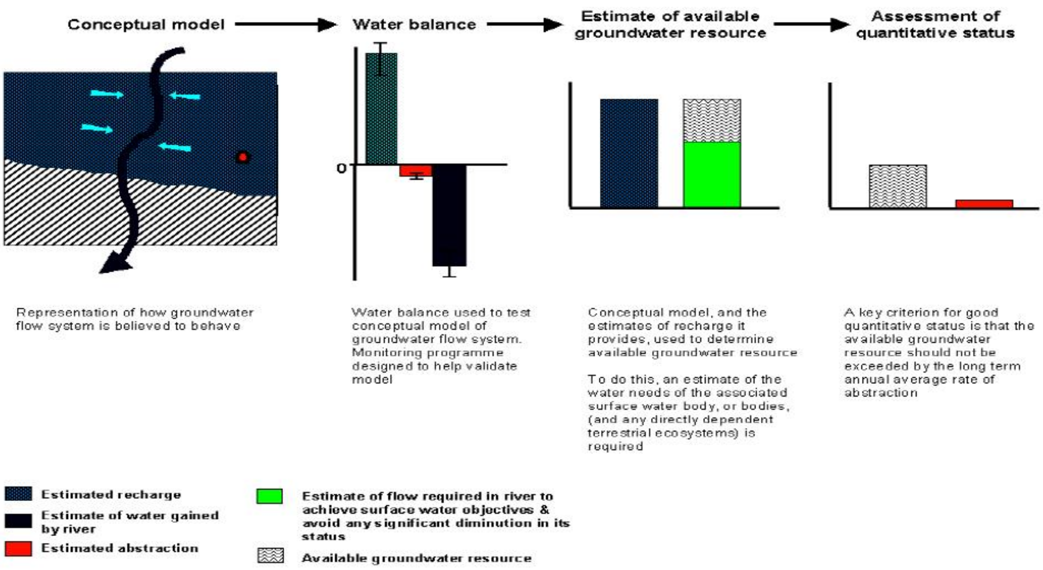
- no saline or other intrusions resulting from anthropogenically induced sustained changes in flow direction.

4.2.4.2. The role of eflows for assessing groundwater quantitative status

In order to assess whether the above conditions have been met or not, a series of classification tests (for both quantitative and chemical status) has been developed (CIS, 2009). In the case of quantitative status have been developed the following 4 test:

a) Test 1: Water Balance. For a GWB to be of good status for this test, long-term annual average abstraction from the GWB must not exceed long-term average recharge minus the long-term ecological flow needs (figure 9). For the water balance test we must assess annual average abstraction against 'available groundwater resource' in the groundwater body. The available groundwater resource means the long-term annual average rate of overall recharge to the body of groundwater minus the long-term annual rate of flow required to achieve the ecological quality for associated surface waters (specified in Article 4), avoid any significant diminution on the ecological status and avoid any significant damage to groundwater dependent terrestrial ecosystems (GWDTE). According to the CIS document, both the surface water and GWDTE environmental flows, and the impacts of groundwater abstraction on low flows must be determined.

Fig. 9. Role of environmental flows in the water balance test. SOURCE: WFD CIS (2009).



b) Test 2: Surface Water Flow. For a GWB to be of good status for this test, there should be no significant diminution of surface water chemistry or ecology that would lead to a failure of

Article 4 surface water objectives (n.b. relating to surface water bodies). This test includes both river and open water bodies such as lakes to which WFD surface water objectives apply. This test requires that eflows or water level requirement of surface water bodies (associated with GWBs) needed to support achievement (and maintenance) of good chemical and ecological status is determined. If this flow/level requirement is not being met as a result of a significant impact from groundwater abstraction, then the GWB will be of poor status unless the surface water body remains of good/high ecological status. Under any other circumstances the GWB will be of good status.

c) Test 3: Groundwater Dependent Terrestrial Ecosystems (GWDTE). For a GWB to be of good status there should be no significant damage to a terrestrial ecosystem that depends on groundwater. The GWDTE tests for both chemical status assessment and quantitative assessment are closely linked. This test requires that the environmental condition required to support and maintain conditions within a GWDTE (e.g. flow or level needed to maintain dependent (plant) communities) are determined. If the conditions are not being met and groundwater level and flow change due to abstraction is determined to be a significant cause, then the GWB is of poor status. In all other cases the GWB will be of good status but potentially at risk.

d) Test 4: Saline (or other) Intrusion. For a GWB to be of good status for this test there should be no long-term intrusion of saline (or other poor quality water) resulting from anthropogenically induced sustained water level or head change, reduction in flow or alteration of flow direction due to abstraction.

Each relevant test (considering classification elements which are at risk) should be carried out independently and the results combined to give an overall assessment of groundwater body chemical and quantitative status. The worst case classification from the relevant quantitative tests is reported as the overall quantitative status. If any of the tests results in poor status (chemical or quantitative), then the overall classification of the body will be poor.

As seen above, in 3 of the 4 previous test is necessary to determine eflows. This gives an idea of the importance of environmental flows when assessing the quantitative status of water bodies.

4.3. Eflows in the program of measures

4.3.1. Eflows as a measure

Article 11 of the WFD states that each Member State shall ensure the establishment "*...of a programme of measures...in order to achieve the objectives established under Article 4*". Gap analysis is essentially the determination for each water body within each river basin district of any discrepancy between its existing status and that required under the Directive.

For surface water bodies that are already at high or good ecological status the focus will then fall on any gap between existing measures and any future measures needed to maintain that status. Where the current status of surface water bodies falls below that required for good ecological status, attention is focused on measures to restore this status. For surface water bodies, identified as heavily modified water bodies or as artificial water bodies the process is similar except that the aim is good ecological potential. A similar gap analysis process is used to identify where action is needed to protect or enhance the quality of groundwater bodies.

According to Article 11 (3), "*basic measures*" shall consist, *inter alia*, of measures to promote an efficient and sustainable water use in order to avoid compromising the achievement of the objectives specified in Article 4 (Art 11 (3) (c)) and controls over the abstraction of both fresh surface water and groundwater, and impoundment of fresh surface water (Art 11 (3) (e)).

More specifically Article 11 (3) (i) states that should also be considered measures to ensure that the hydromorphological conditions of the bodies of water are consistent with the achievement of the required ecological status or good ecological potential for bodies of water designated as artificial or heavily modified. As defined in Section 4.2.1.1., eflows for the GES were defined as the hydrological regime necessary to achieve the values specified for the biological quality elements. It can be said therefore that Article 11 (3) (i) calls for action to ensure environmental flows.

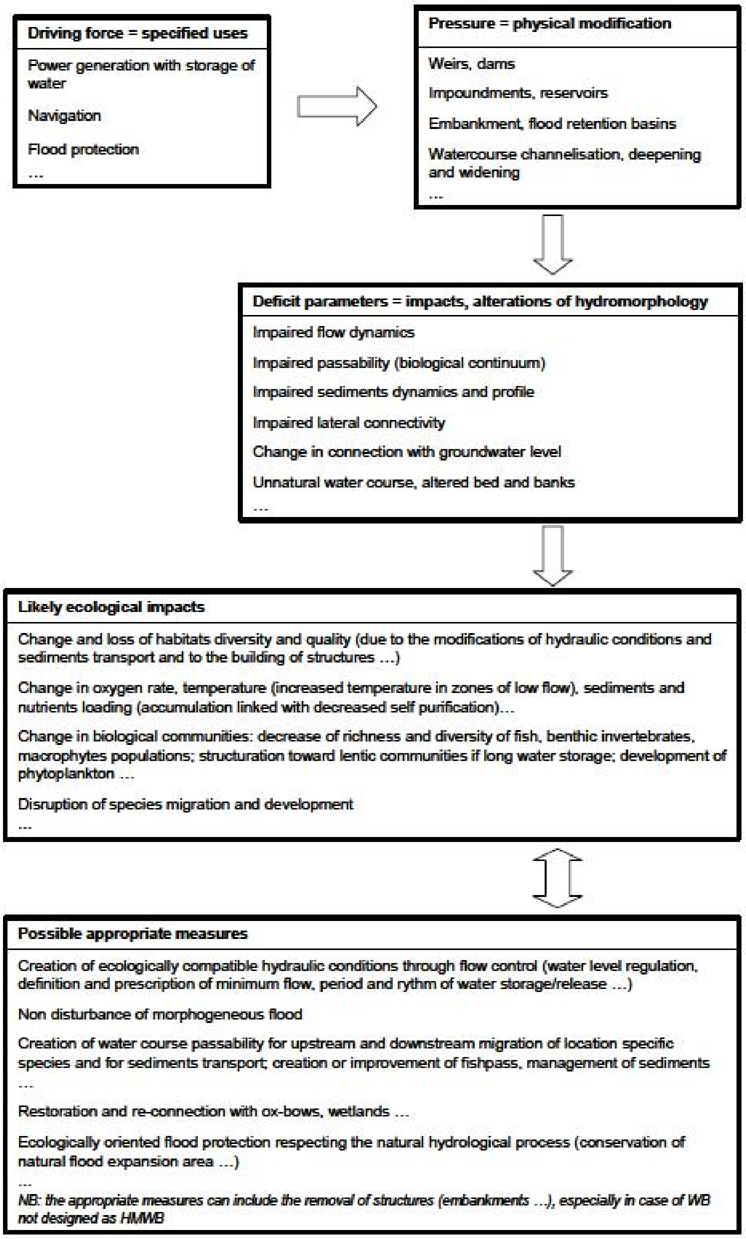
4.3.2. Eflows as a restoration/mitigation measure

The choice of the appropriate restoration and mitigation measures will depend on a number of site specific considerations. Specifically, the appropriate measures will depend on the adverse ecological effects of the physical modifications; on the effectiveness of the measures regarding in particular the improvements of the ecological condition; on the technical feasibility and the cost-effective analysis of implementing the measures at the site; and, in the case of designated HMWB or AWB, on the effects of the mitigation measures on those water uses responsible for the modifications and other uses dependent on the modification. Nevertheless, some examples of criteria for assessment of impacts may be provided, which obviously and directly influence biology and therefore ecological status or potential.

The aim of the Hydromorphological Pressures Technical Report (WFD CIS, 2006) was to provide guidance and good practice examples of how to prevent, remedy or mitigate the adverse ecological effects of human alterations to the structural and hydrological characteristics of surface water bodies in order to achieve the environmental objectives set by the WFD. Figures 10 illustrate the types of measures that may be appropriate in relation to water flow changes and their associated ecological impacts, due to the typical hydromorphological modification needed for particular water uses.

Importance of flow dynamics in the design of restoration/mitigation measures was highlighted in Annex III of this report (WFD CIS, 2006). Under undisturbed conditions the river has maximized its morphological variability in response to the natural fluctuations in the flow. Associated spatial and temporal velocity distributions enable the river to transmit the accompanying sediment load and establish a dynamic stability while retaining a complex of pools, riffles, runs glides and meandering pattern and sustaining bed material heterogeneity. The variability in flow depths, velocities and bed material sizes within a reach is the basis of the natural habitats and their variation and controls therefore the biodiversity of the river reach. Thus the flow dynamic is recognized as a heart-beating of ecosystem. Although the restoration of natural flow dynamics is seen as the most vital step, it is an often neglected aspect in river rehabilitation.

Fig. 10. Examples of drivers, pressures, impacts and possible measures related to water flow changes. SOURCE: WFD CIS, 2006



4.3.3. Cost effectiveness of eflows

Information on the cost and effectiveness of different measure options provides a means of comparing the relative cost efficiency of those options. Such information will therefore provide the basis for making judgements about the combination of measures that will produce a given improvement most cost-effectively.

Annex IV of the Hydromorphological Pressures report presents a list of potential restoration and mitigation measures and their cost-effectiveness. Eflows will appreciate a generally positive experience with few negative side-effects with respect to the ecological significance and often a cost-efficient approach but requires case by case documentation.

One of the primary reasons for the growing shift in perceptions regarding the use of environmental flows is the growing understanding of the scale of their real and potential economic benefits. Numerous studies have looked at the economic value of ecosystem services provided by flows, including habitat creation, recreational opportunities, contribution to housing prices, groundwater recharge, contribution to water quality, and so on (NPS 2001; Emerton and Boss 2004).

For policy making, the benefits of environmental flows must be measured against the opportunity costs of alternative uses of the water, such as foregone agricultural and hydropower production (Katz, 2006). Because many environmental flow benefits are difficult to quantify precisely, they have often been ignored in benefit-cost analyses and planning processes. In some cases, however, even imprecise measures of flow benefits have proven sufficient to justify environmental flows on economic grounds.

5. CONCLUDING REMARKS

In order to address water-quantity related aspects for setting up adequate enabling conditions for the WFD, a set of actions is needed. Those shall include the following:

- The conservation of aquatic ecosystems requires a hydrological regime based on natural flow events, including low, medium and high flows. The natural hydrological regime is a benchmark of management, resulting in essential natural processes and native species are adapted to it.

- Environmental flows are the society's response to the progressive deterioration of aquatic ecosystems due to intensive use of surface water and groundwater. Environmental flows are a key tool to maintain or restore those aquatic ecosystems where alteration of the hydrological regime has led to its degradation.

- Although there are over 200 methods for estimating environmental flows, not all of them are based on current scientific knowledge or practice. Only a small number of promising methods should be applied in the context of the EU, once taken into account the scientific and international experiences and the legal requirements arising from the WFD.

- No single environmental flow assessment technique suits all social, economic, hydrological, and ecological contexts within a country or region. This has led to use different methods for different purposes depending on the specifics of the case study and the type of issue to be addressed (water planning, monitoring, river restoration plan, etc.). A phased hierarchical approach is probably the most efficient way to address the application of methods in order to develop the environmental flow policy in a country, region or basin.

- The hydrological regime is an important quality element in the implementation of the WFD. An adequately assessed hydrological regime would help to better classify the ecological status of water bodies and identify possible causes of failure of environmental objectives. The European Standard CSN EN 15843 evaluates the quality of the hydrological regime.

- Eflows can support Good Ecological Status when defined as the hydrological regime necessary to achieve the values specified for the biological quality elements in order to be classified as Good Status. A hydrological regime consistent with the GES must include the most relevant components of the flow regime to active the ecosystem dynamic, must be based on the natural hydrological regime of the water body and must reflect a large proportion of such natural regime. A comprehensive review of environmental flow studies has been used to suggest flow conditions that would maintain GES. Based on a selection of 159 global case-studies with a classification system of ecological classes similar to the WFD, environmental flows lie roughly between 25% and 50% of the Mean Annual Runoff for the GES class.

- Environmental flows are useful and necessary in the process of identifying and designating HMWB (identify significant changes in hydromorphology, assess the likelihood of failing good ecological status, restoration measure, evaluate possible significant adverse effects on the specified uses, etc.). Additionally, the designation of a HMWB may be due to different hydromorphological changes (hydrological, morphological or a combination of both). This allows distinguishing three situations for which environmental flows are different.

- To the extent that environmental flows can appreciably affect Protected Areas, eflow estimates are necessary, in order to maintain the quality levels of their surface water and groundwater, as well as the ecological requirements of communities, habitats or species. Member States have to know eflows requirements in water-dependent Natura-2000 sites since Article 6(1) of the HD provides that they have to take measures 'which correspond to the ecological requirements of the habitats in Annex I and species in Annex II'.

- In order to assess groundwater quantitative status, a series of classification tests has been developed. In 3 of the 4 test the environmental flow requirements (water balance, surface water flow and Groundwater Dependent Terrestrial Ecosystems) are considered. This gives an idea of the importance of environmental flows when assessing the quantitative status of water bodies.

- The importance of flow dynamics in the design of restoration/mitigation measures has been highlighted in different reports. Eflows have been considered a generally positive experience with few negative side-effects with respect to the ecological significance and often a cost-efficient approach. One of the primary reasons for the growing shift in perceptions regarding the use of environmental flows is the growing understanding of the scale of their real and potential economic benefits. Numerous studies have looked at the economic value of ecosystem services provided by flows.

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