Environmental flows: the European approach through the Water Framework Directive 2000/60/EC

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Abstract

The Water Framework Directive 2000/60/EC is primarily focused on water quality, addressing the quantity as an ancillary element towards achieving good ecological status (GES). However, recent WFD implementation reports reveal that water quality and quantity are closely interrelated and water bodies with significantly altered hydrological regime are not reaching GES. This led the European Commission to focus on hydrology and recently issued an environmental flows (eflows) Guidance Document to assist Member States in ensuring sufficient quantity of good quality water for the European water bodies. The European eflows framework requires continuous hydrological monitoring to provide supplementary information to the biological quality elements and support the implementation of specific steps: i) a preliminary risk analysis to define water bodies at risk of not achieving the WFD objectives due to hydrological alteration; ii) establishment of an extensive hydrological monitoring network; iii) water-body type-specific environmental flow assessments (EFAs) and assessment of the gap between current and reference state; iv) application of measures to restore eflows, towards a flow regime consistent with the requirements to achieve the WFD environmental objectives. A three-level approach for EFAs is proposed, including: i) preliminary desktop analyses using hydrological methods; ii) detailed assessments requiring field data collection according to the holistic approaches; iii) combination of holistic methodologies with advanced habitat modelling. The purpose of this article is to outline the European eflows framework as introduced through the recent eflows Guidance Document, to indicate the strengths/weaknesses of current WFD implementation, and to identify the European progress on EFAs and prevent possible misinterpretations, through detailed reference to heavily modified water bodies and WFD exemptions, towards a sustainable use of the European water resources.

Keywords: Environmental flows, Water Framework Directive, Hydrological regime, GES, HMWB, exemptions

Introduction

Balancing water allocation between the various users of a water body was always a concern for water managers. However, freshwater ecosystems have been improperly disregarded, although they actually comprise irreplaceable and "fragile" natural heritage providing valuable goods and services to people (Postel & Carpenter 1997; Millennium Ecosystem Assessment 2005). According to WWF (2004), more than 45,000 large dams are operating globally, holding over 6500km^3 of water (Nilsson et al. 2005) and over 60% of the world's major rivers are already fragmented. The use of water resources for energy production or abstraction for human uses impact both the hydrology (reduced residual water, changes in seasonality and hydropeaking) and morphology of rivers (longitudinal connectivity interruption, reduced flow velocities). Water scarcity reports (WWF 2010; Veolia Water and IFPRI 2013) indicate that 36% of the global population (almost 2.4 billion people) already lives in water scarce regions and is expected to increase to 52% by 2050. The lack of efficient water management not only threatens the earth's resources but may compromise the well-being of millions of people globally.

Mainly during the 1970s, the United States, followed by Australia, England, South Africa and New Zealand (Tharme 2003), "realized" that a specific volume of water should continue flowing downstream of hydrological pressures, to be utilized by the aquatic communities. Thereafter, an effort was initiated to estimate the so called "environmental flows" - the quantity, frequency, duration, timing and rate of change of water flows to maintain the functionality of freshwater ecosystems (Arthington and Pusey 2003; Brisbane Declaration 2007). Termed environmental flow assessments (EFAs), these methods have been initially applied in the USA for the protection of fish species of interest (Tharme 1996). However, continuous hydrological alteration of water bodies in a global scale resulted to a wide application of EFAs, not only in the USA, but also in Australia and South Africa. The initial hydrology-based EFAs were transformed either to data-driven habitat simulation models (IFIM/PHABSIM – USA) (Stalnaker et al. 1995; USGS 2001) or to expert judgment -based holistic methodologies, addressing the needs of various ecosystem components, such as the Building Block Methodology in South Africa (King et al. 2008) or the ELOHA method in Australia (Poff et al. 2010). These different methodological approaches address the common need for quantitative data to relate the flow regime to the requirements/response of the aquatic communities.

Until recently, the European Union lacked a common implementation strategy - method regarding EFAs. This methodological gap was partially and individually surpassed by the European countries through efforts for data collection and application of EFAs selecting among the methods mentioned above. Since the establishment of the Water Framework Directive 2000/60/EC (WFD), water management throughout Europe shifted towards specific ecosystem objectives. Member States are hence prompted to initiate a programme of measures to enable their water bodies achieve good ecological and chemical status by the end of 2015. However, as WFD implementation is currently ongoing, technical reports (ETC/ICM Technical Report 2/2012; EEA 2012) indicate that habitat and hydromorphological alterations resulting from hydropower production, navigation, agriculture, flood protection and urban development are affecting almost 40% of river and transitional water bodies and 30% of the lake water bodies, preventing them from reaching good ecological status by 2015. It is currently a common understanding that a water body with good chemical quality but with degraded morphology and altered hydrology is not likely to achieve its full potential as a habitat for wildlife (Acreman and Ferguson 2009), translated in failure to reach good status according to the Water Framework Directive. Application of environmental flows is currently in the forefront of science and management towards water sustainability.

Although environmental flow is not explicitly defined in the Water Framework Directive, it is implied in Article 8 as "the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential" and summarized in Annex V, as "the hydrological regime consistent with the achievement of the values specified for the biological quality elements". Considering that WFD implementation has been initially focused more on water quality, a Guidance Document on environmental flows (European

Commission 2015) has been prepared to facilitate Member States towards upgrading the status of their water bodies via the application of methods and measures to ensure the necessary hydrological regime to support good water status. However, implications arise between scientists, water managers and stakeholders relevant to specific exemptions described in the WFD regarding heavily modified water bodies and water bodies with extended timeline to achieve the WFD environmental objectives (Stoddard et al. 2006; Borja and Eliott 2007; Kampa et al. 2009)

The aim of the current article is to outline the European approach to the concept of environmental flows, as introduced through the WFD and is thoroughly described in the relevant EU CIS Guidance Document, addressing the following objectives:

- To indicate the strengths/weaknesses of the current WFD implementation actions;
- To point out the European progress in the field of environmental flow assessments in comparison with other developed regions of the world;
- To describe the concept of environmental flows as introduced and addressed through the WFD (Guidance Document No. 31);
- To highlight the need for a European, data-driven, holistic environmental flow assessment framework.

Changing the focus of WFD monitoring and implementation networks

Currently, almost 40% of the European water bodies are considered unable to reach GES until 2015 due to hydromorphological pressures resulting in flow-regime and habitat alteration (ETC/ICM Technical Report 2/2012; EEA 2012), indicating the necessity to shift towards more holistic approaches for reaching the environmental objectives of the WFD. A step towards this holistic framework is to incorporate hydrology (water quantity) in the current monitoring and implementation actions. Although already foreseen through the WFD, water quantity and flow regime, are considered ancillary hydromorphological quality elements to the biological quality elements (BQEs), supporting them in achieving good ecological status. According to article 8 WFD, “Member States shall establish monitoring programmes to ensure, *inter alia*, the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential”. This can be accomplished by monitoring specific hydrological (and morphological) components, which are indicated in Annex V WFD, described thoroughly in the WFD Guidance Document No. 7 (Monitoring under the Water Framework Directive - European Commission 2003c) and summarized in table 1. Continuous hydrological measurements from an extended monitoring network incorporated in the current monitoring schemes will enable Member States to address the concept of environmental flows and shift towards “a sufficient quantity of good quality water”. Therefore, the surveillance and operational networks already defined in the WFD should be updated to include sites providing continuous hydrological information, aiming at specific environmental flow objectives.

Hydrological measurements from the surveillance network will establish the reference conditions to enable the comparison between hydrologically altered and unimpacted sites. Surveillance hydrological monitoring is also necessary to provide data on long-term anthropogenic and natural changes in the flow regime, including climate change, placing them in a historical context for future reference, identifying trends and predicting impacts. Natural and climate-change induced alterations are more detectable in sites with good/high ecological status of the surveillance network, which do not receive additional influence from anthropogenic pressures.

In cases where the risk of a water body’s failure to meet the GES is attributed to hydrological alteration (pressures from water or groundwater abstraction, water storage and hydropower production), hydrological information is essential to evaluate the degree of divergence from the natural conditions indicated by the surveillance network and the effectiveness of the programme of measures, such as the maintenance of environmental flows. Hydrological information from the operational network shall therefore provide the data to enable the evaluation of the gap between the current hydrological situation and the estimated environmental flow regime to achieve the WFD objectives.

Table 1: The hydrological components indicated in the WFD Annex V as part of the Hydromorphological Quality Elements

RIVER WATER BODIES	HYDROLOGICAL COMPONENTS
Hydrological regime	Quantity and dynamics of water flow - Historical flows, modelled flows, real-time flow, current velocity
Connection to groundwater bodies	Water table height
LAKE WATER BODIES	
Hydrological regime	Inflow and outflow rates, water level, spillway and bottom outlets discharges (reservoirs), mixing and circulation patterns
Residence time	Volume, depth, inflow and outflow

Assessing and implementing environmental flows

Currently there exist at least 200 environmental flow methods, classified in four major categories according to cost-effectiveness, time-efficiency, complexity and focus (Dyson et al. 2003; Tharme 2003; Arthington et al. 2004; Richter et al. 2006; King et al. 2008):

(i) Hydrological methods, relying primarily on historical hydrological data (mean annual flows, monthly flows, high/low flows or more complex hydrological indices) to make flow recommendations, such as the Tennant method (Tennant 1976), the Indicators of Hydrologic Alteration - IHA (Richter et al. 1996), the Range of Variability Approach - RVA (Richter et al. 1997) and the Indicators of Hydrologic Alteration in Rivers - IAHRIS (Martinez and Fernandez 2010). They also enable comparisons between historically-derived and biologically-calculated reference flows to investigate possible divergence and adjust the proposed environmental flow. Although they are cost-effective, time-efficient, easily applicable methods, they are not considered as stand-alone methods, used as initial desktop analyses to assist more complex environmental flow methodologies.

(ii) Hydraulic rating methods, utilizing simple hydraulic variables and proposing environmental flows through the quantifiable relationship between water discharge and instream habitats (Trihey and Stalnaker 1985). These methods have been currently replaced by the more sophisticated hydraulic/habitat simulation methods (described below), possibly forming an integrated category.

(iii) Habitat simulation (modelling) methods; more sophisticated eflow approaches trying to assess the habitat availability for particular aquatic species, being expressed as a unique combination of flow velocity, depth and substrate. Habitat is modelled using mainly 1-D or 2-D modelling habitat modelling software, such as TELEMAC (Galland, 1991), PHABSIM (USGS 2001), CASiMiR (Schneider et al. 2010) and RIVER 2D (Steffler and Blackburn 2002). Habitat preferences for target organisms are calculated (Bovee 1986) and habitat availability is then calculated through the modelling software for different discharges. Included in a holistic framework (described below), these methods provide the most comprehensive assessment and visualize the information to be manipulated by stakeholders and water managers.

(iv) Holistic methodologies, such as the Building Block Methodology - BBM (King et al. 2008), the Downstream Response to Imposed Flow Transformations – DRIFT (King et al. 2006), the Ecological Limits of Hydrologic Alteration – ELOHA (Poff et al. 2010) and others. These methods require multidisciplinary input and expertise (Tharme 1996, 2000; King et al. 2008; Arthington 1998), addressing the flow requirements of multiple ecosystem components (fish, benthic fauna, macrophytes, riparian vegetation) both spatially and temporally and targeting to a flow regime, not just a baseflow. Field data in a monthly basis are required to construct a flow-regime from scratch (bottom-up approaches). In contrast, top-down approaches (DRIFT), are generally scenario-based, defining environmental flows as acceptable degrees of divergence from the natural/reference flow regime, being less susceptible to any omission of critical flow characteristics or processes than their bottom-up counterparts (Bunn 1998).

Several modified approaches have also been proposed and implemented trying to shift the assessment-scale from the micro- to meso-habitat (Parasiewicz 2007; Vezza et al. 2011) but their general concept is based on one of the four aforementioned categories. Although progress in the environmental flow methodologies is quick and specialized, there still remains a critical need for greater understanding of flow-ecological response relationships and enhanced modelling capacity to support river flow management and ecosystem conservation (Arthington et al. 2010). As accurately indicated in the same article, whilst a consistently applied environmental flow methodology is a goal, none has yet emerged from the efforts of the EU Member States. The purpose of the eflows Guidance Document being already implemented is to bridge this obvious European gap, setting the basis for a data-driven, holistic environmental flows framework.

The European environmental flows concept

The European eflows framework, following the global trends, indicates a three-level approach to integrate hydrological, hydraulic-habitat and holistic methods, as described in table 2 in order to implement comprehensive environmental flow proposals. The general concept (Fig. 1) requires the implementation of specific steps to enable the use of environmental flow as a measure towards achieving good ecological status:

(i) A preliminary risk analysis to define water bodies at risk of not achieving the WFD objectives due to hydrological alteration. According to Annex II WFD, each Member State should have already performed an analysis of pressures and impacts for each river basin district in order to classify the representative sites into one of the three monitoring networks, surveillance, operational, investigative. In a similar manner, Member States shall identify the water bodies at risk of failing GES due to hydrological alteration provoked by water abstraction and storage, hydropower generation and other related pressures.

(ii) Establishment of extensive hydrological monitoring schemes providing continuous hydrological information. Monitoring hydrology is a prerequisite for the implementation of the three-level approach described above. Member States should establish the necessary equipment (gauging stations, limnimeters, boreholes, wells, piezometers) to provide continuous hydrological information to be used towards the specific objectives of each type of monitoring network described above. Already established monitoring sites could be used for hydrological monitoring but if necessary, new sites may be added, especially in water bodies affected by hydrological alteration, independently from the initial network, forming an additional hydrological monitoring scheme. A cost-effective alternative could include data extrapolation from lower numbers of hydrological monitoring sites through advanced hydrological modelling, where applicable.

(iii) Assessment of environmental flows according to the water-body type and the divergence between current and reference state (gap analysis). Environmental flows may be assessed according to a three-level approach (table 2), ideally implementing all steps included, depending on the magnitude of the problem addressed. Gap analysis is applied afterwards to evaluate the gap between the flow regime consistent with the environmental objectives of the WFD (reference environmental flow defined from historical and/or biological response data) and the current hydrological situation. This gap analysis is essential to proceed to the programme of measures to (re)establish/restore eflows and achieve GES.

(iv) Application of measures to restore eflows.

(v) Combination of a short-term morphological/habitat and a long-term biological monitoring to assess the effectiveness of the programme of measures. As habitat availability is expected to increase after the provisioning of environmental flows, substrate, river depth and width variation –parameters indicative of habitat- should be initially monitored. Simultaneously, but in the long-term, fish, benthic invertebrates and macrophytes, which respond to flow alteration in different scales should be monitored towards GES, to provide a holistic interpretation of the application of the historically or biologically predicted environmental flow (programme of measures).

As indicated in figure 1, monitoring environmental flows should be perceived as a process of continuous evaluation and adjustment for achieving GES and ecosystem functioning, circling between hydrological, morphological/habitat and biological monitoring and the application of the programme of measures until GES is achieved.

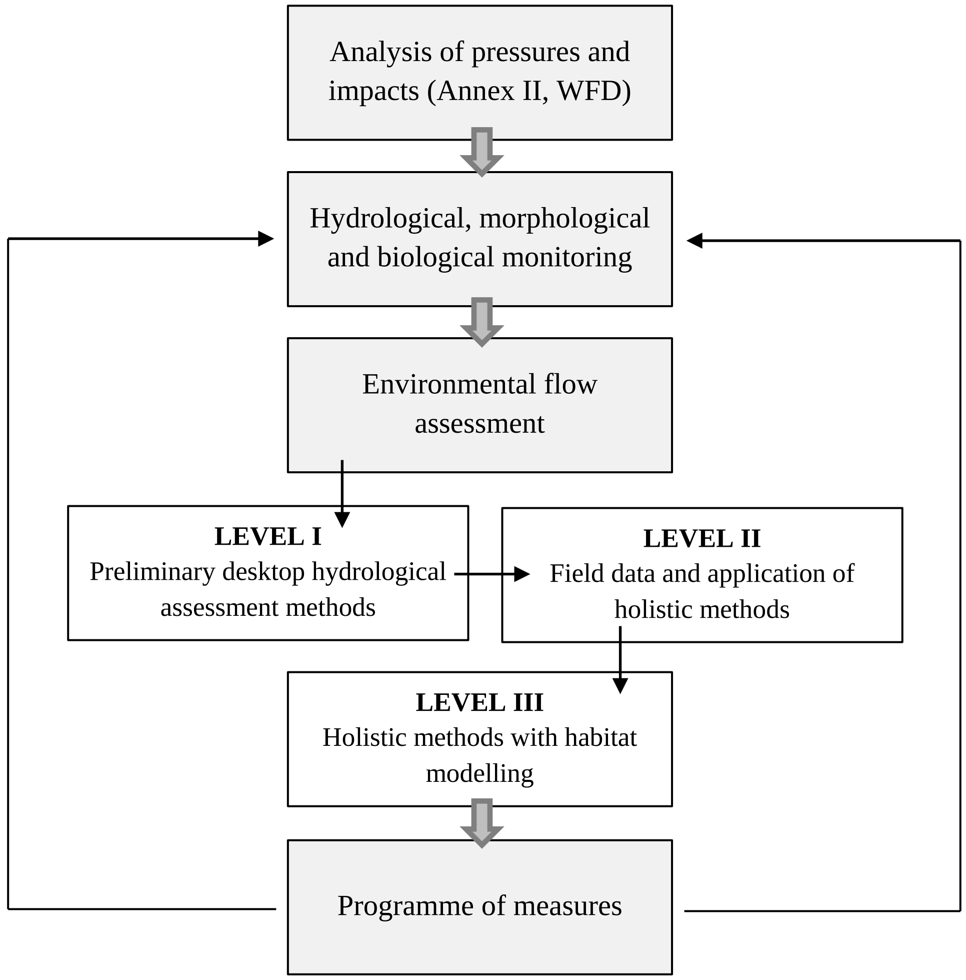

Figure 1: The eflows concept to be implemented according to the requirements of the Water Framework Directive 2000/60/EC towards achieving GES

Table 2: The three-tiered eflow assessment, globally accepted concept, which is proposed to be followed in the European eflows implementation framework. Integrated from European Commission (2015), Dyson et al. (2003), Acreman and Dunbar (2004), King et al. (2008).

ASSESSMENT LEVEL	CHARACTERISTICS	METHODS	REQUIREMENTS & RESULTS
LEVEL 1 - PRELIMINARY Hydrological methods - Look-up tables - Reconnaissance surveys	Regional planning Setting preliminary reference flows using historical records Initial screening and analyzing information for next level methods	Tennant (Montana) method RVA (IHA) method IAHRIS method	Require large sets of long-term (20 year) historical hydrological data Enable comparison between historically derived reference flows and biologically derived reference flows
LEVEL 2 - INTERMEDIATE Holistic methods (expert judgment-based) requiring multidisciplinary input and expertise	Basin-scale planning Ecological, considering the flow requirements of multiple ecosystem components Setting biologically-derived reference flows, targeting to flow-regime and not just a baseflow	ELOHA BBM DRIFT	Require monthly sampling from an inter-disciplinary team of experts, more cost- and time-consuming A stand-alone approach to set biologically-derived reference flows from scratch
LEVEL 3 - COMPREHENSIVE Species-oriented, data-driven, habitat simulation	Reach-scale planning Setting species-specific reference flows Can be included in a holistic framework if applied for multiple ecosystem components (fish, benthic invertebrates, riparian vegetation, macrophytes etc.)	BBM/DRIFT in combination with habitat modelling using PHABSIM, CASiMiR, RIVER 2D, TELEMAC	Very cost- and time-consuming, requiring high level of expertise The most comprehensive approach to derive environmental flow proposals with high level of certainty

Discussion

The holistic concept

One of the main objectives of the WFD is the integrated view on and the protection of aquatic ecosystems using a holistic approach (European Environment Agency 2012a). The aim of the EU eflows Guidance Document is to facilitate the application of environmental flows in all European water bodies, which fail to reach good status due to flow-regime alterations, incorporated in the holistic approach of the Directive. For almost a decade, a global trend is also shifting environmental flow assessments towards holistic approaches (Arthington et al. 2003; Tharme 2003; King et al. 2008) demanding to assess the requirements of all ecosystem components through judgment from multidisciplinary teams of scientific experts. In addition, habitat modelling has simultaneously evolved from simplistic 1D to advanced 2D or 3D models of great accuracy and enhanced visualization, offering a great basis for data-driven approaches, incorporated in the holistic perspective. This trend is indicated by recent studies, which continuously apply habitat modelling to assess the flow requirements of various ecosystem components (Fengqing et al. 2009; Munoz-Mas et al. 2012; Marsilli-Libelli et al. 2013; Yi et al. 2014; Fengqing et al. 2009; Mocq et al. 2013; Holmquist and Waddle 2013). This concept is also adopted and incorporated in a three-level approach proposed in the eflows Guidance Document, highlighting the need for data-driven holistic environmental flow assessments, using habitat modelling for optimum visualization of the information to stakeholders and water managers.

The effectiveness of environmental flows

Variable responses of the aquatic communities to flow alterations are reported in literature (Poff and Zimmerman 2010; McManamay et al. 2011). The scientific interest is mainly focused on fish communities, which consistently show negative response regardless of the type of flow alteration. Algae, on the other hand, typically respond positively to anthropogenic flow alterations, while macroinvertebrates and riparian vegetation show variable responses, with the majority of studies reporting a negative response. Several studies also reveal positive response of the aquatic communities to the application of environmental flows (Wassens et al. 2011; Mackie et al. 2013). This holistic approach is already foreseen in the WFD, which requires monitoring of the ecological water status using various biological quality elements, such as fish, benthic macroinvertebrates, macrophytes and diatoms. Consequently, the effectiveness of environmental flows can be measured through biological monitoring programmes by monitoring the recovery of the various biological quality elements (more frequently and targeting specific BQEs or other indicators until good ecological status is achieved). When the biological quality elements do not reflect good status, adaptation of the programme of measures is necessary, in a process of continuous evaluation and adjustment.

Heavily modified water bodies and environmental flows

The Water Framework Directive allows Member States to deviate from the environmental objectives set under article 4 for water bodies, which have been subject to major physical alterations, such as navigation, water storage, hydropower generation and irrigation, water regulation, flood protection, land drainage, so as to allow for a range of essential water uses described in article 4(3)(a). The term Heavily Modified Water Bodies (HMWB) has been introduced to indicate water bodies, which have been subject to considerable hydromorphological changes of such a scale that restoration to good ecological status may not be achieved without preventing the continuation of the specified use. However, a water body can designated as HMWB only when both its morphology and hydrology have been subject to substantial changes. In case of dams though, substantial hydrological changes, accompanied by subsequent non-substantial morphological changes would be sufficient to consider the water body for a provisional identification as HMWB. When a water body is designated as HMWB, the environmental objective is good ecological potential (GEP), which although controversial (Stoddard et al. 2006), accommodates “slight changes” from the maximum ecological potential (MEP), the state where the biological status reflects, as far as possible, that of the closest comparable natural surface water. The process for HMWB designation (Borja and Elliot 2007) is thoroughly described in the WFD CIS Guidance Document No. 4 (Identification and designation of heavily modified and artificial water bodies - European Commission 2003b), where GEP is described as GES, “considering all mitigation measures which do not have a significant adverse effect on the specified uses or the wider environment”. According to Acreman et al. (2009a), achieving GEP requires some basic elements of the natural regime to be maintained, while UKTAG (2007), indicates that GEP would be achieved by applying best practice to the management of the impoundment (the practice that is applied to the best example of an ecologically similar water body with the same modifications in place).

A major issue arising among stakeholders and water managers is how to estimate the “significant adverse effect”. Articles 5, 9 and annex III WFD indicate, *inter alia*, that HMWBs are subject to economic analysis assessing the costs/benefits of current modifications with the costs of providing other means to achieve the purpose of the impoundment, plus restoration or mitigation of the water body, which may include decommissioning of the impoundment or changing the flow-release regime. However, if the results of the economic analysis do not favor such mitigation or restoration measures due to “significant adverse effects”, environmental flows may be implemented in a less stringent framework to allow the continuation of the specified use. Proper justification should be included in the river basin management plans.

Environmental flows and exemptions to the WFD environmental objectives

Exemptions to the environmental objectives of the WFD may be applied for particular cases other than HMWB designation, ranging from small-scale temporary exemptions to mid- and long-term deviations from the rule "good status by 2015" and including the following aspects:

- the extension of the good status deadline by 2021 or 2027 at the latest or as soon as natural conditions permit after;
- the achievement of less stringent objectives under certain conditions;
- the temporary deterioration of the status in case of natural causes;
- failure to prevent status deterioration of a surface water body due to new modifications to the physical characteristics or alterations to the level groundwater bodies as a result of new sustainable human development activities.

The concept and application of exemptions is described in the WFD CIS Guidance Document No. 20 (European Commission 2009). It must be noted that exemptions to the WFD environmental objectives do not imply permanent deviation from good ecological status but an application of less stringent objectives until 2021 or 2027 due to specific reasons that should be justified in the river basin management plans of each Member State. Considering environmental flows once an exemption is assigned, Member States may apply less stringent flows for an extended period of time but should provide reasonable justification about disproportionate costs or technical infeasibilities, aiming at restoring good ecological status until 2021 or 2027 by also applying environmental flows in a proper time period after 2015. This concept is briefly depicted in figure 2.

Conclusion

Environmental flows considered through the Water Framework Directive comprise a measure towards good surface water status and good quantitative groundwater status which should be estimated and applied for water bodies failing to reach GES due to hydrological alterations. A specific holistic framework is introduced by the European Commission to address the assessment and application of environmental flows, including particular steps to i) identify water bodies at hydrological risk; ii) monitor the current hydrological state; iii) estimate environmental flows and the gap between current and reference state; iv) apply a specific programme of measures; v) monitor the effectiveness of the application of environmental flows; vi) adjust and optimize the programme of measures towards good ecological status. Exceptions are foreseen according to the Water Framework Directive, including heavily modified water bodies and extended timelines to achieve the environmental objectives for specific, justified cases. Trying to balance water allocation between human water needs and the aquatic communities, the European Commission provides an environmental flows framework to facilitate the achievement of the WFD environmental objectives, ecosystem functionality and a sustainable use of the European water resources.

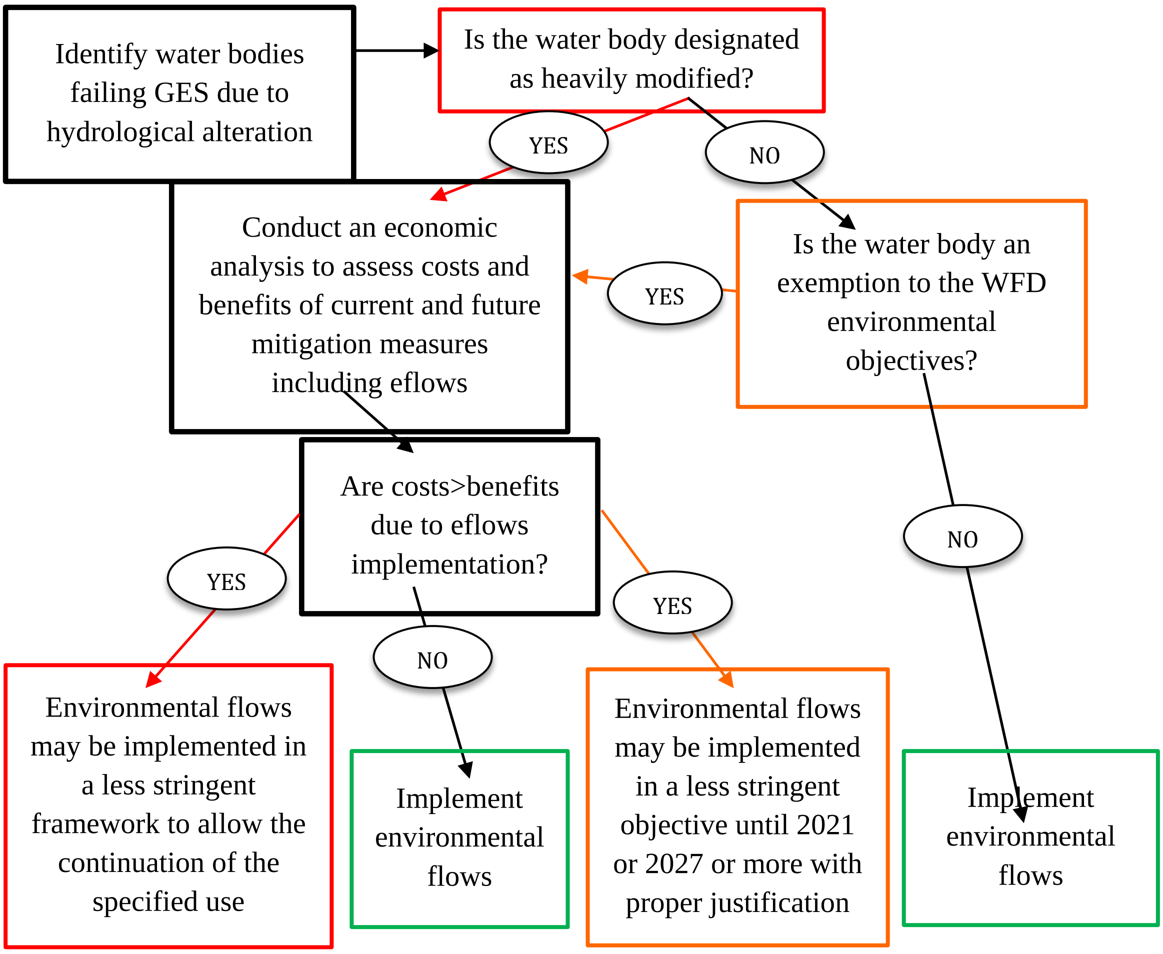

Figure 2: The implementation of environmental flows according to the Water Framework Directive (Guidance Document No. 31), taking into account HMWB designation and WFD exemptions. Red color refers to HMWBs and orange refers to exemptions.

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