WWF Project:“Living Neretva”

Environmental flow working group

‘Environmental Flows is the quality, quantity and distribution of water required to maintain the compounds, functions and processes of aquatic ecosystems on which people depend’

FINAL DRAFT

Domestic legislation definitions

FB&H law on water:

“Environmentally acceptable flow is minimal flow to maintain natural balance and water dependant ecosystems”.

RS law on water:

“Environmentally acceptable flow shall be defined according to ….
… taking into account local ecosystem specifics and seasonal flow variations”.

1. INTRODUCTION

During the past century, the global human population quadrupled, the area of irrigated agricultural land multiplied more than six-fold, and water withdrawals from freshwater ecosystems increased eight-fold (Gleick, 1998; Postel, 1999). Increasing demands for water are degrading rivers worldwide, resulting in a loss of the vital goods and services they provide. Today there is an increasing understanding that each modification at rivers flow needs to be balanced with maintenance of basic water-dependent ecological services. These flows are termed environmental flows.

Aim of this First Project phase was review of the international literature in order to identify all hydro-morphological parameters which affect aquatic ecosystems - either being used by water users/regulators around the world or identified within the research literature. It includes a gap analysis to report on parameters which have not been adopted in reported studies or practices, but which may merit consideration in the local (national) conditions. It provides a focus for discussion between members of the project and the contractors, and a sense of direction for future stages of the project.

What we found during research period within this phase was that in neighbouring country (Serbia) was developed and tested methodology for setting environmental flow (see chapter 6). As it happened it suites local conditions in Serbia, we thought it would be very useful to present it in this paper and also to include in next phase as one for testing.

1.1. STUDY AREA

The Neretva river situated in Bosnia and Herzegovina and Croatia, is the largest carst river in the Adriatic catchments. The total length is 225 km, of which 203 km are in Herzegovina, while the final 22 km are in the Dubrovnik-Neretva county of Croatia.

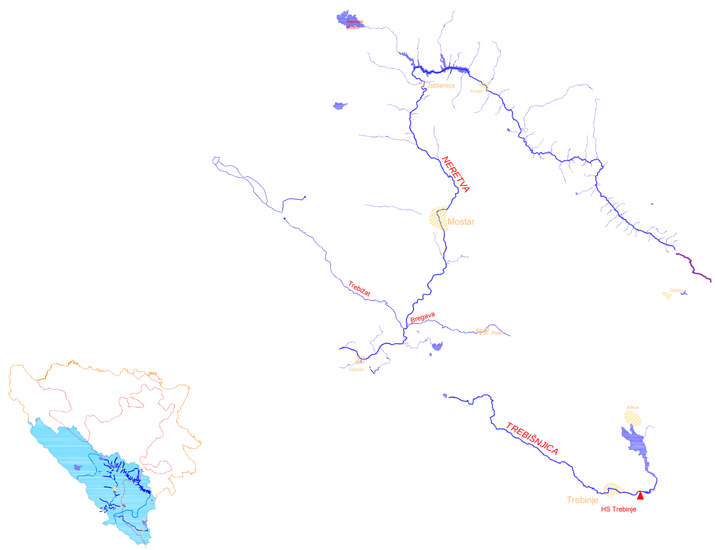


Figure 1: The Neretva river

Rising from the base of the mountain Zelengora in the east part of Bosnia and Herzegovina, through canyons, gulches and hollows of its upper and middle flow, Neretva leaks through Dinarid mountain system and downstream from Počitelj, small town in Herzegovina spreads to large wetland valley, which provides valuable agricultural land, and through branched delta flows to Adriatic Sea.[1]

The main tributaries are smaller rivers Rakitnica, Rama and Trebižat whish flow into Neretva from the right, while Buna and Bregava flow into it from the left. The last 30 km of Neretva's stream form an alluvial delta, before the river empties into the Adriatic Sea.

The biggest city on the Neretva is Mostar. Other towns on the Neretva include Konjic, Metković, Jablanica, Čapljina as well as the historical village of Počitelj. Most favorable situation of spatial water division and specific availability per person is within Trebisnjica and Neretva river basins, where, with 19.8% of BiH river basin area populated with 9.6% of inhabitants, there is flow formed in c/a 34.8% of best water quality.

[1] Retrieved from “http://en.wilkipedia.org/wiki/Neretva”

The upper stream of Neretva has water of Class A purity and is almost certainly the coldest river water in the world, often as low as 7-8 degrees Celsius in the summer months.

Neretva also has some endemic and very delicate, fragile life forms that are near extinction. Clear, cold, pure, spring-drawn waters run in undisturbed rapids and waterfalls, carving steep gorges through this relatively remote and rugged limestone terrain. Neretva also has some endemic and very delicate, fragile life forms that are near extinction. Many local species are endemic, such as the Neretva soft-mouth trout and the Neretva brook trout.

The valley of Neretva's lower flow has biggest and most valuable rests of the Mediterranean wetlands on east Adriatic coast and this is one of the rare areas in the whole Europe. Lately, this wetland area was very much degraded and the rest of this area are like fractured separated islands with intensive worked out and inhabited surrounding. Water regulations, upper part accumulation building and drainage and converting of the wetland into agriculture land have changed look of this area irreversible. Former spatial cane parts and lagoons valuable for wintering and moving of extremely various bird worlds so as for feeding and berry of the fishes are today only rests and people with different human activities are continuing in jeopardizing of this area. However this area has even in its present condition, in aspect of keeping of the biological and landscape variety, international importance. The lower Neretva, with its wetlands and delta, still supports at least 310 bird species. As that lower flow of Neretva is part of the Ramsar list-Converntion about wetlands protection and in program Important Bird Areas which is conducted by the BirdLife International.

Near Jablanica on the river Neretva is created a large accumulation lake and at least three hydroelectric dams between Jablanica and Mostar. The plants are under-utilised, yet the Bosnian government has unveiled plans to build four more hydroelectric power plants and dams upstream from the existing plants. In the complex hydrology of carst landscapes, dams have a widespread impact.

Sub Mediterranean climate, with mild winters, warm summers and rich precipitations in cooler part of the year prevails in the Neretva river basin. Lowest average temperatures in January are in range of 3,4 to 4,8 ^{o}C, while average temperatures in July are over 24 ^{o}C with maximum of over 40 ^{o}C. Precipitations are in range of 1000 mm to over 1800 mm (Trebinje 1837) during summer months (July and August quantities are below 30 mm) with maximums during late autumn and winter months when going up to 150÷230 mm/month (maximum in December, e.g. maximum of average precipitations in December in Gacko is 236 mm).

Watercourses within carst fields of Adriatic river basin have very complex water regimes, characterized with following phenomena:

- Extremely high unevenness of flow caused by high seasonal unevenness in precipitations, with rainfall of high intensity in autumn and winter period and modest precipitations in vegetation period;
- Drainage of those fields is most commonly done over carst formations (abyss, depressions) with parts of ground watercourses of inadequate permeability characteristics in the seasons of high waters, because of what there is flooding of carst fields in periods of clogging what represents great ecological destruction and disables its use;

- Orographic and hydro-geological borders of river basins significantly differ, due complex net of ground carst paths that often have bifurcations, what enables flow in different directions.

In those circumstances the regulation of water regime in carst fields, its ecological protection and bringing to use can be done just by hydro-technical works by implementation of artificial drainages that will overarch problem of inadequate capacity of carst depressions with implementation of accumulations where possible in carst conditions. This is foreseen principle for regulation of most of carst fields in so called middle and high horizons in Eastern Herzegovina.

2. THE NATIONAL POLICY AND LEGAL FRAMEWORK

The Water Framework Directive (WFD, 2000) expands the scope of water protection to all waters and sets a clear objectives that "good status" must be achieved for all European waters by 2015 and that sustainable water use is ensured throughout Europe. A great tool for achieving the "good status" of aquatic ecosystems is exactly the environmental flow.

The enitites water laws (WL, 2006) emphasis that environmental flow shall be determined based on the research works that have been carried out, and in accordance with the methods for its determining, defined in the sub legal act, taking into consideration the specific characteristics of the local ecosystem and seasonal variation of flow.
The Water Low establishes the legal basis for sustainable water resource management.

Until the environmental flow sub legal act will be enacted, the environmental flow shall be established based on hydrological characteristics of water body for characteristic season, as minimum average monthly flow of 95% probability.

3. METHODS FOR ENVIRONMENTAL FLOW ASSESSMENT

Over 200 approaches for determining environmental flows now exist and they are used or proposed for use in more than 50 countries worldwide. Many of the methodologies are country specific and no single country has yet developed an all-encompassing method.
The majority of these methodologies can be grouped into four (of six) categories:

1. Hydrological methods
2. Hydraulic methods
3. Habitat quality methods
4. Holistic methods.

At least 207 individual methodologies, within the main types, were recorded in use for 44 countries, within six broad world regions: Australia and New Zealand, rest of Asia, Africa, North America, Central and South America and Europe with the Middle East. (Figure 2).

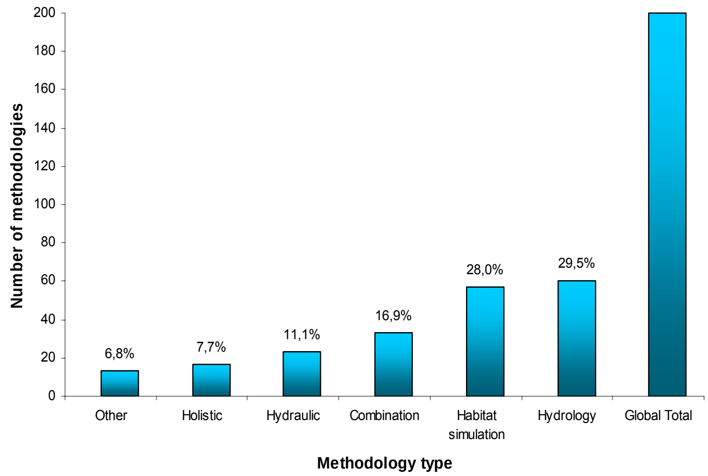


Figure 2: Number of environmental flow methodologies of each type in use worldwide and their relative proportions, compared with the global total. (Tharme, 2003)

For instance, hydrology-based EFMs constituted the highest proportion of the overall number of methodologies recorded (30%, followed closely by habitat simulation EFMs), with a total of 61 different hydrological indices or techniques applied to date (Figure 2). Hydraulic EFMs, represent 11% of the global total.
Several different categorizations of these methods exist, three of which are shown below.

Organisation	Categorization of methods	Sub-category	Example
IUCN (Dyson et al. 2003)	Methods	Look-up tables	Hydrological (e.g. Q95 Index) Ecological (e.g. Tennant Method)
		Desk-top analyses	Hydrological (e.g. Richter Method) Hydraulic (e.g. Wetted Perimeter Method) Ecological
		Functional analyses	BBM, Expert Panel Assessment Method, Benchmarking Methodology
		Habitat modelling	PHABSIM
	Approaches		Expert Team Approach, Stakeholder Approach (expert and non-expert)
	Frameworks		IFIM, DRIFT
World Bank (Brown & King, 2003)	Prescriptive approaches	Hydrological Index Methods	Tennant Method
		Hydraulic Rating Methods	Wetted Perimeter Method
		Expert Panels	
		Holistic Approaches	BBM

Organisation	Categorization of methods	Sub-category	Example
	Interactive approaches		IFIM DRIFT
IWMI (Tarme, 2003)	Hydrological index methods		Tennant Method
	Hydraulic rating methods		Wetted Perimeter Method
	Habitat simulation methodologies		IFIM
	Holistic methodologies		BBM DRIFT Expert Panel Benchmarking Methodology

3.1. Hydrological methods

Hydrological Index Methods

Simplest of all, hydrological methods as typically desktop methodology, are based on the use of hydrological data, usually in the form of historical monthly or daily flow records. This methodology is considered to be most appropriate at the planning level of water resource development.

These are the simplest and most widespread EF methods. They are often referred to as desk-top or look-up table methods and they rely primarily on historical flow records. Environmental flow is usually given as a percentage of average annual flow or as a percentile from the flow duration curve, on an annual, seasonal or monthly basis. Most methods simply define the minimum flow requirement, however, in recognition of the 'Natural Flow Paradigm' more sophisticated methods have been developed that take several (up to 32) flow characteristics into account (such as low-flow durations, rate of flood rise/fall etc).

Hydrological Index Methods provide a relatively rapid, non-resource intensive, but low resolution estimate of environmental flows. The methods are most appropriate **at the planning level of water resources development**, or in low controversy situations where they may be used as preliminary estimates.

The most frequently used methods include the **Tennant Method** (Tennant, 1976) and RVA (**Range of Variability Approach**) (Richter et al., 1997) both developed in the USA.

One of the most applied hydrological methods worldwide is **Tennant method**. The Tennant method was originally called the "Montana method" by Tennant because it was created using data from the Montana region (Tennant 1975), and was developed through field observations and measurements. Tennant collected detailed cross section data that characterized different aspects of fish habitat. These included width, depth, velocity, temperature, substrate and side channels, bars and islands, cover, migration, invertebrates, fishing and floating, and esthetics and natural beauty. These metrics were related to a qualitative fish habitat quality. This allowed for a determination of discharge to fish habitat through the correlation of physical geometric and biological parameters to discharge. Tennant then related percent of the average flows would relate to fish habitat qualities (Tennant 1975) and produced an easy to apply standard that can be used with very little data. The technique utilizes only the average annual flow for the stream. It then states that certain flows relate to the qualitative fish habitat ratings, that is used to define the flow needed to protect fish habitat that is of the quality desired (Table 1.2).

Table 1.2.: Instream flow for fish, wildlife and recreation (Tennant 1975)

Narrative Description of flows*	Recommended base flow regimens Oct.-Mar.	Apr.-Sept.
Flushing or maximum	200% of the average flow	
Optimum range	60%-100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	10% of average flow to zero flow	

*Most appropriate description of the general condition of the stream flow for all parameters listed in the title of this paper.

The Tennant method is considered a standard setting method, meaning that it is uses a single, fixed rule as a minimum base flow. This means that it is easy to apply to any situation without collecting lots of data or being expensive.

3.2 Hydraulic methods

Hydraulic Rating Methods

Hydraulic approaches use changes in simple hydraulic variables, such as wetted perimeter or maximum depth, usually measured across single, limiting river cross-sections, as a surrogate for habitat factors known or assumed to be limiting to target biota.

The most commonly used hydraulic rating methodology worldwide today is the generic wetted perimeter method. Basic assumption is that river integrity can be directly related to the quantity of wetted perimeter. The wetted perimeter is the length of stream bottom substrate that is wet along a cross section oriented perpendicular to the river. Environmental flows are calculated by plotting the variable of concern against discharge. This produces a curve of the relationship between discharge and wetted perimeter (Figure 1.1) that can be analyzed for the breakpoint or inflection point (Reinfelds et al. 2004).Commonly, a breakpoint, interpreted as a threshold below which habitat quality becomes significantly degraded, is identified on the response curve, or the minimum environmental flow is set as the discharge producing a fixed percentage reduction in habitat.

There is an ongoing discussion about how the breakpoint should be defined, and this is the main disadvantage of this method.

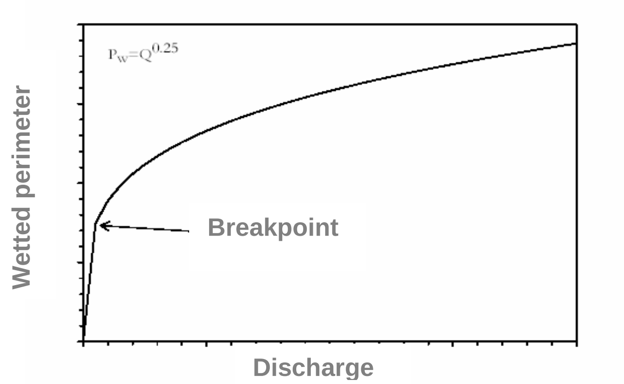


Figure 1.1 An example of a wetted perimeter curve and breakpoint

3.3 Habitat quality methods

Habitat Simulation Methodologies

On the basis of detailed analyses of the quantity and suitability of instream physical habitat available to target species under different discharges (or flow regimes) these techniques attempt to determine environmental flow. Typically, the flow-related changes in physical microhabitat are modeled in various hydraulic programs, using data on one or more hydraulic variables collected at multiple cross-sections within the river study reach. The simulated available habitat conditions are linked with information on the range of preferred to unsuitable microhabitat conditions for target species, life stages, assemblages and/or activities, often depicted using seasonally defined habitat suitability index curves. The resultants outputs, usually in the form of habitat–discharge curve for the biota, or extended as habitat time and exceedence series, are used to predict optimum flows as environmental flow.

PHABSIM (Physical Habitat Simulation System) in one of the commonly used instream flow models. PHABSIM uses four hydraulic criteria that are calculated from field measurements and relate to fish habitat quality. The hydraulic variables included in the model are water depth, flow velocity, substrate, and cover (Gillilan and Brown 1997). The required field data include cross section survey. The outputs of PHABSIM are weighted usable area (WUA) curves that relate discharge to a fish habitat index for different life stages of fish species of interest, and habitat guild (Waddle 2001)(Figure 1.2).

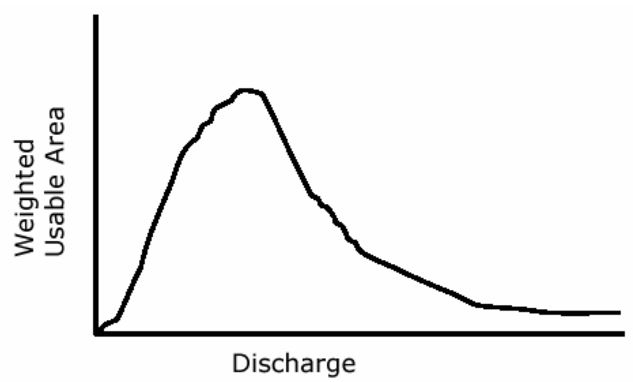


Figure 1.2. An example of a PHABSIM Weighted Usable Area curve

One of the most complete methods from this group is Instream Flow Incremental Methodology (IFIM), developed by the U.S. Fish and Wildlife Services. In IFIM the investigator examines more than a snapshot of the microhabitat characteristics of the stream to determine minimum flow, IFIM also considers at macro habitat characteristics like stream temperature and water quality longitudinally down the stream channel (Gillilan and Brown 1997). These two analysis techniques combine to produce a habitat time series that shows how the fish habitat changes over time as a function of discharge (Gillilan and Brown 1997). IFIM tends to be used to determine the effect of an activity on habitat, and in restoration situations once the effect of the activity is better understood (Gordon et al. 1992). Most users within the U.S. Fish and Wildlife Service found IFIM to either be too complicated to apply (too expensive, not trained well enough, or took too much time), or too simplistic (models or curves needed improvement) (Armour and Taylor 1991). This would suggest that this method may not be the best choice unless the resources necessary to apply this technique are worth the results that may be obtained.

3.4 Holistic methods

Holistic methodologies are actually frameworks that incorporate hydrological, hydraulic and habitat simulation models. They are the only EF methodologies that explicitly adopt a holistic, ecosystem-based approach to environmental flow determinations.

In recent years holistic approach have greatly contributed to the field of environmental flow assessment. Doupe and Pettit (2002) believe that for determination of EF it is necessary to find balance between requirements for water in eco-system and socio-economic environment what leads to holistic and comprehensive approach for water resources management in open watercourses.
In a holistic methodology, important and/or critical flow events are identified in terms of select criteria defining flow variability, for some or all major components or attributes of the river ecosystem. This is done either through a bottom-up or, more common recently, a top-down or combination process that requires considerable multidisciplinary expertise and input (Tharme 1996, 2000; Tharme and King, 1998; Arthington, 1998a). The basis of most approaches is the systematic construction of a

modified flow regime from scratch (i.e. bottom-up), on a month-by-month (or more frequent) and element-by-element basis, where each element represents a well defined feature of the flow regime intended to achieve particular ecological, geomorphologic, water quality, social or other objectives in the modified system (King and Tharme, 1994; Arthington, 1998a; Arthington and Lloyd,1998; Arthington et al., 2000). In contrast, in top-down, generally scenario-based approaches, environmental flows are defined in terms of acceptable degrees of departure from the natural (or other reference) flow regime, rendering them less susceptible to any omission of critical flow characteristics or processes than their bottom-up counterparts (Bunn, 1998).

The building block methodology (BBM) is being an holistic methodology that addresses the health (structure and functioning) of all components of the river ecosystem, rather than focusing on selected species. BBM remains one of only two methodologies in the world for which a manual has been written (King et al., 2000), the other being IFIM (Milhous et al., 1989). The BBM is presently the most frequently applied holistic methodology in the world, with c. 15 standard applications in South Africa (Tharme and King, 1998; King et al., 2000), and single applications in Australia (Arthington and Long, 1997; Arthington and Lloyd, 1998) and Swaziland.

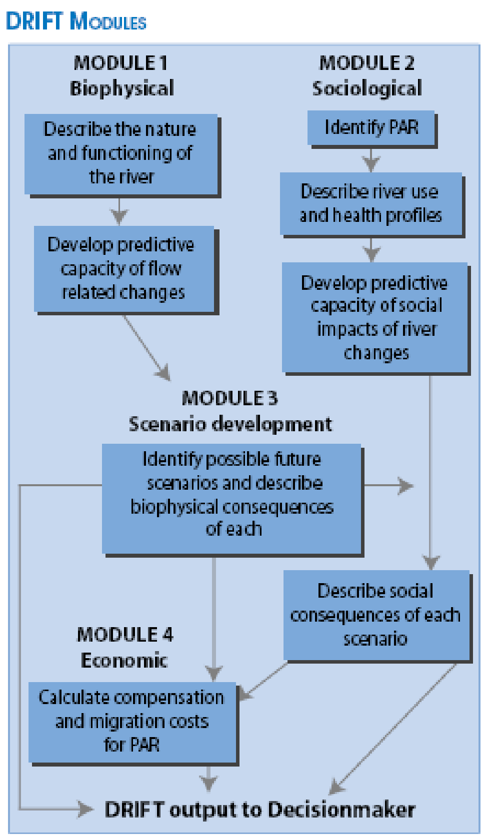
The advantage of the BBM 'expert team approach' is its flexibility and consensus building amongst experts who come to the best solution based on the data and model results available. The disadvantage is that it is not necessarily replicable and another group of experts might come to different conclusions. In addition, not only do the biological experts need to have a good understanding of their field and the functioning of the river under examination, they also need to have a basic understanding of hydrology. Furthermore, all the experts need training in how to follow the process (Flow by IUCN).

Recently evolving from the BBM and other similar methodologies as an interactive, top-down holistic methodology comprising four modules (biophysical, social, scenario development and economic), the downstream response to imposed flow transformations (DRIFT) process (Metsi Consultants, 2000; King et al., this issue) offers innovative advances in environmental flow assessment. It focuses on identification, by a multidisciplinary team, of the consequences of reducing river discharges from natural, through a series of flow bands associated with particular sets of biophysical functions, and of specific hydrological and hydraulic character, in terms of the deterioration in system condition. As the methodology is scenario-based, there is considerable scope for the comparative evaluation of the consequences of a number of recommended flow regimes. The DRIFT methodology is an interactive, scenario-based approach, designed for use in negotiations, and contains a strong socio- economic component, important when quantifying subsistence use of river resources by riparian peoples.

Downstream Response to Imposed Flow Transformation (DRIFT)

A holistic interactive approach - Downstream Response to Imposed Flow Transformation (DRIFT) framework was developed in South Africa, with its first major application being in Lesotho. Similar to the Building Block Methodology it forms a more holistic way of working as it addresses all aspects of the river ecosystem. It is a scenario-based framework, providing decision-makers with a number of options of future flow regimes for a river of concern, together with the consequences for the condition of the river. DRIFT has four modules to determine a number of scenarios and their ecological, social and economics implications. Probably its most important and innovative feature is a strong socio-economic module, which describes the predicted impacts of each scenario on subsistence users of the resources of a river. If there are no common-property subsistence users, modules 2 and 4 can be omitted.

The Downstream Response to Imposed Flow Transformation (DRIFT) Framework uses four modules:



Module 1.

Biophysical*.* Within the constraints of the project, scientific studies are conducted of all aspects of the river ecosystem : hydrology, hydraulics, geomorphology, water quality, riparian trees and aquatic and fringing plants, aquatic invertebrates, fish, semi-aquatic mammals, herpetofauna, microbiota. All studies are linked to flow, with the objective of being able to predict how any part of the ecosystem will change in response to specified flow changes.

Module 2. *Socio-economic*. Social studies are carried out of all river resources used by common-property users for subsistence, and the river-related health profiles of these people and their livestock. The resources used are costed. All studies are linked to flow, with the objective of being able to predict how the people will be affected by specified river changes (last module).

Module 3. *Scenario-building.* For any future flow regime the client would like to consider, the predicted change in condition of the river ecosystem is described using the database created in modules 1 and 2. The predicted impact of each scenario on the common-property subsistence users is also described. certain number scenarios of interest to the client should be developed. Each predict a possible future flow regime; the resulting condition of the river; and the impacts on the population at risk. The widths of inhabited corridors on either bank should be measured and identified the used river resources. Than these resources should be quantified, estimated the costs of resources, and considered cultural links with the rivers. The information will be used to describe the links between the riparian people and the rivers, and how flow changes might affect them.

Module 4. *Economics.* The compensation costs of each scenario for common-property users are calculated.

The biophysical and socioeconomic specialists maintain strong links with each other during data collection. As an example, the botanists will help the social team to identify river plants used by the population at risk, and then allocated each plant species to one of six vegetation zones occurring up the banks. All the zones should be study to define their links with flow. The hydrologist and hydraulic modeller will link each vegetation zone with flow by determining how often it is flooded under current flows. Knowing the links between flow and vegetation zones, the botanist could then describe for each possible future flow regime, how the vegetation zones might expand or contract, and thus whether each plant species would increase or decrease in abundance.
The social team then used this prediction to assess, for each scenario, the impact of vegetation
changes on the population at risk. Because of the complexity of rivers, any study of this nature—either in developing or developed countries–is necessarily undertaken with only limited knowledge.

Although DRIFT is usually used to build scenarios, its database can equally be used to set flows for achieving specific objectives.

Two other activities outside DRIFT provide additional information to the decision-maker:

(a) a macro-economic assessment of each scenario, to describe its wider regional implications in terms of industrial and agricultural development, cost of water to urban areas and so on; and
(b) a public participation process, in which the wider body of stakeholders can voice its level of acceptability of each scenario.

DRIFT has also been applied to the Breede and Palmiet Rivers in South Africa and, in anabbreviated rapid form, in Zimbabwe. Implementation of the chosen scenarios is already underway in the Palmiet system and Lesotho. Because of its multidisciplinary nature, a comprehensive **DRIFT application could cost US$1 million or more** for a large river system. It is often an issue of trade-offs: the greater the investment in assessments and studies, the higher the confidence in the scenarios produced. It is important to put the costs into perspective. Most environmental flow assessments are carried out as part of the project planning for a new dam. A comprehensive DRIFT study will probably cost **less than 1% of the total cost of many dams.**

4. OVERVIEW OF METHODOLOGIES

The table below shows major advantages and disadvantages of environmental flow assessment methodologies.

	Approximate Duration of assessment (months)	**Major advantages**	**Major disadvantages**
Hydrological Index	½	Low cost, rapid to use	Not site-specific, ecological links assumed
Hydraulic rating	2-4	Low cost, site specific	Ecological links assumed
Habitat simulation	6-18	Ecological links included	Extensive data collection and use of experts, high cost
Holistic	12-36	Covers most aspects	Requires very large scientific expertise, very high cost, not operational

4.1. Summary of methods in use in different countries

Table below gives brief overview of methodologies in use in different countries

	METHOD	**Basic concepts**	**Approaches**	**Data used**	**Comments**
Australia	2/3rd rule	Flow regime should 2/3rd natural	Use 2/3rd	Not defined, but probably elements of flow regime, e.g. low flow magnitude, no. floods	Rule of thumb not verified by ecologic data. Precise method of use not defined
Australia	Holistic approach	Whole river ecosystem	Standards set by expert panel separately for each river/site	All available data, flow, hydraulic, morphology, sediment, biological	Integrated inter /disciplinary approach based on data and expert opinion
Australia	Flow events methods	Frequency of flow events is important	Frequency of events (defined by expert panel) under different scenarios compared	Flow time series and at site hydraulic data	New method, currently appropriate for comparing scenarios
Australia	Wetted perimeter	Wetted perimeter indexes river ecosystems	Standard set at inflection point in flow-wp curve	Flow and wetted perimeter	Defines single flow value according to wetted perimeter. Not verified by ecological data
E	RAM	Sensitivity to abstraction	Look up tables for flow duration curve to give	Channel structure, fish, invertebrates,	Concept of sensitivity to abstraction limited not

	METHOD	Basic concepts	Approaches	Data used	Comments
			permitted abstraction given sensitivity	macrophytes	tested ecologically .
	LIFE	Invertebrates index river ecosystem	Slope of flow v. invertebrate score graph indicates sensitivity to abstraction	Invertebrate samples and daily flow time series	Relationship between flow and invertebrate communities define for individual sites but not yet generalised
France	Hydrological rules	Minimum flow	1/10th or 1/40th of mean flow	Daily flow time series	Rule of thumb not verified by ecological data
Italy	Po basin standards	Minimum flow	Minimum flow is related to rainfall, altitude, water quality and conservation objectives	Rainfall, empirical factors	Rule of thumb not verified by ecological data
Norway	River System simulator	Impacts of hydropower operation on salmonid fish	Salmonid habitat assessed for different dam release patterns	Flow time series, hydraulics, morphology	Physical habitat output, but tailored for releases from hydropower dams
Spain	Basic flow method	Environmental flow linked to statistics of annual minimum series	Environmental flow based on mean flow and river type	Flow time series	Hydrological and ecological meaningfulness not tested
	Basque method	Space-time substitution	Compares downstream increase in species richness to increase in flow	Macro-invertebrate data, downstream increase in drainage area/flow	
SAD	PHABSIM	Physical habitat model	Available physical habitat for any species/life stage and flow	Flow time series, hydraulic data from cross-sections, substrate data, habitat suitability curves	Used world-wide for impact assessment. Does not define critical levels of habitat, but indicates sensitivity to abstraction as flow varies
	RCHARC	Hydraulic model	Manage river flow to maintain hydraulic habitat diversity	Hydraulic model and river flow time series	Currently requires site-specific data. Useful when cannot define target species
	Tennant model	Minimum flows for healthy rivers	%natural mean annual flow presented for different life stage functions e.g. 10% for survival , 30% for healthy ecosystems	Flow time series, biological data	Calibrated with biological data from many rivers. Cannot be transferred without recalibration
	Texas method	Minimum flows for healthy rivers	% flow duration curve	Flow time series, biological data	As for Tennant, but more flexible
	IHA/RVA	All components of the flow regime have ecological function	All flow statistics should be within defined limits, e-g- 1 standard deviation of natural flow statistic	Many statistics of river flow time series, e-g- mean flow in each month, number of floods	Conceptually attractive, but not verified by ecological data and difficult to operationalise into standard
Lesotho	DRIFT	Combines hydrology, ecology, sociology and economics	Water allocations and ecological, social and economic consequences of scenarios assessed	Many; including flow time series, hydraulics, water quality, geomorphology, vegetation, fish, mammals, invertebrates	Interdisciplinary method for high profile sites, very expensive to apply
South Africa	Building block methodology	Components of the flow regime have different ecological function	Standards set by expert panel separately for each river/site	All available data, flow, hydraulic, morphology, sediment, biological	Integrated inter-disciplinary approach suitable for application to individual high priority sites based on data and expert opinion

5. SETTING AND IMPLEMENTING ENVIRONMENTAL FLOW RELEASES FROM IMPOUNDMENTS

Setting and implementing environmental flow releases from impoundments involves many different aspects of management, including policy level objective setting, technical definition of flow needs for ecosystem support and financial considerations of the costs of mitigation measures.
The process of defining the target river ecosystem status, setting flow regime releases from impoundments and monitoring their effectiveness in achieving that status is presented below.

STEP 1 Compare reference and impounded flow regimes

Step 1 is an assessment of whether the water body is likely to fail to achieve good ecological status-GES (or an estimate of what GES may be based on current knowledge) judged against reference conditions. It involves comparing the historical (actual) biology of the river below the impoundment with reference biological conditions. Where biological data are inadequate, hydrological conditions can be used as a surrogate and the historical flow regime is compared with reference flow conditions. The reference conditions will normally be the natural flow regime, such as that entering the impounded reservoir or recorded before impoundment construction. If there is a flow gauging station upstream or downstream of the impoundment, these could be used to synthesise historical and naturalised flow regimes. In many cases, both the actual and reference flow regimes will need to be estimated by modeling. It should be noted that there can be considerable uncertainty whatever method is used for estimating flows, and this uncertainty should be taken into account when determining the degree of hydrological impact. The water level regime of the impounded reservoir will be assessed as part of the consideration of that water body and is not included here.
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STEP 2 Decision – does the water body achieve GES?
The analysis undertaken in Step 1 will provide a measure of the degree of alteration of the river ecosystem downstream of an impoundment. In Step 2, the degree of alteration is assessed to decide if the water body is likely to fail to meet GES and thus should be a provisional heavily modified water body (HMWB). In this step it must also be confirmed that the cause of failing to meet GES is physical modification and not other pressures such as water quality.
If the degree of alteration means that it is likely to fail to meet GES (*i.e.,* greater than the specified standard) due to physical modifications, the water body is designated provisional HMWB and step 3 is undertaken to decide on final designation. If the degree of alteration is less than the standard, step 3 is not required and step 4 can be undertaken to decide on designation.

STEP 3 Undertake economic analysis

Biological/hydromorphological assessment (or its surrogate, hydrological alteration) of a water body against reference conditions is only a first step to designation. In Step 3, water bodies that are provisional HMWBs are subjected to economic analysis. The benefits of current modifications are compared with the costs of providing other means to achieve the purpose of the impoundment, plus restoration or mitigation of the water body. This analysis includes defining the purpose of the impoundment, such as its role in managing floods or generating electricity.

STEP 4 Define water body status

If the analysis in Step 3 shows that restoration or mitigation would be disproportionately costly, then the water body can be designated as HMWB and is required to meet good ecological potential (GEP). GEP requires achieving an ecological status similar to the best examples of similar river ecosystems with the same modifications in place; *i.e*. with best practice applied to management of the water body. If the analysis in Step 3 shows that the economic benefits are greater than the costs other means of achieving the purpose of the impoundment plus the costs of restoration or mitigation, then the water body will not be designated as HMWB and the water body should meet good ecological status (GES), which will require a flow regime and associated water quality that will support the river ecosystem in slight deviation from reference conditions. In some cases, this may involve decommissioning or significantly altering the impoundment.

STEP 5 Monitor and test

In this step the monitoring scheme is applied to the river water body downstream of the impoundment to assess its status. A clear requirement of the WFD is not only to achieve the objective of GES or GEP, but also to prevent deterioration from that status. As the status is dependent upon assessing the characteristics of the water body against those of reference biological conditions, a biological monitoring programme will be required. Monitoring should define current conditions as a baseline and future change against the baseline.

The type of monitoring will depend on the characterisation of reference conditions against which the status of the water body will be assessed. The monitoring scheme will define the frequency of samples to be taken, the animal and plant communities that should be present and their expected abundance plus the hydromorphological conditions that should be met.

It is important to recall that if the test for designation of the water body is based on hydrological change, as a surrogate of biological change (step 1), it important that testing in step 5 is biological. This will test not only whether the water body itself meets it target status, but will also test the thresholds for designation employed in step 2.

STEP 6 Decision – does the water body meet the target status?

In step 6, a decision needs to be made as to whether the water body meets the target status set for it (*e.g*. GES or GEP). If it does, the water body needs to be monitored to ensure that there is no deterioration, so eventually steps 5 and 6 will be repeated. If the status is not met and there is good reason to believe that this is due to an inadequate flow release regime from an upstream impoundment, step 7 and 8 should be implemented.

STEP 7 Review impoundment release capability

Step 7 involves assessing the ability of the impoundment to make different releases and Thus to generate various elements of the natural flow regime required to meet its target status. The impoundment's ability may be limited, especially the releasing of high flows or varying flow releases frequently because of, for example, small or inflexible release values. Water quality should be considered along with water quantity since deep reservoirs (>10 m) tend to stratify in summer with cooler, poorer quality water at depth.

In some cases, flow releases could be linked in real-time to flows on a reference catchment, such as the inflow to the reservoir. Assessment of the impoundment in Step 7 will be particularly important for water bodies designated as HMWBs that are required to meet GEP. This is because the reference condition for GEP is the best practice example of a water body with the same modifications *i.e*, a similar impoundment. The assessment will help define the same modification in place within the water body.

Step 7 also involves assessing the implications of altering the current release pattern. Releases may need to be increased or reduced (or both, at different times) to meet the desired status, which may alter the reservoir yield (in the case of water supply), energy production (in the case of hydropower) or flood storage (in the case of flood management). The assessment should consider the purposes of the impoundment (determined in step 3) and the need for additional water resources development that could have greater overall environmental impacts. It should also consider potential impacts on the lake ecosystem, such as changes to level fluctuations.

STEP 8 Design environmental flow release regime to meet designation

This step involves the design of a flow regime release from the impoundment that will maintain the downstream river and upstream lake water bodies in designated status condition (GES or GEP). Defining the extent of impact in Step 1 enables the types of habitat and likely associated fish, plant, macroinvertebrate and algal communities that might be present or should be present if the water bodies downstream were not impacted. For GES, the key activity of this step is to determine which elements of the natural flow regime (floods, freshets, medium flows, low flows) are important for the river ecosystem downstream. The selected elements need to be specified in terms of their magnitude, duration, timing and frequency and combined to define an ecological flow release. Ideally this will be achieved from knowledge of the species that are present (or should be present) and their flow and associated habitat requirements in terms of, for example, temperature, sediment concentrations and oxygen levels. Any potential impact of releases on the reservoir ecosystem upstream should also be assessed. For GEP, a flow regime is required that will achieving an ecological status similar to the best examples of similar reference river ecosystems with the same modifications in place; *i.e*. with best practice applied to management of the water body. Given that river ecosystem may vary even between similar rivers, it may not be appropriate simply to transfer the flow release regime from the reference site. Defining the flow release regime will involve an iterative process of determining the elements of the natural flow regime are important for the river ecosystem downstream and adapting this according to what release regime is possible at the reference impounded site.

STEP 9 Revise the flow release regime according to impoundment capability, purpose and designation

This step involves assessing the environmental flow release regime (defined in step 8) against the current ability of the impoundment to make releases (defined step 7). This will determine the feasibility of implementing the ecological flow regime with the current impoundment infrastructure and operating rules. It should be accepted that the following constraints are likely to apply:

- hydropower reservoirs: outflows may fluctuate according to power demand
- regulating reservoirs: flow may be higher than natural for much of the time

- flood management reservoirs: downstream flood flows will be lower, flows after a natural flood recession will be higher

Particular attention should be given to the potential flexibility in the environmental flow release regime, for example whether it can be achieved to an acceptable degree by limited operating rules, such as constant compensation flows for long periods interrupted by occasional freshets, or whether the flow needs to vary over shorter time periods; seasonally, monthly or daily. Consideration may need to given to ensuring that the reservoir ecosystem is not negatively impacted, such that it fails to meet any target status, due to changes in reservoir level cause by flow regime releases.

STEP 10 Trial regime, monitor and test

Once an environmental flow release regime has been defined that is feasible to implement and that is likely to achieve the desired ecological status, it can be trialed and its impact monitored and tested (step 2). This testing should include water quality and sediment associated with the releases as well as there volumetric quantity.

STEP 11 Decision – does the water body meet the target status?

In step 11 a decision needs to be made as to whether the water body meets the target status (*e.g.* GES or GEP) with the flow release regime that the impoundment can currently deliver. If it does, the water body needs to be monitored to ensure that no deterioration occurs, so eventually steps 10 and 11 will be repeated. If the status is not met and there is good reason to believe that this is due to an inadequate flow release regime, changes to the regime need to be made. Two courses of action are possible:

- if failure is caused by limitations of the impoundment infrastructure precluding the release regime from being implemented effectively, step 12 should be followed.
- (ii) if failure is caused by inadequacies in the release regime itself, step 9 can be repeated.

STEP 12 Assess feasibility and costs of refitting impoundment release structures

Most impoundment structures have a limited ability to make variable releases, especially high flows. Thus it is likely many impoundments will not be able to make suitable releases to achieve the desired status (GES or GEP), particularly if the required release regime involves generating high flows and frequent changes to outlet structure setting.

In step 12, designs need to be made for refitting the impoundment with suitable structures to make the required releases. In the case of HMWBs, particular attention should be given to mimicking the release structures on reference impoundments that meet GEP *i.e.* those considered to be best management practice. If the water body downstream is not a HMWB, decommissioning of the impoundment should be considered. Refitting or decommissioning an impoundment may be extremely expensive and the WFD provides the potential for derogation on grounds of disproportionate cost (Article 4(5)), this is separate from the HMWB designation process.

STEP 13 Decision – is refitting appropriate?

In step 13 a decision needs to be made as to whether refitting the impoundment to meet the status criteria (GES or GEP) is feasible and is not disproportionately costly. If it is feasible and not disproportionately costly the re-fitting can go ahead and step 14 can be implemented. If it is not feasible to refit the impoundment or it is disproportionately costly the status may be derogated and no further action is taken at this stage.

STEP 14 Refit impoundment release structures

If the proposals to refit the impoundment with appropriate release structures (defined in step 12) are feasible and not disproportionately costly (decided in step 13), the re-fitting can go ahead. If re-fitting is too costly, a further derogation can be sought from relevant authorities. Once the impoundment has been refitted, step 9 needs to be undertaken again to revise the release regime according to the new capability, with subsequent monitoring and testing in step 10.

5.1. Designing an environmental flow release regime

This section is aimed at designing environmental flow releases to meet GES (Step 7). GEP is considered as a compromise between GES and the practicalities of impoundment operation. GEP is the ecological status achieved in the best examples of water bodies with the same modifications in place; *i.e*. with best practice applied to management of the impoundment. One of the best known approach to setting environmental flow releases from impoundments is the Building Block Methodology (BBM) developed in South Africa (Tharme and King, 1998; King *et al.* 2000). Its basic premise is that riverine species are reliant on basic elements (building blocks) of the flow regime.

Hierarchical approach

For application, three levels of BBM can be envisaged (table below). This provides a risk-based approach (Faulkner *et al*., 2002) in which greater investment in the assessment yields lower uncertainty in results. In all three approaches, assessments should be carried out by a team of experts that normally includes physical scientists, such as a hydrologist, hydrogeologist and geomorphologist, and biological scientists, such as an macro-invertebrate ecologist, a freshwater botanist and a fish biologist.

Three levels of assessment for BBM application

	Approach	Advantages	Disadvantages
1	desk-top flow	Rapid, does not require field visit, low investment	gives only indicative results, high uncertainty
2	hydraulic assessment	works with physical habitat, medium investment	requires hydraulic measurements, medium uncertainty
3	biological assessment	works with biological data from the water body, low uncertainty	requires biological monitoring, high investment

<u>Desk-top flow assessment</u>

This is an approach in which environmental flow releases from impoundments are considered from available data. The literature on ecological response to flow regimes provides some examples of flow requirements for different river species (Old and Acreman, 2006). However, many of these are specific to the river in question, due to, for example, genetic differences in fish populations. Nevertheless, literature sources can be used as a first approximation to the types of flow regime that would be most appropriate to different rivers. Where possible the literature should be used conjunction with flow data and biological data from fish, invertebrate and macrophyte surveys that characterise the river hydrologically and biologically in its reference (natural) condition.
Most steps are generic, but some vary according to the assessment approach followed.

<u>Hydraulic assessment</u>

This approach recognises that flow itself is not directly driving the usability of a river for different species and biotic communities. Rather it is the hydraulic properties of the river, such as depth, velocity and wetted bed area. Furthermore, many of the species/community requirements are defined in terms of depth and velocity. Although full hydraulic model simulation of river reaches requires considerable site data collection, estimates of the distributions of depth and velocity can be derived from catchment variables or simple site measurements.

Biological assessment

This approach recognises that all river ecosystems are unique and that there is considerable uncertainty in transferring flow requirements of species and communities from one river to another. This may result, for example, from genetic differences between rivers. This assessment level required biological research but yields results with lowest uncertainty.

Steps required to define an environmental flow release regime for different assessment levels

step	**Assesment level**		
	Desk top	**Hydraulic**	**Biological**
1	Define a natural flow regime for the water body in terms of daily discharge time series for a representative 10 year period.		
2	Analyse the flow regime in terms of the magnitude, frequency and duration of high, medium and low flows.		
3	Assemble biological survey data or use models for the water body to determine the expected biological communities and life stages for the river in reference condition		
4		Quantify relationships between flow and hydraulic parameters using hydraulic models	
5	Determine flow regime requirements for each species/community and life stage using published literature	Determine physical habitat requirements of each species/community and life stage using published literature	Undertake biological research including fish tagging to determine flow regime and physical habitat requirements of each species/community and life stage
6	Verify the requirements by identifying elements of the flow regime in the historical record		
7	Check that flow release elements will deliver other important variables such as water quality, including temperature and sediment load		
8	Define the Building Blocks		
9	Record the results in the environmental flow release regime table		
10	Add up the individual flow needs to assess overall implications for water resources		
11	Repeat the analysis for each water body ensuring that environmental flow upstream are sufficient to meet needs downstream		

5.2. Defining a long-term environmental flow release regime

The assessment approaches specified in above Section produce a flow regime through a year based on a set of Building Blocks. In natural systems, the flow regime varies considerably over different time periods including days, months, years and decades. It is evident that some flow requirements may be contradictory, such that high flows are required for river-floodplain connectivity that benefits some species at the same time that flows need to be limited for protection of juveniles of another species. This is consistent with the biological records for natural systems, which show that some years are good for some species and poor for others, *e.g.* one year may be good for one fish population another is good for other fish population. Consequently, it may be necessary to design several flow release regimes that are used on a rotating basis. A further issue is that inflows to the impoundment may be insufficient to make the required releases in any year. Implementation can involve defining one flow release regime for 'normal' rainfall years, when the suite of river ecosystem functions and processes can be expected (termed a maintenance flow), and a different one for drought years when all flow needs cannot be met, which is designed for species survival such that some species may not breed (a drought flow). An alternative strategy is to define environmental flow release regimes in terms of proportions of the natural flow regime. The release regime is then implemented by real-time determination of the natural regime by monitoring of a reference catchment, which could be upstream of the reservoir. Clearly this is a hi-tech solution requiring telemetry and automated operation of release structures. However, it incorporates natural variability and hydrological signals from a natural regime. Partial use of this idea could involve setting releases according to past rainfall or reservoir levels.

Implementation

Once an environmental flow release regime aimed at GES has been agreed by the river scientists, Step 7, it needs to be revised or adapted where appropriate (step 9). Revision may be necessary for three reasons:

- the water body is designated as HMWB and only needs to meet GEP
- the impoundment cannot make the releases as currently specified
- monitoring and testing (Steps 10 and 11) have shown that the release regime is failing to achieve the required status even when modifications to the impoundment release structures have been made (Step 14).

Achieving Good Ecological Potential

GEP requires achieving an ecological status similar to the best examples of similar river ecosystems with the same modifications in place; *i.e*. with best practice applied to management of the water body. This involves assessing similar impoundments on other rivers, how they are operated and how they impact on the river ecosystem downstream. The process starts with consideration of the environmental flow release regime that will meet GES and assessing which elements are delivered by the best examples of the other impoundments. Some elements of the release regime may be dropped if the

target species are maintained in the best examples without these elements. Best practice will involve a compromise between achieving the original objectives of the impoundment (hydropower generation, water supply, flood management), whilst releasing a flow regime appropriate to supporting key aspects of the river ecosystem. The release
regime may therefore include rapid rises and falls in flow (hydropower dams) or flows higher than natural (regulating reservoirs).

Impoundment release limitations
The current ability of the impoundment to make environmental flow releases is assessed in step 8. Limitations may include operational requirements of the impoundment, flood storage, water supply provision or hydropower generation, releases for subsequent abstraction downstream. Release structures may be very small or non-existent. In addition, release structures may take water from only one level in the reservoir, thus although the environmental flow release regime may be deliverable volumetrically, its quality may not be appropriate; including lower temperatures. In adapting the environmental release regime to over come the limitations of the impoundment, particular attention should be given to the potential flexibility in the regime, for example whether it can be implemented to an acceptable degree by limited operating rules that can be practically achieved, such as constant compensation flows for long periods interrupted by occasional freshets, or whether the flow needs to vary over shorted time periods; seasonally, monthly or daily?

Failure to achieve the required status
A third reason for adapting the environmental flow regime is when monitoring and testing
shows that even when the regime is implemented, the water body is failing to achieve the required status even when modifications to the impoundment release structures have been made. This may be due to uncertain scientific knowledge when the release regime was defined in step 8.

6. PROPOSAL OF THE NEW METHOD

New method is being called GEP Method[2]. Its rules of selection are defined in a simple manner. In order to achieve this simplicity there were detailed small water hydrological analyses performed on both several water courses and morphological analyses of the minor river bed wetted perimeter in order to find out rules of morphological relations and flow as basic abiothic indicators of fish habitat quality.

As a starting point for defining proposed method there were following requests:

- to unite all good characteristics of the four groups of methods which are most operatively used in the world eliminating their weaknesses. Methods whose experiences were built into new method are as follows: from the group of traditional methods: a) Montana-Tennant method, undoubtedly world wide most frequently

[2] Prof dr B. Đorđević, regular professor at Civil Engineering Faculty, Belgrad

used method, b) modified Tennant method, c) Statistic methods, and from the group of methods with habitat quality analyses: d) method of the wetted perimeter. Beside mentioned methods whose experiences were directly built in the new EF method, there were other methods experiences' also considered in the process (IFIM, regression methods) with the conclusion that previously mentioned ones can not be applied in our situation due to complex, lengthy and expensive investigation works requesting special experts dealing just with that field. In short: new method should contain all good characteristics of existing methods but to repair its own weaknesses that were spotted during the application in other countries.

- method should be highly operative and usable from the point of view of hydrological data bases which are standardized and ordinary for the activities of the designing works for dams, hydro power plants, accumulations/reservoirs and river water intakes.
- method should be very simple for application in practice. It was achieved in a way that very extensive regional small water hydrological analyses were performed as well as morphological analyses so that whole scope of new method application possibilities are considered, reducing the method itself to very simple rule.
- obtained ecological flows, determined according to new methodology have to always be ecologically more favorable then the results within category "rather good" according the Montana- Tennant method, but without disturbing elements and that with most of its part it is going closer to results within category "good" from the same method.
- method has to be universal, so it can be applied on the water courses of all hydrological regimes and characteristics in this area of Balkan.

There are two periods distinguished during the year:
1) cold period of the year when biocenosis is slow down and there are no critical activities in ichtiofauna development,
2) warm part of the year with very dynamic and vivid vital biocenosis activities including its reproduction. It is obvious that ecological flows has to be adjusted also in that period.

While defining EF methods, rich and precious experiences acquired world wide, when applying range of other methods, were used. All of the most important experiences used for defining this new method are systematized herein.
Except for great experience acquired worldwide by the application the method Montana-Tennant there are also following principles that were adopted: environmental flows dynamism reflected in adopting those two periods during the year (warm and cold part of the year) with different flow values given; experience on flows range comparing to average annual flows with good ecological effects, experience on categories of ecological worthiness of guarantied flows.
Principle of necessary corrections of guaranteed flows is adopted out of modified Tannant method in order to consider unevenness of flow distribution during the year. In that way it is possible to avoid shortcomings of certain traditional methods for rivers with high unevenness where most of the annual flow is realized during the flood, to determine improper, to high guaranteed flows or that with small selected guaranteed flows rivers are degraded-those ones with relatively balanced/even regime.
Very important principle is adopted from the statistic methods - decision on guaranteed flows has to be based on stochastic analyses of small water periods. There were significant improvement made in relation to the mentioned statistic method 7Q20 and method of transforming the curves of annual flows distribution, by using the result of stochastic analyses of long periods of small water duration within the new EF method

(analyses of small monthly waters or, if data on daily flows are available - analyses of probability of 30 days small waters). So the method is, by probabilistic analyses of small water period, significantly brought closer to reality of hydrological regimes that should be improved by discharging guaranteed ecological flows.
From the method of wetted perimeter the important logical principle is adopted -that quality of fish habitat and also quality of water course as biotope depends on wetted perimeter size, especially in period of small waters when survival of biocenosis depends on both continuity of flow and wetted bed perimeter constantly under the water. Morphological analyses performed under this study indicate that on our water courses, point of inflexion exists and that it is often in the flow range of (0,15 ÷ 0,25) $\overline{Q}$. At the first glance it is unexpected to have agreement with discharging category estimated with mark "good" when applying method Tennant. But, more detailed analyses indicate that this agreement is not so unexpected since flows that are in this range practically provide full continuity of the river water plane. As such, even in small water period they are providing rather good conditions for survival and all of fish development activities including migration in the spawn season.
Being operative and its simplicity for application is based on application of the smaller number of parameters that can be achieved with analyses of available hydrological series.

Application of EF method is based on application of three parameters: (1) average multi annual flow on the dam profile, i.e. water abstraction spot ($\overline{Q}$), (2) small monthly water of 95% reservation ($Q_{95\%}^{\min.month}$), (3) small monthly water of 80% reservation ($Q_{80\&}^{\min.month}$). If multi-annual series of daily flows are available then one can use appropriate values of 30-day small water flow of equal probabilities ($Q_{95\%}^{\min.(30)}$) and ($Q_{80\%}^{\min.(30)}$)[3] instead of minimal monthly flows ($Q_{95\%}^{\min.month}$) and ($Q_{80\&}^{\min.month}$). When having those data on disposal then all the mentioned principles of election are condensed in one very simple rule which is defining EF method.

Environmental flow (Q_e) is adopted in following amounts:

(1) In the cold part of the year covering period [October - march] environmental flow Q_e should be selected to be equal to the amount of monthly small water of 95% probability ($Q_{95\%}^{\min.month}$), i.e. small 30-day water of the same probability ($Q_{95\%}^{\min.(30)}$), but that value can not be less then $0{,}1\times\overline{Q}$, or bigger then $0{,}15\times\overline{Q}$. It means, in the cold part of the year Q_e is being selected based on the following relation:

[3] Alternatives are given due to operative reasons. No doubt it is better if there are data on 30-day small water of appropriate probabilities of appearance available since it is more appropriate for the physics of small water phenomenon since extreme small water period, defined with lowest annual flows in continuation of 30 days can cover parts of two months. But insisting only on flows ($Q_{95\%}^{\min.(30)}$)and ($Q_{80\%}^{\min.(30)}$) would not make sense since many of projects does not have multi annual series of daily flows available. Due to that fact it is permitted to use values of small monthly waters of appropriate probabilities. This enables for this method to be applied in all projects since in case of designing hydro power plant one can always have long enough series of monthly flows. Use of small monthly waters instead of 30-day minimal flows gives, by the rule, guaranteed ecological flows on the safe side (somewhat higher values).

$$Qe = \begin{cases} 0.1\times\overline{Q} & za \quad Q_{95\%}^{min.month}\ ili\ Q_{95\%}^{min.(30)} \le 0.1\times\overline{Q} \\ Q_{95\%}^{min.month}\ ili\ Q_{95\%}^{min.(30)} & za \quad 0.1\times\overline{Q} < Q_{95\%}^{min.month}\ ili\ Q_{95\%}^{min.(30)} < 0.15\times\overline{Q} \\ 0.15\times\overline{Q} & za \quad Q_{95\%}^{min.month}\ ili\ Q_{95\%}^{min.(30)} \ge 0.15\times\overline{Q} \end{cases}$$

(2) In the warm part of the year covering period [April - September], Q_e should be selected so that it is appropriate to the amount of monthly small water of 80% probability ($Q_{80\&}^{min.month}$), i.e. small 30-day water of the same probability ($Q_{80\%}^{min.(30)}$), but that value can not be less then 0,15$\times\overline{Q}$, i.e it should not be bigger then 0,25$\times\overline{Q}$. It means, in the warm part of the year Q_e should be selected based on the following relation:

$$Qe = \begin{cases} 0.15\times\overline{Q} & za \quad Q_{80\%}^{min.month}\ ili\ Q_{80\%}^{min.(30)} \le 0.15\times\overline{Q} \\ Q_{80\%}^{min.month}\ ili\ Q_{80\%}^{min.(30)} & za \quad 0.15\times\overline{Q} < Q_{80\%}^{min.mes}\ ili\ Q_{80\%}^{min.(30)} < 0.25\times\overline{Q} \\ 0.25\times\overline{Q} & za \quad Q_{80\%}^{min.month}\ ili\ Q_{80\%}^{min.(30)} \ge 0.25\times\overline{Q} \end{cases}$$

In case that values of environmental flows acquired over defined probabilities of small water are going out of the range defined in above mentioned rules and equations, then the limit values are adopted.

(3) In case of water courses with special ecological or sport and turistic and recreation requests and targets, values that are acquired according to above mentioned rules can be increased: in cold period up to 15% and in warm part of the year up to 30%. It can be done just with special analyses of usefulness of such increase.

(4) Values of environmental flow acquired for the cold part of the year can be treated as constant ones, although it is possible, if necessary, to make their certain variations (certain increase of flow in March, when some fish species are spawning in that cold period (pikes)).

(5) Acquired amounts of environmental flow in warm part of the year are average. They can be adjusted more in details according to needs of biocenosis development, especially of ichtiofauna, so that in critical periods (spawning season, etc.) discharge is being increased, in accordance with possible requests of the services in charge for ecological protection and fishing. Decreases are possible in favorable hydrological situations, when flows on the tributaries are more favorable, but one cannot allow that flows are smaller then those being discharged during the cold part of the year at the section downstream from the dam.

(6) Flow that is discharged for those needs in not energetically lost. Small generators can be implemented at that discharge point which would process that flow in sense of energy. Only obligation is that such outlet has a branch that would provide discharge also in case if generator is out of function due to damage or maintenance.

OTHER MEASURES FOR PROTECTION OF BIOCENOSIS

For providing as favorable as possible ecological conditions downstream from the dam accumulation, in all accumulations where there are thermic separation one should use **selective water intakes** for discharging environmental flows. Dispositions should be foreseen with appropriate number of intakes on various depths so that environmental flows can be discharged from those zones / depths of accumulation in which immediate quality indicators (temperature, chemism) are most favorable for downstream biocenosis.

Valves should be control valves, sized for highest flows that could be requested during the timely variable (dynamic) discharge of environmental flows and flows required for downstream users. If the water is discharged also for the downstream users needs who will abstract required water quantity on their downstream river abstraction points, that amount of water has to be also discharged on selected water intakes for the sake of providing most favorable temperatures from the point of view of downstream river section biocenosis.

Adequate selection of valves for discharging guaranteed flows and flows for downstream users (bevelled control valve with most efficient deaeration of the jet) can improve **oxygen regime** on the downstream water course sections.

Long term programs for following up changes in fish population at one water course would have to be part of the integral strategy for certain river section use. Selection of environmental flow is just one of the starting, extremely important activities in the process of aquatic eco systems management. This program would provide verification of calculated values or change of those in order to adjust to realistic conditions within water course.

In order to have valid data on disposal on the layer that should be used for discharging flows as well as to constantly follow up dynamic development of accumulation as ecosystem it is obligatory to prepare mathematic model of accumulation behavior during the time for all accumulations (module of change of biotic and abiotic parameters of the lake ecosystem). User of the structure is under obligation to provide monitoring system that will enable both calibrating and constant improvement of the module. Abiotic and biotic factors of the water eco system should be measured-those ones necessary for updated follow up of lake behavior in the real time.

7. PROPOSAL FOR THE ACTIVITIES FOR PHASE II OF “LIVING NERETVA” PROJECT (Environmental flow)

As it was set out in ToR for the Environmental working group, main effort was put to analyses and present various approaches in setting suitable methodologies among the existing ones for calculating environmental flow.

Implementing new domestic legislation (Entities Law on water) which is based on philosophy and above more standards set in WFD, will require assessment of whether water bodies meet environmental standards that indicate good ecological status. Good ecological status (chemical and biological components) criterion are not set yet.

As assessment will need to be made of great number of water bodies and probably within a short space of time and available budget, it seems that level of assessment is best suited to a strategic planning/scoping level approach that is simple and quick to apply without need for detailed site visits. A separated and more detailed method would be needed to asses impacts of specific abstractions and impoundments (approach described in chapter 6) on particular water bodies and to determine licence conditions.

The most fundamentally relevant gaps that arise are those that exists between the aspiration to have ecologically relevant regulatory standards which are scientifically well founded and can be implemented in systematic and defensible way, and the means of delivering them.

7.1. Key findings of this phase and recommendations for the follow up

Most countries have various methods of determining environmental flows, each defined for a different purpose, *e.g.* strategic analysis, scoping or impact assessment.

Licensing of reservoir releases and abstractions present quite different problems and different methods have been developed to deal with these issues. With reservoir releases, the whole flow regime (apart from very large floods that by-pass the dam) needs to be created. Abstractions, by and large, have no impact on high flows and so the focus is on low flow impacts.

Where data are scarce, expert opinion is used, and increasingly a formal structured approach to getting consensus amongst a group of experts, including academics and practitioners is favoured.

There is wide acceptance that all parts of the flow regime have some ecological importance. As a result, there is a growing move away from single low flow indices.

Many methods determine environmental flows in relation to the natural flow regime of the river. Some methods define flow in terms of site characteristics, but it has not been possible to examine the data or the basis of these derivations. Other methods define environmental requirements in terms of more direct hydromorphological elements, such as water depth and velocity.

Small scale studies have shown that flow interacts with morphology to define physical habitat (such as width, depth, velocity and substrate) for specific organisms. These quality elements vary spatially; water is deep in pools and shallow on riffle; velocity is high in riffles and slow in pools. Standards based on these quality elements at the broad water body scale cannot be readily defined. To implement standards at the reach scale, site data are essential.

Other issues not included in the WFD quality elements, such as land use, may also be important in protecting the ecological status of waters and so would also need to be considered as part of the next phase of the project.

Particular consideration should also be given to the protection of 'high status' waters where the hydromorphological quality elements are given specific protection in addition to the role they play in delivering the ecological quality elements.

7.2. Overall goal of second project phase

Overall aim should be to develop methods for the establishment of regulatory standards for rivers and lakes (water bodies).

Implementation of the WFD will require that environmental standards are applied for all bodies regardless of hydrological and ecological data available. Consequently, standards are required that can be applied without having to visit the water body. This means that standards must be related to parameters than can be obtained from maps or digital databases, such as river flow, catchment area or geology. Any resulting standards will have less predictive power at a local scale and cannot be tested using site data.

A hierarchical approach may be needed in which a broad scale approach, perhaps based on flow, is used as a screening tool to assess all water bodies. A more detailed approach, perhaps based on depth or velocity, may be applied to a smaller number of sites identified as requiring close attention.

The flow regime is complex and is characterised by timing, magnitude, duration and frequency; all of which are important for different aspects of the river ecosystem. To produce operational standards, there is a need to identify a small number of parameters that capture its most significant characteristics. For example the number of high flow events greater than three times the median flow has been shown to be related to the structure of macrophyte and macro-invertebrate communities in New Zealand (Clausen, 1997).

The equivalent for lakes is the water level regime. Water level is of direct ecological relevance since it determines the area of littoral zone exposed and, given its variability, the timing and duration of exposure. It is also directly related to water depth; it influences a range of system state variables including effective fetch, wave-base and re-suspension of fine-grained bed sediments; and it is linked to residence time. As for the river flow regime, there is a need to identify the most significant characteristics of the lake water level regime; for example annual or weekly ranges, seasonal maxima or minima, or rates of rise and fall.

Nevertheless, meaningful seems that hierarchical approach to standards should be developed, where broad scales methods based on flow are used for screening, but detailed scale methods based on more directly ecologically meaningful parameters, such as depth and velocity, are used for site level impact assessment and license setting.

The measures and parameters that typically affect the relative ecological sensitivity of surface waters to changes in the flow regime, and the thresholds for these parameters that are important in maintaining the ecological status of surface waters need to be identified. As a minimum, next project phase must consider all those parameters that are covered by the ecological, continuity and hydro-morphological quality elements set out in the WFD. The best current scientific understanding of the links between hydromorphology and ecology must be applied in order to justify the selected parameters and thresholds.

In order to deliver the ecological objectives of the Water Framework Directive (WFD), regulatory standards are needed that will allow the regulatory body to determine the ecological flow requirements.

These standards must provide sufficient protection for the water environment so as to restore and maintain the ecological status of waters and so meet the WFD and other environmental objectives. To promote the sustainable use of water and allow water users to continue to operate without unnecessary restrictions, these standards must be set in relation to the ecological sensitivity of waters to changes in hydro-morphology.

The programme for the follow up phase shall be structured as follows:

1. Identification of all relevant parameters to which aquatic ecology is sensitive.

These will include hydrological parameters such as the flow (discharge), but also broader hydromorphological parameters such as water velocity, water depth or level, channel form, or wetted area and may also include groundwater contribution (temperature, quality and/or quantity), seasonality etc. as appropriate. Once identified, these parameters may, where appropriate, be grouped into generic sub-categories that allow those circumstances where they are of ecological importance to be defined. In tandem with this work, from review and appraisal of existing internationally applied standards, will be carried out to determine where there are any gaps - any parameters that have been identified as relevant but for which there are no existing standards available.

2. The creation of a typology for rivers and lakes and the identification of the ecological sensitivity of each 'type' to changes of the parameters defined in previous step.

This stage of the project aims to develop a meaningful typology to categorise the ecological sensitivity of rivers and lakes to the hydromorphological pressures that are created by abstraction and impoundment. This typology should then be used, along with the data collected as part of the literature review, to identify which specific parameters, from the full set identified in previous step, are relevant to the ecological requirements for each of the types.

3. To develop the regulatory standards (i.e. the thresholds for each of the parameters identified) by reference to the five categories of ecological status as defined in the WFD (High, Good, Moderate, Poor and Bad).

This step should result in standards (i.e. thresholds) defined as relevant for selected parameters: for example: macrophytes, macro-invertebrates, recommended standards for river types for achieving GES , etc relevant both to restrictive flow management (abstraction) and active flow management (flood, impoundment flow releases) for specific type of water bodies.

8. Conclusion

Review of existing methods applied in various countries, then available data for river basin Neretva (hydrologic, hydromorphology, biology, geology etc..) and requirements and suggestion from beneficiaries, overall approach should be as follows:

a) Methodology should be applicable in all situations. Selected model parameters for environmentally acceptable flow dependant on both physical and biological characteristics. Seasonal variations of flows also included

b) Parameters flexible to possible reevaluation having in mind activities related to set up of reference conditions and water bodies delineation and status defining

c) Methodology should be flexible to data availability.

2. Methodology based on GEP Methodology with modifications:

- $Q_{gep} = k\ Q$, whereas
  k - parameter that needs to be defined;
  Q_{gep} – guarantied ecological flow
  Q – average annual flow

- „k“ parameter needs to be defined in relation to:
  Flow variability,
  abiotic parameters of water bodies,
  hydraulic conditions,
  groundwater regimes,
  etc
  In other words quantified in a manner to present relation between various flow regimes. Substrates of river bad and banks, hydraulic conditions, ground water paths and flow, water quality reference conditions etc.

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