Environmental flows and integrated water resource management

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ABSTRACT: Current regulations consider environmental flows only in the form of minimum instream flows released downstream water diversions; this approach has some limits, especially when applied to Integrated Water Resource Management (IWRM). In order to overcome these limits, a research has been promoted for the definition of the environmental performance of various management options. The approach of microhabitat methodology has been used and an environmental score has been defined. This approach has been implemented and applied to a case study using different techniques. In particular a tool based on Bayesian Belief Networks (BBNs) has been developed in order to clearly express and to take into account the role of different stakeholders. Moreover the application of this approach in the framework of optimization and multi–criteria methodologies is under development; it will allows to take the environmental objective into consideration explicitly in the development of IWRM plans.

1 INTRODUCTION

The concept of Minimum Instream Flow was originally introduced for a very specific purpose, i.e. protecting the aquatic fauna downstream river diversions. Since then it has had several different applications and interpretations. Its original meaning is now been extending and, in some recent regulations, it is considered as an instrument that, in the framework of Water Management and Protection Plans and together with other measures, permits the achievement of water quality targets.

These recent developments induce to consider environmental flows in the context of Integrated Water Resource Management (IWRM). This last concept has been defined "a process that promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems" (GWP, 2000). It is considered a basic principle in the definition of a sustainable development and in the attempt at reconciling multiple and competing water uses and environmental protection. One of the important tools that has been recommended for implementing this approach in the water allocation process is multi – criteria analysis (e.g. *Guidelines for the allocation and management of water for maintaining the ecological functions of wetlands*, adopted in the Resolution VIII.1 of COP8 to Convention on Wetlands).

This case study aims to show how environmental flows can be considered in IWRM tools. In particular, the problem of the inclusion of environmental objective in multi – criteria analysis will be faced; given a water management policy, the main difficulty is the definition of an environmental score that can be computed and foreseen for different scenarios, possibly inaccessible to experimentation and measure. In order to overcome this problem, the approach of some Minimum Instream Flow methodologies will be used, an environmental score will be defined, and it will be implemented using various techniques. Moreover methods to take the role of different stakeholders into account, according to the most recent recommendations in this matter, have been explored and applied.

2 METODOLOGY

The conventional way to address environmental impacts of water diversions is the definition of Minimum Instream Flow (MIF) requirements. As stated above, this approach has some limits, especially related to its application in IWRM. In order to overcome these limits, a research has been promoted and initiated in the framework of System Research on Electrical Sector. The aim is therefore to develop an index connected to instream flow, in order to be able to define the performance of various management options. In this way, it would be possible to take the

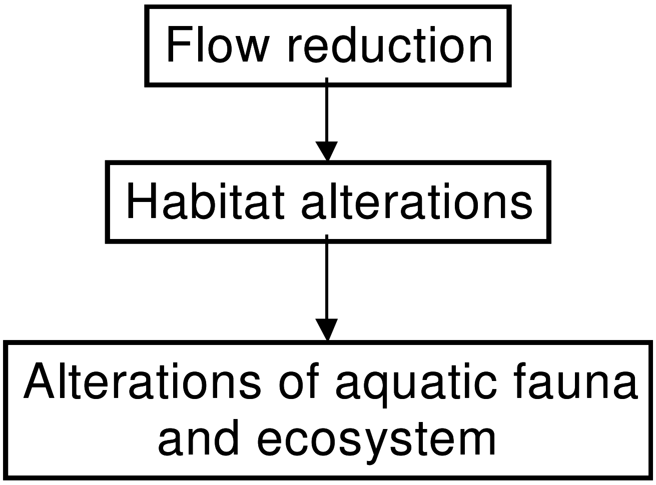

Figure 1. Process for the quantification of flow reduction impact.

environmental objective into consideration explicitly in multi–criteria methodologies used to develop an integrated water resource management plan.

The starting point of this activity is the approach used in the microhabitat methodology (Stalnaker, 1979, Bovee, 1982, Milhous et al. 1981) for the estimation of environmental flow requirements.

Microhabitat methodology adopts a deterministic approach for simulating the fish response to a water diversion considering the causal relationships that determine the influence of the flow diversion on aquatic life. Actually, the main result of the application of microhabitat methodology is not the definition of a value for MIF, but rather an estimation of the response of the aquatic ecosystem to different flows; more generally, microhabitat approach is suitable whenever there is a need to estimate the effect of a perturbation on a specific river habitat.

A microhabitat simulation consists of a two step process (Fig. 1): in the first the microhabitat response to flow variation is computed by means of a hydraulics simulation; in the second step the suitability of the new habitat conditions is computed by means of a set of preference or suitability curves. The result is an index, called Weighted Usable Area (WUA), with the dimension of an area (m^2). It represents an area weighted for the fish preference. As such it is not a physical and measurable quantity but must be considered an index.

The actual result of the microhabitat simulation is the curve representing the habitat response to different river flows. The function WUA versus the discharge can be considered the transfer function that transforms the hydrologic information into the biological one.

These characteristics make this approach suitable for the development of an environmental performance index of various water management policies.

In the approach developed in this project, natural and regulated time series are taken into account by means of the respective flow duration curves. The comparison of these curve yields a “hydrologic distance” between the natural flow regime and the regulated one; this distance could be used as a performance index but has little environmental significance. The curves “WUA versus flow” allow the translation of the hydrologic forcing factors into a biological response. This makes it possible to derive a WUA duration curve starting from a flow duration curve, which is usually easily available, and compute an effective environmental index.

To carry out explicitly this process, let $Q_D(D)$ be the flow duration curve, i.e. the discharge not exceeded for the D fraction of time (here $0 \leq D \leq 1$), and let $W(Q)$ be the WUA corresponding to the flow Q. If W is a monotone, increasing function of Q, the WUA duration curve can be computed as:

$$W_D(Q) = W\left(Q_D(D)\right) \qquad (1)$$

If W is not monotone, the previous formula become only a little more complex without setting any problem. Nevertheless in this work $W(Q)$ is supposed to be increasing monotone because it is assumed that a water diversion cannot have a positive effect on the environmental system.

Note that from these assumptions follow the inequalities:

$$\begin{aligned} Q_D^R(D) &\leq Q_D^N(D) \\ W_D^R(D) &\leq Q_D^N(D) \end{aligned} \qquad (2)$$

where superscripts N and R refer to the natural and regulated regime, respectively.

The environmental cost of a water management policy can be defined as an appropriate distance between natural and regulated WUA duration curves. For instance, this distance can be defined as (Fig. 2):

$$\mathrm{EC} = \int_0^1 \left[W_D^N(D) - W_D^R(Q)\right] dD \geq 0 \qquad (3)$$

where EC stands for “environmental cost”.

The performance index is called here an “environmental cost” because the higher the value is, the worse the environmental impact results; this does not of course imply any monetary translation of the environmental impact.

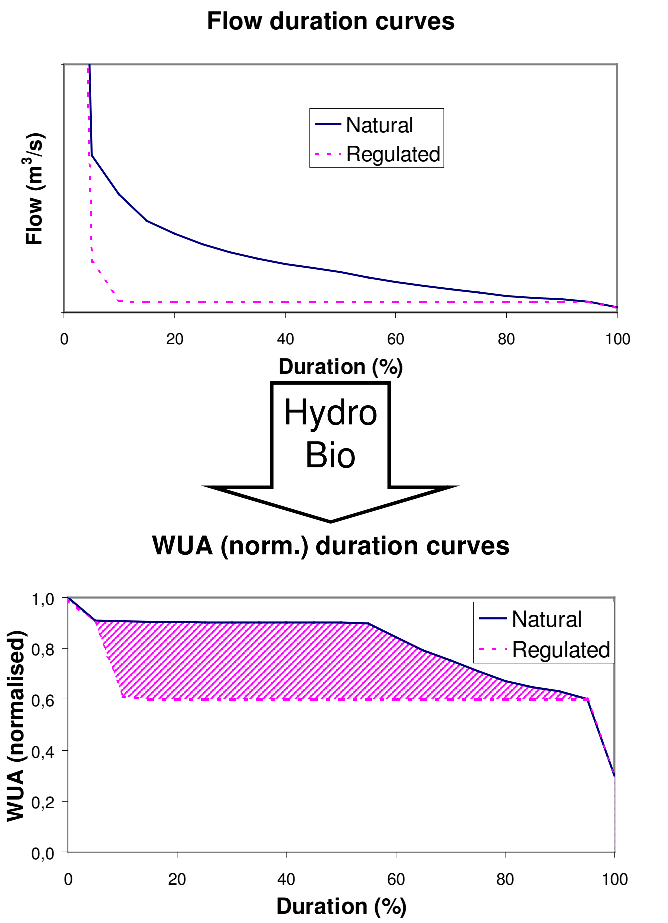

Figure 2. Derivation of the "environmental cost" from the flow duration curves.

3 APPLICATIONS

The approach outlined in the previous section is equivalent to the time series analysis of WUA presented in Milhous (1990). The central idea of the present work is the translation of hydrologic information into biologic information by means of the W(Q) function and its use in methodologies for the optimization of water uses. This last step can be implemented in different ways, with different levels of integration with the others components of the optimization tool.

3.1 *Post processing tool*

The previous methodology and the formulation of the index were implemented using Bayesian Belief Networks (BBN) and influence diagrams in the framework of the EU MERIT project (Managment of the Environment and Resources using Integrated Techniques, http://www.merit-eu.net). The aim of the project is to develop a methodology for IWRM that can be applied at the catchment scale; one distinctive aspect of the project is the use BBNs for the practical implementation of such methodology into a generic management tool, which is being applied to four case studies in different EU countries. The Italian site is the Vomano watershed and the following objectives were pursued in the Italian case study:

- to develop a tool for the quantification of the “environmental cost” of a management policy
- to develop a tool that allows stakeholders to assign their own weights
- to demonstrate the use of bayesian network technique in integrated water resource management

In BBNs the system is represented as a set of nodes, linked in a way to represent cause and effect within the system. Once a network is complete the impact of a decision can be evaluated by entering the action into the relevant node. In this way the impact on the whole system can be evaluated. The structure of the tool is outlined in Figure 3.

The input is the time series of regulated flows, provided by some appropriate optimisation and simulation tool. In the Vomano application the input was provided by a parallel activity carried out by Politecnico di Milano, in which some optimal water management policies were identified using a multi - objective approach and stochastic dynamic programming (Soncini-Sessa 2002). The preprocessor is needed to compute a regulated flow duration curve from the flow time series and to assign the right parameters for the bayesian network.

The other input represents the weights assigned by the stakeholder. The result is an environmental cost of the management policy that has produced the regulated flows.

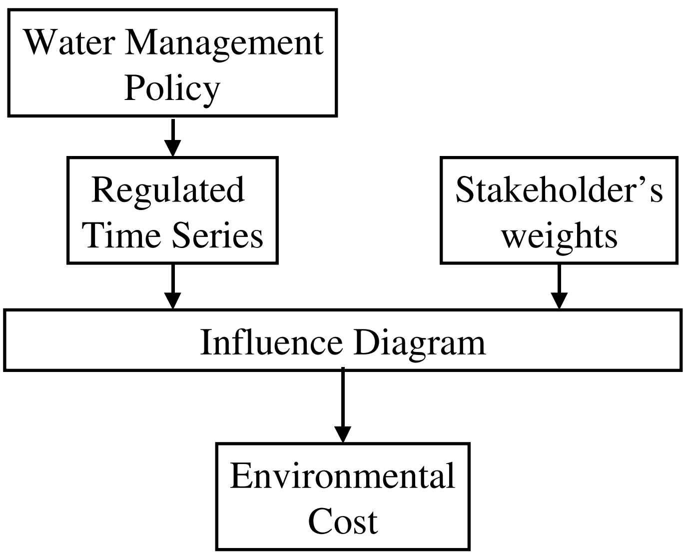

Figure 3: Evaluation of policy environmental cost by means of BBN

By using BBN, a tool that permits to assign a cost to a pre - determined management policy was developed. It addresses the issue of fish habitat preservation through the concept of an environmental index instead of minimum instream flow. Its main advantage is that it allows stakeholders to assign their owns weights in a simple way and to evaluate the environmental performance of a water management policy according to their own point of view. This option reflects the fact that environmental value is not perceived by different groups in the same way.

3.2 *Stochastic Dynamic Programming*

In the above cited application the different water management policies are derived without any reference to their environmental performance, which is evaluated only *a posteriori*, allowing only a comparison among already available scenarios.

At present an application carrying out the simultaneous optimization of environmental performance and of the other objective function is being developed. The optimization tool will be based on Stochastic Dynamic Programming and implemented through a computer code for the derivation of the management rule of reservoirs and regulated lakes. Other objective function will be computed in order to take into account all different water uses (hydropower, agriculture).

The environmental objective will be determined by means of the quantification of the cost on a daily basis, according the procedure outlined in the Methodology paragraph. The key ingredient will be again the use of the function W(Q) in order to translate the "hydrologic distance" into a "biologic distance" between the natural situation and the regulated one:

$$EC(i) = W(Q_i) - W(Q_i^R) \quad (4)$$

where *i* represent the i-th time step.

The analysis will allow to compute various optimal water management policies, depending of different weights assigned to the various objectives.

4 CONCLUSIONS

Although IWRM is widely recognised as a basic approach in order to pursue sustainable development, its application in practice poses some difficult challenges; one of these is the translation of the environmental objective into a well – defined and quantitative measure apt to be used in mathematical modelling and optimisation tools in order to evaluate the effect of different water management policies. These results in turn would inform policies and negotiations on environmental flow requirements and measures to provide them.

5 ACKNOLEDGMENTS

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