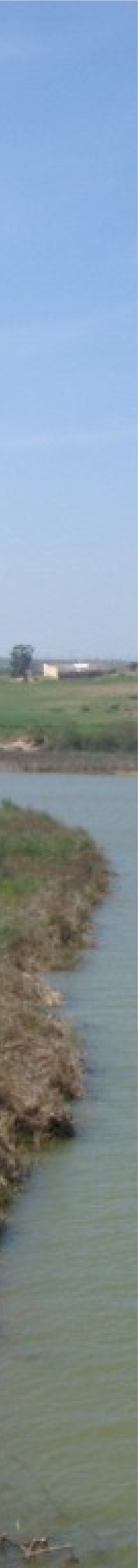

Assessment and Provision of Environmental Flows in Mediterranean Watercourses

- Basic Concepts, Methodologies and Emerging Practice

Mediterranean Case Study

Environmental Flows and Integrated Water Resource Management: the Vomano River case study

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Environmental Flows and Integrated Water Resource Management: the Vomano River case study

1 INTRODUCTION

Recent developments of legislation in Italy tend to consider environmental flows in the context of Integrated Water Resource Management (IWRM). Here, IWRM has been defined "a process that promotes the coordinated 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"[1]. It is considered a basic principle in sustainable development and in the search for ways to reconcile multiple and competing water uses with environmental protection. One important tool for implementing this approach in the water allocation process is multi-criteria analysis[2], wherein an environmental flow assessment provides a way to quantify the environment criteria.

The concept of a Minimum Instream Flow was originally introduced in Italy in the late 1970's for a very the specific purpose, i.e. protecting the aquatic fauna downstream river diversion. Since then several different applications and interpretations have evolved that extend the original meaning. In some recent regulations, it is considered to be an instrument to achieve water quality targets - together with other measures, in the framework of the Regional Water Management and Protection Plan.

Environmental flows are now prescribed in the national legislation in Italy in general terms, as framework laws. The individual River Basin Authorities are required to set up specific rules for rivers under their responsibility. Current norms consider environmental flows only in the form of a minimum instream flows to be present downstream of water diversions. Eventually these rules are to be acknowledged by Regional Authorities in their Water Protection Plans, in which other specifications can possibly be made (e.g. different MIF requirements to address specific issues).

This case study describes a pilot scheme to integrate environmental flow assessments with IWRM tools in the Vomano River in central Italy. Rivers flows in this basin are highly regulated, mainly for hydropower generation. It shows how environmental objectives were incorporated in multi-criteria analysis to develop an integrated water resource management plan and flow regulation policies. Typically the main challenge in such circumstances is to define an environmental score that can be computed for different scenarios – one that is inaccessible to experimentation and measure. The approach described overcomes this problem by using existing Minimum Instream Flow methodologies to define an environmental score, and combine this with Bayesian Belief Network techniques. It was thus possible to involve stakeholders explicitly in flow tradeoffs using multi-criteria formulations, and recommend an environmental flow regime that reflected both scientific analyses using the best available information and stakeholder perspectives.

2 THE EVOLVING ITALIAN LEGISLATIVE FRAMEWORK

In Italy the provision of flow releases downstream of water diversions to protect the aquatic ecosystem has been recognised since the late 1970s, when local authorities set up rules for dam operators. These

[1] Global Water Partnership 2000. *Towards water security: a framework for action.* GWP, Stockholm, Sweden.

[2] See, 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 (Ramsar)

regulations were initially established in Alpine areas, where the water resource exploitation is high, especially for hydropower generation. The driving force for local action was the growing of public concern about environmental protection. These rules were based on the concept of a Minimum Instream Flow (MIF) to protect aquatic fauna and aimed to warrant a discharge not too far from the natural one. The early methods were referenced to some hydrologic measure (such as a drought index or a specific discharge) but without any reference to the site-specific conditions. Their main advantage was their simplicity; their main drawbacks were:

- Only new diversion or abstraction licenses were expected to fulfil MIF obligations
- Only a small part of the national territory was subject to these rules
- The quantification of the MIF was rather arbitrary
- Protection of an ecological component (the aquatic fauna) was pursued by means of a purely hydrological approach (e.g. an index or rating method)

The last drawback points out the lack of any reference in the earlier methods to both species-specific responses and site-specific conditions (such as the shape of the river section, the substrate, and the other variables that contribute to characterize the local habitat). Nearly all regulations left local authorities the discretion of increasing the minimum flows released downstream water diversions to take site-specific factors into account, but rarely was this done.

From the 1980s activities in this field have aroused public interest that prompted the development of both scientific investigations and activities in the regulatory context. As in other countries, in Italy experimentations were conducted in order to make the quantification of MIF more scientifically based and to estimate the actual benefits of a new water release regime. In particular, the microhabitat methodology, which simulates the effect of a flow reduction on the local habitat of particular fish species was applied to several sites throughout the country. This work was carried out both in the framework of research programmes and as actions jointly promoted by local authorities and water users.

One result of this research and experimentations was a new set of regional rules for the quantification of MIF requirements to be fulfilled by new water exploitation plans. However, the competence for issuing these rules was not clearly established. Thus both River Basin Authorities and regional governments adopted various formulas. These rules were still formulated as simple hydrological expressions so as to make their application easy. They also had some river basin specific coefficients, and in some cases, corrective coefficients to take additional factors into account (for instance naturalistic value, water quality, interaction with groundwater, and so on). However, the quantification of these coefficients in relation to local conditions was hardly ever undertaken.

For instance, in 1992 the Po River Basin Authority adopted the following formula for one river basin within its competence (Valtellina, in Northern Italy), after some serious events due to the hydrogeological instability of the area. The formula stated that the MIF must be at least:

$$MIF = 1.6\ P\ A\ Q\ N\ (l/s/km^2)$$

Where: P is a rain precipitation factor (ranging from 1.0 to 1.8); A accounts for the average altitude of the catchment; Q and N account for the site-specific characteristics and the naturalistic value of the river stretch under consideration.

Only the precipitation factor was quantified. Others were left unspecified. The formula was to be applied to new water exploitation projects. For existing diversions, experimental and provisional releases were planned due to an agreement among local authorities and hydropower producers, so as to detect and measure possible environmental improvements.

As a further example, the regulation adopted in 1995 by Piemonte Region (in North West Italy) was intended to be applied to new diversions and for renewal projects. It is explicitly based on Q_{355}, i.e. the flow not exceeded more than 355 days per year. This means that, on the average, the natural flow is less than the Q_{355} value only for 10 days in a year. Of course this index can be derived only in gauged stations, but the rule contains also a rationalisation procedure to compute Q_{355} in river sections where hydrometric time series are not available.

The MIF is then obtained applying three multiplicative corrective coefficients to the natural $Q_{355,}$ where:

- K_A, ranging from 0.7 to 1.0 is used to account for different environmental sensitivities of the interested river stretch
- K_B, ranging from 0.25 to 1.0 and provides a gradual time application of the norm (starting from 1995 till 2005, when the rule was supposed to be in full play)
- K_C, ranging from 1.0 to 1.5 to account for different level of protection due to the naturalistic value of the interested area (for instance in protected areas)

An interesting and uncommon aspect of this rule is the possibility to prescribe a time variable MIF in some cases. The formula defining the temporal modulation is:

$$MIF_t = \begin{cases} Q & \text{when } Q < MIF \\ MIF + 0.1(Q - MIF) & \text{when } Q \geq MIF \end{cases}$$

Where: Q is the natural flow; *MIF* is the above defined MIF, and MIF_t is the time-variable MIF. To the author's knowledge, the temporal modulation of MIF has never been applied, perhaps because of its difficult practical application.

These approaches overcame some flaws of the earlier rules, but they still suffered drawbacks. For instance, the lack of any specific procedure for quantification of site-specific coefficients made their application rather difficult. So MIF estimation continued to overlook specific, local conditions and the morphology of the river stretch subject to the flow reduction. In addition, the fact that all these rules applied only to new licenses limited the diffusion of environmental releases.

At the same time, river protection through the provision of reserved flows downstream of water diversions was recognised in some important National Acts. This extended from the 1983 Soil Protection Act, which first introduced the River Basin Authorities in Italy, to the Water Protection Act (1999), which rearranged the entire Italian normative framework for the protection of water bodies. In particular, the Water Protection Act introduced some very basic but, important concepts into Italian environmental legislation, namely:

- The integration of quantitative and qualitative aspects
- The watershed as the basic unit for water management
- Water environmental quality targets formulated in terms of ecological criteria

It is worth to note the statement in this Act that environmental flows must contribute to achieve the water quality targets. In addition to these principles, the norm has prescribed that all water exploitation licenses would have to be re-examined in order to establish environmental flow releases. The application of many principles in the Act was left to rules and regulations to be issued by local authorities (mainly River Basin and Regional Authorities) so that their practical effect is difficult to estimate at the moment.

As it is apparent considering the three points stated above, for many aspects the basic approach of this Act resembles the EU Water Framework Directive that was approved one year later, in 2000.

Following the approval of the 1999 Water Protection Act, some River Basin Authorities have issued new MIF requirements (for instance the Po River Basin Authority, the largest in Italy), while others have the task in progress. These criteria are usually the result of extended experimentations and are formulated, as before, as a hydrological formula, possibly corrected by means of some coefficients that take different environmental aspects into account.

Box 1: Evolution in Defining MIF in different Italian regulations(*)

"a minimum residual flow in order to assure fish life" (1978)

"the flow necessary to life in rivers so that ecosystem equilibrium will not be damaged" (1994)

"the flow that must be maintained downstream water diversions in order to maintain vital, although near critical, instantaneous conditions of ecosystem functionality and quality" (1995)

"The quantitative protection of the water resource contributes to the achievement of quality targets by means of uses planning meant to avoid impacts on water quality and to permit a sustainable water exploitation" (1999)

"the flow that must be maintained downstream water diversions in order to maintain vital conditions of ecosystem functionality and quality" (2002)

(*) Free translations of the author

As for their application to existing water licenses, a gradual application of the norms is usually planned; for instance the Po RBA's norm sets these intermediate objectives:

- By 2008, all existing water diversions will release al least the "hydrologic" MIF, i.e. without the application of corrective factors.
- By 2016, the "hydrologic" MIF will have to be adjusted with the application of the corrective factors (if needed).

Considering these developments, it is worth noting that the gradual transformation of MIF from a pure hydrologic index to an instrument for the protection of the whole river ecosystem (see Box 1), as well as an increase in the basic coefficients of the hydrological part of the proposed formula; for instance, if attention is restricted to Alpine areas, the typical specific flow for MIF requirements has raised from 1.6 – 2.0 l/s/km^2 of the first norms to 4,0 – 6,6 l/s/km^2 of the more recent ones.

3 THE VOMANO WATER SYSTEM

The Vomano River is located in Central Italy and its watershed is 782 km^2 wide. It originates in the Gran Sasso Massif at 2155 masl, flows 68 km in an eastward direction to the Adriatic Sea. At the Ponte Vomano river section (136 masl, near Villa Vomano), an ordinary low flow of 5.6 m^3/s has been observed, which can be compared to an ordinary high flow of 19.2 m^3/s. The low flow usually occurs in August (about 4.5 m^3/s) while the high flow occurs in April, when high spring precipitation and snowmelt coincide.

The quality of water in the Vomano has been assessed as good, especially in the upper stretches of the streams. The 2002 Report on Water Quality and Fish Distribution classified 12 out of 16 stations as "non impacted" according to the Extended Biotic Index. The lowest station, near the Vomano mouth into the Adriatic Sea, was classified as "polluted". In addition, numerous sites of remarkable naturalistic value were identified. Salmonids (trout) represent the most valuable fish species, and are present in the upper and medium course of the streams. In the lower course, cyprinids gradually take the place of salmonids. Some cyprinids of valuable scientific interest are also present as recognized by the establishment of two sites of community importance.

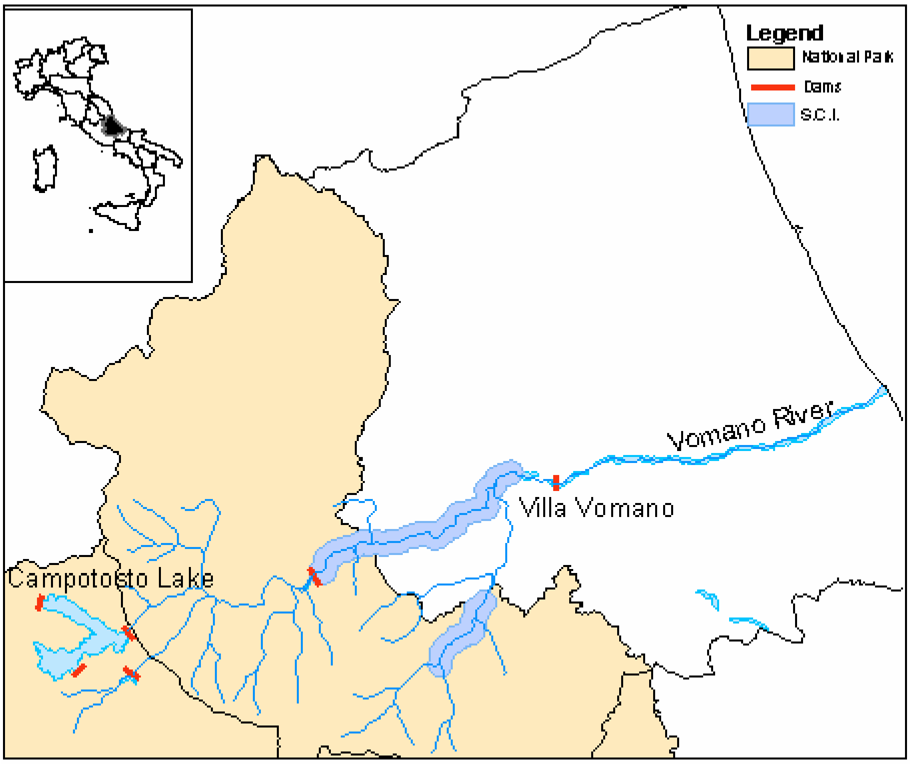


Figure 1: The Vomano River System

Several protected areas are present in the Vomano watershed. The most important is the Parco Nazionale del Gran Sasso e dei Monti della Laga that covers a surface of 150.000 hectares and is one of the largest in Italy. The Park includes three mountain groups: the chain of Gran Sasso d'Italia, the massif of Laga and the Monti Gemelli. It also has the highest peak of the Apennines, the Corno Grande (2912 meters) and the only Apennine glacier, the Calderone, which is the most southern glacier in Europe. The Park is counted among the Italian Special Protection Zones, established according the EU Directive "Birds" (79/409/CEE). Moreover, two Sites of Community Importance (S.C.I., instituted according to the contents of European Habitat Directive, 92/43/CEE) are present. Both sites were selected for the high quality of the river water and habitat and for the value of the natural landscape; both SIC represent the southern border of the diffusion area for some fish species (for instance, Chondrostoma genei).

The hydrological regime of the Vomano has been heavily modified by many hydraulic structures and by public works. For instance the construction of the highway tunnel through the Gran Sasso Massif perturbed one large aquifer of the region, and thus lowered the piezometric surface of near 600 m that affects the discharge of several springs that flow out from Gran Sasso. Apart from this, the following environmental problems connected to the water management in the Vomano Basin have been identified:

- river bank erosion and habitat loss caused by hydro-peaking, that is the steep variations of flow due to daily modulation of hydropower production;
- impacts of flow diversions in the protected areas, and
- water-mixing across different watersheds.

All these issues are related to the current uses of the water resource in the area (hydropower, irrigation and drinking water supply).

The Vomano hydropower plants produce 700 MW, and at this important in the regional power grid. The first element of the system is the Compotosto Lake reservoir located at 1317 m a.s.l. It is closed by three dams and is located between two different watersheds. Two other artificial reservoirs are used for hydropower generation. The total capacity of these three reservoirs is about 220 Mmc (of which 217 Mmc are from the Campotosto Lake alone), which can be compared to 509 Mmc per year flowing at Villa Vomano river section (136 m a.s.l.), downstream the main hydropower plants.

Waters from the Campotosto Lake and other reservoirs produce electric power in four main hydropower stations, two of which work also as pumping stations to move water from one reservoir to another placed upstream, for pumped storage.

At present the only water release from the hydraulic conduits is at Montorio al Vomano, in the medium course of the river, where a 1.2 m^3/s flow is maintained. After a 1200 m fall passing through four hydropower stations, the water is eventually returned to the river at Villa Vomano, where once again it is partially diverted for consumptive use to supply an irrigation district.

Figure 2: The Vomano River at Senarica station (at 610 m a.s.l.)[3]

Supply of drinking water to urban settlements is the most important consumptive use of the water. Here the Italian regulatory framework gives priority to human consumption among the different uses. Up to now the exploitation of the water resource has not aroused major public conflicts, because there are no water shortages. But new requests (e.g. for drinkable water supply) and different needs now demand a more developed management approach. Public awareness of environmental protection implications and sustainable development has also increased local interest in the regulatory framework.

Abruzzo Region is now planning some activities to implement the National recommendations about the definition of the Regional Water Protection Plan and, in this framework, of criteria for the quantification of reserved flows for environmental purposes. The most relevant environmental issues are connected, above all, to flow diversions for hydropower production; the most impacted zones seem to be the protected areas in the National Park, the trout zone (with particular reference to the Vomano reach downstream Provvidenza dam) and the two sites of community importance.

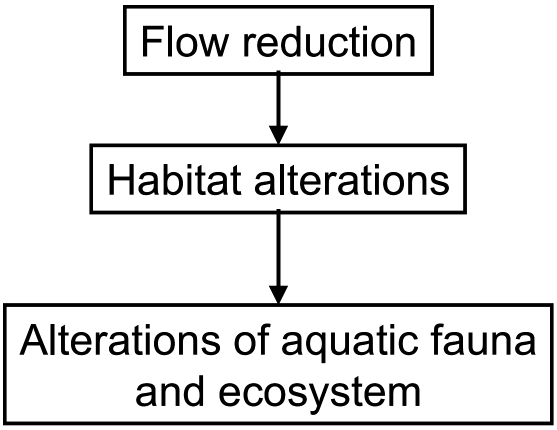
[3] From the 2002 Regional Report on Water Quality and Fish Distribution

Box 2: Relevant events and activities

1934:	The hydro electrical development of the Vomano River Basin and the construction of Campostosto Lake dams are proposed
1939:	The building of the dams that will form the Campotosto lake begins
1949:	Power production begins in Provvidenza hydropower plant (downstream Campotosto Lake)
1983:	River Basin Authorities are introduced in Italy
1999:	The Italian Water Protection Act is approved
2000:	The Water Framework Directive is approved by EU Commission
Present:	Regione Abruzzo is planning its Regional Water Protection Plan and is developing criteria for the estimation of environmental flows

4 METHODOLOGY

The conventional way to address environmental impacts of water diversions is the definition of MIF requirements. As discussed previously, this approach has some limits, especially related to its application in IWRM. In order to overcome these limits, a research programme promoted and initiated in the framework of System Research on Electrical Sector (funded by the Italian Ministry of Productive Activity) to pilot test a new approach. The Vomano River was chosen as a study basin. The main aim was to develop an index connected to instream flow that would help define the performance of various management options. In this way, it would be possible to take the 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 for the estimation of environmental flow requirements, but not limited strictly to MIF. 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. A microhabitat simulation (often implemented by means of the well known PHABSIM program) consists of a two step process: 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, rather it must be considered to be an index.

The function WUA versus the discharge can be considered the transfer function that transforms the hydrologic information into biological information. 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. These characteristics make this approach suitable for the development of an environmental performance index of various water management policies.

In this pilot approach developed in CESI, natural and regulated time series are taken into account by means of the respective flow duration curves and 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. Finally the environmental cost of a water management policy is defined as an appropriate distance between natural and regulated WUA duration curves (Figure 3). 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.

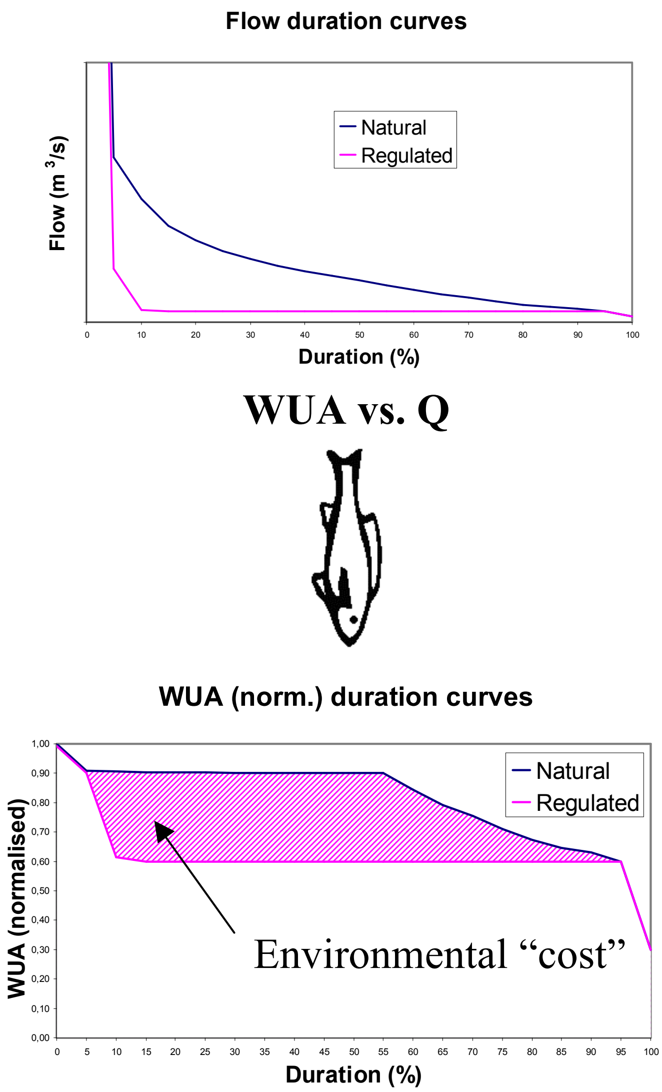
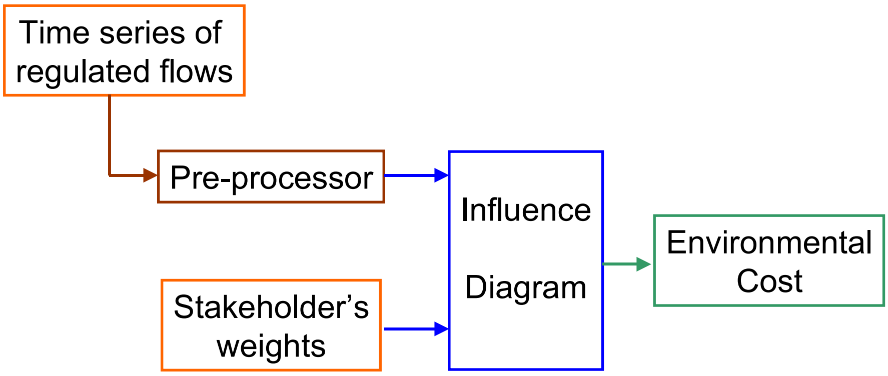


Figure 3: Derivation of the "environmental cost" from the flow duration curves and WUA vs. Q function

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 (Management of the Environment and resources using Integrated Techniques). The aim of the project is to develop a methodology for IWRM that can be applied at the catchment scale. A distinctive aspect of the project is the use of Bayesian belief network 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 BBN, 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 our tool is outlined in the following figure.



The input is the time series of regulated flows, provided by some appropriate optimisation and simulation tool. In this application the input will be 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[4]. The pre-processor is needed to compute a regulated flow duration curve from the flow time series and to assign the right parameters for the Bayesian network. A critical point was the availability of the WUA curves. They are a key element in the procedure because they make it possible to translate the hydrologic information into biological information. They are also site-specific and their determination needs some intensive experimental surveys, which has not been carried out yet. Therefore in this application actual curves were not available and realistic (but not real) curves had to be introduced in the influence diagram.

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.

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

[4] Soncini-Sessa, R., A. Castelletti, and E. Weber, 2002. Participatory decision making in reservoir planning, Plenary lecture at iEMSs 2002, Integrated Assessment and Decision Support 24-27 June 2002, Lugano, Switzerland.

policy according their own point of view. This option reflects the fact that different groups do not perceive environmental value in the same way.

In the Vomano pilot application, some stakeholders (local authorities, National Park representatives, and river anglers) were directly involved in the development of the tool and in the determination of different sets of weights. At present, the work is in progress and feedback from stakeholders is being collected in order to evaluate the effectiveness of the approach. In general one objective of the MERIT project will be to develop techniques to encourage and enable full stakeholder involvement in the construction of BBN and, ultimately, in the decision making process.

5 FUTURE DEVELOPMENTS AND 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 that can be used in mathematical modelling and optimisation tools to evaluate the effect of different water management policies. These results, in turn, would inform negotiations and policies on environmental flow requirements and measures to provide them.

In this Vomano case study an environmental score was developed to quantify and compare the environmental performance of different policies. It is based on methods originally developed in the framework of Minimum Instream Flow evaluation methods and it has been implemented using Bayesian Belief Network; where a preliminary application to the Vomano River has been demonstrated.

Bayesian belief networks were used to develop a decision support system in order to give the possibility to different stakeholders to introduce their points of view in the evaluation of the environmental performance of a given water management policy. More generally, BBNs seems to be an effective tool to enable stakeholders' involvement in the use of decision support systems and to promote their participation in the decision-making process. In order to extend the method and apply it in practical situations, it would be necessary to carry out extensive experimental surveys, to obtain the real responses of river habitats to flow variations, and to complete the stakeholder consultation process, possibly using the BBN tool.

In addition, it may be worth noting that only environmental aspects connected to river habitat are included in this approach. Of course they don't exhaust the environmental issues connected to water diversions in rivers or, more generally, to variations of the hydrological regime. In order to entirely include the environmental aspects in Integrated Water Resource Management, it would be necessary to define similar scores for each of them.

Acknowledgements

The activities that are described in this paper are funded partly by System Research on Electrical Sector of the Italian Ministry of Productive Activity (contract COMPA) and partly by the European Commission within the framework of the MERIT Project (Management of the Environment and Resources using Integrated Technique). Helpful discussions with the other MERIT partners are kindly acknowledged.

Websites

www.regione.abruzzo.it:	Website of Regione Abruzzo
www.gransassolagapark.it	Website of the Gran Sasso and Monti della Laga National Park
www.ricercadisistema.it	Website of the Italian research on the Electrical System
www.merit-eu.net	Website of MERIT Project